POTENTIAL UPTAKE AND IMPACT OF NEW CROP SPRAYING TECHNOLOGY ON UK ARABLE FARMS

by

ANTHONY KENNETH SMITH B.A.

Thesis submitted for the degree of Doctor of Philosophy of the University of London and for the Diploma of Imperial College

Department of Pure & Applied Biology

Imperial College

Silwood Park

Ascot

Berkshire

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TO MUM AND DAD

Abstract

Possible future trends in pest control on arable farms in the U.K. are discussed with particular reference to recent advances in pesticide application technology. A review of past and present practices in plant protection on farms is presented.

The logistics of, and constraints to crop spraying operations are discussed in detail. Theories of the adoption and diffusion of innovations are outlined, and an analysis is made of farmer's attitudes to present and innovative plant protection practices. A personal interview survey of 76 farmers in central East Anglia and south Oxfordshire was conducted to obtain information on attitudes and use of present plant protection technology; also awareness, attitudes to, and use of a number of innovative devices and techniques. A personal interview survey of 26 users of an innovative crop sprayer was also carried out. The innovative behaviour of farmers is measured and compared with personal and situational farmer attributes. A discussion on possible future developments in pest control is supplemented by results from a postal survey of 167 experts in relevant sectors of agriculture.

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CHAPTER 1

INTRODUCTION

Great technical advances are currently being made in the field of crop protection, not only with the pesticides applied, but also the means by which pesticides are applied to the target. This thesis attempts to evaluate the possible future uptake and impact of such new crop spraying technology, particularly those innovations making use of new nozzle designs. In doing this, a multidisciplinary approach is used.

For over fifty years sprayers have been in widespread use in British agriculture. The nozzles principally used work by means of a flow of liquid being forced through a small aperture in order to produce droplets. Subsequent dispersion over a target is achieved by reliance upon natural air movements and gravity; in some sprayers an airstream may be used to direct droplets towards the target. The type of sprayer in most common usage on British farms consists of nozzles working by hydraulic pressure, mounted along a horizontally arranged boom. Liquid is held in a spray tank, from which it is moved to the nozzles by means of a pump or gravity feed system. The apparatus is mounted on a vehicle (usually a tractor - a tractor mounted sprayer), or trailed on a frame behind the vehicle (trailed sprayer). Presently, increasing use is being made of vehicles other than tractors, and for some very large units the sprayer apparatus may be permanently attached to a specially designed vehicle (self-propelled sprayer).

Several types of specialized crop sprayers exist; for instance band sprayers and orchard sprayers. In addition, chemicals may be applied as a solid, e.g. as granules or dusts. Chemicals may also be applied from the air. However, the majority of this thesis is concerned with ground liquid sprayers for arable crops.

Chapter Two gives an overview of aspects of crop protection relevant to this thesis, attempting to explain farmers' motivations in (i) applying chemicals to crops, and (ii) replacing machinery on the farm. Past and current crop protection practices on British farms are reviewed in Chapter Four. The relevance of such a review is that it is essential to study past patterns in attempting to evaluate future trends. Data presented in Chapter Four are collected in two ways. The first is a review of relevant published literature. Secondly farmer surveys can be carried out in order to find out about crop protection practices such as the types and timing of chemicals applied, and their method of application. The methodology of surveys conducted in order to obtain information for this thesis is reported on in Chapter Three. Questionnaires used in surveys are reproduced in the Appendix.

In order to place a chemical as accurately as possible, the farmer should consider the major factors influencing the targetting of the chemical. Among these factors, the droplet size and droplet size distribution are perhaps the most important.

Depending upon liquid pressure, the nature of the nozzle orifice and the physico-chemical characteristics of the spray liquid, hydraulic-pressure nozzles can produce droplets of sizes ranging from 10µm to 500µm. In the course of a season, the farmer will need to spray against a variety of pests, thus it is desirable to have the facility to spray droplets of different sizes. For instance, soil-acting herbicides are best applied with a droplet size of around 250-300 µm, whilst fungicides and insecticides tend to achieve good targetting using droplets in the range 125-200µm. However, it is difficult to achieve a monodisperse droplet spectrum with hydraulic-pressure nozzles; the vmd/nmd often lies between 1.9 and 2.6 (Matthews, 1979, p58). Whilst for some targets a wide range of droplet sizes may be desirable, it may also lead to wastage of chemical, and the escape of pesticides from their arena of action. For instance, very small droplets unintentionally produced may lead to spray drift, whilst very large droplets may drench their targets with more chemical than is neccessary or desirable, and run off onto the ground. The loss of chemicals in this manner may mean that the farmer is using more active ingredient than is neccessary.

Over the past few years, several types of nozzle have been developed that attempt to produce monodisperse droplets, the size of which can be easily controlled, in order to treat different targets. The droplet size is chosen to give maximum retention on the target together with the appropriate droplet density to ensure adequate coverage and convey sufficient chemical to achieve the desired biological response (Bals, 1978). This is otherwise known as Controlled Droplet Application (CDA) (Heijne, 1980). Nozzles included in this category are: centrifugal-energy nozzles (i.e. spinning-discs or rotary atomizers), and nozzles utilising electrostatic forces. A brief discussion of these two types of nozzle are given in Chapter Four. The major advantages of nozzles allowing CDA application are that vmd/nmd ratios are nearer unity (1.1-1.7 for spinning-discs (Matthews, 1979, p58), and 1.0-1.1 for electrostatic sprayers (Coffee, 1980)). This close control of droplet spectra means that farmers could be able to vary droplet sizes according to the weather conditions, and consequently spray in conditions considered unsuitable when using hydraulic-pressure nozzles. For instance, farmers may be able to spray in higher windspeeds than is currently the case by selecting droplets which will tend to drift less. An account of how environmental conditions influence the time available for spraying is given in Chapter Five. Furthermore, accurate droplet sizing will generally lead to more accurate targetting of chemicals. This means that a reduction in the amount of diluent and/or active ingredient is often possible with such nozzles. A reduction in the amount of diluent applied can lead to increased machinery workrates, as refilling is done less often. The influence of volumes and other spraying parameters on machinery workrates are discussed in Chapter Five.

Crop spraying machinery is simply a means of ensuring that pesticides are applied as efficiently as possible across a target. Accordingly, considerations of biological efficacy are very important in the design of new crop spraying technology. Although boom-mounted spinning-disc sprayers have been commercially available in the UK for a number of years, electrostatic sprayers have yet to become available. In both cases there are many gaps in information available regarding the comparitive biological efficacy of different nozzles. Several authors have indicated that this is at least partly due to difficulties in experimental design (e.g. Taylor, 1981). The main accent of this thesis is to examine how "non-biological" factors can be influential in determining the adoption and impact of new crop spraying technology. Two such factors are mentioned above, viz. the influence of the weather on crop spraying, and the logistics of the crop spraying operation.

In considering the attributes of new technology, it is often the case that the new technology shows considerable performance and efficiency advantages over the devices or practices that it is meant to replace. Despite this, it is invariably found that there is often some reluctance to change from existing practices among many farmers. What factors predispose farmers towards or against change? How can the propensity to change be evaluated or predicted? An attempt is made in Chapter Six to answer questions such as these, using data obtained from the farmer surveys described in Chapter Three.

There are several methods available for the forecasting of future trends and events. One of the most commonly used methods, canvassing expert opinion, is used to evaluate future trends in British arable plant protection. This is done by means of a survey of workers in relevant sectors of agriculture; the results from such a study are reported in Chapter Seven.

CHAPTER 2

AN OVERVIEW OF CROP PROTECTION

2.1. Introduction

In the last forty years, large increases in yields have been achieved for crops such as wheat and potatoes in the U.K. (HMSO, 1979, p. 8). With increasing fertiliser inputs, the cropping system is more attractive to pests of all descriptions. Over this time period there has been a tendency away from formal rotations towards continuous or near-continuous cereal growing, which has an agroecosystem sometimes favouring the development of large pest populations. Therefore an increased use of pesticides over this time (HMSO, 1979, p. 10) has been needed to protect the crop from pest damage. In 1981, £242.4 million was spent in the use of pesticides and growth regulators. (BAA annual report, 1981/2). In addition, quality controls have become keener over this period; many pesticide applications, particularly on crops due for fresh produce markets, may receive sprays to maintain the cosmetic appeal of the crop, rather than to prevent yield loss arising from pest damage.

Although few pests, if any, are of sufficient importance in the U.K. to influence political, sociological or economic decisions by government (Wheatley & Coaker 1969), the introduction and use of pesticides in other societies may have far-reaching effects on the community (Miller, 1982). Social and economic factors associated with chemical usage will be discussed later in this chapter (Section 2.5).

As it is often difficult to compute the true value of pesticide applications at the field level (Wheatley & Coaker, 1969), much attention has been paid to how farmers make decisions about spraying in the face of imperfect knowledge and uncertainty as to outcomes (Mumford, 1981, 1982; Norton, 1976, 1982). Section 2.4 gives a brief discussion of decision making, and Section 2.5 with the economics of pest control. Section 2.6 is concerned with the economics of agricultural machinery, with particular reference to crop sprayers. Section 2.7 discusses alternatives to machinery ownership and contract work.

This chapter seeks to outline some of the situational characteristics relevant to the farmer. The actual use of chemicals on crops will be outlined in Chapter Four, and the effects of the weather and labour availability on spraying operations will be discussed in Chapter Five.

2.2. Damage caused by pests in the U.K.

Table 2.1 indicates some of the main fungal and insect pests of major U.K. arable crops.

If the value of chemicals used is an indicator of the importance of a pest, then weeds appear to be relatively much more important than insect or fungal diseases. In 1981, U.K. sales of herbicides for agricultural or horticultural use amounted to £133.5 million, compared with £18.0 million for insecticides and £50.7 million for fungicides (BAA, 1982). The value of losses caused by weed infestations may be large: Thomas (1975, quoted in Gough 1977) estimated that herbicide treatment of wild oats and black-grass alone in the U.K. could result in total benefits of over £27 million, by reducing competition for resources with the crop, and preventing harvesting difficulties. However, Elliot (1978) has indicated that little is known about the economic justification for applying cereal herbicides, specifically on weed threshold populations. Benefits from weed control may be cumulative, ranging over more than one crop, or season. Trends toward reduced cultivations and autumn sowing of cereals have changed and reduced the opportunities available for the timely chemical treatment of weeds. Less time is available for pre-emergent herbicide

TABLE 2.1 Major fungal and insect pests of the main arable crops in the U.K.

CROP		PEST	REMARKS
CEREALS	Wheat bulb fly	(*Delia coarctata*)	
	Grain aphid	(*Sitobion avenae*)	
	Cereal cyst eelworm	(*Heterodera avenae*)	
	Mildew	(*Erysiphe graminis*)	Fungal diseases economically
	Leaf blotch	(*Rhyncosporium secalis*)	more important than insect
	Brown rust	(*Puccinia hordei*)	pests on cereals.
	Net blotch	(*Pyrenophora teres*)	
	Yellow rust	(*Puccinia striiformis*	
	Glume blotch	(*Septoria nodorum*)	
	Leaf spot	(*S. tritici*)	
	Eyespot	(*Pseudocercosporella herpotrichoides*)	
	Take-all	(*Gaeumannomyces graminis*)	
POTATOES	Potato cyst nematode	(*Heterodera* spp.)	
	Wireworms	(*Agriotes* spp)	
	Blight	(*Phytophora infestans*)	
	Peach potato aphid	(*Myzus persicae*)	
OILSEED RAPE			
	Pollen beetle	(*Meligethes aeneus*)	Fungal diseases uncommon
	Cabbage seed weevil	(*Ceuthorhyncus assimilis*)	on rape.
	Cabbage stem flea beetle	(*Psylliodes chrysocephala*)	
	Bladder pod midge	(*Dasinema brassicae*)	
SUGAR BEET			
	Peach-potato aphid	(*Myzus persicae*)	Fungal diseases uncommon on sugar beet.

applications, and herbicides that can be applied after the crop has emerged may have to be applied in late autumn or early spring, when the weather may not favour spraying. Later on in the season, the problem changes to one of preventing wheelings damage when applying chemicals, ensuring adequate penetration of the crop canopy, and adequate cover of the weed by the herbicide.

Weeds in row crops, such as sugar beet and potatoes, can be treated easily by mechanical means. More time is available for pre-emergence applications, and once a full canopy is formed, sugar beet and potatoes are strong competitors for resources. When a full canopy has formed, oilseed rape also offers strong competition to weeds.

2.3 Chemical control in relation to other methods of pest control.

In intensive cropping systems, such as most field-scale arable crops in the U.K., chemical control is the predominant method used for regulating pest populations. Using chemical control methods, Wheatley & Coaker (1969) indicated various means by which costs of control could be regulated in order to maximise the relevant cost/benefit ratios: see Table 2.2. Fenemore (1982, p. 168) summarises the advantages and disadvantages of the major pest control methods, including the methods to pest control alluded to in Table 2.2. He also indicates that some control methods can be antagonistic to, or incompatible with, other control methods; however, it could be advantageous if means could be found of using two or more methods of control simultaneously so that they work together rather than against one another (Fenemore, 1982, pp. 217-18). Despite a number of alternatives to chemical methods of control suggested over the years, Geissbühler (1981) concludes that "none of the ... alternatives (to chemical control) or even a combination of them will be able to replace

TABLE 2.2 Methods available to regulate levels of pest control and costs (adapted from Wheatley and Coaker, 1969).

Methods of adjusting control efficiency	Source of savings and costs
Dose adjustment	Savings of chemical
No. of pest control operations	Savings in operation costs, possibly offset against increased degree of risk and cost of advice
Combinations of control methods	Select most profitable combination of methods.
Different control methods	Select most profitable methods

chemicals in any major sector of pest and weed control".

Although non-chemical control methods may not have more than a minor or specialist role in intensive arable crops in the next few years, the "integrated control" of pests was being practised long before the term was invented (Way, 1977). One of the major aims in integrated control methods is to preserve natural enemy action, with pesticides acting in a supplementary role. Nevertheless, Gough (1977) asserts that in the foreseeable future, growers will remain crucially dependent upon chemical pesticides for pest, disease and weed control. Furthermore, "in present conditions, genuine integrated control has nearly always become acceptable only as a result of failure or impending failure of the straightforward chemical approach" (Way, 1977).

It would appear that in the foreseeable future the prospect for genuine integrated control in most U.K. field-scale arable crops is poor.

2.4 Crop protection decision making

2.4.1 The nature of risk and uncertainty

In most activities where the outcome of an event or action lies in the future, there is not perfect knowledge as to the nature of that outcome, i.e. the future is not known with perfect certainty. Economists recognize two types of imperfect knowledge about future outcomes: risk, and uncertainty. Risky situations occur when there is a range of possible outcomes, each outcome having an objectively known probability. Uncertainty exists when there is more than one possible outcome to a course of action, the form of each possible outcome is known, but the probability of obtaining any one outcome is not known (Bannock *et al*. 1978).

The problem of quantifying the likelihood of conditions occurring under uncertainty can be at least partly solved by subjectively assessing the probability of outcomes. Valuations as to the probability of outcomes occurring can be made on the basis of personal belief, describing the effects of uncertainty in defined and understood numerical terms. These numerical assessments provide a quantifiable basis for comparison between the assessments of individuals (Moore & Thomas, 1976, pp. 135-6). An example of a 'risky' decision to be made is that of predicting whether an unbiased coin will give heads or tails when tossed.

Heady (1952) describes several categories of uncertainty prevalent in agriculture:

a) Price uncertainty. Factors such as economic cycles or the weather can influence prices for crops.
b) Technical uncertainty. Yields of crops can be influenced by the nature and level of inputs supplied. For instance, a new pesticide applied may influence yield and profit in various ways which cannot be readily quantified by the farmer.
c) Technological uncertainty. Farmers may allocate resources differently following a consideration of possible future technological advances. For instance, a farmer may defer the purchase of a sprayer until new or improved techniques for spraying crops come on the market.
d) Uncertainty due to tenure, government regulations, etc. Farmers may consider that future laws could be enacted banning pesticides, or certain spraying techniques. This could influence decisions to purchase chemicals or machinery, or perhaps the continued growing of certain crops.

Many assessments of future outcomes in agriculture can be at least partially quantified, thus these problems of assessment are a mixture of risk and uncertainty. As a farmer gains experience, acquiring a "stream" of historical knowledge, e.g. about weather conditions, pesticide efficacy etc., less subjective and more objective assessments as to future outcomes can be made. However, due to the complex nature of agriculture, information gaps (Norton, 1982) can only be closed in exceptional and highly specific circumstances.

2.4.2 Perceptions of losses in crops.

Norton (1976) indicated four main areas relevant in pest control decisions at the farm level:

- perceptions of organisms as pests
- options for control
- farmer objectives
- rationality - decision rules used

Results from Turpin & Maxwell (1976) indicate that perceptions of losses by pests are not the only reason for chemical use. Tait (1977) found that among a sample of English fruit and vegetable growers, there was a greater variation in the use of pesticides between farmers than between crops on the same farm. Moreover there was evidence that some farmers used a 'standard operating procedure' which may cut down effort involved in decision-making, meaning that a number of crops had a number of sprays applied, regardless of pest infestation levels. Mumford also found that the use of different groups of pesticides on farms was associated. Mumford (1982) has proposed several hypotheses to explain this association. In addition to Tait's standard operating procedure, the individual's risk attitude, and their perception of the damage that pests are perceived to be able to cause to each crop are thought to be associated with this linked pesticide usage effect. Five factors may help form the farmers perceptions of pest hazards:

a) experience remembered of a pest on a crop,

b) remembered experiences of the same or similar pests on another crop,

c) perceived experience of different pests on the same crop,

d) awareness of solutions to pest problems on crops,

e) presence of a "key pest" in a crop, heightening perceptions of other pest /crop combinations.

The current widespread use of tank mixes has probably acted as an impetus to multi-pest applications due to the costs of application relative to the opportunity costs that may arise if subsequent applications prove necessary.

2.4.3 Models of decision- making in crop protection

Models of decision-making generally have four implicit factors, as outlined in Section 2.4.2: farmer objectives, perceptions of the nature of pest attacks, available control measures, and the decision rules used. Using these factors in a decision model, Mumford (1981) and Lane (1981) have attempted to explain crop protection decision-making behaviour in sugar beet and oilseed rape respectively. Tait's model of crop protection decision behaviour (Tait, 1982) hypothesises that actual behaviour is a function of behavioural intentions, which are determined by attitudes and the 'subjective norm' (indicates the influence of other people on decision-making).

In many situations it may not be possible to apply formal decision models, as there is inadequate information, limited managerial ability or extreme risk constraints (Norton, 1976).

In Chapter Six, decision-making in the adoption of innovations is discussed.

2.5 Pest control economics

2.5.1 Introduction

Although methods other than chemical control are used to manage pests to at least some extent in all crops, the nature of these control methods may be subtle, and embedded in the whole farming system. Thus assessing the value of such control methods can be extremely difficult. The costs and benefits of pesticides are relatively easier to assess: consequently most work on pest control economics has concentrated on the effects of chemicals.

The number of options available for controlling a pest depends upon:

1) variations in yield and crop quality due to pest attacks
2) variations in yield and crop quality due to other factors
3) variations in price
4) variations in the effectiveness of control schemes. (Southwood & Norton 1973).

From figures for 1963 on values of inputs and outputs of farms in the U.S.A., Headley (1968) estimated that the benefit:cost ratio for pesticides in the USA was approximately four. "Pesticide applications can reduce unit costs and the variability of income, and so act as an insurance policy on the heavy investment required for modern agriculture" (Headley, 1972).

Schumann (1976) stated that the farmer can expect to have a return of 3:1 to 9:1 on his investment in crop protection. In special cases the benefit ratio may rise to 100:1.

2.5.2 Pest control economics at the farm level

At the farm level, decisions about pest management tactics are based on knowledge of the costs of control measures and expected revenues from the crop (Southwood & Norton, 1973). Generally, in countries such as the U.K. or USA, the higher the expected value of the crop the larger the pesticide input will be for that crop (Bullen, 1970).

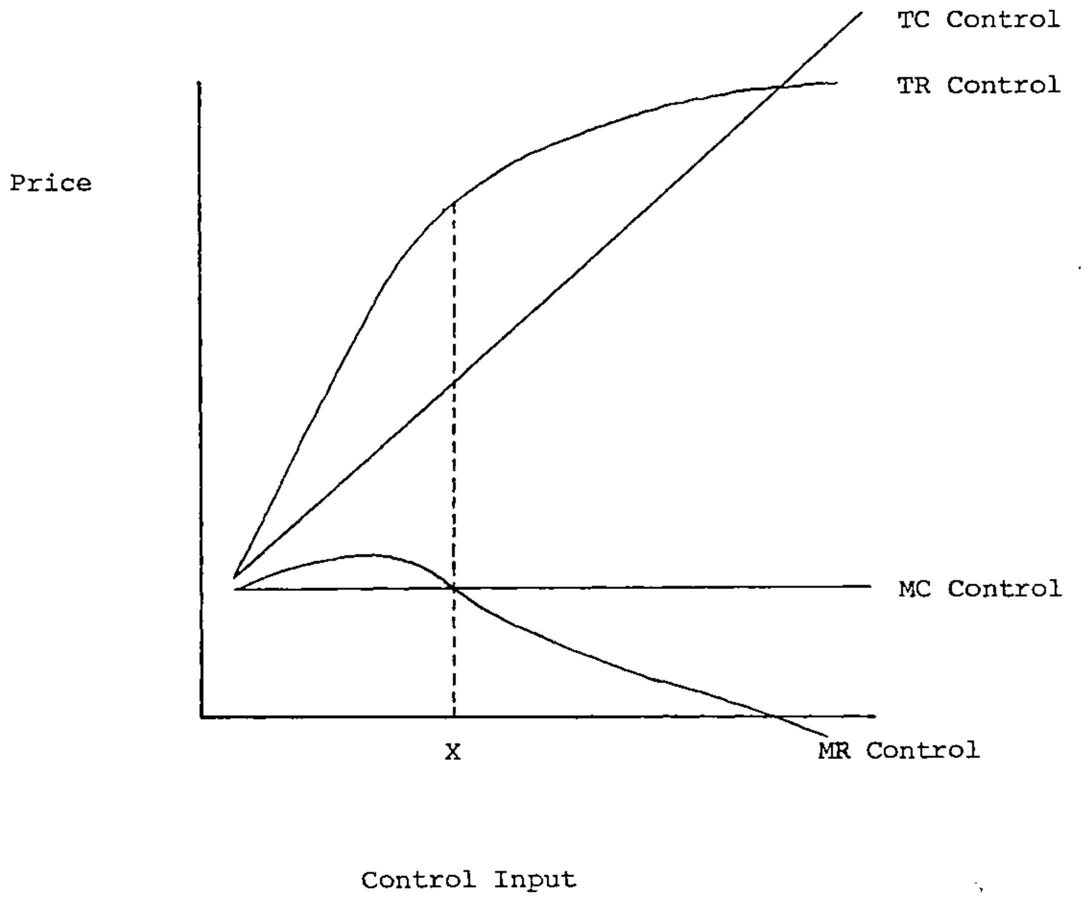
Most analyses of the benefits and costs of pest control, particularly chemical control, have relied on an evaluation of marginal revenues and marginal costs in determining optimal pest control strategies. In deciding what value of inputs to allocate to pest control, an indication of the amount of damage to the crop that can be caused by the pest should be obtained. The indicators of pest attack most commonly used are the 'economic injury level' and the 'economic threshold'. Over the years there has been considerable discussion over the exact definition of these terms; the economic threshold has been defined as "the (pest) density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level" (Stern _et al_, 1959). The economic injury level was defined by Stern _et al_ (1959) as being the "lowest (pest) population density that will cause economic damage (which is) the amount of injury which will justify the cost of artificial control measures". Headley (1975) defines economic threshold as that level of the pest population where the marginal cost of control equals the marginal revenue. Price effects influence economic thresholds in two ways:

(i) the critical population level will become smaller as the value of the product increases given constant control technology and constant prices for control inputs. The economic threshold is therefore a function of product price.

(ii) Increases in the unit cost of control methods will shift the control cost curve to the right, and increase the slope of the cost curve - the economic threshold is moved toward higher population levels.

Using the above definition of the economic threshold, point X in Figure 2.1 indicates the level to which control should applied, indicated by Southwood & Norton (1973) as being the point at which:

FIGURE 2.1. Sketch of total and marginal costs and revenues from pest control. From Southwood & Norton (1973).



$$(C(a) - C(a-1)) = (Y(S(a))\ P(S(a)) - Y(S(a-1))\ P(S(a-1)))$$

where Y = yield

P = price/unit of yield

S(a) = level of pesticide attack as modified by control action

C(a) = total cost of control action

a-1 = previous control action

However, in order to arrive at a model that describes the economics of pest control more accurately, several other factors must be considered.

1) knowledge of control functions and damage functions (Southwood & Norton, 1973) is limited. The parameters of the damage function curve are defined by such factors as the part of the plant attacked, and the end use of the crop. Control function parameters are determined by such factors as the efficacy of control methods.

2) Closely related to the concept of control and damage functions is the relationship between yield and quality. The price obtained for a crop is not only related to the yield, but also on the grading of the crop regarding it's quality. Due to factors such as declining consumer tolerance for blemishes on produce, increasing popularity of processed and preserved foods and the introduction of quality guidelines and regulations by such bodies as the EEC, the quality of produce is becoming an important determinant of revenue.

3) Pest control actions are not necessarily independent of other pest control actions, or of other inputs. Cochran & Robinson (1981) considered chemical sprays to be "durable assets" that generated services (i.e. protection of crop against pests) lasting longer than one "decision period" (the time over which important variables change in the decision environment).

4) Uncertainty exists regarding the weather, which has a great influence on crop and pest development.

5) The farmer does not have perfect knowledge on how other factors, such as cultural practices, and plant varieties, influence the potential for pest damage (Headley, 1972).

Pest control may be said to be characterised by two major problems: uncertainty and dynamics. Faced with the problem of uncertainty in pest control decisions, the farmer will be interested in expenditures reducing that uncertainty. The farmer is therefore interested in turning the expected value of damage into a part of his cost of production; in other words, insuring against expected losses (Headley, 1972). The second major problem area is that of the dynamic nature of crop and pest development, and of decision-making. Pest control actions may have an effect over a number of pest generations in a season, or even over several seasons. A model of pest development and control shows that static single period decision-making does not provide higher net benefits than decisions made over two periods (Taylor 1972, quoted in Headley 1975, p. 87). Cochran & Robison (1981) assert that "assets" such as sprays can provide services over more than one time period. Their definition of the time period is not arbitrary but is intended to reflect the rate of change of important variables in the decision environment. It is suggested that time periods in the context of pest control decision-making is related to the frequency of scouting - following each crop scouting, a decision whether or not to spray can be made. Sprays are considered as a durable asset which can generate services which last longer than one time period.

Cochran & Robison (1981) state that: 'marginal analysis .... is appropriate when inputs are divisible in acquisition and use and where time is not an important consideration'. However, when inputs are 'lumpy' and assets such as sprays prove to be durable (sprays being effective over more than one time period), then 'a new procedure is necessary (from using marginal economic analysis) since costs & benefits change with both input usage and the passage of time'. The economic threshold is then defined as the "density that the pest population reaches in the time period when it becomes economical to spray again .... replacement of one spray with another will occur in the time period when the net returns from the first spray are less than the average net returns over the life of the second spray" (Cochran & Robison, 1981).

Stern (1973, p. 260) asserts that "the concept of an economic threshold as the major criterion for pesticide use has been essentially ignored", and 'it would appear that because of the small amount of effort placed on determining economic treatment levels, pesticides are applied on most of the world's pests as a prophylactic measure". 'Decision-making in pest control is thus often conducted in a clouded atmosphere of biased and fragmentary information particularly where there are no guidelines to yield/pest density ratios." Some recent publications have attempted to construct guidelines for pest control based on an assessment of economic factors , e.g. Reichelderfer, Carlson & Norton, 1983).

2.5.3 Pest control and society

Headley and Lewis (1967, p. 24) indicate that the objectives of society in using pesticides should be in "securing that level of pesticide usage, given the technology in any point in time that provides the maximum positive benefits over and above the negative benefits, or costs associated with that level of usage". The Seventh Report of the Royal Commission on Environmental Pollution (HMSO, 1979) states that "it should be a declared policy aim to reduce pesticide usage to a minimum consistent with efficient food production".

If an application of a pesticide affects the welfare of other groups of people without this effect being priced or compensated for, this is termed an externality. Whilst externalities may be beneficial or harmful to those whom they affect, the public view of chemicals that escape from their arena of action and interfere with other organisms is that these effects give rise to social costs. These costs may be priced or compensated for by taxation on the offending item, or legislation to control use may be enacted. These are discussed in the next section.

2.5.4 Legislation and chemical applications

Macrory and Gilbert (1983) have carried out a comprehensive review of existing U.K. legislation affecting the transport, storage, handling and application of agricultural chemicals.

In the U.K., the Pesticides Safety Precautions Schemes (PSPS) is used to govern the use of chemicals. In this scheme, the manufacturers undertake "not to market a product containing any new chemical for use in agriculture, horticulture or food storage, or to introduce a new use of a chemical already on the market, or to introduce a new formulation, until recommendations for safe use have been agreed with the government departments concerned" (MAFF, 1980). Further schemes exist to officially approve chemicals, e.g. the Agricultural Chemicals Approval Scheme, which helps "users to select, and advisers to recommend, efficient and appropriate crop protection chemicals and to discourage the use of unsatisfactory products" (MAFF, 1980). Unlike many countries, schemes such as these are voluntary. Regulations on dealing with methods of handling, and application of chemicals on farms are not numerous, mainly dealing with dress for operators when handling and applying chemicals, regulating aerial applications, and the control of water-borne pollution (Macrory and Gilbert, 1983).

In addition to government regulations controlling their use, pesticides may be selectively taxed in an attempt to compensate for the externalities generated by the application of agricultural chemicals. However, this is rarely carried out.

2.6 Economics of agricultural machinery

2.6.1 Introduction

This section attempts to outline the economics of use and investment in a durable asset: agricultural machinery. In the U.K., farm mechanisation has led to a dramatic drop in labour requirements for cropping. In 1930, about 54 labour-hours went into producing an acre of cereals: (Barnard & Nix, 1976) the comparable figure in 1982 was approximately 5.5 labour - hours (Nix, 1981). Much of this drop can be attributed to an increased level of mechanisation on farms. In addition to replacing labour, mechanisation can offer further advantages in that yields may be increased (e.g. through improved timeliness of operations) and prices obtained for crops may increase (e.g. through improved produce quality). However, the main reason for mechanisation is to reduce costs (Barnard & Nix, 1976). The twelfth edition of Nix (1981) gives up-to-day estimates of levels of fixed costs on various types of farm. These are given in Table 2.3. In this table, fixed costs refer to those costs that remain unallocated in determining enterprise gross margins. Fixed resources are generally 'lumpy' in character due to the nature of the measured items: the annual wage of an extra man, the annual depreciation on a new machine or building. Nix (1981) states that the approximate average composition of the fixed costs for machinery are: depreciation 40%, repairs 22½%, fuel and oil 20% (included as a fixed cost due to difficulties in recording and allocation), contract work 12½%, vehicle tax and insurance 5%. In addition to fixed costs, there are

TABLE 2.3 Mean levels of investment in various types of fixed costs for various categories of farm (£/ha) (Nix, 1981).

Category	Mainly Cereals			Mixed Cropping		
	<100ha	100-200ha	>200ha	<100ha	100-200ha	>200ha
Regular Labour	115	95	80	165	145	125
Machinery	175	160	145	230	210	190
Rent and Rates	75	70	70	85	80	80
General Overheads	40	35	30	50	40	35
Total	405	360	325	530	475	430

All contract work costs are included, although normally regarded as variable costs.

running or variable costs associated with machinery operation, which vary according to the use made of the machine. The nature and magnitude of fixed costs will be discussed later in this section.

In a study of large, predominantly arable farms in Southern England (Walford,1979), the mean investment in spray machinery as a % of the total investment in agricultural machinery on the farm was 2.3% (standard deviation = 1.08), the percentages for two-wheel drive tractors, cultivation implements and fertiliser spreaders being 13.4% (S.D. = 3.48), 19.8% (S.D. = 4.85) and 2.6% (S.D. = 1.28) respectively.

2.6.2 Fixed costs - Depreciation

Depreciation is the largest single machinery cost item (Barnard & Nix, 1976). Depreciation may be said to occur for three main reasons: a) obselescence, b) gradual deterioration with age, c) wear and tear with use (Barnard & Nix, 1976). Obselescence can occur due to the changing technical nature of other assets or inputs, or changing farmer objectives. The first two factors limit the economic life of the machine in years, whilst the latter can limit the degree of use. If the third factor predominates over the first two, which is not uncommon on large farms, depreciation is no longer fixed per annum and can be taken instead as a constant sum per hectare, just like running costs (Barnard & Nix, 1976).

Table 2.4 gives the rates of depreciation as a % of the new price of a 'complex' machine, (e.g. sprayers) with varying frequencies of renewal (Nix, 1981, p. 91).

Figure 2.2 shows the estimated useful life of crop spray machinery in relation to annual use (Figures from Nix (1981)), and also shows how the cost of spares and repairs for sprayers rises steeply with use. The

TABLE 2.4 Depreciation rates.

Frequency of Renewal (years)	1	2	3	4	5	6	7	8	9	10
Average annual fall in value as a % of new price-complex machinery	34	24½	20	17½	15	13½	12	11	10	9½
			↑ HEAVY use		↑ AVERAGE use	↑ LIGHT use				

rising cost of maintenance with machine use was used by Dunford and Rickard (1961) to indicate a time period with a minimal "holding cost", and thus indicate at what time period a machine should be replaced. For replacement policy options, and an explanation of the holding cost, see Section 2.6.4.

2.6.3 The effects of taxation

It is widely believed that the timing of machinery investment in the U.K. is conditioned by tax considerations (CAS, 1978, quoted in Crabtree, 1981). In fact there are indications that generous tax allowances have encouraged over-frequent replacement of most machinery (Farmers Weekly, 4/12/81).

Tax regulations most relevant to agricultural machinery are those giving allowances for capital expenditure. A first year tax allowance of 100 per cent of the cost of machinery and plant is available, but need not be claimed in full. Furthermore, all leasing and hiring payments are tax allowable. The 100% allowance is best regarded as a crude compensation for the erosion in value by inflation of money allowances spread

FIGURE 2.2.- Graph showing estimated useful life and estimated percentage cost of maintenance with annual use of sprayers. Figures from Nix (1981).

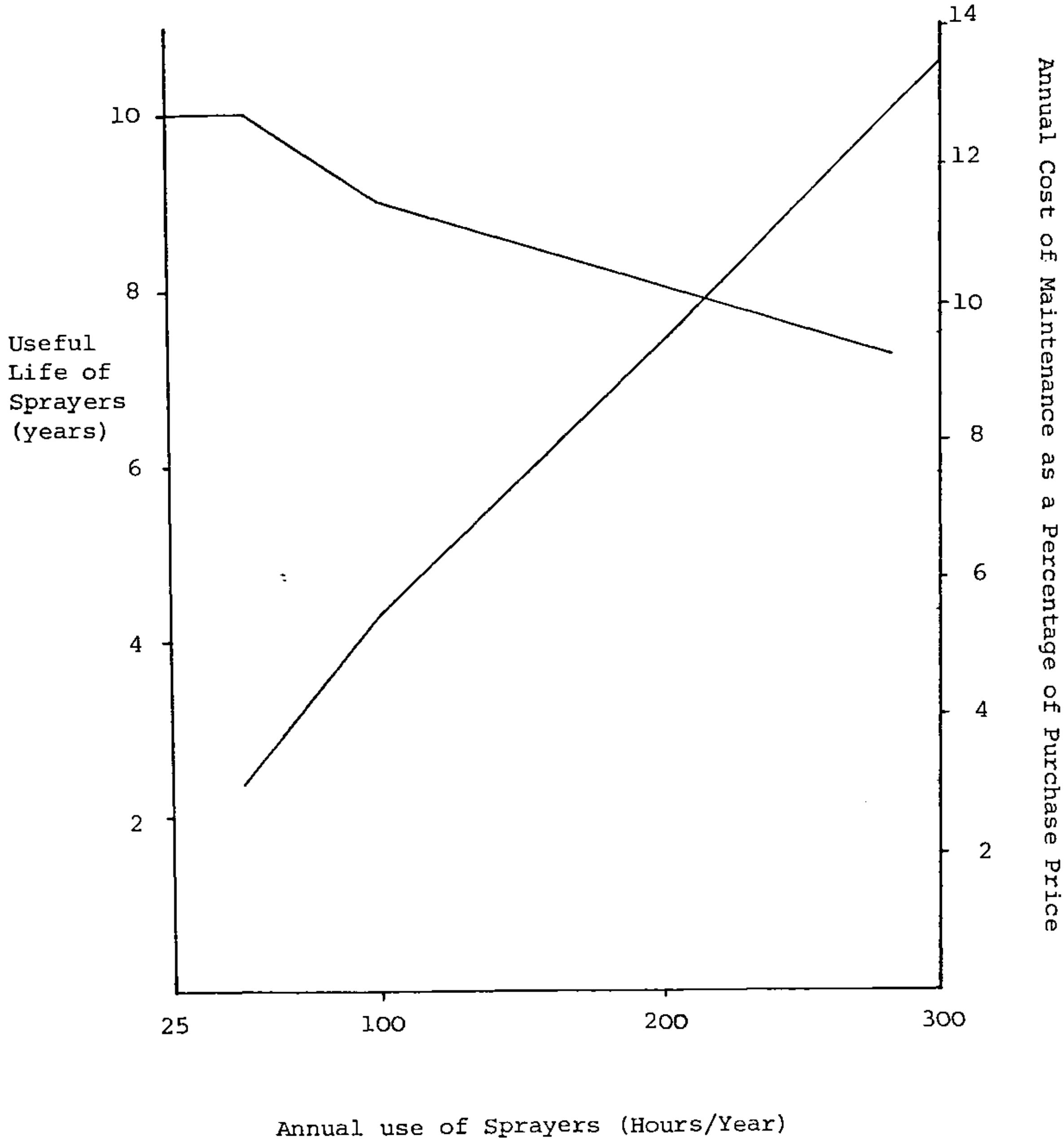
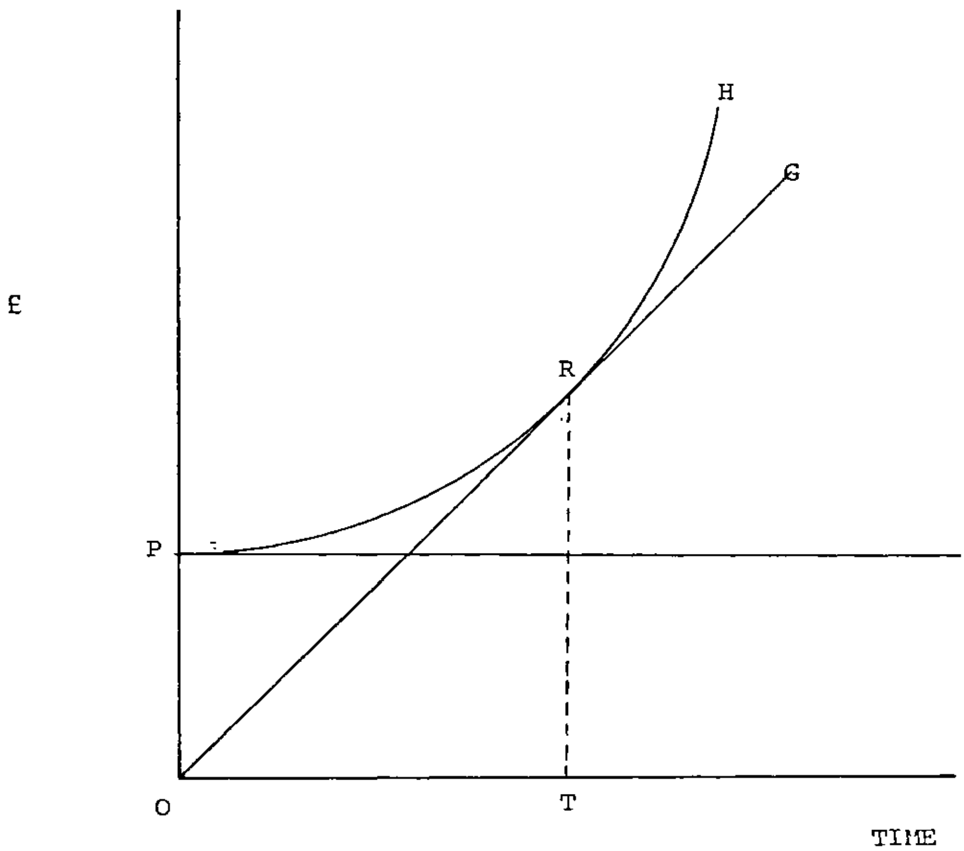


FIGURE 2.3. Graph showing relationship between holding cost and time. From Dunford and Rickard (1961).



over the life of an asset (Crabtree, 1981). Crabtree (1981) has developed a model incorporating adjustments made for different interest and inflation rates in the context of existing U.K. tax law. The model indicates that investment decisions may be affected by the marginal tax rate on a business, and the inflation rate: a business taxed consistently at high marginal rates may engage in machinery purchases that would not be viable at lower tax rates.

It may be that the present tax structure could cause wanton investment in machinery: sound economics in machinery replacement might become obscured by 100 per cent tax allowances and good harvests (Farmers Weekly, Dec, 1981). Moreover, attitudes to agricultural machinery innovations may change if the farmer feels compelled to purchase machinery in order to reduce the marginal tax rate. In these conditions farmers may become less risk averse, and may consider new types of machinery in a different, and more favourable way.

Too much machinery purchased for tax-reducing reasons may in fact lead to excessive machinery costs (Barnard & Nix, 1976): increases in profits following tax-induced mechanisation may actually offset the tax saved by allowances on expenditure.

2.6.4 Replacement policies for agricultural machinery

Replacement policies are discussed separately from ways in which to optimise machinery combinations, which are briefly discussed in Chapter Five. The influence of contractors on machinery purchasing decisions is discussed in Chapter Four.

Barnard and Nix (1976) outlined the main factors affecting the optimum replacement date. The rate of depreciation can be important in decisions on investment policy. The slower the rate of depreciation, then the more worthwhile early replacement is, since it will involve a smaller loss in value. However, this is not to say that machinery which depreciates rapidly due to it becoming technically obsolete should be retained. For instance, complex machinery which depreciates rapidly, such as sprayers, should be replaced if performance and efficiency suffers with age. Due to technical advances, replacement machines will often be technically superior: innovation is an important factor in the timing of machinery replacement (Dunford and Rickard, 1961). Moreover, the widespread adoption of innovations may well depress the salvage value of technologically obsolete machinery.

The faster repair costs increase, the more beneficial early replacement is likely to be, because the saving in repair costs will be greater. Dunford and Rickard (1961) suggested a graphical method of indicating the optimum time of replacement for a machine by finding the point at which the 'holding cost' per year (or some other unit of time) was minimised. The holding cost (Fox 1958, quoted in Dunford & Rickard,1961) may be defined as the sum of the capital cost and the cumulative repair cost, shown as line PH in Figure 2.3. OP is the initial cost of the machine, and (assuming low or no inflation) the replacement cost. The optimum time of replacement of a machine occurs where the holding cost per time period is minimised (Dunford & Rickard, 1961). This occurs where the (tangential) line from the origin OG touches PH, at R in the diagram. The method emphasises the influence of repair costs, and the initial machine price on replacement policy. There are several reasons why farmers may replace machinery before the minimum holding cost is reached. The introduction of machinery technically superior to that owned at present by the farmer may cause a change to the technically superior model. Secondly, farmers averse to the risk of mechanical failure may replace their machines more rapidly. Some farmers may try to reduce risk further by keeping a very old machine on the farm as a standby.

Other factors influencing the frequency of replacement are: the capital position of the farmer, the relevant opportunity costs, and the real interest rates prevailing.

Figure 2.4 shows the age distribution of arable sprayers, obtained from a survey of cereal growers in Oxfordshire and East Anglia. For details of this survey, see Chapter Three. Of the 76 farmers interviewed 66 owned at least one arable crop sprayer. When the 66 respondents in this survey were asked how often owned sprayers were changed, one changed every two years or less, 17 changed sprayers at 2-5 years, 32 changed between 5-10 years, and 16 changed sprayers only when they were over ten years old. Reasons for changing owned sprayers are given in Table 2.5.

2.7 Alternatives to machinery ownership and contract work

Leasing or hiring machinery enables capital to be saved for other projects, whilst most of the advantages in owning a machine are enjoyed. Although leasing and hiring arrangements vary quite a lot in detail, leasing and hiring are in general slightly more costly than owning a machine (Barnard and Nix, 1976). However, all lease and hire payments are tax allowable. Apart from releasing capital for alternative investment, the advantages are that costs are known in advance, and can be stopped at the end of the contract, and high annual repair costs are avoided.

In a survey of 76 cereal farmers in Oxfordshire and central East Anglia (described further in Chapter Three), thirteen farmers leased at least one sprayer, seven of these growers not owning any sprayers at all. A total of fourteen sprayers

FIGURE 2.4. Age distribution of owned sprayers on 65 farms in Oxon. and East Anglia (in 'random farmer' survey - see Chapter Three), interviewed Feb. - April 1982. Total no. of sprayers owned = 84 (arable sprayers only).

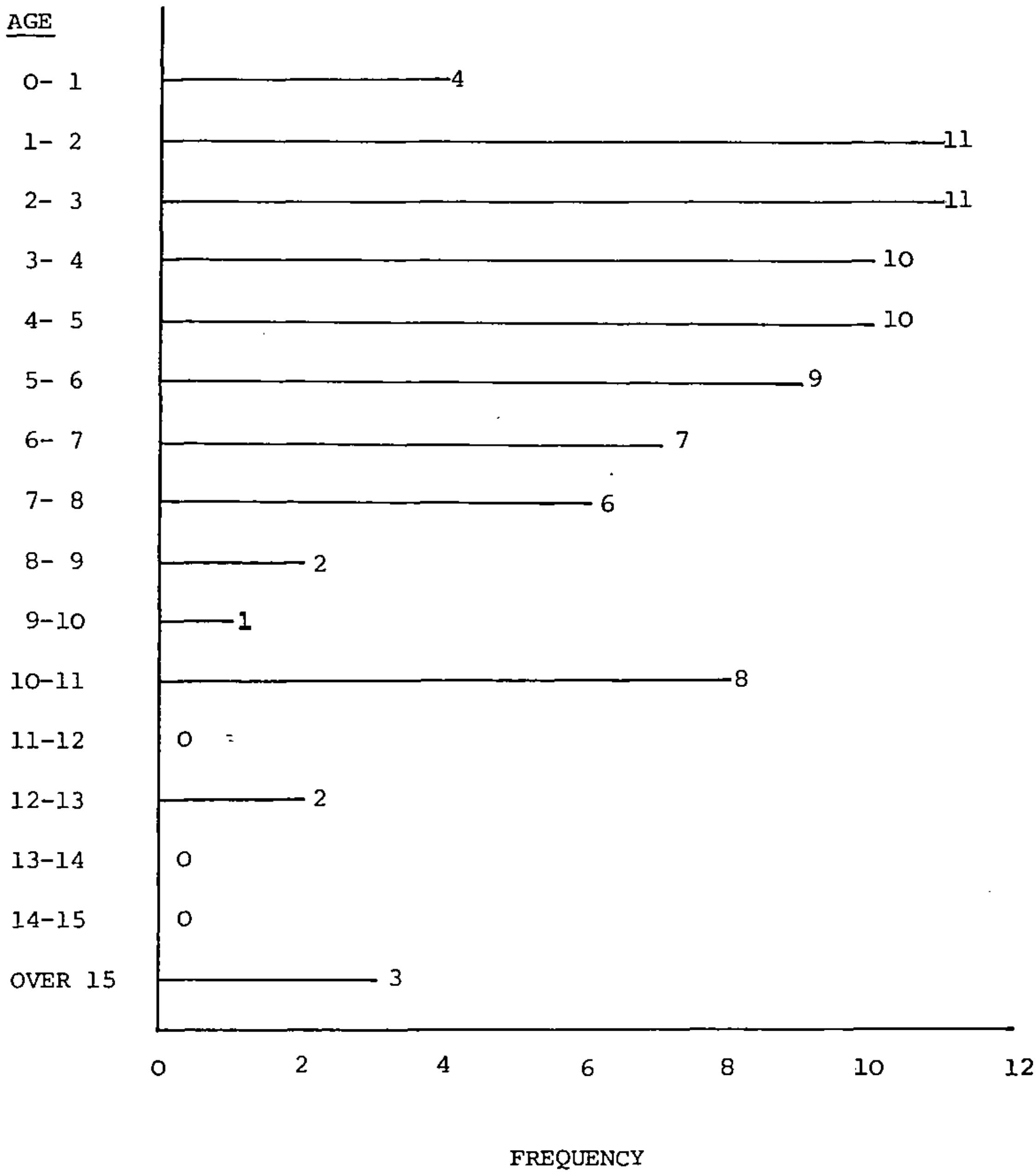


TABLE 2.5 Reasons given for changing owned sprayers. The number of reasons listed (95) exceeds the number of respondents (66 respondents owned sprayers) as some respondents gave more than one reason.

REASON	NO
When existing sprayer wears out/becomes inefficient	30
Design improvements in sprayers	23
Increase machine size	12
Take advantage of new sprayer technology	7
When maintenance and repair costs become excessive	6
When a major machine component fails	5
Good second-hand value	2
Change sprayer so can "tramline"	2
When sufficient funds available	1
When "out of date"	2
Large sprayer won't wear out quickly	1
Fixed replacement policy	1
Due to high cost of sprayers will contract out in future	1
First sprayer owned on farm	2
	95

in the survey were found to be leased. When asked the reasons why they leased sprayers, six respondents stated that there was a cost advantage in leasing sprayers; five respondents leased sprayers from a company that also supplied chemicals, with a sliding charge for the sprayer; one respondent each stated that: initial outlay was avoided, a modern sprayer was kept on the farm, a decision to buy new types of crop sprayers was being deferred, and one grower 'borrowed' his sprayer from a neighbour. Leasing appears to be increasing in popularity in U.K. agriculture; between 1980 and 1982, the total value of plant and machinery assets leased rose from £70 million to £168 million, a rise from 13.8% to 29.7% of gross capital formation (Arnold, 1983).

There is some evidence for a limited sharing of machinery by farmers in the U.K. In a survey of 30 farms under 80 hectares, Sturrock et al (1977) found that fourteen respondents shared some items of agricultural machinery with other farmers. It was found that among the most commonly shared items were sprayers. Although capital costs may be reduced, it may not be always possible to ensure timeliness, and there is a certain loss of independence suffered by the individual farmer. Sturrock et al (1977) identify the latter factor as being particularly important to small farmers, who generally have a full, or nearly full machinery complement even on quite small farms.

Successful, organised "machinery rings" have been found to exist in West Germany (West African Farming, 1981).

2.8 SUMMARY OF CHAPTER TWO

1) Total U.K. sales for pesticides and growth regulators in 1981 was £242.4 million. There is an upward trend for sales in most chemical types. In terms of value of chemical applied, weeds are more important

in the U.K. than insects or fungal diseases.

2) In British arable cropping systems, the predominant form of pest control is by using chemicals. The prospects for genuine integrated control in most field-scale arable crops in the U.K. in the foreseeable future is poor.

3) Imperfect knowledge of the possible outcomes of future events can lead to risk and uncertainty. Most decisions in agriculture have elements of riskiness and uncertainty in them. Pest control decisions by individuals are influenced by the farmer's objectives, the farmer's perception of organisms as pests, and the available control options.

4) The cost:benefit value of an application of pesticides is generally between 3:1 and 9:1. The value of a pesticide application is usually assessed in marginal terms. Recent work has tried to evaluate pesticide application as a durable asset, the time period being the interval between pest scouting operations.

5) Government policy, as suggested in the Seventh Report of the Royal Commission on Environmental Pollution, should be to reduce pesticide usage to a minimum consistent with efficient food production.

6) Mechanisation is a means of reducing total farm costs, labour usually being replaced. Depreciation is the largest single machinery cost item. Obselescence in various forms necessitates replacement of machinery at intervals. Crop sprayers constitute about one fortieth of total machinery investment on large arable farms, and are generally replaced between five and ten years of age.

CHAPTER 3

SURVEYS: AIMS AND OPERATION

3.1 Introduction

This chapter outlines the means by which much of the data for this thesis was collected. Three surveys were used to gather information. The survey objectives, survey design, and execution of surveys are described.

In carrying out the three surveys, it was desired that a set of primary objectives be investigated:

1) evaluate present practices and orientations to new technology among a random sample of farmers.
2) contact users of new crop sprayer technology to find out their experiences of the innovation.
3) attempt to forecast prospects for new crop spraying technology.

Each of the three surveys in this chapter attempts to fulfil at least one part of the strategy. Brief details of each of the surveys carried out are provided in Table 3.1.

3.2 The knowledge gap

Initially, existing information on aspects of pest control on arable farms in the U.K. was gathered, and is reported on in Chapters Two and Four. In reviewing the information available, it was felt that in the context of assessing likely future developments in pest control, several areas required further research to provide a more complete picture of present practices, and to give an indication of possible future trends:

1) current spraying practices. This includes: the type and number of sprayers on the farm, the farm spraying programme, and use of

TABLE 3.1 Outline of main surveys carried out in the thesis.

Date carried out	Sampling frame	Method of interview	Numbers in survey	% Response (as a % of those suitable)	Common 'name' in text	Refer to Sections
Feb-April 1982	Telephone directories: names under 'Farmer' taken from directories in central East Anglia and south Oxfordshire and surrounding districts.	Personal	37 in central East Anglia 39 in south Oxfordshire and surrounding districts	80 (76/95)	Random Farmer survey or Random User survey.	3.3.3
Dec 1982 - Feb 1983	List of persons supplied by CDA Ltd, Lockinge, Oxon, who purchased an "Ulvamast" sprayer in Berks, Oxon, N. Hampshire, Bucks & Surrey to 1981	Personal	26 in Berkshire, Oxon, Hants, Bucks & Surrey	79 (26/33)	Ulvamast user survey	3.3.13
Nov 1982 - Feb 1983	Selected list of experts in relevant agricultural sectors	Postal	238 questionnaires sent out to individuals	70 (167/238)	Postal survey	3.3.15

contractors in spraying.

2) Awareness, attitudes to, and uptake of, relevant arable devices and techniques. This is with particular reference to innovations recently on the market, or soon to come on the market. The adoption and diffusion of innovations is discussed in detail in Chapter Six.

3) Investigation of the logistics of crop spraying operations. A large proportion of the time assigned to spraying may be spent in operations other than physically applying chemicals to the crop. What are the factors important in influencing the speed of sprayer operations? An investigation of the nature and level of parameters affecting the efficiency of crop spraying operations is outlined in Chapter Five. In this case, survey results are complemented by modelling the effects of changes in spraying parameters on the rates of work attainable. This is also discussed in Chapter Five.

4) Finding out about how weather impinges upon spraying operations. Recommendations are issued by several organisations when it is safe to spray, e.g. by ADAS, chemical companies. Does the farmer stick to the guidelines? Is the weather a major constraint in spraying operations? If so, what are the elements of the weather most active in constraining spraying? Findings in these areas can be complemented by an analysis of historical data from appropriate weather stations. Data on these topics is discussed in Chapter Five.

5) The use of information sources for finding out about such topics as weather forecasts, and new machinery.

6) Opinions on possible future developments in pest control on arable farms in the U.K.

Having elucidated the general areas where the desired information should be obtained, the next step is to outline the methods by which relevant data can be collected. For much of the information, it is necessary to conduct surveys of relevant individuals. These are outlined in Section 3.3.

3.3 Survey Objectives and Methods

3.3.1 Introduction

In this section, more specific objectives concomitant with the research areas outlined in the last section are presented. From the objectives, more specific proposals for investigation are also presented, which are embodied as one or more questions in the questionnaire - the methods used for gathering information are personal and postal surveys of relevant individuals. In this case, the "proposals for investigation" may be said to be roughly equivalent to a hypothesis, where 'hypothesis' is defined as "a subordinate thesis; a particular case of a general proposition" (one of a number of definitions, cited in the Shorter Oxford English Dictionary, 1944). Rosenberg (1968) warns against the uncritical use of hypotheses in survey research;"even if an hypothesis is drawn from theory and is supported by the data, the data do not prove the theory, they only support it". Rosenberg also states that relationships detected between variables may be spurious, and that "much can be learned in survey analysis which is not based on the explicit testing of clearly stipulated preformulated hypotheses". However, posteriori analyses should be used with some caution, using guidelines such as those suggested by Rosenberg (1968). Selvin and Stuart (1966, quoted in Moser & Kalton, 1971) used the term "hunting" for a lack of prior hypotheses, subsequently generated from an inspection of the data. 'Generally, in conducting a survey, some hypotheses, no matter how crude and unstated, are generally implicit' (Rosenberg, 1968).

3.3.2 Survey objectives - strategy

It was decided to pursue the first five research areas outlined in Section 3.2.1 by means of interviews with farmers. The sixth research area, that of elucidating opinions on possible future developments in pest control measures, was to be carried out by a postal survey of experts in relevant sectors of the agricultural industry.

The six research areas to be investigated were divided into three groups: research areas 1, 2 and 5 ("attitudes and innovativeness"), research areas 3 and 4 ("sprayer logistics and weather constraints"), and research aim (6) to be covered in a postal survey of experts. Three separate surveys were proposed, covering the three groups of research areas. Leaving the survey concerned with research aim (6) aside, some overlap in the material covered in each of the farmer surveys was intended, in order to allow at least some validation of the results obtained from the other survey. In the event, considerable overlap occurred between the two surveys, particularly in the matter of uptake of innovations: the survey mainly covering sprayer logistics and weather constraints was conducted among users of an innovative crop sprayer.

3.3.3 Survey objectives - survey investigating farmer attitudes, innovativeness and spraying behaviour ("Random farmer survey").

Bearing in mind the research aims, and the need to overlap to some extent with the other personal interview survey, six main objectives were selected for study in the survey:

1) enquiring into current spraying practices and sprayers presently on the farm
2) finding out about awareness, attitudes to, and use of selected items of new technology on the farm,
3) finding out about the role of contractors in spraying

4) finding out about the use of information sources in weather forecasts, decisions on when to spray, and how new machinery is heard about.
5) detecting problems encountered with sprayers, chemicals, and difficulties caused by labour shortages and inclement weather.
6) finding out farm and crop acreages, and personal characteristics of the farmer.

In carrying out a survey to achieve these objectives, it was decided that certain farm size and crop area requirements should be set. This is to ensure that farmers interviewed have a substantial interest in arable cropping, and are of a size large enough to justify having a tractor-size crop sprayer on the farm, and to be in a position to consider using new crop spraying technology.

Consequently, a farm size requirement of at least 125 acres (50 hectares) was set, with at least 50 acres (20 hectares) of cereals being grown. However, during the course of the survey, the area requirement was relaxed to 70 acres (28 hectares). Further details of the method of sampling is given in Section 3.3.7.

3.3.4 <u>Selection of farming areas to be surveyed - random farmer survey</u>

Several criteria were set when deciding which area, or areas, were to be surveyed:

1) since the topics to be covered concern crop spraying, the areas to be surveyed should ideally be predominantly arable.
2) It was decided that an area in two regions should be surveyed, in order to detect if regional variations were present.
3) Areas to be surveyed should be fairly near to a weather recording station, as it was intended to do a parallel analysis of historical weather data collected at the weather station.

4) The areas to be surveyed should be reasonably homogeneous, in terms of topography and land use. Large variations within an area will require a larger sample size in order to fully record these variations. However, some degree of heterogeneity is desirable, as if results are to be extrapolated outside the sampled population at all, then greater validity can be claimed if results incorporate at least some variation.

5) It is intended in the survey to measure the innovativeness of farmers by recording their length of use of a number of innovative arable devices and techniques. The areas selected to be surveyed should not have features mediating against the use of one or more of the innovations in that area. This applies particularly in the case of the adoption of an item such as direct drilling, where some soils may exhibit a substantial risk of lower yield if combine-harvested crops are direct drilled, than if they are conventionally cultivated (Cannell, Davies and Pidgeon, 1978).

Taking into account the above criteria, it was decided to interview farmers in central East Anglia and south Oxfordshire. The two areas are predominantly arable - over 50% of much of these two areas is devoted to cereals (Finch, 1974, quoted in Cannell et al, 1978). In each of the two areas, there is a weather station nearby: RAF Benson in south Oxfordshire, and RAF Honington in central East Anglia. A further description of each of these two areas is in the next two sections.

3.3.5 Land around RAF Benson

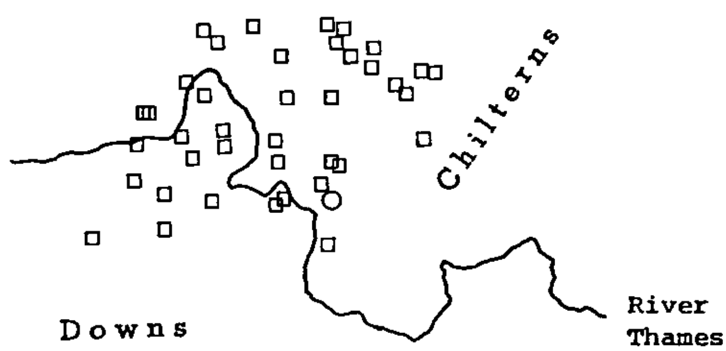
In describing the agricultural use of land around Oxford and Newbury, the Agricultural Land Classification Report number 158 (ADAS, 1976) notes that large arable farms, mainly growing cereals, predominate in this area, with large mixed farms along the upper Thames Valley above Oxford.

FIGURE 3.1. Distribution of farms sampled in the random user survey, around RAF Benson. n=39. Scale = 1 : 1 000 000.

KEY

□ Farm

○ RAF Benson



Despite dairying being the major type of farming in several low-lying areas, a considerable amount of cereals are also grown. Intensive horticultural holdings occur in the Thames Valley between Oxford and Reading, and on Upper Greensand soils around Harwell and Milton Hill.

In a map showing the soil suitability for direct drilling of combine-harvested crops, the majority of soils in this area are amenable to direct drilling (Cannell et al, 1978). Some soils, particularly those adjacent to the Thames, are classed as "Category 3", or not particularly suitable for direct drilling. However, these soils are likely to be devoted to dairying.

In this area, the altitude varies considerably - from below 61m to over 229m, with extensive flat or gently sloping land in the Thames Valley. The Berkshire Downs and Chilterns are typified by a "rolling" relief (ADAS, 1976).

In the survey, it was decided to exclude farms situated on the Chilterns and on the Berkshire Downs, for several reasons: in order to ensure that the farm type and relief was fairly homogeneous, and to ensure that the survey area was fairly compact for reasons of travelling time and cost. Further details of the survey are given in Section 3.3.8.

In the survey, farmers were interviewed at sites up to 30 kilometres from RAF Benson. Few farmers were interviewed at sites to the south and south east of RAF Benson, because as stated before, farms situated on the Berkshire Downs and Chilterns are omitted (see Figure 3.1). As the farms are mostly situated at an altitude and relief similar to that at RAF Benson, it is hoped that weather conditions experienced and recorded at Benson are similar to those encountered by farmers in this area.

The reason for interviewing farmers around a weather station is that in Chapter Five an analysis of weather data from RAF Benson is made, in order to evaluate spray-days available. Using local weather data increases the relevance of the weather data analysis findings, and some "tying-in" may be possible.

3.3.6 Land around RAF Honington

This area is covered by Agricultural Land Classification Report number 136 (ADAS, 1974). One of the most distinctive features of this area is the Brecklands, an extensive sandy tract, much of which is forest or heathland. Much of the land in the area is gently undulating, and the highest point on the map is 122 metres.

Over most of the area, the land use is predominantly arable. However, in the east of the area covered by the report, more land is under permanent grass, but arable cropping (cereals, sugar beet, beans and peas) does occur.

The brown calcareous sands characterising the Brecklands are classed by Cannell et al (1978) as being in "category 3" as regards soil suitability for direct drilling of combine-harvested crops: "compared with conventional cultivation there is a substantial risk of lower yield, especially with Spring sown cereals". Due to the nature of the soils however, there is much forest and heath in this area, rather than arable farming.

In the survey, farmers were interviewed at sites up to 34 kilometres from RAF Honington (see Figure 3.2). Few farms were situated on the Breckland soils.

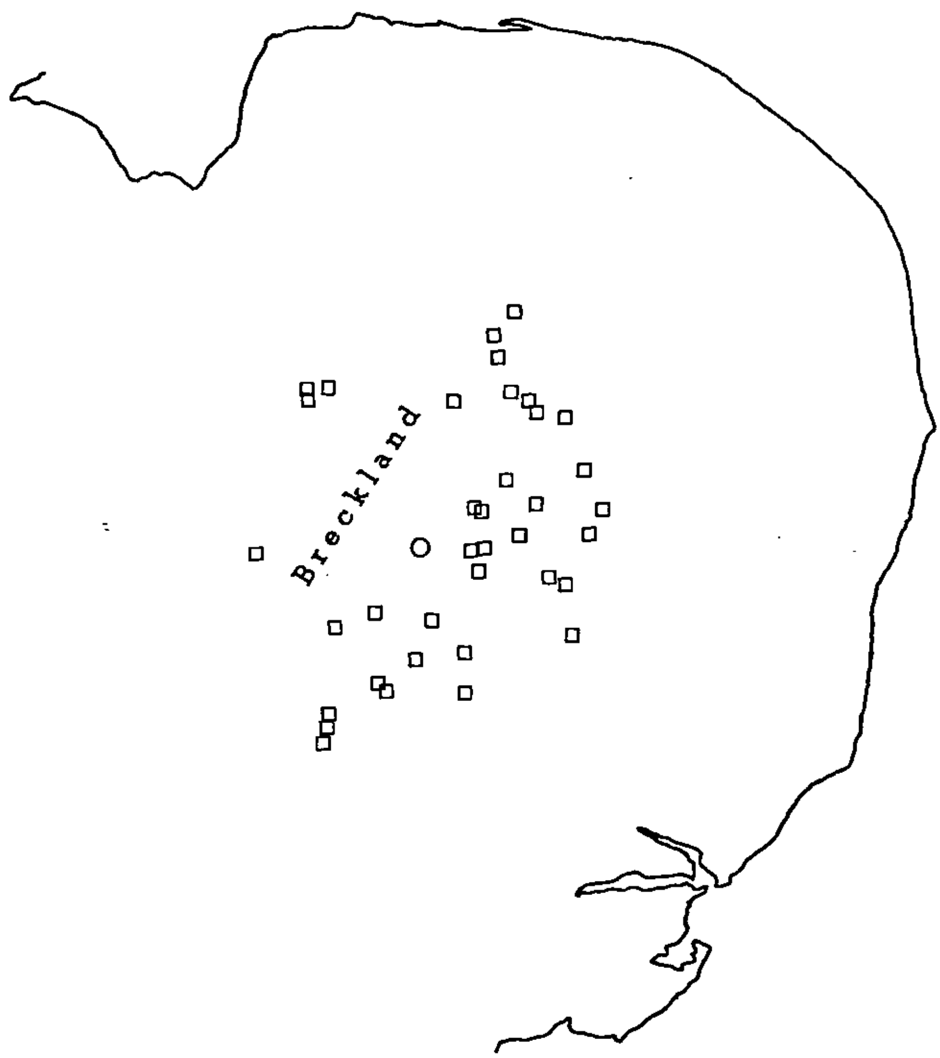
As the farms are mostly situated at an altitude and relief similar

FIGURE 3.2. **Distribution of the farms sampled in the Random User survey,** around RAF Honington. n=37. Scale = 1 : 1 000 000

KEY

□ Farm

○ RAF Honington



to that at RAF Honington, it is hoped that weather conditions experienced and recorded at Honington are similar to those experienced by surveyed farmers. (In fact only data from the weather station at RAF Benson was subsequently analysed - see Chapter Five).

3.3.7 "Random farmer" survey-sampling frames used

The Ministry of Agriculture, Fisheries and Food (MAFF) is considered to be the only body keeping a complete up-to-date list of growers in England and Wales, due to the Annual Returns that the occupant of all holdings is required to make. However, this source is not readily available for use. Consequently telephone directories were used as a sampling frame: farmer's addresses can be found under the heading in the "Yellow Pages". Persons who use their telephone for business purposes are entitled to one entry in the Yellow Pages. Farmers are encouraged to register their telephone as a business line, rather than as a domestic one, as it may then be possible to offset the telephone costs against taxation on the farm enterprise. Notwithstanding this, it is likely that a number of farmers in an area will not be listed under "Yellow Pages" for one of several reasons.

1) the telephone is registered for domestic rather than business use.
2) the farmer does not possess a telephone.
3) some farmers may be listed under a heading other than "Farmer".
4) the farmer may choose to be ex-directory.

In addition, the telephone listing of a region may be up to one year out of date, as directories are only revised every twelve months.

Despite these possible shortcomings for using telephone directories as a sampling frame, it was felt that the Yellow Pages were still acceptable. Reasons (1), (2), and (3) above would apply mostly to the small farmer. Since it was intended that only farmers with at least 20 ha of cereals and 50 hectares of land (later relaxed to 28 hectares - see Section 3.3.8) should be interviewed, it was felt that farms this size or greater would usually be in the directory. In addition, as farming is a fairly "static" occupation, with little change occurring in time periods as short as a year, it was felt that even a year-old telephone directory would still be satisfactory for sampling from. Other researchers have used telephone directories for sampling farmers, e.g. Newby (1977). The sampling frame will only be biased if non-entry is due to one or a number of reasons; if non-entry is truly random, then this will not introduce bias.

Farmers are arranged alphabetically in the Yellow Pages, with their address, telephone exchange and phone number. Although it is not possible to ascertain the precise areas covered by telephone exchanges (being an Official Secret) it is possible to obtain a rough idea from the name of the telephone exchange, and the addresses of the farmers which that telephone exchange serves. For the purposes of the survey, it was decided to include farmers whose quoted telephone exchange served at least part of the area within a fifteen-mile radius of the appropriate weather station site. Some farmers were interviewed at an address sited upto 34km (21 miles) from the weather station; this was because the area covered by the particular telephone exchange ranged out from an area just within an area defined by the fifteen mile radius.

Tables 3.2 and 3.3 give a list of telephone exchanges where at least part of the area served by that telephone exchange is within a fifteen mile radius of the respective weather station. Also included are the telephone directories used, and the number of farmers served by each of the telephone exchanges. Figures are for the 1981 directories.

TABLE 3.2 List of telephone exchanges covering areas in a 15-mile radius of RAF Honington. The figures indicate the number of farmers served by each telephone exchange, in the 1981 directory.*

Colchester area directory

Exchange	Number
Bacton	38
Haughley	12
Mendlesham	30
Rattlesden	44
Stowmarket	44
	168

Norwich area directory

Exchange	Number
Attleborough	79
Botesdale	30
Bressingham	37
Caston	35
Diss	29
East Harling	11
Garboldisham	19
Great Hockham	15
Mellis	35
New Buckenham	42
Quidenham	22
	354

Total 'sampling frame' size (number of farmer entries) : 1011

Cambridge area directory

Exchange	Number
Beyton	16
Bury St. Edmunds	27
Chevington	16
Cockfield	34
Coney Weston	17
Culford	12
Elmswell	26
Elveden	5
Eriswell	6
Feltwell	17
Great Barton	8
Hartest	16
Hawkedon	19
Honington	12
Horringer	10
Isleham	31
Methwold	21
Mildenhall	37
Mundford	14
Ousden	5
Pakenham	16
Sicklesmere	16
Stanton	21
Thetford	38
Walsham-le-Willows	32
Wickhambrook	17
	489

*If more than one phone number is given for one farm, this is counted as one entry; if more than one farm is given for an individual, the number of entries equals the number of farms.

TABLE 3.3 List of telephone exchanges covering areas in a 15-mile radius of RAF Benson. The figures indicate the number of farmers served by each telephone exchange in the 1981 directory.*

Oxford area directory

Exchange	Number
Abingdon	19
Blewbury	12
Brill	40
Charlton-on-Otmoor	16
Childrey	7
Clifton Hampden	9
Cumnor	10
Didcot	16
Drayton	4
East Hendred	10
Frilford Heath	11
Garsington	5
Great Milton	16
Haddenham	11
Harwell	5
Ickford	15
Kidlington	17
Kingston Blount	25
Long Crendon	18
Longworth	10
Nunenham Courtenay	12
Oxford	49
Stadhampton	23
Standlake	20
Stanton St. John	16
Sutton Courtenay	5
Tetsworth	18
Thame	20
Wantage	27

Oxford directory (continued)

Exchange	Number
Warborough	3
West Hanney	10
Wheatley	11
	490

Reading area directory

Exchange	Number
Wallingford	17

Total 'sampling frame' size (total number of farmer entries) = 507

* If more than one phone number is given for one farm, this is counted as one entry; if more than one farm is given for an individual the number of entries equals the number of farms.

Farmers were selected for interview after contact by phone to ascertain if the farm size and cereal acreage were sufficient. Details of this are given in Section 3.3.8.

The survey design may be summarised as a simple random design carried out in two areas. The lack of knowledge of the farmers in the Yellow Pages does not permit any more complex a priori sampling designs.

3.3.8. Random farmer survey method

Initially, a "pilot" survey of farmers was carried out, in order to test the veracity of the questions and the survey method. For the pilot survey, a list of farmers was drawn at random from the appropriate telephone directories. These farmers were contacted by letter (reproduced in Appendix). The letter requests co-operation from farmers if their farm size exceeds 50 ha (125 acres), with at least 20 ha of cereals (50 acres). Following the initial contact letter, the farmers were then contacted by telephone, and asked a) if their farm conformed to the size criteria stipulated in the letter, and b) if they were willing to participate in the survey.

Numbers contacted and interviewed in the pilot survey are reported in Table 3.4.

As a result of responses given to questions in the pilot survey, some minor amendments were made to the questionnaire. The main portion of the survey was then carried out, using the same survey method as that used for the pilot survey. Numbers contacted and interviewed in the main survey are reported in Table 3.5.

In carrying out the survey in this manner, it should be noted that the population of farmers to be sampled in the survey can only be estimated at the end of the survey: it is not known in advance which farmers are of the necessary size to be included in the survey. An estimate of the population sampled from is given in Section 3.3.9.

In both the pilot and the main survey, a number of farmers were contacted who agreed to participate in the survey who when interviewed were found to be too small regarding the farm size and/or the cereal area grown, with respect to the size criteria stipulated in the initial contact letter (⩾50 ha farm, ⩾20 ha cereals). Three farmers were interviewed who grew less than 20 ha cereals: one farm was 20 ha in size (14 ha cereals), another farm was of 28 ha (19 ha cereals), the third farm was 67 ha but with only 17 ha cereals. As less than 20 ha cereals were grown on these farms, it was felt that these farmers were not substantial cereal growers, and accordingly these three respondents were excluded from the survey analysis.

Seven farmers interviewed grew over 20 ha cereals but had a farm size of less than 50 ha. The size of these farms were:

Total Farm Size (ha)	Cereal area (ha)
28	22
40	38
43	28
47	38
49	32
49	36
49	40

As it was felt that these farmers were substantial cereal growers, it was decided to include them in the survey analysis: the objective of the farm and cereal area requirements are to filter out the small farms that would not be able to justify the purchasing of new crop spraying technology.

As these farmers grew over 20 ha cereals, it was felt that these were substantial cereal farmers. Accordingly it was decided to include these farms in the survey analysis: there is a posteriori change in the farm size criterion from 50 ha down to 28 ha. This obviously has ramifications regarding response rates. From information supplied over the telephone when selected farmers were contacted it is estimated that two other farmers (one in each of the two areas surveyed) among those sampled should have been interviewed had the size requirement of 28 ha been stipulated in the initial contact letter. Estimates of the population with given size attributes are made in Section 3.3.9.

When contacted by telephone, several farmers declined to be interviewed. Reasons given for this were: "too busy lambing or calving (4 farmers)", "too busy - don't want you to bother me" (3), "too busy - all cereals sprayed by contractor" (1), "messed about by previous interviewers" (1), "no gain for me in being interviewed" (1), and with one farmer a mutually convenient time couldn't be arranged. Non-respondents therefore appear to split into two groups : farmers who were seasonally very busy, e.g. with lambing, and a number who were not prepared to be interviewed under any circumstances.

Seventy-nine farmers were interviewed in the survey. In all cases, efforts were made to contact the name quoted in the telephone directory. An interview was requested with the person on the farm responsible for decision-making in the machinery purchasing and crop spraying operations.

Interviews were conducted by arranging a convenient time with the farmer. Most interviews took place on the farm. The length of the interview ranged between 20 - 50 minutes, most taking about 30 minutes. The pilot interviews were conducted in February 1982. The main survey

TABLE 3.4 Pilot survey response, broken down by area and size criteria

			Result of telephone contact			Comments
"Honington" area.						
Farm size	<50 has, <28 has	<20 has cereals	Not interviewed	4		N.B. Total number of farmers in telephone
Farm size	<50 has ≥28 has	≥20 has cereals	Interviewed	1	40 has cereals	list = 1011 (from Table 3.2).
Farm size	≥50 has	≥20 has cereals	Interviewed	4		Two going on holiday, 1
			Not interviewed	3		refusal ("just moved house").
"Benson" area						
Farm size	<50 has <28 has	<20 has cereals	Not interviewed	4		N.B. Total number of farmers in telephone list = 507
Farm size	<50 has ≥28 has	≥20 has cereals	Interviewed	1	47 has cereals	(from Table 3.3).
Farm size	≥50 has	≥20 has cereals	Interviewed	5		
			Not interviewed	1		Refusal ("too old")

TABLE 3.5 Main survey response, broken down by area and size criteria.

Honington area			Result of telephone contact		Comments
Farm size	<50 has,	<20 has cereals	Not interviewed	14	
	<28 has		Interviewed	2	Excluded from survey analysis
Farm size	<50 has	≥20 has cereals	Interviewed	4	1 farm @ 28 has,
	≥28 has		Not interviewed	1	3 @ 49 has
Farm size	≥50 has	≥20 has cereals	Not interviewed	8	6 refusals, 2 on holiday
			Interviewed	28	
			NON-CONTACT	3	
				60	

N.B. Total farmer list size = 1011 (from Figure 3.4).

TABLE 3.5 (continued)

Benson area			Result of telephone contact		Comments
Farm size	<50 has <28 has	<20 has cereals	Not interviewed	20	
Farm size	⩾50 has	<20 has cereals	Interviewed	1	Excluded from survey analysis
Farm size	<50 has ⩾28 has	⩾20 has cereals	Interviewed Not interviewed	1 1	Farm size : 43 has Farm size : 48 has
Farm size	⩾50 has	⩾20 has cereals	Interviewed Not interviewed	32 5	 Refusals
				60	

N.B. Total farmer list size = 507 (from Figure 3.5).

was conducted in March and April 1982. Owing to the variability of interview length, and the distance between respondents, only 3 or 4 interviews could be carried out each day. Interviewing was carried out by the author. Over 4,000 miles were travelled in interviewing.

As amendments made following the pilot survey were minor, and the sampling frame used was the same as for the main part of the survey, results from the pilot and the main survey are analysed and reported together in the following chapters. When a question was not asked in either the main or the pilot survey, or the wording changed, this will be indicated in the text.

3.3.9 Population estimates

For a simple random sample of size n from a finite population of size N, the test to estimate the proportion of the population with some particular attribute is given by the standard error of the proportion:

$$S.E._{(p)} = \sqrt{(1 - \frac{n}{N}) \times \frac{p(1-p)}{n} \times \frac{N}{(N-1)}} \qquad \ldots (1)$$

(Moser & Kalton, p. 147, 1971) p = proportion with the attribute in the sample.

Combining the pilot and main survey results for each of the two areas, then in order to estimate the proportion of farms with over 20 ha cereals and 50 ha total farm size, the relevant numbers are added from Tables 3.4 and 3.5.

For the 'Benson' area, N = 507. The number of farms known to be ≥50 ha with ≥20 ha of cereals (gathered from information obtained over the phone or at the interview) is 43, from 71 contacted. Therefore p = 43/71 = 0.606. The standard error of the estimator is then:

$$S.E._{(p)} = \sqrt{(1 - \frac{71}{507}) \times \frac{0.606(1-0.606)}{71} \times \frac{507}{(507-1)}} = 0.054$$

The estimate for the proportion of the population of farms being of a size ⩾50 ha with ⩾20 ha of cereals at the 95% confidence level is

$0.606 \pm (1.96 \times 0.054)$

$= \quad 0.606 \pm 0.106$

Thus between 0.50 and 0.71 of the telephone entries are of the requisite size or between 254 and 361 farms. If the farm size requirement is reduced to 28 ha, then n = 46, and the $S.E._{(p)}$ = 0.053 meaning that at the 95% confidence level, between 276 and 381 farms in the 'Benson' area farmer lists are ⩾28 ha with ⩾20 ha cereals.

For the "Honington" area telephone lists N = 1011. If the three farmers who could not be contacted are excluded, then n = 69. The number of farms known to be ⩾50 ha with ⩾20 ha cereals is 43. Thus the $S.E._{(p)}$ = 0.056. At the 95% confidence level, between 573 and 686 farms in the 'Honington' area sampling frame are ⩾50 ha with ⩾20 ha cereals. If the farm size requirement is reduced to 28 ha, then n = 48. The $S.E._{(p)}$ is then 0.053. At the 95% confidence level, between 650 and 757 of the farms in the 'Honington' area sampling frame are ⩾28 ha with ⩾20 ha of cereals.

The manipulation of equation (1) is one of the means by which an estimate can be made of the number of samples needing to be taken from a population in trying to answer the question: 'How big a sample do I need?' This will be discussed further in Section 3.3.10.

As it is intended for some parts of the analysis to combine the data from the two areas, it may be instructive to compare the two population groups. The standard error for the difference between the two sample proportions is estimated by:

$$S.E._{(p_A - p_B)} = \sqrt{p(1-p)(\frac{1}{n_A} + \frac{1}{n_B})}$$

where $p = \frac{r_A + r_B}{n_A + n_B}$ (Moser & Kalton, 1971, pp. 75-6)

where n_A and n_B are the sample sizes

r_A and r_B are the numbers of individuals in each of the samples having a given attribute.

For testing differences between the proportions of the two populations where farm size ≥50 ha cereals ≥20 ha.

For the 'Benson' area, $n_A = 71$ $r_A = 43$ .. $p_A = \frac{r_A}{n_A} = .606$

For the 'Honington' area $n_B = 69$ $r_B = 43$ .. $p_B = \frac{r_B}{n_B} = .623$

Then p = 0.614

S.E. $(p_A - p_B) = 0.082$

Assuming a null hypothesis, the difference between p_A and p_B will be significantly different at the 95% confidence level if

$$| p_A - p_B | > 1.96 \times (S.E._{(p_A - p_B)}).$$

As 0.017 $\not>$ 0.16,

there is not sufficient evidence to suggest that there is a significant difference in the proportions of farms of size ≥50 ha and cereals ≥20 ha in the two areas. When the farm size requirement is relaxed to 28 ha (with ≥ 20 ha cereals), $p_A = 0.648$, $p_B = 0.696$; $S.E._{(p_A - p_B)} = 0.079$ and at the 95% confidence level differences in the proportion of farms of this size in the two areas are not significant.

At the 95% confidence level, between 276 and 381 farms in the 'Benson' sampling frame are ≥28 ha with ≥20 ha cereals. The range for the 'Honington' sampling frame are 650 and 757. Adding the figures together gives an estimate of between 926 and 1138 farms in the two areas with a farm of

⩾28 ha and ⩾20 ha cereals, with a middle value of 1032.

3.3.10 Sample sizes

It is the trade-off between added information and added costs that makes sample size determination difficult (Tull and Hawkins, 1976). However, if cost and other practical limitations do not enter into the picture, there is no basic difficulty in determining the desired sample size; nevertheless, in practice the task of deciding on sample size is more complicated than theoretical considerations alone would suggest (Moser and Kalton 1971).

There are several factors to be considered when deciding on the sample size in a survey:

1) the level of confidence it is wished to place on inferences drawn from the data. For instance, it may be wished to examine differences between figures with a stated chance (say 1 in 20) that the figures are significantly or not significantly different.

2) The level of precision required of a result. For instance, in wishing to estimate the proportion of a population with a given attribute, it may be desired to estimate the proportion within a given range (e.g. 53% ± 5%), for a given level of confidence. Decisions on sample size are often largely governed by the way the results are to be analysed.

3) Population size. Most methods for estimating population size (see below) assume a very large population size. Moser and Kalton's method does take into account "small" populations by means of a "finite population correction". Population size corrections are unlikely to have much effect on sample size considerations until the population drops below 1000 (Russell and Thompson 1975) or the sample size is likely to exceed 5% of the total population (Moser & Kalton 1971).

4) Survey design. Most methods of calculating the sample size assume a simple random design; for more structured designs, the proper estimation of sample size may be quite complex (Moser and Kalton, 1971). Generally, the more complex the survey design, the larger the sample required.

5) Questionnaire content. Most surveys have a number of objectives which will require the measurement of a greater or lesser number of variables. A sample size big enough for one variable may be inadequate for another that requires greater precision (Moser and Kalton, 1971). For example, some questions may demand a simple yes/no answer, whilst others may have a number of alternatives. This latter situation generally demands a larger sample size, and a consideration of the proportions of respondents falling into each response section. Also variables measured in fulfilling objectives may have different precision levels placed upon them. Thus sample size may be governed by the methods of data analysis, and the requirements regarding data quality for interpretation of that data.

   In theory, this variety of stipulations would demand that the sample size be big enough to conform to the desired precisions for all the variables. However, this could lead to very large sample sizes. Thus it may be necessary to rank objectives or assess their need at all.

6) Statistical considerations may have to be tempered with time, cost and personnel considerations. Moser and Kalton (1971) state that in such circumstances, "it is best to take the largest sample financially possible and to discard questions for which a much larger sample would be needed to give useful results".

Several authors have considered sample size requirements in surveys, such as Yates (1960), Sokhal and Rohlf (1969), Moser and Kalton (1971), Tull and Hawkins (1976) and Russell and Thompson (1975). Methods involved generally require a consideration of the nature of the population and possible sampling errors. For instance, in attempting to estimate the proportion in a population with a particular attribute (π), then ignoring corrections for a finite population,

$$\text{standard error}_{(p)} = \sqrt{\frac{\pi(1-\pi)}{n}} \qquad n = \text{sample size} \qquad \ldots.(2)$$

(Moser and Kalton, 1971)

By roughly estimating π and the s.e.$_{(p)}$, an estimate of the sample size from equation (1) can be made:

$$n = \frac{\pi(1-\pi)}{[\text{s.e.}_{(p)}]^2} \qquad \ldots.(3)$$

If the population size N, is small enough, then a finite population correction (f.p.c.) is needed:

$$n' = \frac{n}{1 + (n/N)} \qquad n' = \text{sample size adjusted for f.p.c.} \quad ..(4)$$

Confidence limits may be applied to equation (3) by multiplying (3) by the appropriate t- statistic, as used by Russell and Thompson (1975). In using a similar method, Tull and Hawkins (1976) use nomographs to enable a quick calculation of the requisite sample size. Using equation (4), if $N = 1032, \pi = 0.5.$ and s.e.$_{(p)} = 0.05$, then $n' = 92$. If s.e.$_{(p)}$ is changed to 0.06, then $n' = 66$. In obtaining a sample of 76, the size is of a reasonable number taking into account the standard error estimates. Time and money considerations also played a major part in deciding on a sample size. Mumford (1977) and Lane (1981) used similar statistical analyses as is intended to carry out on data from the survey of 76 farmers; numbers of farmers sampled are similar to these two researchers.

In addition to the 'traditional' method of determining sampling size is determined by applying the appropriate standard error formulae (Tull & Albaum 1973), other methods may be used. These are reviewed in Tull and Albaum (1973) and Tull and Hawkins (1976).

3.3.11 Non-sampling error

Five main types of non-sampling error are outlined by Tull and Albaum (1973). These are:

1) Surrogate Information Error. It may be necessary to obtain information that is surrogate due to the inability or unwillingness of respondents to provide the required information. For instance, in research concerned with future behaviour, one cannot directly observe future behaviour, but use some form of surrogate: past and present behaviour, attitudes, etc.
2) Measurement Error - in transmission of, or response to, the question, and in coding and analysis of data.
3) Frame Error - the noncorrespondence of sought to required sample. Regarding the suitability of telephone directories as a sampling frame, this is discussed in Section 3.3.7.
4) Selection Error - the noncorrespondence of selected to sought sample. For example, this may arise due to interviewing a person other than the selected respondent.
5) Nonresponse Error - the noncorrespondence of the achieved to the selected sample.

Tull and Albaum outline three strategies to deal with non-sampling errors: ignoring them, estimating them, or measuring them. In the three surveys outlined in this chapter, non-sampling errors are mentioned where relevant with the results, but generally not corrected for due to difficulties in estimation or measurement. However, this may mean that inferences drawn from the data must be subject to a greater degree of circumspection. Errors of measurement are likely to occur, particularly in respondent recall. When this factor may be important in affecting response accuracy, this is mentioned with the relevant results. Selection error was minimised by requesting to interview the machinery purchasing (and crop protection) decision-maker for the farm in the "random user" survey. Whilst every effort was made to contact farmers selected, three could not be contacted. Every effort was made to persuade farmers to be interviewed, but no corrections were subsequently made for non-response. In the postal survey, reminder letters were not sent out. However, Scott (1961) emphasises the value of reminder letters in increasing the response level in postal surveys.

3.3.12 Questionnaire design and question wording

A copy of each of the contact letters, the questionnaires and prompt cards used are reproduced in the Appendix. Questionnaire structure was guided by stated objectives and explicit hypotheses. Advice on question wording can be obtained from works such as Oppenheim (1966) and Moser and Kalton (1971).

3.3.13 Survey objectives - survey enquiring into sprayer operation on the farm and weather constraints - "Ulvamast user" survey

Based on the requirements of the research aims, and the need for some overlap with the survey outlined in the previous section, five main objectives were selected for study in the survey.

1) information on farm size, cereal acreage grown, sprayers on the farm, and the age and farming experience of respondents.
2) information on spraying activity: cereal spray rounds, the timing of applications, the number of days spent spraying through the year, spraying speeds, workrates, refilling arrangements and volumes used in spraying.

3) the influence of the weather on spraying operation.

4) observations, attitudes to, and use of new crop spraying technology on the farm.

For this survey, a list was obtained from CDA Ltd., of the purchasers of the 'Ulvamast', an innovative crop sprayer first marketed in the mid-1970's. It was decided to use this list as the sampling frame, and add a further objective in the survey to those outlined above.

5) information on use, observations and attitudes to the Ulvamast, being a recent example of new crop spraying technology.

The survey locates adopters of a "new" type of crop spraying machinery, and examines these farmers as innovators, as well as investigating the objectives outlined above.

3.3.14 Survey design - Ulvamast user's survey

CDA Ltd., the manufacturers of Ulvamasts, were approached for a list of persons who have purchased at least one Ulvamast. Approximately 363 persons in Great Britain have purchased at least one Ulvamast, about 445 units being sold. At the present time, the Ulvamast is manufactured "to order" and is not being actively marketed. For a full description of the Ulvamast, see Section 6.7.

In order to save time and money, and to facilitate at least some comparisons with results from the 'random user' survey, it was decided to see as many purchasers as possible from a fairly small area, around RAF Benson. As the number of Ulvamast users in the region surveyed around Benson in the random user survey was small, the area to be surveyed in was extended to cover Ulvamast users in Berkshire, Buckinghamshire, North Hampshire, Oxfordshire and Surrey. Table 3.6 gives details of the numbers contacted in each county, and response levels in the survey. Persons were contacted who had adopted the Ulvamast to the end of 1980. Table 3.6 also shows those purchasers interviewed in the pilot survey. Following results from the pilot survey, the questionnaire content was slightly amended for the 'main' survey. Accordingly, some questions were not asked to all respondents in the survey; the occurrence of this will be mentioned for the appropriate results. The pilot and the main survey results were analysed together when the question was the same in both the pilot and the main survey. The pilot survey was carried out in December 1982, and the main part of the survey in January and February 1983.

Contact with purchasers of the Ulvamast was initially made by sending a contact letter (see Appendix) explaining the purpose of the survey, and subsequently telephoning, requesting an interview with the purchaser of the Ulvamast. In one case it was not possible to talk to the original purchaser of the Ulvamast; the succeeding farmer was interviewed, as he had had experience of using the Ulvamast.

A copy of the questionnaire used is given in the Appendix, as are copies of the two 'flash cards' used. The length of interviews was between 20 minutes and one hour, the average being half an hour. As with the random user survey, no information or opinion relevant to the questions was given by the interviewer beyond that mentioned in the initial contact letter.

One difficulty encountered in carrying out the survey was that whilst wishing to discuss the questionnaire with the purchaser of the Ulvamast, the respondent was not always the one who performed or even arranged spraying operations. In the main survey, respondents were asked whether they carried out much spraying themselves in the last year. Only 35% (6/17) had done any. This explains some of the 'missing values' in the results due to respondents in some cases not knowing or being

TABLE 3.6 Numbers of farmers contacted for the Ulvamast user survey, and response levels.

COUNTY	MAIN (M) OR PILOT (P)	NO. PURCHASERS OF NEW ULVAMASTS UPTO END OF 1980 *	NUMBERS CONTACTED BY LETTER	NUMBERS INTERVIEWED	% RESPONSE (as % of those contacted by letter).	COMMENTS .
Berkshire	P	8	7	6	87	1 non-contact, 1 a contractor not doing crop spraying anymore
Surrey	P	1	1	1	100	
N Hampshire	P	4	4	2	50	2 non-contacts
Bucks	M	2	2	2	100	
Oxon	M	21	19	15	79	2 refusals, 1 non-contact, 1 purchaser had left farm. Two Ulvamast purchasers were not selected as they were interviewed in an earlier survey.
TOTALS		36	33	26	79%	

*No knowledge about purchasers of second-hand Ulvamasts from lapsed users or repeat purchasers.

able to recall facts, e.g. for spraying speeds.

Results from the Ulvamast user survey are presented in two chapters. Chapter Five incorporates the data on crop spraying logistics and weather constraints; Chapter Six utilises the information on the uptake of a number of arable innovations.

Owing to some difficulty in arranging interviews, and the distance between respondents, generally not more than two interviews in a day could be arranged.

Many respondents took a great interest in the survey, and a short report on results from the survey was sent to those interested in receiving one.

3.3.15 Survey objectives - postal survey on possible future developments in pest control in the U.K.

The fundamental objective of the postal survey was to gather the opinions of individuals in relevant sectors of the agricultural industry on possible developments in British arable crop protection activities in the "medium term" (to about 1990). Six major topics were looked at:

1) adoption levels of crop protection machinery (and associated devices) on farms.
2) utilization and performance of crop sprayers.
3) volumes of chemical and diluent used in spraying.
4) possible statutory controls on crop protection activities.
5) the development of a range of approved chemicals for use with new application technology.
6) the packaging of chemicals.

In the letter accompanying the postal questionnaire, it was emphasised

TABLE 3.7 Sampling frames used, numbers contacted, and response percentages, postal survey. Questionnaires were distributed in November and December 1982.

GROUP	SAMPLING FRAME	NUMBER SENT	NUMBER REPLIES RECEIVED	NO. OF USABLE REPLIES *	% RESPONSE (as a % of questionnaires sent out)
AGROCHEMICAL COMPANIES	1982 members of the British Agrochemical Association. Questionnaires addressed to "Technical Manager".	49	30	26	53%
SPRAYER & ACCESSORY MANUFACTURERS & LGPV MAKERS	1981 members of the AEA involved in sprayer or sprayer accessory manufacture + list in 1981 MAFF booklet of sprayer LGPV makers. Questionnaires addressed to "Technical Manager".	52	44	39	75%
ADAS MECHANISATION OFFICERS	Mechanisation Officers in England and Wales, 1982.	54	45	44	81%
INDEPENDENT CROP CONSULTANTS	Members of National Assn. of Independent Crop Consultants attending a crop consultants' conference, 9th Nov. 1982 (plus several questionnaires sent to non-attending consultants).	46	32	32	70%
AGROCHEMICAL MERCHANTS	Selected agrochemical merchants contacted through UKASTA.	24	15	15	62%
"OTHERS"	Academic, advisory & training bodies concerned with application technology.	13	13	11	85%
	totals	238	179	167	70%

*Not all replies were usable; some of those contacted wrote back stating they were not qualified to answer the questionnaire.

that the respondent's personal opinions were sought, rather than the policies or objectives of the organizations they represented. This was done as it was felt that personal opinions were of the most interest for the purposes of this survey, and individuals in an organisation would be much less willing to reply to the questionnaire if they saw themselves acting as "spokesmen" for the organisation they work for.

"Relevant sectors" of the agricultural industry were judged to be: agrochemical companies, sprayer and sprayer accessory manufacturers, manufacturers of LGPV's, ADAS Mechanisation Officers, independent crop consultants, agrochemical merchants, and other bodies concerned with various aspects of application technology.

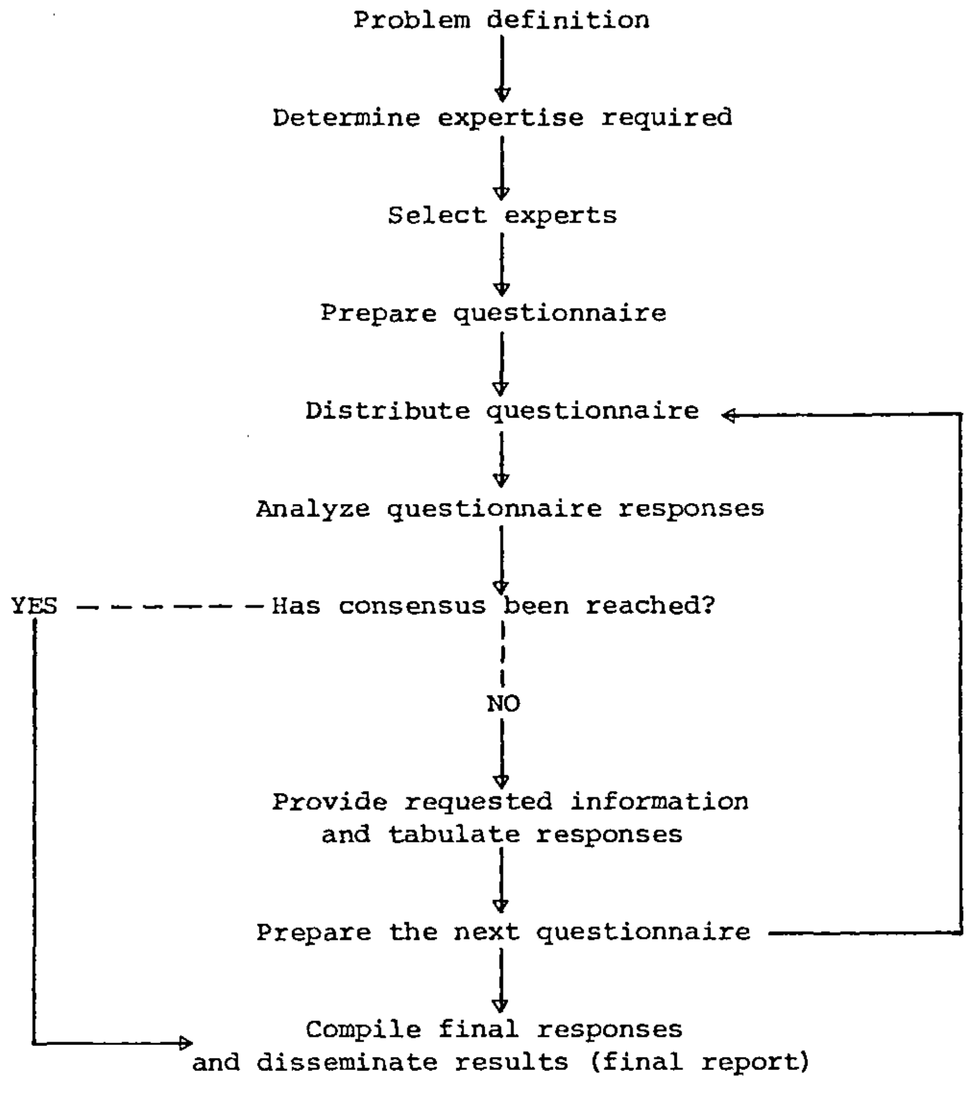
3.3.16 Survey design - postal survey

In carrying out the postal survey, an expert opinion/"Delphi"-type survey method was used.

In attempting to assess possible future events in plant protection, the problem was seen as one of technological forecasting. The objectives cover a number of topics: group decisions in forecasting are necessary when the scope of a problem is such that no one individual has sufficient expertise and knowledge to effect a solution (Riggs, 1983). The Delphi technique is a written technique that avoids the need for the "coming together" of experts. Furthermore, the Delphi technique avoids the problems associated with interacting groups or discussions: domination of a discussion by one or a few personalities or topics, and group pressures for conformity and compromise (Riggs, 1983).

A summary of the "true" Delphi method is outlined in Figure 3.3. The first known use of the Delphi technique was in 1948 to predict the results of horse races (Adams, 1980). Subsequently, the technique has

FIGURE 3.3. A typical Delphi process. From Riggs (1983).



been applied to a wide variety of problems, particularly in the forecasting and planning fields (Adams, 1980). The use of technological forecasting methods has increased over the last few years, and perceptions of the importance of such techniques has increased greatly (Balachandra, 1980a). This rise in usage of technological forecasting techniques may be seen to be a corollary of rapid changes in technology resulting in constant and frequent improvements in existing products (Balachandra, 1980a). Balachandra (1980b) carried out a survey of the use of technological forecasting techniques in US industry. Eliciting expert opinion was seen to be the most useful technique; of the forecasting techniques demanding much effort in their execution, the Delphi technique was seen as being the perceived second most useful technique. In a survey of the use of Delphi techniques, it was found that the majority of Delphi studies focussed upon applied research (Brockhaus and Mickelson, 1977). In addition, the authors indicated that the Delphi method has been most successful when used in forecasting and planning; Delphi methods have also been successful in identifying the major ramifications of significant technological breakthroughs (Brockhaus and Mickelson, 1977).

The Delphi technique is a procedure that relies on the opinions or estimates of experts in the field being investigated (Adams, 1980). Five attributes should characterise experts used in the Delphi process:

1) the recognized authorities in the field being researched
2) should feel personally involved in the problem of concern
3) should have pertinent information to share
4) be motivated to respond
5) feel that the results of the procedure will provide information that they value and to which they would not otherwise have access (Adams, 1980).

These attributes should also be present in persons selected for "expert opinion" surveys.

In carrying out the postal survey, respondents were not asked to fill in more than one questionnaire in the survey. In this respect, the "Delphi" element in the survey is truncated; however, a report of the results was sent to all respondents, and requests for any further comments were made. Even in a truly iterative Delphi process, as illustrated in Figure 3.3, a consensus is not always reached on every point of investigation.

The questionnaire was sent to groups of individuals in the agricultural sector to whom the topics under investigation would have some professional relevance. Individuals were polled in: agrochemical companies, agricultural sprayer machinery and sprayer accessory manufacturers, the ADAS Mechanisation Unit, independent crop consultancies, and other relevant institutions. In the interests of cost and simplicity, only one person in each organisation contacted was asked to complete a questionnaire (except ADAS, where all Mechanisation Officers were polled). For a description of the sampling frame, see Table 3.7. Contact with the experts was made by posting a questionnaire together with a covering letter (see Appendix) and stamped addressed envelope; the procedure varied for crop consultants and agrochemical merchants - see Table 3.7. No reminders were sent out. The survey was conducted between 1982 and February 1983. Replies were received up to four months after sending out the questionnaire.

Moser and Kalton (1971) and Lloyd (1975) outline the problems and advantages of postal survey work. Three important factors in determining the accuracy and level of response are:

1) the length of the questionnaire and time required to fill it in
2) the perceived relevance and usefulness of the survey objectives and questionnaire content,
3) straightforward and unambiguous instructions and questions.

Scott (1961) reviewed aspects of response to a number of Government Social Survey mail surveys. The author found that responses to surveys could vary from 10% to 90%. Of all the factors that may affect the response to surveys, "the follow-up (i.e. reminders to complete and return questionnaire) is the only technique which has been consistently found to raise response by a substantial amount" (Scott, 1961). Reminders were not sent out in the postal survey, due to a lack of time; however, the high response rate (70%) was encouraging. Non-response leads to bias, or the systematic tendency to be wrong. In a survey looking at future events, it may be that respondents are those holding better developed opinions of future events due to being more knowledgeable. If non-respondents are qualitatively less knowledgeable about relevant areas, than their opinions may be of less interest, therefore the degree of bias caused by non-response is not as great as it may at first seem.

The response rate for chemical companies was markedly less than for other groups (see Table 3.7). This may be explained partly by the fact that chemical companies are large organisations, and a letter addressed to the "Technical Manager" may not be specific enough; furthermore, addresses quoted in the BAA handbook are generally offices; the relevant experts may be sited on a field station, remote from the office site.

3.3.17 Questionnaire design and question wording - postal survey

Statements on possible future events in plant protection were formulated in accordance with the objectives outlined in Section 3.3.15. In order to keep the questionnaire as brief as possible, a "tick box" format was used in most of the questionnaire. In order to allow qualifications or comments on the agree/disagree choice offered for each statement, a space was left below each statement and at the end of the questionnaire, with comments being explicitly encouraged in the instructions.

Instructions given at the top of the questionnaire attempted to define the position as precisely as possible, i.e. "possible future developments in the ground spraying of fungicides, herbicides and insecticides on arable crops in Britain" (see Appendix). Statements were designed to be concise, yet unambiguous, and mean the same to all in the survey. This latter requirement leads to the use in some instances of arbitrary numbers, e.g. "twenty percent" is used in preference to "a significant proportion". In addition, respondents were urged to agree or disagree with a statement: no box was provided to indicate "unsure", "not certain" or "don't know". However, some respondents did decline to express a preference to some statements (see results in Chapter Seven).

It was felt that some topics were not amenable to an agree/disagree statement; these are found on the last page of the questionnaire.

In carrying out the survey, several comments were given that were critical of questionnaire design and content. One respondent stated: "future developments cannot be assessed sufficiently accurately to enable all questions to be answered". Another respondent commented that his "answers were guesses and mere indicators of a trend rather than agreeing with your absolute values". In fact the survey does attempt to identify medium-term trends: stated time scales ("By 1990..." etc.) and arbitrary percentages are used in attempting to make the statements mean the same to all surveyed.

The format of the questionnaire sent to independent crop consultants differed from that sent to others. However, most of the statements were identical; any differences in statement content will be discussed in the results section.

3.4. Data analysis

As the number of variables amassed per case (farmer) may total over 200 in an interview, data collected from the personal interview surveys was coded, punched onto cards and placed on a hard disc.

Statistics from the data were obtained by using the Statistical Package for the Social Sciences (SPSS). The package comprises a set of programmes for data analysis and was written originally for social scientists, but has since been expanded and now includes many general purpose statistical routines. A full description of the subprogrammes available from the standard package is available in Statistical Package for the Social Sciences (Nie, Hull, Jenkins, Steinbrenner and Bent, 1975). The SPSS package held at the University of London Computer Centre (ULCC) contains a number of modifications and additions to the package described by Nie *et al* (1975). Information was held at ULCC on a system file, comprising the SPSS control card deck, and the data.

The SPSS subprogrammes mainly used in order to obtain statistics were:

1) FREQUENCIES produces frequency tabulations and descriptive statistics, such as the mean, median, standard deviation, etc.
2) CROSSTABS, producing two-way tables showing the joint frequency distribution of pairs of variables.
3) SCATTERGRAM, a graphical output showing the relationship between two variables.
4) T-TEST calculates Student's t and its probability level for testing the difference between two means.
5) ONEWAY - analysis of variance.
6) NPAR TESTS - non-parametric statistical tests, such as Kolmogorov-

Smirnov one-sample and two-sample tests, and the Mann-Whitney U Test.

Texts on the analysis of statistics from survey results include: The Logic of Survey Analysis (Rosenberg, 1968) and relevant sections from Moser and Kalton (1971). The latter describes ways in which tests of significance may be misapplied or misinterpreted.

3.5. Programming to sort data.

In order to produce tables of figures such as those in Tables 4.3 and 4.11, programming in FORTRAN was carried out in order to break down the application of chemicals by i) chemical type; ii) method of application; iii) farmer or contract application; iv) crop type; v) area. SPSS cannot easily be instructed to process data and describe it in this fashion.

3.6. Extrapolation of results

In accepting that the samples taken in the survey have a reasonable sampling error, then following the application of signficance tests, one may wish to estimate values for the population. In fact Moser and Kalton (1971) emphasise that "what is usually of importance is the magnitude of effects (e.g. the size of the difference between proportions in the population) rather than a test of whether the difference is statistically significant or not". Moser and Kalton then go on to comment that estimation is generally more important than merely stating the significance level of tests.

Due to a lack of initial knowledge about the population, sampling on a simple random basis took place to the extent that a significant proportion of the population were being sampled in the random user survey (~ 5% in the Honington area, ~ 12% in the Benson area). In applying the findings of the survey over a wider area, one must be much more tentative, and statements should be accompanied by an appropriate caveat.

3.7 Summary

1) In reviewing information needs for the project, a programme of three surveys was planned.

2) For each survey, research aims were distilled into objectives and key questions in compiling the questionnaires.

3) Two major cereal growing areas in southern England, with weather stations making hourly readings were sampled in the random user survey.

4) Sampling of farmers in the random user survey is carried out using telephone directories ("Yellow Pages") as a sampling frame. Farmers are contacted by letter and subsequently by telephone in order to gauge their willingness and suitability for interview. It was intended to interview farmers with over 20 ha cereals, with a total farm size of at least 28 ha. Seventy six farmers were interviewed; a response level of 80%.

5) Using standard error formulae, population estimates for the random user survey are made in Section 3.3.9.

6) Several formulae are available for calculating the desired sample size, for given levels of confidence, precision and population proportions or standard deviations. However, considerations as to how the data is to be analysed, what the statistics are to be used to show, and time and money constraints, are also prominent considerations in judgements regarding sample size.

7) There are several types of nonsampling error. Although errors arising from nonsampling errors can be easily appreciated, estimation and measurement are difficult. Possible significant sources

of nonsampling error are mentioned, but no correction is made for them, other than appending caveats to results.

8) The Ulvamast user survey is carried out in an area containing the farmers sampled around RAF Benson. All purchasers to the end of 1980 of the Ulvamast in Oxon, Berks, Bucks, Surrey and north Hampshire were sampled. Twenty-six Ulvamast users and ex-users were interviewed, a response level of 79%.

9) A postal survey of experts in relevant sectors of agriculture was carried out in order to assess possible future developments in plant protection. The technique used was a truncated Delphi. One hundred and sixty seven questionnaires were returned, a response level of 70%.

10) In analysing data, the SPSS package was used extensively, and some programming in FORTRAN was performed, in data sorting.

CHAPTER FOUR

THE APPLICATION OF CROP PROTECTION CHEMICALS IN THE UK

4.1. Introduction

In order to evaluate future trends in plant protection, it is necessary to examine past and present farmer behaviour in this topic. This chapter is dedicated to a review of such behaviour, examining the types of chemical applied to crops, the method and timing of application, and plant protection machinery on farms. Contractors have a significant role in plant protection activities nationally; their contribution to plant protection will also be discussed in this chapter.

The chapter concludes with a presentation of the new technology available, or shortly to be available for use in plant protection activities.

4.2. Past trends in chemical usage in Britain

Since the war there has been a marked increased in the number of pesticides available (Patton, Craig and Conway, 1982). The number of approved products available as differing commercial formulations increased from 63 in 1944 to 810 in 1972; however, in the last decade a levelling-off in the growth of products available has occurred: in 1981 810 Approved Products were listed in the Approved Products list (MAFF, 1981; Sly, 1977). In 1981, 214 pesticide types were available, the largest type category being herbicides (90) followed by insecticides (57) and fungicides (51) (Sly, 1977, MAFF, 1981).

In terms of the area sprayed, amount and type of chemicals applied, Table 4.1 indicates trends in the estimated annual usage of pesticides for two periods in the 1970's.

Sly carried out surveys on the usage of pesticides in arable crops in 1974 and 1977 (Sly, 1977, Steed & Sly, 1979). In cereals, the usage of

TABLE 4.1 Estimated annual usage of pesticides in agriculture and horticulture in England and Wales, 1971-1974 and 1975-1979. Source : Sly (1981).

Pesticide	1971-1974		1975-1979	
	'000 Spray hectares	Tonnes	'000 Spray hectares	Tonnes
Organochlorine insecticides and acaricides	148	131	146	166
Organophosphate insecticides	845	430	975	534
Other insecticides, acaricides, molluscicides	93	1286	597	907
Seed treatments	3718	565	3753	591
Fungicides	1895	2400	2253	2336
Herbicides and defoliants (including chemicals for burning-off)	6003	15250	7868	19925
Other pesticides	81	2000	203	1038

insecticides increased eight-fold, the usage of systemic fungicides doubled, and there was a four-fold increase in the use of chlormequat on winter wheat. There was some increase in the amount of herbicides used to control grass weeds.

On "other" arable crops (potatoes, sugar beet, oilseed rape, beans and mustard) in 1974 and 1977, there was a decline in usage of insecticides, organophosphorus insecticides being replaced to an extent by carbamates. There was an increase in usage of dithiocarbamate fungicides, with a reduction in the use of fentin compounds. As with cereals, there were no major changes in herbicide usage.

Further changes in patterns of use of pesticide have undoubtedly occurred since 1977, due to changes in: available products, pests, weather and crop spraying technology. Data on chemical usage for the 1980-81 growing season for respondents in the random user survey are given in Section 4.3.

Spray variable costs on 399 farms in Eastern England have been measured for the last decade by Murphy (1983). Figure 4.1 shows trends in spray variable costs for winter wheat and sugar beet, which show consistently rising real chemical costs. Trends in spray costs of oilseed rape and barley crops show a similar pattern.

4.3 The application of chemicals through the growing year

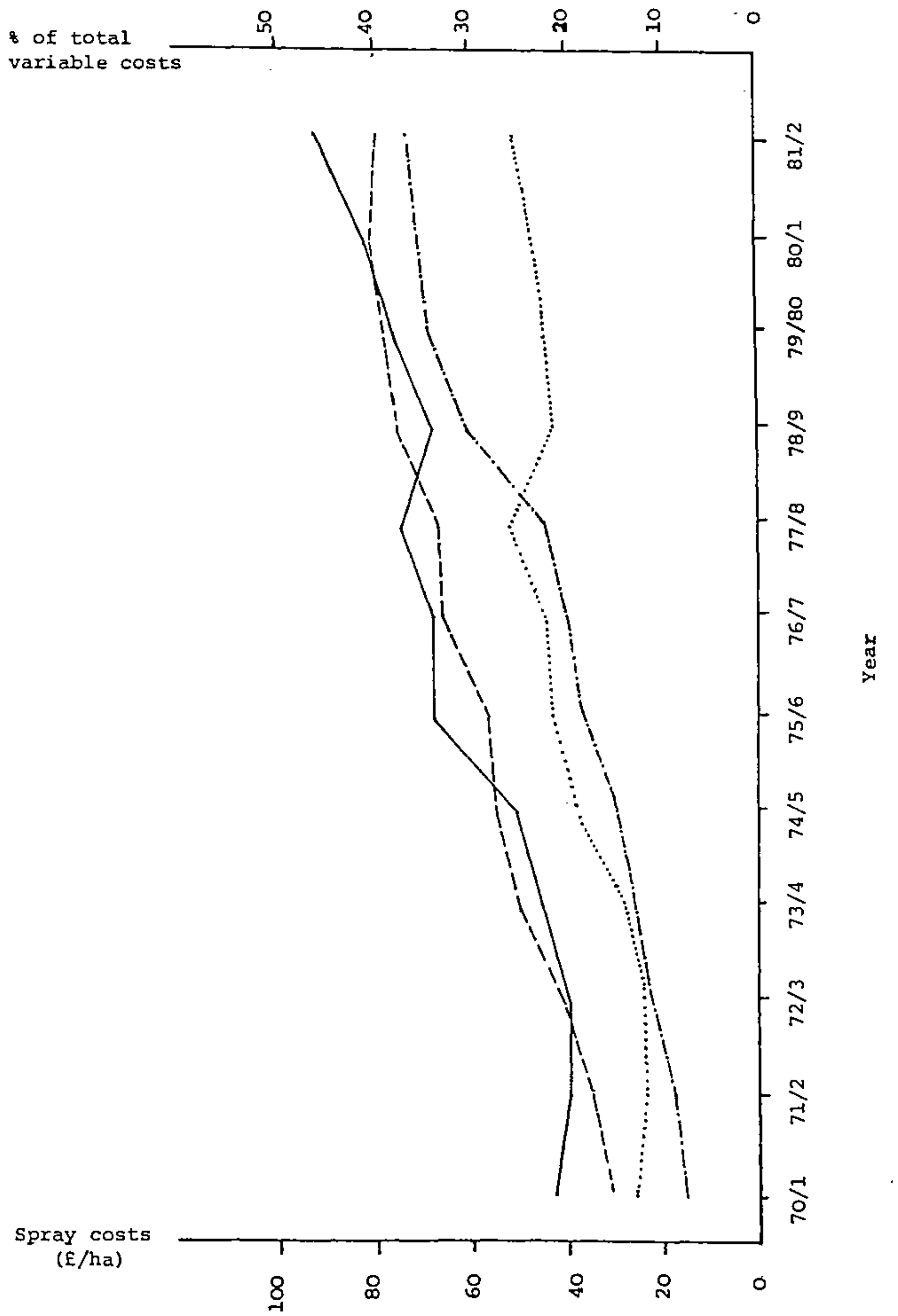
4.3.1 Introduction

In this section the characteristics of crop protection applications will be detailed for six major arable crops in Britain: winter wheat, winter and spring barley, potatoes, sugar beet and oilseed rape. In the random farmer survey 17,296 hectares were farmed by respondents;

FIGURE 4.1. Changes in spray variable costs over time for sugar beet and winter wheat. Data from Murphy (1983), at 1981/2 prices.

KEY

———————	Sugar beet spray costs
…………………	Sugar beet spray costs as a percentage of total variable costs
—·—·—·—	Winter wheat spray costs
— — — — —	Winter wheat spray costs as a percentage of total variable costs



3716 ha were grassland, woods, rough etc., and of the remaining 13580 ha, 96% was planted with one of the above six crops in 1980-81. The remainder consisted of field-scale vegetables, forage crops, and legumes.

In Table 4.2 areas grown in each of the two areas surveyed of the random farmer survey are given. In addition, figures for England and Wales are also supplied. There are three points of note in these figures:

1) The rise in the oilseed rape area.
2) Sugar beet is not commercially grown in counties such as Oxfordshire.
3) The potato area appears to be low. In central East Anglia, areas with soil very good for potato growing lies just to the west of the survey areas. As farmers growing potatoes in these areas would have a marked comparative advantage in production, it is to be expected that the area surveyed would have few potatoes grown.

4.3.2 Chemical usage by 76 farmers in the 1980-81 season.

In the survey carried out in South Oxfordshire and central East Anglia a number of questions were asked on the chemicals applied to crops grown in the 1980-81 growing year. Tables 4.3a and 4.3b give the spray area (the total area of crop treated with a pesticide counting each application separately) for the 2 regions surveyed, by chemical type for each crop, and whether the chemical was applied in the autumn or spring and summer period. Whilst the names of chemicals were not obtained the type of chemical was noted (i.e. herbicide, fungicide, etc.), and whether different chemical types were tank mixed together. Tank mixes of only one chemical type (e.g. 2 proprietary formulations of herbicide mixed together) were recorded as just being of one chemical type. Tank mixes in general will be discussed in Section 4.3.3. The tables refer to applications made as field sprays, aerial sprays, band sprays, or granular

TABLE 4.2. Areas grown of six major arable crops. Data from the MAFF Agricultural Census (England & Wales) for 1981 (in millions of hectares) and from the random farmer survey for 1980/1 and 1981/2 (in thousands of hectares).

CROP	England & Wales 1980/1	Farmer sample around RAF Benson (n=39)		Farmer sample around RAF Honington (n=37)	
		1980/1	1981/2	1980/1	1981/2
Winter Wheat	1.46*	3.07	3.14	3.17	2.96
Winter Barley	0.79	2.09	1.87	1.84	1.78
Spring Barley	1.04	0.49	0.52	0.92	0.91
Potatoes	0.14	0.04	0.04	<0.01	<0.01
Sugar Beet	0.21	0	0	1.20	1.15
Oilseed Rape	0.12	0.05	0.12	0.18	0.24

* Includes winter and spring wheats

TABLE 4.3a. Types of chemicals applied on six crops over the 1980/81 growing year. Data from the random user survey, on 37 farmers in East Anglia. Note that the terms 'herbicide','fungicide' etc. may refer to one or several proprietary formulations of the same chemical type. The time of application is split into 2 groups: "autumn" (AUT) - from end of previous crop to end of 1980, and "spring" (SPR) - from the start of 1981 to harvest time. When the time of application is unknown, "U/K" is used to designate this. Areas in spray hectares.

	CROP						
	Winter Wheat	Winter Barley	Spring Barley	Sugar Beet	Oilseed Rape	Potatoes	TOTALS
CROP AREA (has)	3166	1839	920	1199	183	1	7308
CHEMICAL TYPE & TIME APPLIED							
AUT Pre-emergent Herbicide	691	240	223	176	0	0	1330
AUT Post-emergent Herbicide	1660	1068	-	-	244	-	2972
AUT Fungicide	624	0	-	-	121	-	745
AUT Herbicide + Fungicide	14	44	-	-	0	-	58
SPR Pre-em. Herbicide	-	-	70	730	0	0	800
SPR Post-em. Herbicide	1693	598	369	1758	0	0	4418
SPR Fungicide	3080	1988	445	921	0	3	6436
SPR Insecticide	1119	55	0	1135	183	0	2492
SPR Plant growth regulator	445	104	6	0	12	0	567
SPR Herbicide + Fungicide	782	429	166	0	0	0	1377
SPR Insecticide + Fungicide	459	61	0	0	0	0	520
SPR Plant growth regulator + Fungicide	1020	40	0	0	0	0	1060
SPR Herbicide + Fungicide + Insecticide	0	159	0	0	0	0	159
SPR Insecticide + Herbicide	0	174	0	82	0	0	256
SPR Plant growth regulator + Herbicide + Fungicide	240	0	0	0	0	0	240
SPR Plant growth regulator + Herbicide	172	0	0	0	0	0	172
SPR Dessicant	0	0	0	0	61	0	61
U/K Herbicide	161	19	31	89	0	0	300
U/K Unknown chemical	194	401	0	0	0	0	595
TOTALS	12354	5380	1310	4891	621	3	24558

TABLE 4.3b. Types of chemicals applied on six crops over the 1980/81 growing year. Data from the random user survey, on 39 farmers in south Oxon.

CROP

	Winter Wheat	Winter Barley	Spring Barley	Sugar Beet	Oilseed Rape	Potatoes	TOTALS
CROP AREA (ha)	3072	2088	487	0	51	36	5734
CHEMICAL TYPE & TIME APPLIED							
AUT Pre-emergent Herbicide	1444	416	15	0	0	0	1875
AUT Post-emergent Herbicide	1794	1803	-	-	121	-	3718
AUT Fungicide	251	182	-	-	0	-	433
AUT Herbicide+Fungicide	0	0	-	-	0	-	0
SPR Pre-em. Herbicide	-	-	0	0	0	0	0
SPR Post-em. Herbicide	1235	785	398	0	20	35	2473
SPR Fungicide	2222	2233	217	0	40	145	4857
SPR Insecticide	835	121	0	0	81	32	1069
SPR Plant Growth Regulator	892	483	0	0	0	0	1375
SPR Herbicide+Fungicide	1776	1151	91	0	0	0	3018
SPR Insecticide+ Fungicide	1405	788	0	0	0	65	2258
SPR Plant Growth Regulator+Fungicide	85	0	0	0	0	0	85
SPR Herbicide+Fungicide+ Insecticide	0	0	0	0	0	0	0
SPR Herbicide+ Insecticide	0	0	0	0	0	0	0
SPR Plant Growth Regulator+Herbicide+ Fungicide	48	0	0	0	0	0	48
SPR Plant Growth Regulator+Herbicide	98	0	0	0	0	0	98
SPR Dessicant	0	0	0	0	0	0	0
U/K Herbicide	273	163	28	0	0	0	464
U/K Unknown Chemical	57	57	0	0	0	0	114
TOTALS	12415	8182	749	0	262	277	21885

applications but does not refer to seed treatments. The frequency of use of various means of chemical application will be discussed later in the chapter.

Table 4.4 gives the number of spray rounds applied for 'autumn' and 'spring' applications for each crop in each of the two areas surveyed. In this case, a spray round can be defined as an occasion on which the crop or soil is treated with one or more pesticides at the same time by field spray, aerial spray, band spray or granular application, but not with seed treatments. The two areas are generally similar in the number and timing of sprays, as measured by the 'autumn' and 'spring' criteria. Pesticide applications to spring barley are noticeably less than on the winter cereals.

In addition to arable crop sprayers being used for the application of pesticides, liquid fertilisers and foliar nutrients may also be applied. Liquid fertilisers are concentrated aqueous solutions of salts containing nitrogen, potassium, and sometimes phosphates. They are generally applied at low pressures in a 'stream' rather than a 'spray', and can create difficulties in application through machine corrosion and pipe and nozzle blockage. Of the 73 respondents who had a sprayer on the farm in the random user survey, thirteen used some liquid fertilisers on crops. Liquid fertilisers are often supplied by companies which also lease sprayers for the purpose.

Twelve respondents used foliar nutrients, always in a tank mix with pesticides. Foliar feeds generally contain trace elements that may be scarce in the soil, such as manganese, boron and copper.

4.3.3 Tank mixes

As can be seen from Tables 4.3a and 4.3b, a significant proportion

TABLE 4.4. Spray rounds for six arable crops in each of the areas surveyed in the random farmer survey. 'Autumn' applications refer to all applications made (except seed treatments) from the previous harvest to the end of 1980; 'Spring' refers to all applications (except seed treatments) made from the beginning of 1981 to the harvest of that particular crop.

(i) Benson (n=39)

PERIOD	Winter Wheat	Winter Barley	Spring Barley	Sugar Beet	Oilseed Rape	Potatoes
"AUTUMN"	1.14	1.15	0.03	0	2.37	0
"SPRING"	2.80	2.66	1.45	0	2.76	7.70
TOTAL*	4.04	3.92	1.54	0	5.13	7.70

(ii) Honington area (n=37)

PERIOD	Winter Wheat	Winter Barley	Spring Barley	Sugar Beet	Oilseed Rape	Potatoes**
"AUTUMN"	0.94	0.74	0.22	0.15	1.99	0
"SPRING"	3.63	1.96	1.15	3.86	1.40	3.00
TOTAL*	4.69	2.93	1.41	4.08	3.39	3.00

* The timing of some chemical applications was not recorded: these are included in the total but not in autumn or spring sub-totals.

** Only one respondent in this group grew potatoes (1 hectare).

of chemicals applied in 1980/81 were applied as tank mixes. Tank mixes can be defined as a mixture of more than one proprietary formulation prepared for crop application. Proprietary formulations may themselves contain more than one active ingredient. Tables 4.3a and 4.3b in fact under-represent the occurrence of tank mixes, as a mixture of two or more of the same types of chemical (e.g. herbicide plus herbicide in the mixture for application) are not included. Tables 4.3a and 4.3b indicate that the most common mixtures of chemical types are spring herbicide plus fungicide mixtures (4395 spray hectares or 9.0% of total spray hectares), spring insecticide plus fungicide mixtures (2778 spray hectares or 5.7% of total spray hectares), and a spring application of fungicide and plant growth regulator (1145 spray hectares or 2.3% of total spray hectares). Steed and Sly (1979) indicated that the more common mixtures involving insecticides were dimethoate or demeton-S-methyl with a fungicide, for use on cereals and potatoes. In addition, sugar beet sometimes received a mixture of HCH plus a pre-emergent herbicide to sugar beet.

Regarding the fungicides, tridemorph and carbendazim were commonly used together on barley (Steed and Sly, 1979). A mixture that was often applied to cereals was fungicides and post-emergent herbicides, and/or growth regulators. The most common mixtures were carbendazim or tridemorph with dicamba mixtures or mecoprop; the growth regulator chlormequat was commonly mixed with carbendazim (Steed and Sly, 1979).

Steed and Sly (1979) found that mixtures of herbicides were common on cereals, particularly translocated herbicides, the most common being mecoprop with 2, 4-D or MCPA, and dicamba and dichlorprop with MCPA. Plant growth regulators were often mixed with a herbicide. Sugar beet herbicide mixtures were used to effect broad-leaved and grass weed control together, either post-emergent or at pre-drilling, using soil-acting herbicides (Steed and Sly, 1979).

In a survey of 76 cereal growers in central East Anglia and south Oxfordshire, questions were asked on the frequency of use, and reasons for use of tank mixtures. Forty farmers (53%) used tank mixes at "every available opportunity", whilst only one respondent never used tank mixes. Farmers using tank mixes at every available opportunity were asked why they used tank mixes. (This question was only asked in the "main" survey, and not the "pilot" part of the survey - 32 users of tank mixes "at every opportunity" were asked the question). Table 4.5 shows the reasons for use of tank mixes offered by respondents. The number of reasons exceeds the number of respondents as some respondents gave more than one reason.

TABLE 4.5 Reasons given by respondents for using tank mixes "at every opportunity". n = 32.

Saves wheelings in crop	16
Saves time	15
Saves labour	3
Better control when chemicals combined than with separate applications	3
Saves sprayer running costs	3
Essential to spray whenever possible owing to weather constraints	1
Ensure that timeliness of application of chemicals is satisfactory	7
Ensure that chemicals are compatible	2

Tank mixes appear from the above results to mainly offer savings in wheelings through the crop, and 'time', components of which are undoubtedly labour and cost considerations. However, the use of mixtures of proprietary formulations can cause difficulties. Using mixtures of chemicals may mean that the timeliness of application of the individual chemicals is not always optimal with regard to the relevant pest population. Secondly, different chemical formulations may be incompatible; mixtures may cause precipitation or crystallisation of one or more components, or a blockage of nozzles and filters. The viscosity of the final mixture may also vary from the original liquids, affecting rates of application.

In addition to problems of mixing and application, crop damage can result through the application of incompatible chemicals. This can result from chemical reactions in mixing, producing phytotoxic products, or the nature of the final formulation giving rise to an imperfect droplet distribution. Effects from this may include crop yellowing, crop scorch, stunting or abnormal crop growth, and even the death of plants. Furthermore, a loss in effectiveness of the chemicals applied is possible. However, only one respondent indicated that tank mixes could be harmful to crops, and six indicated that the use of tank mixtures could give rise to problems of chemical compatibility. Despite the problems that could possibly arise from the use of tank mixtures, there is an indication that the frequency of use of tank mixtures is rising; fifteen respondents stated that they wished to increase the use of tank mixtures in their spray programme.

When deciding to use tank mixes, growers may find it difficult to obtain recommendations on tank mixtures. The MAFF Agricultural Chemicals Approval Scheme Approved Products List for Farmers and Growers (1983, p. 22) states that 'when mixing products together for use in spray programmes, see if the labels give information on which products are physically compatible and may be safely mixed without causing damage to plants or loss of effectiveness. If there is any doubt, consult the manufacturer". Manufacturers do make recommendations on tank mixes, but these are generally only among combinations of their own products, or products of another company made under licence by the recommending company. Guides to recommended tank mixes are available from chemical manufacturers, or from compilations of guides published in such magazines as the Farmer's Weekly (Farmer's Weekly 1980, 1982).

In addition to chemicals such as herbicides, fungicides, insecticides and plant growth regulators, products such as foliar feeds and wetting agents may also be mixed in.

4.3.4 Application of chemicals through the year: chemicals applied.

Sly carried out a survey on the use of chemicals on 306 farms in England and Wales for 1977 (Steed and Sly, 1979). Among the information presented is the application of chemicals broken down by month of application. Table 4.6 shows the relative spraying effort through the year on surveyed farms.

In the case of winter cereals, there is a pronounced peak of applications in April and May. Most of these chemicals were herbicides. Nearly two-thirds (64%) of all chemicals applied to winter cereals are applied in these two months. There is a second, smaller peak of application in autumn, centred around October. There is a peak of insecticide application in June (9.8% of all chemicals applied).

For spring-sown cereals, there is a very pronounced spring peak in applications: over two-thirds of all chemicals (68.2%) are applied in May. There are hardly any autumn applications; most of the remaining

TABLE 4.6. Percentage of spray hectares applied each month for all chemicals, among a number of arable crops. Data for 1977, from Steed and Sly (1979). Chemicals applied by any means other than using seed treatments are included. Tank mixes are counted as one application.

MONTH	CROP				
	Winter Cereals	Spring Cereals	Maincrop Potatoes	Sugar Beet	Winter Oilseed Rape
Jan.	0.1	0.0	0.0	0.0	1.9
Feb.	0.2	0.9	0.0	0.6	1.9
Mar.	4.1	7.1	1.3	23.6	3.8
Apr.	31.7	9.1	8.6	31.1	2.0
May	32.5	68.4	9.3	25.2	3.6
Jun.	11.2	12.2	17.1	13.6	1.6
Jul.	4.4	0.7	30.4	2.8	0.0
Aug.	4.4	0.7	23.5	2.8	6.2
Sep.	2.3	0.4	6.5	<0.1	17.2
Oct.	4.9	0.4	3.3	<0.1	17.1
Nov.	3.6	<0.1	0.0	<0.1	22.3
Dec.	0.6	<0.1	0.0	<0.1	22.3
TOTAL	100	100	100	100	100

applications are made in March, April and June.

Maincrop potatoes are generally mostly sprayed between April and August. In terms of spray area by chemical type, fungicides are relatively more significant than herbicides, particularly in July and August (when spraying against blight is carried out). Herbicides are generally applied in April and May, when the canopy is not complete.

Herbicides predominate among the applications to sugar beet, mainly being applied from March to May. However, some insecticidal applications are made in all months from March to August, with peaks in March and June.

In common with sugar beet, herbicide applications predominate on winter oilseed rape. Most herbicide applications are in the autumn. Insecticides are applied through most of the life of the crop, reflecting the variety of pests that may infest the crop.

4.3.5 Labour requirements for spraying through the year.

In addition to the requirement for a spray rig and tractor, one or two persons will be needed in order to carry out the spraying, fetch water, mix chemicals, and so on. Table 4.7 shows the requirement for labour through the year for spraying operations (data from Nix (1981)). Compared with the labour requirements that would be needed for the 'modal' spray programmes for crops outlined in Section 4.3.6, the figures given by Nix (1981) appear to be slightly low, particularly for winter oilseed rape. There are seasonal peaks to the spraying requirements for each crop, and therefore seasonal fluctuations to the labour requirements in spraying (Table 4.6 and Figure 4.2). Although some flexibility in the timing of chemical applications is possible, costs arising from effects on crop quality or quantity may arise, or a 'carry-over' of pests from

FIGURE 4.2. Labour use through the year on a 587 ha farm, consisting of 237 ha winter wheat, 115 ha winter barley, 15 ha spring barley, 65 ha oil seed rape, and 155 ha grass. Farm has 4 full-time tractor drivers and 1 casual worker. One mounted and one trailed sprayer on the farm. Diagram reproduced from Walford (1979).

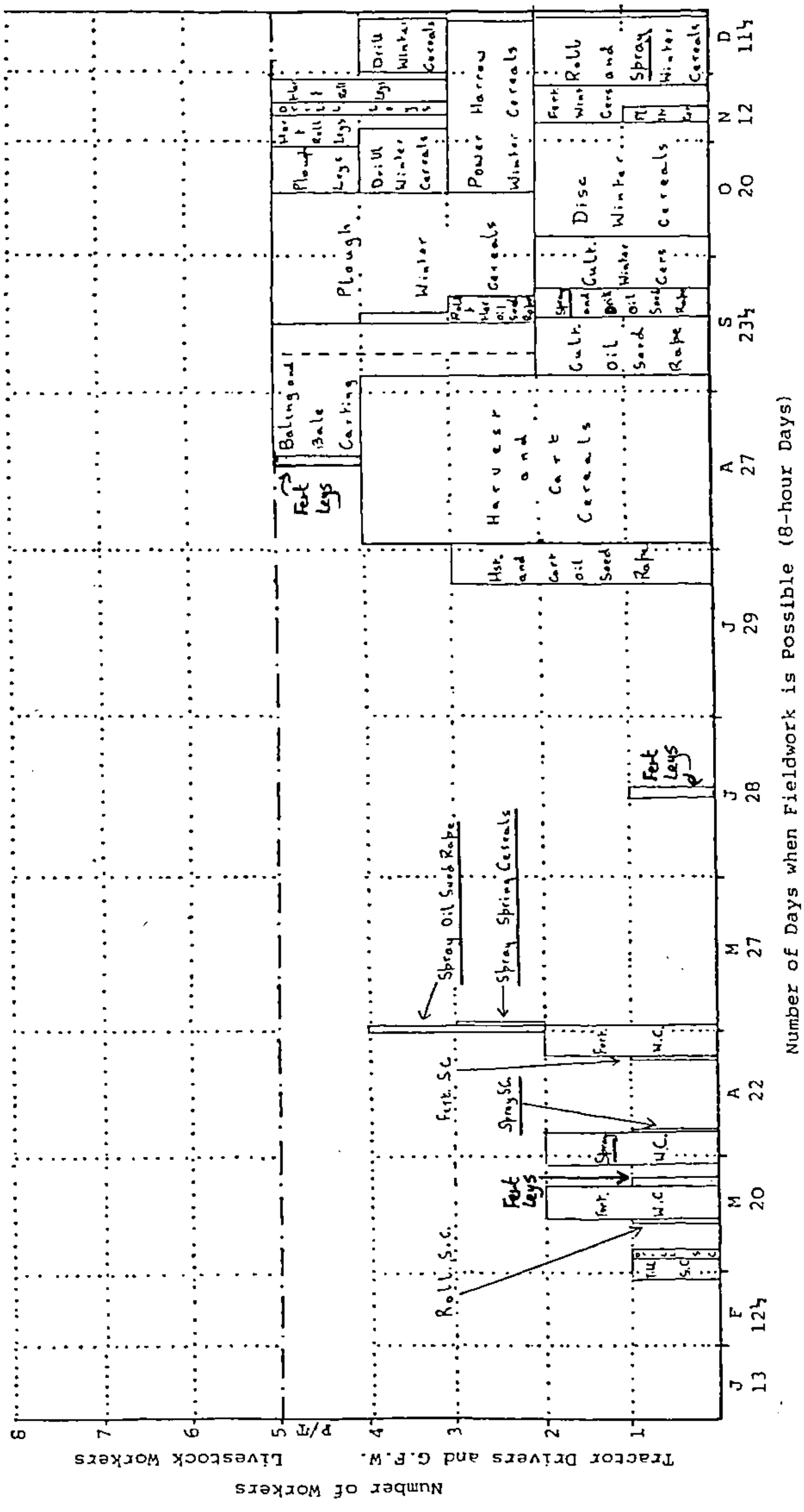


TABLE 4.7. Estimates of labour requirements for spraying operations for six arable crops. Data from Nix(1981). Figures in hours/ha for an average farm. Requirements may vary depending on the spraying regime, available equipment and number of people used in the spraying operation.

MONTH	CROP					
	Winter Wheat	Winter Barley	Spring Barley	Maincrop Potatoes	Sugar Beet	Winter Oilseed Rape
Jan.						
Feb.						
Mar.				1.6	1.4	
Apr.	0.6	0.6		0.8	0.6	
May	0.5	0.5	0.5	0.6		
Jun.						
Jul.				1.2	0.6	
Aug.				0.8		
Sep.				0.4*		
Oct.				0.4*		
Nov.						0.5
Dec.						
TOTAL	1.1	1.1	0.5	5.8	2.6	0.5

* Dessicating haulm

one season to another may arise. For many arable crops, there are seasonal peaks in spraying requirements occurring between March-May and October-November. However, these periods often coincide with two factors which can act as a constraint on spraying operations. Firstly, weather conditions during these periods are not always suitable, and in fact the number of "spray-days" available may be quite limited. The effects of weather on spraying is discussed further in Chapter Five. Secondly, the periods March-May and October-November also coincide with peak labour requirements on the farm. Figure 4.2 shows the labour usage through the year on a large mixed farm (Figure from Walford (1979)). The figure shows that labour is required for several tasks other than spraying, and that spraying is only intermittently important through the year. However, other farms may spray crops more intensively than this example through the year. Therefore, there may well be a significant 'opportunity cost' to the application of materials on farms where there are many other jobs to be done at the time. Only the farmer can estimate this opportunity cost (Webster, 1982). However, the effects of uncertainty about control and damage functions, and costs and revenues of inputs and outputs may combine to produce a risk-averse state in the farmer. This may mean that spraying would be carried out in preference to many other operations (and therefore alternative uses of labour), even if the perceived opportunity cost of labour is quite high. In response to large perceived opportunity costs of labour, the farmer has several alternatives: he can offer overtime to full-time labour, employ part-time or part-year workers, use livestock workers for fieldwork, or the manager, farmer or his family carry out manual labour (Walford, 1979). The farmer may also use contractors to carry out spraying. Leaving out uncertainty, a farmer may feel justified in calling in a contractor if:

opportunity cost of farm-supplied labour + other inputs	>	perceived extra revenue earned as a result of spraying	>	contract charge

Taking uncertainty into account would probably encourage greater use of contractors. The use of contractors in farm operations is discussed in more detail in Section 4.5.

4.3.6 Modal spraying programmes

Based on data from Steed and Sly (1979), Nix (1981) and Murphy (1983) it is possible to depict a 'modal' spray regime on a British arable farm that is typical of the past few years. Table 4.8 gives a summary of what an average grower might apply to six arable crops. Actual amounts sprayed by an individual depend on such factors as the value of the crop, what crop was planted in the previous season, the spraying strategy adopted by the grower (e.g. prophylactic or spraying following monitoring), and risk aversity to pest attacks. Growers in different regions may also have special considerations regarding locally epidemic pests.

Table 4.8 does not include seed treatments or granular applications made at the time of sowing.

4.4 Application Machinery

4.4.1 Machinery in current use

Excluding rotary atomizers (discussed in the "new technology" Section, 4.6), orchard sprayers and fogging equipment, there are three categories of field-size chemical applicator in common use in UK field crops at present: 1) hydraulic pressure sprayers, ranging from small, tractor-mounted boom sprayers to large, self-propelled sprayers are the commonest sort. 2) Band sprayers are used in row crops where precision of application is required. 3) The use of dusts has declined over the last few

TABLE 4.8. Chemical costs and usage in a 'typical' year, for six crops. Prices at 1982 levels.

CROP	Winter Wheat	Winter Barley	Spring Barley	Winter Oil-Seed Rape	Sugar Beet	Maincrop Potatoes
CHEMICAL COST PER HA *	73.7	52.0	25.0	54.3	91.5	115.8
MODAL NUMBER OF SPRAY ROUNDS	4	3	3	2	3	6
MODAL NUMBER OF DIFFERENT CHEMICALS PER CROP	4	3	3	3	5	5
TYPICAL APPLICATION REGIME THROUGH YEAR	General weed control (Oct) General weed control + Fungicide (Apr) Aphicide (late May)	General weed control (Oct) General weed control + Fungicide (Apr) Fungicide (May)	Pre-drilling Herbicide (Feb) General weed control + Fungicide (May) Fungicide (late May)	Grass weeds + volunteer cereals (Nov) Insecticide (May)	General weed control + Insecticide (Apr) General weed control + Insecticide (May) Insecticide (Jun)	Pre-emergent weed control (Mar) General weed control (May) Blight spray + aphicide (Jun) 3 blight sprays (Jul-Aug)

* From Murphy (1983)

years in the UK, the main use now being for seed treatment (Matthews, 1979). In contrast, the number of pesticides formulated as granules, and the volume of granules applied has increased (Jepson, 1976 quoted in Matthews, 1979, p. 215). Consequently, machinery for the application of granules is fairly common on UK arable farms. Table 4.9 gives details of sprayers on the 73 respondents in the random user survey having sprayers on the farm.

Matthews (1979) describes and discusses the mechanism of hydraulic -pressure sprayers, band sprayers and granular applicators. New technology, including both new crop spray machines and implements associated with plant protection activities, are discussed in Section 4.6.

4.4.2 The Number of Sprayers in England and Wales

Every year, the Ministry of Agriculture, Fisheries and Food carries out a census of farms in England and Wales. Questions asked in the census vary slightly from year to year; questions seeking information on farm machinery are generally asked of a sample of farmers, with estimates of the number of machines held nationally are made from this sample. Questions on sprayers are generally asked every four to five years. Figure 4.3 shows the number of sprayers on farms in England and Wales, assessed in two ways: 1) estimated national figures based on a sample of farmers; 2) estimates of the total number of sprayers in England and Wales made every year by the Ministry of Agriculture, Fisheries and Food.

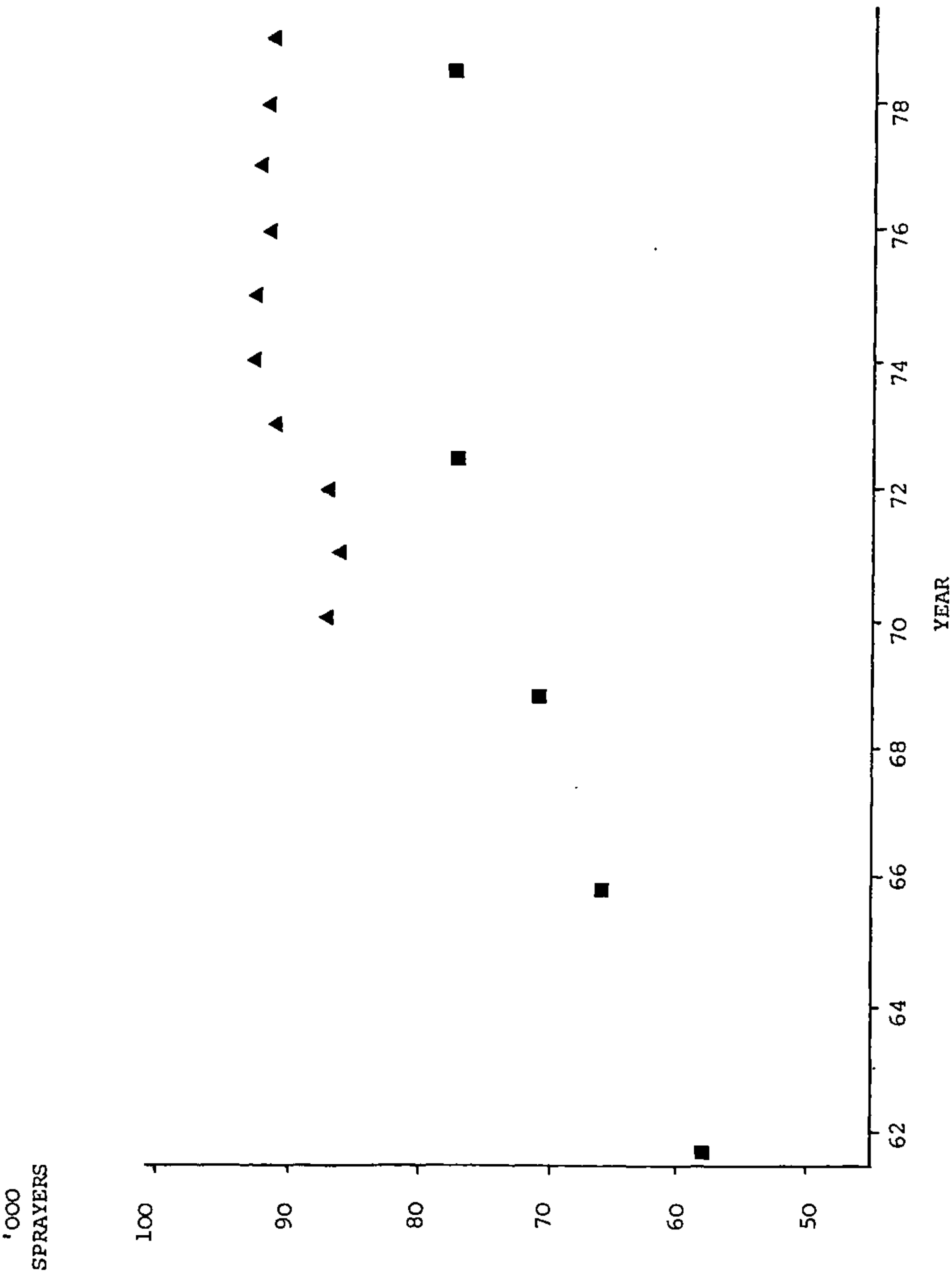
Steed & Sly (1979) in a survey carried out in 1977, found that very few farms had no pesticide applicators. Larger farms tended to have more applicators, but even the smallest holdings had,on average, more than one applicator. Steed and Sly also found an upward trend from 1974 in the use of trailed sprayers and granular applicators, particularly

FIGURE 4.3. Numbers of powered sprayers in England and Wales.

KEY

■ MAFF Agricultural Census figures. Except for 1978, air-assisted fruit sprayers under 50 gallons not included. 1969 figure does not include power-assisted dusters. Knapsack sprayers not included.

▲ MAFF yearly estimates of total sprayer numbers on farms, and owned by contractors.



of placement applicators.

4.4.3 Numbers of sprayers on surveyed farms

In a survey of 76 farms in south Oxfordshire and central East Anglia, questions were asked of the sprayers held on the farm at present (survey was carried out in Spring, 1982). Information on the type of sprayer, its make, ownership, age, tank capacity and boom width were asked for. Data on the age structure of the arable crop sprayers held on farms was presented in Figure 2.4. Tables 4.9a and 4.9b give information on sprayers held by each respondent in the survey, as well as hydraulic sprayer application rates, farm size and area used for cereals in 1981/2. In addition, a figure is given which attempts to assess the 'sprayer density' on each farm. The dimensions of this figure are:

$$\frac{\text{litres total tank capacity/metres total boom width/100 hectares of cereals grown (1981-2)}}{\text{litres applied/hectare}}$$

The total tank capacity of all hydraulic pressure sprayers on the farm (i.e. neglecting spinning-disc sprayers, band and orchard sprayers, and granular applicators) is summed, and divided by the total boom width of all the hydraulic pressure sprayers. This figure is then adjusted to give a value of litres per metre per 100 hectares of cereals. The resultant figure is then divided by the application rate used by the farmer. Where the respondent quotes a range of values for the application rate, the average of the two range values is selected. As an example, if a farmer grows 50 has of cereals, and has one arable hydraulic pressure sprayer, of boom width 5.5m and tank capacity 675 litres, and sprays at 200 ℓ/ha, then the calculations to obtain the sprayer density are:

$$\text{Sprayer density} = \frac{\frac{675}{5.5} \times \frac{100}{50}}{200} = 1.2 \quad \ell/\text{m}/100\text{ha}/\ell/\text{ha}$$

TABLE 4.9a. Table showing farm, crop sprayer and application details for 39 farms in south Oxon., 1981/2 (random user survey).

KEY

TYPE

- T Trailed sprayer
- M Mounted sprayer
- S Self-propelled sprayer
- B Band sprayer
- O Orchard sprayer
- G Granular applicator
- C Spinning-disc sprayer

OWNERSHIP

- O Sprayer owned by respondent
- H Sprayer leased/hired

MISSING VALUES

* - denotes where information was not asked for or recorded, or in the case of the sprayer density value, cannot be calculated.

AREA (has)-1982		DETAILS OF SPRAYERS ON FARM - MAR 1982						APPLIC. RATE (T,M,S sprayers) (l/ha)	HYDRAULIC SPRAYER DENSITY
TOTAL FARM	ALL CEREALS	TYPE	OWNERSHIP	MAKE	AGE (YRS)	TANK CAPACITY (l)	BOOM WIDTH (m)		
85.0	24.3	M	O	Evers & Wall	5	1125	5.5	*	
47.0	38.0	M	O	Evers & Wall	8	297	6.0	*	*
289.8	174.0	M	O	Everard	3	450	12.0	*	*
101.2	79.7	M	O	Dorman	2	700	12.0	*	*
		G	O	Nodet	*	*	*		
64.8	55.4			NO SPRAYERS OWNED				*	*
72.8	40.5	M	O	Evers & Wall	4	495	12.0	225	0.42
445.2	404.7	T	O	Evers & Wall	<1	1485	12.0	225	0.14
42.9	38.4			NO SPRAYERS OWNED				*	*
133.6	32.4	M	O	Evers & Wall	7	540	12.4	225	0.60
485.6	377.2	M	O	Evers & Wall	1	396	12.0	112	0.12
		M	O	Evers & Wall	5	810	12.0		
126.7	80.1	M	O	Evers & Wall	10	360	7.3	200	0.31
230.7	87.0	M	O	Ransomes	4	1620	12.0	225-405	0.49
748.7	505.9	T	O	Shell	3	1485	12.0	112-225	0.12
		T	O	Shell	3	1485	12.0		
		S	O	*	2	675	12.0		
		G	O	Nodet	*	*	*		
57.0	35.6	M	O	Evers & Wall	6	600	12.0	225	0.62
708.2	404.3	T	O	Evers & Wall	7	1530	20.1	225	0.07
		M	O	Lely	7	1125	20.1		
202.3	157.8	M	O	Evers & Wall	1	810	12.0	200	0.21
		O	O	Drake & Fletcher	>15	675	*		
		B	O	*	*	180	*		
58.7	56.3			NO SPRAYERS OWNED					

continued...

TABLE 4.9a continued.

FARM AREA	CEREAL AREA	TYPE	OWNER-SHIP	MAKE	AGE	TANK CAPACITY	BOOM WIDTH	APPLIC. RATE	SPRAYER DENSITY
141.6	97.1	T	O	Dorman	6	1200	12.2	225	0.45
76.5	72.8	T M	O O	Everard Evers & Wall	4 10	1000 450	12.2 9.9	225	0.4
64.8	38.4	M	O	Ransomes	15	450	10.7	225	0.49
242.8	145.1	M G	O O	Evers & Wall *	2 *	720 *	12.2 *	225	0.18
121.4	61.5	M M M	O O H	Allman Allman *	7 5 4	315 495 495	9.1 9.2 18.3	225	0.26
161.1	53.0	M	O	Evers & Wall	10	360	7.3	225	0.41
170.0	92.7	M	O	Allman	3	675	12.0	225	0.27
202.3	62.3	M	O	Lely	1	540	12.0	225	0.32
60.7	45.7	T	O	Everard	1	2000	12.0	225	1.6
168.8	89.0	T	O	Allman	5	1350	9.1	112-225	0.99
607.0	449.2	T C C	O O O	Everard Pictons (chassis) CDA	5 4 1	1350 1350 250	12.0 12.0 *	225-337	0.09
348.0	344.0	T M G	O O O	Hardi Everard Everard	7 4 *	990 905 *	12.2 12.2 *	225	0.10
127.9	117.4	T M	O O	Allman Evers & Wall	9 2	1350 594	12.0 10.0	112-225	0.45
429.8	177.7	M	O	Ransomes	3	750	12.0	225	0.16
153.8	103.2	M	O	Ransomes	6	697	9.6	112-225	0.42
384.5	214.5	M G	O O	Allman Nodet	5 *	1125 *	12.0 *	225	0.20
97.1	33.2	M	O	Ransomes	12	675	10.6	225	0.85
89.0	81.3	M	O	Ransomes	3	450	9.4	225	0.26
182.1	131.9	M	O	Evers & Wall	2	787	12.0	225	0.22
380.4	210.4	T	O	Everard	2	1980	12.2	225	0.32
404.7	303.5	T	O	Allman	<1	1500	12.0	168-225	0.21
221.0	135.6	M	O	Evers & Wall	8	800	9.9	225	0.27

N.B. Sprayer density calculated from mounted, trailed, self-propelled sprayers on the farm (applicators above the dotted line). Other types of applicators on the farm are included for completeness.

TABLE 4.9b. Table showing farm, crop sprayer and application details for 37 farms in East Anglia, 1981/2 (random user survey. Units and key as for Figure 4.12a.

FARM AREA	CEREAL AREA	TYPE	OWNER-SHIP	MAKE	AGE	TANK CAPACITY	BOOM WIDTH	APPLIC. RATE	SPRAYER DENSITY
176.4	131.5	M	O	Lely	2	675	7.3	225	0.31
		B	O	Ransomes	*	270	*		
40.5	28.3	M	O	Ransomes	4	675	9.6	*	*
388.5	242.8	T	H	FBC	3	1620	12.3	*	*
		B	O	Dorman	2	270	*		
159.4	114.1	T	O	L & K	1	1500	12.0	*	*
		M	O	Berthoud	7	600	12.0		
		B	O	Hardi	4	225	*		
		G	O	Tive	*	*	*		
		G	O	Hestair	*	*	*		
167.9	99.1	M	O	Ransomes	6	495	7.6	*	*
		B	O	*	5	495	*		
		G	O	Vikon	*	*	*		
200.3	157.8	T	O	Lely	3	1080	12.2	168	0.33
		G	O	Nodet	*	*	*		
517.6	393.8	S	H	Chafer	<1	2500	18.0	168	0.21
66.8	59.1	T	O	Shell	4	1485	12.0	225	0.93
404.7	404.7	S	O	Sands	<1	2000	24.0	200	0.10
566.6	429.0	M	O	Lely	1	1170	12.2	225-337	0.09
		T	H	FBC	6	1350	12.2		
		T	H	FBC	6	1350	12.2		
		B	O	*	*	450	*		
		G	O	Tive	*	*	*		
		G	O	Nordstrom	*	*	*		
182.1	153.8	S	O	Berthoud	10	1620	13.7	225	0.34
		B	O	*	*	450	*		
		G	O	*	*	*	*		
129.5	61.9	M	O	*	>15	225	*	225	*
		M	O	Ransomes	>15	450	9.1		
		T	O	FBC	4	1575	11.9		
		B	O	*	*	*	*		
229.9	141.6	T	O	Lely	4	1800	12.8	225	0.28
		M	O	Allman	1	540	12.8		
		B	O	*	*	540	*		
		G	O	Horstine Farmery	*	*	*		
242.8	74.9	T	H	Chafer	5	2025	12.0	225	1.00
		B	O	Ransomes	*	270	*		
		G	O	Nodet	*	*	*		
		G	O	Tive	*	*	*		
489.7	299.5	T	O	Moteska	5	1575	12.0	225	0.21
		M	O	*	1	1800	12.0		
		B	O	Ledenham	<1	675	*		
		G	O	Tive	*	*	*		
1189.8	849.9	T	H	Chafer	3	1800	12.2	225	0.07
		T	H	FBC	3	1350	12.2		
		G	O	*	*	*	*		

continues....

TABLE 4.9b continued.

FARM AREA	CEREAL AREA	TYPE	OWNER-SHIP	MAKE	AGE	TANK CAPACITY	BOOM WIDTH	APPLIC. RATE	SPRAYER DENSITY
141.6	90.7	M	O	Evers & Wall	6	495	12.0	225	0.2
		B	O	*	*	495	*		
48.6	36.4	M	O	Lely	<1	752	9.1	225	1.0
		B	O	Ransomes	12	135	*		
86.6	55.8	T	O	Shell	2	900	12.2	200	0.66
48.6	32.4	M	O	Ransomes	3	675	10.8	225	0.86
		B	O	*	*	180	*		
		G	O	*	*	*	*		
195.1	121.4	M	O	Dorman	5	540	10.8	225	0.18
		B	O	Dorman	*	135	*		
303.5	161.9	M	O	Evers & Wall	5	630	12.2	225	0.14
		C	O	Microcide	1	1350	12.2		
		B	O	*	4	270	*		
48.6	39.7	T	O	Dorman	10	1620	12.2	225	1.48
314.4	219.3	M	O	Evers & Wall	10	630	12.0	225	0.18
		T	O	FBC	3	1575	12.0		
		T	H	FBC	2	995	12.0		
		G	O	Nodet	*	*	*		
57.9	34.8	M	O	Dorman	2	567	12.8	225	0.56
		B	O	Dorman	2	567	*		
121.4	78.1	T	O	Allman	6	1350	15.5	225	0.50
		B	O	Ransomes	10	135	*		
68.8	44.5	M	O	Dorman	12	450	7.3	225	0.62
182.1	121.4	T	H	FBC	3	1350	12.2	225	0.40
		B	O	*	*	675	*		
		G	O	Horstine Farmery	*	*	*		
314.0	202.3	T	H	FBC	2	900	10.6	225	0.19
		B	O	Vikon	6	495	*		
		G	O	*	*	*	*		
28.3	22.3	M	O	Ransomes	10	270	7.3	225	0.74
		G	O	Nodet	*	*	*		
71.2	61.9	M	O	Evers & Wall	6	800	12.2	112-225	0.63
		B	H	*	*	270	*		
202.3	141.6	T	H	Chafer	6	2000	12.2	450	0.26
		B	O	Ransomes	5	135	*		
420.9	319.7	M	O	Ransomes	10	382	9.1	225	0.10
		M	O	Hardi	2	450	12.2		
		T	H	FBC	6	1575	12.2		
		B	O	*	10	450	*		
131.5	95.1	M	H	FBC	4	800	12.2	225	0.31
		G	O	Nodet	*	*	*		
208.4	121.4	S	O	Allaeys	4	3500	24.0	225	0.40
		M	O	Allman	3	450	12.2		
		B	O	Ledenham	3	450	*		
		G	O	Nodet	*	*	*		
141.6	72.8	M	O	Ransomes	1	675	12.0	225	0.34
52.6	32.4	M	O	Ransomes	2	450	10.9	225	0.56
		B	O	Ransomes	15	202	*		
		B	O	Ransomes	15	202	*		

Of course factors other than those used in the equation are important in determining how quickly a sprayer can go through a crop, e.g. refilling arrangements, spraying speed are important. Nevertheless, the spraying density gives an indication from the point of view of the machinery stock on the farm of the likelihood that spraying is done at the desired time. The higher the figure given, the greater the sprayer density will be.

Factors in addition to the machinery complement can influence the timeliness of operations; for instance labour availability and weather conditions. Labour requirements were discussed in Section 4.3.5; the influence of weather on spraying and the overall logistics of spraying will be discussed in Chapter Five.

There are several points of interest arising from the data presented in Tables 4.9a and 4.9b. Firstly, although the mean values for sprayer density in the two areas are not greatly different (mean density for south Oxon = 0.37; mean for central East Anglia = 0.44, p = n.s.), there are markedly more band sprayers and granular applicators on the farm sample in central East Anglia. Sixteen central East Anglian respondents have at least one granular applicator on the farm, as against six among farmers in south Oxon. Fertiliser applicators can be converted for the application of pesticide granules; applicators are only included in the survey if the respondent has used them for pesticide application. Also, twenty-four central East Anglian farmers have at least one band sprayer, as against only one in south Oxon. They may be found on farms of a fairly small area. Band sprayers are probably common due to the popularity of row crops such as sugar beet in central East Anglia. Field-size spinning-disc sprayers were found on only two farms in the survey, one in each of the areas. In addition, two lapsed users (of Ulvamasts) were interviewed in south Oxon, and one person who had used one once on the farm.

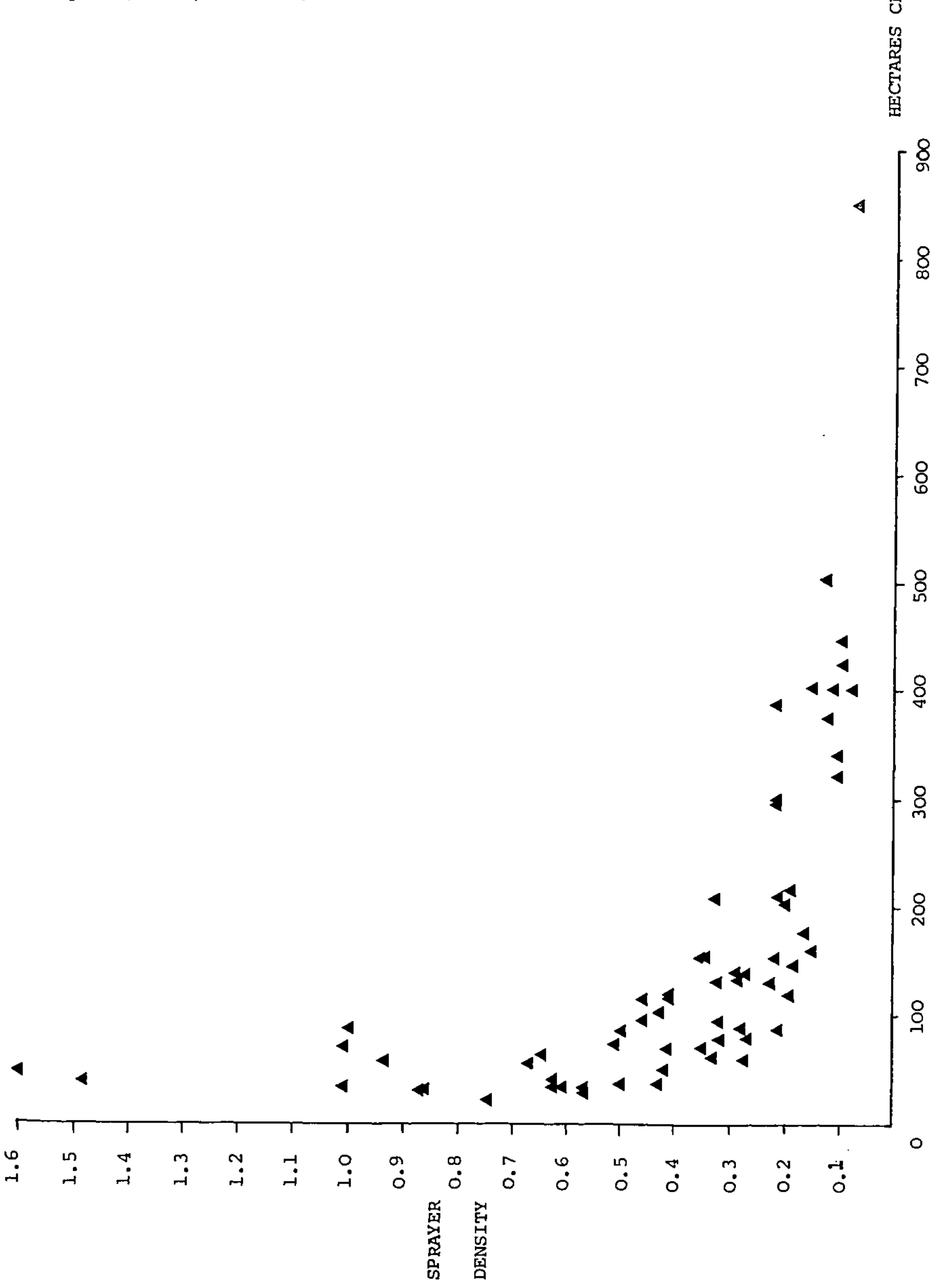
Evers and Wall, and Allman sprayers are popular in south Oxon; Ransomes and Dorman sprayers may be found on many farms in central East Anglia.

Twelve respondents in East Anglia lease or hire at least one sprayer, compared with only one in Oxon. Companies found to be particularly active in leasing sprayers to growers are FBC and Chafer. The leasing charge for a sprayer is generally on a sliding scale depending on the volume of chemical purchased from the lessor. The lessor generally undertakes to maintain leased sprayers. Hiring and leasing farm machinery is discussed in Section 2.7.

The modal boom width for sprayers is 12m, with a mean boom width of 11.9m. This reflects the increasing tendency toward tramline systems, which requires several types of cultivating machinery to have similar widths in the field.

Figure 4.4 shows an interesting relationship between sprayer density and cereal area grown in 1981-2. The probable explanation for the shape of this curve is that small farms have an overcapacity of spray machinery in relation to the crops grown, and hence requirements for spraying. Larger farms can afford to purchase, and utilise more efficiently, larger equipment, which has been shown to be more efficient than small implements in the field (Sturrock, Cathie and Payne, 1977). Smaller farmers can justify this sort of overcapacity by purchasing second-hand machinery, and keeping sprayers for longer periods. Overcapacity of some sort is almost inevitable, as machines are a "lumpy" input. Sturrock et al (1977) found that the utilization of a given size

FIGURE 4.4. Graph of sprayer density (see text) vs. cereal area grown, 1981/2. n= 64.



of machine would be greater on a large than a small farm.

An alternative explanation for the variation in sprayer density may be the use of contractors, or the respondents using their machines to perform contract spraying. The use of contractors in spraying operations is discussed in Section 4.5.

4.4.4 Method of application of chemicals to crops

Steed and Sly (1979) collected data for 1977 on the method of application of chemicals to crops. Table 4.10 presents the data for several major arable crops. The table excludes seed treatments, but this is neglecting a major contribution to plant protection by contractors: if seed treatments were included, the figures for 'contractor/ground' applied chemicals would rise from 510 486ha to 3 388 995ha for cereals, 26008ha to 429 698ha for sugar beet, and from 11103ha to 42617ha for oilseed rape. Thus on an area basis, contractors applied 36.4% of chemicals in 1977 if seed treatments are included. Excluding seed treatments from the calculation, the contribution of contractors becomes more modest: 12.8% of all applications were carried out by contractors.

Ground contractor applications on oilseed rape and sugar beet were mainly of herbicides; in cereals, 73% were of herbicides or plant growth regulators, 15% of insecticides, and 12% of fungicides. Seventy-three percent of the ground contractor area on maincrop potatoes was to apply dessicants.

When contractors were used for aerial applications, it was solely for insecticides on oilseed rape and sugar beet. Seventy-seven percent of aerial applications on cereals was of insecticides, sixteen percent being of fungicides. On maincrop potatoes, 99% of aerial applications were for fungicides.

TABLE 4.10. Method of application of chemicals to arable crops in England & Wales, 1977. Data from Steed & Sly (1979). Seed treatments are excluded. Areas are in hectares, and are national estimates, based on a sample of 306 farms.

CROP	METHOD			
	Self/Ground	Contractor/Ground	Contractor/Aerial	CROP AREA
Cereals	5 494 486	510 486	389 390	3 209 331
Maincrop Potatoes	931 189	43 661	69 730	145 333
Sugar Beet	685 059	26 008	997	201 848
Oilseed Rape	93 050	11 103	1518	55 110
TOTALS	7 203 784	591 258	461 635	

In a survey of seventy-six farmers in south Oxfordshire and central East Anglia, questions were asked on the method of application of chemicals to crops, excepting seed treatments. Table 4.11 summarises results from the two areas of acreages sprayed by different means. Eighty four percent of all chemical applications are by using hydraulic pressure arable sprayers. Granular applications are used for five percent of the spray hectares. Band sprayers are used in only three percent of the applications but are used for a substantial amount of the applications on sugar beet (24%). Controlled droplet applicators, such as rotary atomisers, are used for five percent of applications by area; although only three rotary atomisers were being used in the sample of 76, the two farms that did have them were large, using the rotary atomisers frequently. Some respondents used hydraulic pressure sprayers for low volume spraying (at or under 100 ℓ/ha): in total, 1009 hectares were sprayed by hydraulic pressure arable sprayers at or under 100 ℓ/ha (2%).

The use of low ground-pressure vehicles in spraying operations was asked about. The amount of spraying carried out with LGPV's was small: one percent (487ha).

Slightly under five percent of the spraying by area was carried out by contractors (4.6% - 2145 has.). The use of contractors in spraying will be discussed further in Section 4.5.

4.4.5 Problems with sprayers

In a survey of seventy-six farmers in south Oxfordshire and central East Anglia, the seventy-three farmers who had sprayers on the farm were asked what problems they had encountered with them in the field. The results are pictorially represented in Figure 4.5. The number of problems exceeds the number of respondents, as some respondents named more than one problem. The problems range from trivial ones to quite

TABLE 4.11. Methods of application of plant protection chemicals (excluding seed treatments) among 76 farmers in the random farmer survey, for 1980/81. Figures in hectares.

CROP

	Winter Wheat	Winter Barley	Spring Barley	Sugar Beet	Oilseed Rape	Potatoes	TOTALS
1980/81 AREA	6233	3927	1407	1199	234	37	13037
METHOD OF APPLICATION							
Farmer - Hydraulic sprayer	20678	11733	1916	3013	786	53	38269
Contractor - Hydraulic	439	283	96	50	98	0	966
Farmer - Rotary Atomiser	1307	749	0	89	0	194	2339
Farmer - Granules	1272	172	30	469	0	32	1975
Contractor - Granules	156	79	17	24	0	0	276
Farmer - Band Sprayer	0	0	0	1118	0	0	1118
Contractor - Band Sprayer	0	0	0	69	0	0	69
Contractor - Aerial	633	142	0	59	0	0	834
Unknown Method	194	401	0	0	0	0	595
TOTALS	24769	13559	2059	4891	884	279	46441

FIGURE 4.5. Pictorial representation of problems found with sprayers in the field. Figure reproduced from ADAS Mechanization Leaflet 2 (1976a). Data from 73 farmers in random farmer survey with at least one arable sprayer on farm. The number after the problem is the frquency of mentions of that fault.

No Problems (11)

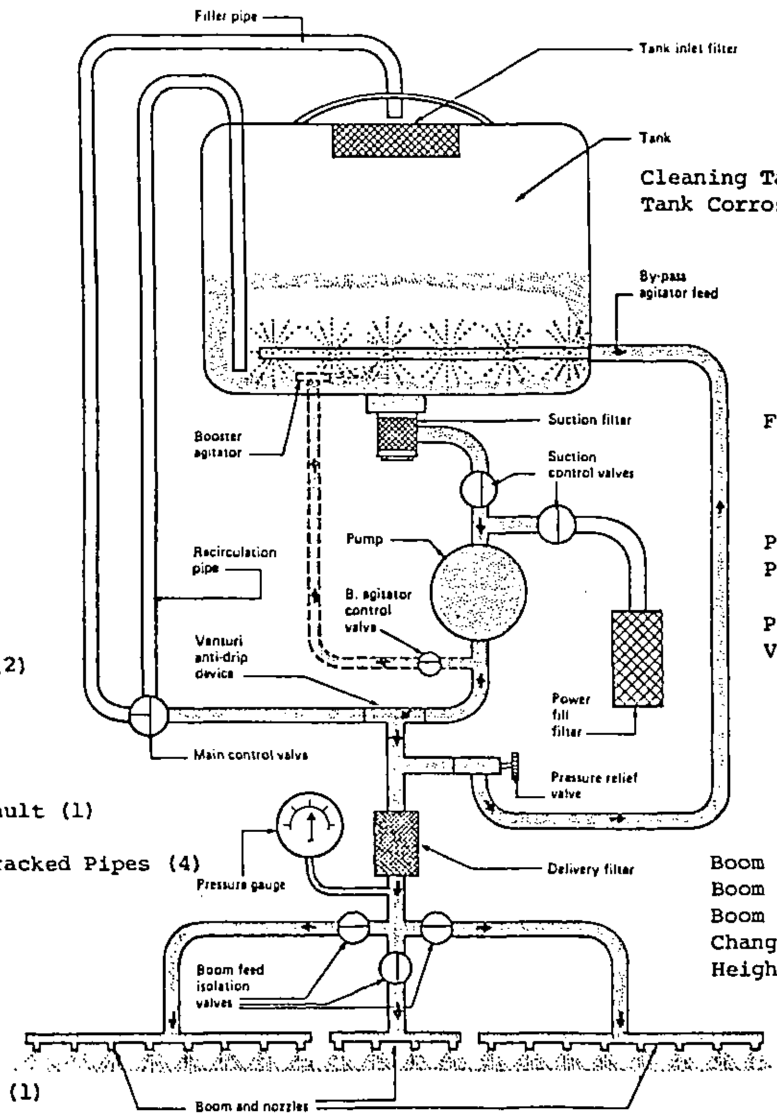
High Operating Costs (1)

Low-Volume Spraying Difficult With Current Sprayer (2)

Low workrates (1)

Sprayer Dimensions Too Small (3)

Excessive Weight (5)



serious ones; the nature of the problems are by no means similar. However, it is possible to identify the two areas where problems are most common: booms and nozzles. Boom whip, with the variations in application consequent upon it, was seen as a problem by fifteen respondents; ten respondents mentioned that they had problems with booms breaking or cracking. Twenty-eight respondents mentioned nozzle blockage as a problem; other respondents mentioned jet wear (5) and filter blockage (4).

Most respondents mentioned specific problems with their sprayers; some, however, made more general observations, mentioning factors such as cost and rates of work.

4.5 The Use of Contractors in Plant Protection

4.5.1 General description

In response to a lack of labour and/or suitable machinery, a farmer may enlist a contractor to perform operations on the farm. Generally, specific operations are requested by the farmer, but many contractors can offer a whole range of agricultural operations, including crop spraying, granular applications and aerial application facilities.

Riches (1979) identified five categories of agricultural contractor in the UK:

1) all income from contracting - general or specialist operations undertaken.
2) farmer - contractor: farmers with an established contracting business
3) farmers contracting on an occasional basis utilising spare machinery capacity.
4) machinery dealers-cum-contractors.
5) transient contractors.

TABLE 4.12. Table of chemical types sprayed by farmer or contractor, from a survey of 76 farmers - the random farmer survey. Figures refer to the 1980/81 cropping year. Areas in hectares. "AUT" refers to autumn-applied pesticides, "SPR" refers to spring-applied chemicals, "U/K" is used when the timing of application is unknown.

CHEMICAL & TIME APPLIED	CONTRACTOR	FARMER	TOTALS
AUT Pre-emergent Herbicide	251	2938	
AUT Post-emergent Herbicide	322	6384	11131
AUT Fungicide	0	1178	
AUT Herbicide + Fungicide	0	58	
SPR Pre-emergent Herbicide	46	760	
SPR Post emergent Herbicide	206	6891	
SPR Fungicide	558	10734	
SPR Insecticide	555	3007	
SPR Plant Growth Regulator	19	1922	
SPR Herbicide+Fungicide	56	4158	33870
SPR Insecticide+Fungicide	0	2778	
SPR PGR + Fungicide	0	1145	
SPR Herbicide+Fungicide + Insecticide	0	159	
SPR Herbicide + Insecticide	8	247	
SPR PGR + Herbicide + Fungicide	38	251	
SPR PGR+Herbicide	29	242	
SPR Dessicant	49	12	
U/K Herbicide	23	741	1473
U/K Unknown Chemical	0	709	
TOTAL	2160	44314	

Riches (1979) estimated that there were 6000-7000 agricultural contractors in the UK. A MAFF survey (1975, quoted in Riches, 1979) estimated that there were approximately 1200 contractors in categories (1) and (2) above in 1975. The organization representing contractors interests is the National Association of Agricultural Contractors. From their 1980 Membership list, 139 NAAC members offered ground spraying of liquids, 79 offered granular application services, and 60 offered aerial applications.

It is estimated that over sixty percent of full-time holdings use contractors regularly or occasionally (NEDO, 1972, quoted in Riches 1979). In a survey of 76 growers in south Oxon and central East Anglia, (the random farmer survey) sixty-one respondents (80%) have used contractors for spraying at some time. However, only seven respondents had regular arrangements with a contractor to carry out spraying operations. When asked what their main reason was for using contractors to perform spraying operations, the most common answer was in order to prevent crop damage, as shown in Table 4.13.

TABLE 4.13. Main reason for using an agricultural contractor in spraying operations. Question asked of sixty-one respondents in a survey in south Oxon and central East Anglia who have at some time used contractors.

Reason	No.
Prevent crop damage	18
Soil conditions	11
Frees farm labour for other tasks	9
'Emergency' application	9
To avoid the high costs of specialist equipment	7
To ensure timeliness of application	6
Health reasons	1
	61

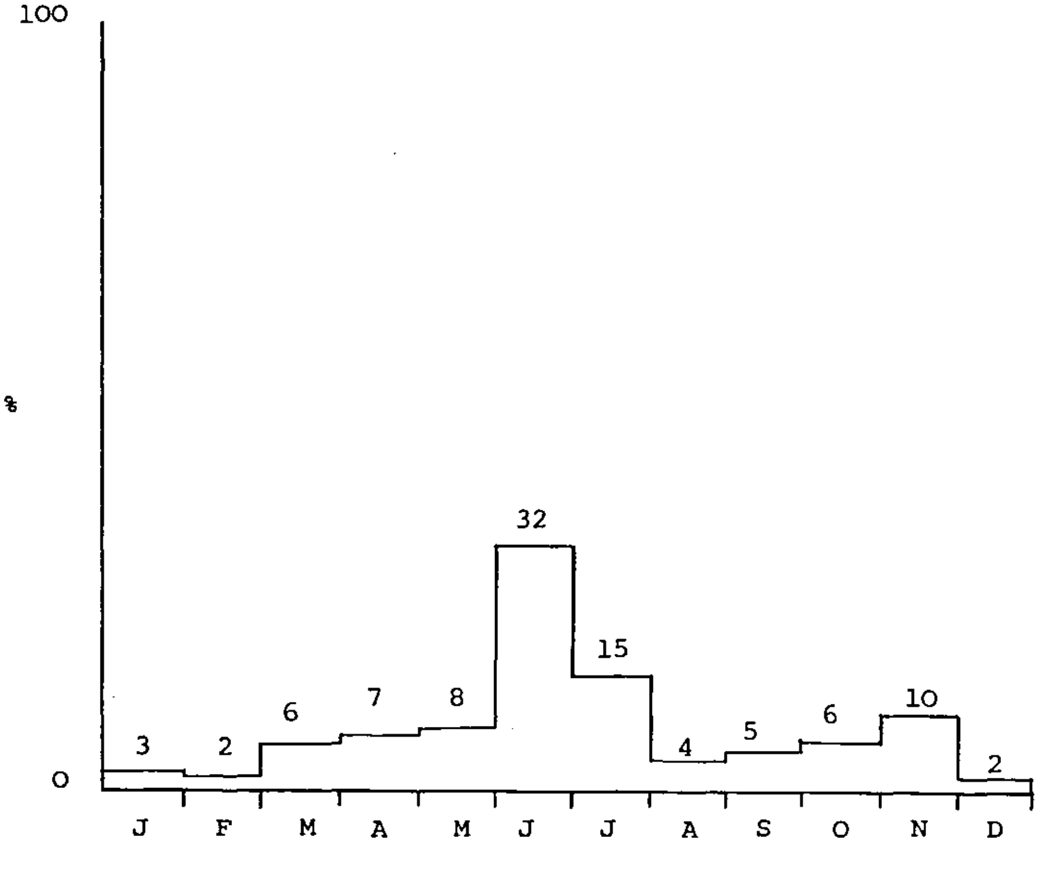
When asked the type of contractor used, 80% (49/61) used a full-time specialist, ten percent (6/61) used a farmer-contractor, five percent (3/61) used a dealer-contractor, and one respondent employed a neighbour on a casual basis (2 missing values).

Table 4.12 details the applications made by contractors on the 76 farms in the survey in 1980-81. The area sprayed by contractors amounted to five percent of total spray hectares. Contractor use seemed to be most substantial in the application of fungicides and insecticides; these may have to be applied late in the season, when it is difficult to get into the crop, and where a delay of a few days in treatment can be costly. Figure 4.6 gives an idea of the approximate distribution of contract spraying effort through the year. The amount sprayed by contractors can fluctuate from year to year; the British Agrochemicals Association (quoted in Riches, 1979) have estimated that in some years upto 50% of all applications may be made by contractors (in years of high insect attack, and poor weather); however, this value does include seed treatments.

Contractors are an important input purchasing sector in the UK farming economy; in 1979, the estimated total investment in agricultural machinery was £250 million, the annual investment being £90 million. Furthermore, contractors in 1979 spent £22 million on agricultural chemicals, or 20% by value of all plant protection chemicals in that year (Riches 1979).

Contractors may have a role to play in facilitating the spread of new practices and devices. As contractors are generally able to justify the heavy use and frequent replacement of machinery, they are often in a position to be able to purchase new machinery, and possibly be among

FIGURE 4.6. The distribution of contract spraying effort through the year. Data from Long (1977), for one contractor in 1976. The figures above the columns indicate monthly work done, as a percentage of the total.



the first to purchase large machines embodying new technology. In the main part of a survey of farmers in south Oxon and central East Anglia, sixty-five respondents were asked if they use contractors sometimes in order to see how a "new" item of machinery works on their farm. Twelve respondents said that they have done this for a machine in the past, and a further nine respondents said they would do this, if the appropriate opportunity presented itself. The twelve respondents who stated that they had used contractors to see how a new machine performs were asked which machines they had done this on in the past. The results are shown in Table 4.14. The number of machines exceeds the number of respondents answering the question, as some respondents named more than one machine.

TABLE 4.14: Machinery named as having been arranged for use by a contractor in order to enable the respondent to assess their performance (n = 12).

Machinery	No
Cultivating equipment	5
Low ground-pressure vehicle	4
Sprayers	3
Spreaders	2
Tractors	2

Riches (1979) stresses that contractors can be a source of information and advice to farmers helping in farmer decision-making. He stresses three possible advisory roles that may be played by the contractor:

1) **VENTILATIVE:** contractor plays a minimal role in decision-making, merely discussing ideas on a certain topic, or listening to farmer's views.

2) **EXPLORATORY:** the contractor examines and indicates alternative courses of action to the farmer.

3) **ADVOCATIVE OR PRESCRIPTIVE:** the farmer's role in decision-making is minimal. The advisor suggests the best alternative, and prescribes a plan of action.

Contractors may have some influence on farmer decision making regarding the adoption of new technology. There are three major recent innovations that contractors have had some influence in diffusing: forage maize, the direct drilling of cereals, and tramlining in crops (Riches, 1979).

In his results of a survey of agricultural contractors, Riches (1979) states that "apart from decisions on timing of operations and field methods, contractors reported giving most advice and taking most decisions in connection with disease weed and pest control". He goes on to conclude that "the ever-changing choice of chemical treatments and safety procedures make the use of a contractor to spray the crops attractive".

When respondents in the main part of the survey were asked to agree or disagree with the statement "contractors lead the way in using new machinery and techniques", thirty (49%) agreed, 19 respondents (31%) disagreed, with 12 respondents being "neutral".

In addition to being asked about contract spraying done on their farms, respondents were asked if they ever carried out any contract spraying. Twenty-four respondents stated that they have at some time done contract spraying, fifteen of which had done some contract spraying in 1981. Areas sprayed ranged from 5has to 81has, the total being 381has. Only two respondents advertised their spraying services, or had regular customers. The remaining respondents doing contract spraying believed that contract spraying was not important in their farm economy.

4.5.2 The economics of using contractors

There are several reasons why it may be advantageous for a farmer to use a contractor rather than carry out an operation using on-farm resources. Firstly, the farmer may wish to avoid opportunity costs that may arise in various ways. Opportunity costs of labour and management may be important at certain times of the year. In addition, the use of contractors may allow the more timely application of chemicals, thus preventing possible costs arising through crop yield and quality reduction.

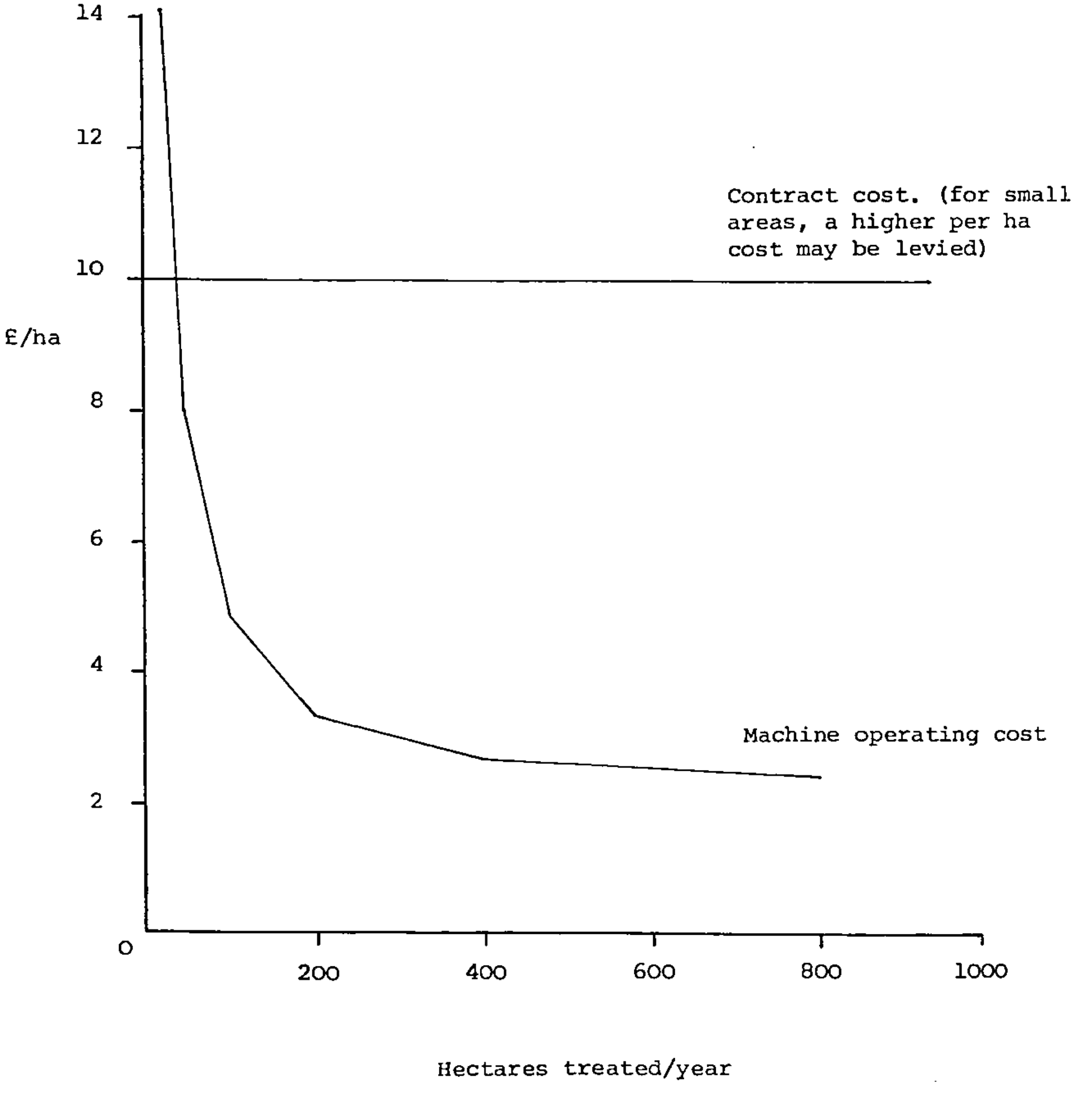
In the longer term, the regular use of contractors may enable a reduction in fixed machinery costs; the farmer may use contractors instead of investing in machinery, with the concomitant reduction in costs of depreciation and the opportunity cost of capital. The use of contractors may also lead to labour substitution on the farm - "yesterday's farmhand is today's contract driver".

In attempting to assess whether or not investment in a crop sprayer can be justified against the cost of having the work carried out by contractors, the operating costs per hectare for varying degrees of machinery usage can be compared. This is performed in Table 4.15, and graphed in Figure 4.7. The breakeven point for ownership of a sprayer of this sort occurs at 43 has/year, taking into account an opportunity cost of capital of 15 percent. Opportunity costs of labour may arise to push the curve to the right, but risk considerations would exert an opposite effect, if the grower were risk-averse. The breakeven point is low, suggesting that most farmers could well find it justifiable to own a sprayer even on quite a small farm. However, contractors quite often carry out crop spraying work on farms even when there are sprayers

TABLE 4.15. Comparison of the operating costs of a 600 litre, 10 metre boom width sprayer at various levels of usage. Depreciation and the opportunity cost of capital (15%) included. Values at 1982 prices, chemical costs excluded. Adapted from Matthews (1979)

							VARIABLE & REMARKS	
Initial Capital Cost (£)	1100	1100	1100	1100	1100	1100	a	1982 prices
Area Sprayed Annually (ha)	25	50	100	200	400	800	b	
Life of Sprayer (yrs)	10	10	10	10	9	7	c	from Nix (1981)
Workrate (ha/hour)	6	6	6	6	6	6	d	
Overall Work-rate (50% efficiency)	3	3	3	3	3	3	e	seasonal average
Use (hours/yr)	8.3	17.0	33.0	67.0	133.0	267.0	f = b/e	
Annual Cost of Ownership (£/year)	110	110	110	110	122	157	g = a/c	
Repairs & Maintenance (%)	3.0	3.0	3.0	3.8	6.8	12.2	h	as a % of purchase price from Nix (1981).
Repairs & Maintenance (£)	33	33	33	41.8	74.8	134.2	i	h% of a
15% Interest on Capital (£)	165	165	165	165	165	165	j	
TOTAL COST OF OWNERSHIP (£)	308	308	308	316	361.8	456.2	k = j+i+g	
Ownership Cost per Hectare (£/ha)	12.32	6.16	3.08	1.58	0.90	0.57	l = k/b	
Labour Cost per Hectare (£/ha)	0.833	0.833	0.833	0.833	0.833	0.833	m	based on labour cost of £2.50/hour
Tractor Cost per Hectare (£/ha)	0.983	0.983	0.983	0.983	0.983	0.983	n	50 h.p. tractor, tractor works 1000 hrs/year @ £2.95/hour
TOTAL OPERATING COSTS (£/ha)	14.14	7.98	4.90	3.40	2.72	2.39	o = l+m+n	

FIGURE 4.7. Comparison of the operating costs of a 600 litre, 10 metre boom width sprayer with costs of contract spraying. Chemical costs excluded. Data for sprayer costs from Table 4.15. 1982 prices. Contractor cost from Nix (1981). The 'breakeven' point is at 43 has/year.



on the farm. The reason for this is that growers may temporarily find themselves with insufficient labour and/or machinery to carry out a task, either due to there (temporarily) being more profitable uses for labour and/or machinery, or adverse weather conditions,or the state of the crop means that only the contractor has the specialist equipment to overcome the constraints. By employing a contractor at times like these, the farmer avoids the necessity of owning extra machinery and employing more men as an insurance against uncertain weather conditions (Camm & Hine, 1964).

4.5.3 Aerial applications

Aircraft have been used in agricultural operations for over fifty years. They have achieved a particular usefulness in the fields of plant protection and pest control (Akesson & Yates, 1974). The use of aircraft in agriculture in the UK has risen steadily from approximately 40,000 hectares in 1961 to approximately 650,000 hectares in 1980 (HMSO, 1979).

Aerial applications accounted for 2-3% of the total spray hectares on all crops in 1980 (Sly, 1982), or 366,000 hectares. Over half the applications were on cereals, being mostly fungicides and aphicides. Other large applications were fungicides on potatoes and insecticides on oilseed rape.

4.5.4 Summary of reasons why farmers use contractors

1) To carry out work at short notice.
2) To enable appropriate timeliness of operations.
3) Reduction in total machinery costs and labour substitution.
4) To be able to view the operation of new technology.
5) Easing of management problems.

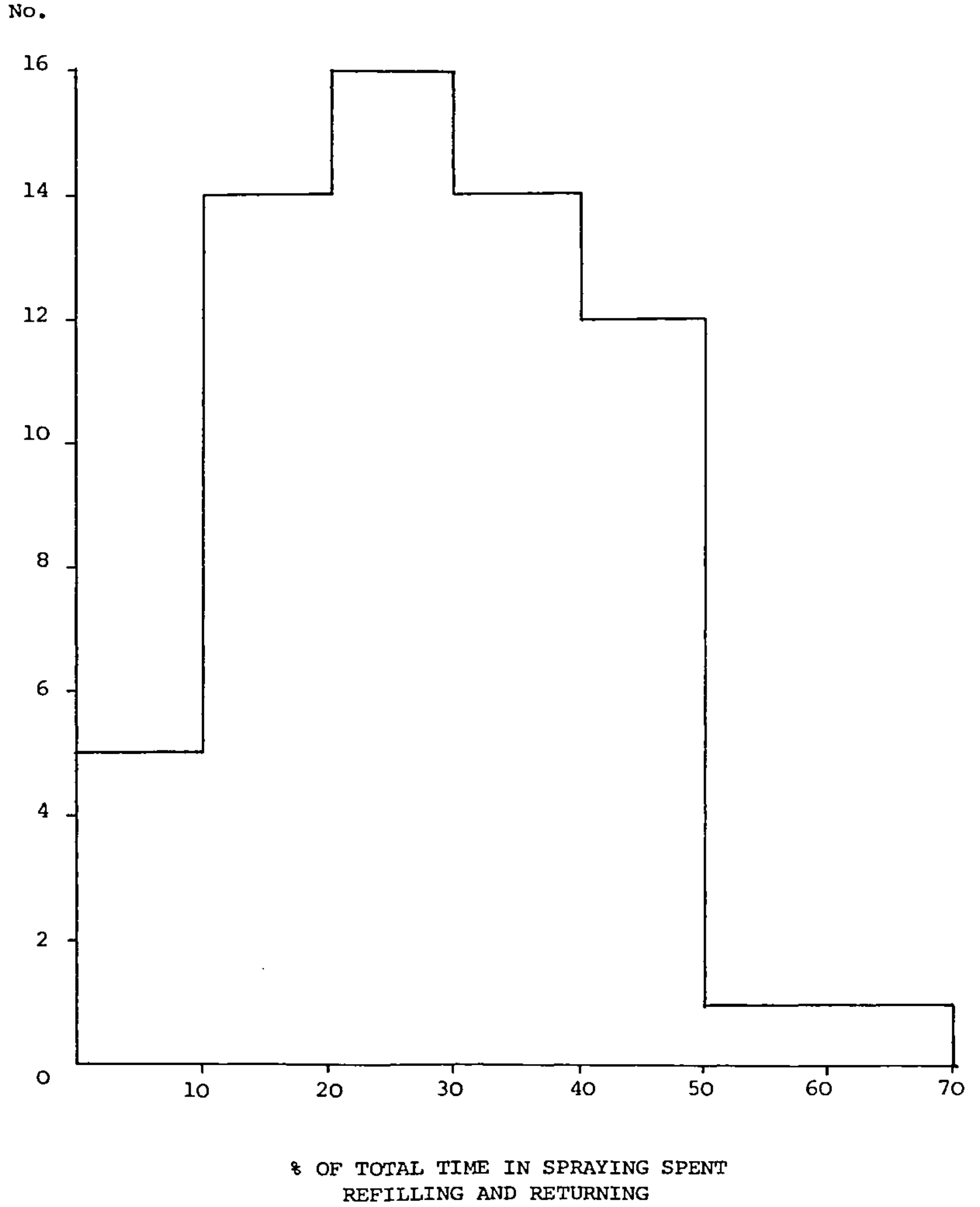
4.6 New Application Technology

4.6.1 Introduction

In the past few years, many changes in the types of chemical available have occurred: there has been a continuing trend towards greater sophistication, specificity, and a greater awareness of the need to confine the treatment to the target (Darter, 1981). Indeed, there is much scope for improving the targetting of chemicals: less than 1% of an insecticide may reach the insect pests within the foliage; even if the foliage is the target, only 30% of the chemical will be targetted accurately (Graham-Bryce, 1977). Other factors stimulating the development of appropriate application technology are: a desire to improve the operational efficiency of spraying operations, easing the environmental constraints on spraying operations and improving on the targetting and timeliness of applications, keeping down the costs of chemicals and of the application process, and improving on operator safety and environmental care.

Improving the operational efficiency of spraying operations is often desirable due to difficulties in collecting and carting water to sprayers: reducing the volume of spraying has eased this constraint, particularly in the tropics, with ultra-low volume (ULV) spraying (Matthews, 1982). In the UK, travelling and filling can occupy upto 70% of the total time spent spraying - see Figure 4.8. Reducing the spray volume and rapid-fill facilities can dramatically increase efficiency. The logistics of the spraying operation, and those parameters most influencing sprayer workrates, are discussed in Chapter Five. Developments aimed at improving operational efficiency include wider spray booms, faster vehicles, low ground-pressure vehicles (which can be used under wetter ground conditions than most tractors), field bowsers, and reductions in spray volumes (Darter, 1981).

FIGURE 4.8. Percentage of time spent refilling and returning when spraying. Data from 63 respondents owning a sprayer in the main part of the random farmer survey.



Ensuring that the chemical reaches the target at the right time, and in the correct amount, may be achieved by selecting the appropriate method of application. Darter (1981) names five systems that may become more widely used in the future:

1) Controlled droplet applications (CDA) e.g. using spinning-disc sprayers.
2) Electrically charged sprays. The charged droplets may be produced using "conventional" nozzles, by a spinning-disc arrangement, or by electrical forces.
3) Controlled release of pesticides, e.g. by micro-encapsulation, hollow fibres, impregnated blocks and laminated strips.
4) Precision application of granules.
5) 'Over the crop' application - mechanical and electrical means of selectively killing tall problem weeds. An example is of the "weed lickers", a wick and roller system where tall weeds receive a smear of chemical from a roller by physical contact.

To an extent, conventional hydraulic pressure sprayers may be adapted to the needs of different targets, by altering the pump pressure or nozzle orifice. By altering parameters such as these, application rates and droplet sizes can be altered.

In order to ensure accurate application, particularly with the advent of longer booms, faster speeds, and reduced volumes, attention should be paid to boom design, and monitoring and control systems. Wide variations in spray deposit may be caused by the vertical and horizontal errant movement of the booms (Nation, 1980). Consequently, gimbal-type mountings have been developed.

Monitoring and control systems are now becoming available for many tractors and sprayers so that a closer control can be kept over application performance.

Operator safety and environmental care are attended to partly by ensuring that pesticide use is as efficient as possible, minimising drift, vapour drift, run-off and leaching. Developments in clothing, cab ventilation and closed measuring and mixing systems are areas where progress is currently being made.

As a result of their current and possible future reference to crop spraying in the UK, a number of the developments outlined above will be discussed in more detail in the next sections.

4.6.2 New application technology - Rotary Atomisers

Rotary atomizers - or "spinning-discs" - were first developed as a means of applying chemicals to crops by Edward Bals in the 1950's. The use of this method was initially as a hand-held, battery-powered device, well suited for applications to tropical crops. Subsequently, the use of rotary atomisers has spread, and a number of varying designs of boom-mounted spinning-disc sprayers are currently available in the UK, e.g. the "Microdrop" sprayer. A variant of the tractor-size spinning-disc sprayer is a vertically-mounted arrangement where droplets in the range of 50 - 100 μm are produced (depending on disc speed and flow rate to the disc) and used in drifting chemicals through the crop, with consequently wide swath widths, thus enabling very high workrates to be achieved. Such an example of this type of sprayer is the "Ulvamast". A survey of "Ulvamast" users has been carried out; results are reported in Chapter Six.

The main operating principle of rotary atomisers is that liquid is fed near the centre of a rotating surface so that centrifugal force spreads the liquid to the edge at or near which the droplets are formed (Matthews, 1979). At certain liquid flow rates and disc speeds, droplets produced are regular and predictable in size. This applies particularly when discs have serrated edges, and radially-arranged grooves on the disc surface, a fact that commends these discs for controlled droplet applications.For sprays produced by conventional hydraulic nozzles, the vmd/nmd ratio is typically in the range 1·5-3·0; CDA sprays have a vmd/nmd ratio close to one, usually less than two (MAFF, 1981).

Further development in application using spinning-discs include the "stacking" of discs, and using air blast in order to direct the droplets toward a target.

By ensuring regular droplet sizes using a spinning-disc, it is hoped that there will be several demonstrable advantages:

a) elimination of small drift-prone drops.

b) reduced drift hazard increases the number of available spraying days and improves the chances of better timing of herbicide application in cereals.

c) more predictable and possibly enhanced biological results.

d) smaller volume rates improve the logistics of the spraying operation.

e) reduced weight of equipment will cause less damage to soil and crops (Linke, 1978).

However, Linke (1978) concluded after a review of trial results upto 1978 that CDA sprayers used performed respectably, "but did not quite reach the standard of conventional spraying". Taylor (1981) states that for herbicide applications, "CDA has little advantage to offer where lower volume conventional spraying can be used", and that "CDA holds the promise of more efficient spraying under a wider range of conditions than is possible with conventional systems, but there is, still, little published information to show that this has been achieved". However, as Taylor (1981) also points out, "application methods and specifications which could be compared vary widely" and "most published experiments do not permit an evaluation of the effect of each variable independently as, too often, they offer only a contrast between a CDA package and a hydraulic application package".

There are few chemicals that are recommended for use with tractor-size CDA equipment: a MAFF publication on the controlled droplet application of agricultural chemicals (MAFF, 1981) states that, "tractor-mounted CDA equipment is still being developed and users should consult the manufacturers and advisory services to ensure that the appropriate droplet size, application rate and formulation are used for each chemical", and that "only a limited number of products have been cleared through the Pesticides Safety Precautions Scheme (PSPS) for use with controlled droplet applicators". No chemicals are cleared under the Agricultural Chemicals Approval Scheme for use with tractor-mounted controlled droplet applicators producing droplets in the range 200 - 300 μm.

Using large, monodisperse droplets, rotary atomizers can achieve some lessening of the wind constraints to spraying from hydraulic pressure sprayers, and the reduced volumes compared with hydraulic pressure sprayers may enable higher daily workrates to be achieved.

It is estimated that at the end of 1982, there were 1000 "field" CDA sprayers (Power Farming, March 1982). For an estimate of the possible future UK market for CDA sprayers, see Chapter Seven.

4.6.3 <u>New application technology - Electrostatic crop sprayers</u>

Droplet charging and electrostatic-deposition technology has been proposed and investigated by various researchers as a potential means for improving the basic droplet impingement process on which the efficiency of pesticide-spray application onto living plants depends (Law and Lane, 1981). The physics of using charged droplets in crop protection have been described in Law (1980) and Coffee (1979, 1980).

The feasibility of using electrostatics in applying chemicals to crops was first demonstrated in the mid 1940's by Hampe (Coffee, 1981). This machine was capable of applying dusts. Several other machines capable of dusting by electrostatic means were then developed over the succeeding years (Felici, 1964, Coffee 1971, both quoted in Coffee, 1981). Subsequently work has been done on charging and applying liquid droplets with electrical forces. A charged water-based spray was produced by a machine manufactured by FMC in the US in the mid 1970's, but was regarded as being cumbersome for commercial application because it incorporated a large compressor (Power Farming, Jan. 1982).

A number of types of electrostatic sprayers capable of applying liquids are currently under development in the UK (1983). These include systems utilising hydraulic nozzles and spinning discs in producing the droplets. However, the design that is probably nearest to being marketed commercially is a sprayer incorporating an electrodynamic nozzle (Coffee, 1979), which presently is known as the "Electrodyn", the trademark of ICI Plant Protection Division. In its simplest form, the Electrodyn has no moving parts, relying on an electric field to establish a standing wave in the surface of the liquid as it emerges (by gravity) through a nozzle, the crests of which emit jets: droplets then issue from each jet (Coffee, 1981).

Large droplets (say 250 μm) have a sufficiently large terminal velocity to move down by gravity to a target without appreciable sideways movement due to drift. However, large droplets may lead to inefficiencies in the distribution of chemical. For example, the LD_{50} for the common housefly is approximately 10^{-9}g of pyrethroid. A 250 µm droplet has about 10^4 greater mass than the required lethal dose of chemical (Coffee, 1981). It may therefore, for some targets, be preferable to form smaller droplets from a volume of spray, the number of droplets of which are formed multiply by a factor of eight as the drop diameter is halved. However, a small droplet, say 100 µm, has a terminal velocity of only 0.3 m/s, which may not be sufficient to prevent drift. Using electrically charged droplets, it is claimed that droplets will be attracted to earthed objects (the biological target), moving along the lines of flux. The force of this attraction, in combination with gravity is thought to be much greater than wind forces that tend to cause drift. Electrostatic sprayers may thus relax the wind constraints operating on hydraulic pressure sprayers (with a broad spectrum of droplet sizes). In addition, the logistic advantages of using very low volumes of chemical can be enjoyed.

It is expected that vehicle-mounted electrostatic sprayers will be marketed in the UK by 1984 or 1985 (Power Farming, Jan. 1982).

4.6.4 Ground-pressure reducing techniques

In this section, the machinery that will be alluded to are double wheels (doubling the number of tyres per axle) and flotation tyres (tyres specifically made for a large surface contact with the ground) for tractors, and low ground-pressure vehicles (LGPV's) as an alternative means of conveyance to tractors.

It is thought that one of the main reasons for the growth in use of ground-pressure reducing techniques has been the trend in the last few years toward autumn-sown combinable crops. This has had the effect, through the necessity of autumn cultivations, in giving rise to a pronounced autumn labour and machinery peak, particularly where a large proportion of the farm is sown with winter crops. Rutherford (1980) identified the autumn application of herbicides as being the factor which has been the spur to development of "special machines", and also of appropriate contracting services. In addition, Rutherford and Timmins (1981) identified two other trends in chemical usage requiring applications under difficult ground conditions: firstly, the practice of "splitting" fertiliser applications, and the application of autumn and early spring fungicides on winter cereals. With liquid fertilisers, rates of application may go up to 400 ℓ/ha, a rate that can only be achieved using a hydraulic pressure spraying system.

Rutherford and Timmins (1981) identified four main methods available to growers in trying to reduce ground pressure:

1) employ a specialist contractor. Charges range from £10/ha (low-volume spraying) to £22/ha (high-volume, spraying)-Nix(1981). This excludes chemical costs.
2) modifications to tractors, such as dual wheels and flotation (oversize) tyres. These may cost several hundred pounds, and can halve the effective ground pressure of the tractor. They do not generally require modification to the tractor, but recalibration of sprayers will be necessary.
3) modifications to mass produced pickup trucks, load carriers and personnel vehicles. These may be encountered as "one-off" machines, manufactured by the farmer. Reductions in ground pressure of one half to two thirds of ground pressure exerted by tractors are possible.

4) special purpose agrochemical applicators. A requirement for speed is vital since the machines are designed to ensure timeliness. Expected speeds range from 10 km/hr to 20 km/hr. This compares with most tractors, where with their combination of high centre of gravity, short wheelbase and lack of suspension, the speed when spraying is usually limited to 10 km/hr. or less (Elliott, 1980). Although LGPV's may not be able to apply chemicals the year round, they should be capable of working over a long period of time on soil near to the field capacity without damaging the crop (by excessive pressure or wheel slippage) or causing rutting of the soil. The effects of weather conditions on spraying will be discussed further in Chapter Five.

The attraction of LGPV's is their low ground pressure and high speed; payload is of necessity low, therefore low application rates of chemical are often used in concert with LGPV's.

The low ground pressure possible in LGPV's is generally made possible by widening the tyres, and possibly increasing their number above four. Between October and early May, the months with the greatest probability of waterlogged soils, then this conformation is acceptable. However, between early May and harvest, the use of an LGPV in a crop may well not be necessary, as the soil moisture deficit is generally sufficiently low, and may in fact cause crop damage by the LGPV having insufficient crop clearance, by flattening the crop, from which it might not recover (even if tramlines are used), and by causing "scrubbing" of the crop when turning at headlands (this last effect may happen at any time of the year). Between May and harvest, the soil moisture deficit is usually sufficiently low to permit the use of narrow section wheels which allow an increased ground clearance, thereby reducing the possibility of direct crop damage.

At 1981 prices, LGPV's retail for between £6,000 and £8,000. Modified trucks etc., may be made by individual growers for considerably less. Rutherford (1980) has indicated that the total market for LGPV's would be at about 3,000 holdings. In comparison, approximately 4,000 rough-terrain fork-lift trucks have been sold (cost at 1980 prices: £10,000 - £15,000) to date, a machine which is applicable to similarly sized farms.

4.6.5 Electronic sprayer monitors and control systems

Recent developments in application technology, and a background of rising pesticide prices, have led to a need for the sprayer operator to ensure more precision in application. Technologies appropriate to achieving this are electronic monitoring and control systems.

In order to ensure that the correct dose of chemical per unit area is being applied, two main factors must be considered:

1) the speed of the machine.
2) the flow at the nozzle, which depends on the pressure (Givelet, 1981).

It is important that the volume applied per unit area remains constant, and that ideally the output from each nozzle is similar. Mechanical and hydraulic systems have been used in the past to ensure constancy of application, but the greatest opportunities for monitoring and control lie in the use of micro-electronics. The essence of the problem of monitoring and control is in comparing information (Givelet, 1981). If the process is viewed as a "system", then the system may be of two types:

1) an open-loop system where operator intervention is required for the correction of an error condition, usually the ground speed of

the vehicle.

2) a closed-loop system not involving the operator, where the spray rate is automatically regulated by the forward speed to maintain a pre-set spray volume per unit area (Woodworth, 1980).

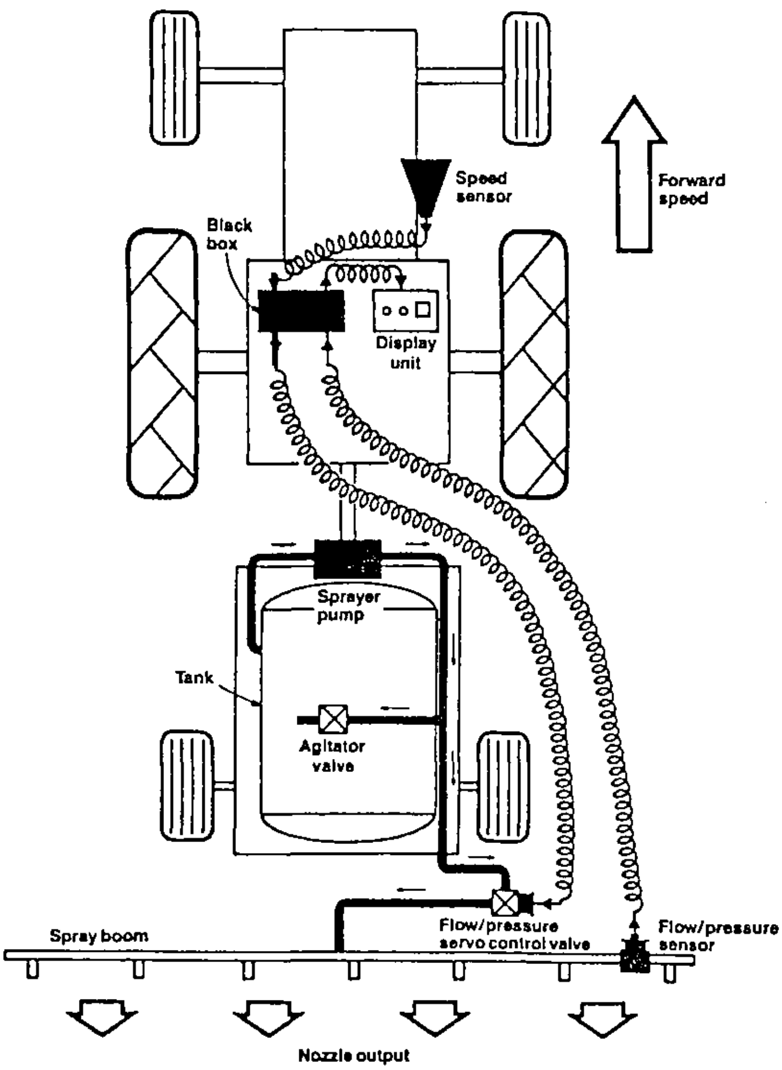
Category (1) broadly covers monitoring devices, whereas (2) concerns both monitoring and control systems.

At the minimum, conventional sprayers and tractors have a pressure relief valve and pressure gauge so as to maintain and indicate the correct pressure. Tractors are fitted with tachometers which are not suitable for indicating forward speed, due to wheel slippage, slopes etc. Only devices which can measure the actual ground speed can be relied on for accurate spraying (Howard, 1983). A speedometer is therefore a useful device to aid in spraying operations. The various types of speedometer available include magnetic or inductive wheel slip sensors, jockey wheel speed sensors, and radar speed sensors (ADAS, 1981a).

An elementary monitoring device will combine information on boom width, speed and pressure/flow rates to give a readout of speed, area, application rate and quantities applied. However, the sprayer operator is left to decide what should be done.

The second category above includes the more sophisticated control systems, where the control system measures the input data of speed, nozzle pressure and flow rate; if they differ from those set by the sprayer operator, the control system initiates action to restore them to the required levels. This is performed, as in Figure 4.9 with a servo control valve. Control systems therefore balance pressure and speed so that if the speed varies the pressure is increased or decreased pro-

FIGURE 4.9. Diagram of a sprayer fitted with an Automatic Volume Regulating (AVR) system. Diagram from Howard (1983).



portionately (Howard, 1983). This is known as an automatic volume regulating system (AVR).

Speedometers range from £145 - £310, whilst monitors cost from £130 to £950. Control systems can cost between £1,000 and £2,000 (Howard, 1983: current prices). McAllan (1980) indicates that only a small percentage of holdings in Britain are large enough to justify the cost of an electronic control system. However, cheap monitoring systems and cheaper control systems could find a much wider audience.

Recent developments in electronic control systems for spraying include boom-levelling devices, and devices that act on a change of speed by keeping the spray pressure constant and varying the amount of chemical added from a smaller tank containing only chemical. This prevents changing the droplet characteristics (eg. VMD/NMD ratio) as the pressure is varied.

4.7 Summary.

1) Data from several surveys on recent and current plant protection practices in the UK are presented and discussed.
2) There is evidence to suggest an upward trend in chemical usage (as measured in terms of spray area or spray rounds) in arable crops. For most crops, the values of chemical inputs have risen consistently over the past decade.
3) The tank mixing of several proprietary formulations of chemicals is an established and common practice. Savings in time and prevention of crop damage are the main justification for their use.
4) In applying chemicals to crops, there are two seasonal peaks: in the Spring (April-May) and Autumn (October-November). There is some indication that autumn applications are becoming more significant, but at present the bulk of spraying is carried out in

the spring.

5) The hydraulic pressure sprayer is the most common applicator. Most farms have at least one mounted sprayer. There is a very constant inverse relationship between the 'sprayer capacity' on the farm, and the farm size.

6) The 'problem areas' of hydraulic pressure sprayers appear to be the booms (whip and breakage) and nozzles (blockage).

7) Contractors are commonly, though intermittently, used by farmers for plant protection. Contractors are in general called in only when the grower cannot carry out the operation (through a lack of appropriate machinery/personnel), or fears crop or soil damage. Much of the contractor's work is in late season applications (June-July), with a secondary peak in the autumn (October-November).

8) There are a whole cluster of innovations relevant to plant protection at the present time. Their introduction and widespread use may influence the application of plant protection chemicals in many ways. However, it appears that many of the innovations are at present suitable only for larger growers.

CHAPTER 5

APPLICATION PRACTICES

5.1 Introduction

In this chapter, the two most important factors in crop spraying operations are discussed: the logistics of crop spraying, and constraints on crop spraying operations caused by weather conditions.

In Section 5.2 the organisation of crop spraying operations is discussed, with a consideration of the factors affecting sprayer workrates. Results are presented from the random user and Ulvamast user surveys. Section 5.3 outlines several models of sprayer operation, by which workrates can be calculated. Two such models, the Baltin model (Baltin, 1959) and a model by Renoll (Renoll, 1981) are outlined, and written in the form of a computer program. In Section 5.3.5, the model is validated using data collected in the Ulvamast user survey.

Four main groups of spraying system parameters are discussed: sprayer dimensions (boom width, tank capacity), refilling arrangements (distance to refill, rate of refilling), application rates,and spraying speeds. In addition a consideration is made of the effect on workrates of field size, field shape and farm conformation.

A discussion of results from the model is given in Section 5.3.6.

Section 5.4 discusses the effect of various environmental parameters upon spraying operations. Data is presented from the Ulvamast user survey. Among the factors discussed are the effects of temperature, windspeed, precipitation and soil moisture deficits. Section 5.4.7. introduces the concept of spray-days.

In Section 5.5 an analysis is made of weather data from RAF Benson for the period August 1981 - July 1982. Section 5.5.3 outlines the level of environmental constraints set in order to assess suitable spraying periods. In Section 5.5.4 results are presented and discussed, with windspeed and soil moisture deficit parameters being varied. In Section 5.6.1 data is presented from the Ulvamast user survey on the time spent spraying cereals in the growing year 1981 - 82.

Section 5.7.1 attempts to pull together results from the logistics and weather sections, in outlining a model which can suggest a suitable spraying system for a given farm and set of spraying requirements. The model is summarised in Figure 5.19. A worked example of the model is provided in Section 5.7.2.

5.2 The Organisation of Crop Spraying Operations

5.2.1 Introduction

There are six main groups of factors influencing the operational efficiency of farm spraying operations:

1) sprayer dimensions
2) spraying and ferrying speeds
3) refilling arrangements
4) application rates used
5) field size, shape and farm conformation
6) time required for calibration, breakdowns and delays.

These six groups of factors are discussed in this section, and the model of sprayer operations presented in Section 5.3 will mainly concentrate on the first four factors.

5.2.2 Sprayer dimensions

The two sprayer dimensions most directly affecting the rate of work are the tank capacity and the boom width. Increasing the tank capacity enables the operator to spray for a longer time before stopping to refill the tank with chemical and diluent. Tank capacities of sprayers can range from 500 ℓ for the smallest mounted sprayer, to 4500 ℓ for the largest trailed or self-propelled sprayer. However, half the sprayers in the UK have a tank capacity of less than 750 ℓ (Matthews, 1979).

Increasing the spray boom width will increase the 'effective' width covered by the machine: the spot rate of work (speed x effective width (ADAS, 1976)) will be increased. Matthews (1979) indicates a formula by which a 'suitable' boom width for a farmer may be calculated. In order to prevent excessive wheelings through a crop, and in line with the increasing tendency to "tramline" through cereal crops, the sprayer boom width is often related to the width of the seed drill (Matthews, 1979). In a survey of sprayers on ninety-one farms, (ADAS, 1976) 59% of all sprayers were found to have a boom width between 10 m and 12.5 m. Seventy-two percent of respondents in the Ulvamast user survey (18/25 - one respondent was out of farming) use sprayers with a boom width of 12 m. Boom sizes may vary from 6 m to 24 m. The coverage given by the sprayer depends on the type and spacing of the nozzles along the boom; these may also affect optimum boom heights.

5.2.3 Spraying speeds

The speed of spraying must be related to the output at the nozzle or disc. Unless the tractor has an automatic volume regulating system

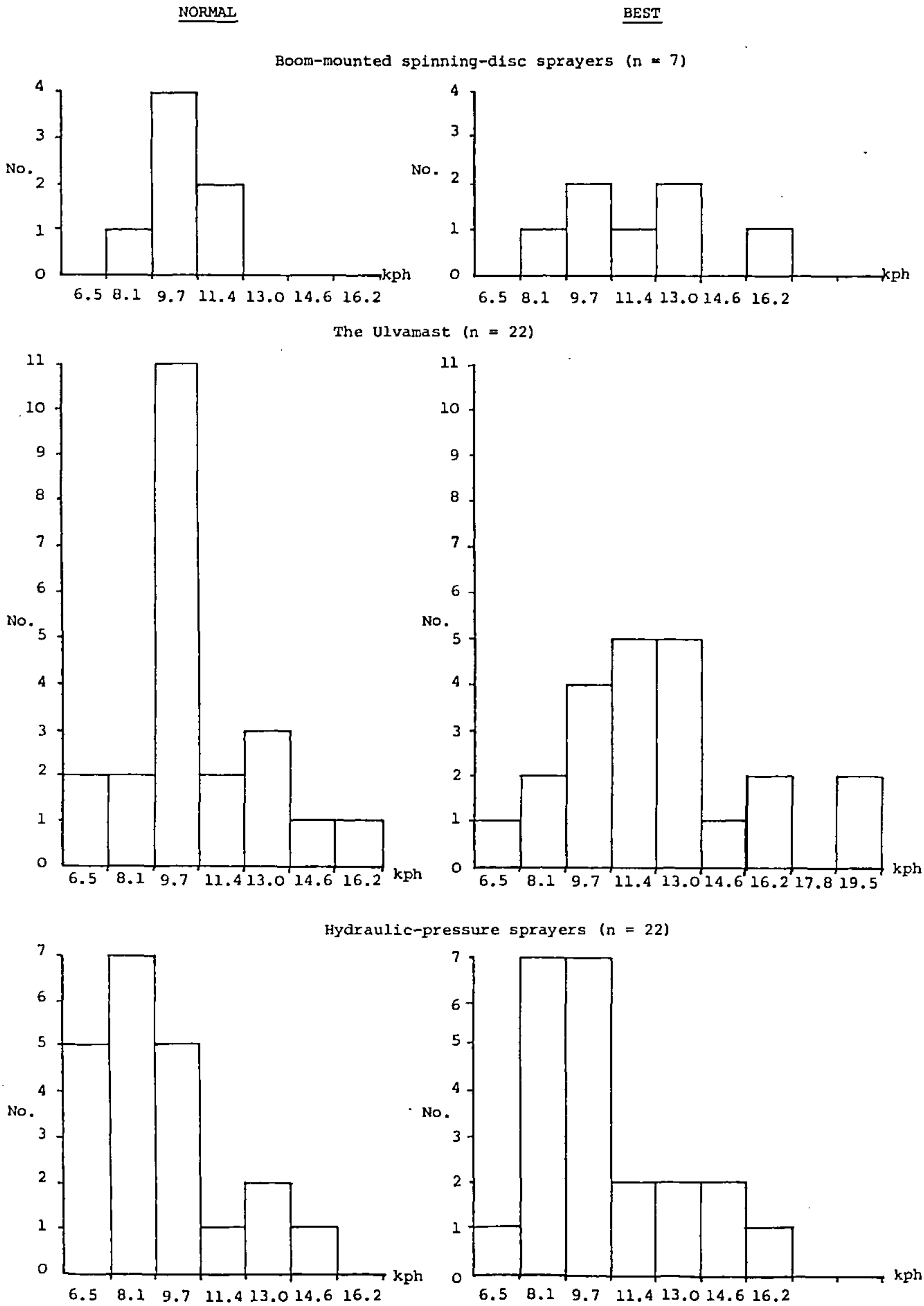
(AVR - see Section 4.6.5), if the sprayer speed changes without alteration to the flow rate, then overdosing or underdosing of the crop by the chemical may occur. In addition, a high speed of spraying may exacerbate problems of boom bounce, which may also adversely affect the distribution of chemical. Figure 5.1 shows the spraying speeds used by respondents in the Ulvamast user survey. Data is supplied for hydraulic-pressure sprayers, the "Ulvamast", and for any boom-mounted spinning-disc sprayers encountered on farms in the survey. Figures are given for speeds "normally" achieved and "best" figures. There are some "missing values" owing to some respondents not being able to recall these values. Spraying speeds can range from 4 mph (6.4 k.p.h. or 1.8 m/s) to 12 mph (19.2 k.p.h. or 5.3 m/s). Faster spraying speeds may be achieved by the use of specialist vehicles, e.g. low-ground pressure vehicles. At higher speeds, boom suspension is even more important, in order to prevent uneven applications resulting from boom tilt or bounce.

Undulations or slopes in the field may also affect spraying speeds. In the Ulvamast user survey, forty-four percent of respondents in farming (11/25) stated that undulations slowed them down in at least some fields on their farm, and 28% (7/25) had slopes in some fields steep enough to slow down spraying operations.

5.2.4 <u>Refilling arrangements</u>

Refilling arrangements are an important consideration when arranging spraying operations: in a survey of 91 farms (ADAS, 1976) it was found that the time spent filling sprayers as a percentage of time spent spraying ranged from under 20% to over 100%. The median category was 30 - 40%. Time spent travelling to and from fields ranged from

FIGURE 5.1. "Normal" and "best" spraying speeds with three different types of sprayer. Figures from Ulvamast user survey. Several respondents were not able to recall these values. Speed in kilometres per hour.



under 10% to over 30%, the median category being 10 - 20%. In the random user survey, of the 73 farmers operating their own sprayer, estimates of the time spent refilling and returning ranged from under 10% to 70%, with the median category being 21 - 30% - see Figure 4.8.

In the random survey of 76 farmers, of the 73 respondents operating their own sprayer, the majority returned from the field to the farm, as shown in Table 5.1. In a survey of 91 farms (ADAS, 1976) it was found that of the 50% of respondents returning to a mains supplied source of water, half obtained water directly from the mains, the remainder obtaining water from an header tank filled with mains water. The survey also found that the farms with the fastest filling rates generally used a raised header tank or a bowser system: when the sprayer itself pumped the water from a low level tank or a stream, there were wide variations in filling rate, generally lower than that achieved with bowsers or header tanks. Measured rates of tank filling on the farms surveyed by ADAS (ADAS, 1976) ranged from under 0.5 ℓ/s to over 2.5 ℓ/s, the median category being 0.5 - 1.0 ℓ/s.

In addition to the time taken to fill the tank with water, account must be taken of the time required to add the chemical, and ensure thorough mixing of the chemical.

TABLE 5.1 Method of refilling sprayers. Data from the random user survey, involving the 73 respondents operating a sprayer.

Method	Number
Return to farmyard	39
Bowser	19
Static tanks, rivers, ditches	5
Bowser + return to farmyard	4
Static tanks, rivers, ditches + return to farmyard	5
Bowser + static tanks, rivers, ditches	1
	73

5.2.4.1 The use of bowser systems in crop spraying

Bowser systems involve carting water to a sprayer as opposed to the sprayer being taken to the water. In the survey of 26 Ulvamast users, questions were asked on the method of refilling for all types of sprayer. Nine respondents stated that they used bowsers for a substantial part of their spraying operations when using hydraulic sprayers. Nine respondents returned to the farmyard to fill up, four respondents had static sites around the farm to fill up, and four respondents used a variety of methods.

For hydraulic sprayers, it was found that the mean time taken to refill the tank and mix in chemicals was 10.5 minutes, with ranges of 2 - 20 minutes. There was no significant difference (at the 95% level) between bowser and non-bowser systems. However, a highly significant difference ($p < 0.01$) was detected between bowser and non-bowser systems regarding the total time taken to return the empty sprayer to the refilling point, refill, and return to spray. The mean time taken with bowser systems was 11 minutes, whilst with non-bowser refilling systems it was 25.4 minutes. Thus it appears that the time benefit to be gained by using bowsers is mostly due to the physical proximity of the bowser to where spraying is being carried out. Table 5.2 shows the maximum and average stated distances travelled by the sprayer to the water supply for bowser and non-bowser systems.

TABLE 5.2 Distances (m) travelled to refill hydraulic sprayers, using bowser and non-bowser systems.

	Mean value: bowser systems, hydraulic sprayers n = 9	Mean value: non-bowser systems hydraulic sprayers n = 13 *
Maximum stated distance to water	518	2006
Average stated distance to water	294	737

*Farmers using a variety of refilling methods excluded.

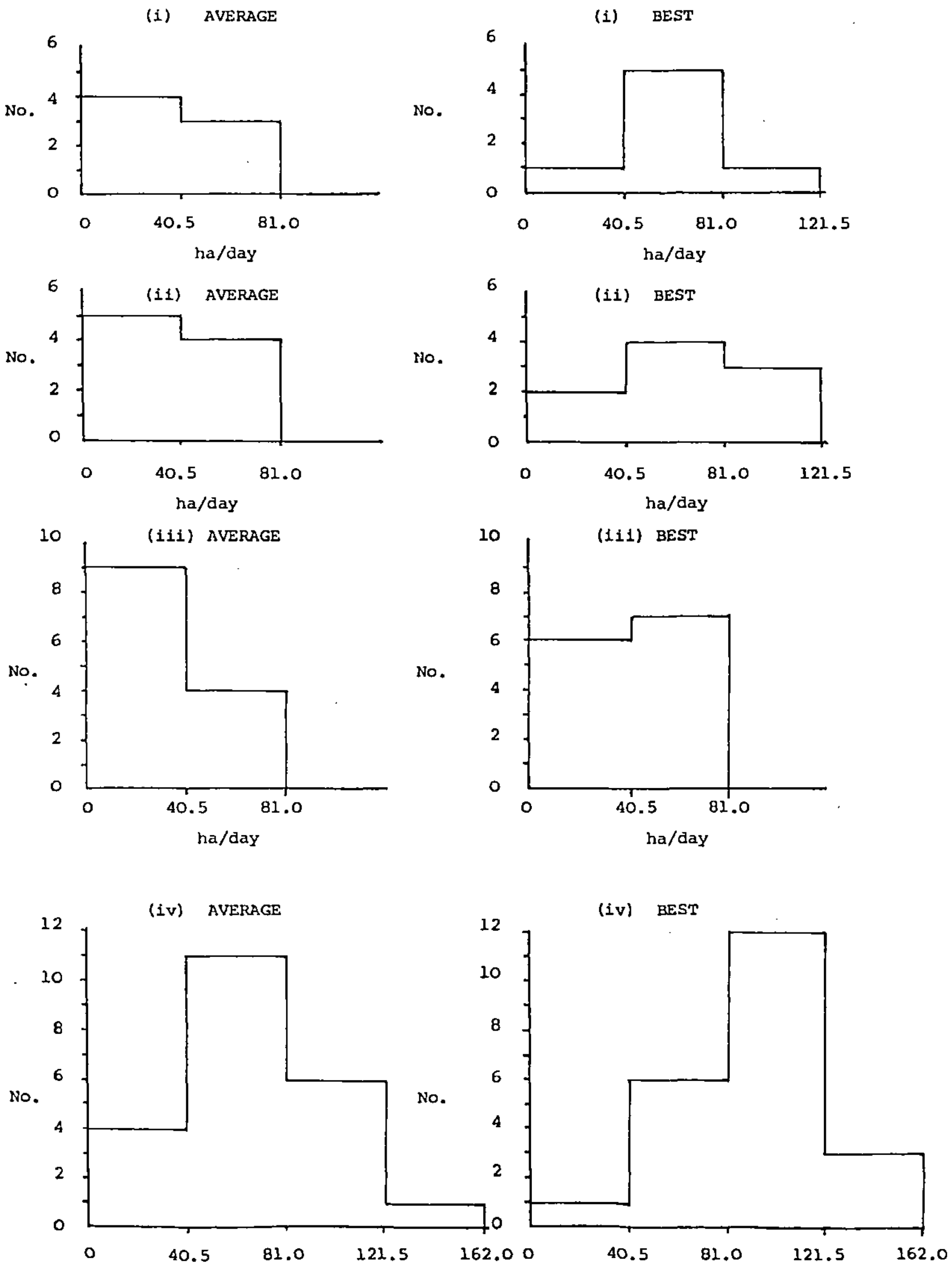
FIGURE 5.2. Rates of work achieved per day by different spraying systems. Data supplied from the Ulvamast user survey. Figures for "average" and "best" workrate achieved in a ten hour spraying day by four systems:

(i) Tractor-mounted spinning-disc sprayers (n = 7)

(ii) Hydraulic pressure sprayers, using a bowser refilling system (n = 9)

(iii) Hydraulic pressure sprayers, returning to farm or going to static tank to refill (n = 13)

(iv) The Ulvamast (n = 22)



Reductions in refilling time achieved by using bowser systems are partly offset by the extra labour requirement to operate bowser systems: six of the nine users of bowser systems stated that two full-time men were needed for spraying operations requiring bowsers.

The use of bowsers enable an increased efficiency in the use of sprayer machinery; if different tank capacities are corrected for, and sprayers are compared that have a 12m boom width, Table 5.3 demonstrates the increased usage that may be obtained from spray machinery refilled with a bowser system.

TABLE 5.3 Mean area (hectares) sprayed per day per 450 ℓ tank capacity, for sprayers with a 12m boom, using bowser and non-bowser refilling systems.

	BOWSER SYSTEM		NON-BOWSER SYSTEM	
	Average/day	Best/day	Average/day	Best/day
Hectares per 10 hour day per 450ℓ tank capacity with a 12m boom	16.7	21.4	9.1	11.3
	n=8*		n=10*	
			T-test: $p < 0.05$	T-test: $p < 0.05$

*Data only included for sprayers with booms 12m - 12.8m long.

5.2.5 Application rates

The effect of refilling arrangements on the sprayer workrate is greatly influenced by the application rate of chemicals to the crop. In the random user survey, the data on the application rates used are given in Figures 4.9a and 4.9b. The median figure for hydraulic sprayers is 225 ℓ/ha (20 gal/acre), with ranges from 112 ℓ/ha to 450 ℓ/ha. The type of chemical to be applied may determine the volume of diluent to be used; insecticides may be applied in volumes as low as 100 ℓ/ha with hydraulic sprayers, whereas some herbicides may demand 225 ℓ/ha, and dessicants to 450 ℓ/ha. There appears to be a trend towards using lower volumes of diluent generally with hydraulic sprayers, e.g. the "seven gallon" system, promoted for use with sugar beet herbicides.

New crop spraying technology, such as rotary atomisers, claims a great reduction in the volume of diluent required, with satisfactory control at 50 ℓ/ha being claimed to be possible for many chemicals. The effects of varying application rates on workrates of sprayers are explored in a model of sprayer workrates, as outlined in Section 5.3.6.5.

An ADAS study of spraying practices on 91 farms (ADAS, 1976) has among its conclusions that "a major limiting factor in chemical application to arable crops is handling the diluent. Faster filling from a bowser in the field has been suggested as a cheap and simple way of improving work rate and many farmers would benefit if this advice was more widely adopted".

5.2.6 Field size, shape and farm conformation

Field size, shape, and spatial distribution can have a great influence on the rate at which field operations are carried out.

A distinctive trend on British arable farms is the increase in field size. The three main benefits regarding spraying operations arising from field amalgamation are:

1) for a given area, the number of turns at the end of the field is reduced (saves time, and may reduce effects due to "scrubbing" of wheels on the crop).
2) Some headlands are eliminated, rendering the operation easier. If the correct way to spray a field is adhered to (Matthews, 1979,

p. 150), the elimination of a headland between two fields can save a considerable amount of time.

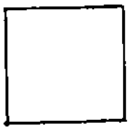
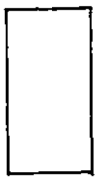
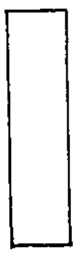
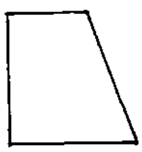
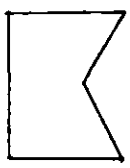
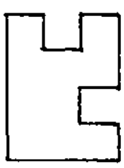
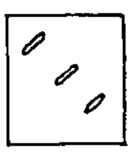
3) A reduction in movements between fields. Movements may entail the folding of booms etc., which is time-consuming. (Sturrock, Cathie and Payne, 1977).

Increasing the field size can increase the proportion of time spent in effective work, as shown in Table 5.6. In addition, implement size and speed of operation can influence the effective rate of work; these three factors interact and reinforce each other, and the effect of any one of them is very much less than all these three together (Sturrock et al, 1977). The effects of varying factors influencing workrates are investigated in a model of sprayer operation, the results of which are presented in Section 5.3.

An awkward field shape can add appreciably to the time taken to cultivate a field (Sturrock et al, 1977). The authors outline seven different shapes of field, and calculate the time taken to cultivate different shapes of field,i.e. time taken for cultivations (as well as turning, headlands and changing the field). The shapes, and an index value of the estimated time taken to cultivate the field is shown in Figure 5.3. The effects of field shape on sprayer workrates are also explored in the sprayer operating model, as outlined in Section 5.3.6.6.

Farm conformation may be important in operations such as refilling the sprayer using a static, "non-bowser" refilling method, and in the time taken to move between fields. Fragmented farms can require much more time in spraying operations than a compact farm with a central water source.

FIGURE 5.3. Effect of field shape on time required to carry out field operations. Figures apply to a 10 hectare field: all field areas equal. Field shapes and index values from Sturrock <u>et al</u> (1977). Note: row lengths can be variable in irregularly-shaped fields.

SHAPE	NAME	AVERAGE ROW LENGTH (m)	INDEX OF TIME REQUIRED TO CULTIVATE (including turning, headlands & changing field)
	Square	316.2	100
	Rectangle 2:1	447.2	95
	Rectangle 4:1	632.5	93
	Standard	316.2	105
	Re-entrant side	316.2	104
	Building plots	316.2	107
	Obstacles	316.2	109

5.2.7 Breakdowns and delays

In a survey of 91 farms (ADAS, 1976), temporary delays in the spraying operation or breakdowns of the sprayer or tractor were recorded, and presented as a percentage of the total time devoted to the spraying operation. The median category was no delays or breakdowns (38%), the next being 0% - 5% of the time (29%). Six percent of respondents had delays or breakdowns for over twenty percent of the total time devoted to spraying. The results indicate that a fairly small percentage of the time is spent in overcoming delays in spraying or breakdowns of sprayers. Delays in spraying operations due to the weather are probably more important. (The effect of the weather on spraying is discussed in Section 5.4). However, perceived opportunity costs for transient delays in spraying are probably high, and farmers would generally be expected to do all they could to avoid them.

In the Ulvamast user survey, the mean difference between "average" and "best" workrates for a 10 hour day is approximately 36% (n = 22), with hydraulic pressure sprayers. For the Ulvamast (n = 22) and boom-mounted rotary atomisers (n = 7) the increases are 44% and 62% respectively. The lower average figures may be partly explained by some respondents stating that as most of the crop could be covered in one day by the sprayer, then there was little need to spray any more efficiently (in terms of has/day).

5.2.8 Calibration of sprayers

Calibration of crop sprayers is carried out in order to ensure correct application rates and individual nozzle outputs, and to ensure a correct spray pattern. The procedure of calibrating a sprayer is different for hydraulic-pressure sprayers and rotary atomizers. A guide to the calibration of hydraulic-pressure sprayers is given in

Power Farming (January 1981, p. 12)*. Electronic aids are now available to help improve the accuracy and speed up the process of calibration.

It is recommended that the process of calibration be carried out: at the beginning of each season, at every 100 hectares, and after changes of tractor or sprayer wheel tyres,nozzle tips or operating pressure (Power Farming, Jan 1981 p. 12).

In the random user survey, the 73 respondents who had a crop sprayer on the farm were asked how frequently they calibrated their hydraulic-pressure sprayers. Thirty four percent of respondents (25/73) never calibrated their sprayers, twelve percent (9/73) calibrated them under once per year, 29% (21/73) calibrated them once per year, with only 25% (18/73) calibrating them more than once a year.

A study of the variability of nozzle output for 91 sprayers on farms (ADAS, 1976) found that on some farms the output from some nozzles varied considerably along the same boom. Regarding calibration procedures, the report concluded that "the majority of the operators (in the survey) were achieving satisfactory results but the large errors recorded on some farms underlined the need for the operator to be able to calibrate his machine".

It is estimated that calibration of an hydraulic-pressure sprayer can be carried out in 15-30 mins.

*Methods of calibrating rotary atomisers usually involve setting the appropriate flow rate to the head, and ensuring the correct disc speed, e.g. CDA Boom Owners Manual (ANON, undated).

5.3 A Model of Sprayer Operations

5.3.1 Introduction

In attempting to describe and evaluate a relatively complex system such as the operation of crop sprayers on a farm, one possibility is to construct a simulation model of the system. A model may be represented as any set of rules and relationships that describe something. Models are an attempt to represent and simulate real-life events; in attempting to model a system, it is hoped that some insight into the system will be gained. In attempting to simulate a system, models need not contain representative parameters of all factors likely to be influencing a given system. In fact it is unlikely that such comprehensive information is available. However, it is vital to include the important parameters.

In this section, a dynamic, nonoptimising deterministic model of spraying operations is outlined. The model does not rely on a simulation of a day's real-time spraying operations, but relies on an algorithm to describe spraying activities through the day. Real-time modelling of sprayer operations has been carried out by Nation (1978).

The model results are validated in Section 5.3.5; results from runs of the model are presented in Section 5.3.6. A discussion of the implications of results from the model is made in Section 5.3.7.

5.3.2 Models of sprayer operation

The main groups of factors influencing spraying operations have been outlined in Section 5.2. It is desirable to consider all of these in any model of sprayer operations.

An early example of a formula with which the workrate of a sprayer can be calculated is given by Baltin (1959). The original formula refers to aerial spraying operations:

$$t = 10^4 \left(\frac{T_r Q}{Q_f} + \frac{1}{V_s b} + \frac{T_w}{bL} + \frac{2aQ}{V_f Q_f} + \frac{C}{vF} \right)$$

where

- t = work time per hectare (s/ha)
- T_r = time for loading and taxiing (s)
- Q = application rate (ℓ/m^2)
- Q_f = Quantity of chemicals loaded per flight (ℓ)
- V_f = Speed when ferrying (m/s)
- V_s = Flying speed when spraying (m/s)
- b = Swath width (m)
- T_w = Time for one bend at the end of a spray run (s)
- L = average length of parcel (m)
- a = average distance airstrip to fields (m)
- F = average parcel size (m^2)
- C = average distance between the parcels (m)

Lovro (1975) outlined a number of formulae to calculate the work-rate of an aerial spraying system in order to find the optimum area that can be treated from one airfield. Nation (1978) outlined a computer-based model simulating a day's spraying. In this model the field size and shape are kept constant. Methods of refilling can be stipulated, and a number of swaths around the field can be sprayed before starting parallel swaths.

Sprayer dimensions, spraying speeds and application rates can be varied.

Renoll (1981) presented a general formula to predict machine field capacity under given machine, field and operating conditions.

The formula as presented is:

$$T = A + B$$

and

$$C = \frac{1}{T}$$

where

T = total time (hours/hectare)

A = time spent actually performing the specific operation (hours/ha)

B = time used for support activities, row-end turning, and other delays (hours/ha)

C = performance rate (has/hour)

In addition, $A = \frac{10}{SW}$

and $B = \frac{2.8P}{WM} + [(f_2 + f_3 + f_4 + f_5 + f_6 + f_7)\frac{10}{SW}] + \frac{VU}{60D}$ (h/ha)

where S = machine ground speed (km/hour)

W = machine width (m)

P = average time per turn (s)

M = row length (m)

f_2 = coefficient for adding seed

f_3 = coefficient for adding fertiliser

f_4 = coefficient for adding water and chemicals

f_5 = coefficient for adjustments

f_6 = coefficient for idle field travel

f_7 = coefficient for rough field surface

V = time for round trip, barn to field and return (minutes)

U = number of round trips barn to field and return required to complete the field operation

D = hectares in the field.

The coefficients f_2 to f_7 are dimensionless; typical values for them are supplied by Renoll (1981). However, the author states that "the accuracy of the prediction formula is greatly influenced by coefficient selection" and that "this selection is not always easy".

In the next section, a computerised deterministic model of ground spraying operations is outlined, using and comparing results from the formulae supplied by Baltin (1959) and Renoll (1981).

5.3.3. A computerised model of spray machinery workrates.

In order to assess the effect on sprayer workrates of varying factors such as sprayer dimensions, speed, refilling arrangements, and field size and shape, a program in FORTRAN was written. The model was computerised in order to avoid the large number of calculations that would have to be done by hand when considering so many variables.

Both the Baltin (adapted for ground spraying, as done by Heijne, 1981), and the Renoll formulae were used, and the overall results that they gave were compared. Coefficients for use in Renoll's formula were obtained from suggested values in his paper (Renoll, 1981). In addition, values were calculated of the percentage of time in the day spent spraying and turning, refilling, and in transit between fields. The Baltin formula was used to calculate these.

Superimposed on the formulae is a correction factor to account for field shape. Calculations by Sturrock et al (1977) have estimated the relative time taken to cultivate (including turning, headlands and changing field) different shaped fields for a 3m wide machine with a forward speed of 6 Km/hour. Field shapes, and the index of relative time taken are given in Figure 5.3. Although the relative values may change slightly with changing boom widths and forward speed, the values presented in Figure 5.3 are used in the model as a basis for estimating the change in time taken to spray, turn, and change fields with varying field shapes. The relative values refer to a 10 ha field, except where otherwise stated.

On smaller fields, the loss of time caused by an awkward shape would be greater; on larger fields, the shape would be of less significance (Sturrock et al, 1977).

The program for calculating workrates, with explanatory notes, is given in the Appendix.

Each run of the model simulates different combinations of distance to refill, rate of refill, application rate and spraying speed, for a number of sprayers with different dimensions. Computer runs are repeated, incorporating field length changes and correction factors for fields of differing shapes. An example of output from the computer-based model is given in Figure 5.4.

5.3.4 Model constants and variables

Several factors are constants in the model: the time taken to turn the sprayer at the end of the row is 10s; the distance between fields, (which are all assumed in one run of the model to be equidistant, the same size and shape) is 1 km, and the ferrying speed of the sprayer, i.e. the speed at which the sprayer moves when going to or returning from refilling, or moving between fields, is 5 m/s. The field size is generally 10 ha, except where otherwise stated. Depending upon the

FIGURE 5.4. Example of output from the computer model. See Appendix for programme.

```
    FIELD SHAPES TYPE 4
NO. SPRAYERS TESTED= 6

        ASSUME 10 HOUR WORKING DAY,
        INCLUDING 30 MINS IDLE AT START ANDEND OF DAY
         RELIEF DRIVER AVAILABLE

CONSTANTS IN MODEL:
TIME TO TURN AT END OF SPRAY RUN(S)=10.0
FIELD LENGTH(M)= 316.2
FIELD SIZE(SQ.M)=100000.0
DISTANCE BETWEEN FIELDS(M)=1000.0
FERRYING SPEED(M/S)= 5.0
```

DISTANCE TO FILL(M)=1000.0
RATE OF REFILL= .75 L/S OR 9.9 GALLS/MIN
APPLIC.RATE(L/HA)= 200.0000 OR 81.0 L/ACRE OR 17.84 GALLS/ACRE
FORWARD SPEED(M/S)= 1.6700 OR 6.0 KM/HR. OR 3.7 M.P.H.

NAME OF SPRAYER	TANK CAPACITY (LITRES)	BOOM WIDTH (METRES)	WORKRATE(HAS/DAY) (BALTIN)	WORKRATE(HAS/DAY) (RENOLL)	PERCENT OF TIME: SPRAYING & TURNING	PERCENT OF TIME: REFILLING AND RETURNING	PERCENT OF TIME: IN TRANSIT BETWEEN FIELDS
SPRAYER	250.0	12.0	23.15	33.90	50.93	47.64	1.43
SPRAYER	250.0	18.0	26.66	43.56	43.50	54.85	1.65
SPRAYER	250.0	24.0	28.84	50.80	38.88	59.34	1.78
SPRAYER	2000.0	12.0	35.63	47.95	62.97	34.83	2.20
SPRAYER	2000.0	18.0	44.66	69.86	53.59	43.65	2.76
SPRAYER	2000.0	24.0	51.15	90.54	46.85	49.99	3.16

DISTANCE TO FILL(M)=1000.0
RATE OF REFILL= .75 L/S OR 9.9 GALLS/MIN
APPLIC.RATE(L/HA)= 200.0000 OR 81.0 L/ACRE OR 17.84 GALLS/ACRE
FORWARD SPEED(M/S)= 2.5000 OR 9.0 KM/HR. OR 5.6 M.P.H.

NAME OF SPRAYER	TANK CAPACITY (LITRES)	BOOM WIDTH (METRES)	WORKRATE(HAS/DAY) (BALTIN)	WORKRATE(HAS/DAY) (RENOLL)	PERCENT OF TIME: SPRAYING & TURNING	PERCENT OF TIME: REFILLING AND RETURNING	PERCENT OF TIME: IN TRANSIT BETWEEN FIELDS
SPRAYER	250.0	12.0	26.44	42.98	43.96	54.41	1.63
SPRAYER	250.0	18.0	29.47	53.18	37.54	60.64	1.82
SPRAYER	250.0	24.0	31.26	60.34	33.75	64.32	1.93
SPRAYER	2000.0	12.0	44.06	68.37	54.22	43.06	2.72
SPRAYER	2000.0	18.0	53.16	98.40	44.76	51.96	3.28
SPRAYER	2000.0	24.0	59.29	126.10	38.40	57.94	3.66

DISTANCE TO FILL(M)=1000.0
RATE OF REFILL= .75 L/S OR 9.9 GALLS/MIN
APPLIC.RATE(L/HA)= 200.0000 OR 81.0 L/ACRE OR 17.84 GALLS/ACRE
FORWARD SPEED(M/S)= 3.3300 OR 12.0 KM/HR. OR 7.4 M.P.H.

NAME OF SPRAYER	TANK CAPACITY (LITRES)	BOOM WIDTH (METRES)	WORKRATE(HAS/DAY) (BALTIN)	WORKRATE(HAS/DAY) (RENOLL)	PERCENT OF TIME: SPRAYING & TURNING	PERCENT OF TIME: REFILLING AND RETURNING	PERCENT OF TIME: IN TRANSIT BETWEEN FIELDS
SPRAYER	250.0	12.0	28.47	49.64	39.67	58.58	1.76
SPRAYER	250.0	18.0	31.12	59.80	34.06	64.02	1.92
SPRAYER	250.0	24.0	32.63	66.62	30.84	67.14	2.01
SPRAYER	2000.0	12.0	49.99	86.93	48.05	48.86	3.09
SPRAYER	2000.0	18.0	58.77	123.76	38.93	57.44	3.63
SPRAYER	2000.0	24.0	64.43	157.02	33.05	62.97	3.98

DISTANCE TO FILL(M)=1000.0
RATE OF REFILL= .75 L/S OR 9.9 GALLS/MIN
APPLIC.RATE(L/HA)= 200.0000 OR 81.0 L/ACRE OR 17.84 GALLS/ACRE
FORWARD SPEED(M/S)= 5.0000 OR 18.0 KM/HR. OR 11.2 M.P.H.

NAME OF SPRAYER	TANK CAPACITY (LITRES)	BOOM WIDTH (METRES)	WORKRATE(HAS/DAY) (BALTIN)	WORKRATE(HAS/DAY) (RENOLL)	PERCENT OF TIME: SPRAYING & TURNING	PERCENT OF TIME: REFILLING AND RETURNING	PERCENT OF TIME: IN TRANSIT BETWEEN FIELDS
SPRAYER	250.0	12.0	30.85	58.81	34.62	63.47	1.90
SPRAYER	250.0	18.0	32.97	68.36	30.13	67.83	2.04
SPRAYER	250.0	24.0	34.14	74.41	27.64	70.25	2.11
SPRAYER	2000.0	12.0	57.82	119.60	39.92	56.51	3.57
SPRAYER	2000.0	18.0	65.75	167.07	31.68	64.26	4.06
SPRAYER	2000.0	24.0	70.59	208.43	26.65	68.99	4.36

DISTANCE TO FILL(M)=1000.0
RATE OF REFILL= .75 L/S OR 9.9 GALLS/MIN
APPLIC.RATE(L/HA)= 100.0000 OR 40.5 L/ACRE OR 8.92 GALLS/ACRE
FORWARD SPEED(M/S)= 1.6700 OR 6.0 KM/HR. OR 3.7 M.P.H.

NAME OF SPRAYER	TANK CAPACITY (LITRES)	BOOM WIDTH (METRES)	WORKRATE(HAS/DAY) (BALTIN)	WORKRATE(HAS/DAY) (RENOLL)	PERCENT OF TIME: SPRAYING & TURNING	PERCENT OF TIME: REFILLING AND RETURNING	PERCENT OF TIME: IN TRANSIT BETWEEN FIELDS
SPRAYER	250.0	12.0	32.86	40.72	64.16	33.81	2.03
SPRAYER	250.0	18.0	40.39	55.50	55.95	41.56	2.49
SPRAYER	250.0	24.0	45.62	67.81	50.24	46.94	2.82
SPRAYER	2000.0	12.0	43.73	49.41	75.93	21.37	2.70
SPRAYER	2000.0	18.0	58.16	73.01	67.99	28.42	3.59
SPRAYER	2000.0	24.0	69.66	95.90	61.66	34.04	4.30

stated field shape, the average row length varies with shape, as shown in Figure 5.3.

The major groups of variables in the model are sprayer dimensions, refilling arrangements, application rate and spraying speed. Values used in the model represent the range of values that might be encountered on British farms.

Values for the coefficients in the Renoll formula are taken from examples in Renoll (1981). A continuous nine hour spraying day is assumed, with a relief driver being available. In addition, half an hour "idle" time at the beginning and end of the day is added for sprayer preparation or storage. Total day length is thus 10 hours. This also applied to the Baltin equation. Five minutes is added to the time taken to refill the sprayer with diluent in order to account for extra time needed to add chemicals, make adjustments and attend to personal needs.

5.3.5 Validating the model

The usefulness of a model should be judged against what would be used in the absence of the model. However, it is important to ensure through validation that the model simulates events reasonably well, giving values reasonably in accord with observed or judged values in the "real world".

In order to indicate how reliable a model is when used to predict outcomes in the "real world", results from the model should be checked against some real world data which has not been used in constructing the model. Results from the Ulvamast user's survey will be used in attempting to validate the model. Questions were asked on sprayers and sprayer performance in the survey (Question 21). For the purposes of validating the model, data for hydraulic-pressure sprayers are used. Twenty-two respondents use hydraulic sprayers for pesticides. In addition to the best workrate that is attained in a ten-hour day, data are given in Table 5.4 that act as inputs for the model. These are: relevant sprayer dimensions, refilling arrangements, application rate and normal spraying speed. These data are given for each respondent.

Assumptions made in the model for validation are:

1) 10-hour working day, involving nine hours of spraying operations, with half an hour at the beginning and end of the day for preparing and storing the sprayer.
2) Fields are 10 ha in size, of a "standard" shape (see Figure 5.3), with an average row length of 316.2 m. The distance between fields is 1 km (except in Section 5.3.6.8. where this factor is varied).
3) Time taken to turn at the end of a spray row is 10 seconds.
4) When not spraying, the ferrying speed is 5.0 m/s.

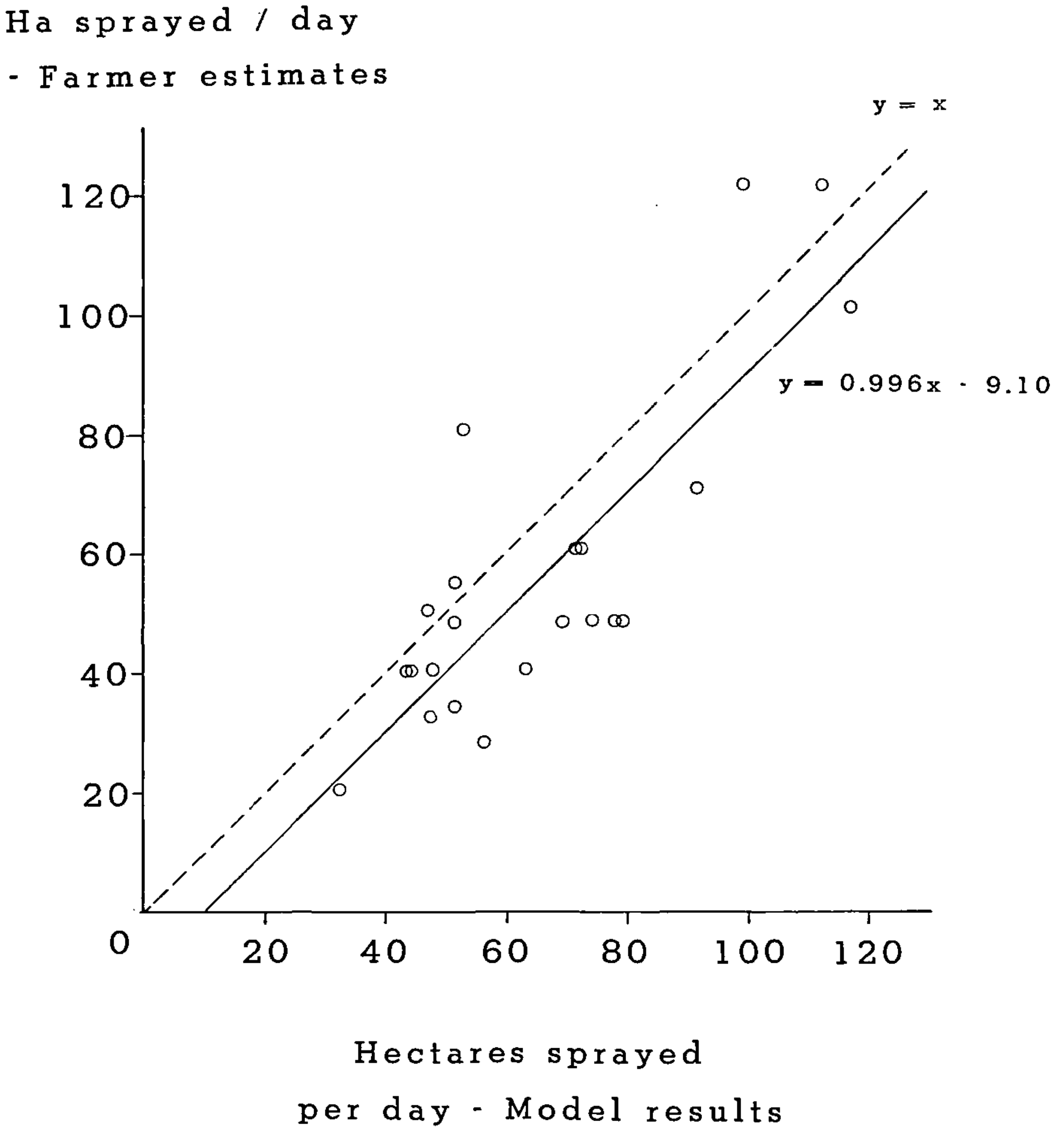
Workrates were calculated using the above parameters. The model using the Baltin equation as its basis was found to give values closer to the value stated by the respondent than did the model using the Renoll formula. The Renoll equation in fact gave very optimistic areas covered each day, upto 50% higher than the corresponding estimate using the Baltin equation. Consequently, results from the model using the Baltin formula are presented for each respondent in Table 5.4, and the Baltin formula is used in the results sections. The graph in Figure 5.5 shows how the "farmer supplied" and estimated values fit.

Some stated workrates diverge considerably from the model-estimated workrate, particularly for smaller values. There may be several

TABLE 5.4. Table of parameters, stated workrates and model-calculated workrates for one hydraulic spraying system on the farm. Data from 22 farmers in the Ulvamast user survey; four respondents could not give values for all the parameters required in order to be able to compare model-calculated results with stated results. Data pertaining to only one (present or past) hydraulic sprayer system on each farm was taken, even if there was more than one hydraulic sprayer currently on the farm.

DIMENSIONS OF HYDRAULIC SPRAYER		AVERAGE DISTANCE TO REFIL (m)	MEAN TIME TAKEN TO REFILL TANK AND MIX CHEMICALS (s)	AVERAGE VOLUME APPLIED (l/ha)	NORMAL SPEED (m/s)	STATED 'BEST' WORKRATE IN 10-HOUR DAY (ha)	MODEL-CALCULATED WORKRATE FOR A 10 HOUR DAY (ha)
TANK CAPACITY (l)	BOOM WIDTH (m)						
1485	17.7	805	900	180	2.67	60.7	72.7
2000	12.2	1609	1200	225	2.67	80.9	53.0
1600	12.2	402	900	225	2.23	55.0	51.7
2000	12.0	805	600	225	1.78	32.4	47.8
5400	12.0	100	120	202	4.15	101.2	117.2
1575	12.8	805	900	225	2.00	40.5	48.0
2000	12.0	457	600	225	3.57	48.6	78.0
2500	20.0	1073	600	253	2.23	48.6	79.5
2025	12.0	805	600	225	2.67	40.5	63.3
1600	12.0	100	150	100	3.57	121.4	99.8
1350	12.0	100	120	225	2.67	60.7	71.7
1350	12.0	402	750	225	1.78	40.5	43.8
2000	12.0	805	900	225	3.57	48.6	69.6
1500	12.0	805	600	225	1.78	40.5	44.8
2000	15.0	805	600	185	3.57	70.8	91.9
450	12.2	100	180	84	1.78	34.4	51.4
1500	12.2	1207	300	150	3.10	48.6	74.6
675	12.2	403	1200	225	2.20	20.2	32.6
1800	12.0	403	600	225	2.23	28.3	56.5
1125	12.0	100	600	225	2.23	48.6	51.5
1000	12.0	100	1200	200	2.67	50.6	47.3
4500	18.0	100	180	152	2.23	121.4	101.7

FIGURE 5.5. Graph of farmer-estimated sprayer workrates vs. model-calculated sprayer workrates, in hectares sprayed per ten hour day. A perfect set of predictions by the model would give a regression line of y = x. The actual regression line is y = 0.996x - 9.10. The two regressions do not have significantly different slopes or intercept values. The value for R-squared is 0.62. Data from Ulvamast user survey and the Baltin equation.



explanations for this:

1) one or more of the assumptions do not hold for the individual farm, e.g. field size or shape, distance between fields.

2) Values stated by respondents may be inaccurate: different respondents may have interpreted the meaning of questions differently.

3) No account has been taken in the model of stoppages due to sprayer breakdown, nozzle blockage, the need to fold booms to get through narrow gates or lanes, and slowing down the sprayer speed due to slopes or field undulations. Some figures for the incidence of sprayer breakdowns and delays is given in 5.2.7. and the incidence of effects due to field undulations or slopes is given in 5.2.3.

4) The "correct" way to spray a field is to spray a number of swaths around the field before starting parallel swaths (Matthews, 1979, p. 150). As the Baltin equation is basically designed for aerial operations (which generally rely upon parallel swaths - Matthews, 1979, p. 258), no account is taken of this in the Baltin formula. A model proposed by Nation (1978) does take account of this.

Notwithstanding these factors, it appears that the model using the Baltin formula provides a reasonable approximation to workrates stated as having been obtained by respondents, as can be seen in Figure 5.5. A perfect fit of stated vs. model estimated values would give a regression line $y = x$; in the event, the regression line was $y = 0.996x - 9.10$. The slope of the lines are virtually identical. The difference in intercepts may be explained by the model not taking account of factors such as breakdowns, punctures, stoppages and reductions in speed that may be encountered due to slopes and undulations. A t-test between the intercept values of the two lines yields a value of -0.78, indicating that the intercepts are not significantly different at the 95% level

(2-tailed test).

5.3.6 Model results

5.3.6.1 Introduction

Constants in the model are the same as those used in validating the model, as given in Section 5.3.5. Field size is constant in all sections, except 5.3.6.7. Except where otherwise stated, times and percentages quoted in spraying activities refer only to the nine hours spent in spraying operations, the "idle" half hour at the beginning and end of the day being excluded.

Each set of results is accompanied by a statement of the parameters held constant in that particular figure or table.

The results attempt to incorporate the effects of interactions between components in the spraying system, i.e. interactions between sprayer dimensions, refilling system, spraying speed, application rates, field size, field shape and farm conformation.

5.3.6.2 Model results - effect of sprayer dimensions on workrate

The two most relevant sprayer parameters influencing workrates are the tank capacity and boom width. The increasing use of tramlines in crops means that farmers cannot easily change boom width without altering other items of machinery on the farm.

For constant refilling arrangements, boom width and spraying speed, increasing the tank capacity of the sprayer has the greatest effect on the workrate at higher application rates, the effect diminishing as the application rate is reduced. At an application rate of 200 ℓ/ha, the percentage of time spent in spraying and turning the sprayer ranges from 46% to 61% for the smallest and largest tank capacities respectively. The equivalent figures at an application rate of 50 ℓ/ha are 71% and 83%. It therefore appears that large tank capacities are most needed at high application rates, the size of tank becoming less critical with lower application rates (Figure 5.6).

Figure 5.7 illustrates the effect of tank capacity on workrate with different methods of refilling. It appears that the rate of refilling of the tank becomes more important with increasing tank capacity, and that the distance travelled to refill is more significant with smaller tank capacities. However, with the use of a bowser (distance to refill = 100 m) the percentage of time spent in spraying and turning at the end of a row varies from 56% to 82% for the smallest tank (250ℓ) and the largest tank (3000ℓ) respectively, for the top curve in Figure 5.7. Therefore with larger sprayers, high refilling rates are desirable to ensure efficient sprayer utilisation, and high workrates.

5.3.6.3. Model results - spraying speed

The speed of spraying is one of the parameters that can have a major influence on sprayer workrates. Figure 5.8 demonstrates that at low application rates, increasing the sprayer speed can dramatically increase workrates. The application rate appears to be a major constraining variable on workrates at higher speeds of spraying. At low speeds, the boom width appears to be more critical than the tank capacity in determining sprayer workrates, this situation being reversed at higher speeds, as shown in Figure 5.9. The method of refilling employed also becomes more critical at higher speeds, particularly the rate of refilling, as shown in Figure 5.10.

5.3.6.4. Model results - refilling arrangements

The two main variables in this category are the distance required to travel to refill with water and chemicals, and the rate of refilling of the sprayer.

FIGURE 5.6. Graph of sprayer workrate vs. tank capacity, with various application rates. Parameters held constant are: boom width (12m), spraying speed (2.5 m/s), distance to refill (1000 m), and rate of refill (1.00 l/s). Field shape is "standard" with an average row length of 316.2 m.

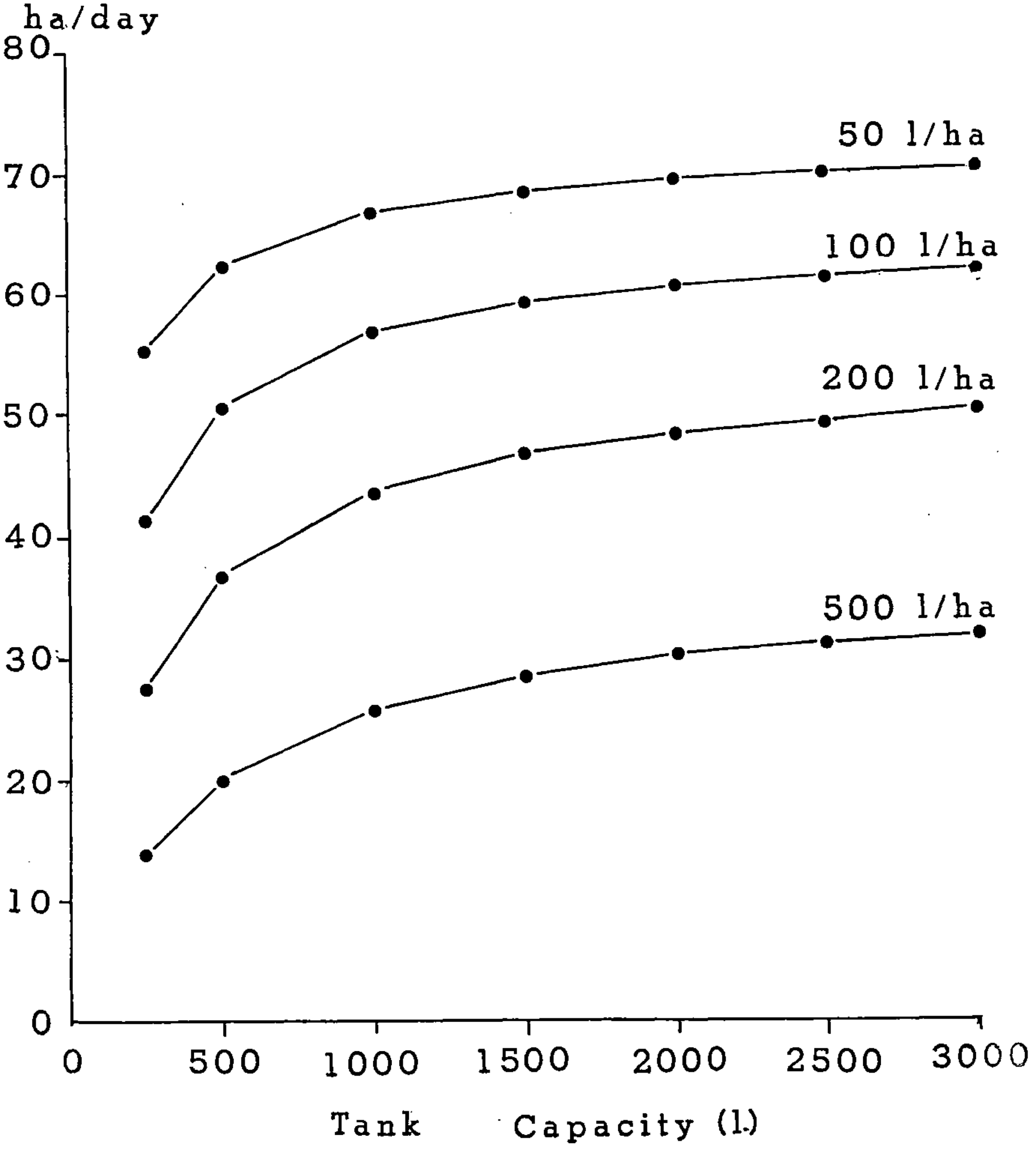


FIGURE 5.7. Graph of sprayer workrate vs. tank capacity with differing refilling methods (distance to refill and rate of refilling). Parameters held constant are: boom width (12.0m), spraying speed (2.5m/s), and application rate (200 l/ha). Field shape is "standard", the average row length being 316.2m.

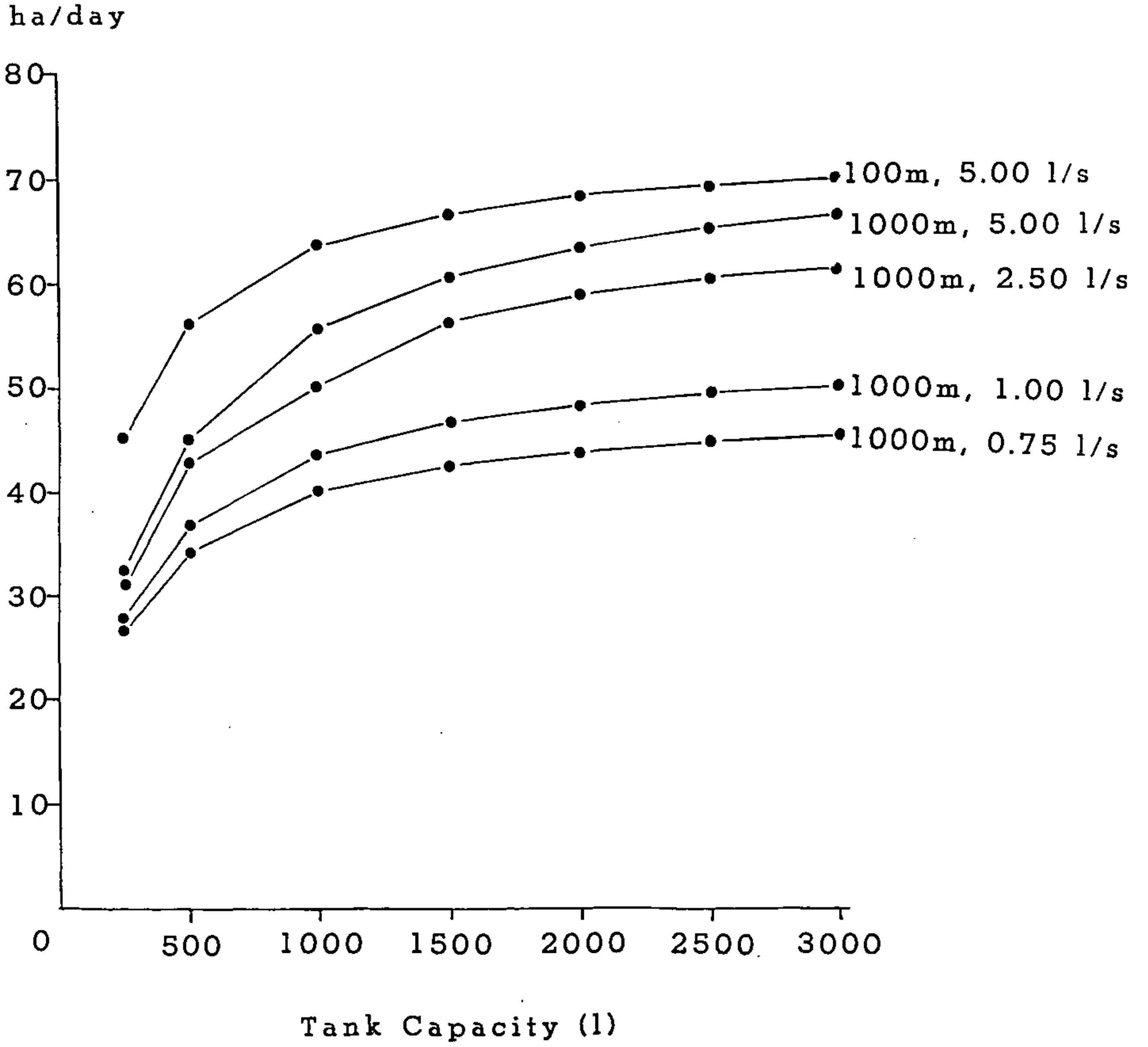


FIGURE 5.8. Graph of spraying speed vs. workrates with differing application rates. Parameters held constant are: refilling arrangements (distance to refill = 1000m, rate of refill = 1.00 l/s) and sprayer dimensions (2000 l tank capacity, 12.0 m boom width).

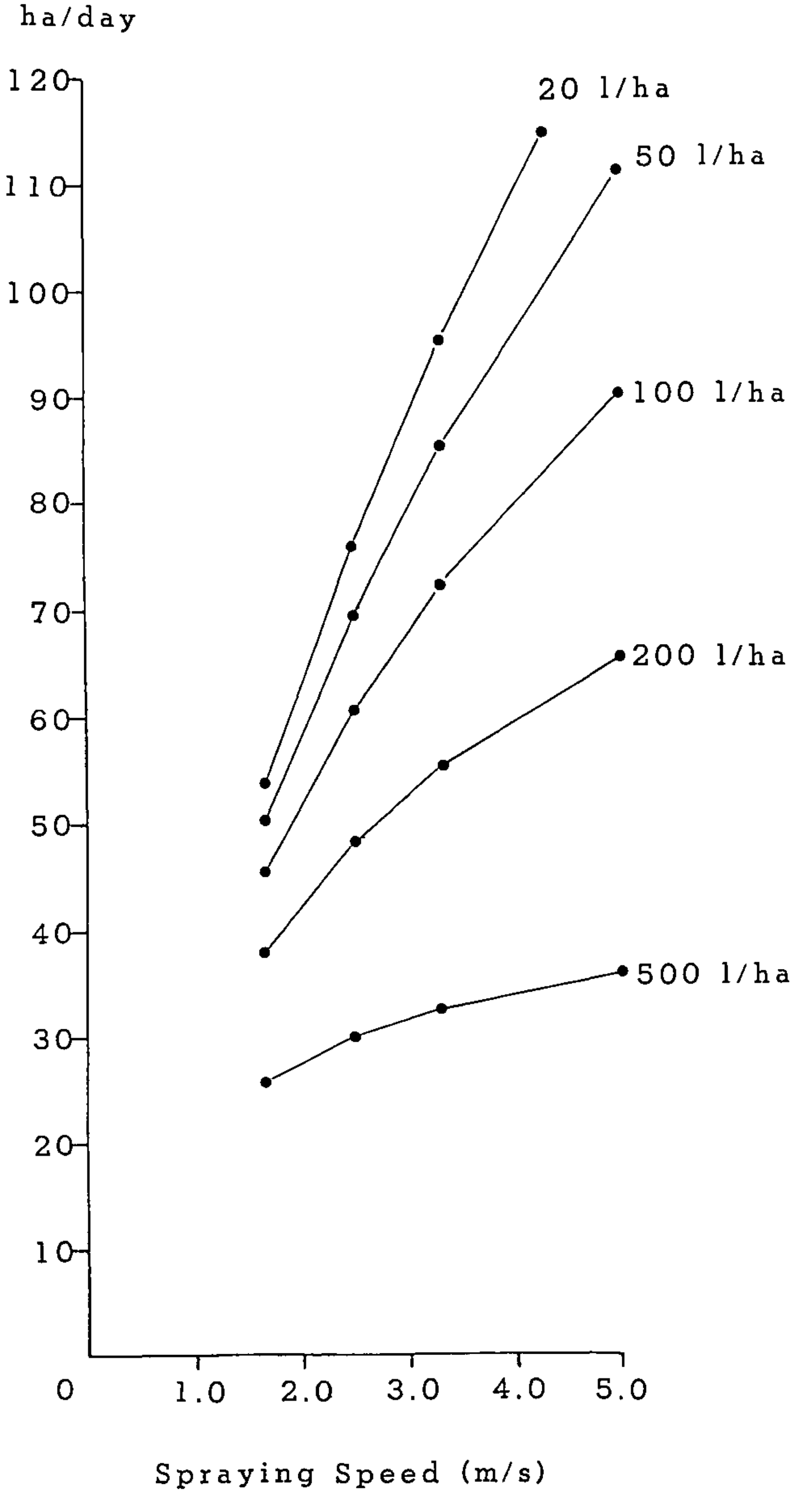


FIGURE 5.9. Graph of spraying speed vs. sprayer workrate, with differing sprayer dimensions (tank capacity and boom width). Parameters held constant are the application rate (200 l/ha), refilling arrangements (distance to refill = 1000m, refilling rate = 1.00 l/s) and field shape (standard).

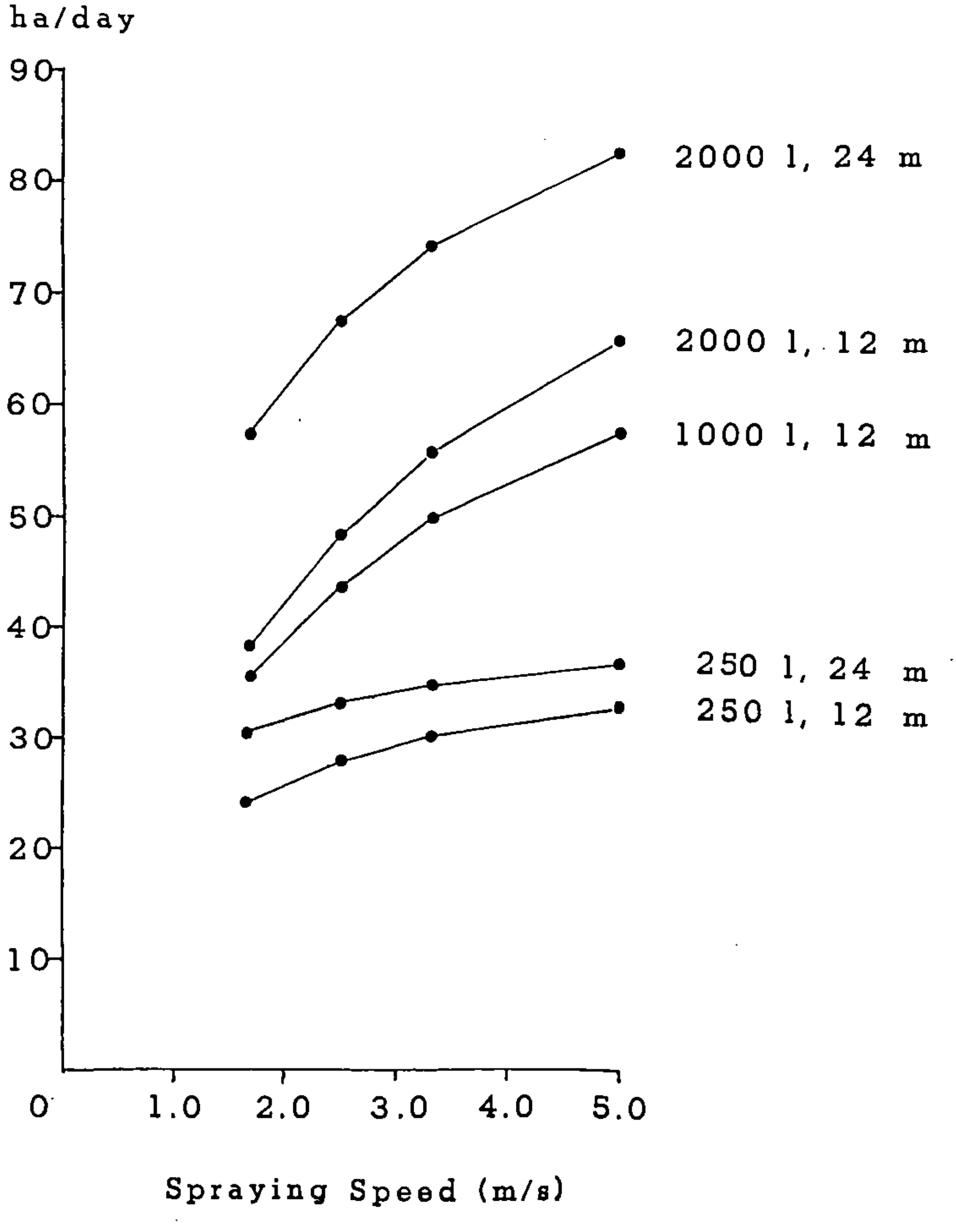


FIGURE 5.10. Graph of sprayiny speed vs. sprayer workrate for differing refilling arrangements (distance to refill and rate of refilling). Parameters held constant are: application rate (200 l/ha), sprayer dimensions (2000 l tank capacity, 12.0 m boom width), and field shape ("standard").

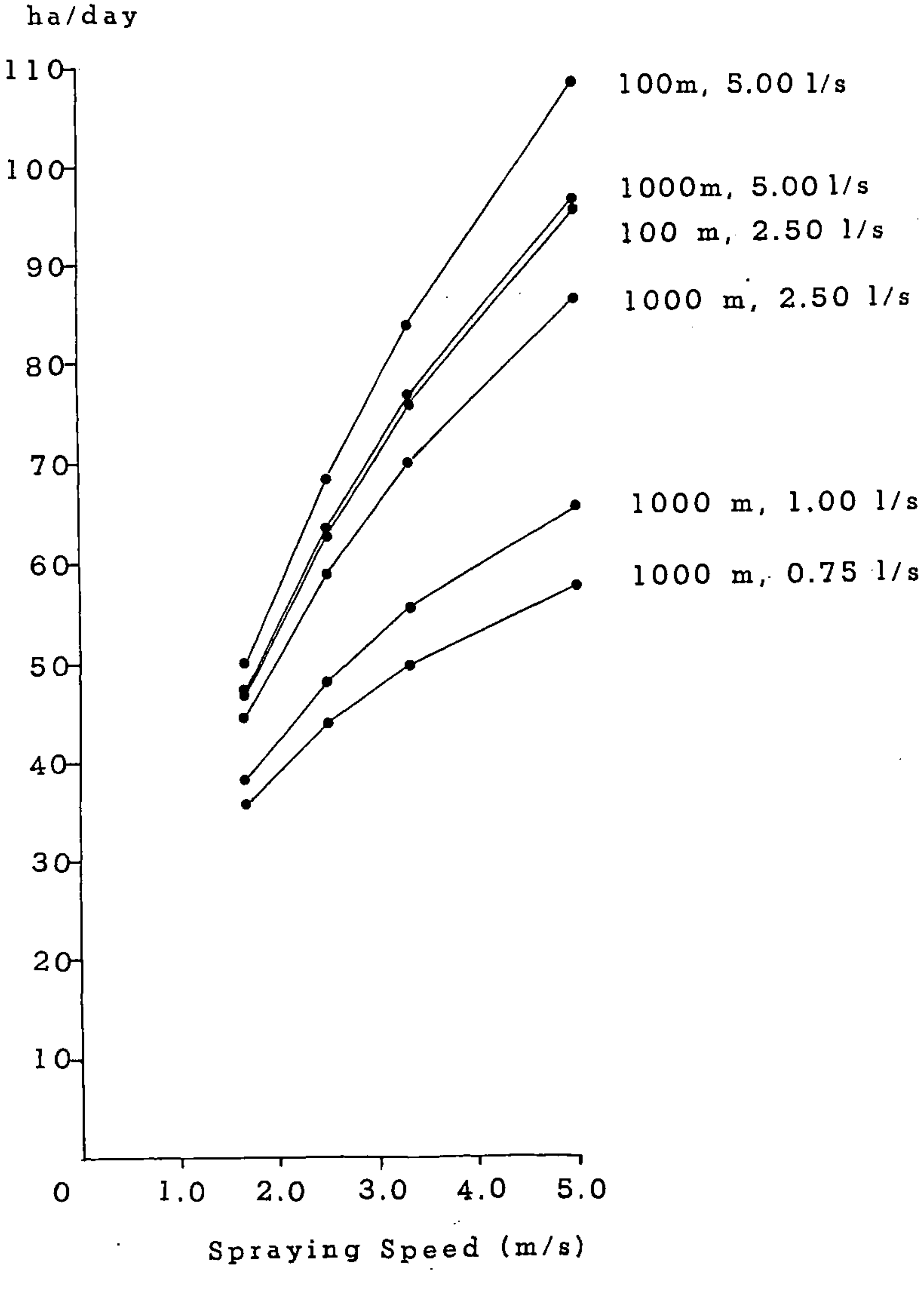


Figure 5.11 shows that application rates can be an important factor affecting workrates at varying rates of refill, particularly at lower refilling rates. At higher application rates, the distance required to travel to refill the sprayer can be important, and a high refilling rate can substantially improve the workrate attainable.

Figure 5.12 demonstrates the effect of tank capacity on workrates; at higher rates of refilling, the boom width also appears to be important.

Increasing the spraying speed can significantly improve the workrate of sprayers, particularly at higher rates of refilling. This is demonstrated in Figure 5.13.

5.3.6.5 Model results - application rate

Reducing the application rate gives the largest proportional increases in workrate for small tank capacities and when the original application rate was high, as can be seen in Figure 5.6. However, the highest workrate is still achieved with a large tank. Figure 5.14 demonstrates that the advantages of a larger tank diminish with lower application rates, and that the boom length becomes a relatively more important determinant of workrates at low application rates.

Figure 5.15 demonstrates the advantages conferred by a high refilling rate, or a source of water close to the spraying operation, particularly at higher application rates.

5.3.6.6 Model results - field shape

Although the effects of field shape were not investigated in using survey results attempting to validate the model, it is hoped that the

FIGURE 5.11. Graph of rate of refilling vs. sprayer workrate for differing distances travelled to refill and application rates. Parameters held constant are: sprayer dimensions (2000 l tank capacity, 12.0 m boom width), spraying speed (2.5 m/s), and field shape ("standard").

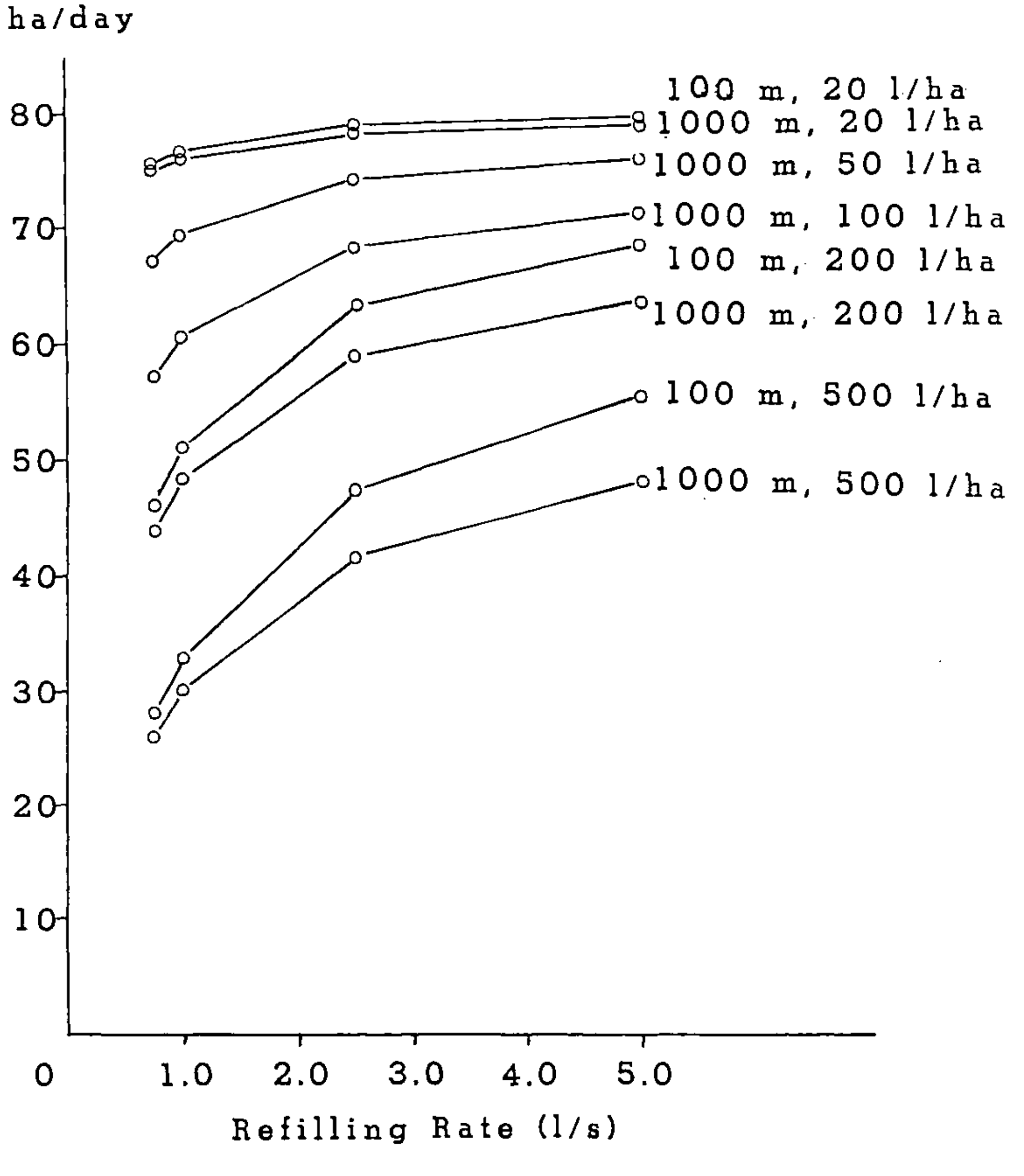


FIGURE 5.12. Graph of rate of refilling vs. workrates, for differing sprayer dimensions (tank capacity and boom width) and distance to travel to refill. Parameters held constant are: spraying speed (2.5 m/s), application rate (200 l/ha) and field shape ("standard").

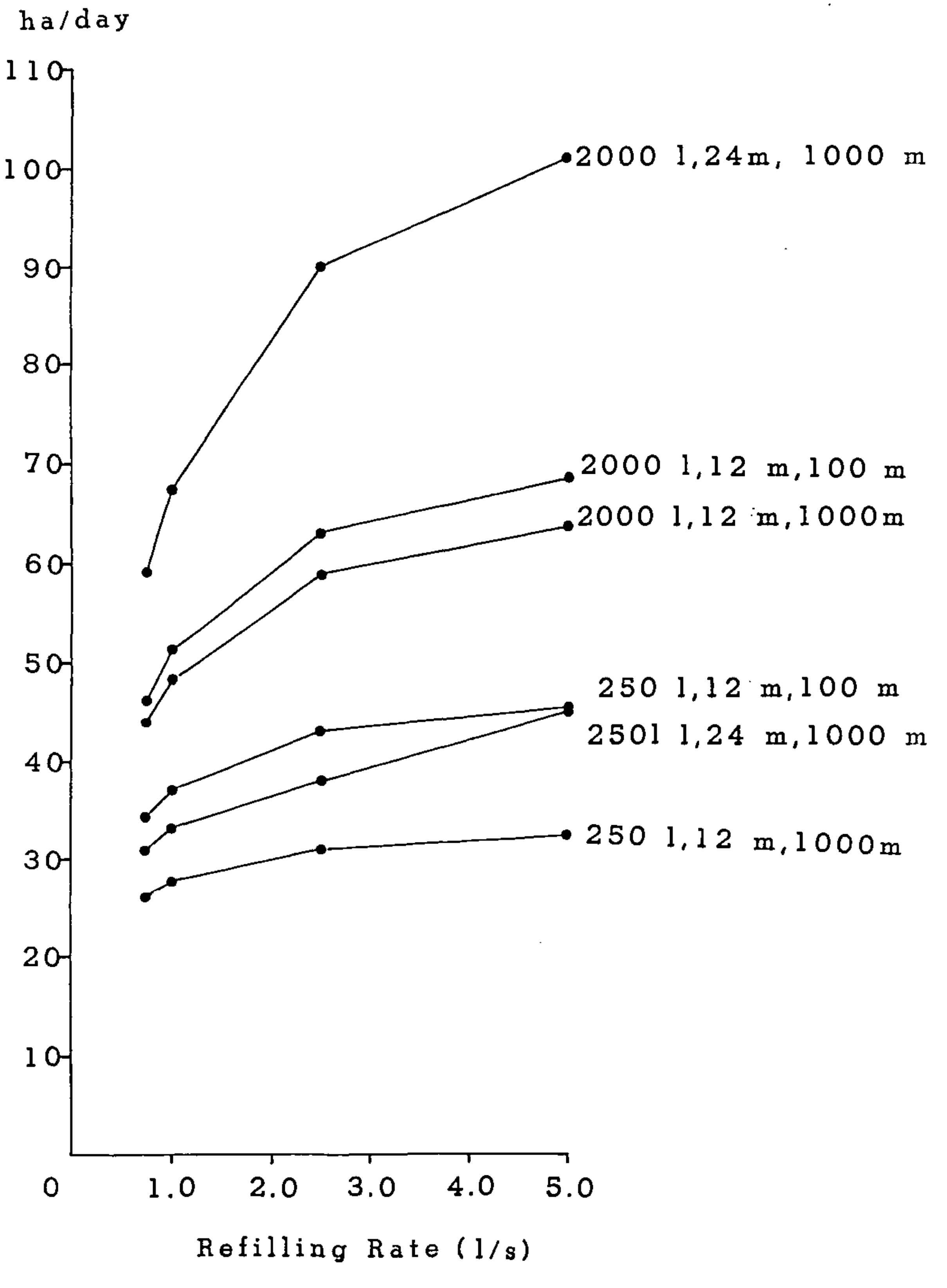


FIGURE 5.13. Graph of rate of refilling vs. sprayer workrate, for differing spraying speeds and distances to refill. Parameters held constant are: application rate (200 l/ha), sprayer dimensions (2000 l tank capacity, 12.0 m boom width), and field shape.

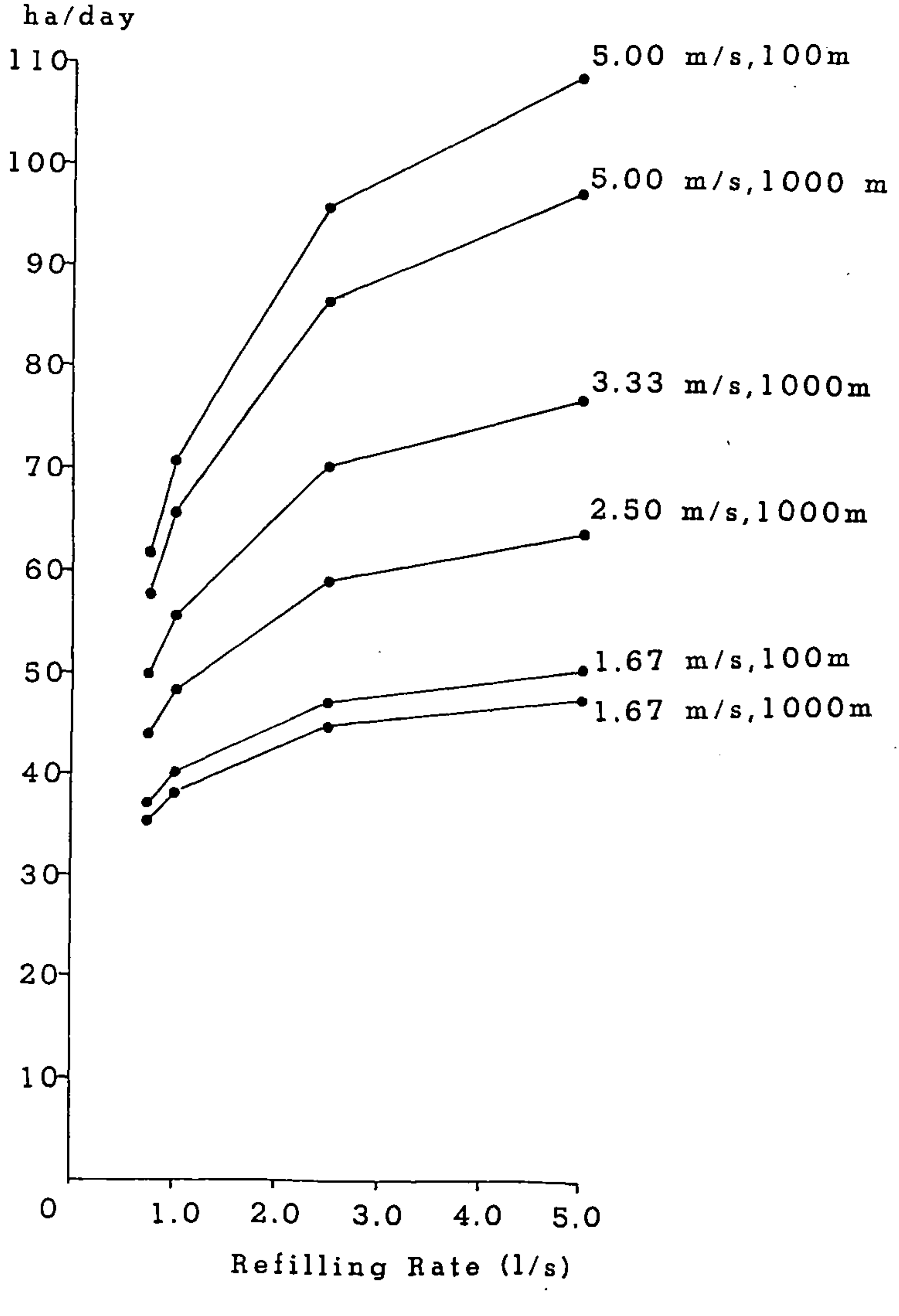


FIGURE 5.14. Graph of application rate vs. workrate, for differing sprayer dimensions (tank capacity and boom width). Parameters held constant are: spraying speed (2.5 m/s), distance to refill (1000 m), rate of refilling (1.00 l/s) and field shape.

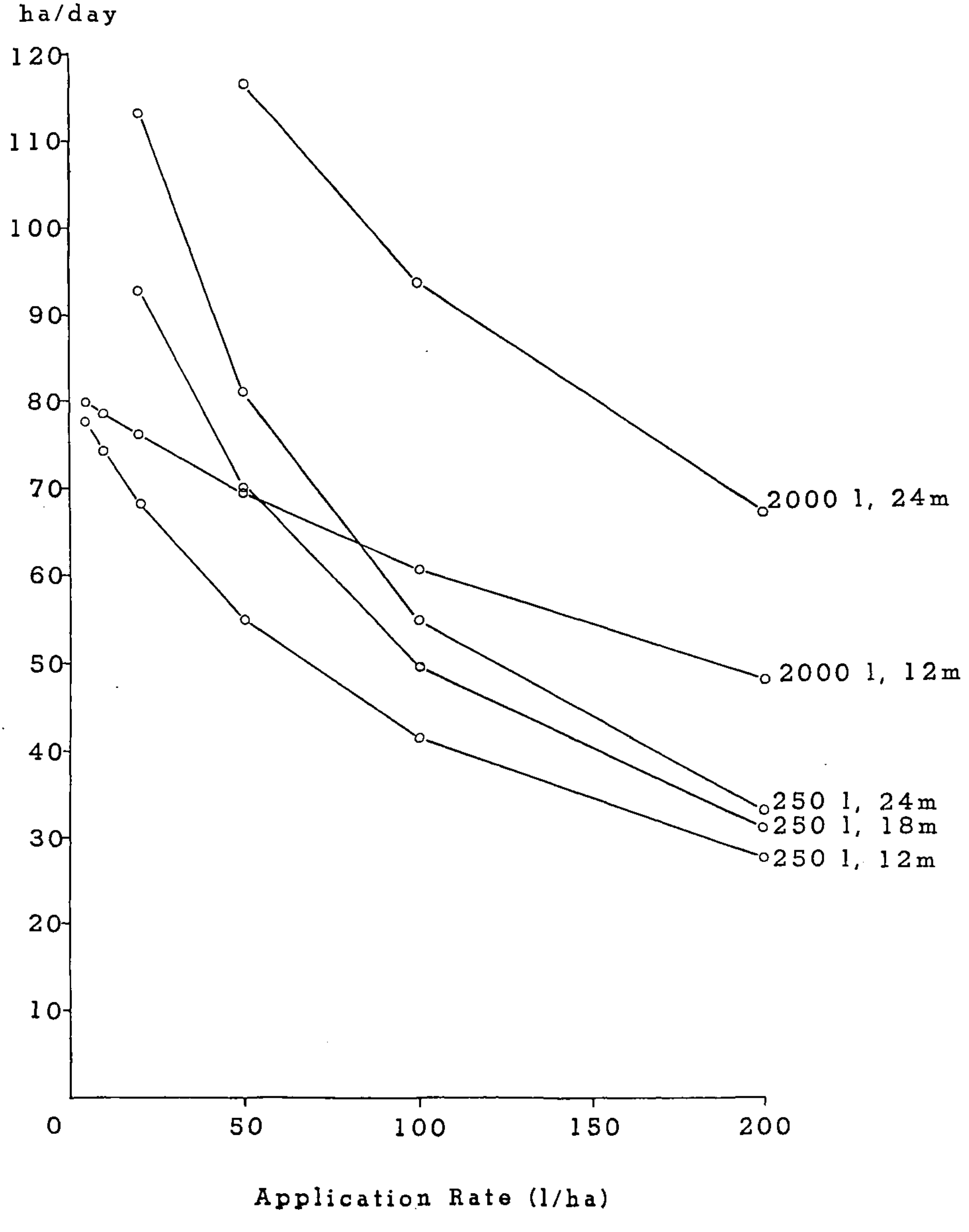
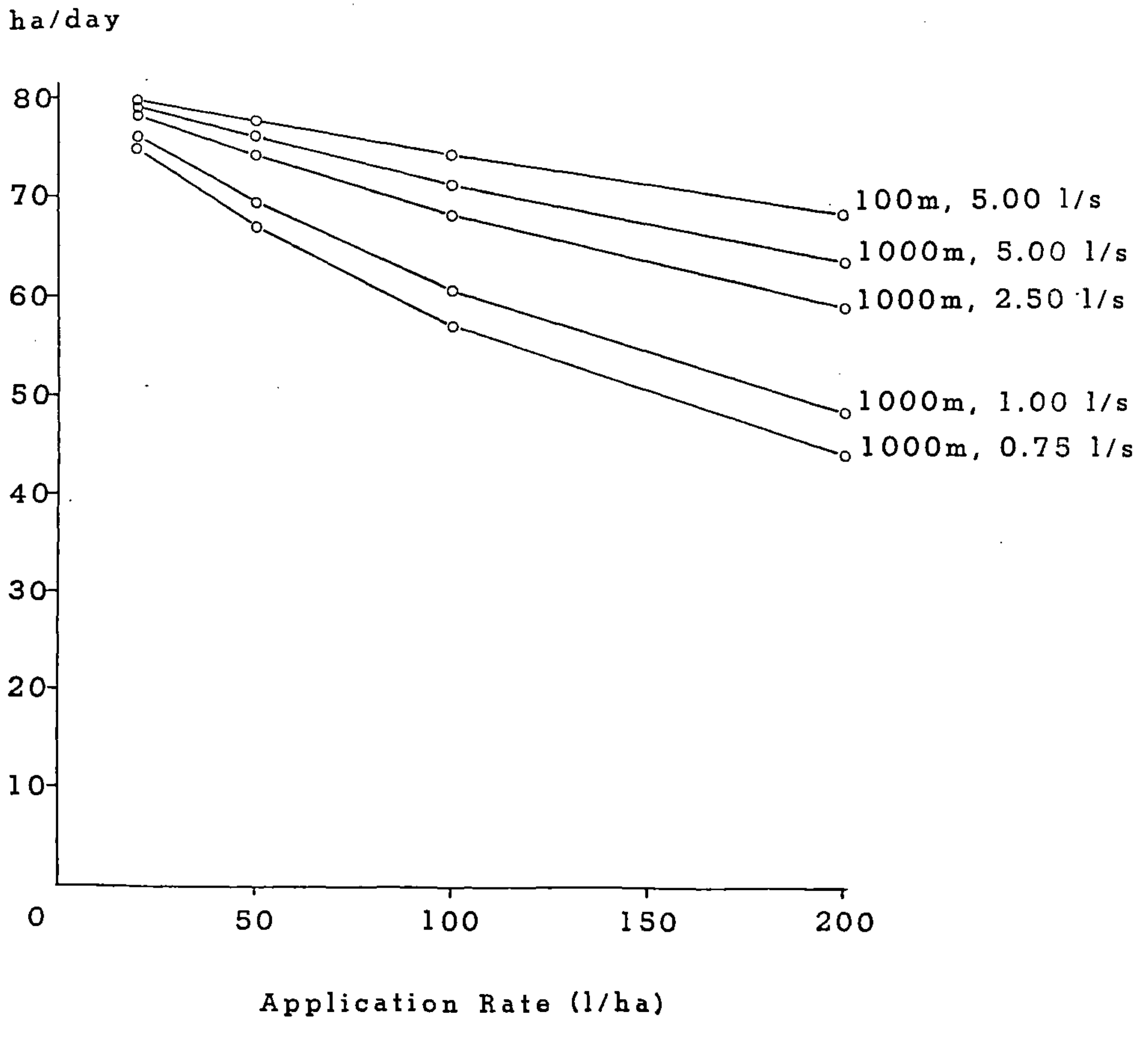


FIGURE 5.15. Graph of application rate vs. sprayer workrate, with differing refilling arrangements (distance to refill and rate of refilling). Parameters held constant are: spraying speed (2.5 m/s), sprayer dimensions (12 m boom width, 2000 l tank capacity) and field shape.



coefficients given by Sturrock et al (1977 - see Figure 5.3) give an approximation of the effects of different field shapes upon spraying operations. In all of the results in Sections 5.3.6.2 to 5.3.6.5 a "standard" field shape is assumed, with two non-parallel field sides. This shape is chosen as very few fields on English farms are regular in shape (Sturrock et al, 1977).

Assuming that the method of spraying a field involves parallel swaths, then for regularly-shaped fields it is straightforward to calculate the average row length. However, for irregularly-shaped fields (such as Sturrock's "building plots" or "obstacles") the calculations to determine average row length depend upon the shape to be sprayed in an individual field. Average row lengths have been arbitrarily set for the irregularly shaped fields, as given in Table 5.5. This figure also gives the workrates in a ten-hour day for each field type shown in Figure 5.3. Regularly-shaped fields with long row lengths seem to give the highest daily rates of work.

5.3.6.7 Model results - field size

The advantages of increasing field size are discussed in Section 5.2.6. Table 5.6 gives some figures generated by the model of the effect of field size on workrates for a ten-hour day. As with field shape, no figures are available from surveyed farms that allow direct validation of the model, but similar trends in workrate with changes in field size as occur in Table 5.6 have been recorded by Sturrock et al (1977).

From Table 5.6, substantial improvements in sprayer workrate and efficiency of sprayer utilisation occur up to a 20 ha field size; beyond this, improvements start to tail off.

TABLE 5.5. Effect of field shape on sprayer workrate. Parameters held constant: application rate (200 l/ha), spraying speed (2.5 m/s), refilling arrangements (1000 m to refill, 1.0 l/s refilling rate), and sprayer dimensions (2000 l tank capacity, 12.0 m boom width). Field size is 10 ha. For field shapes, refer to Figure 5.3. The workrate figure refers to a farm where all fields are of the same shape and size.

Field shape type	Average row length (m)	Workrate (ha/ 10-hour day)
Square	316.2	49.9
2:1 Oblong	223.6	50.5
2:1 Oblong	447.2	52.0
4:1 Oblong	158.1	50.0
4:1 Oblong	632.5	53.0
"Standard" (one side not parallel)	316.2*	48.5
"Re-entrant" (one side of field concave)	316.2*	48.7
"Building Plots" (small areas removed from field perimeter)	316.2*	47.9
"Obstacles" (obstacles in fields, e.g. pylons)	316.2*	47.4

* Customarily shorter by an amount depending on the individual field, but held constant in this case. Shorter row lengths will decrease sprayer workrates.

TABLE 5.6. Table demonstrating the effect of field size on workrate. Parameters held constant are: refilling arrangements (distance to refill = 1000 m, rate of refill = 1.00 l/s), sprayer dimensions (2000 l tank capacity, 12.0 m boom width), spraying speed (2.5 m/s), and application rate (200 l/ha). Fields are assumed to be all of similar size and shape ("standard").

Field size (ha)	1	2	5	10	20	40	80	100	200
Average row length (m)	100	141.4	223.6	316.2	447.2	632.5	894.4	1000.0	1414.2
Workrate (ha/ 10 hour day)	36.53	42.84	48.32	50.77	52.29	53.23	53.83	53.97	54.29
% OF TIME:									
spraying & turning	52.71	57.76	61.31	62.47	62.96	63.11	63.12	63.11	63.05
refilling & returning	24.75	29.02	32.73	34.39	35.43	36.07	36.88	36.89	36.95
moving between fields	22.55	13.22	5.96	3.13	1.61	0.82	0.00	0.00	0.00
TOTAL %	100.1	100	100	99.9	100	100	100	100	100

5.3.6.8 Model results - farm conformation : distance between fields

The more compact in conformation the fields to be sprayed are, the more quickly tasks can be performed. This is demonstrated in Table 5.7, which shows that when the distance between fields is 100 m, the time spent moving between fields is only 0.41% of the time spent spraying. At the other extreme, when the fields are 10 km apart, 28.5% of the day is taken up in travelling between fields. When fields are over 1 km apart, the efficiency of utilisation of the sprayer begins to be significantly diminished, with more time being spent moving between fields.

5.3.7 Model results - discussion

Results from the model indicate that higher workrates can be achieved by reducing the application rate, increasing the speed of spraying, increasing sprayer dimensions, increasing the rate of refilling of the tank and decreasing the distance to travel to the water. In addition, field size, shape and farm conformation can have important effects.

Spray machinery innovations generally seek to reduce the application rate and/or increase the speed of spraying compared with conventional spraying practices. Sections 5.3.6.5 and 5.3.6.3 indicate the effects of varying the application rate and the spraying speed respectively. Figure 5.8 demonstrates the effect of different application rates at different spraying speeds. It can be seen that very high workrates are possible by spraying at high speeds and low application rates. If these are achieved, then the distance to refill or the rate of refilling become relatively less important, as can be seen from Figure 5.15. Consequently, sprayers that apply chemicals at low rates may have smaller tanks without substantially decreasing the sprayer workrate. Sprayers propelled at higher speeds are generally smaller (with regard to tank

TABLE 5.7. Table demonstrating the effect of farm conformation (i.e. field layout) on workrates. Parameters held constant are: refilling arrangements (100 m to refill, rate of refill = 2.5 l/s), sprayer dimensions (2000 l tank capacity, 12.0 m boom width), application rate (200 l/ha), spraying speed (2.5 m/s), field size (10 ha) and field shape ("standard").

Distance between fields (m)	100	200	500	1000	2000	5000	10000
Workrate (ha/ 10 hour day)	65.62	65.34	64.52	63.20	60.71	54.30	46.18
% OF TIME:							
spraying & turning	76.91	76.61	75.51	74.25	71.52	64.47	55.53
refilling & returning	22.68	22.59	22.30	21.85	20.99	18.77	15.96
moving between fields	0.41	0.81	1.99	3.90	7.50	16.76	28.50
TOTAL %	100	100.1	100	100	100.1	100	99.99

capacity) to reduce the power required to pull the sprayer, and to prevent damage to the machinery being pulled along. However, at low application rates and high speeds, wider booms may significantly increase workrates, e.g. see Figure 5.9. Unfortunately at higher speeds booms may become unstable, and boom yaw, bounce and even boom breakage may result. As a result of this, in recent years much work has gone into boom suspension design and boom levelling systems (Nation, 1980, Cowling 1980, Farmers Weekly, Mar. 12th, 1982).

Bowsers are important if large sprayers or high application rates are used.

Examples of innovative crop sprayers that may enable reduced application rates are rotary atomisers, and electrostatic sprayers. Hydraulic pressure sprayers can be used for low volume applications by decreasing nozzle orifice size, or pump pressure, or by increasing the spraying speed. However, changing nozzle characteristics or pump pressure may adversely affect the droplet spectrum. in addition, conventional tractors may not permit any large increase in speed due to possible suspension problems. Thus if higher speeds are to be employed, specialist traction equipment may have to be considered, e.g. low-ground pressure vehicles. Automatic volume regulating (AVR) systems (see Section 4.6.5) would allow fluctuations in speed, constantly changing output at the nozzle to an appropriate level.

A crop sprayer capable of high workrates would incorporate the following features:

1) ability to perform at high speeds. This may necessitate specialist vehicles.
2) reduced application rates. New methods of spraying may be most desirable, e.g. rotary atomisers, electrostatic sprayers. The

feasibility of reducing the application rate will depend to a large extent on the nature of the chemical and target.

3) Long booms with adequate boom suspension. This is particularly important if small drops are employed, as the "flight time" of small drops will be longer, it will be desirable to keep booms much closer to the target, and greater uniformity of the (much lighter) deposits is necessary to obtain satisfactory control (Nation, 1980).

4) Automatic volume regulation. This will keep application rates constant, even at varying spraying speeds.

If the above are provided, a large tank capacity and rapid refilling system are not as important in contributing to increased workrates but their provision will undoubtedly contribute to an increased workrate.

Making field shapes more regular, increasing field size and rendering the arable area of the farm into a more compact shape will all contribute to improved sprayer workrates.

In conclusion, the validation process demonstrates that the Baltin formula can be adapted to predict sprayer workrates with some accuracy. The model may be used not only for prediction of workrates but also to suggest optimal combinations of relevant parameters in order to give a good daily workrate.

In order to ensure the timeliness of applications, a good workrate is necessary, as well as a suitable number of "spray-days". The influence of the weather on spraying operations is discussed in the next section.

5.4 Spraying and Environmental Parameters

5.4.1 Introduction

Droplet size is of great importance in pest management, in ensuring efficient targetting with minimum contamination of the environment (Matthews, 1979).

Much work has been done on the physics of individual droplets in differing environmental conditions. For instance, work has been carried out on the effects of evaporation on droplet lifetime (Amsden, 1962), and on the time taken by droplets of different sizes to fall from varying heights (Johnstone, 1971). Studies of the behaviour of droplet clouds have also been conducted, e.g. in assessing drift deposition downwind (Johnstone, 1971, Byass and Lake, 1977). Nordby and Skuterud (1975) investigated the effects of an environmental parameter- windspeed ; in addition, they studied the effects of varying application machinery parameters on a field-size hydraulic-pressure sprayer: boom height and working pressure. Smith, Harris and Goering (1982) studied the effects of a host of meteorological, operational and equipment variables on spray drift. They found that horizontal wind velocity and nozzle height were prominent among the variables associated with drift. Göhlich (1983) outlines five major factors relevant to drift considerations in sloping vineyards: application method, droplet-size spectrum, windspeed, "special-risk" areas and chemical characteristics. Göhlich proposes a matrix of spray risk interactions in order to help determine whether the spray drift is acceptable for a given working situation.

The purpose of Section 5.4 is not to discuss the physics of droplets, but to outline the main environmental parameters influencing spraying operations, and how the level at which constraints operate have a great influence on the number of spray-days available.

5.4.2 Perceived importance of weather elements

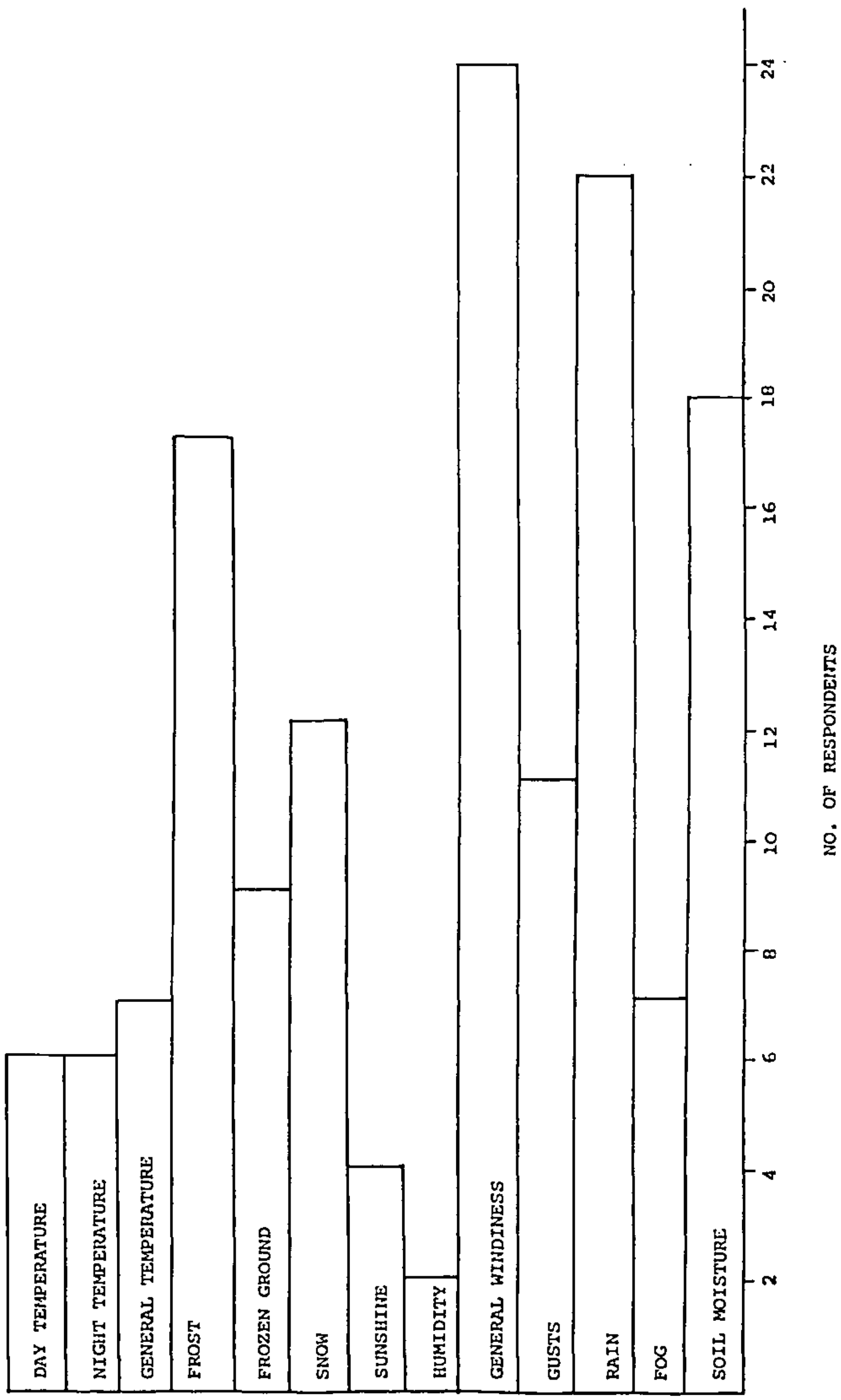
In the survey of Ulvamast users, questions were asked on the importance of weather elements in spraying operations. Respondents were asked which features of the weather were important in decisions to spray. The results are given in Figure 5.16. Wind, rain, soil moisture and frost were seen as the four most important features. In a survey of the use of weather forecasts by farmers, Hogg (1972) asked respondents which features of the weather it was important to know about in advance when considering spraying. Windiness, rainfall, temperature and humidity were the most frequently mentioned weather elements.

In the following sections, the more important weather elements affecting spraying operations will be discussed: temperature, windspeed, precipitation and soil moisture. Data on hourly windspeeds, precipitation and temperature, and weekly soil moisture deficits and daylight hours for the area at and around RAF Benson are analysed, in order to assess the number of suitable "spray-days", at varying levels of windspeed and soil moisture deficit (SMD) constraints.

5.4.3 Temperature

Low temperatures can be undesirable in spraying operations for several reasons. Temperatures below 0°C can cause freezing and expansion of the mixture, causing damage to pump, tank or pipes. At temperatures just above freezing, there may be problems with formulations, e.g. excessive viscosity. The biological activity of chemicals may be low at low temperatures, due either to the effect of temperature on the formulation, or on the organism. As a rough guide, the air temperature should be greater than 1.0°C during spraying, and at least 7.0°C at some time during the day (Spackman and Barrie, 1982).

FIGURE 5.16. Features of the weather mentioned by farmers as being important in decisions to spray. Data obtained from 26 respondents in the Ulvamast user survey.



High temperatures or a high insolation level may be detrimental; leaf scorch and other phytotoxic effects may occur due to droplet evaporation. In addition, "vapour drift" of chemical may occur, e.g. with ester formulations of "hormone" herbicides (ADAS 1981).

5.4.4 Wind

Figure 5.16 indicates that windiness is one of the most important factors that farmers take into account when deciding to spray. This was also found by Hogg (1972).

Whenever there is any wind when spraying, there is some drift of chemicals. Very small droplets have a low terminal velocity, and turbulent flow may serve to keep droplets airborne for a considerable time. In this time, they may drift some distance. The actual amount of chemical that drifts depends on the windspeed, the method of application (i.e. height of boom above target, initial velocity of droplets, droplet size spectrum), and the characteristics of the chemical being applied. Droplet size is one of the factors that has been most extensively researched. The relationship of wind to hazardous drift from chemicals is ill-defined; some spray chemicals' drift may be harmless enough to spray in high winds, whereas 10 km/h might be too high a value for very toxic sprays used near susceptible crops (Thompson, 1982).

Tyldesley (1974) stated that if conventional hydraulic spraying were to be done, the windspeed (at 10 m, the standard height above ground at which wind characteristics are measured at weather stations) should not exceed 4.1 m/s, whilst Adams (1978) stated that the maximum for hydraulic sprayers should be 4.1 m/s to 5.1 m/s, and the use of CDA spray methods (e.g. for a uniform droplet size of 250 μm) would enable a maximum acceptable windspeed for spraying of 6.7 m/s. Heijne (1980) calculated an upper limit for CDA spraying, using droplet distribution data from field and laboratory experiments, of 7.5 m/s. Spackman and Barrie (1982) suggest an upper windspeed limit of 4.6 m/s, or 6.2 m/s for "Higher Windspeed" sprayers. The windspeed at 45 cm above the crop is approximately half that encountered at 10m.

Environmental parameters recorded at a weather station may not necessarily have been experienced at points around the weather station. This is particularly so in the case of wind. Features such as windbreaks or local topography can cause local conditions considerably different to those recorded at the weather station.

Gusts of wind may be an important factor affecting spraying operations. Gusts are in effect temporary windspeed maxima, with consequent implications for drift. Gusts may serve to drift chemical into undesirable areas due to their motive power. When assessing the suitability of wind conditions for spraying, gustiness, or the maximum windspeed encountered, should be considered.

The direction of the prevailing wind may be an important factor on some farms, particularly if susceptible crops or special-risk areas are nearby, or if drift-spraying techniques are being employed. An example of the latter is the Ulvamast, which relies for it's method of application on the wind being in a suitable direction so that the chemical being applied will be "drifted" into the target crop.

In the Ulvamast user survey, respondents were asked what would be the ideal windspeed, and the maximum windspeed they would spray in, for a) the Ulvamast, b) hydraulic-pressure sprayers (if any on farm) and c) boom-mounted spinning-disc sprayers (if any). Results are shown in

FIGURE 5.17. Ideal and maximum windspeeds sprayed in, with (i) boom-mounted spinning-disc sprayers (ii) Ulvamasts (iii) hydraulic-pressure sprayers. The windspeed categories correspond to those in the Beaufort scale: C=calm, LA= light air, LB=light breeze, GB=gentle breeze, MB=moderate breeze, FB= fresh breeze. See Figure 5.18 for speed definitions. Data from 26 respondents in Ulvamast user survey.

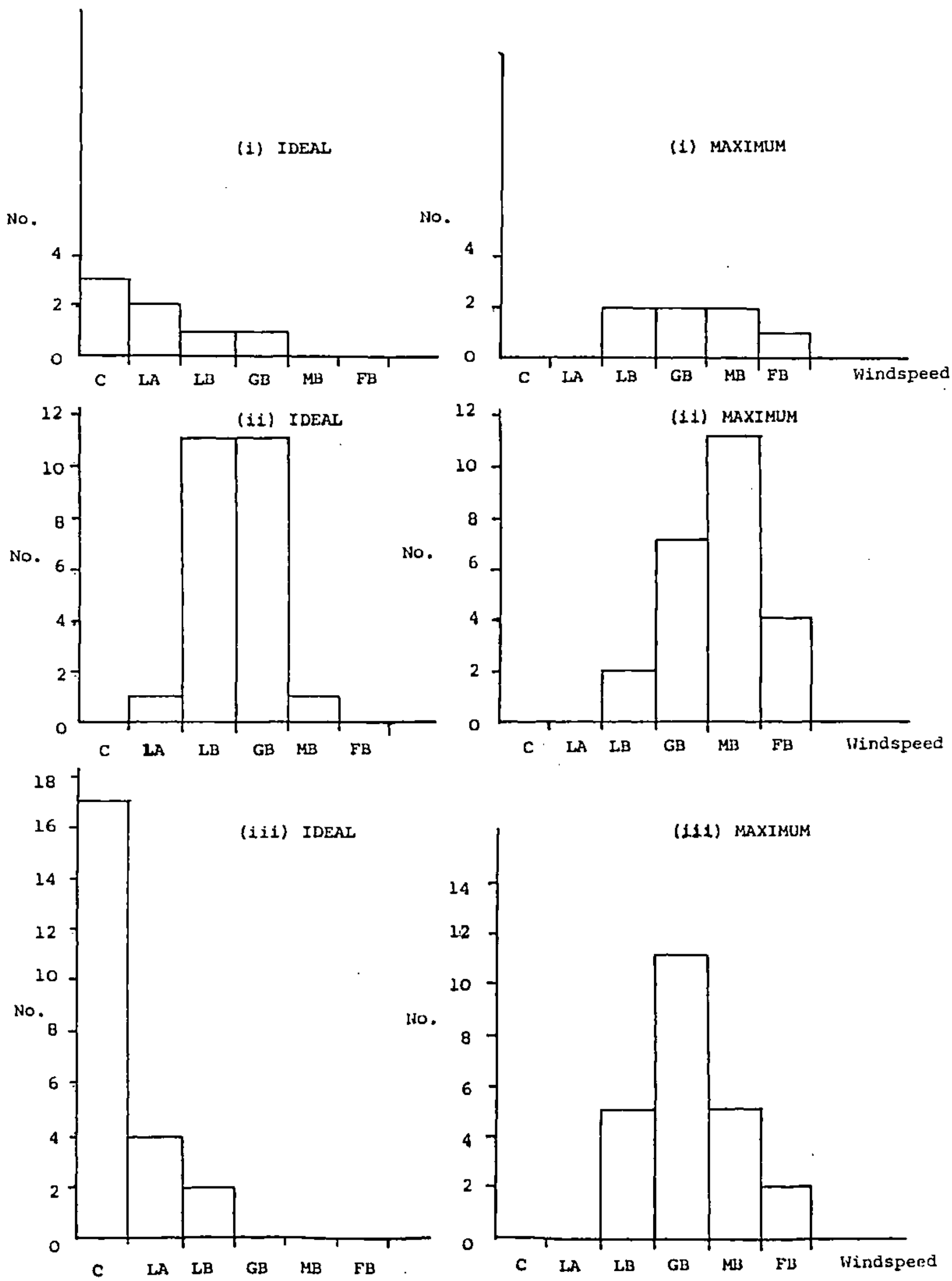


FIGURE 5.18. Prompt card used for windspeed question in Ulvamast user survey. Also acts as a key to bar chart categories in Figure 5.17. The windspeed categories, and features associated with each category, are from the Beaufort Scale for windspeeds on land.

CATEGORY	FEATURES	WINDSPEED (miles per hour)
C = calm	smoke rises vertically	0 - 1
LA= light air	smoke starts to drift	1 - 3
LB= light breeze	leaves rustle, wind felt on face	4 - 7
GB= gentle breeze	leaves & small twigs in constant motion	8 -12
MB= moderate breeze	small branches moved, raises dust & loose paper	13 -18
FB= fresh breeze	small trees in leaf begin to sway	19 -24

Figure 5.17. For this question, respondents were shown a "prompt card", with categories of windspeeds corresponding to those found in the Beaufort scale. Accompanying the categories were descriptive characteristics taken from the Beaufort scale for windspeeds experienced on land. These are shown on the prompt card, reproduced in Figure 5.18.

5.4.5 Precipitation

The duration of rainfall is important in that spraying chemicals is not advisable whilst it is raining. If rain is predicted, then spraying will not be possible for some time before and after the rain. The exact time will depend on such factors as the nature of the target and the rainfastness of the chemical. Heavy or prolonged rain may wash chemicals away from the crop or target.

For non-rainfast chemicals such as glyphosate, 12 hours should be allowed between application and the start of expected rain. For contact herbicides, e.g. paraquat, the interval is less important. For some soil-acting chemicals, a little rain soon after application may be beneficial, in distributing chemical through the soil profile.

5.4.6 Soil Moisture

The amount, duration and intensity of rainfall influence the soil moisture content. Soil moisture, or the lack of it, is most commonly measured by the soil moisture deficit (SMD). The soil moisture content determines its trafficability, i.e. the ability of the soil to carry field machinery without undue soil damage. Other soil factors that can be important are water-holding capacity, hydraulic conductivity and how soils are affected by compressive and shearing forces, e.g. wheel slippage (Thompson, 1982).

5.4.7 Spray-days

'Spray-days' are days, or an appropriate portion of the day, when environmental conditions permit spraying operations. The length of the "appropriate portion" of the day may be four (Heijne 1980) or five (Spackmann & Barrie, 1982) consecutive hours when conditions are right.

In assessing days suitable for spraying, five parameters are considered: temperature, windspeed, precipitation, SMD and daylight.

A number of authors have attempted to assess numbers of spray-days available with constraints operating at various parameter levels. Table 5.8 shows the levels used by various authors when analysing weather data from UK weather stations. Interest in spray-days may arise from investigating the effectiveness of techniques that may ease weather constraints, such as low-ground pressure vehicles or 'higher windspeed' sprayers (e.g. Thompson 1982, Spackman & Barrie 1982). Others are interested in how environmental parameters influence chemical effectiveness, such as uptake (e.g. Hough, 1982), whilst weather data may be evaluated for the likelihood of timely applications, and the size of spray-day "windows" (e.g. MacKerron & Lawson, 1982).

In addition to spray-days, Hough (1982) investigated the frequency of occurrence of "spray-nights" (2200 - 0500) when assessing the possibility of applying glyphosate to maximum effect, which requires warm, humid conditions. The author found that more opportunities for spraying glyphosate occur during the night, especially in July and August.

An assessment of the relative risks in terms of drift for several environmental factors has been made by Rutherford and Thompson (1982). Factors incorporated into the method of assessing drift risk include

TABLE 5.8. Threshold values quoted by authors for major environmental parameters influencing ground spraying.

PARAMETER	THRESHOLD AT WHICH SPRAYING IS CONSTRAINED
Hourly mean windspeed (@ 10 m)	<u>Hydraulic-pressure sprayer</u> < 4.1 m/s (Tyldesley, 1974) 4.1 - 5.1 m/s (Adams, 1978) ≤ 4.6 m/s (Spackmann & Barrie, 1982) <u>'CDA' sprayers</u> < 7.5 m/s (Heijne, 1981) 5.1-6.7 m/s (Adams, 1978) ≤ 6.2 m/s (Spackmann & Barrie, 1982) ≤ 5.7 m/s (MacKerron & Lawson, 1982)
Precipitation	No precipitation either during or for one hour preceding the spraying (Tyldesley, 1974) At least four consecutive hours without rain (Heijne, 1981) Total rainfall between 0900 and 2100 less than 0.6 mm (Hough, 1982) Under 0.5 mm during the period (MacKerron & Lawson, 1982)
Soil moisture	Cumulative rainfall after a dry day must not exceed 15 mm before the next dry day, or allow an extra 24 hours before commencing spraying to allow for drainage (Heijne, 1981) Days when Soil Moisture Deficit (SMD) < 5 mm (conventional vehicles), with no SMD constraint for LGPVs (Spackmann & Barrie, 1982)
Daylight	Daylight, but not earlier than 0600 or later than 2000 GMT (Spackmann & Barrie, 1982) 0700-2100 (Hough, 1982)
Temperature	Over 7°C (Heijne, 1981; MacKerron & Lawson, 1982) Air temerature greater than 1.0°C during spraying, with the air temperature greater than 7.0°C sometime during the day (Spackmann & Barrie, 1982)

not only windspeed but insolation, atmospheric stability, temperature and method of application.

5.4.8 Use of weather stations to provide weather forecasts

One way of attempting to see if weather observations recorded at weather stations are similar to those experienced by farmers in the locality is to investigate where farmers obtain weather forecasts from. In the random user survey, respondents were asked where they obtained weather forecasts from when intending to spray (see Appendix). Of the 73 respondents with crop sprayers on the farm, 42% (31/73) gave the weather station in the locality of the farm around which interviews were conducted in the random user survey (RAF Benson or RAF Honington). Details on the sources of information used for weather forecasts are given in Tables 5.9a and 5.9b.

5.5 Analysis of Weather Data from RAF Benson

5.5.1 Introduction

Data was obtained from the Meteorological Office, Bracknell, of hourly windspeeds, precipitation/snowfall, and air temperatures for the period August 1981 to July 1982, recorded at RAF Benson, Oxfordshire. In addition, weekly estimates for the SMD value of soils in the area were computed using the MORECS suite of programs, at the Meteorological Office, Bracknell. These weekly values were interpolated to provide daily values. Information on sunrise and sunset (i.e. daylight) was obtained from standard tables.

Data was obtained on microfiche and print-out from the Meteorological Office, and was analysed by hand.

TABLE 5.9a. Source of weather forecasts for spraying purposes among respondents around RAF Benson. Data from the random farmer survey, n=36. More than one source may be named by respondents.

SOURCE	No.
RAF Benson	16
Other weather stations	9
TV/Ceefax	8
Radio	8
Own judgement	8
Phone (British Telecom message)	3
Press	1
TOTAL	53

TABLE 5.9b. Source of weather forecasts for spraying purposes among farmers around RAF Honington. Data from the random farmer survey, n=37. More than one source may be named by respondents.

SOURCE	No.
RAF Honington	15
Own judgement	9
Radio	8
Other weather stations	6
TV/Ceefax	5
Press	2
Phone (British Telecom message)	0
TOTAL	45

5.5.2 Caveat

In analysing data from RAF Benson, it should be borne in mind that the weather conditions recorded at the site may not be exactly the same as conditions experienced in the locality. There are several reasons for this. Differences in local topography can influence many environmental parameters. Hedges or windbreaks may reduce windspeeds in fields. Thus the number of spray days enumerated from an analysis of weather data (with stated environmental parameter values) should be treated with some caution: some farmers in the locality may experience significantly more or less spray-days due to topographic or other variations. However, it is very useful to compare the number of spray-days available when varying the level of environmental constraints, to see the effects of relaxing or tightening constraint levels.

The criteria are only to provide a rough indication as to suitability to spray, and may not be suitable for all chemical, pest crop or soil types, and no account is taken of the stage of development or condition of the crop or pest to which the spray is to be applied. In addition environmental factors other than those recorded at the weather station may influence the desirability of spraying; Rutherford and Thompson's (1982) method of assessing the risk of spray drift considers insolation and cloud cover, high temperatures, atmospheric stability and droplet spectrum in addition to windspeed. However, dangers from high temperatures, insolation and atmospheric instability are usually encountered in the summer, when farm spraying requirements are not usually at their peak.

Results from one year should be used with caution when generalising for other years. The winter of 1981-2 was exceptional for prolonged periods of very low temperatures and standing snow.

5.5.3 Criteria set for environmental parameters in order to determine "spray periods"

Half-days for the period August 1981 to July 1982 are examined individually to see if the below criteria are satisfied. By 'half-day' is meant the period from midnight to noon GMT ("morning") and from noon to the following midnight ("afternoon"). Thus in the year, 730 periods are assessed as to their suitability for spraying. Half days, as opposed to whole days, were the periods chosen to indicate the suitability of conditions for spraying (e.g. Heijne (1980)) for several reasons:

1) it is often periods around dawn and dusk that are most suitable for spraying: in the middle of the day, windspeeds are often higher.
2) Farmers often spray cereals in parts of a day rather than throughout the day. In the main part of the Ulvamast user survey, respondents were asked if they tended to spray the whole day long, or in parts of a day. It was found that two thirds of the respondents tended to spray in part days.

The count of "spray periods" is based upon the following criteria:

1) $\leqslant$ 1.0 mm of rain to fall on the date that the spray period is in. No rain for at least four hours during the period. No snow on the date that the spray period is in.
2) Hourly temperature $\geqslant$ 7.0°C sometime during the date that the spray period is in.
3) Hourly temperature $\geqslant$ 1.0°C for at least four hours during the period.
4) At least four full hours of daylight for the period.

Two criteria have variable levels:

5) Hourly windspeed values at 10 m to be equal to or less than 9 knots (4.6 m/s), 12 knots (6.2 m/s) or 15 knots (7.7 m/s) for at

least four consecutive hours.

6) Soil moisture deficit for 'medium' average water capacity soils to be set at ⩾ 0 mm (i.e. no constraint), > 0 mm, and ⩾ 5 mm.

All criteria (except (3)) must be satisfied simultaneously for at least four successive hours in any one period.

5.5.4 Results and Discussion

The number of spray periods in the morning and afternoon for each month is given in Table 5.10. Note the varying of windspeed and soil moisture deficit constraints. The SMD values are estimates for soils of average water capacity.

Several points can be made from a comparative analysis of the results:

1) Easing the soil moisture and windspeed constraints increases the number of spray periods available for most months in the year.
2) The number of morning and afternoon spray periods is roughly the same within each month. Generally, either both the morning and afternoon periods are suitable, or neither are suitable.
3) There is considerable variation in the number of periods available in each month. Most were available in the period June - August, when in fact relatively little spraying is performed. Rather fewer were available in the periods September to November, and March to May, the months when most spraying is carried out. Very few spray periods were available November to February. However, very little spraying is customarily done in these months on most British farms (Table 4.6).
4) It appears that removing any SMD constraints to spraying (SMD ⩾ 0 mm) gives rise to a greater increase in spray periods than from relaxing the windspeed constraint from 9 knots to 12 knots or 15 knots.

TABLE 5.10. Numbers of spray periods, August 1981 to July 1982, with varying wind and soil moisture constraints. Figures refer to soils with a medium average water capacity. Data obtained from readings taken at RAF Benson. 'am' covers the period from sunrise to noon; 'pm' covers the period from noon to sunset. Other environmental parameters and constraints are outlined in the text.

CONSTRAINTS	AUG 81		SEPT		OCT		NOV		DEC		JAN 82		FEB		MAR		APR		MAY		JUN		JUL		TOTALS	
	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm
NO SMD CONSTRAINT, WINDSPEED ≤ 7.7 m/s	27	27	16	17	12	14	17	20	4	4	7	10	10	8	10	11	26	24	19	18	21	21	25	24	194	198
NO SMD CONSTRAINT, WINDSPEED ≤ 6.2 m/s	26	27	14	14	12	12	12	15	4	4	6	8	7	4	10	9	18	17	14	14	17	17	19	18	159	159
NO SMD CONSTRAINT, WINDSPEED ≤ 4.6 m/s	24	23	8	10	7	8	8	10	3	3	1	3	2	1	7	7	10	11	12	9	15	13	10	9	107	107
SMD > 0 mm, WINDSPEED ≤ 7.7 m/s	27	27	15	16	11	12	12	13	0	0	1	2	10	8	9	9	26	24	19	18	21	21	25	24	176	174
SMD > 0 mm, WINDSPEED ≤ 6.2 m/s	26	27	13	13	11	10	9	11	0	0	1	1	7	4	9	8	18	17	14	14	17	17	19	18	144	140
SMD > 0 mm, WINDSPEED ≤ 4.6 m/s	24	23	8	10	7	7	6	9	0	0	0	1	2	1	7	7	10	11	12	9	15	13	10	9	101	100
SMD ≥ 5 mm, WINDSPEED ≤ 7.7 m/s	27	27	14	15	0	0	0	0	0	0	0	0	0	0	2	2	21	19	19	18	21	21	25	24	129	126
SMD ≥ 5 mm, WINDSPEED ≤ 6.2 m/s	26	27	12	12	0	0	0	0	0	0	0	0	0	0	2	2	14	15	14	14	17	17	19	18	104	105
SMD ≥ 5 mm, WINDSPEED ≤ 4.6 m/s	24	23	8	10	0	0	0	0	0	0	0	0	0	0	2	2	8	9	12	9	15	13	10	9	79	75

This was particularly so for the period October to April, a period when a fairly large amount of spraying may be carried out (Table 4.6).

The question of whether the number of spray periods was sufficient to spray cereal crops with sufficient timeliness also involves a consideration of spraying requirements, and workrates available with spraying and refilling machinery. Section 5.6.1 presents data from the Ulvamast user survey on the number of days spent spraying in the 1981 - 82 crop year by respondents. Section 5.7.1 considers the possibility of combining details of spraying requirements for a given farm, together with an analysis of weather data and output from the sprayer performance model in attempting to suggest a suitable sprayer/refilling system for that farm.

5.6. Number of days spent spraying, 1981 - 2

In the Ulvamast user survey, respondents were asked a number of questions on their cereal spraying operations for the 1981-2 growing season. Among the questions asked were some on : the number of cereal spray hectares and cereal spray rounds, and the number of days taken in spraying using hydraulic-pressure and CDA sprayers (including summed part days). The growing year was split into three time periods: from the 1981 cereal harvest to Xmas 1981, from Xmas 1981 to Easter 1982 (April 12th), and from Easter 1982 to the 1982 cereal harvest. Table 5.11 gives data on these topics.

Questions were also asked whether respondents felt there were more days for spraying than were actually used. Of the 21/26 respondents who felt able to reply, 81% (17/21), 86% (18/21) and 86% (18/21) of respondents stated that there were more days suitable for spraying in each of

TABLE 5.11. Mean number of cereal spray rounds, cereal spray hectares, and days taken in spraying crops, for the 1981/82 growing season. Figures refer to all methods of spraying, i.e. hydraulic pressure & CDA spraying. Results from Ulvamast user survey. Mean cereal area = 314 ha.

	Cereal harvest 1981 to Xmas 1981	Xmas 81 - Easter 82*	Easter 82* - cereal harvest	TOTAL	n
Cereal spray rounds	0.8	0.9	1.7	3.4	25**
Cereal spray hectares	306	344	578	1228	25**
Days taken in spraying	7.1	7.8	11.4	26.3	19***
Hectares sprayed/day	43.1	44.1	50.7	46.7	19***

* 11 th April 1982

** One set of values missing as one respondent out of farming

*** One respondent out of farming, and six respondents could not recall the total number of days it took them to spray.

the three respective time periods.

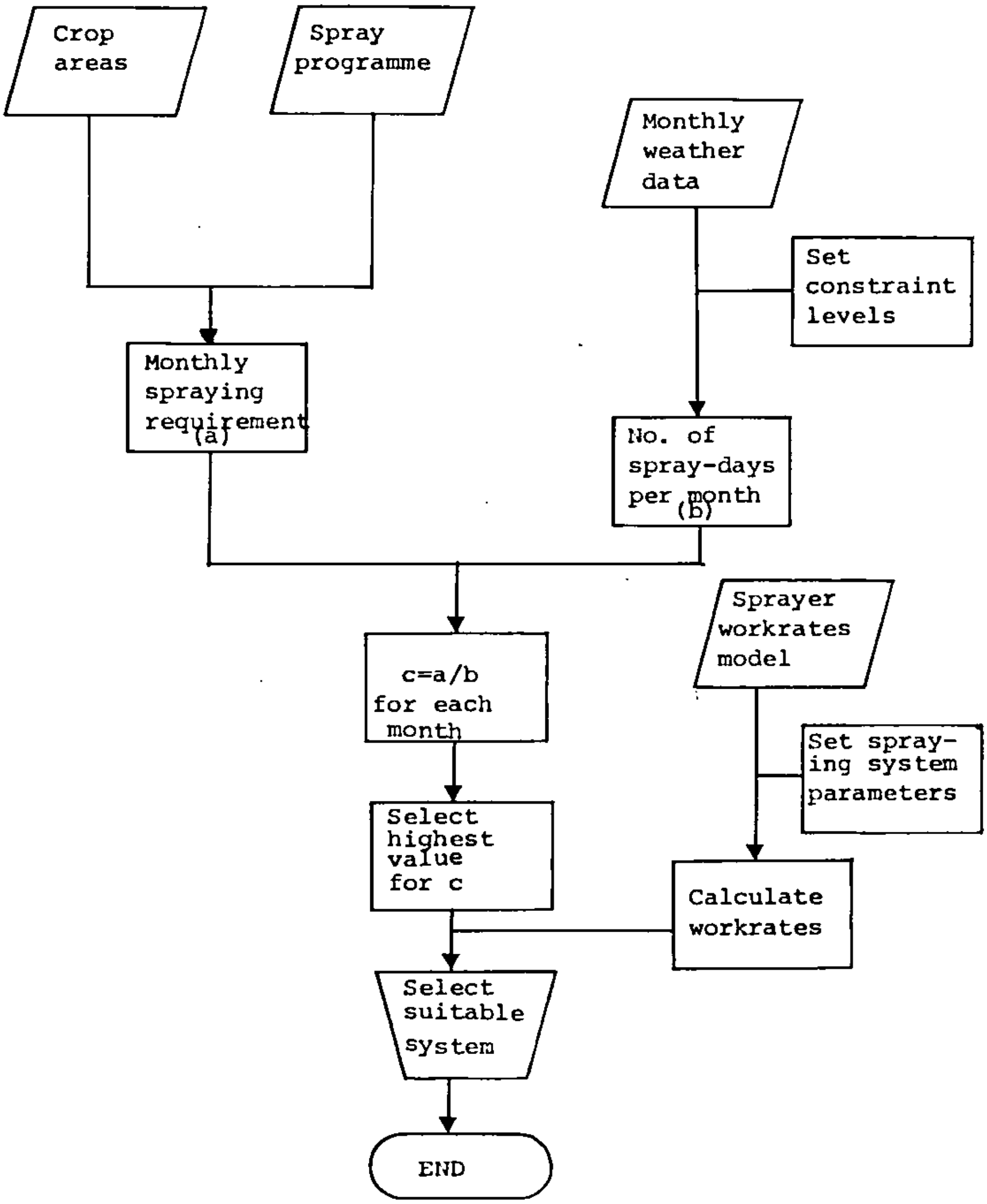
5.7. Proposed model suggesting a suitable sprayer system for a given farm.

For a given farm, with given crop areas, it is possible to suggest a likely programme of spraying through the crop year (e.g. Table 4.8), and hence a monthly spraying area requirement. Weather observations taken from an appropriate weather station can be used to calculate the number of spray-days in each month. From an inspection of the number of spray-days available, and the monthly spraying requirement, it is possible to locate the most "constrained" months, i.e. when a high monthly spray requirement occurs in a month with few spray-days. For these months, the workrate/day necessary in order to carry out the spray programme can be calculated, and, by working back from output of the sprayer workrates model (described in Section 5.3), it is possible to select a combination of sprayer dimensions, refilling arrangements, spraying speed and application rate that will be capable of fulfilling the spraying requirement in the most constrained months (in terms of spray-days). This combination will of course be capable of carrying out the spraying requirement in less spray-day constrained months.

Figure 5.19 outlines a flow diagram of the model. Several points should be made in connection with such a model:

1) as farmers may wish to be able to carry out their spraying requirements in the worst of years, "worst weather" data should be used in calculating numbers of spray-days available in each month.
2) The model uses time periods of one month in which to carry out spraying operations: it may be necessary for some chemicals to be applied within the space of a few days, e.g. aphicides, crop growth stage (MacKerron & Lawson, 1982), whereas other chemicals

FIGURE 5.19. Flow diagram of model suggesting a suitable spraying system for a farm.



may be considerably more flexible in the timing of their application.

3) It may be difficult to predict requirements for chemical applications.

4) The model will not suggest the use of more than one crop sprayer, though it could be adapted to do so.

5) If a farmer feels that some applications are highly constrained by the weather, he may prefer to have the operation carried out by ground or aerial contractors.

6) Farm spraying operations may be constrained by factors other than the weather, e.g. labour availability.

Notwithstanding these difficulties, the model may be instructive in highlighting alternative options to the farmer, as to the organisation of spraying on the farm.

In reality, it appears that many farms, particularly smaller farms, have a high "sprayer capacity" (Figure 4.4). Results from the Ulvamast user survey suggest that workrates normally achieved by sprayers is somewhat below the best attainable workrates (Figure 5.5, Table 5.4).

5.7.1 Example

The farm is 800 acres (324 ha), sited near to Boscombe Down weather station in Wiltshire. Four crops are grown: 162 ha of winter wheat, 81 ha of spring barley, 40.5 ha of potatoes and 40.5 ha of winter oilseed rape. The crop spraying regime is that given in Table 4.8.

Spackman and Barrie (1982) have calculated spray-occasions using data from different weather stations around the UK. Data from Boscombe Down is used as it is the nearest weather station to RAF Benson for which data is analysed. Criteria set to determine spray occasions are the same as those given in Section 5.5.3, except that

1) only daylight hours between 0600 and 2000 h. GMT are considered.
2) Windspeed constraint levels are 9 knots, (4.6 m/s) and 12 knots (6.2 m/s) for "higher windspeed" (CDA) sprayers.
3) Criteria are satisfied simultaneously for at least 5 successive hours. It is assumed that on each spray day, 9 hours of spraying is possible, with a further hour required for preparing and storing the sprayer.
4) SMD constraints are ⩾ 0 mm (low ground pressure vehicles) and ⩾ 5 mm (conventional tractor). The SMD is calculated using the bare soil model.

Table 5.13 gives the number of spray-occasions in the third worst year of each month for 1971-80, calculated from data recorded at Boscombe Down. Data for the third worst year is an attempt to account for a farmer's risk averseness when selecting sprayer systems. The top figures apply when the windspeed constraint is ⩽ 4.6 m/s (conventional sprayer), with no SMD constraint (⩾ 0 mm - low ground pressure vehicle). From information supplied in Spackman and Barrie's paper it is possible to calculate the approximate number of spray-occasions in the third worst year of each month for 1971-80, for a windspeed constraint of ⩽ 4.6 m/s (conventional sprayer) with an SMD constraint of ⩾ 5 mm (conventional vehicle), and for a windspeed constraint of ⩽ 6.2 m/s (CDA sprayer) with no SMD constraint (low ground pressure vehicle). These are also given in Table 5.13.

Table 5.12 gives details of the spraying requirement through the year for each of the four crops, and is taken from Table 4.8. From the total projected area spraying requirement for each month, and the number of

TABLE 5.12. Typical spraying requirement through the year, for a notional 324 ha (800 acre) arable farm, based on Table 4.8.

CROP	AREA (ha)	SPRAYING REQUIREMENT IN EACH MONTH (ha)												
		AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	TOTAL
Winter Wheat	162			162						162	162			486
Spring Barley	81							81			162			243
Potatoes	40.5	40.5							40.5		40.5	40.5	81	243
Winter Oilseed Rape	40.5				40.5						40.5			81
TOTAL	324	40.5	0	162	40.5	0	0	81	40.5	162	405	40.5	81	1053

TABLE 5.13. Number of spray-occasions in the third worst year of each month, for 1971-1980. Data from Boscombe Down weather station, taken from Spackman and Barrie (1982). A spray occasion indicates that 5-9 hours in a day are suitable for spraying.

WINDSPEED CONSTRAINT	SMD CONSTRAINT	SPRAY-OCCASIONS IN EACH MONTH											
		AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
$\leqslant$ 4.6 m/s (conventional sprayer)	$\geqslant$ 5 mm (conventional tractor)	19	13	2	1	0	0	0	0	6	9	15	16
$\leqslant$ 4.6 m/s (conventional sprayer)	NONE (low-ground pressure vehicle)	21	16	9	5	1	1	2	4	8	10	16	17
$\leqslant$ 6.2 m/s (CDA sprayer)	NONE (low-ground pressure vehicle)	29	23	15	6	2	2	4	8	15	18	25	26

TABLE 5.14. Area (ha) to be sprayed on each spray-occasion, for each month. Each spray-occasion is assumed to allow nine hours of spraying. Values in each month are the total spray requirement for each month (Table 5.12) divided by the number of spray-occasions in each month (Table 5.13). "*" signifies that no spraying-occasions are available for spraying operations in that month; the spraying requirements are carried over to the next month when there are spray-occasions. The circled values are the highest daily values in the year, and hence the most critical month for sprayer workrates.

WINDSPEED CONSTRAINT	SMD CONSTRAINT	AREA TO BE SPRAYED ON EACH SPRAY-OCCASION (9 hours/occasion)											
		AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
≤ 4.6 m/s (conventional sprayer)	≥ 5 mm (conventional tractor)	2.1	0	81.0	40.5	0	0	*	*	47.2	45.0	2.7	5.1
≤ 4.6 m/s (conventional sprayer)	NONE (low-ground pressure vehicle)	1.9	0	18	8.1	0	0	40.5	10.1	20.2	40.5	2.5	4.8
≤ 6.2 m/s (CDA sprayer)	NONE (low-ground pressure vehicle)	1.4	0	10.8	6.7	0	0	20.2	5.1	10.8	22.5	1.6	3.1

TABLE 5.15. Some sprayer systems that will fulfil spraying requirements through the year, in the third worst year for each month, 1971-1980, for readings taken at Boscombe Down weather station. See Table 5.14.

(i) With a windspeed constraint of $\leqslant$ 4.6 m/s, and an SMD constraint of $\geqslant$5 mm, October is the most constrained month; at least 81 ha must be sprayed on each spray-day. Assuming 9 hours spraying, 1 hour preparation, suitable systems include:

TANK CAPACITY (l)	BOOM WIDTH (m)	MEAN DISTANCE TO REFILL (m)	RATE OF REFILL (l/s)	APPLICATION RATE (l/ha)	SPRAYING SPEED (m/s)	MODEL-CALCULATED WORKRATE (ha/day)
2000	12	1000	2.5	200	5.00	86.7
2000	12	100	2.5	200	3.33	76.2
2000	12	1000	2.5	100	3.33	83.8
2000	24	1000	2.5	100	1.67	87.1
500	12	1000	2.5	100	5.00	80.3

(ii) With a windspeed constraint of $\leqslant$4.6 m/s and no SMD constraint, February and May are jointly the most constrained month, with a daily spraying requirement of 40.5 ha. Suitable systems include:

1000	12	1000	2.5	200	1.67	40.9
500	12	1000	2.5	200	2.50	42.7
500	12	100	2.5	200	1.67	41.1

(iii) With a windspeed constraint of $\leqslant$6.2 m/s and no SMD constraint, May is the most constrained month, with a daily requirement of 22.5 ha. Suitable systems include:

250	12	1000	0.75	20	1.67	49.4
2000	12	1000	0.75	200	1.67	35.6
250	18	1000	1.00	200	3.33	33.2

spray days available in each month for each spraying system, it is possible to calculate the area/day that must be covered in order to carry out all of the spraying. This is presented in Table 5.14.

Table 5.15 details several combinations of sprayer systems that can produce the required workrates to overcome the effects of various levels of constraints. The results indicate that spraying systems overcoming SMD constraints can achieve monthly spraying requirements even if the dimensions of the sprayer are smaller, or the forward speed lower. Thus small sprayers may be mounted on LGPV's, with a high probability that all of the work can be carried out. Sprayers overcoming the SMD and windspeed constraints may be virtually any size and be assured of fulfilling the monthly spraying requirement. Labour and other time constraints will mean that such spraying systems are nevertheless capable of high daily workrates.

The availability of more spray-days through the year may in fact encourage a change in spraying programmes, as previous programmes may incorporate considerations of spray-days available in their design.

A model such as the one outlined above could be computerised in order to rapidly evaluate alternative spraying systems for a given farm and set of spraying requirements.

5.8. Other methods of evaluating optimal machinery sets

Alternative methods of assessing optimal machinery sets may involve a consideration of the economics of machinery ownership and use (e.g. Donaldson, 1967, Ihnen & Heady 1964). Several authors have attempted to evaluate the use of new machines or techniques within a farm-management context, emphasising the aspects of resource allocation and the existence of economic and technical constraints (Audsley, 1981;

Krutz, Combs and Parsons, 1980). The "lumpiness" of machinery inputs may also be an important consideration, particularly with expensive machines available in only a few sizes, such as combine harvesters (Donaldson, 1967). The use of such techniques has not been used in this study for several reasons:

1) This thesis is concerned with only one type of farm machinery, rather than the whole farm machinery complement.
2) Sprayers are available in a large number of sizes, i.e. differing boom widths and tank capacities, thus are less "lumpy" in nature than many types of farm machinery.
3) Relative to other types of farm machinery where timeliness may be important (e.g. harvesters) sprayers are relatively cheap. Over a number of years the value of chemicals applied by a sprayer are much higher.
4) The economics of the benefits obtained from the use of sprayers to apply chemicals are difficult to assess.
5) Farmers may call on the services of contractors.

Probabilistic approaches to assessing optimal machinery capacities in the face of risky weather conditions have been detailed by Donaldson (1968) and Donaldson and McInerney (1967). These involve balancing possible timeliness costs against cost of machinery ownership. Gemmil (1969) found that timeliness costs were much more important than machinery costs, and that there was a large variation in their level between different years. Edwards and Boehije (1980) mentioned the utility of risk reduction and minimising income variation. They stated that due to fluctuations in weather, minimising costs in one year may be much too large or much too small in other years. Thus a machinery complement over and above what is needed in normal years may be viewed as "insurance".

Whitson, Kay, LePori and Rister (1981) observed that machinery investments per hectare increased as adversity to weather risk increased.

Donaldson (1968) stated that a primary effect of technological innovation in agriculture is the removal of some of the uncertainty from farm production, e.g. by the expediting of physical operations by the use of better farm machinery. As investments such as these require capital, evaluations of investments in new technology should include an assessment of the variability which the investment will reduce. The example of the model outlined in Section 5.7.2 demonstrates how the use of technology relaxing windspeed and SMD constraints can increase the time available for completing the operation, thus making the completion of the operations more likely.

5.9 Summary of Chapter

1) Six main groups of on-farm factors influence farm spraying operations. Four factors may be said to comprise the spraying system: sprayer dimensions, spraying and ferrying speeds, refilling arrangements, and application rate. Two other groups of factors also have an influence: the farm layout, comprising field shape, size and farm conformation; and time spent on calibration, repairing breakdowns, and on other delays.

2) Bowser systems enable a significant increase in daily sprayer workrates to be carried out, with hydraulic pressure sprayers. Very high workrates are possible with the "Ulvamast". Generally, workrates obtained on average with sprayers are somewhat below the best stated workrates.

3) An adapted version of the Baltin equation is verified by survey data as giving results similar to those experienced on farms. Results from the model are presented, all groups of factors included

in the model being varied, in order to assess their influence on workrates. Although there are many factors influencing workrates, spraying speed, application rates and sprayer boom widths have marked effects on workrates.

4) Several elements of the environment can impinge upon spraying operations. Prominent among these are: windspeed, temperature, precipitation and soil moisture. Each of these factors are discussed in turn. New machinery technology seeks to ease windspeed and soil moisture constraints. Data is presented from RAF Benson on the effect of varying the constraining level of these two environmental parameters. Easing the soil moisture constraint has a major effect on the number of opportunities for spraying operations, particularly at times of the year likely to be 'busy' in terms of spraying operations. Verification of the use of data from weather stations in this way is provided from survey results, which indicate that a significant proportion of the farmers around a weather station contact that weather station for weather advice.

5) In the 1981-2 growing year, respondents in the Ulvamast user survey felt that more days were available for spraying than were actually used.

6) Findings from investigations into the logistics of sprayer operations and weather constraints to spraying are combined in a model which can suggest suitable alternative spraying systems for farms. In particular, the model shows the benefits of easing environmental constraints, especially at peak times of the year.

CHAPTER SIX

ADOPTION AND DIFFUSION OF NEW TECHNOLOGY

6.1. Introduction

In this Chapter the theories explaining the adoption and diffusion of new agricultural technology will be discussed. In attempting to assess innovativeness, or the relative earliness of uptake of innovations, data from the random user survey are presented and discussed. The Chapter concludes with a case study of the adoption of a new type of crop sprayer.

Section 6.2 discusses the economic effects of the introduction of new farm technology. The behaviour of farmers in this treatment is assumed to be rational and profit-maximising. However, as will be shown in this Chapter, these assumptions are not always true. The influence of risk on adoption, and various aspects of the adoption of innovations are discussed in Section 6.3. Much of this Chapter is devoted to literature reviews of various topics connected with adoption. Some findings are presented from the random user survey. Among the topics covered are innovation orientation and problem orientation, risk and innovation, pre- and post- adoption rejection of an innovation.

In Section 6.4 a literature review is conducted of the important economic and technical attributes of innovations that may influence the uptake of that innovation.

Section 6.6 deals with innovativeness. Using data from the random user survey, an index of innovativeness is formed from information on the time of adoption of six types of arable innovations. These arable innovations are discussed in Section 4.6. Various personal and situational variables are examined for associations with ranked categories of innovativeness in Section 6.6.12. Correlations of farm and farmer attributes with other measures of orientation toward new crop spraying technology are presented in Section 6.6.14.

A review of the means by which the adoption of innovations can be predicted, using results such as those presented in Section 6.6.12 is given in Section 6.6.13.

The Chapter concludes with a case study of the adoption and diffusion of an innovative spraying device, the Ulvamast.

6.2. The economics of new technology

A technological change differs from a change in technique in that it represents a shift in the production function : a given combination of inputs yields a larger total product (Upton, 1976).

Generally, individual farms are too small to influence prices in input or produce markets. If an innovation is introduced, and if the marginal product per unit of any factor of production increases as a result of that innovation, then the optimum use of that factor will be increased : the farmer will have the incentive to use more of that factor (Upton, 1976); profits will be maximised at higher levels of production. Early adopters of an innovation will usually receive benefits from this extra production greatly in excess of costs because the increment of production gained by them does not affect the market price (Hunt, 1970). However, if the innovation is adopted by large numbers of producers, product prices will fall, as more will be supplied at any given product price. If the demand for the product is inelastic, then the total revenue obtained by farmers from the sale of that product will decline, unless the new technology lowers the costs of production relatively more than revenues (R.F. Smith, 1971). When the innovation is to be used by most farmers, the average farmer then has to adopt the new technology simply to maintain income : he does not benefit from the new technology, and adopts it merely to survive. Consequently, the only way the farmer can appropriate the gains from new technology is by being first to adopt a cost-reducing technology (Barkley, 1978). In general, new agricultural technology benefits consumers and better-off farmers, while smaller farmers producing under adverse production conditions have been the most likely losers (Pinstrup - Andersen, 1981). This is because the technology may not be suited to small farmers, eg. because of high per hectare costs.

Griliches (1960) found that the adoption of hybrid maize in the U.S. "Corn Belt" varied regionally depending upon the absolute profitability of adopting the hybrid maize. In addition, differing availability of hybrid maize seed from merchants accentuated differences in adoption rates between areas. This factor may in turn increase regional disparities in levels of income and rates of growth. In fact concern about income disparities and the release of labour from farming caused by technological change may stimulate political action (Dexter, 1977).

In assessing requirements of the various sectors of the agricultural industry, Dexter (1977) stated that in the case of EEC grain production, opportunities remain to absorb the products of new technology. In addition, the economic gains from the impact of new technology in agriculture are sufficiently large to justify paying the research and development costs and the social costs resulting from the introduction of new technology.

Jones (1971) emphasises the limitations of microeconomic theory in attempting to explain patterns in the adoption of innovations among a farming community:

> 'classical economic theory assumed that the entrepeneur in taking a decision sought to maximise his satisfaction (usually meaning his profit) and acted completely rationally and with perfect foresight; in addition, and somewhat more implicitly, the complete independence or social autonomy of the decision-maker was also assumed.
>
> "The farmer, both as a consumer of new ideas and practices, and as a user of them, is very different in reality. He is concerned with various objectives, of which a satisfactory profit or net income is likely to be one, but he usually acts in ways which are less than perfectly rational, and is influenced by the activities of other farmers"

The personal decision-making approach to the adoption of innovations is discussed in Section 6.3, and the diffusion of new technology is discussed in Section 6.5.

6.3 The Adoption of Innovations

6.3.1 Introduction

"Our problem is to learn why, given one hundred different innovations conceived of at the same time - innovations in the form of words, in mythological ideas, in industrial processes etc., - ten will spread abroad while ninety will be forgotten" (Tarde, 1903, quoted in Rogers 1962, p. 140). Since the time of this statement, researchers from several disciplines have contributed to the body of research on adoption and diffusion. Among the disciplines utilised in adoption and diffusion studies have been anthropology, geography, social psychology, sociologists from several backgrounds, market researchers and educationalists. Much work has been done in the Americas and some Asian countries, less in European countries. Upto 1974, there were 1800 published works on diffusion studies (Rogers, 1976); a bibliography covering the period 1969 - 1980 lists 719 adoption and diffusion studies (CAB, 1981).*

The adoption of innovations may be viewed as a limited example of the learning process, where an individual responds to stimuli by a permanent change in their individual behaviour (adoption or rejection of the innovation) (Rogers, 1962). Rogers also states that the adoption process is one type of decision-making, which itself is "the process by which an evaluation of the meaning and consequences of alternative lines of conduct is made" (Rogers, 1962, p. 78).

In this section, reports from the literature are made on aspects of the individual adoption process. Some results are presented from the random user survey.

6.3.2 Adopter categories

In common with many phenomena in the social sciences, for any given innovation there is a continuum of the time of uptake, which often manifests itself as a normal, or near-normal curve. For cumulative diffusion curves, Jones (1971) stated that for British data, "recognizably S - shaped curves describe the diffusion of many agricultural innovations which are open to adoption by individual farmers, such as various kinds of agricultural machinery". Assuming a symmetrical S curve in its cumulative form, which equates to a bell-shaped, or normal curve in its incremental form (Figure 6.1), classification of adopters may be made according to their relative position on the bell-shaped curve. Rogers (1958) suggested classifications of adopters of innovations based on

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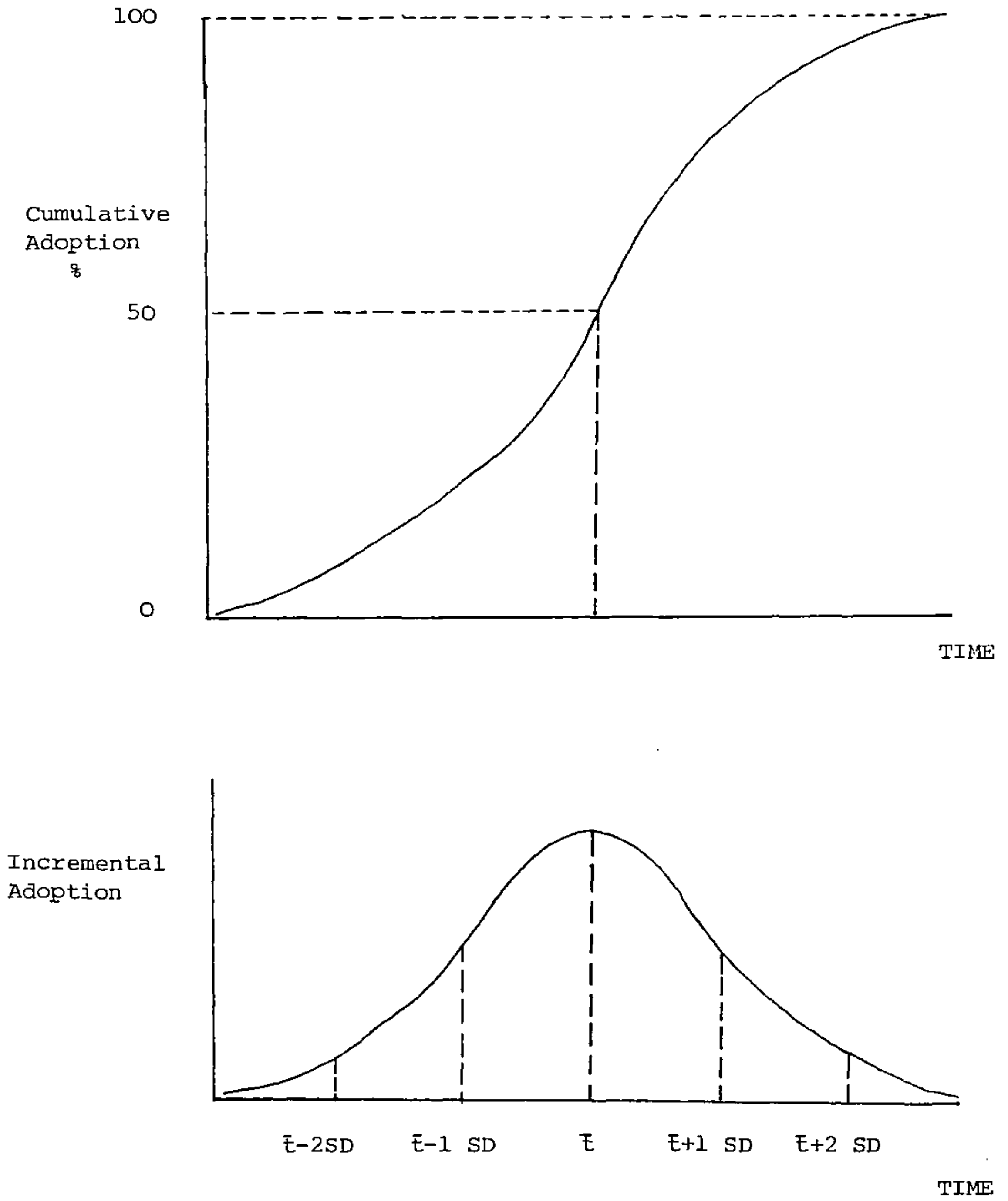
*Studies carried out in the U.K. on the adoption of farm innovations include Jones (1961) on bulk milk handling techniques, Howell (1968) on a number of dairying innovations, Staniforth (1966) looked at vacuum silage, and Foxall (1980) investigated the uptake of rough-terrain fork-lift trucks.

FIGURE 6.1. Cumulative and incremental adoption curves.

$\bar{t}$ = mean time of adoption;

SD = standard deviation



their distance from the 'mean' time, measured in terms of standard deviations - fixed proportions of the total population concerned are in each category. Rogers' categories are now widely used in adoption studies (Jones, 1971). In using this method to define categories of adopters, four points should be stressed:

1) the full incremental curve implies that adoption is complete - 100% of the population have adopted. No account is taken of discontinuance of the innovation following adoption.
2) Attributes of the various categories of adopters are outlined in Table 6.1. It is not suggested that all of the adopters in a given category possess all of the attributes in the corresponding description, merely that they are generalizations.*
3) Farmers may be innovators for one or a group of innovations, yet may be considered to be more laggardly regarding adoption of a different innovation, or group of innovations. For instance, a dairy farmer may adopt the latest devices for milking parlours or feed rations very soon after their introduction, yet be slow to adopt new techniques or devices for use on his cereals. Thus the terms may apply to one, or a number of innovations related in their applications; for instance "dairying" "arable" or "horticultural" innovations.

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*Rogers (1962) described "ideal types" to be found in each of the adopter categories: "ideal types are conceptualizations that are based on observations of reality and designed to institute comparisons..... The function of the ideal types is to guide research efforts and serve as a framework for the synthesis of research findings" (Rogers, 1962, p. 168).

TABLE 6.1. Characteristics of farmers in five categories of adoption. Table taken from Jones, (1971 p. 46).

Adopter category	Personal characteristics	Salient values and social relationships	Communication behaviour
Innovators	Highest social status; largest and most specialized operations; wealthy; often young; well educated; often experience in non-farming environment.	'Venturesome', willing to accept risks; some opinion leadership; cosmopolite.	Closest contact with scientific information sources; interaction with other innovators; relatively greatest use of impersonal channels of information.
Early adopters	High social status; often large and specialized operations.	'Respected'; regarded by many others in the community as a model and an influential; greatest opinion leadership of any adopter category in most communities.	Greatest contact with local change agents (including extension or advisory services, commercial technical advisers, etc.); competent users of mass media.
Early majority	Above-average social status; average-sized operations.	'Deliberate'; willing to consider new ideas only after peers have adopted; some opinion leadership.	Considerable contact with change agents and early adopters; receive mass media.
Late majority	Below-average social status; small operations; little specialisation; relatively low income.	'Sceptical'; overwhelming pressure from peers needed before adoption occurs; little opinion leadership.	Interaction with peers who are mainly early or late majority; less use of mass media.
Laggards	Little specialisation; lowest social status; smallest operations; lowest income; often oldest.	'Traditional'; oriented towards the past; avoid risks; little if any opinion leadership; almost isolated socially.	Neighbours, friends and relatives with similar values are main information source; suspicious of change agents.

Note: This table is based on findings in several British studies, and confirmed by many studies in other countries.

4) The terms used in the categories in Table 6.1 relate to the farming population under study; an innovator regarding new arable devices or practices in one farming population may be regarded as as much less innovative if placed in another population. Thus, it is important to define the social system, or particular farming community to which the terms are being applied.

6.3.3 The adoption process

The process of decision making leading to adoption tends to be purposive and generally rational in nature, involving a sequential process which includes various forms of reasoning and information (Jones, 1971).

The North Central Rural Sociology Subcommittee for the Study of the Diffusion of Farm Practices (1955) recognised five distinct stages in the process of adoption:
1) Awareness; 2) Interest; 3) Evaluation; 4) Trial; 5) Adoption.
This sequence has been verified by a number of independent researchers, and extensive use has been made of this model in subsequent studies (Jones, 1966a).

Awareness of an innovation arises where the adopting unit knows of an innovation's existence, but lacks detailed knowledge of it (Jones, 1966a). Awareness of the innovation could have been acquired involuntarily, or by chance; if this awareness leads to a recognition that the innovation could help in a hitherto unrecognised problem, then a state of cognitive dissonance has been brought on by the innovation which will ultimately lead to the rectification of the dissonance (or mental discontent) by proceeding through the process of adoption. This process, brought on by the innovation, may be termed innovation orientation (Cambell, 1966). Alternatively the farmer may be forearmed with a recognised problem, and be actively seeking for solutions to this problem causing dissonance. If this latter case is the means by which the adoption process is started, it is termed problem orientation (Campbell 1966) - see Section 6.3.4.

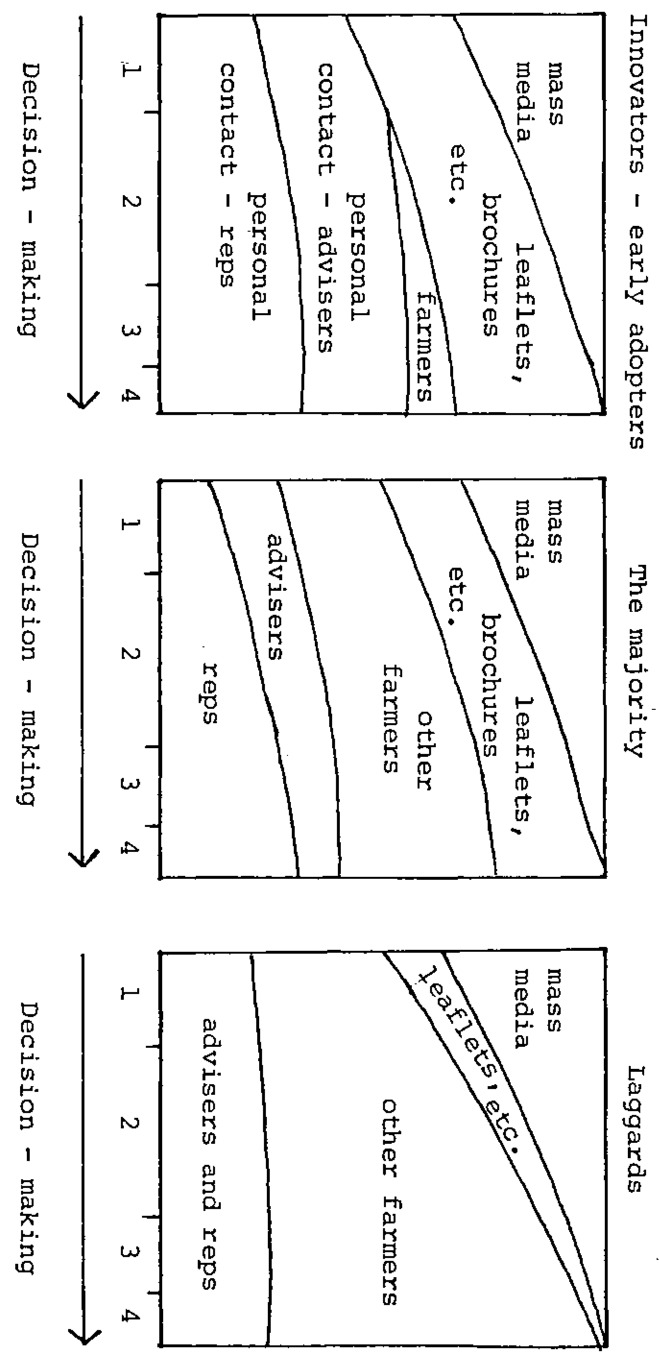
Interest in an adoption is the stage at which the farmer is actively seeking information about the adoption. Jones (1966a) stated that information-seeking occurs due to "uncertainty concerning the innovation arising from lack of knowledge at the point of awareness". There will generally be several sources of information available, even for innovations. Different categories of adopter (i.e those conforming most nearly to one or other of the adopter stereotypes outlined in Section 6.3.2) will tend to use and trust differing information sources, depending upon their relative position in the adoption process, as summarized in Figure 6.2. The process of information gathering is not confined to the interest stage of adoption; throughout the adoption process, information will be gathered from varying sources. The fact that information gathering can and does occur through the process of adoption indicates that the sequential model as indicated may not always reflect a true picture of the adoption process; in fact the third stage, that of evaluation, is very closely linked to interest : the two stages are not really discrete, but are closely interlinked and overlap in the individual's thought processes. Evaluation is the stage at which the individual assesses the innovation's usefulness, and expected outcomes following adoption.

If the adoption process is followed through, and the nature of the innovation under investigation makes it possible, a small-scale trial

TABLE 6.2. Table showing cumulative adoption of innovations by year. The table does not take into account discontinuance, or innovations introduced onto farms before the entry into farming of the respondent. The bottom seven rows indicate how many of six innovations respondents have adopted in each year. Data from the random farmer survey.

YEAR		TO END 1967	68	69	70	71	72	73	74	75	76	77	78	79	80	81	TO MAR. 82
No. innovations available		2	3	3	4	4	5	5	6	6	6	6	6	6	6	6	6
No. of respondents in farming		51	56	56	59	61	63	63	65	66	67	68	70	71	71	73	73
No. of respondents not yet in farming		22	17	17	14	12	10	10	8	7	6	5	3	2	2	0	0
Direct Drilling							2	3	5	7	9	10	15	18	20	21	22
+50% Winter Cereals		3	3	7	8	11	11	12	20	25	29	36	41	48	52	54	54
LGP Techniques		3	3	3	7	7	9	9	12	13	13	16	24	27	34	45	47
Tramlines					1	1	2	2	2	3	7	13	18	25	28	38	42
LV/CDA Spraying											2	4	4	7	8	17	22
Sprayer Monitors											1	1	2	3	3	6	7
ADOPTION INDEX	0	46	51	47	46	45	43	42	34	31	27	20	13	8	6	4	3
	1	4	4	8	10	13	16	16	23	24	26	25	26	25	20	18	14
	2	1	1	1	3	3	4	5	8	9	10	17	21	19	21	14	17
	3	0	0	0	0	0	0	0	0	2	2	4	5	13	16	21	19
	4	0	0	0	0	0	0	0	0	0	1	1	4	4	6	9	12
	5	0	0	0	0	0	0	0	0	0	1	1	1	2	1	6	7
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

FIGURE 6.2. Relative importance of main information and advisory channels sought by farmers (in three adopter categories) during their decision-making on innovations. Figures taken from Jones (1971, p47). Decision-making stages: 1=Awareness; 2=Information, interest and evaluation; 3=Trial; 4=Adoption.



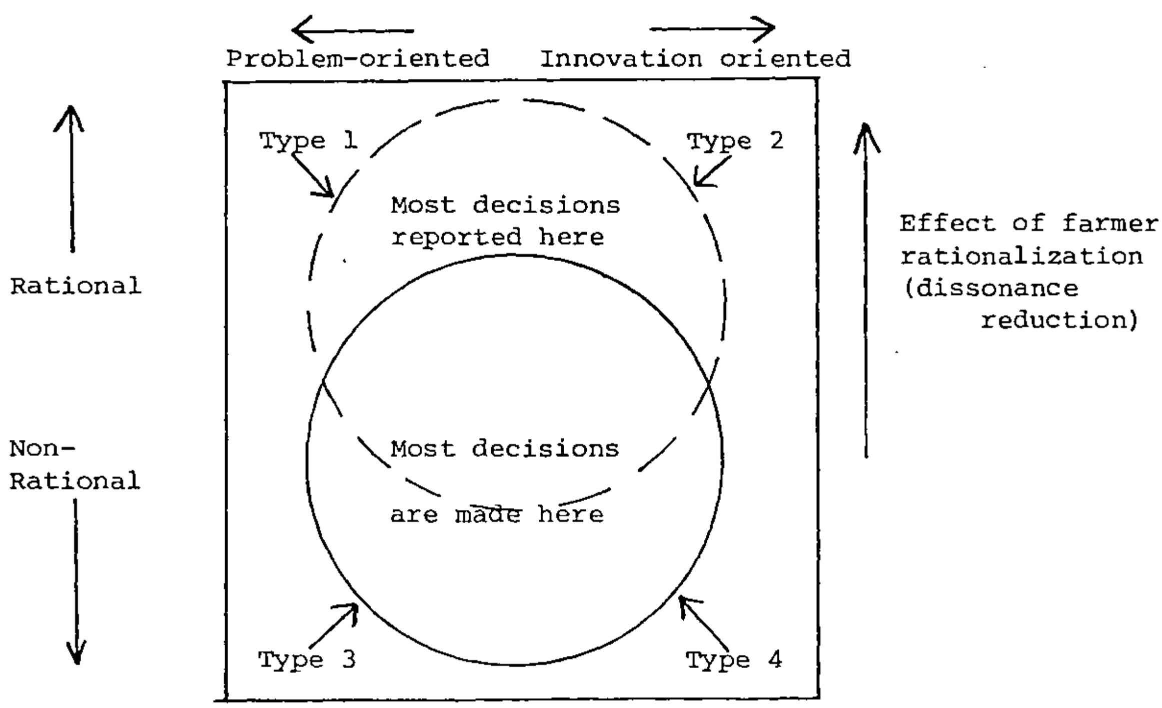
of the innovation may be conducted. The final step is adoption, where the individual fully takes up the innovation, using it as a normal practice in farm enterprises.

The five-stage model assumes adoption to be a sequential process, with individuals moving inexorably from one stage to another. This may not be so, for several reasons:

1) the process need not always end in a decision to adopt; rejection of the practice may occur at any stage of the adoption process.
2) The stages do not always occur in the specified order, some of them may be skipped, and there may be a considerable overlap of one adoption stage with another, e.g. between interest and evaluation.
3) Post-adoption actions may occur to help reinforce the adoption decision, acting to reassure the adopter and remove dissonance resulting from the decision to adopt (Rogers and Shoemaker, 1971).
4) Campbell (1966) argued that the degree of rationality and whether the decision was innovation-oriented or problem-oriented has a great influence on the adoption process. Campbell proposed a "paradigm demonstrating individual decision-making and adoption", a diagrammatic representation of which is given in Figure 6.3.

The time taken from awareness to adoption, or between any stages of the adoption process, may vary greatly, depending on factors such as whether the farmer is problem- or innovation-oriented, the farmer's and society's attitudes to change,and the nature of the innovation. However, the key determinant is the farmers personal characteristics. Jones (1971) has incorporated many of the above modifications to the five-stage adoption process in a model he has presented (p. 38).

FIGURE 6.3. A paradigm of individual decision-making and adoption. From Campbell (1966). The four adoption process archetypes are:
1) Rational-Problem Oriented. 'Stages': (i) problem (ii) awareness (iii) evaluation (iv) rejection or trial (v) adoption or rejection.
2) Rational-Innovation Oriented: (i) awareness (ii) interest (iii) evaluation (iv) rejection or trial (v) adoption or rejection.
3) Non-Rational-Problem Oriented: (i) problem (ii) awareness (iii) adoption or rejection (iv) resolution (e.g. information-seeking)
4) Non-Rational-Innovation Oriented: (i) awareness (ii) adoption or rejection (iii) resolution (including information-seeking).



6.3.4 Problem and innovation orientation

The traditional assumption of awareness as the starting point of the adoption process may be an incomplete conceptualization (Reynolds, 1971). The traditional model of adoption, that of awareness - interest - evaluation - trial - adoption, depicts awareness as a random event, where the farmer cannot seek something not known about. When the farmer becomes aware of an innovation, a degree of dissonance is created in the farmer's mind over what should be done. This is resolved by adopting or rejecting the innovation. The above process is known as innovation-oriented decision-making, or in short, innovation orientation (Campbell, 1966). In contrast, problem orientation is stated by Campbell to arise from awareness of a problem in the farmer's existing situation. This may give rise to dissonance, and some activity in seeking innovations, in order to reduce or eliminate the feelings of dissonance. Thus the motivation for decisions precedes awareness of the innovation.

There appears to be few published studies on the incidence of innovation and problem orientation in the adoption of new agricultural technology. In the random user survey, the 76 respondents were asked to agree or disagree with the statement "Being on the lookout for new ideas helps me recognise problems on my farm". Sixty two respondents (82%) agreed with the statement, which may imply that the majority of respondents view an active seeking of new ideas or practices as being helpful in locating shortcomings in farm management or farm operations.

The level of active seeking for new devices or practices may be related to the level of satisfaction with existing practices. In the random user survey, respondents were asked to agree or disagree with the statement, "Over the past few years I have been satisfied by the performance of my spray gear". Of the 75 replies (1 missing value), 60 (80%) agreed with the statement. Does a high level of satisfaction with existing technology mediate against searching for new ideas or practices, and could this satisfaction significantly influence adoption rates?

6.3.5 Attitudes to risk and adoption

Attitudes to risk in relation to the adoption and diffusion of farm practices has received relatively little attention (Mason and Halter, 1980). Whilst models of adoption do not generally explicitly incorporate an individual's consideration of the riskiness of an innovation, their attitudes to risk in generally are believed to be of a given state, corresponding to the adoption category that the farmer most closely resembles (see Table 6.1).

Jones (1971) indicates that innovators are venturesome, and willing to accept risks, whilst at the other extreme laggards are traditional and avoid risks. However, Mason and Halter (1980) found that when a current practice was being forcibly discontinued by government legislation (grass seed stubble burning in Oregon), early adopters of new, alternative means of sanitization tended to be more risk-averse. This was because the early adopters viewed the field sanitizing innovations as ultimately reducing the risks in farming, in the context of the forced discontinuance of current practices.

Cancian (1967) studied the relationship between wealth, risk attitudes and innovation. Arising from a number of conflicting effects, Cancian found the relationship between wealth and economic rank to be curvilinear, and inclination to risk to be important in adoption decisions. In addition, Cancian found that individuals in the middle of the economic rank inuum tended to be more conservative than may have been expected. These findings, and the theories on which they are based, have been partly supported by some workers (Frey et al, 1978) and refuted by others (Morrison et al, 1976).

A review of the literature does not leave the reader with a clear view of the relationships between innovativeness, economic rank and risk. Intuitively, earlier adopters of an innovation appear to be more venturesome and risk-preferring; however this may not be the case for all innovations.

6.3.6 Managing risk and uncertainty

In attempting to tackle problems caused by risk and uncertainty, the farmer must define objectives, even if only subconsciously. The strategy adopted by an individual in decision-making under risk and uncertainty is determined by the farmers' attitudes. In this case attitude may be defined as a "state of mind of the individual toward a value" (Allport, 1954, p. 23). Smith (1958, p. 29) indicated that attitudes are formed by contributions from four major factors : trial-and-error, general perceptions, perception of others' actions and outcomes of those actions, and from verbal instructions. These factors may be of varying importance; with agricultural innovations, social system norms and the individual's experiences are undoubtedly important in helping form attitudes.

In decision-making leading to the choice of a course of action, the farmer may have one of a number of objectives to mind:

1) maximize the minimum pay-off resulting from a decision (maximin)
2) maximise the pay-off resulting from a decision (maximax).
3) minimize perceived opportunity costs arising from the difference

between the actual pay-off and the pay-off from the best possible outcome (method of least regret).

4) minimize variation over a number of pay-offs.

5) maximizing expected monetary value.

6) obtaining a "satisfactory" pay-off (satisficing).

The farmer's attitudes to risk in general will determine personal utility functions (Mumford, 1978), and hence which objective is best suited to the farmer's personal disposition. The farmers adoption behaviour will be seen to be in line with whatever economic objective(s) the farmer has set himself.

6.3.7 Rejection and discontinuance

At any stage in the process of adoption decision-makers may reject the innovation under consideration. The rejection of an innovation does not necessarily imply that a non-rational, or "wrong" decision has been made. Farmers may reject an innovation despite having adequate information and have mentally accepted the innovation as being a "good idea" : the farmer may feel unable to afford or accommodate the innovation, or it may be incompatible with existing farm practices (Jones, 1971). Alternatively the level of dissonance or dissatisfaction regarding existing practices caused by the innovation may not be great enough to merit a furtherance in the adoption process.

Many new items of farm equipment are rejected by smaller-scale farmers when first introduced, despite acceptance of the practice as being a "good idea"; such farmers will quickly acquire the equipment when it becomes relatively cheaper, made in an appropriate smaller-scale form, or when second-hand models become available (Jones, 1971).

Reasons for the non-adoption of a number of innovations enquired about in the random farmer survey are given in Table 6.3a. Note that not all of the answers show final rejection of an innovation; a restarting or continuation of the adoption process may occur, or be in operation.

Table 6.3b show reasons given by respondents in the random user survey for discontinuance of innovations. As with rejection, discontinuance need not be irrevocable; a previously discontinued item may be re-adopted for use.

It is rare that an innovation arises that is a genuinely novel product, and whose use results in the establishment of hitherto unknown consumption patterns (Foxall, 1980). These may be termed discontinuous innovations. That many, if not most, innovations are continuous in nature, means that the adoption of such an innovation results in the discontinuance of a current practice. Through time, innovations become current practices, and are themselves discarded for subsequent innovations.

Amongst innovations introduced onto the market, a rejection rate of about 90% is often found among new consumer items (Rogers, 1976). The figure may be lower for durable goods, but is probably still very high.

Work on farmer rejection of innovations has been carried out by Sheppard (1961) on the rejection of new techniques in U.K. grassland farming, and Hill (1964) on the rejection by farmers of the NAAS (now ADAS) farm management services.

Table 6.3 a. Reasons for non-adoption of arable innovations. Results from random user survey, n = 73. Number of reasons exceeds number of respondents in some cases as more than one reason sometimes given.

INNOVATION (and No. Not Adopted)	NO.	REASON
DIRECT	13	Soil not suitable
DRILLING	9	Believe in ploughing
(50)	8	Ploughing gives better pest control
	6	Would have to use contractors
	5	Haven't considered
	3	Am considering
	2	Doesn't fit my system
	2	Possible extra costs
	1	The lazy way
	1	Prefer good burn
	1	Satisfied with present system
	1	Follow neighbours and will be OK
	1	No yield benefit
OVER 50% OF	1	Soil not suitable
CEREALS AS	1	Can't get sugar beet out in time
WINTER CEREALS	1	Heading towards it, but heavy land.
(3)		
GROUND-PRESSURE	8	Dry land
REDUCING	3	4-wheel drive tractors sufficient
DEVICES	3	Considering purchase of double wheels
(23)	2	Keep off land until soil dry
	3	Not considering
	1	Building LGPV
	1	Double wheels mean more damage
	1	Price too high for double wheels
	1	Satisfied with caged wheels

Table 6.3a (continued)

INNOVATION (and No. Not Adopted)	NO.	REASON
TRAMLINES	13	Not considered
(29)	5	Haven't got matching machinery
	4	Considered
	2	Use stick and rope system
	2	Use foam system
	2	Want to prevent rutting
	1	Causes crop lodging
	1	Don't like to see in field
	1	Don't go through field often enough
	1	Lots of trouble
	2	Tramlining in near future
LOW VOLUME SPRAYING	21	Not considered
	17	Considered
(51)	5	Satisfied with 20 galls / acre
	3	Investment required
	3	Needs proving
	3	Nozzle blockage at low volume
	3	Poor biological results
	2	Better kill with more water
	2	Not on small acreage
	1	Waste of time
	1	Would like it
	1	Drift problems
ELECTRONIC SPRAYER MONITORS	37	Not considered
	10	Considered
(66)	7	Existing "simple" systems satisfactory
	5	Not needed if calibration performed
	5	Farm too small to justify purchase
	4	Excessive cost
	2	Complex apparatus, may go wrong
	2	May purchase with new sprayer
	2	Considered but present monitors on sale not very good.

Table 6.3 b Reasons given for discontinuing the use of arable innovations, once they have been adopted. Results from random user survey, n = 73. See Section 6.6.4 for definitions of adoption.

PRACTICE	NO	REASON
DIRECT DRILLING	11	Soil type not suitable
	2	Weed problems
	1	Slug damage
	1	Problems with establishment
	15	NO. OF DISCONTINUERS
LOW VOLUME SPRAYING (< 100ℓ/ha)	2	Jet blockage with high-pressure/low-volume hydraulic spraying systems.
	1	Poor results with low-volume hydraulic spraying systems.
	1	Used Ulvamast against aphid attack - paid for in one season - haven't used since.
	1	Tried out Ulvamast - wasn't successful.
	5	NO. OF DISCONTINUERS

6.4 The Innovation

6.4.1 Introduction

"There are four crucial elements in the analysis of the diffusion of innovations : (1) the innovation; (2) it's communication from one individual to another; (3) in a social system; (4) over time" (Rogers, 1962, p. 12). Rogers and Shoemaker (1971) defined an innovation as being "an idea, practice or object perceived as new by an individual" (p. 19).

In this section, the attributes of innovations, and how the attributes influence adoption decisions, will be discussed. Decisions to adopt or reject an innovation are not based solely on any single attribute (Fliegel and Kivlin, 1966). The characteristics of an innovation that may affect uptake may be classified into two main areas : economic and technical attributes, and are discussed in the following two sections.

6.4.2 Economic attributes of innovations

Rogers (1962) found that wealth, income and productivity are strongly and usually positively related to rate of adoption. However, adoption may not only be a function of production scale but also a result of differences in perceptions (Kivlin and Fliegel, 1967). Thus differences in perceived economic factors appear to be important in the diffusion process (Kivlin and Fliegel, 1967). Among the attributes of agricultural innovations that may be important in adoption decisions are: purchase costs,costs of maintenance and repair (M & R), rate and frequency of return on investment, and comparitive financial advantages over existing practices which the innovations under consideration are aimed at replacing. In a study of perceptions of farm practice attributes, and their effects upon adoption, Fliegel and Kivlin (1966) found that for a number of dairying innovations high initial costs, high M & R costs, and low rates of return were not found to be closely related to the rate of adoption. The authors concluded that "to some extent, cost attributes had low or unimportant correlations with rate of adoption". In a comparative study of "small-scale" and "middle-scale" US dairy farmers, Kivlin and Fliegel (1967) found that initial cost and M & R cost were negatively correlated with rate of adoption amongst small-scale farmers, the opposite being found for middle-scale farmers. This was explained by the authors as showing that small-scale farmers do not view M & R expenses as aggregate items, and see initial costs as representing expense rather than investment. The authors conclude that for small-scale farmers, costs, risk and uncertainty are perceived as more important, particularly where small farmers are the norm in the social system. In addition, "direct economic pressures could also be expected to be more important (for small farmers) because there is more to lose by trial of an innovation". See also Section 6.2.1.

Kivlin and Fliegel (1968) explained the greater adoption by middle-scale farmers of innovations involving a high initial investment as demonstrating that perceived high costs were offset by perceptions of correspondingly higher profits. In addition the quicker adoption by middle-scale farmers arises from their financial commitment. Conversely, small-scale dairymen have less of a financial commitment, and tend to avoid those modern practices which they perceive would commit them further. Thus, it appears that not all scales of farm enterprise may compete in farming (Kivlin and Fliegel, 1968); small-scale farmers may choose not to join the "technological treadmill"(Cochrane,1958), whilst larger farmers will accept change and innovation rather more passively due to their larger financial commitment. This commitment will also lead the larger farmer to consider long-run financial implications more than smaller farmers, who are seen as being relatively more receptive to innovations perceived as yielding short-term profit (Kivlin and Fliegel, 1968).

6.4.3 Technical attributes

The technical attributes of innovations that influence their uptake may be broadly grouped as:

1) Complexity of the innovation, e.g. degree of difficulty of operation, mechanical complexity. Other factors that may influence the perceived complexity of a practice are the ease of comprehension of its principles, and how easy it is to gauge the economic effects. Fliegel and Kivlin (1966) found that complexity was a mild deterrent to rapid adoption, being more pronounced among smaller-scale farmers. Lionberger (1960) outlined a "gradient of complexity" of innovations, ranging from those needing only a simple change in materials (e.g. seed) to those requiring a change in an enterprise (e.g. a switch from arable to horticulture).

2) Compatibility of the innovation with existing techniques. Kivlin and Fliegel (1967) found a low correlation figure between compatibility and rate of adoption, and concluded that this attribute is not important in adoption decisions. In fact the authors suggested that incompatibility between old and new may enhance adoption, particularly if some characteristics of the old practice have a 'negative' value.

   Fliegel and Kivlin (1966) examined the association with dairying of innovations and uptake among dairy farmers, and found that "the more directly an innovation contributes to the decision-maker's main enterprise, the more rapid is the rate of adoption".

3) Congruence of an innovation with respect to other innovations and existing farm practices. This is linked closely with compatibility, differing in that compatibility is with reference to existing techniques, and congruence considers how similar innovations are with existing related practices, compatability referring more to the possibility of using new and existing techniques side-by-side. Brandner and Straus (1959) found a correlation between the amount of hybrid maize in an area, and the rate of diffusion of hybrid sorghum in that area. Hybrid sorghum represented an innovation in that yields are higher than with pure-line sorghum. The congruence lies in the fact that the use of hybrid maize promotes an appreciation of the attributes of hybrid sorghum over pure line sorghum. Consequently, hybrid sorghum was taken up more quickly in areas where hybrid corn was grown, than in areas which had a greater experience of the sorghum crop. However, Griliches (1960) argued that adoption occurred more on the basis of absolute profitability rather than congruence. Brandner and Kearl (1964) suggest "the possibility of hastening the adoption of any new practice by emphasizing its similarities or congruency with other practices previously accepted".

4) Divisibility of an innovation for "trialling" may help to reduce risk and uncertainty (Kivlin and Fliegel, 1967). At one extreme of the spectrum of divisibility of products are items such as seed and chemicals, where small amounts may be purchased and tested. At the other extreme are large machines. The use of the services of contractors by farmers in the UK can allow the trialling of machinery on farms without committing the farmer to the capital investment. The possibility of using contractors as a tool for adoption is dis-

cussed in Section 4.5 .

Fliegel and Kivlin (1966) conclude that "divisibility may be an important factor in encouraging rapid adoption". However, Kivlin and Fliegel (1967) detected a lesser concern with divisibility amongst small-scale farmers, presumably because as they tend to adopt more slowly, the risk in adopting is less due to the vicarious experience with innovations, in observing larger farmers trialling with and adopting the innovation.

5) The conspicuity of a practice may be important, influencing awareness and knowledge about an innovation. Innovations may vary greatly in their conspicuity; a new machine or crop is more conspicuous than a new type of milking parlour, or a new method of recording milk yields. In a survey of grass farmers, Sheppard (1963) demonstrated a trend between the knowledge by farmers of their neighbours using tripods for haymaking, and factors influencing how conspicuous this practice was in the innovator's fields. Measures of conspicuity were given by the years of use of the innovation, the number of acres over which the hay tripods were used, and nearness to main roads.

In complex "multicharacteristic" devices, such as tractors, it is possible over time to detect incremental innovations, which can be defined as "a series of quantitative changes in known parameters, or into the introduction of a given product of technical characteristics already used in some similar product", (Saviotti, Stubbs, Coombs, and Gibbons, 1982). This is distinct from a radical innovation, which is the appearance of a new technical characteristic. If the definitions of incremental and radical innovation are slightly amended, so as to encompass processes of production and cultural operations, then non-mechanical production and operation innovations may be assigned as being radical or incremental innovations. Another dimension of the attributes of innovations is that of the continuity of the innovation with existing practices, as defined by Foxall (1980) - see Section 6.3.7.

If the degree of radicalness and the level of continuity of an innovation with existing farm practices are treated as variables with different dimensions, then a table of continuity versus radicalness may be drawn up, as in Figure 6.4. Incremental and continuous innovations are most quickly and universally taken up, whilst radical, discontinuous innovations are approached with a greater deal of circumspection by most farmers.

6.4.4 Attributes of innovations and their adopton : Discussion

If the work carried out by Kivlin and Fliegel (1968) on Wisconsin dairy farmers applies to British farmers to at least some extent, then some significant and counter-intuitive inferences may be made. Firstly, larger farmers may be expected to embrace new technology more quickly than their smaller neighbours due to their greater commitment (in absolute terms) to the enterprises. For these farmers, initial cost of an innovation may not be as important as one might expect. However, an important qualification must be added in that the long-term profitability is seen as being very important for high-cost innovations.

Evidence is conflicting in the direction of influence of compatibility and congruence of innovations with existing practices. It appears that the complexity of an innovation may have a mild deterrent effect on adoption. An interesting question that may be posed at this point is whether it is important for farmers to comprehend the principles of operation of an innovation, or if new technology may be taken as a "black box", an understanding of its workings not being seen as necessary. In the case of new spraying technology, understanding and confidence in the

FIGURE 6.4 Values of continuity with existing farm practices, and radicalness of the innovations attributes, for a number of recently introduced arable practices. Degrees of continuity and radicalness (for definitions, see text) are with reference to current medium-volume hydraulic-pressure spraying.

	Continuous	Discontinuous
Incremental	Increase in area of winter cereals Tank mixes Reduced-volume hydraulic spraying Power steering in tractors Tramlines	
Radical	Spinning-disc nozzles Electrostatic nozzles Double wheels	Sprayer monitors Farm computers "Electrodyn" system Low ground-pressure vehicles Rough-terrain fork lift trucks Direct drilling

Incremental ↔ Radical

Continuous ↔ Discontinuous

new technology may be aided by promoting the use of "hand-held" crop sprayers in concert with field-scale sprayers with similar principles of operation. The use of "hand-held" sprayers may also be seen as an example of the divisibility of an innovation. An alternative form of divisibility with new agricultural technology is the employment of contractors to use new machinery on the farm; by doing this, the farmer can evaluate the new technology without entering into any financial commitment. There is some evidence in the use of contractors for such purposes (see Table 4.14). However, it must be pointed out that contractors are liable for the quality of the tasks they perform for the farmer; contractors may well be unwilling to offer services using machinery that is untried or controversial, as a "bad job" done with such a machine may occur.

Conspicuity of a new practice may be locally important in creating awareness and stimulating interest, but it is not likely to be important in the latter stages of adoption. Indeed, the example of the hay tripod, cited by Sheppard (1963) is such a case : even though the innovation is very conspicuous, the diffusion was very local, and the use of this practice soon died out.

Amongst innovations, there is a gradation of"newness". For instance, small advances may be embodied in existing equipment,e.g. power steering, or a new gearbox design in tractors. In purchasing a new tractor with such advances, the farmer may hardly be aware of them, and the sequential adoption process may be short-circuited. However, with more radical innovations, more time and effort may be put into the adoption process, as the newness of the innovation is qualitatively greater. Radical innovations that create new and unexpected consumption patterns are those that may involve the most active and careful consideration by farmers;

consequently, the time taken to adopt may be longer.

The strategy of promotion of innovations must be varied according to how radical and discontinuous the individual innovation is. For instance, a new pesticide will require a different promotion effort than that of a new type of crop spraying nozzle; in turn, innovations that involve the creation of new consumption patterns should be promoted with different objectives in mind.

6.5 The diffusion of innovations

6.5.1 Introduction

"Viewed sociologically, the process of diffusion may be characterised as (i) the acceptance; (ii) over time; (iii) of some specific item - an idea or practice,; (vi) by individuals, groups or other adopting units, linked; (v) to specific channels of communication; (vi) to a social structure, and (vii) to a given system of values or culture" (Katz et al, 1963). In the process of diffusion, the individual may be seen as participating in the social reaction to an innovative item (Jones, 1966).

Prior to the adoption of an innovation by many farmers in a farm community, the diffusion of awareness, and of interest in that innovation, will precede it. These will shape and influence attitudes and opinions to the innovation, which will ultimately be major factors in determining the rate at which the adoption of an innovation proceeds through a community.

The study of the diffusion of innovations extends across several research areas: "the importance of the study of diffusion of innovations is clearly reflected by the rich stream of literature published in recent years and the multidisciplinary applications that have been found for the various theories developed" (Sharif and Ramanathan, 1981). The authors distinguish two approaches to the modelling of diffusion of innovations, which are briefly outlined in Section 6.5.2.

> "Many of the findings (of diffusion research) are organised around a series of generalizations which summarise the evidence available about the relationship between two or more concepts.... as such, the generalizations range somewhere between hypotheses and principles" (Rogers, 1962, p. 12).

6.5.2 Models of diffusion

It has been demonstrated in many studies of differing types of agricultural innovation that the cumulative diffusion curve approximates an S-shape (Jones, 1966a). Examples of innovation leading to such a curve among the farming community is given by Griliches (1957), Sprague (1968), and many other authors. From available British data, S-curves describe the diffusion of many agricultural innovations, such as various kinds of agricultural machinery (Jones, 1971). The S-curve illustrated in Figure 6.1 indicates how diffusion through the farm community occurs. Diffusion starts at a relatively slow pace, becoming increasingly rapid upto the point at which half of the potential adopters have adopted. The rate of uptake then slows as the farm community becomes "saturated" with the innovation.

Sharif and Ramanathan (1981) found in a review of the literature that there were two main approaches in studies of the diffusion of innocations. Work on the spatial aspects of diffusion are exemplified by the studies of Hagerstrand, e.g. Hagerstrand (1965). In this study, the diffusion of innovations was found to follow a "Monte Carlo" type pattern of diffusion, and that expected barriers to diffusion, such as lakes and limited road networks, did as expected, prevent the diffusion of innovations, operating as barriers to communication.

The second main approach to studies of diffusion look at temporal patterns of diffusion, e.g. by fitting algebraic functions to S-curves of diffusion, seeking to estimate the parameters of the S-curve (e.g. Powell and Roseman, 1972), or by seeking to explain the regularity of the S-pattern of diffusion in economic, sociological or information-transfer terms.

In order to explain more fully the causes behind diffusion of an innovation, much work has been done on how two groups of factors in particular influence diffusion (Sharif and Ramanathan, 1981). These are factors influencing (i) demand and (ii) supply of an innovation. Factors influencing demand include characteristics of the adopter and the innovation, extraneous economic factors, how decisions to adopt are made, and the number of adopters and potential adopters at any one point in time. Factors influencing the supply of an innovation include marketing, pricing and advertising actions, relevant official regulations, and public and private sector recommendations.

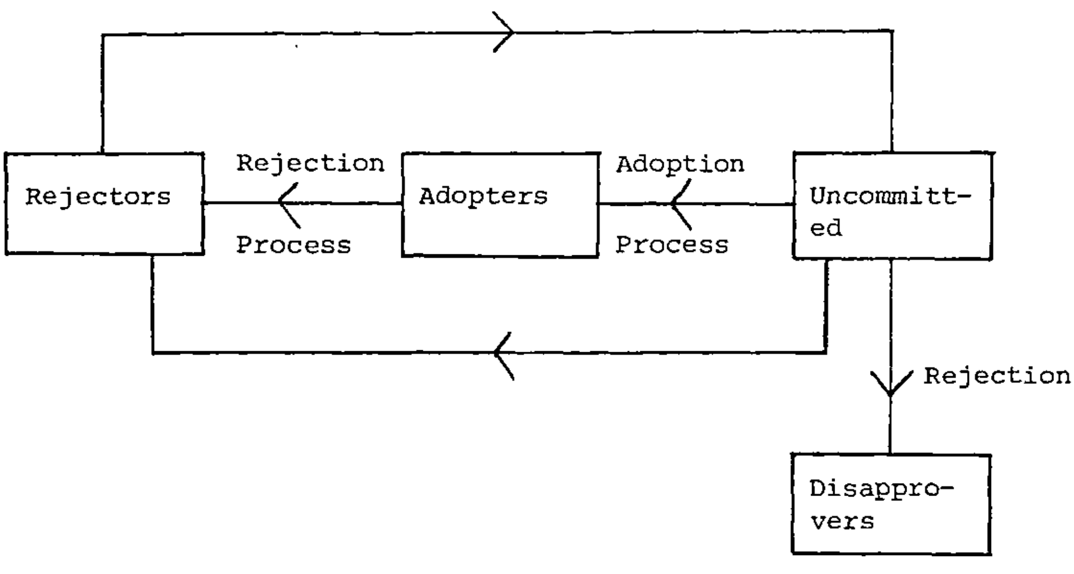
Figure 6.5 outlines the actor groups in a social system relevant to diffusion studies, as proposed by Sharif and Ramanathan (1982). They have proposed this model in order that several phenomena should be accounted for:

(i) the possibility of less than 100% adoption.

(ii) the influence of individuals discontinuing the use of an innovation may dissuade other uncommitted farmers from the use of that innovation.

In seeking to explain the diffusion of innovations amongst respondents in the random user survey, it is assumed that for most innovations, the proportion of the population that are "rejectors" or "disapprovers" are fairly small. One exception to this may be the diffusion of direct drilling - see Section 6.5.3. In fact most diffusion studies ignore the

FIGURE 6.5. Actor groups in a social system which are relevant to diffusion studies, as proposed by Sharif and Ramanathan (1982b). The boxes constitute members of the social system, and the lines indicate how roles may change through time.



numbers and influence of rejectors and disapprovers, seeking to explain diffusion curves in terms of "uncommitted farmers" (i.e. potential adopters), and adopters. Thus most diffusion studies assume a special case regarding the model in Figure 6.5, in that the influence of rejectors and disapprovers is nil, or negligible.

If the presence of rejectors and disapprovers of a given innovation is assumed in a farming community, it may be difficult to collect data in order to verify the model, as Sharif and Ramanathan (1982) have claimed. Thus, in many diffusion studies, it may only be possible to roughly estimate the influence of rejectors and disapprovers on the diffusion curve of an innovation.

6.5.3 Diffusion of six innovations

In the random user survey and Ulvamast user survey, questions were asked on the date of uptake of a number of arable innovations. These were:use of direct drilling, over 50% of the cereal acreage down to winter cereals, use of ground-pressure reducing techniques, tramlining through drilled crops, use of low volume spraying systems, and use of sprayer monitors/ control systems.

For each innovation type, cumulative adoption curves among respondents by year are given in Figures 6.6a to 6.6f. On each graph, three curves are given : one represents the uptake by respondents in the Ulvamast user survey, one by respondents in the random user survey sited around Benson weather station, in Oxfordshire and respondents around the Honington weather station in Suffolk.

Several of the figures show a fairly consistent and reasonable approximation to an 'S' curve, e.g. 6.6a shows almost complete S-curves,

FIGURE 6.6. Graphs of the cumulative diffusion of six types of innovations among respondents in the random farmer survey and the Ulvamast user survey. The graphs do not take into account discontinuance or instances where an innovation on a farm precedes the entry of the respondent into farming. For each innovation, and each of the three 'groups' (respondents in Ulvamast user survey, and respondents in random farmer survey around (i) RAF Benson and (ii) RAF Honington), the number of respondents to whom the innovation is applicable, and the number adopting (as of Spring 1982) are given.

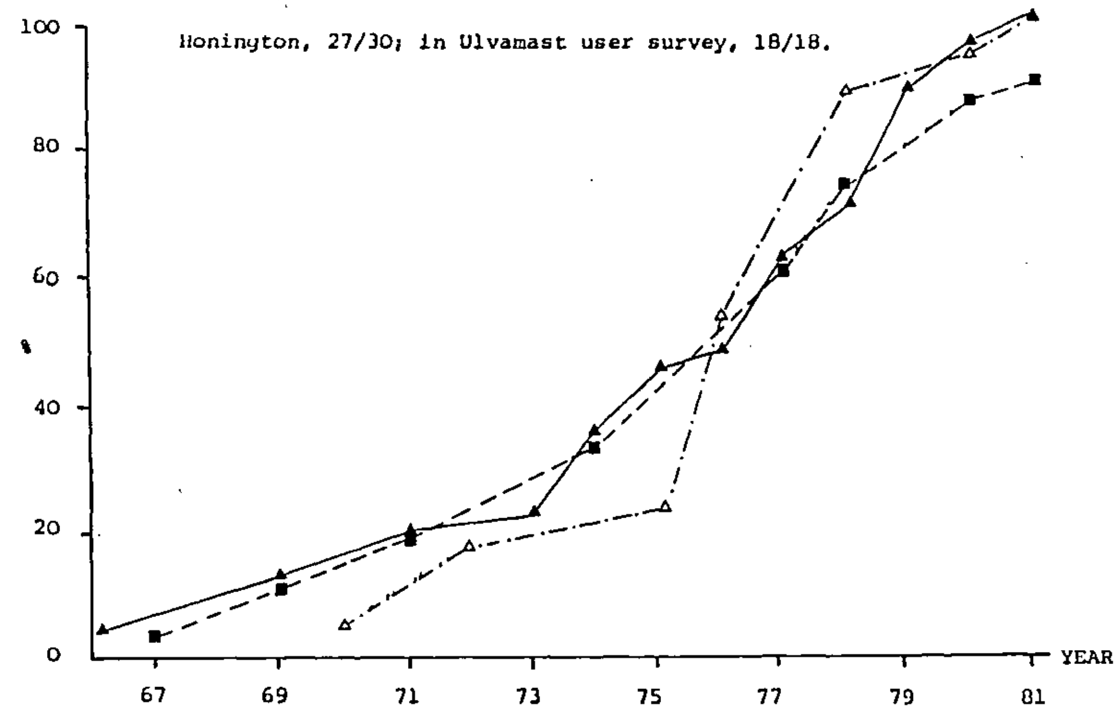
KEY

▲——▲ Diffusion around RAF Benson

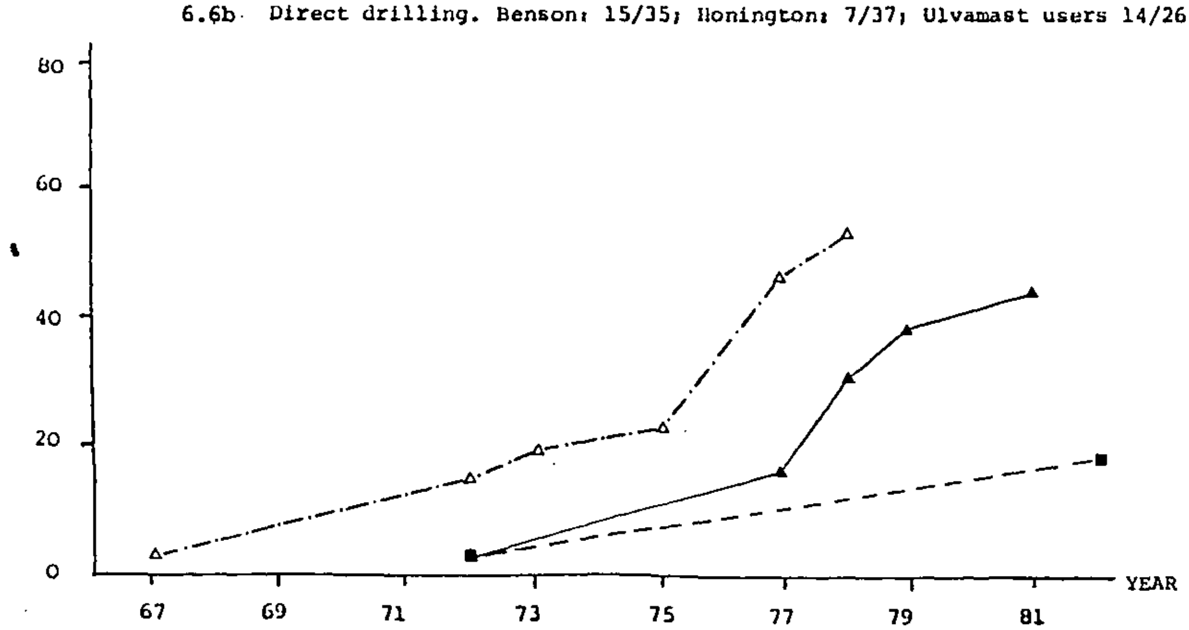
■- - - -■ Diffusion around RAF Honington

△–·—·–△ Diffusion among Ulvamast users

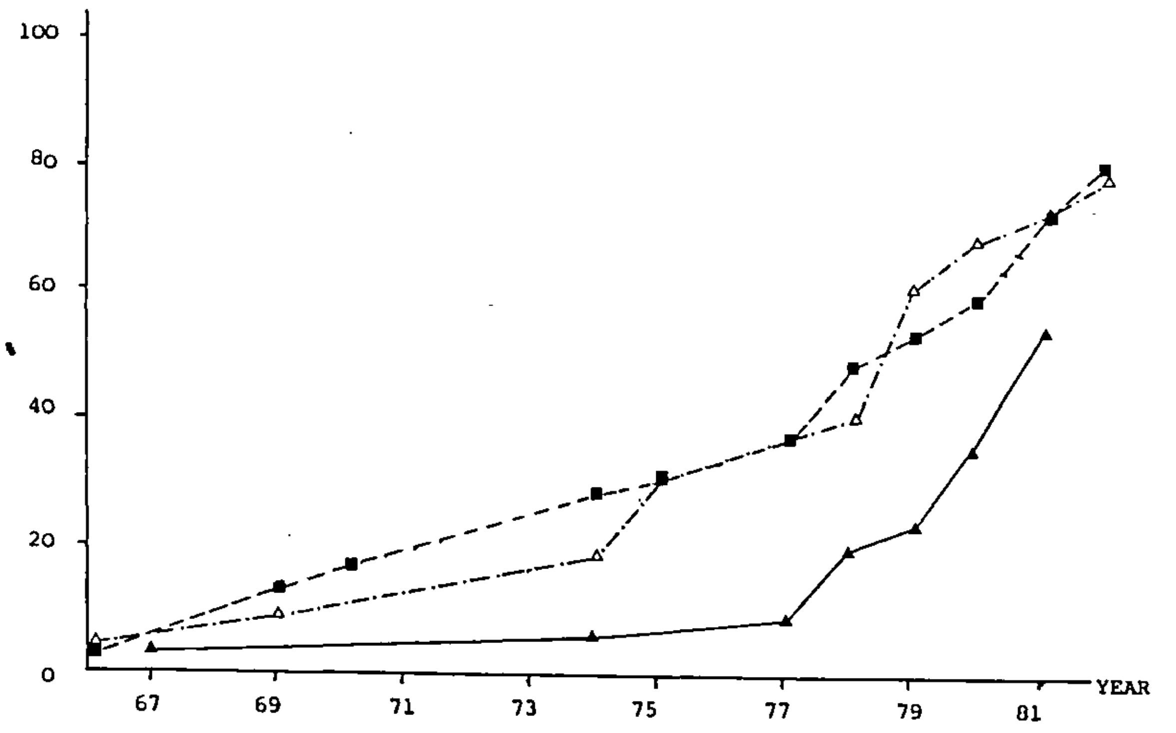
6.6 a. Graph of cumulative adoption of over 50% of total cereals area sown with winter cereals. For each group, numbers of adopters / number of applicable respondents: farmers around RAF Benson, 24/24; around RAF Honington, 27/30; in Ulvamast user survey, 18/18.



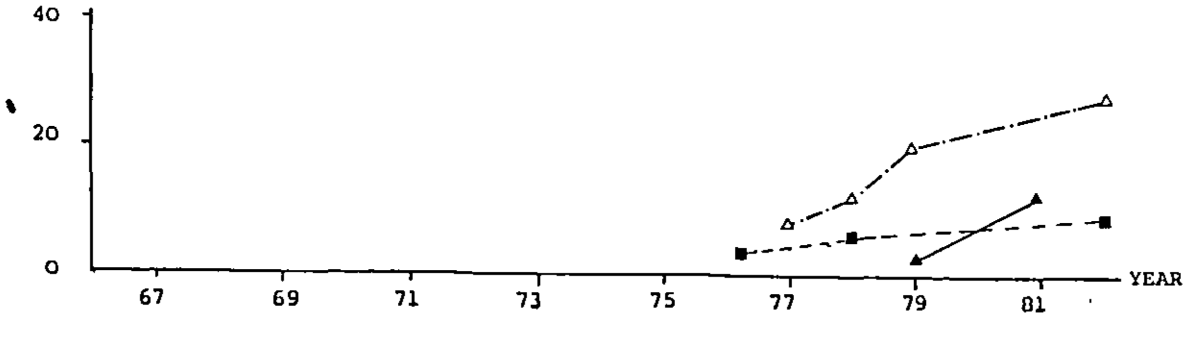
6.6b Direct drilling. Benson: 15/35; Honington: 7/37; Ulvamast users 14/26.



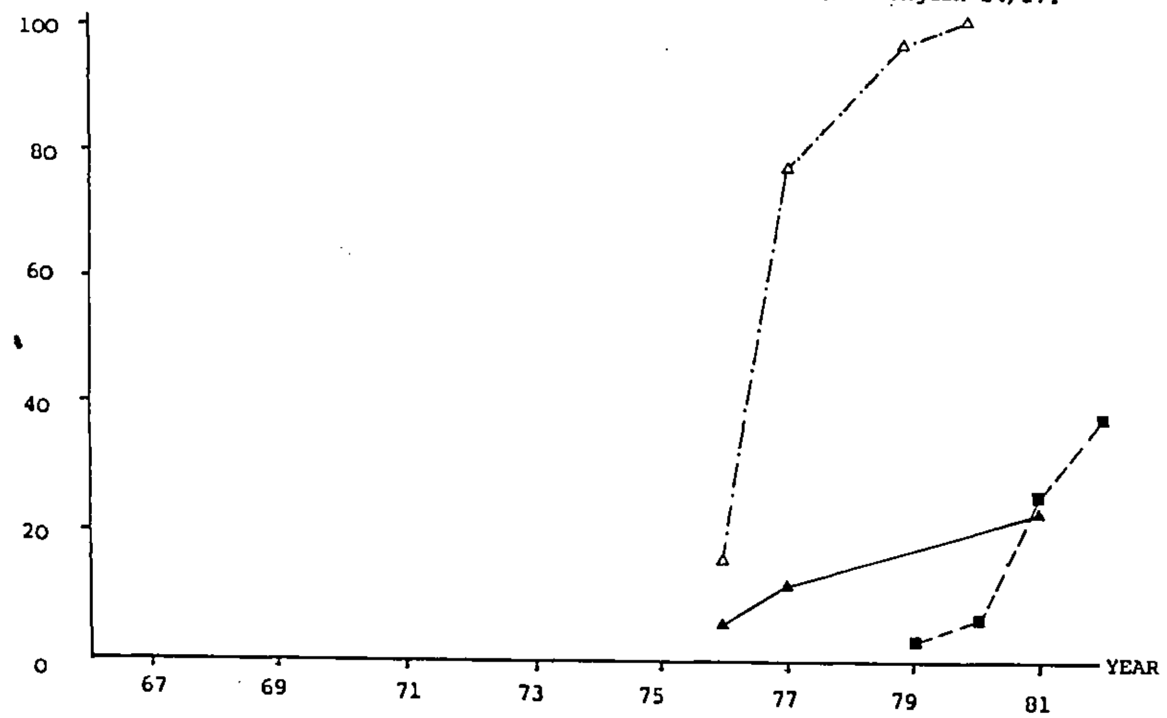
6.6c. Low ground-pressure techniques (LGPV's, double wheels, flotation tyres). Benson: 19/35; Honington: 28/35; Ulvamast users: 20/26.



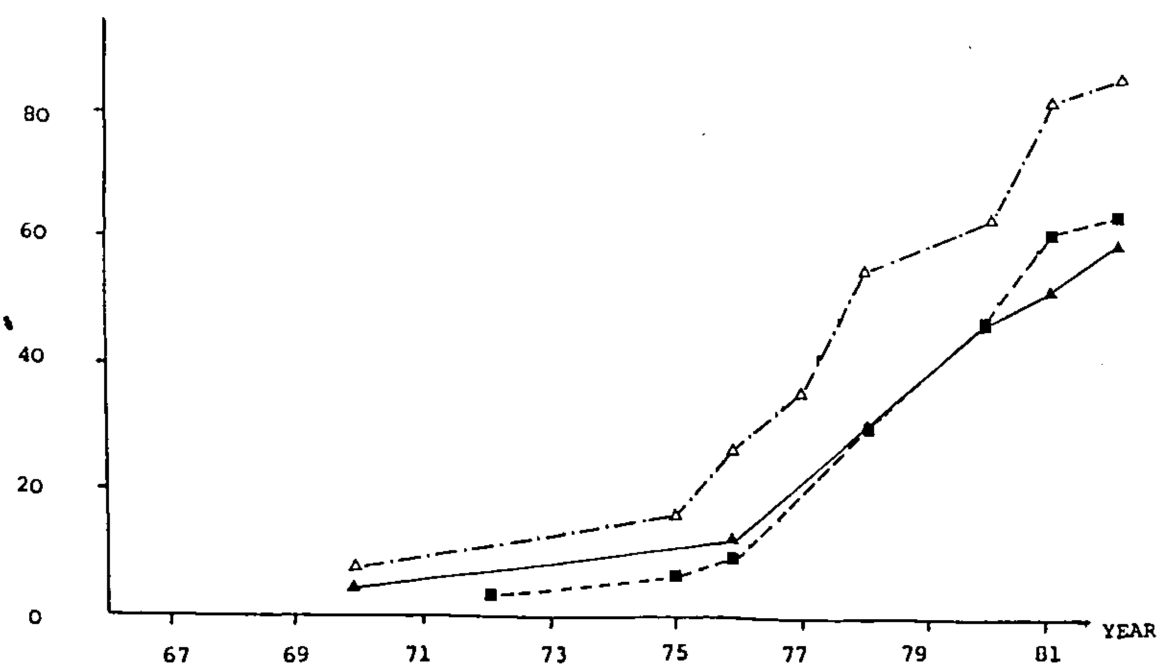
6.6d. Sprayer monitors and/or control systems. Benson: 4/36; Honington: 3/37; Ulvamast users: 7/26.



6.6e. Low-volume ground spraying practices (at or under 9 gallons/acre (100 l/ha) total volume applied). Benson: 8/36; Honington 14/37.



6.6f. Tramlines. Benson: 20/35; Honington: 22/36; Ulvamast users 20/24.



whilst Figures 6.6c and 6.6f show what may be partially complete S-curves. In Figure 6.6c the adoption of low volume spraying (itself a criterion for inclusion in the Ulvamast user survey) by respondents in the Ulvamast user survey (U) shows an approximate S-curve, whereas the B and H curves, and all curves in Figures 6.6d are too rudimentary to tell if adoption will follow an S-curve upto full adoption of the innovation. Figure 6.6b, that showing the diffusion of direct drilling, has curves that look less like S-curves than those in any other figure. In this case, discontinuance has been appreciable (see Table 6.3b), and a number of respondents offered strong reasons for rejecting the notion of using direct drilling methods, including the influence of neighbours who had discontinued using direct drilling techniques. Thus in the case of direct drilling a significant proportion of the population appear to be acting as disapprovers or rejectors. The influence of discontinuance on the numbers using an innovation may be seen from Table 6.17, for use of the Ulvamast among respondents in the Ulvamast users survey. However, in the case of the Ulvamast several respondents stopped using it only to take up horizontal boom -mounted spinning-disc sprayers (see Section 6.7.6); respondents stopped using the Ulvamast as a result of the introduction of a newer, more efficient product, discontinuing using the Ulvamast as a result of it's relative obselescence.

In comparing the diffusion of innovations among respondents in the Ulvamast user survey with those in the random user survey, Figure 6.6e should be disregarded, as adoption of this practice is embedded in adoption of the Ulvamast, which is a criterion for selection in the survey. Respondents in the Ulvamast user survey generally show up as being more innovative. Respondents in the two areas in the random user survey take up the innovation at approximately the same rate, except in the case of

TABLE 6.4 Summary of literature review on associations with innovativeness, made by Havens (1962), presented in Finley (1968).

Factor (as related to adoption)	No. of Studies	Direction of Association	Relationship	
			Significant (at 5% level)	Not Significant (or in wrong direction)
Size of operation	30	+	27	3
Education	25	+	24	1
Social status	21	+	21	0
Age	8	-	4	4
Contact with information	18	+	17	1
Social participation	13	+	11	4
Local group identification	9	-	6	4
Neighborhood norm on adoption	5	+	5	0
Opinion leadership	5	+	5	0
Management practices	4	+	4	0
Self-perception of innovativeness	3	+	2	1
Attitude toward credit	3	+	3	0
Interaction with other adopters	3	+	3	0
Reading farm bulletins & magazines	4	+	3	1

ground-pressure reducing techniques, where respondents grouped around RAF Honington seem to have adopted at an appreciably faster rate.

6.6 Innovativeness

6.6.1 Introduction

Innovativeness, or "the propensity to adopt new ideas and techniques earlier than one's fellows, has generally been the dependent variable in studies of the adoption of innovations" (von Fleckenstein, 1974). Studies summarising the relationships between innovativeness and personal and situational attributes include Havens (1962) and Pizam (1972). Table 6.4 summarises the findings of Havens (1962).

In this section, particular attention is paid to measuring innovativeness and farm and farmer attributes. In Section 6.6.13 the possibility of predicting future adoption behaviour is discussed. Section 6.6.14 outlines other measures of "orientations toward new technology". A discussion of the associations with innovativeness and other measures of technology orientation is given in Section 6.6.15.

6.6.2 Measuring innovativeness

Innovativeness indices, or scales, have often been used in an attempt to score the innovative behaviour of an adopting unit within a given social system (Jones, 1966b).

An index seeks to summarize a number of observations into a smaller number, or single scale value. Indices or scales must start from a concise conception of what is to be measured; the most important step is in the choice of the relevant indicators (Moser and Kalton, 1971). In sociological research, there are often problems in measurement; indices are "very crude instruments whose significance is often questionable, but which nevertheless (can be) often useful" (Mayntz, Holm and Hoebner, 1976).

Indices of innovativeness have been useful in past analyses of the adoption of innovations, provided that the caveats in constructing an index are borne in mind, results are analysed with an appropriate degree of caution, the index giving a reasonable indication of what is meant by "innovativeness".

Ideally, to construct an index of innovativeness, information is required on:

1) the quantity of a selected number of innovations that have been adopted.
2) The time at which the innovations were adopted.
3) The stage reached in the adoption process for each named innovation.

Due to difficulties that can be experienced in attempting to measure factor (3), it is rarely used in constructing innovativeness indices. In this study, only factors (1) and (2) will be used in compiling an index of innovativeness.

Rogers (1962) indicated four properties that innovativeness indices should show:

1) Validity, or the degree to which an index measures the desired dimension.
2) Reliability, or the degree to which an index measures the same dimension over time.
3) Internal consistency, or the degree to which a scale's items are inter-related.
4) Unidimensionality, or the degree to which a scale measures a single dimension, that of the behavioural characteristic of innovativeness.

With regard to the internal consistency of scales of innovativeness, the innovations used in constructing such an index should strike a balance between:

1) Mutually exclusive items. In an investigation of "restricted" innovativeness (e.g. innovativeness only with regard to arable crop machinery), then the items used in index construction should be a device or technique synonymous with new arable machinery. If one or more of the innovations selected have little or nothing to do with arable machinery, then the scale may not accurately represent the individual's innovativeness with respect to arable farm machinery.
2) Mutually inclusive items. Scales should avoid using innovations where one innovation used in constructing the scale may only be taken up with another innovation used in the scale: neither or both of the innovations will be adopted, never just one of them.
3) Mutually repulsive items. Where there are two innovations used in the scale that are very similar in function, then only one of the items would ever be justified on farms. Thus, only one, or neither of the innovations would be likely to be taken up : the adoption of one innovation substantially influences the likelihood of the adoption of another innovation on the scale, to the detriment of the measurement of innovativeness.

6.6.3 Innovations included in the index

The applicability of the innovations to the farming practices of the social system being sampled should be considered. If the uptake of new milking-parlour devices is among those under investigation, then it is clear that only farms with a dairy enterprise should be included in the population to be sampled from. In addition, if a farmer has a small herd of cattle, it may be out of the question for the farmer to rationally adopt the milking-parlour due to its cost and size. Thus, innovations chosen for inclusion in compiling an index of innovativeness should be applicable to as many farms as possible in the population.

In the random user survey, farms were pre-selected on the basis of cereals acreage and overall farm size - at least 20ha of cereals were being grown on a farm size of at least 28 ha. For details of sampling frame construction, see Section 3.3. The innovations used in constructing an index of innovativeness were: use of direct drilling, over 50% of cereal acreage down to winter cereals, use of ground-pressure reduction devices, use of tramlines, use of low-volume spraying, and the use of electronic sprayer monitor and/or control systems. The definitions of adoption for each practice are defined so that the use of any of the above innovations are applicable to all of the respondents in the random user survey who had sprayers on the farm, as shown in Table 6.5 . Consequently three farms in the random user survey were excluded from the analysis as there was no sprayer on the farm. Those respondents leasing or hiring sprayers - as opposed to owning them - were included, as it was felt that the innovations were also applicable to farmers under these circumstances. Seventy-three responses from the random user survey were used in compiling the index of innovativeness. Question 23 in the random user survey questionnaire seeks information on the time of adoption of innovations (see Appendix).

The number of innovations used in constructing an index should be sufficient to allow discrimination between different adopter categories, and to enable the objectives of the investigation to be carried out, which in this case is to carry out a study of innovativeness regarding a "restricted" range of innovations. In the random user survey, the innovations selected for the index are all associated with arable enterprises, all are directly or indirectly associated with arable machinery, and most are associated with cereal crop protection activities. Jones (1966b) states that the heterogeneity of a population is important in determining the number of innovations to use in constructing an index of innovativeness : the more homogeneous the characteristics of the population are, and the more restrictive the investigation is (with regard to the "type" of innovativeness under study, e.g. arable machinery innovations), the fewer the number of innovations that need to be used. Conversely, a "general" study of innovative behaviour among a highly varied population will mean that a higher number of innovations must be used in constructing an index.

Jones (1966b) suggests that for general investigations of innovativeness, 14 - 15 innovations are a satisfactory number in constructing an index. However, Jones goes on to state that "little agreement exists in the various research studies on the number of items which should be included if meaningful indexes of innovativeness are to be obtained". A survey of corn-growing and dairying Wisconsin farmers, reported by Presser (1969) used six innovations for the construction of innovativeness scales, whilst some investigations have used as few as three or four.

There are several justifications for using as few as six items to construct an index of innovativeness:

1) Universal agreement does not exist on the "correct" number to use.
2) If the survey is "restricted" in nature, e.g. arable innovations among arable farmers, and a relatively homogeneous social system population is being sampled from them the number of innovations need not be as high as in a "general" study of innovativeness, or if a highly variable population is being sampled from.

3) If the innovations being considered are themselves "categories", where each category includes different individual types of innovation, then a larger number of innovations are being asked about than is immediately apparent. Table 6.6 shows that each innovation category may contain more than one innovative device or technique. In order to avoid undue mutual repulsion effects (see Section 6.6.2) when assessing the uptake of innovations, it was decided to lump together individual innovations into the six innovation "categories".

4) It is possible for individuals to exhibit innovative behaviour for one cluster of innovations, yet be relatively less innovative for another cluster of innovations. Thus on a mixed farm, a farmer may quickly adopt innovations associated with stock enterprises, yet be fairly laggardly in taking up new arable devices. If both arable and stock innovations are included in the list to assess innovativeness, then a conflicting and contradictory value for innovativeness may be given. It is preferable in studies such as the one presented in this thesis to concentrate on a "restricted" range of innovations, where individual behaviour is likely to be consistent.

5) In a "restricted" study of this sort, the number of innovations suitable for inclusion are quite small.

The major factor favouring the use of more rather than less innovations is the method of collection of data. In this case, information is collected by talking to farmers. As opposed to written records, farmers may remember the date of adoption incorrectly, particularly if it happened some time ago. However, most of the innovations on the list were reported by respondents as being first taken up within the last decade, many being taken up in the last five years. In this case, asking for the year of adoption should not lead to an excessive number of errors.

Chapter Three of Sudman and Bradburn (1974) describes the effects of time on memory. Jones (1966b) suggests that the effect of misremembering dates can be minimised by: keeping the amount of recall down, using items which have been undergoing diffusion in a particular social system for a relatively short time, and trying to use items whose time of adoption is likely to remain highly significant in a farmers mind.

6.6.4 Defining adoption

In measuring innovativeness, it is important to define what is meant by "adoption". This is because the date at which a new device or practice was taken up is a very important factor in scoring an individual's innovativeness. Obviously, the earlier an individual adopts an innovation, the greater will be his innovative behaviour relative to the other members of the social system population under consideration. Definitions of adoption may be very flexible: "adoption may be defined as continued full-scale use since the first trial; increasing scale of use since first trial; trial, use and later discontinuance; or just trial alone. For new ideas, even intention to use is sometimes classified as adoption. There are differences in definition of adoption by researchers, and even between practices for the one researcher" (Presser, 1969). In stating what adoption is for each of the innovation categories (see Table 6.5), it is intended that the definitions of adoption show acceptance by the farmer of the use of an innovation on the farm. Thus in the definitions, it is not necessary to purchase a direct drill in order for the practice of direct drilling to be adopted on the farm; the use of contractors to direct drill a crop is sufficient evidence of acceptance by the farmer of the practice of direct drilling.

The definition of adoption for each innovation is set so that all respondents in the survey are considered to be of a sufficient size to merit adoption, or at least consideration, of all of the innovations.

6.6.5 Non-recommended innovations, and discontinuance of innovations

Innovations may be recommended, non-recommended or discouraged for use by various official and other authoritative bodies : not all new devices and techniques are necessarily "good", or suitable for use by all farmers. The status of an innovation regarding recommendations for its use may influence uptake by farmers : for instance, if ADAS chooses not to recommend an innovation, this may have a great influence on rate of adoption. In this case, non-adoption will not necessarily reflect a lack of innovativeness, but may demonstrate foresight and rationality. Sheppard (1961) examined reasons for the non-adoption of "controversial" innovations among U.K. grassland farmers. Most adoption studies implicitly assume that the innovation(s) under study are "beneficial" to the farmer, and it is rational to adopt them. Of the six categories of innovations in this study, it is assumed that it is rational for all respondents to adopt all of the innovations, bearing in mind the definitions of adoption given in Table 6.5.

The discontinuance of adopted innovations is not usually taken into account in constructing innovativeness scales, as it is the action of adoption of an item or practice that is important in constructing the scale. However, a high level of post-adoption rejection may imply that an innovation is unsuitable for use in a given area,or that it is being superceded by another new device or technique. A high level of discontinuance may alter the shape of the cumulative diffusion curve, due to the influence of those who have discontinued the innovation or those who have yet to take up the innovation.

6.6.6 Measuring and weighting innovativeness

In constructing indices or scales, data transformation of some

TABLE 6.5 Innovations covered in the investigation of innovativeness, and the definitions of their adoption.

INNOVATION CATEGORY	INDIVIDUAL INNOVATIONS IN THE CATEGORY	ADOPTION DEFINITION
Direct drilling	Direct drills	First year of hire, purchase, or use by contractors of direct-drill implements for any crop on the farm.
At least 50% of cereals planted to winter cereals	Various winter cereals	First year (planting) when at least 50% of cereal acreage planted to winter cereals.
Low ground-pressure techniques	Double wheels, flotation tyres, low ground-pressure vehicles	First year of hire, purchase, or use by contractors of: double wheels, flotation tyres, low ground-pressure vehicles (including "home-made" models).
Tramlines	Establishment in drilled crops by blocking coulters, or when carrying out subsequent field operations.	First year of use of tramlines in at least part of any cereal crop, established by blocking coulters at drilling, or by subsequent passes through field.
Low volume spraying	Ground spraying using spinning-disc sprayers or high-pressure/low-volume hydraulic systems.	First time that ground liquid spraying conducted at or under 100 ℓ/ha, or use of "spinning-disc" sprayers by farmer or contractor.
Electronic sprayer monitors	Electronic control, monitoring or regulating systems.	First use by farmer of electronic aids to spraying accuracy. May be purchased with sprayer or bought as an accessory. Category includes monitoring and electroni control devices.

kind is unavoidable. When using "time" and "quantity" criteria in assessing innovativeness, most indices weight innovations equally, greater weighting being given when adoption occurs relatively earlier. Such an index is used in this study. Categorization of the time of uptake of an innovation may occur into quartiles, quintiles, etc., or into standard deviations around the mean time of uptake. In an index, as many relevant factors as possible should be taken into account, e.g. recent immigration of potential adopters, applicability of innovations to the farm community, etc., whilst minimising the number of data transformations. Care should be taken to prevent ascribing interval-type properties to ordinal-level information, e.g. assuming that the "distance" between having adopted 4 and 3 innovations can be directly compared with the distance between 3 and 2 innovations. The nature of the weighting processes used are generally arbitrary, but it is hoped that the weighting reflects the degree of endeavour required to adopt an innovation(s) relatively earlier than other farmers.

6.6.7 Characteristics of innovations under study.

Table 6.6 presents various attributes of the innovation types whose time of adoption is used in compiling the innovativeness index. From Section 6.4, several perceived attributes of innovations have been shown to be important in influencing adoption rates, such as cost, complexity, conspicuity, congruity, compatibility and divisibility of an innovation. As these factors may influence innovative behaviour, they should be taken into account when constructing an innovativeness index. Due to difficulties in weighting each innovation according to their various attributes, in this study each innovation will be treated equally.

TABLE 6.6. Attributes of innovations used in constructing an index of innovativeness.

ITEM	YEAR OF FIRST USE IN SAMPLE	COST OF ADOPTION	REASONS FOR NON-ADOPTION IN PROFIT-MAXIMISING SYSTEMS	REMARKS
Direct Drilling	1972	High if purchased	Unsuitable soils	In early stages adoption involves reappraisal of the value of 'traditional' techniques. Many crops can be direct-drilled; service is available from contractors. Alternatives to direct drilling include reduced tillage techniques.
Over 50% of cereal area in winter varieties	"Always" among some farmers	Variable, depending on machinery investment	Cropping constraints	Availability of potent and selective herbicides has reduced rotational requirements. The selected figure of 50% is an arbitrary one.
Ground-pressure reducing techniques	1966 for double wheels 1978 for LGPV's	Medium to high, depending on method adopted	Very light soils	LGPVs may be home-made, used by contractors, or purchased. A means of reducing tractor ground pressure is to partly deflate tyres, or use bald tyres. Caged wheels may also reduce ground pressure.
Tramlines	1970	Variable, depending on machinery investment neccessary		Requires a drill allowing coulters to be blocked, and field cultivation equipment of a standardised width.
Low-volume spraying on arable crops	1976	Low-high, depending on method adopted		Encompasses several different techniques, e.g. hydraulic pressure spraying, drift spraying, other CDA spraying methods.
Electron c sprayer monitoring and/or control systems	1976	Low-medium, depending on sophistication		May be standard on very large, or self-propelled sprayers.

6.6.8 Spatial effects influencing innovativeness

Spatial effects are areal influences on the homogeneity of the population under study. In the random user survey, samples of farmers were taken in two English cereal growing areas. The population to be sampled is defined in terms of cereal enterprise size, and farm size. These prerequisites go some way to defining the social system being interviewed in. In constructing the innovativeness scale, and assessing the innovativeness score for each individual, information on farmers from the two areas is aggregated. This action is justified on the grounds that the social system from which each of the two samples were taken is roughly contiguous. This point of view may be reinforced by comparing the characteristics of farms and farmers from each of the two areas sampled in - see Section 6.6.9.

Some spatial effects may arise from communications and situational factors varying between the two areas surveyed in. For instance, initial awareness of the innovations under study, and differential sales and marketing efforts of companies in the two areas may lead to differences in adoption rates in the two areas. However, these effects are likely to be insignificant, as the two areas surveyed are both major cereal growing areas, and the flow of information on innovations and promotional efforts associated with innovations are likely to be roughly similar in the two areas.

Spatial effects may arise due to variations between the two areas in situational factors, e.g. farm area, soil type, crops grown, and the weather. Farm area can influence adoption, as it is closely associated with income, the two of which are important determinants of innovativeness.

Soil type may influence the applicability of the innovations to the farmer; for instance, direct drilling is not as effective on certain soil types. From a map published by Cannell et al, (1978) it appears that most farmers in the survey are on soil types where similar yields of winter cereals may be expected with good management. Even among the farmers who appear to be on soils classified as having "a substantial risk of lower yield compared with conventional cultivation", a number have tried direct drilling. There is a need to adopt ground-pressure reducing techniques on most, if not all, soil types, since most reach field capacity at some time during the year.

The crops grown in an area may influence the uptake of certain innovations. For instance, several reduced-volume spray "packages" are marketed for use on sugar beet. These promote not only the chemicals, but also fine-orifice nozzles permitting spraying with volumes as low as 80 ℓ/ha. As sugar beet growing is confined to one of the two areas surveyed, this may influence the adoption of low-volume spraying techniques (under 100 ℓ/ha).

6.6.9 Characteristics of farmers in East Anglia and Oxfordshire.

The purpose of this section is to investigate the characteristics of farmers interviewed in the random user survey in East Anglia (around Honington weather station) and Oxfordshire (around Benson weather station). If farm and farmer characteristics are roughly similar in each area, then it supports the assertion that the farmers sampled in both areas are in a contiguous social system, and thus data on innovative behaviour and other attributes may be aggregated to draw inferences for the population at large.

Information on farm sizes, crops grown, chemicals applied and spray machinery on farms in each of the two regions are presented in Chapter Four. These features do not seem to be very different between the two areas.

The experience of respondents in each of the two areas is virtually identical; the mean number of years experience among sampled farmers in Oxfordshire is 20.7 years, whilst for East Anglia it is 20.8 years. The age structure of the two samples are also very similar, the modal age category for Oxfordshire farmers being 40 - 50, and that for East Anglian farmers being jointly 30 - 40 and 40 - 50 years.

For educational characteristics, thirty-six percent of Oxfordshire farmers had formal qualifications in agriculture, the figure for East Anglian farmers being forty-one percent. Thirty-nine percent of Oxfordshire farmers (or their sprayer operators) had attended courses on crop sprayers or spraying, whilst forty-one percent of East Anglian farmers had done so.

Sixty-four percent of respondents in Oxfordshire owned at least part of their farm, whilst seventy-eight percent of farmers in East Anglia did so.

The impression gained from the above results is that the characteristics of the farmers in the two areas are roughly similar, and that respondents from the two areas are members of very similar, if not the same social system. Patterns of uptake of innovations are roughly similar for both areas (Figures 6.6a to 6.6f).

From the evidence presented in this section, it appears that respondents from the two areas in the random user survey are part of a contiguous social system, and accordingly the innovative behaviour of respondents may be grouped together for analysis, as shown in Section 6.6.11.

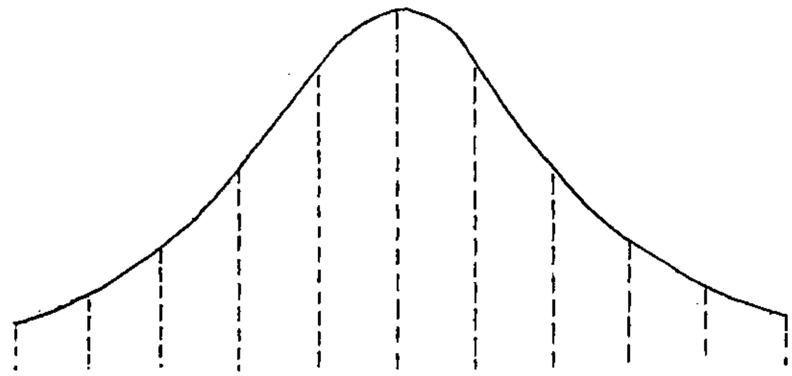
6.6.10. Sten scores

Sten scoring is the method used in evaluating an individual's innovativeness. A sten score requires the property upon which it is to be used to have a normal, or near-normal distribution. "The 'sten score' is based on the division of any frequency distribution, such as the number of farmers adopting a given practice in each year, into ten units, the proportion in each unit being equal to that contained in the corresponding segment of a normal curve which has been partitioned into five equal divisions on each side of the mean" (Jones, 1966b). The areas under the normal curve in each category vary as shown in Figure 6.7. The stem value is an arbitrary method of scoring the relative position of a value on the normal distribution curve. If the sten value is being used to score the relative earliness of an adopter, then one of the very first persons to adopt an innovation will achieve a high sten score, later adopters scoring less.

6.6.11. Method of measuring innovativeness

The various methods of measuring innovativeness have been reviewed by Jones (1966b) and Presser (1969). One of the main problems in constructing a scale of innovativeness is that of recent entrants to farming (in particular, starting farming after the introduction of one, or more than one of the innovations), and farmers who have left the area or died in the last few years. Fairly little can be done in respect of the farmers who have left farming, but Jones (1966b) suggests a method to compensate for the recent entry of farmers. Table 6.2 shows the year of

FIGURE 6.7. Sten scoring system for a normally-distributed property.



% under curve	2.3	4.4	9.2	14.9	19.2	19.2	14.9	9.2	4.4	2.3
Cumulative %	2.3	6.7	15.9	30.8	50	69.2	84.1	93.3	97.7	100
Sten score	9	8	7	6	5	4	3	2	1	0

entry into farming of the 73 respondents in the random user survey whose uptake of innovations is analysed in this chapter.

Jones' suggested system is called "double sten scoring". Sten scores are given for two values associated with adoption of innovations. Firstly, a sten score is given for each innovation for each individual based upon their relative earliness of adoption of that innovation (the "date" of adoption).

As can be seen from Table 6.2, an appreciable number of respondents in the survey commenced farming after the introduction of at least one innovation. Even if these new entrants are highly innovative individuals, their innovativeness, as measured by their earliness of adoption of innovations relative to others in the sample, will be depressed. Therefore, a way should be found of "not penalizing late adopters who are late simply due to the fact that they had not started farming until the diffusion of an innovation was relatively advanced" (Jones, 1966b). The second sten score is an attempt to correct for this factor, known as the "age" sten score. The "age" of adoption requires the difference (in years) between the year in which the practice was adopted, and the year in which it first became available <u>or</u> the year when the respondent took over the management of the farm at which they were interviewed, whichever is the later. The "age" of adoption relies on a total number of years spent managing a farm rather than the number of years spent managing the present farm alone.

Innovations on the farm predating the entry of the respondent into farming are discounted, and the innovation is assessed as being not applicable to the respondent, as the innovation is not brought on to the farm as the result of a decision by the respondent.

For each innovation applicable to a respondent, their "age and "adoption" sten scores are calculated. The sten values given indicate an earliness of adoption relative to the times of adoption by other respondents in the sample, there being no reference to any outside yardsticks of adoption. This is a major advantage of the technique, in that it does not need to rely on predictive techniques (Jones, 1966b). However, if results are to be extrapolated, the sample must be a representative one from the social system under study.

The index of innovativeness is a summation of the scores obtained by each farmer for the practices which are applicable to him, divided by the number of practices (Jones, 1966b):

$$\text{Index of Innovativeness} = \sum \frac{(\text{"Date" Sten Score}) \times (\text{"Age" Sten Score})}{\text{Number of Applicable Practices}}$$

The index, and the scores for each individual practice, may vary from zero to 81.

Tables 6.7 and 6.8 show the sten scores given for the "date" of adoption, and "age"of adoption, respectively. These tables are used to calculate the innovativeness score for each individual.

This method has been used for assessing innovativeness for several reasons: the process does not need any figures external to those collected from the sample: the method is internally valid. Relatively few data transformations are carried out, and reasonable assumptions are made as to the nature of the data, e.g. that the relative adoption curves are normal, or nearly normal in nature. Furthermore, this method has been used in studies of innovativeness (Howell, 1968).

TABLE 6.7. "Date" of adoption sten scores for six arable innovations. Within each innovation category, there are three columns: the left-hand shows the cumulative number of respondents adopting the practice; the centre column shows the cumulative adopters as a percentage of the sample to which the innovation is applicable; the right-hand column shows the sten score associated with the percentage value. The figure excludes cases where the innovation predates the entry of the respondent into farming.

INNOVATION	DIRECT DRILLING			OVER 50% WINTER CEREALS			LOW-GROUND PRESSURE TECHNIQUES			TRAMLINES			LOW-VOLUME SPRAYING			SPRAYER MONITORS		
NO. OF RESPONDENTS TO WHOM THE INNOVATION IS APPLICABLE.	72			57			70			71			73			73		
"DATE" OF ADOPTION																		
TO END 1966				1	1.7	9	1	1.4	9									
67				3	5.3	8	3	4.3	8									
68				3	5.3	8	3	4.3	8									
69				7	12.3	7	3	4.3	8									
70				8	14.0	7	7	10.0	7	1	1.4	9						
71				11	19.3	6	7	10.0	7	1	1.4	9						
72	2	2.8	8	11	19.3	6	9	12.9	7	2	2.8	8						
73	3	4.2	8	12	21.0	6	9	12.9	7	2	2.8	8						
74	5	6.9	7	20	35.1	5	12	17.1	6	2	2.8	8						
75	7	9.7	7	25	43.8	5	13	18.6	6	3	4.2	8						
76	9	12.5	7	29	50.9	4	13	18.6	6	7	9.9	7	2	2.7	8	1	1.4	9
77	10	13.9	7	36	63.2	4	16	22.9	6	13	18.3	6	4	5.5	8	1	1.4	9
78	15	20.8	6	41	71.9	3	24	34.3	5	18	25.3	6	4	5.5	8	2	2.7	8
79	18	25.0	6	48	84.2	2	27	38.6	5	25	35.2	5	7	9.6	7	3	4.1	8
80	20	27.8	6	52	91.2	2	34	48.6	5	28	39.4	5	8	11.0	7	3	4.1	8
81	21	29.2	6	54	94.7	1	45	64.3	4	38	53.5	4	17	23.3	6	6	8.2	7
TO MAR 82	22	30.6	6	54	94.7	1	47	67.1	4	42	59.1	4	22	30.1	6	7	9.6	7

TABLE 6.8. "Age" of adoption sten scores for six arable innovations. Within each innovation category there are three columns: the left-hand column shows the cumulative number of respondents adopting each practice, the middle column shows the cumulative adopters as a percentage of the sample to whom the innovation is applicable, and the right-hand column shows the sten score associated with the percentage value. The figures exclude instances where the innovation predates the entry of the respondent into farming.

INNOVATION	DIRECT DRILLING			OVER 50% WINTER CEREALS			LOW-GROUND PRESSURE TECHNIQUES			TRAMLINES			LOW-VOLUME SPRAYING			SPRAYER MONITORS		
FIRST YEAR OF USE BY RESPONDENTS	1972			1966			1966			1970			1976			1976		
NO. OF RESPONDENTS TO WHOM THE INNOVATION IS APPLICABLE.	72			57			70			71			73			73		
"AGE" OF ADOPTION																		
0	2	2.8	8	3	5.3	8	1	1.4	9	3	4.2	8	3	4.1	8	1	1.4	9
1	4	5.6	8	6	10.5	7	3	4.3	8	4	5.6	8	5	6.8	7	1	1.4	9
2	6	8.3	7	7	12.3	7	6	8.6	7	5	7.0	7	5	6.8	7	2	2.7	8
3	8	11.1	7	13	22.8	6	8	11.4	7	5	7.0	7	9	12.3	7	3	4.1	8
4	10	13.9	7	16	28.1	6	12	17.1	6	8	11.3	7	10	13.7	7	3	4.1	8
5	11	15.3	7	19	33.3	5	13	18.6	6	10	14.1	7	17	23.3	6	6	8.2	7
6	15	20.8	6	21	36.8	5	16	22.9	6	12	16.9	6	22	30.1	6	7	9.6	7
7	18	25.0	6	23	40.3	5	18	25.7	6	19	26.8	6						
8	20	27.8	6	32	56.1	4	20	28.6	6	25	35.2	5						
9	21	29.2	6	35	61.4	4	20	28.6	6	31	43.7	5						
10	22	30.6	6	37	64.9	4	21	30.0	6	33	46.5	5						
11				41	71.9	3	25	35.7	5	40	56.3	4						
12				45	78.9	3	31	44.3	5	42	59.1	4						
13				50	87.7	2	34	48.6	5									
14				53	93.0	2	42	60.0	4									
15				54	94.7	1	46	65.7	4									
16							47	67.1	4									

The actual innovativeness "scores" range from 0 to 47. A score higher than this was not achieved, as no farmers were old and experienced, yet innovative enough to be one of the first to take up the innovations. The scores do not have the quality of interval-level data; the analysis of innovativeness index data relies on grouping the scores into four groups, corresponding to rankings from low innovativeness scores, through to high innovativeness scores. Since past research has found that a small number of farmers tend to be the most innovative, with the bulk of farmers being in the middle, it was decided to split the scores into four groups, 'tailed' at the top and bottom of the range. Thus, the percentages in each category were 20:30:30:20. In other words, the top 20% of scores go into the first category, the next 30% into the second category and so on. Tests of the innovativeness categories are made to locate correlations between personal and situational characteristics of respondents, and their innovativeness, as indicated by which ordinal rank of innovativeness each respondent is in. These results are reported in Section 6.6.12.

6.6.12. Factors correlated with innovativeness.

As stated in Section 6.6.11, results from an evaluation of respondents innovativeness are used to form four categories of innovativeness, in categories where the number of respondents in the lowest and highest innovativeness categories are reduced, (so as to reflect the special status of farmers scoring in these categories) so that the percentage of scores in each category are 20:30:30:20.

Tests of association with innovativeness are made with respondents' personal and situational characteristics. The "quality" of information of such attributes may be divided into three groups: nominal, ordinal and interval-level information.

The level of measurement of a variable has an important influence on the statistics that can be used on it. In this section, innovativeness is an ordinal level variable. In examining the association of innovativeness with interval- and ratio- level variables, parametric F-tests are used, as in one-way analyses of variance. With ordinal-level variables, correlations with innovativeness may be investigated using Spearman or Kendall rank correlation coefficients. With nominal-level variables, the Contingency Coefficient may be used. Details of the parametric statistics used may be obtained from Nie *et al* (1975), and of the non-parametric statistics from Siegel (1956). Statistical values were computed mainly by using the SPSS package (Nie *et al*, 1975), options ONEWAY (analyses of variance), NONPAR CORR (Spearman correlation coefficients) and CROSSTABS (Contingency coefficients).

Table 6.9 gives the degree of correlation between several farm characteristics and two measures of innovativeness : categories of innovativeness based on division of innovativeness scores into 20:30:30:20 ranks.

The fact that certain variables are found to be correlated with innovativeness may be used in predicting future behaviour patterns as regards the adoption of innovations. This is discussed further in Section 6.6.13.

6.6.13 Predicting adoption.

A number of physical, economic and sociocultural factors shape an individual's adoption behaviour (Moulik *et al*, 1966). A manifestation of adoption behaviour is the innovativeness of an individual. A review of factors found to be correlated with innovativeness are given in Table 6.4 , and factors found in the random user survey to correlate

TABLE 6.9 a. Correlations of farm and farmer characteristics (interval-level) with innovativeness categories. Results are based on the significance of F-values between groups in one-way analyses of variance.

*** = $p \leqslant 0.001$

** = $p \leqslant 0.01$ — - = negative association

* = $p \leqslant 0.05$ — + = positive association

n.s. = $p \gtrsim 0.10$

Feature		Association with "tailed" innovativeness ranking.
1982	Cereal area	+ ***
1982	Arable area	+ ***
1982	Total area	+ ***
1980/81	Cereal spray hectares	+ ***
1980/81	Total spray hectares	+ ***
1980/81	Cereal spray rounds	+ ***
1980/81	Total spray rounds	+ ***
1982	Number of crops	n.s.
1982	Sprayer density (see 4.4.3)	n.s.
	% area under arable 1982	n.s.
Years experience in farming (1982)		n.s.

TABLE 6.9 b. Correlations of ordinal-level measures of farmer characteristics with innovativeness categories. Results are based on the significance of Spearman correlation coefficients.

Feature	Association with "tailed" innovativeness ranking
Age category	- p = 0.07
Attendance on spraying courses	+ ***
Qualifications in agriculture	+ *
AGREEMENT WITH STATEMENTS	
"Successful farmers are generally among the first to take up a new practice"	- n.s.
"Neighbours often come to me for information and advice"	+ ***
"Being on the lookout for new ideas helps me recognise problems on my farm"	+ n.s.
"Neighbours experiences of a new item are important in helping me decide or not to buy that new item"	- p = 0.099
"Profit maximising is the main aim in farming"	+ n.s.
"I am usually among the first in my district to take up a new idea or practice"	+ ***
"Over the past few years, I have been satisfied by the performance of my spray year"	- *

TABLE 6. 9 c. Tests of association between nominal level farmer characteristics with ranked innovativeness categories. Results are based on the significance of the Contingency Coefficient.

Feature		Association with "tailed" innovativeness ranking
Tenurial status	Owner Non-owner	n.s.
Region farmed in	around RAF Benson around RAF Honington	n.s.

with innovativeness are given in Section 6.6.12.

Prediction, or the foretelling of future events, requires a consideration of past events relevant to the nature of the prediction study. In the case of adoption behaviour, a dependent variable, innovativeness, is the subject of the prediction study. Since in this instance it is the future behaviour of individuals that is being examined, then the independent variables used to foretell future behaviour are those concerning an individual's personal, situational and psychological characteristics, e.g. those tested in Section 6.6.12. The aim of prediction studies is to locate a number of independent variables that correlate with the dependent variable of innovativeness in order to explain as much of the variance in adoption behaviour as possible. Prediction studies are generally empirical in nature, seeking to find associations between variables, rather than examining causal links.

There have been two main approaches to the analysis of data in prediction studies. Stuckert (1957) outlined a configurational approach to prediction, where a sample of respondents is divided into relatively homogeneous subsamples, on the basis of each of several independent variables. The variables used in successive breakdowns are those which are best at accounting for previous adoption actions. Slightly different approaches have been used by Rogers and Havens (1962), and Finley (1968).

The goal of multiple correlation approaches to prediction is to explain a maximum of the variation in the dependent variable (innovativeness), and finding the relative contribution of each independent variable in explaining the dependent variable. Finley (1968) stated that the configurational approach to prediction is more accurate and efficient than such methods as multiple linear regression, as it made fewer advance assumptions on data quality. Another advantage of the configurational approach is that it only requires ordinal-level data, whereas the multiple-correlation method requires interval-level data.

Finley (1968) emphasised the importance of validating methods used to predict adoption by using data that was not used when constructing the method of prediction: "there is no prediction by an instrument until it has been applied to cases other than the ones from which it has been constructed, or to the same cases at a different point in time".

No prediction analysis has been carried out using data from the random user survey, but a brief discussion of the associations between measures of innovativeness and independent variables is given in Section 6.6.15.

6.6.14. Other measures of adoption behaviour

Correlations of innovativeness with farm and farmer characteristics are presented in Section 6.6.12. In addition to innovativeness as a measure of "orientations toward new technology", this section presents two further measures of this dimension.

In the random user survey, questions were asked whether respondents had heard of "spinning-disc" sprayers, and electrostatic sprayers (questions 24 and 25 - see Appendix). Of the 73 respondents included in the innovativeness study, 7 claimed not to have heard of either type of sprayer; 24 respondents stated they had heard of spinning disc sprayers, but not of electrostatic sprayers, and 42 respondents had heard of both types of sprayer. These three categories of answer were then used as categories for an ordinal-level scale of awareness of new types of crop spraying technology.

Questions 24 to 24c in the survey questionnaire were concerned with the "stage of adoption" reached with field-size spinning-disc sprayers. Of the 73 respondents included in the innovativeness study, seven claimed to be unaware of spinning-disc sprayers; 38 respondents were aware of spinning-disc sprayers, but had not considered using them; 23 respondents had considered using them, but had not used them on their farm at the time of interview, and 5 respondents had used a spinning-disc sprayer on their farm. These four categories were used in an ordinal-level measurement for the stage of adoption that had been reached of spinning-disc sprayers. It can be argued that smaller farmers may not wish to consider using spinning-disc sprayers on the grounds that they are too expensive; however, since one user of spinning-disc sprayers farmed only 47ha, it was felt that the use of spinning-disc sprayers was applicable to all farmers in the survey.

Correlations of farm and farmer characteristics with (the ordinal measures of) new spraying technology awareness and stage reached in the adoption of spinning-disc sprayers are given in Tables 6.10a, 6.10b and 6.10c.

In interpreting results from Tables 6.10a, 6.10b and 6.10c, a note of caution should be added regarding a priori and a posteriori comparisons. An a priori comparison is planned, designed and chosen independently of experimental results, and before the experiment has been carried out. In contrast, tests carried out as a result of previous statistical analyses (such as analyses of variance) are termed a posteriori comparisons. Such comparisons suggest themselves as a result of the completed experiment, and are performed only if "preliminary" analyses of variance

TABLE 6.10a. Correlations of farm and farmer characteristics (interval-level) with awareness and adoption of new spraying technology. Results are based on the significance of F-values from analyses of variance.

*** = $p < 0.001$ - = negative correlation

** = $p < 0.01$ + = negative correlation

* = $p < 0.05$

n.s. = $p > 0.10$

Feature	STAGE of adoption of spinning-disc sprayers	AWARENESS of new crop spraying technology
1982 Cereal area	+ p = 0.09	+ **
1982 Arable area	n.s.	n.s.
1982 Total area	+ p = 0.08	+ *
1980/81 Cereal spray hectares	+ *	+ *
1980/81 Total spray hectares	+ *	+ **
1980/81 Cereal spray rounds	+ **	+ ***
1980/81 Total spray rounds	+ *	+ ***
1982 Number of crops	n.s.	n.s.
1982 "Sprayer density" (see Chapter Four)	n.s.	n.s.
% area under arable 1982	n.s.	n.s.
Years experience in farming (1982)	- **	- ***

TABLE 6.10b. Correlations of farmer characteristics (ordinal-level) with awareness and adoption of new spraying technology. Results are based on the significance of Spearman correlation coefficients.

Feature	STAGE of adoption of spinning-disc sprayers	AWARENESS of crop spraying technology
Age category	- **	- ***
Attendance on spraying courses	+ **	+ ***
Qualifications in agriculture	+ *	+ ***
AGREEMENT WITH STATEMENTS:		
"Successful farmers are generally among the first to take up a new practice"	+ n.s.	- n.s.
"Neighbours often come to me for information and advice"	+ p = 0.080	+ *
"Being on the lookout for new ideas helps me recognise problems on my farm".	+ n.s.	+ n.s.
"Neighbours' experiences of a new item are important in helping me decide whether or not to buy that new item".	- n.s.	- n.s.
"Profit maximizing is the main aim in farming".	+ n.s.	- n.s.
"I am usually among the first in my district to take up a new idea or practice".	+ n.s.	+ p = 0.057
"Over the past few years, I have been satisfied by the performance of my spray gear".	- p = 0.066	- ***

TABLE 6.10c. Tests of association between nominal-level farmer characteristics with ranks measuring stage of adoption and awareness of new crop sprayers.
Results are based on the significance of the Contingency Coefficient.

<u>Feature</u>		Association with STAGE of adoption of spinning-disc sprayers	Association with AWARENESS of new crop spraying technology
Status	Owner Non-owner	n.s.	n.s.
Region farmed in	around RAF Benson around RAF Honington	n.s.	n.s.

are significant (Sokal and Rohlf, 1969). If the latter is the case, formal *a posteriori* tests are necessary. Several tests are available, and are described in Sokal and Rohlf (1969) and Nie *et al* (1975).

In the case of the analyses of variance carried out and reported in Tables 6.9a and 6.10a, such analyses were planned in advance of the analysis and therefore formal *a posteriori* testing is not considered necessary.

6.6.15 Discussion

Measures of area and area sprayed are very highly positively correlated with innovativeness. Interestingly, the number of spray rounds are also highly correlated with innovativeness rankings. Perhaps counter-intuitively, experience in farming was not found to be significantly associated with innovativeness, but there was some evidence for a negative association of age with innovativeness. Educational characteristics were found to be positively correlated with innovativeness.

In using simple tests of association, it must be emphasised that causal inferences cannot be drawn: for instance, does a large farm size lead to greater innovative behaviour, or has innovative behaviour led to the formation of larger farms? Although empirical approaches may not allow causality to be established, such an approach is useful in prediction studies, (see Section 6.6.13) and for 'change agents' to identify the likely early adopters of innovations. Indeed, causal links may be guessed at, using commonsense and previous experience. Simple methods for indicating causal links are described in Rosenberg (1968), whilst statistical techniques for establishing causality are described in Nie *et al* (1975).

With the attitude statements, a strong positive association is found with innovativeness on the statements dealing with self-assessment of innovativeness, and the extent to which the respondent is contacted by other farmers for advice. Satisfaction with current spray gear is found to be negatively correlated with innovativeness.

Two measures of orientation towards new technology were compiled and are described in Section 6.6.14. There are several differences from the patterns of association observed with innovativeness ranks. Firstly, stage of adoption of spinning-disc sprayers and level of awareness of new crop spraying technology are not associated with arable area. Secondly, unlike innovativeness ranks, there is a strong negative correlation between the ranked measures of orientation toward new spraying technology and years experience in farming. In addition, there was not a very great association between self-rating of innovativeness and awareness of new crop spraying technology.

6.7 A Case Study in Adoption and Diffusion : the Ulvamast

6.7.1 Introduction

The Ulvamast is manufactured by CDA Ltd., at Lockinge, near Wantage, Oxon. In the latest production model, a single set of stacked spinning discs is mounted on an adjustable vertical boom, with a 250 ℓ tank. Information on the use of Ulvamasts has been obtained from a survey of 26 sometime Ulvamast users. Details of the main objectives and the methods used in the Ulvamast user survey are outlined in Section 3.3.13. In addition information on sales was obtained from CDA Ltd., as well as with an interview with the proprieter of CDA Ltd.

6.7.2 The Ulvamast

The Ulvamast method of spraying chemicals was first conceived in

1975 when Mr. John Haigh read an article on Micron Sprayers Ltd., and the range of hand-held spinning-disc sprayers that were sold by them. He first used a Micron spinning-disc head for applying insecticides on cattle. Following an attack of cereal aphids in 1976, the possibility of applying insecticides to crops was considered, and early work was carried out using hand-held spinning-disc sprayers. Subsequently, several Ulva rotary atomisers were lashed to the back of a tractor and fed with liquid from a makeshift tank. It was possible to spray up to 600 acres in a day. From the activities of this prototype on the Lockinge farm, several neighbouring farmers came to Haigh, interested to know what he was doing. Subsequently, the first working Ulvamast was made in April 1977, consisting of a small tank, and a frame with six single spinning discs on it. Five were supplied in early 1977 to local farms, and news of their use spread by word of mouth.

The main working principle of the Ulvamast is that it drifts chemicals through crops, producing droplets mainly in the size range 75 - 100 μ. Because droplets are produced by a spinning disc, the droplet size is fairly uniform. However, the nmd of droplets is much smaller than those produced by most hydraulic-pressure sprayers, and neither the Pesticides Safety Precautions Scheme nor the Agricultural Chemicals Advisory Service recommend the use of any chemicals applied by tractor-mounted controlled-droplet applicators where the droplet range lies outside 200 - 300 μm. However, the MAFF Advisory Committee on Pesticides has recommended that "in principle clearance for the use of pesticides through the Ulvamast can be granted"if chemical manufacturers apply, having concluded that "as long as the Ulvamast is used correctly, no additional precautions are required above those already in force or advised for the protection of operators of tractor-mounted hydraulic sprayers when applying specific pesticides "(MAFF letter, 1982).

In order to achieve a correct level of drift with the Ulvamast, there is a considerable reliance on wind speed and wind direction. Several respondents in the Ulvamast user survey stated that in some fields they established tramlines perpendicular to the prevailing wind, in order to make use of the Ulvamast as often as possible.

6.7.3 Ulvamast user survey: characteristics of respondents

The mean area farmed by respondents was 446 hectares, ranging between 121 ha and 1335 ha. The mean cereal acreage was 314 ha, ranging between 93 ha and 899 ha. In the random user survey, which covered much of the Ulvamast survey area, the respective figures were: mean area 238 ha, mean cereal area 153 ha.

Ulvamast purchasers, as at the time of the survey, had had an average of 24 years experience in farming, the modal age category being 40 - 49.

6.7.4 Awareness

In order to judge demand for the Ulvamast, Haigh arranged a meeting of local farmers in order to demonstrate the Ulvamast, and a boom sprayer with Herbi heads. Three hundred invitations were sent out; one hundred attended the demonstration, of which twenty ordered Ulvamasts. In the Ulvamast user survey, most respondents stated that they first became aware of the Ulvamast almost as soon as it was first produced (23/26). When asked how they first heard about it, a strong personal element was active in their awareness: see Table 6.11. This personal

TABLE 6.11. Source of initial awareness of Ulvamast. Results from Ulvamast user survey, n = 26. Note that number of sources exceeds number of respondents as more than one source sometimes given.

Source	No
Personal contact with/from Haigh	11
Demonstration of Ulvamast	7
Press	6
Circular	3
Other users, neighbours	2
Farm group	1
Can't recall	2

TABLE 6.12. Reasons given for purchasing an Ulvamast. Results from Ulvamast user survey, n = 26. Note that the number of reasons exceeds the number of respondents as more than one source is sometimes given.

REASON	NO.
Reduction in chemicals	18
High workrates/speed	9
Specific pest problem	6
Cheap machine	3
More time for other operations	2
Reduces crop damage	2
Allows late applications	1
Idea appealed	1
Cost-cutting on low value crops	1
Droplets stick	1
Improved timeliness	1
Increased bout width	1
Allows insurance spraying	1

contact is not surprising, as those surveyed were among the first adopters, and the place of manufacture of the Ulvamast is in the centre of the area surveyed: the mean distance of respondents in the Ulvamast survey from Lockinge is 16 miles.

6.7.5 Reasons for purchasing

When asked what their main reasons were for purchasing an Ulvamast, a variety of reasons were given by respondents, but prominent among these reasons were the reductions possible in the volumes of chemical applied to the crop: see Table 6.12.

According to Haigh, the cereal aphid infestations of the mid-to-late 1970's that coincided with the launch of the Ulvamast provided an impetus to sales in the first stages after introduction of the Ulvamast.

6.7.6 Use of and satisfaction with the Ulvamast

When respondents in the Ulvamast survey were asked if they were satisfied with the performance of the Ulvamast, 58% (15/26) stated that they were, while 31% (8/26) were not. Three respondents (11%) could not answer the question. Those not satisfied with the Ulvamast were asked why this was so. Reasons are given in Table 6.13.

As a result of some user dissatisfaction with the original model, in early 1978 a model was brought out which had one set of "stacked" discs (similar to the Micron Battleship head) instead of six single discs. This was introduced owing to pipe problems, and not being able to drive the discs fast enough.

At the time of interviewing (Dec 82 - Feb 83) 46% (12/26) of respondents were still using Ulvamasts. Of the 12 users at least eight were using the model with stacked discs, up to four respondents using the older model.

Of the fourteen respondents who had discontinued using the Ulvamast, the most commonly quoted reason why they had given up using it was an excessive reliance on wind, as shown in Table 6.14.

Respondents in the survey were asked, on the basis of their overall experience with the Ulvamast, what they could see as being the main advantages and disadvantages of the Ulvamast system, broken down by whether the respondent is a current or a lapsed user of the Ulvamast. Results of this are given in Table 6.15.

That respondents had discontinued the use of Ulvamasts is not a sign of their rejection of CDA techniques : six of those who have discontinued using Ulvamasts use a boom-mounted CDA sprayer, thus 18/26 respondents use either an Ulvamast or a boom-mounted CDA sprayer. Only one of the respondents still using an Ulvamast has a boom-mounted CDA sprayer. Four of the respondents using a boom-mounted CDA sprayer do not have an hydraulic-pressure sprayer on the farm, all spraying being carried out with the CDA machine.

6.7.7 Chemicals applied with Ulvamast

The use of the Ulvamast and of boom-mounted spinning-disc sprayers for different types of chemicals is summarized in Table 6.16.

In concluding that the Ulvamast may be used for specific pesticides without any additional precautions over and above those safeguarding the operators of tractor-mounted hydraulic sprayers, the Advisory Committee on Pesticides warns against the use of "corrosive or dessicating agents, highly active herbicides and chemicals of high toxicity"

TABLE 6.13. Reasons why respondents not satisfied with performance of the Ulvamast. Question asked of respondents in the Ulvamast user survey professing to be not satisfied with the performance of the Ulvamast, n = 8. Note that the number of reasons exceeds the number of respondents as more than one reason is sometimes given.

REASON	NO
Drift concept	2
Reliance on wind	2
Poor electric motors	2
Blocked restrictors	2
Poor pipe network	1
Tank cleaning difficult	1

TABLE 6.14. Reasons given for discontinuing use of the Ulvamast. Results from Ulvamast user survey, question asked of respondents discontinuing use of the Ulvamast, n = 14. Note that the number of reasons exceeds the number of respondents as more than one reason is sometimes given.

REASON	NO.
Reliance on wind speed/direction	5
Replaced by "CDA Boom" sprayer	4
Not using at present, still on farm	3
Drift hazard	1
Inconclusive biological results	1
Blocking of tubes	1
Hydraulic pressure sprayer performance as good	1
Drift hazard	1
Machine reliability	1
(Respondent out of farming)	1

TABLE 6.15. Main advantages and disadvantages of the Ulvamast, for current (C) users (n = 12) and lapsed (L) users (n = 14), from the Ulvamast user survey.

ADVANTAGES	C	L
High rates of work/speed	8	3
Reduced chemical use	7	4
Reduced volumes of water	1	1
No refilling	1	1
Good cover	1	1
Less crop damage than with hydraulic sprayers	1	0
Flexibility in timing	1	0
Wider bouts	1	0
High rate of return on investment	1	0
Matches well with LGPV's	1	0
Good level of control	1	0
Cheap machine	0	1
Quick refill	0	1
Allows preventative applications	0	1
	24	13

DISADVANTAGES	C	L
Wind speed/direction requirements	2	10
Spray visibility	1	1
Excessive drift	1	1
Poor crop cover	1	1
Limited no. of chemicals available	1	0
Can't use near woods	1	0
Less accurate than hydraulic pressure sprayers	1	0
Only part days spraying possible due to wind changes	1	0
Poor biological efficacy	0	4
Operator training needed	0	1
Operator hazard	0	1
	9	19

through the Ulvamast, "without added safeguards and a prior assessment of the site" (MAFF letter, 1982).

6.7.8 Diffusion of the Ulvamast

From information supplied by CDA Ltd., 363 enterprises in the British Isles have purchased Ulvamasts, the total sales of the Ulvamast being approximately 445.

Table 6.17 shows information supplied by CDA Ltd., on the yearly and cumulative sales for all Ulvamasts sold, and the yearly and cumulative number of new users of the Ulvamast in the British Isles. In addition survey data is presented on the yearly and cumulative numbers of sales amongst the enterprises surveyed, and the number of Ulvamasts remaining in use, taking into account discontinuing of use of the Ulvamast.

Until late in 1979, the method of selling was direct to the farmer, with a "road show" arrangement. In the period, 20 - 25 meetings were arranged through the country at agricultural colleges, featuring a demonstration of the Ulvamast. Mailed invitations were made to large farmers in each locality. Of 7,000 invitations in total to the demonstrations, approximately 10% of those invited turned up and 10% of those attending purchased Ulvamasts. In addition the Ulvamast was promoted at agricultural shows, such as the Royal Smithfield. Interestingly, Mr. Haigh stated that the level of sales was closely related to the promotional effort.

In 1980, a new model of the Ulvamast was developed, with the electric motor drive being replaced by a cable. This was launched in the summer of 1981.

TABLE 6.16. The use of the Ulvamast and boom-mounted CDA sprayers for applying chemicals. Results from the Ulvamast user survey. For the Ulvamast, n = 24 (2 missing values), and for boom-mounted CDA sprayers n = 7.

Chemical type	Ulvamast	Boom-mounted disc sprayer
Fungicide	21/24	6/7
Insecticide	14/24	5/7
Herbicide	2/24	6/7
Plant growth regulators	3/24	5/7
Trace elements	1/24	-

Since 1979, CDA Ltd. have set up a network of dealers. Sales are made through the dealers, with the manufacturers undertaking to train the farmer and the operator in the use of the CDA Boom. Mr. Haigh stated that in order to make chemical applications effective, a proper training of the operator is required, in calibration and operation of the sprayer, and ensuring correct weather. The system appears to be geared more towards the farmer who does his own driving, who is possibly more attentive and feels more responsibility than an employed operator.

In 1981, the CDA Boom was introduced, a horizontal boom-mounted spinning disc sprayer. Sales of the CDA Boom to date have been about 250, and they appear to have been achieved at the expense of sales of the Ulvamast. In addition, the Ulvamast is no longer actively advertised or promoted - see sales figures in Table 6.17.

Mr. Haigh believes that the Ulvamast has been a "successful" machine, being cheap and simple to operate if the rules are understood. Some of the models suffered from mechanical problems with motors, and for some applications, the biological efficacy has been suspect.

6.7.9 Diffusion and use of the Ulvamast:discussion.

Since its introduction, the Ulvamast has been a "controversial" technique, not being fully approved by official bodies, or chemical manufacturers. The Ulvamast was first introduced in seasons when there were serious aphid infestations on cereals. This may have provided an impetus to sales. Other attractive features were the high workrates that were achievable, and the considerable savings in chemical costs that were possible. The reduction in rates of chemical applied was one of the most quoted reasons for satisfaction with the machine given by respondents in the Ulvamast user survey. One respondent in the random user survey who had purchased an Ulvamast stated that the machine paid for itself in

TABLE 6.17. Figures showing total sales of the Ulvamast, numbers of new users of Ulvamasts in the British Isles (figures supplied by CDA Ltd.), and data from the Ulvamast user survey.

	YEAR					
	TO END 1977	1978	1979	1980	1981	TO END 1982
Total no. of sales each year*	20	45	75	100	195	10
Cumulative sales*	20	65	140	240	435	445
No. of new users (adopters) of Ulvamasts in British Isles each year**	14	39	61	83	148	8
Cumulative adopters in British Isles**	14	53	114	197	345	353
Sales among respondents in Ulvamast user survey***	16	3	9	3	0	0
Cumulative sales among respondents***	16	19	28	31	31	31
No. of Ulvamasts in use among respondents at end of each year***	16	18	24	21	18	12

* Approximate figures supplied by CDA Ltd.

** There were 10 missing values regarding the year of adoption; thus the total number of Ulvamast adopters in the British Isles = 363

*** Number of respondents in Ulvamast user survey = 26

Total number of adopters in England & Wales = 354.
Total number of adopters in Scotland & Ireland = 9.

one day's use.

The main problem stated by respondents in the Ulvamast user survey was that of the wind strength and direction. The increasing use of tramlines through cereals means that in order to take full advantage of the Ulvamast, it is necessary to tramline perpendicular to the prevailing wind. If the wind direction is very variable, the number of suitable days for spraying is lowered, and it may be harder to arrange spraying in advance. One respondent in the Ulvamast user survey was so frustrated by the lack of available spray-days that he sold his Ulvamast, having hardly used it at all. Other major faults of the Ulvamast seem to have been mechanical breakdowns, and doubts as to the biological efficacy of the machine. With a controversial machine such as the Ulvamast, there must be considerable numbers of pre- and post-adoption rejectors around who have influenced the decisions of others to adopt.

Fourteen of the respondents in the Ulvamast user survey have discontinued using an Ulvamast. One of the respondents is out of farming, and six of the remaining thirteen have a boom-mounted rotary atomiser on the farm. Five of these six respondents have no other sprayer than a rotary atomiser. Of the twelve respondents still using an Ulvamast, only one has a boom-mounted rotary atomizer. From this tenuous evidence, it appears that for some farmers, the Ulvamast represented an interim step in the adoption of new spraying techniques : a substantial proportion of farmers discontinuing using the Ulvamast have adopted boom-mounted rotary atomizers (e.g. the CDA 'Boom'). For many farmers, the adoption of the Ulvamast means acceptance of the technique of controlled droplet application, continued after discontinuance of the Ulvamast in the use of boom-mounted rotary atomizers.

When asked to give a self-rating of innovativeness, all respondents in the Ulvamast user survey saw themselves as being at least 'averagely' innovative; almost one third saw themselves as being among the most innovative. Figures 6.9 a to 6.9 f generally bears this out. Early users of techniques such as the Ulvamast may be considered as being the type of farmer who is among the early adopters of new technology, particularly innovations concerned with arable farming and spraying.

6.8 Summary

1) Due to the generally inelastic demand for food, the widespread adoption of new technology in agriculture generally leads to a drop in the total revenue obtained by the industry. Profitability can only be increased if costs are reduced by more than the drop in revenue caused by the use of new technology. Government or EC intervention may seek to prevent serious drops or variances in income.

2) The adoption process may be viewed as a decision-making exercise which need not be rational in nature, but is usually characterised by a sequence of distinct stages. The adoption process does not necessarily terminate with the full uptake of the innovation : post-adoption reinforcing or rejection may occur.

3) From a continuum of adoption behaviour, regarding the time of adoption of an innovation, several "ideal types" may be identified. Characteristics of these ideal types are given in Table 6.1.

4) The uptake of innovations involves a degree of uncertainty, particularly in the early stages of adoption when there is little information. From a review of the literature, the relationship between attitudes to risk and adoption behaviour appears to be unclear.

5) Various economic and technical attributes appear from the literature to be important in influencing the rate of uptake of innovations, such as the rate of return on investment and the compatibility of the machine with existing practices and enterprises.

6) Various channels of communication are important in different stages of the adoption process, and for different categories of adopter, as shown in Figure 6.2.

7) Relatively few studies have been carried out on the adoption of innovations in the U.K. Most have been carried out in the Americas and Asia.

8) Diffusion is the spread of an item through a community. For agricultural innovations, the diffusion curve may often be roughly represented as an S-curve. However in certain circumstances, particularly where pre- and post- adoption rejection of an innovation is high, significant deviations from this curve may occur.

9) In the random user survey, the use of six categories of innovation has been followed. There is some evidence for the following of an S-shaped diffusion curve; the innovation most sharply divergent from this pattern is that of the spread of direct drilling.

10) Jones' (1966b) method is advocated as a means of measuring innovativeness. Innovativeness is assessed on the basis of the relative earliness of adoption of six innovations among respondents in the random user survey.

11) Several farm and farmer characteristics are associated with innovativeness, such as age, farm size, amount of spraying carried out, education,

and self-perceptions of innovativeness (Table 6.9.). These correlations may be used to empirically predict future adoption behaviour with similar types of innovation.

12) Two other measures of farmer orientation towards new technology are constructed : awareness of new crop sprayer technology, and the stage of adoption with regard to spinning-disc sprayers. With a few exceptions, the pattern of association with farm and farmer characteristics is similar to that for innovativeness.

13) A case study of the adoption and diffusion of a "controversial" sprayer, the Ulvamast, is presented. Information is from a survey of 26 sometime Ulvamast users, an interview with the manufacturer of the Ulvamast, and with information supplied by CDA Ltd.

CHAPTER SEVEN

TECHNOLOGICAL FORECASTING

7.1. Introduction

In Chapter Four a review was made of current practices in British arable crop protection. Chapter Five detailed the logistic and weather constraints under which crop sprayers operate. New crop spraying technologies often have attributes permitting a relaxation of the weather and logistic constraints that operate on currently used sprayer systems. In Chapter Five a model was developed quantifying the performance and efficiency advantages of new crop spraying technologies. In Chapter Six an assessment was made of how an individual's social, psychological and situational characteristics may influence attitudes and behaviour towards new technology in general. Economic, communications and social factors were shown to be important in influencing the diffusion of an innovation through a social system.

Chapters Four, Five and Six provide evidence by which an evaluation of the future use of new and current spraying technology may be made. In fact in this chapter, the means by which the future uptake and impact of new crop spraying technology is assessed is by canvassing expert opinion on a variety of subjects associated with, and relevant to, crop protection activities. Results from a postal survey of 167 experts in relevant agricultural sectors are presented in Section 7.3.

In Section 7.4 an attempt is made to evaluate the prospects for the various types of new crop spraying technology. The types of new crop spraying technology considered are : boom-mounted rotary atomizers, electronic sprayer monitors, electrostatic crop sprayers and low-ground pressure vehicles. An attempt is also made to crudely enumerate the numbers of farmers who might be expected to adopt a notional electrostatic crop sprayer by 1990, assuming a UK launch in 1985.

Although new crop spraying technology can show advantages over conventional systems in performance and efficiency terms, other factors will also influence the rate of adoption of new crop spraying technology. Among these will be the changing patterns in use of chemicals, prices of inputs and output, statutory controls on spraying operations, and the influence of "competing" technology. In Section 7.5 the influence of these factors on the adoption of new crop spraying technology are discussed.

7.2. Methods of technological forecasting.

"Technological forecasting is an attempt to anticipate the rate and direction of technological change and the nature, rate of diffusion, and effect of the new processes and products that are used in a particular field" (Mansfield, 1969).

Mansfield (1969) defines three main methods of technological forecasting:

1) Extrapolation of statistical trends, e.g. extrapolating curves in Figures 6.6a to 6.6f to see how the diffusion of an innovation proceeds. The accuracy of this method is generally inversely related to how far one attempts to peer into the future.
2) Modelling the process by which new techniques arise and become accepted. The models attempt to relate in a systematic way various aspects of this process to a set of measurable explanatory variables, e.g. deciding on the shape of curve that would most closely follow the diffusion of an item.

3) Forecasting based upon expert opinion. This is the method of forecasting used in this chapter, and the methodology is explained in Chapter Three. Although results may be subject to large errors, particularly when trying to predict far into the future, it is hoped that in an industry such as agriculture, where the need for technological change is accepted by most farmers (as in the U.K.), then expert opinion may indicate general trends in the industry in the next few years. This is what was hoped for in carrying out the survey, rather than expecting specific predictions as to what would happen.

7.3 Survey results

7.3.1 Introduction

Several comments were made by respondents in the postal survey on the questionnaire, and on survey design. Although one respondent commented that surveys of this nature were "most important and valuable", others were more critical of the questionnaire's contents:" by introducing factors like 50% or 'three times something'.....(it) makes it impossible to answer your survey". Another respondent stated that plant protection is "a subject so much influenced by technical, economic, political and social criteria and attitudes that looking forward to 1990 and beyond is too risky to be worthwhile". Nevertheless, over two thirds of those contacted in the course of the survey felt confident and motivated enough to respond, and give some indication of what they thought might happen in the future. In addition, seventy-one of the 167 respondents (43%) offered constructive comments on one or more of the statements in the questionnaire (see Appendix).

As was pointed out in Section 3.3.17, arbitrary percentages were set in the questionnaire so that all respondents understood the statements and questions to mean the same. However, in interpreting the survey results, inferences will be stated in more general terms. Only when a substantial majority of respondents give the same reply to a statement or question can reasonably firm conclusions be drawn; in less clear-cut cases the inference must necessarily be more tentative.

Another area of interest in analysing the results is the extent to which respondents from different "groups" (i.e. ADAS Officers, crop consultants etc.) vary in their responses. In the results sections, where individual groups differ considerably in their responses from the aggregate percentage, this will be mentioned. A "considerable difference" in this case will be set at $\pm$ 15% different from the aggregate percentage figure. If this occurs, a group is "divergent". When percentages for individual groups are approximately similar ($\pm$ 15%), then the groups are "convergent" in their results.

Percentages answering for each statement or question in the postal survey are given in Sections 7.3.2 to 7.3.7. In some cases the percentages do not add to 100%. This is because some respondents did not reply to all questions.

7.3.2 Adoption of new crop protection machinery

The first five statements in the postal survey questionnaire (see Appendix) deal with the adoption of new crop spraying technology, as does Statement 12 and Question number three.

Eighty-six percent of respondents agreed with Statement number 1 : "By 1990, the number of sprayers on farms allowing farmers to control droplet size accurately will have increased by at least three times". Thirteen percent of respondents disagreed. Clearly, a large majority agree with this statement, with little divergence between groups. Comments made by respondents indicated that as there are so few machines of this nature (i.e. rotary atomizers) on farms at the present time (probably 700 - 800), then a trebling of numbers may occur in as little as 2 - 3 years.

Statement number 2, "By 1990, at least 20% of British arable farms will have an electrostatic-type sprayer", was disagreed with by 58% of respondents, 37% agreeing. There is some divergence in answers between the groups surveyed for this statement- whereas only 22% of ADAS Officers agreed with the statement, 54% of machinery manufacturers did. Among the comments received, five respondents thought a figure of 10% by 1990 was possible. Only one respondent mentioned a lack of awareness of electrostatic sprayers by farmers as a reason why this level of uptake might not be achieved.

In assuming an expansion in use of new sprayer technology, Statement 3 seeks to find out the future usage of hydraulic pressure sprayers: "By 1990, with increased use on farms of "spinning-disc" and electrostatic sprayers, the acreage sprayed by hydraulic pressure sprayers will decline by at least 50%". Twenty-three percent of respondents agreed with the statement, 75% disagreed. A clear majority disagree, with convergence between the various groups' replies. One respondent stated that there is a "limited value of spinning-disc and electrostatic sprayers for herbicide application....(which) will limit the development and uptake of these types of machine". A decline in use of hydraulic sprayers by 20 - 30% was mentioned by five respondents as being more likely.

Eighty-four percent of respondents agreed with Statement 4: "By 1990, the number of arable farms having "low ground-pressure" vehicles, flotation tyres, or double wheels for tractors, will increase by at least three times". Fourteen percent disagreed, with all groups converging. Several respondents stated that over a third of arable farms already use such pressure reducing implements, thus a further trebling was impossible. One reason given by a respondent for continuing increases in numbers was "the trend and necessity of early application of pesticides will....continue the trend towards winter application of ... early post-emergent pesticide application".

Statement number 5 covers the use of electronic sprayer monitors : "By 1990, the use of electronic sprayer monitors will be standard on all but the smallest sprayers". A substantial majority agreed with the statement (79%, 20% disagreed), with convergence in percentages from all groups surveyed. One respondent commented that "monitoring devices will be part of the tractor equipment, not the implement".

There is almost complete unanimity among all groups in agreeing with Statement 12: "By 1990, most new sprayers will have improved measuring and mixing systems which will reduce operator exposure to concentrated chemicals". Ninety-five percent of respondents agreed with the statement, with five percent disagreeing. One respondent commented, "the chemical manufacturers will also improve the safety of product handling, i.e. increases in soluble sachets, pods of sealed chemical to plug into the sprayer".

All but 13 of the 165 respondents suggested a percentage in response to the question, "Over the next 15-20 years, what percentage of British arable farms do you think will have hydraulic pressure sprayers completely replaced by new designs?" Answers ranged from 0% to 100%, with a mean of 39% (S.E. = $\pm$ 2%).

7.3.3 Utilization and performance of crop sprayers

Statement numbers 6, 7, 8 and 11, and Questions 1 and 2 deal with this topic. The object was to examine how current practices may change in the next few years.

Statement 6 examines how much night spraying might be carried out: "By 1990, at least 25% of all spraying operations will be performed at night". Eighty-two percent of respondents disagreed, with 14% agreeing. There is some divergence between group percentages: whilst only 4% of chemical company replies and 9% of ADAS Officers agreed with the statement, 28% of consultants agreed with it.

Responses to Statement 7 did not produce a clear-cut verdict. The statement was, "It will always be important for the sprayer operator to be able to see the spray droplets produced during spraying". Forty-six percent of respondents agreed with the statement, with 52% disagreeing. Furthermore, there were considerable divergences in opinion between the groups surveyed. Eighty-four percent of independent crop consultants agreed with the statement, the percentages agreeing for other divergent groups being: 64% chemical company replies, 31% ADAS Officers, 26% machinery manufacturers and 9% for others. One respondent commented that "this is a basic psychological need for operators, and is probably one of the reasons for slow acceptance of spinning-disc equipment". Five respondents commented that some form of electronic monitoring could assume the roles of checking on nozzle performance and drift.

Statement 8 dealt with windspeed constraints on sprayers: in response to the statement "By 1990, new sprayer designs will allow safe spraying at 25% higher windspeeds, or greater", 52% agreed, 43% disagreed. No clear-cut majority emerged in any group. Results from this statement may be ambiguous, as some respondents criticised the wording:

what was meant by 'safe', and '25% higher' than what?

Sixty-eight percent of respondents agree with Statement 11 : "By 1990, sprayers will be operating, on average, at 25% higher forward speeds, or greater". Twenty-nine percent of respondents disagreed, with convergence among group percentages. In the comments, the reasons given for sprayers travelling faster were varied: use of LGPV's, vehicles and/or spray booms having improved suspension systems. Respondents differed in their views whether the use of rotary atomizers would allow higher forward speeds.

Questions 1 and 2 deal with changes in the number of passes through a field to apply chemicals by 1990 and the change in acreage of crops aerially sprayed by 1990 respectively. Respondents were asked if the two values would increase, stay the same, or decrease by 1990. For question 1, 42% believed that an increase would occur, 28% believed the value would stay the same, whilst 26% indicated a decrease was likely. For changes in acres aerially sprayed, 25% indicated an increase, 26% were for the value staying the same, with 47% believing that a decrease was likely. The results indicate that the number of passes through a field are likely to increase by 1990, indicating more chemical applications. Conversely, a majority of respondents believe that the acreage sprayed by the air will decrease by 1990. One respondent commented that "pressure from the environment lobby will force a decrease in the number of products approved for application from the air". Another explanation is that the growth in ownership and use of such items as LGPV s means that soil wetness is less of a constraint when considering spraying operations.

7.3.4. Volumes used in spraying operations

Two statements, 9 and 10, were used to assess if (i) the volume of diluent used in spraying will tend to decline, and (ii) if the volumes of active ingredient will also be less.

A very substantial percentage agree (91%) with Statement 9: "By 1990, average total volumes applied in spraying will be reduced by at least 25%. Seven percent of respondents disagree, with convergence for all group percentages. Note that the statement does not specify types of machinery in use. Currently hydraulic pressure sprayers apply about 200 ℓ/ha on average. A 25% reduction by all farmers would lead to an average application rate of 150 ℓ/ha by all farmers, a reduction not difficult to achieve with hydraulic pressure sprayers. Alternatively, it may be that many farmers will maintain spraying at 200 ℓ/ha, with remaining farmers taking advantage of developments in hydraulic spraying technology and newer crop sprayer designs, and applying chemicals at 50 ℓ/ha, for instance. For those farmers reducing volumes applied, there will be implications for performance levels of sprayers on farms compared with those maintaining existing practices.

Sixty-five percent of respondents agree with Statement 10: "By 1990, the amount of chemicals (active ingredient) used per acre for one application will be, for most chemicals, at least 25% less". Thirty-two percent of respondents disagree, with group percentages convergent. Several respondents commented that it may not be possible to reduce volumes for soil-acting chemicals and some other herbicides. Three respondents stated that 'little and often' applications may replace the less frequent and heavier applications often used today: a consideration of the answers from Question 1 in combination with Statement 10 indicates that this may indeed be the case in the future.

7.3.5. Statutory controls on crop protection activities

Two statements were directed towards eliciting forecasts on this topic, numbers 13 and 16. Statement number 13 is "By 1990, current voluntary schemes covering chemical usage will be replaced by legislated controls". Overall, 64% agreed with the statement, 31% disagreeing. However, there was some divergence between group percentages. Whilst 47% of ADAS Officers agreed with the statement, the figure for chemical company respondents was 88% agreeing, and for 'others' 82% agreed. Other groups were more convergent on the aggregate percentages. Three respondents mentioned the EEC as being a possible source of legislated controls.

Twenty-six percent of respondents agree with Statement 16, "By 1990, sprayer operators will have to be licensed to apply most agricultural chemicals". Sixty-nine percent of respondents disagreed. There is some divergence in the percentages between groups. Fifty percent of replies from 'other' bodies agreed with the statement, whilst only 11% of ADAS Officers agreed. Three respondents indicated that licensing could happen to agricultural spray contractors.

It appears that a majority of respondents believe that there will be legislated controls on chemical usage by 1990, but these will not extend to the licensing of sprayer operators.

7.3.6 Chemicals for use with new application technology

Two main nozzle types are currently under development to compete with conventional hydraulic-pressure nozzle sprayers. These may be termed "spinning-disc" sprayers, and electrostatic-type sprayers. Several makes of boom-mounted spinning-disc (or rotary atomizer) sprayer are currently available, and have been since the late 1970's, e.g. CDA "Boom", the "Microdrop". Electrostatic-type sprayers are not yet commercially available in the UK (August 1983). In considering the likely uptake of sprayers incorporating the new types of nozzle, farmers will naturally be interested in the range of chemicals that will be available for use with the new types of nozzle. Although there are no legally enforceable restrictions on the use of chemicals through any type of ground-based nozzle at present, this situation may not persist. Accordingly, Statements 14 and 15 are concerned with the range of chemicals that will be available for use with new technology.

Statement 14 is "By 1990, "spinning-disc" sprayers will have a full range of chemicals approved for use with them". Sixty percent of respondents agreed with the statement, 38% disagreeing. Group percentages are convergent on the overall percentage values.

Forty-one percent of respondents agree with Statement 15, "By 1990, electrostatic-type sprayers will have a full range of chemicals approved or use with them". Fifty-seven percent of respondents disagree with the statement, with all groups being convergent on the aggregate percentages.

More respondents believe that a full range of 'approved' chemicals will be available by 1990 for "spinning-disc" sprayers than for electrostatic-type sprayers. Several respondents commented that it would depend on the approval schemes in force at the time, and that limited, not necessarily full, ranges may be available for use with them.

Several respondents stressed the versatility of hydraulic-pressure sprayers in comparison with new technology: "new spray designs lack the versatility of conventional hydraulic systems", "the hydraulic sprayer still copes with all spraying requirements, whereas CDA has limited use", and "improvements in the design of hydraulic nozzles in reducing application volumes by 50 - 70% would suit farmers much better than complicated CDA equipment". One respondent mentioned the effect of possible alternative uses of spray machinery: "in many arable areas, the numbers of liquid fertiliser users are fairly high - around 10% here, which greatly influences the adoption of "new technology" units, as these farms tend to be the innovators".

Several respondents indicated possible limitations in the use of new technology: "no sprayers will be completely replaced by new designs unless the low volume sprayers can undertake the full range of spraying activity", "electrostatic spraying has .... a limited application, i.e. in systems where foliar density is low, in pre-emergent and early post-emergent herbicides".

The fact that a sprayer may not be able to perform all of the spraying tasks that can be undertaken by currently used crop sprayers has implications for their uptake in the farming community. If a new type of crop sprayer can only complement rather than completely replace currently used sprayers, then only farmers with spraying requirements which justify more than one sprayer on the farm will seriously consider purchasing such a machine. The influence of this factor on the number of potential adopters among farmers in England and Wales will be discussed in Section 7.5.

In the Ulvamast user survey, there were five respondents who only used boom-mounted spinning-disc sprayers on the farm. Thus it appears that for some farmers, spinning-disc sprayers can apply all necessary chemicals.

7.3.7 Chemical packaging

ICI are currently developing an electrostatic spraying system, the 'Electrodyn', which may treat chemical packaging as a much more integral part of the spraying system than is currently the case. For instance, containers of chemical for the "Electrodyn" system may be sold with a nozzle attached. When used in spraying operations, the container would then "double up" as a spray tank. This nozzle/container/tank arrangement may be designed to be returnable, or disposable. Although Statement 12 (discussed in Section 7.3.2) touched on the subject of chemical packaging, Statements 17 and 18 address themselves more directly to the topic.

Statement 17 asks the respondent to agree or disagree with the proposition that "The future marketing of chemicals in returnable containers is a good idea". Overall, 45% agree, with 53% of respondents disagreeing. However, two of the respondent groupings are markedly divergent from the aggregate percentage. Only 16% of respondents from chemical companies, and only 7% of agrochemical merchants surveyed agreed with the proposition. The merchant's attitude is of particular interest, as it is they who might be expected to administer the return scheme. Several respondents commented that even if it was a good idea, it was not practical, due to transport, laundering and cost problems.

Statement 18 examines the topic of disposable combined containers and nozzles: "In the future, the marketing of chemicals in combined disposable containers with nozzles (for use on mounted sprayers) is a good idea". Overall, 50% of respondents agreed, and 47% disagreed. Only respondents from "other bodies" (73% agree) markedly diverged from aggregate percentages. Five respondents commented that the cost of chemicals packaged in this way could be high. Another respondent commented that containers with nozzles could lead to restrictions in choice, which would not be of benefit to the farmer. However, this assertion depends on one or a few companies manufacturing and promoting chemicals in this way, which may not necessarily be the case.

Respondents may also have felt that farmers may resist disposing of containers and nozzles that are perfectly serviceable. However the notion of using an item once and then disposing of it has permeated British society over the years, e.g. the development of disposable razors, disposable milk cartons, and the rise and fall of drink cans and deposit-paid bottles respectively. The main problem that farmers would face is the safe and satisfactory disposal of such containers-cum-nozzles.

7.3.8 Further comments

Respondents in the postal survey had an average over 20 years experience in agriculture.

The possibility of new technology stimulating development of conventional systems was indicated by one respondent: "new methods (centrifugal/electrostatic) which are currently of such interest, will have little impact in themselves, but will engender refinement of hydraulic sprayers".

Several methods of promoting the use of technology were considered by respondents: "air assistance in some form is necessary to make reduced volume spraying in cereal and other field crops more effective in the future", "if the farmer wants only one sprayer on the farm, have combined hydraulic/CDA or hydraulic/electrostatic sprayers".

Future economic conditions was seen by some as an important factor in the uptake of new technology: "economic pressures may push farmers toward using less chemical than recommended, i.e. an economic decision, not agronomic. This may well hold back the introduction of electrostatics, which is unlikely to show critical benefits to the user".

Operator education was seen by some respondents as being a constraint on the uptake of new technology: "the biggest limitation to successful use of technical innovations is still going to be the education of the operator", "priority should be placed on improving operator performance, particularly with regard to calibration, maintenance, ensuring correct application rates, and bout matching". Some respondents considered that an increase in the cost and complexity of crop sprayers could lead to an increase in the amount of work carried out by contractors.

Farm size was seen as an influential factor in the adoption of new technology: "(future) developments should not forget the needs of the average and small farming sectors", "to talk (in the survey) of all British arable farms is misleading. The average size of farms and fields in Britain is still very small".

7.4 Future UK adoption of new spraying technology

7.4.1 Introduction

In this section, an attempt will be made to provide a rough estimate of the possible number of adopters of new spraying technology. These figures are subject to a number of qualifications and uncertainties, but it is hoped that the figures will provide guidance, and may be within an order of magnitude of the true values. Estimates of numbers are given in Section 7.4.3, using indicators given in Table 7.1.

In arriving at estimates of adopter numbers, a number of implicit assumptions have been made of factors which may influence adoption. Among these factors are input and output prices, changes in chemical usage, legislated controls on plant protection activities, and the influence of competing technology. Such factors are discussed in Sections 7.5.1 to 7.5.5.

7.4.2 Indicators of adoption

In attempting to assess the potential uptake of new crop spraying technology, it is necessary to define, and if possible, enumerate the population of potential adopters.

Table 7.1 gives details of the number of farms growing cereals (excluding maize) in England and Wales, grouped by size of cereal enterprise. This table will provide the basis from which potential numbers of adopters

TABLE 7.1. Distribution of holdings by total cereals area size groups (in hectares - excluding maize). Data from the MAFF June 1982 Census, England and Wales (MAFF, 1983).

Area category	≤ 4.9	5.0 - 9.9	10.0 - 19.9	20.0 - 29.9	30.0 - 39.9	40.0 - 49.9	50.0 - 74.9	75.0 - 99.9	100.0 - 124.9	125.0 - 149.9	150.0 - 199.9	≥ 200
No. of holdings	13004	10375	12369	7888	5392	4101	6831	4123	2732	1763	2111	2855

are assessed.

Results from the postal survey will be used, as well as estimates provided by Rutherford (1980) in attempting to enumerate potential adopters of new crop spraying technology in Section 7.4.3.

7.4.3 Uptake of new crop sprayer technology

In response to the question on the level of uptake of "new designs", replacing hydraulic pressure sprayers, the mean estimate was 39% (see Section 7.3.2). Excluding very small cereal enterprises (those under 5ha), then the total number of adopters of new crop sprayers is suggested as being 23610. However, this assumes that models are available that are suitable for smaller farmers. If it is assumed in respondent's estimates that smaller farmers will not be catered for (say cereal area under 30 ha), then a total market of 11660 holdings is suggested.

A majority of respondents disagreed with Statement number 2: "By 1990, at least 20% of British arable farms will have an electrostatic-type sprayer". However, a number of respondents commented that a figure of 10% by 1990 might be possible. Assuming this figure of 10%, and excluding holdings growing under 5 ha cereals, 6050 holdings are projected to adopt electrostatic sprayers by 1990. However, if it is assumed that smaller farmers will not find electrostatic sprayers suitable for their needs (say those farmers with a cereal area under 30 ha), then the total number of adopters, assuming the "10% rule", will be about 2990 holdings. The above figures assume that electrostatic crop sprayers can completely replace hydraulic pressure sprayers on the farm. This may not be the case : electrostatic sprayers may not be able to apply all the chemicals required in a typical spray programme. If this is so, then only larger farms will be able to justify owning an electrostatic sprayer in addition to another arable crop sprayer, so that all chemicals may be applied by the farmer. It may be that only farms which currently have more than one arable crop sprayer will feel able to bear the cost of an electrostatic sprayer.

In the random user survey, eighteen respondents had more than one working arable crop sprayer on the farm. If it is wished to estimate the proportion of the population with a given attribute (such as having more than one sprayer on the farm) then it is necessary to test the standard error of the proportion - see Section 3.3.10. The formula is:

$$S.E._{(p)} = \sqrt{(1 - \frac{n}{N}) \times \frac{\pi(1 - \pi)}{n}}$$

where π = proportion with the attribute in the sample: 18/76 in the random user survey have more than one sprayer on the farm = 0.24

n = sample size = 76

N = population sampled from = 1032 (see 3.3.9).

Thus the standard error of the proportion of farms with more than one sprayer on them is:

$$\sqrt{(1 - \frac{76}{1032}) \times \frac{0.24\ (1 - 0.24)}{76}}$$

$$= 0.047$$

Thus the proportion of farmers in the population with more than one arable crop sprayer on the farm is 0.24 ± 0.047, or between 195 and 290 farms in the population. If it is further assumed that the sampled population is representative of farmers in England and Wales, then an estimate can be made of the number of holdings in England and Wales with more than one arable crop sprayer on them, by carrying out 2 standard error calculations, one where $\pi_1 = 0.24 - 0.047$, and one where $\pi_2 = 0.24 + 0.047$, and by taking the highest and the lowest values from the estimated ranges.

n = 76 farms sampled with cereal area over 28 ha.

N = 31486 (approximately) farms in England and Wales with a cereal area over 28 ha.

$\pi_1 = 0.24 - 0.047 = 0.193$

$\pi_2 = 0.24 + 0.047 = 0.287$

In this case the $S.E._{(p)}$ for $\pi_1 = 0.045$ and the $S.E._{(p)}$ for $\pi_2 = 0.0518$, indicating that the number of farms with over 28 ha cereals which has more than one arable crop sprayer on lies between extreme values of 4654 and 10667. If 10% of these farms have adopted an electrostatic sprayer by 1990, this suggests 450 - 1050 adopters, based on this criterion.

In analysing data supplied by CDA Ltd. on the extent of the diffusion of the Ulvamast (a crop sprayer that can apply only a restricted range of chemicals - fungicides and insecticides) through England and Wales, it was found that five years after it's introduction, the extent of diffusion of the Ulvamast among cereal growers with more than 125 ha of cereals in the MAFF regions ranged from 4.1 % to 10.3% (see Table 7.2). Assuming that an electrostatic sprayer offering a restricted range of chemicals appeals to a similar type of farmer who adopted the Ulvamast, then this may be used as a fourth criterion in estimating possible numbers of adopters. The total number of farmers in England and Wales growing over 125 ha cereals is 6729. Five years after the introduction of the Ulvamast, a best penetration of 10% was achieved in one MAFF region. If electrostatic sprayers begin to be available in 1985, then after 5 years (1990) assuming a penetration of 10% (similar to the best the Ulvamast could achieve), then approximately 670 farmers will have adopted.

Table 7.3 shows the possible number of adopters in England and Wales

TABLE 7.2. Adoption of Ulvamasts in MAFF Regions, 1977-1982.

MAFF Region	No. of adopters of Ulvamast	No. of farms with ≥ 125 ha cereals (1982)	% adoption of Ulvamasts (as a % of holdings with cereal area ≥ 125 ha)
Northern	41	998	4.1
Midlands & Western	34	805	4.2
Eastern	168	2906	5.8
South Eastern	72	1250	5.8
South Western	36	741	4.9
Wales	3	29	10.3
ENGLAND & WALES	354	6729	5.3

TABLE 7.3. Potential and projected numbers of adopters in England and Wales by 1990 of an innovative sprayer introduced in the mid-1980s.

Criterion	Chemical range available with innovative sprayer	Potential farmer adopters in England & Wales (1982 figures)	No. of contractors	No. of adopters by 1990, assuming 10% of farmers adopt, and 100% of contractors in England & Wales	Sales in British Isles to 1990*
Cereals area ≥5 ha	Full	60 540	140	6190	7770
Cereals area ≥30 ha	Full	29 900	140	3130	3910
At least two arable sprayers on farm	Restricted	4650 - 10670	140	600 - 1210	730 - 1480
Cereals area ≥125 ha	Restricted	6 729	140	810	990

* Figure obtained by multiplying the projected number of farmer adopters in England and Wales by 1.26 = $\frac{445}{354}$ = $\frac{\text{Total sales of Ulvamast in British Isles}}{\text{Total number of adopters of Ulvamasts in England \& Wales}}$ (see Table 6.17)

+ 140 for adoptions by contractors.

by 1990, using the four criteria outlined in this section. There are approximately 140 contractors who are members of the National Association of Agricultural Contractors and who offer ground crop spraying services in England and Wales (NAAC, 1980). In arriving at total numbers of adopters, it is assumed that all of these contractors adopt electrostatic sprayers.

From Table 6.17 it can be seen that five years after the introduction of the Ulvamast, there were approximately 1.26x as many sales of the Ulvamast as there were adopters in England and Wales (i.e. purchases from Scottish and Irish farmers, repurchasing, multiple purchasing). Assuming the introduction of electrostatic sprayers in 1985, then after five years (1990), sales in the British Isles could be approximately 1.26x the number of adopters in England and Wales - figures are given in the right-hand column of Table 7.3.

Farming adopters of electrostatic sprayers would tend to be growers with large arable enterprises. This would have a disproportionate contribution on the arable area sprayed with such machines, compared with other sprayers in use. According to diffusion theory, with time more laggardly farmers (i.e. smaller farmers) would adopt electrostatic sprayers. Owing to the difficulties involved in quantifying the costs and benefits of plant protection activities, it might be expected that such new technology would never reach 100% adoption, particularly among smaller farmers. In fact most respondents in the postal survey did not believe that "new designs" of crop sprayer, such as rotary atomizers and electrostatic sprayers, would completely replace current technology, such as hydraulic pressure sprayers. However, small-farmer adoption of new technology might be encouraged by making smaller, cheaper models available. In addition to psychological and sociological factors contributing to resistance to change, smaller farmers use machinery less, meaning that it is replaced less frequently. In addition, purchases of second-hand machinery may retard the adoption of new technology.

7.4.4 Ground-pressure reducing techniques and sprayer monitors

Ground-pressure reducing techniques cover articles such as double wheels, flotation tyres, as well as low-ground-pressure vehicles (LGPV's). In the random user survey, 68% of respondents were found to have at least one of the above devices. However, only 7 (9.6%) owned an LGPV. The responses to statement 4 suggest that by 1990 virtually all arable farms will have some sort of device to reduce ground pressure. However, this is not always going to be an LGPV. Rutherford (1980) stated that only farmers with more than 100 ha of cereals would be able to justify purchase of "specialist spraying machines". From 1982 figures of cereal holdings in England and Wales (Table 7.1), this suggests that there are 9461 potential farmer adopters, plus more contractor adopters. Rutherford (1980) suggests that specialist spraying machines will be taken up on about 3000 holdings.

Although only 9.6% of respondents in the random user survey had some form of electronic sprayer monitoring or control system, the response to Statement 5 in the postal survey suggests extensive use by 1990. Approximately 80,000 sprayers are in use on farms in England and Wales at present (Figure 4.3). Sprayers last approximately seven years before they are replaced (Table 2.5) suggesting average yearly sales of sprayers among farmers in England and Wales as approximately 11400. By 1990 several tens of thousands of electronic sprayer monitors may have been sold, particularly if supplied with new sprayers.

7.4.5 Summary

Whilst there will be substantial increases in the use of new crop spraying technology by 1990, expert opinion also believes that the use of hydraulic pressure sprayers will still be widespread.

By 1990, crop sprayer designs may be more wind-tolerant. Spraying will be carried out at a higher speed, using reduced volumes of both diluent and active ingredient. Some legislated controls will be in force on spraying operations, but controls will not extend to the licensing of operators.

It is felt by the majority of experts consulted that rotary atomizers will have a full range of chemicals approved for use with them in 1990. However, electrostatic sprayers are more likely to have only a restricted range of chemicals, and this may affect sales accordingly. Returnable containers appear to be unpopular, particularly amongst agricultural merchants and agrochemicals manufacturers, but the concept of disposable nozzles was received more favourably.

7.5 Other factors influencing the uptake of new technology.

7.5.1 Introduction

In deciding on responses to questions and statements in the postal survey, respondents make a number of implicit and unstated assumptions. In this section, some of the factors that may have influenced respondent's replies and provoked comments are outlined. If these factors differ in their influence on adoption in a manner different from that envisaged by respondents, forecasts of the adoption levels of new technology may change, also the rate of diffusion of an innovative device through the farming community.

7.5.2 Chemicals

Machinery associated with crop spraying is basically the vehicle for ensuring that crop protection chemicals are applied as efficiently and economically as possible. Accordingly the fate of new crop spraying technology is intimately bound with developments in plant protection chemicals, and it is therefore constructive to examine possible future developments in the UK agrochemicals market.

Indicators from Chapter Four and responses to Question 1 of the postal survey suggest that for some crops at least, the frequency of applications will rise by 1990 (but not necessarily the volume applied). Respondents commenting in the postal survey suggest that growth areas in the chemicals market are: autumn-applied chemicals (herbicides and fungicides) and spring herbicides.

Regarding the development and introduction of new chemicals to the market, the possible future position is not clear. What is not in doubt is the predominance on world markets of chemicals for cotton, soyabeans, maize, rice and wheat. Due to the size of the chemicals market for each of these crops, most R & D efforts toward the production of new chemicals is slanted towards these crops, and towards the needs of the US market. "New" chemicals sold for use in the UK are generally "spin-offs" of chemical developments for other crops in other countries or are re-formulations of existing chemicals. Future introductions of new chemicals seem likely: most research workers in the pesticide industry, while accepting that the discovery of suitable new compounds is becoming more difficult, maintain that the potential resources are still extremely large (Patton, Craig and Conway, 1982).

New crop spraying technology allows the dosage, distribution and timing of chemical applications to be carefully controlled. This not only leads to greater efficiency in pesticide use, and so results in precise levels of kill without broader environmental contamination (Conway, 1982). Varying the dosage, distribution and timing of pesticide applications are alternative tactical options for influencing the rate at which resistance develops to individual chemicals (Comins and Conway, 1982). Thus new spray technology may help prolong the useful life of some pesticides. However, where farmers adopt new technology that may conserve pesticide susceptibility, their efforts may be nullified by the migration of resistant pest populations from neighbouring farms where high pesticidal selection is being exerted (Conway, 1982). Individual farmers therefore have little incentive to adopt new spraying technology on the grounds that it prolongs the useful life of chemicals. In order to combat resistance to chemicals, methods of application must be used over a whole region, the use of such methods being promoted or legislated for by governments or other official bodies.

7.5.3 Statutory controls

The effects of statutory controls on the uptake of new crop spraying technology cannot be easily predicted. Restrictions on the use of certain chemicals or machines may promote or retard the diffusion of machinery innovations, depending on exactly what is banned or restricted. When a government wishes to restrict the use of an item, it has as an alternative the possibility of imposing taxes on the item. If taxes on pesticides are imposed or increased, the adoption of new crop spraying technology may be promoted, as innovative crop sprayers may use less active ingredient. They also direct chemicals to the target more accurately, with less waste. In fact the adoption of new crop sprayer technology may pre-empt demands for the restriction of use of chemicals.

7.5.4 Other technology

Among respondents in the postal survey, a substantial majority disagreed with the proposition that the acreage sprayed by hydraulic-pressure sprayers would decline by more than 50% by 1990. One respondent commented that the development of new nozzle types would stimulate defensive R & D for the hydraulic pressure nozzle. Some chemicals are approved for use with hydraulic-pressure sprayers in volumes as low as 80 ℓ/ha (the "seven gallon" system). At these volumes, and ensuring rapid tank refilling, high spraying speeds and suitable sprayer dimensions, it was shown in Chapter Five that hydraulic-pressure sprayers could compete with new crop spraying technology applying chemicals and diluent at much lower volumes. However, in order to achieve high work-rates with hydraulic sprayers as outlined above, a high quality of management is required.

It was indicated in Section 5.4.6 that soil wetness was one of the most critical environmental factors constraining spraying operations. The use of LGPV's and other ground-pressure reducing implements may in fact lessen the justification for adoption of new crop spraying technology (rotary atomizers, electrostatic nozzles), even though such nozzles may be more wind tolerant. This is because the number of spray-days achieved by using an LGPV with an hydraulic-pressure sprayer may be sufficient for most farmers' needs. On the other hand, a rotary atomiser or electrostatic sprayer mounted on an LGPV could offer an unsurpassable number of spray-days through the year (Section 5.5.4).

In the future, it may be that market breakthroughs will be brought about by development of new formulations, in addition to new application techniques. Such formulations would include seed dressings, granules, encapsulated chemicals and impregnated strips. Alternatively, new application methods may be further developed, such as rope wick applicators (Wills and McWhorter, 1981), or new "cultural" methods, such as electrical weed control (Kaufman and Schaffner, 1982). The introduction and extensive use of such techniques would have uncertain effects on the adoption of new nozzle types.

Although biological control will not have any significant impact in UK arable crops in the foreseeable future (see Section 2.3), "integrated control programmes" may come into use. This would integrate chemical and non-chemical pest control methods with the use of forecasting systems, eg. the "EPIPRE" system(Rijsdijk,1982). Results from a "Delphi"-type survey on future developments in insect control (Anon, 1982) indicate that the widespread use of integrated control programmes is not likely in Europe before 1990, with the possible exception of pest forecasting systems. Integrated control programmes encourage the use of application methods that allows the accurate application of the minimum amount of chemical consonant with adequate pest control.

7.5.5 Input prices, and exogenous economic factors

Changes in relevant economic factors may have uncertain effects on the spread of new crop spraying technology. Whilst factors such as a rising real price of pesticides may encourage the uptake of methods reducing the use of active ingredients in pest control, the effects of changing crop prices are less predictable. As indicated in Section 6.2.1, farmers are on a "technological treadmill", and must constantly innovate in order to remain competitive, and stay in business. If crop prices are falling, then economic theory dictates that farmers should innovate at an increased rate, so as to take advantage of increased efficiency of inputs in the production function (Section 6.2.1) in order to maintain profitability. However, falling crop prices in an economy where crop prices are usually stable or rising (as a result of government intervention with some form of subsidies to ensure stability) may be indicative of unstable and uncertain markets. In such conditions, farmers may choose not to innovate, as the risks and uncertainties associated with the uptake of new technology are too great. At present, the UK and EC provide farmers with a very stable economic and production climate, where it benefits farmers to maximise production. However this may not necessarily persist.

7.6 Summary

1) Technological forecasting attempts to anticipate technological change. The method of technological forecasting used is that of expert opinion, using a truncated "Delphi"-style survey, as described in Section 3.3.16.

2) Respondents believed that a substantial penetration of new crop spraying technology would occur among British farmers by 1990. The use of hydraulic pressure sprayers and aerial spraying was forecast to decline by 1990.

3) Respondents indicated that reductions in diluent and active ingredient applied would occur by 1990. Sprayers may also travel faster, and be more wind tolerant.

4) A majority of respondents view some form of legislated control on spraying likely by 1990. The development of a full range of chemicals approved for use with rotary atomisers is thought more likely than with electrostatic sprayers. Respondents do not approve of returnable containers, but are more positive about combined disposable containers-cum-nozzles.

5) Using four different criteria, an estimate was made of the likely numbers of adopters of a notional electrostatic sprayer by 1990. With a full chemical range on offer, an estimate of 3130 - 6190 adopters in England and Wales was made. With only a restricted range of chemicals, the number of likely adopters dropped to 600 - 1210.

6) Factors which may radically influence adoption levels of new crop spraying technology by 1990 are discussed.

CHAPTER 8

CONCLUSIONS

In this last section it is the intention to briefly summarise findings of interest in the previous chapters, and to discuss the implications of these findings with reference to the adoption of new crop spraying technology.

In Chapter Two an overview was made of the topic of crop protection; subjects covered included methods of pest control available, and economic aspects of chemical applications and machinery. It is indicated that the prospects are poor for integrated pest management schemes in major arable crops in the foreseeable future. However certain forecasting methods may be in widespread use within a few years, e. g. the EPIPRE system (Rijsdijk, 1982). Advances in remote sensing devices and the widespread uptake of farm computers and other information collecting and disseminating systems (e.g. Prestel) may facilitate the uptake of such forecasting systems. The use of such information has implications for the strategies that farmers will adopt in applying chemicals.

It is almost impossible for the average farmer to be able to quantify such factors as economic thresholds for spraying, or cost/damage functions, for a given crop-pest combination. Instead the farmer must rely upon experience, the perception of losses caused by insect attacks, and the perceived value of available control methods. The increased use of computerised information systems and the growth of independent crop consultants may help many farmers decide whether to apply a chemical in a more efficient and informed manner.

Due to increasing investments in machinery, and the increased use of such items as fertiliser, pesticide and irrigation techniques, farmers can often predict the yield of their crops to within an order of magnitude. This fact, combined with the nature and extent of production subsidies offered by the EC and UK governments, means that for many farmers, profit maximisation is almost synonymous with maximizing yield. Farmers therefore have every reason to adopt new technology that increases yields or reduces input costs. However in Section 6.2 it was indicated that for many agricultural innovations, earlier adopters obtained the greatest economic benefits from new technology, the remainder of farmers following on the technological treadmill. The cumulative influences of technological change in agriculture can be to have widespread economic and social effects; apart from farmers, other groups may benefit differently or even suffer costs due to the introduction of new technology. In evaluating the effects of new technology, economic benefits are typically estimated but potential costs ignored (Zuiches, 1983).

Governments and regulatory bodies should routinely evaluate all benefits and costs when considering actions likely to influence the availability, uptake and impact of agricultural innovations. Examples of such actions are legislation, official recommendations and regulations, and resource allocation (e.g. directing funds for research). However it is often difficult to confidently predict what the future impact of new technology will be, particularly when specific types of new technology are considered. In this thesis, 'micro'-scale aspects of specific items of new technology have mainly been considered, rather than 'macro'-scale (social, political) effects of new technology in general.

Taxation may distort rational replacement policies on the farm; machines may be bought more for their ability to reduce the marginal taxation rate, and for capital benefits, rather than for urgent need of the machinery. The effect of tax may be to encourage speculative purchasing, among which new machinery technology could be adopted for less than entirely rational reasons.

The increasingly intensive methods of cereal production in British farming, and the dominance of autumn-planted cereal varieties means that the autumn months are the busiest of the arable farmer's year. New technology capable of improving workrates in operations carried out at this time of year would therefore be looked upon particularly favourably. There is some evidence that more autumn spraying is being carried out, using pre-emergent and early post-emergent herbicides, and of the use of fungicides. In addition, oilseed rape is an increasingly popular crop that relies upon several autumn herbicide applications.

Undoubtedly chemicals applied to crops in the next few years will change as new chemicals are introduced, older pesticides phased out, and the nature of pest problems change.

In Chapter Three the methodology of surveys carried out are outlined. The high response rates from each of the three surveys carried out indicates that possible bias brought about by non-response is probably not of sufficient significance to endanger the validity of survey results.

In Chapter Four it is demonstrated that spraying operations tend to be a fairly small part of the yearly workload on most farms, being only intermittently important as a proportion of all other jobs on the farm. However, the sensitivity of spraying to the weather, the uncertainty associated with crop/pest relationships, and the possibility of high perceived opportunity costs following the untimely application of a pesticide mean that the importance of spraying operations to most farmers is likely to be out of proportion to the total time taken up in spraying operations through the year.

In the postal survey of experts in agriculture a significant percentage of respondents believed that the number of passes through cereals applying chemicals will increase in the next few years. New crop spraying technology may support this trend; sprayers using new nozzle types (e.g. spinning-discs) are often capable of high daily workrates, and are less constrained by the weather than conventional spraying systems. Accordingly farmers will find it possible to apply chemicals to crops on more occasions through the year; this may lead to changing patterns in chemical usage. However, the trend towards increased number of applications may be countered by an increasing tendency to tank-mix chemicals; evidence for this trend is given by the recent introduction of tank-mix advisory supplements given in such magazines as Farmers Weekly.

In comparison with many other articles of farm equipment, and also relative to the value of the chemicals applied through them each year, sprayers are fairly cheap. They also appear to be frequently neglected. Information from the random user survey and an ADAS survey of sprayers on farms (ADAS, 1976) indicates that on many farms calibration is carried out infrequently, nozzles are allowed to emit poor spray patterns, and sprayers do not seem to be replaced particularly often. In addition, relatively few farmers have attended courses on spraying run by the ATB, ADAS, or other concerned bodies. In conclusion, the level of training in spraying and the maintenance of sprayers seems to be fairly poor.

Contractors appear to be an important factor to take into account when considering the likely spread of new farm machinery. Riches (1979) indicated that contractors have been important in facilitating the spread of certain agricultural innovations, including farm machinery. Contractors are heavily used for spraying operations when the farmer cannot get in to the crop, either due to soil wetness, or the height of the standing crop. Spraying is often an operation that has to be carried out under these conditions. In addition to farmers, contractors may also form an important market for new farm technology.

Many items of farm machinery, sprayers included, are becoming increasingly complex in operation and maintenance. The range of chemicals, additives and potential tank-mix combinations now available may have a bewildering effect on many farmers. These trends may provide a cue for many contractors to provide services using machines that farmers feel unwilling or unable to purchase or operate. In the postal survey, a majority of respondents indicated that less aerial applications would be likely by 1990. The widespread use of specialist vehicles for field operations may well be associated with this change. By specialist vehicles are meant LGPVs, high-clearance vehicles and other high speed transportation. The widespread adoption of small CDA sprayers capable of very high workrates may well presage a change from using tractors to draw the sprayer to smaller, higher speed vehicles.

In Chapter Five the logistics of crop spraying operations were discussed in detail. Six groups of factors were described which can influence the workrates attainable from farm spraying operations. Three groups of factors may be manipulated in spraying systems design: sprayer dimensions, potential spraying speeds, and range of available application rates. The farmer has direct control over a fourth factor, refilling arrangements. Two other factors, whilst less easily altered, are very important in influencing workrates: field size/farm conformation, and time spent in calibration, adjustments, breakdowns and delays.

The Baltin model was used as a basis for simulating farm spraying operations; good agreement was achieved between simulation results and workrates claimed by farmers. Using the model the influence of individual factors and combinations of factors on attainable workrates was explored. In the results, it was found that small (tank capacity & boom width), high-speed sprayers at low application rates can match much larger sprayers using conventional application rates (e.g. medium volume - 200 l/ha) and moderate speeds, even if using fast refilling systems. However, at high spraying speeds, boom bounce is a constant danger: the most commonly encountered problem with sprayers among respondents in the random farmer survey was boom whip and breakage. Secondly, at high speeds, the performance of individual nozzles must be watched carefully in order to ensure even coverage of the target. This is especially critical when applying chemical at low volumes. Therefore high-speed/low-volume spraying systems demand consistently high standards in operation and maintenance.

A crop spraying system capable of a high workrate, flexibility in application and accurate chemical targetting should possess the following attributes:

1) Capable of high speeds/low ground pressure/ high clearance
2) Capable of spraying at low application rates, with some flexibility in rates that can be applied, and control over droplet sizes.

3) Good boom suspension

4) A sprayer operator trained to a high standard

5) An automatic volume regulating system (AVR) present, with a monitoring device to indicate nozzle malfunctions.

Note that whilst CDA sprayers (e.g. spinning-disc, electrostatic) pulled by a specialist vehicle can satisfy most of the above criteria, it may also be possible for hydraulic-pressure nozzle sprayers to do so as well.

It may not be possible to reduce total volumes used by a great amount when applying certain chemicals, e.g. soil-applied herbicides, dessicants. If CDA sprayers cannot apply at the rates required for all chemical applications on the farm, then if a farmer is considering the purchase of a CDA sprayer he will take into account the implications of only being able to apply a limited range of chemicals. Similarly, certain CDA sprayers may only have a restricted range of chemicals for use with them, owing to formulation difficulties.

Also in Chapter Five, the effect of environmental parameters on the feasibility of crop spraying was discussed. Wind, rain, soil moisture and frost are among the most significant weather constraints. However, farmers are prepared to be fairly flexible in the windspeeds in which they are prepared to spray.

Using weather observations made at Benson for the 1981/2 growing season, it was found that there were very few spraying opportunities available using tractors not equipped with flotation tyres or double wheels. Eliminating the soil moisture constraint ensures spraying opportunities are available for most of the year. This is especially so when wind constraint levels are relaxed. In addition, oil-based formulations (e.g. "CODA", chemicals for use in the "Electrodyn" system) may prove to be more rainfast on leaves and thus help to ease precipitation constraints.

With spraying systems which are capable of applying chemicals at any soil moisture level and the wind constrains spraying only at $\ngtr$ 7.7 m/s, then there are a large number of spraying opportunities available through the year. In this case the necessity for a large sprayer is reduced, as relatively small combinations will find it possible to do the job given the number of spray-days available.

In Chapter Six the method by which innovations are taken up and diffuse through farming communities were discussed. The adoption of innovations is taken as a particular case of decision-making under risk and uncertainty. An attempt was made to measure innovativeness and other orientations to new technology. An investigation was made of the factors found to correlate with a propensity to adopt arable innovations. From the results of this study, using data from the random user survey, a picture may be built up of the characteristics of an earlier adopter of arable innovations:

1) Large cereal farmer
2) Sprays crops quite intensively at present
3) Fairly young
4) Likely to be formally qualified in agriculture
5) A source of information and advice for other farmers (i.e. some degree of "opinion leadership").

6) High self-rating of innovativeness

7) Some dissatisfaction with current spray gear.

Results from previous studies on innovativeness have much the same pattern as above; in addition, results from the Ulvamast user survey tend to bear out this pattern.

Farm and farmer characteristics may be used as independent variables in locating correlates with past innovativeness (the dependent variable), in attempting to predict future adoption behaviour. Methods used in prediction studies are outlined in section 6.6.13. Hooks et al (1983) carried out a survey on the use of new technology among Ohio farmers. It was found that variables indicative of wealth and access to funds (e.g. farm size) tended to be better predictors of the adoption of new technology than were variables selected to represent aspects of the diffusion process (e.g. use of information sources). The authors conclude that "farmers with larger farms tend to use more complex technologies and to employ high technology equipment" (Hooks et al, 1983). Using findings such as these, change agents (e.g. extension officers, company representatives) can channel resources more efficiently in attempting to facilitate the uptake of new technology among farmers.

Between 1977 and 1982 the number of agricultural holdings in England and Wales fell from 199 131 to 185 414. During the same time period the number of holdings with over 100 hectares of land rose from 28 781 to 29 173. From these figures it appears that structural changes are still taking place among British farms. As holdings merge the number of potential adopters of innovations will change. For the innovations which tend to be applicable to larger farms, the structural changes may well increase the number of potential adopters.

In Chapter Seven a report was made of results from the postal survey of agricultural experts. The impression given from the results is that considerable changes will occur in plant protection practices by 1990, not the least of which will be the widespread adoption of new technology. It remains to be seen which nozzle system will be most widely used to apply the farming community's chemicals. In Chapter Seven the likely number of adopters by 1990 of an innovative sprayer first introduced in this decade was discussed. Depending on the range of chemicals available with such a sprayer, and it's applicability to smaller farmers, the likely number of adopters in England and Wales may range from 600-1210 with a restricted range of chemicals available, or 3130-6190 with a full range of chemicals available.

In conclusion this thesis has examined the non-biological factors relevant in the consideration of how new crop spraying technology will fare in British agriculture. Data from surveys has been heavily used in attempting to establish the likely utility and fate of new technology. It is hoped that it is not only the reader of this text in 1990 that will be in a position to judge the usefulness of this work, but that it will stimulate discussion and criticism amongst more contemporary readers in the never-ending task of peering into the future.

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APPENDIX

Glossary

nmd	-	Number median diameter. A term which applies to a collection of spray droplets. The droplet diameter x at which the number of droplets with a diameter less than x equals the number of droplets with a diameter greater than x. Also see vmd.
pest	-	Any organism contributing to a reduction in crop quality or quantity
pesticide	-	A chemical that checks or destroys pests
SMD	-	soil moisture deficit. The amount of precipitation required (in mm) to bring soil to its field capacity. A soil's field capacity may be defined as the amount of water held in a freely draining soil 24 hours after that soil was saturated with rainwater.
vmd	-	volume median diameter. A term applying to a collection of spray droplets. The droplet diameter x at which the total volume of droplets with a diameter smaller than x equals the total volume of droplets with a diameter larger than x.

IMPERIAL COLLEGE, SILWOOD PARK

Ascot. Berks SL5 7PY Telephone: 0990 23911 ext. 308/309
Director: Professor M.J. Way. M.A., D.Sc.

I am writing to request your help in a survey I am conducting on farmer's attitudes to crop spraying machinery.

I am a research student at Imperial College, London University. At present I am interviewing farmers, as part of a project aimed at developing a better understanding of farmer's needs from crop sprayers. The main aim of the project is to provide engineers with information on the requirements of farmers from their sprayers. This will help them in designing more efficient and effective machines.

I am planning to interview a number of farmers in your area who have a farm size of 125 acres (50 hectares) and over, with at least 50 acres (20 hectares) of cereals. I am writing to you in the hope that if your farm is in this category, you will agree to co-operate in my survey. I realise that you have a great many demands on your time, but the interview will only take about half an hour. All the information you give me will, of course, be treated in the strictest confidence. Results from the survey will be presented in a "pooled" form, so the individual farmers cannot be identified.

I hope you will agree to participate in my survey. I will contact you by telephone in the next few days to arrange a convenient time to visit you.

Anthony Smith

IMPERIAL COLLEGE

MACHINERY SURVEY - FEB/MAR 1982

CONFIDENTIAL

Date ____________

Farm No. __________

Grid Ref. _________

1) What area do you farm on? (all crops; include owned, rented land)

__________ acres __________ hectares

2) Which crops are you intending to grow for 1982, what is the approximate area for each crop? (place answers in table below Q. 3)

3) Have insect, weed or fungal attack contributed to any change in acreage/hectarage for each crop from last year?

CROP	1982 AREA (has./ acres)	F, W, I, CAUSING AREA CHANGE
1		
2		
3		
4		
5		
6		

3)a) Do you have a system of rotation? (If YES, PROBE, put answer above)

4) How many sprayers do you: OWN ______ (excluding knapsack/hand-held sprayers)

LEASE ______

(temporarily) HIRE ______

5) Can I have more details of your sprayers - the make, type, age, and approx. tank capacity and boom width.

MAKE	TYPE (M, T or S)	AGE (years)	TANK CAP. (l./galls.)	BOOM WIDTH (yds./m.)	O, L or H

(IF NO SPRAYING/GRANULAR APPLICATORS O, L or H GO TO 12)

Do you have any band sprayers? YES ______ NO ______

(If YES) Can you give me details. (ENTER ANSWERS IN TABLE BELOW Q. 5)

Do you have any granular applicators that you apply chemicals with? YES ______ NO ______

(If YES) Can you give me details. (ENTER ANSWERS IN TABLE BELOW Q. 5 - for tank cap. enter hopper cap.)

6) (IF MORE THAN ONE SPRAYER ON FARM) Do you use all your sprayers the same amount? YES ______ (GO TO 7) NO ______

Which one(s) do you use most often? ______________________

7) (IF ANY SPRAYERS LEASED) What are your reasons for leasing sprayers? ______

How often are they changed? ______________________

8) (IF ANY SPRAYERS OWNED) How long do you keep your sprayer(s) (that you use the most,) before you replace it (them)? (RING ONE)

0-2 years 3-5 years 6-10 years 11+ years other ______

What are your reasons for changing it (them) at this frequency? ______

9)a) When you are spraying, how do you refill your sprayers? travel back to farm bowser/"spray assistant" river/pond other ______ (RING METHODS USED)

9)b) What volume do you generally spray at? ______

9)c) What percentage of time spraying is spent refilling your sprayer, and travelling to and from refilling?

0-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 80+

10) What are the main problems you've met with your sprayers in the field?

BOOMS VOLUME WEIGHT GAUGES CONTROLS ACCURACY CALIBRATION DRIFT TANK COMPLEXITY NON-HYDRAULIC DRIP FLEXIBILITY REPAIRS (RING, & PROBE)

11) How often do you calibrate your sprayers? every: ______ hours

______ weeks ______ months every year

other answers ______________________ (FILL IN/RING)

THREE

12) For the last growing year, 1980-81, what was your spray programme, for:
(REFER TO TABLE)

CROP	Aut. H	Spr. H	F	I	PGR	TANK MIXES
W. Wheat						
W. Barley						

(If any, fill in details for major other crops grown)

Were any of these applications tank mixes of chemicals? YES ____ NO ____(go to 12c)
(If YES) Which chemicals were tank mixed? (Place answers in table)

12c) About how often do you use tank mixes when spraying?

at every opportunity   mostly   sometimes   rarely   never   (RING ONE)

How often would you like to use tank mixes when spraying? ________________

____

____

13) Do you buy chemicals well before you intend to use them, or do you wait until you need them, before buying? BUY AHEAD ________ WAIT UNTIL NEEDED ____

What are your reasons for doing this? ________________________________

____

14a) When you spray your cereals, how do you decide when to spray the crop with:
1) Pre-emergent herbs. 2) Post-em. herbs. 3) Fungicides 4) Insecticides

	1 (DATE)	2 (MEDIA)	3 (REP)	4 (MONITOR)	(State alternatives as on sheet 14a)
PRE-EMERGENT HERBS.	___	___	___	___	(TICK METHOD(S) USED IN EACH ROW)
POST-EMERGENT HERBS.	___	___	___	___	
FUNGICIDES	___	___	___	___	
INSECTICIDES	___	___	___	___	

(IF COLUMNS 2 OR 3 USED) What is your source of information?

2: press   radio   TV   mail   Specify: ________________

3: ADAS   rep   consultant   Specify: ________________

FOUR

14b) When you sprayed your crops last year, did you run into any problems, regarding:

i) the EFFECTIVENESS of any of your chemical applications against pests, weeds or diseases (PROMPT & PROBE)

ii) LABOUR SHORTAGES when you wanted to spray in the AUTUMN, SPRING or SUMMER

iii) the WEATHER preventing you from spraying when you wanted to, in the AUTUMN, SPRING or SUMMER. (PROMPT & PROBE)

(RECORD ANSWERS IN TABLE BELOW)

TIME OF APPLICATION	CHEM. EFFECTIVENESS against pests, weeds & diseases	LABOUR SHORTAGE at spraying time	WEATHER prevents spraying - specify which elements
Jan.			
Feb.			
Mar.			
Apr.			
May			
Jun.			
Jul.			
Aug.			
Sep.			
Oct.			
Nov.			
Dec.			

(FILL IN PORTIONS OF TABLE ACCORDING TO RESPONSES- SEE KEY SYSTEM BELOW)

Scoring system	Crop key	Weather elements
0 = NO PROBLEMS	WC = WINTER CEREALS	W = WIND
1 = FEW PROBLEMS	SC = SPRING CEREALS	R = RAIN
2 = SOME PROBLEMS	SB = SUGAR BEET	T = TEMPERATURE
3 = CONSIDERABLE PROBLEMS	O = OIL SEED RAPE	S = SOIL MOISTURE
4 = SEVERE PROBLEMS	P = POTATOES (abbreviate others appropriately)	(describe others in matrix)

5) When you are intending to spray, where do you get weather forecasts from?

PRESS   RADIO   PHONE WEATHER STATION   OWN JUDGEMENT   (RING ONE)

- 365 -

FIVE

16) Have you ever received any complaints about drift from your spraying activities? YES _______ NO _______

(IF YES) Who from? ____

____ (GO TO 18)

17) Do any other farmers find spray drift to be a problem in this district?

YES _______ NO _______ DON'T KNOW _______

(IF NO SPRAYERS O, L or H GO TO 19)

18) Do you ever do any contract spraying?

YES _______ NO _______

(IF NO, GO TO 19)

What area did you spray under contract in 1981?

_______ acres _______ hectares

Do you advertise your services, or do you just spray from time to time for neighbours? ____

____

How important is contracting to you when measured against your other farming activities? ____

(PROMPT: very important, quite important, fairly imp., not very imp., insignificant)

19) Have you ever had any ground or aerial contract spraying done on your farm?

YES _____ NO _____ (GO TO 23)

SIX

19 - cot'd) What crops did you have contract sprayed in 1981? How many times was each crop sprayed, and against what was each crop sprayed?

CROP	NO. OF TIMES CONTRACT SPRAYED	PESTS IN CROP	A(aerial) OR G(ground)

20) Were any of these applied from the air? (PUT "A" IN TABLE ABOVE)

21) Do you have a regular arrangement with a contractor for spraying your crops?

YES _______ NO _______

Does your contractor supply the chemicals? YES ____ NO ____ _____ %

21)b) What is your main reason for calling in a contractor to do spraying for you?

LABOUR TIMELINESS CHEMICAL HANDLING APPLICATION COST FIXED COSTS EMERGENCY ____ (RING, EXPAND BELOW)

____

22) What type of contractors do you use? FULL-TIME SPECIALIST

ESTABLISHED FARMER-CONTRACTOR NEIGHBOUR ON A CASUAL BASIS MACHINERY DEALER (RING ONE)

When you are interested in a new type of machine, do you get a contractor to use his machine on your farm, so you can see how it performs?

YES _____ NO ____ WOULD DO IF SITUATION AROSE _____

If YES, what machines have you done this in the past on? _______________

____

SEVEN

23) When did you first introduce the items on this list onto your farm, if you have done so? (introduce: buy, lease, hire) (SHOW FLASH CARD)

ITEM	YEAR FIRST USED	REASONS FOR NOT ADOPTING/DISCONTINUING
DIRECT DRILLING		
50+% W. CEREALS		
for		
LGPV's/DOUBLE WHEELS (delete one)		
TRAMLINES		
ULV/VLV/CDA SPRAYING (including "7 gallon system")		
SPRAYER MONITORS		

What are your reasons for not buying/practising those you have not mentioned? (PUT ANSWERS IN TABLE)

Do you still use all of those items that you have indicated using in the past - if not, why not? (PUT ANSWERS IN TABLE)

24) Have you heard of "spinning-disc" sprayers?

YES ____ NO ____ (GO TO 25)

How have you heard about them? ____________________

EIGHT

24a) Have you ever considered using them on your farm?

YES ____ (go to 24c) NO ____ (go to 24b)

24b) Why not? ____________________ (GO TO 25)

24c) Have you used them at all?

YES ____ (go to 24e) NO ____ (go to 24d)

24d) Why not? ____________________ (GO TO 25)

24e) Were/are you satisfied with it?

YES ____ (go to 25) NO ____ (go to 24f)

24f) Why not? ____________________

25) Have you heard about electrostatic sprayers?

YES ____ (GO TO 25a) NO ____ (GO TO 26)

25a) How have you heard about them? ____________________

25b) Do you know what advantages this type of sprayer has to offer? ____________________

26) How do you usually find out about new types of machinery? ____________________

27) Are you a:

owner-occupier tenant manager partner other ________ (RING ONE OR SPECIFY)

28) How long have you been running a farm? ________ years

29) Have you, or your sprayer operator, been on any courses on handling chemicals, sprayer calibration, or spraying operations?

YES ____ NO ____

30) Have you ever done any diplomas or degrees in general agriculture?

YES ____ NO ____

Please indicate how much you agree or disagree with each of the following statements.

Circle the number on the scale which is nearest your own view.

	DISAGREE	NEUTRAL	AGREE
Spraying is difficult to plan well ahead.	-1	0	1
It is worthwhile to calibrate sprayers as often as the manufacturers recommend.	-1	0	1
Contractors lead the way in using new machinery and techniques. . .	-1	0	1
Sprayers are difficult and expensive to maintain.	-1	0	1
Successful farmers are generally among the first to take up a new practice. . . .	-1	0	1
Crop protection chemicals are nowadays quite safe.	-1	0	1
Neighbours often come to me for information and advice.	-1	0	1
The amount of water needed to be mixed with chemicals is excessive.	-1	0	1
Being on the lookout for new ideas helps me recognize problems on my farm. . . .	-1	0	1
My sprayer doesn't always get the spray where I want it.	-1	0	1
Neighbour's experiences of a new item are important in helping me decide whether or not to buy that new item.	-1	0	1
Preparing the spraying mixture can be a hazardous operation.	-1	0	1
Profit maximizing is the main aim in farming.	-1	0	1
I am always among the first in my district to take up a new idea or practice. . . .	-1	0	1
Over the past few years, I have been satisfied by the performance of my spray gear.	-1	0	1

NINE

31) Which age group are you in:

under 20   20-29   30-39   40-49   50-59   60 plus

I've got a few more questions here I would like to ask you. They will take another 5 - 10 minutes. You can fill them in yourself if you wish. Would you l to fill them in now, or would you prefer to complete the questions at your conveinience? I can leave a stamped, addressed envelope to post it back to me you wish.

YES ______ (LEAVE S.A.E. & SHEET (marked with responde name), GO TO 31)

NO ______ GO TO 30

32) Do you wish to fill the questions in yourself, or would you like me to rea them out?

READ THEM OUT ______ proceed; go to 31

HAND OVER SHEETS ____ go to 31

33) Thank you very much for this information. Do you have any further comments about sprayers and spraying you would like to have recorded?

1) I PLAN SPRAYING WELL IN ADVANCE, AND DO IT "BY THE CALENDAR"

2) I SPRAY FOLLOWING WARNINGS IN THE PRESS, RADIO, OR MAIL THAT THE INSECT, WEED OR DISEASE MAY LOWER YIELDS

3) IF VISITING ADAS FIELDMEN, CHEMICAL REPS., OR A CROP CONSULTANT ADVISE SPRAYING, I WILL DO SO

4) I SPRAY ONLY FOLLOWING PERSONAL FIELD INSPECTION, COUNTING INSECT, WEED OR DISEASE LEVELS

---

23 FLASH CARD

DIRECT DRILLING

WINTER CEREALS OVER 50% OF TOTAL CEREAL ACREAGE

LOW GROUND PRESSURE VEHICLES OR DOUBLE WHEELS

TRAMLINES

VERY LOW VOLUME OR ULTRA LOW VOLUME SPRAYING TECHNIQUES (under 9 galls./acre)

ELECTRONIC SPRAYER MONITORING OR REGULATING UNITS

SCPM

SILWOOD CENTRE for PEST MANAGEMENT

IMPERIAL COLLEGE AT SILWOOD PARK, Sunninghill, Ascot, Berkshire SL5 7PY
Tel: ASCOT (0990) 23911 Telex: 261503

3rd January 1983

Dear Sir,

I am writing to request your assistance in a survey being conducted from Imperial College, London University. This survey is part of a study on users' opinions of several new types of crop sprayers. The results will be of use to engineers and designers in constructing new crop spraying machinery, to improve spraying in the future.

In the course of this study of spraying machinery, I have been in contact with CDA Ltd., manufacturers of 'Ulvamast' sprayers. They have provided a list of individuals who have purchased Ulvamast machines. Since the best way of obtaining an unbiased view of users' opinions on sprayers such as the Ulvamast is to ask the users themselves, I am writing to ask if I could arrange an interview with you to get your opinions of the Ulvamast, and other sprayers. The interview would take about 20-25 minutes and will concentrate on spray machinery, not the chemicals applied by the machines.

This study is being carried out independently of any sprayer manufacturer, and individual answers will not be made available to CDA Ltd., nor to anyone else. Results will be published in a 'pooled' form, so that individual users cannot be identified. A summary of the results of the survey will be made available to you if you would like a copy.

I realise that you have a great many demands on your time, but I hope you will agree to participate in this survey. I will contact you by telephone in the next few days to arrange a convenient time to visit you.

Yours sincerely

Anthony Smith

IMPERIAL COLLEGE
ULVAMAST USER'S SURVEY - 1983

Date ______________
No. ______________
Grid Ref. ______________

1) What area do you farm? (all crops: include owned, rented land)

______________ acres ______________ hectares

2) What types of sprayers are there on your farm?
(prompt as neccessary, place information in table below.
Probe about Ulvamast(s), date(s) of purchase)

MAKE	TYPE (M,T,S,C)	AGE (yrs.)	TANK CAPACITY (galls/l)	BOOM WIDTH (yds/m)	O or L

I would like to find out how many passes sprayers made through your cereals in the last growing season (1981-2). Firstly,
3) What were your cereal acreages for the last growing season (1981-2)

CROP	AREA	NO. SPRAYS BEFORE XMAS	NO. SPRAYS XMAS - EASTER	NO. SPRAYS EASTER-HARVEST

4) How many passes through each crop applying herbicides, fungicides, insecticides or plant growth regulators did you make from (i)Before Xmas (ii) Xmas-Easter (iii)Easter-Harvest
5) (If Ulvamast still used) What was the Ulvamast used for applying?
(If CDA-type sprayer on farm)What was the CDA sprayer used for?

6) In 1981-2, on how many days were you spraying:

	SPRAYED	COULD HAVE SPRAYED	PART DAYS
BEFORE XMAS			
XMAS - EASTER			
EASTER - CEREAL HARVEST			

7) Could you have sprayed on more days than you did? (place answer above)
8) At what times of the year do you tend to spray in <u>parts</u> of a day?

9) When did you first hear about the Ulvamast? ______________

10) How did you first hear about it? ______________

11) What were your main reasons for buying one? ______________

12) Are you satisfied with the performance of your Ulvamast?

YES ______________ go to 14 NO ______________

13) If NO, why not? ______________

14) Have you stopped using your Ulvamast?

YES ______________ NO ______________ go to 16

15) If YES, why? ______________

16) What advantages or disadvantages does the Ulvamast have compared to ordinary hydraulic spraying machines? ______________

17) Have you heard of any new developments in spray machinery recently?

18) (If electrostatics not mentioned) Have you heard of electrostatic sprayers?

YES ______________ NO ______________ go to 21

19) How have you heard about them? ______________

20) What do you think of them? ______________

21) Now I would like to ask you some questions on the use & performance of the sprayers on your farm: the (largest) hydraulic sprayer(s), the Ulvamast(s),(if discontinued, their past use/performance) (& CDA boom-mounted sprayers, if any).

	HYDRAULIC	ULVAMAST	BOOM-MOUNTED DISC (if any)
CROP/CHEMICAL USE (SUMMARY)			
NORMAL SPRAYING SPEED km/hr mph BEST			
AVERAGE WORKRATES (h or ac/10 hr.day) BEST			
no. of hours spent spraying in a full working day:			
TOTAL VOLUMES GENERALLY USED (state units)			
METHOD OF REFILLING			
TIME TAKEN TO REFILL TANK			
AVERAGE TIME TAKEN TO REFIL TANK & MIX CHEM PER REFIL			
TOTAL TIME TAKEN TO REFIL & RETURN			

22a) What is the maximum distance you have to travel in order to get to your water supply?

__________ yds/miles/km

22b) What is the average?

__________ yds/miles/km

23) Do farm gates have any effect on how quickly you can move a sprayer around the farm?

YES __________ NO __________ go to 26

24) If yes, how long does it take to stop, open & close gates, & restart?

__________ s/min

25) On average, how many times would you do this in a days spraying?

____

26) Do undulations in the field slow you down at all?

YES __________ NO __________ go to 28

27)(if YES)How many more acres could you spray in a day if the undulations were absent from your fields?

__________ acres/%

28) Do slopes slow down your spraying operations at all?

YES __________ NO __________ go to 30

29)(if YES) How many more acres could you spray per day if slopes were absent from your fields?

__________ acres/%

30) Is your current spray gear adequate to deal with your spraying requirements on time:

a) in an AVERAGE growing season? YES ________ go to b) NO ________

(31) If NO, in what way? ____________________

____

b) for the WORST season for TREATING cereal insect, weed or fungal infections you have had in the LAST TEN YEARS?

YES ________ go to 32 NO ________

32) If NO, in what way? (which year, why) ____________________

____

33) (If answer to (b) NO) How many years out of 10 is it adequate? ________

34) In the last year, have you suffered any yield or crop quality losses because you could not spray when you wanted to, due to the weather?

YES ________ NO ________ go to 35b

35a) If YES to above what was the situation(s) (PROBE)

____

____

35b) What about in the past? (place answers above)

36) The weather may often prevent spraying when you want to do it. When you are thinking about spraying, which elements of the weather ON THIS LIST do you pay PARTICULAR ATTENTION to?
(hand list to respondent)

ELEMENT	ATTENTION	MONTHS
DAY TEMP		
NIGHT TEMP		
GENERAL TEMP		
FROST		
FROZEN GROUND		
SNOW		
SUNSHINE		
HUMIDITY		
GENERAL WINDINESS		
GUSTS		
RAIN		
FOG		
SOIL MOISTURE		

37) For each of those mentioned, during which months of the last growing year were they important? (place answers in table above)

38) How close to the start of rain will you risk spraying? ________

____

39) What is the maximum windspeed you will spray in, with:

	MAXIMUM	IDEAL
HYDRAULIC sprayers		
ULVAMAST sprayers		
CDA boom sprayers		

(show card with BEAUFORT definition)

40) Do you have either of these on your farm:

	YES/NO	FIRST YEAR ON FARM
DOUBLE WHEELS/FLOTATION TYRES		
LOW GROUND PRESSURE VEHICLES		

41) Could you have sprayed on more days if LGPV's, double wheels or flotation tyres were used instead of an ordinary tractor, in 81-82:

BEFORE XMAS ________

XMAS-EASTER ________

EASTER-CEREAL HARVEST ________

42) Over the year, have you been satisfied with the number of spray-days available, given existing machinery?

YES ________ NO ________

43) How can you improve it? ____________________

44) What sources of information do you use for:

	SOURCES	SATISFIED?
Weather forecasts		
New machinery		

45) Are you satisfied with the weather forecasts? (place answers in table above)

46) When did you first introduce the practices on this list onto your farm, if you have done so?

	YEAR FIRST ADOPTED	YEAR DISCONTINUED	REASONS FOR NOT ADOPTING, DISCONT.
DIRECT DRILLING			
TRAMLINES			
> 50% WINTER CEREALS			
SPRAYER MONITORS			
SPRAYING <9g/ac (if predates Ulvamast)			

47) What are your reasons for not buying/practising those you have not mentioned? (place answer(s) in table above)

48) Do you still use all those items that you have indicated using in the past - if not, why not? (place answer(s) in table above)

49) About where would you rate yourself in respect of adopting new farm practices:

-usually among the first
-usually before average
-about average
-usually later than average
-usually later than most

50) What age are you?

21-30   31-40   41-50   51-60   60+   (ring one)

51) How many years experience do you have in farming?

_________years

52) How many years have you spent at this farm?

_________years

53) Would you describe the soil type on your farm as:

LIGHT   MEDIUM   HEAVY

54) Is there a person regularly assigned to do the spraying on your farm?

____

55) Did you carry out much spraying yourself in the last season?

____

DAY TEMPERATURE	NIGHT TEMPERATURE	GENERAL TEMPERATURE	FROST	FROZEN GROUND	SNOW	SUNSHINE	HUMIDITY	GENERAL WINDINESS	GUSTS	RAIN	FOG	SOIL MOISTURE

CALM	smoke rises vertically	0-1 miles per hour
LIGHT AIR	smoke starts to drift	1-3 m p h
LIGHT BREEZE	leaves rustle, wind felt on face	4-7 m p h
GENTLE BREEZE	leaves & small twigs in constant motion	8-12 m p h
MODERATE BREEZE	small branches moved, raises dust & loose paper	13-18 m p h
FRESH BREEZE	small trees in leaf begin to sway	19-24 m p h

SCPM

SILWOOD CENTRE for PEST MANAGEMENT

IMPERIAL COLLEGE AT SILWOOD PARK, Sunninghill, Ascot, Berkshire SL5 7PY
Tel: ASCOT (0990) 23911 Telex: 261503

Dear Sir,

I am writing to request your assistance in a survey being conducted from Imperial College, London University, looking into likely developments in crop spraying and sprayer technology in British agriculture. Results from the survey will be of interest to organisations concerned with all aspects of crop spraying.

In attempting to assess expert opinion on this subject, I am circulating the enclosed questionnaire. I would be grateful if you could fill it out and return it to me, using the stamped addressed envelope provided. Your personal opinions - which will be considered as strictly confidential - are of particular interest in this survey. The questionnaire should not take more than five to ten minutes to complete.

Please indicate in the box on the questionnaire whether you would like a brief summary of the pooled results obtained from the survey.

Thanking you in advance for your co-operation,

Anthony Smith

Anthony Smith

IMPERIAL COLLEGE: MACHINERY SURVEY, 1982

CONFIDENTIAL

No. ________

Below, and on the next page, are statements about possible future developments in the ground spraying of fungicides, herbicides and insecticides on arable crops in Britain. Please indicate if you agree or disagree with each statement by ticking the appropriate box. The statements compare future practices with the situation at present. Please put any comments or qualifying remarks you have in the space below each question.

1) By 1990, the number of sprayers on farms allowing farmers to control droplet size accurately will have increased by at least three times.

AGREE ☐ DISAGREE ☐

2) By 1990, at least 20% of British arable farms will have an electrostatic type sprayer.

AGREE ☐ DISAGREE ☐

3) By 1990, with increased use on farms of "spinning-disc" and electrostatic sprayers, the acreage sprayed with hydraulic pressure sprayers will decline by at least 50%.

AGREE ☐ DISAGREE ☐

4) By 1990, the number of arable farms having "low-ground pressure" vehicles, flotation tyres, or double wheels for tractors, will increase by at least three times.

AGREE ☐ DISAGREE ☐

5) By 1990, electronic sprayer monitors will be standard on all but the smallest sprayers.

AGREE ☐ DISAGREE ☐

6) By 1990, at least 25% of all spraying operations will be performed at night.

AGREE ☐ DISAGREE ☐

7) It will always be important for the sprayer operator to be able to see the spray droplets produced during spraying.

AGREE ☐ DISAGREE ☐

8) By 1990, new sprayer designs will allow safe spraying at 25% higher windspeeds, or greater.

AGREE ☐ DISAGREE ☐

Please turn over

/continued...

9) By 1990, average total volumes applied in spraying will be reduced by at least 25%.

AGREE ☐ DISAGREE ☐

10) By 1990, the amount of chemicals (active ingredients) used per acre for one application will be, for most chemicals, at least 25% less.

AGREE ☐ DISAGREE ☐

11) By 1990, sprayers will be operating, on average, at 25% higher forward speeds, or greater.

AGREE ☐ DISAGREE ☐

12) By 1990, most new sprayers will have improved measuring and mixing systems which will reduce operator exposure to concentrated chemicals.

AGREE ☐ DISAGREE ☐

13) By 1990, current voluntary schemes covering chemical usage will be replaced by legislated controls.

AGREE ☐ DISAGREE ☐

14) By 1990, "spinning-disc" sprayers will have a full range of chemicals approved for use with them.

AGREE ☐ DISAGREE ☐

15) By 1990, electrostatic-type sprayers will have a full range of chemicals approved for use with them.

AGREE ☐ DISAGREE ☐

16) By 1990, sprayer operators will have to be licensed to apply most agricultural chemicals.

AGREE ☐ DISAGREE ☐

17) The future marketing of chemicals in returnable containers is a good idea.

AGREE ☐ DISAGREE ☐

18) In the future, the marketing of chemicals in combined disposable containers with nozzles (for use on mounted sprayers) is a good idea.

AGREE ☐ DISAGREE ☐

Please turn over

/continued...

Please circle one of the answers for each of the two questions below:

Do you think that by 1990 the number of passes through a field of winter cereals to apply chemicals will:

INCREASE STAY THE SAME DECREASE

The number of acres sprayed from the air has steadily increased over the last 20 years. Between now and 1990, in your opinion, will the acreage sprayed from the air:

INCREASE STAY THE SAME DECREASE

Over the next 15 - 20 years, what percentage of British arable farms do you think will have hydraulic pressure sprayers completely replaced by new designs, allowing spraying at low volumes (4 galls/acre or 40 l/ha) or less?

____________%

Position held ____________________

Years in agriculture ____________ years

Do you have any further comments on developments in spraying?

If you would like a summary of the results from this survey, please tick box ☐
and return to: Anthony Smith
Imperial College Field Station
Silwood Park
Ascot
Berks SL5 7PY

THANK YOU

```
      PROGRAM SPRAYER(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C -MEASURES THE MAX. ATTAINABLE WORK RATES BY
C SPRAYERS, USING THE "BALTIN EQUATION" AS A BASIS FOR THE MODEL
C (BALTIN, 1959).
C          DESCRIPTION OF CONSTANTS,VARIABLES & ARRAYS:
C  NAME     STATUS                  DESCRIPTION
C T        ARRAY         STORES DIFFERENT DISTANCES TRAVELLED TO REFILL
C RATE        ARRAY        STORES DIFFERENT REFILLING SPEEDS
C R        ARRAY                DIFFERENT REFILLING TIMES
C A        ARRAY         STORES APPLICATION RATES
C S        ARRAY         SPRAYING SPEEDS
C IX      ARRAY         NAMES OF SPRAYERS
C X       ARRAY         TANK CAP. & BOOM WIDTH
C ITNS   VARIABLE      NO. OF SPRAYERS UNDER TEST
      DIMENSION IX(150),X(150,3),Z(150,200),T(2),R(4),A(4),S(4)
      DIMENSION IFLD(7),FLDAT(7)
C IFLD,FLDAT, CORRECT FOR DIFF TYPES FIELDS (STURROCK ET AL ,1977)
      DIMENSION RATE(4),C(150)
      DIMENSION PCSPRAY(15),PCREFIL(15),PCTRNST(15)
      DATA (IFLD(I),I=1,7)/1,2,3,4,5,6,7/
      DATA (FLDAT(I),I=1,7)/1.00,0.95,0.93,1.05,1.04,1.07,1.09/
      READ (5,76)T(1),T(2)
      READ (5,66)RATE(1),RATE(2),RATE(3),RATE(4)
      READ(5,67)A(1),A(2),A(3),A(4)
      READ(5,67)S(1),S(2),S(3),S(4)
      READ(5,64)ITNS
      READ(5,*)F4,F5,F6,F7
      READ(5,*)IFLDTYP
      READ(5,*)FLDLNGT
      READ(5,*)FLDSIZE
      FLD=0.0
      DO 60 I=1,7
      IF(IFLDTYP.EQ.IFLD(I))THEN
      FLD=FLDAT(I)
      WRITE(6,61)IFLD(I)
      ELSE
      ENDIF
   60 CONTINUE
   61 FORMAT(//5X,17HFIELD SHAPES TYPE,1X,I1)
C COEFFICIENTS IN RENOLL MODEL - F4 F5 F6 F7
      WRITE(6,164)ITNS
      TRNTIME=10.0
C FIELDS ARE SQUARE, SIZE 10 HECTARES
      DSTANCE=1000.0
      FERRY=5.0
C ABOVE ARE CONSTANTS IN MODEL
      WRITE(6,332)TRNTTIME,FLDLNGT,FLDSIZE,DSTANCE,FERRY
      MITS=0
      DO 80 IJ = 1, ITNS
      READ (5,68) IX(IJ),(X(IJ,J),J=1,2)
   80 CONTINUE
      DO 79 II= 1, 2
      DO 79 JJ= 1, 4
      DO 79 KK= 1, 4
      DO 79 LL= 1, 4
      MITS=MITS+1
      I=0
       DO 78 K = 1, ITNS
      I=I+1
C CONVERT RATE(L/S) TO R(SECONDS REQUIRED TO REFILL)
      R(JJ)=(X(I,1)/RATE(JJ))+300.0
C 300S ADDED TO ACCOUNT FOR HANDLING CHEMICAL ETC.
      ATOT=(R(JJ)*(A(KK)/10000))/X(I,1)
      BTOT=(1./(S(LL)*X(I,2)))*FLD
C FLD- CORRECTION FOR VARIOUS FIELD SHAPES
      CTOT=(TRNTIME/(X(I,2)*FLDLNGT))*FLD
      DTOT=(2.*T(II)*(A(KK)/10000))/(FERRY*X(I,1))
      ETOT=(DSTANCE/(FERRY*FLDSIZE))*FLD
      WRKRATE=(1./(ATOT+BTOT+CTOT+DTOT+ETOT))*0.36
C ASSUME 9 HOUR SPRAYING DAY, RELIEF DRIVER AVAILABLE
C Z(I,J)=RATE OF WORK/DAY
      Z(K,MITS)=(WRKRATE*9)
      CHEMHR=A(KK)*WRKRATE
C  CHEMHR = AMOUNT OF CHEMICAL APPLIED/HR.(=APPLN.RATE/WORKRATE)
      REFHR=CHEMHR/X(I,1)
C REFHR=NO. TANK REFILLINGS/HOUR (=CHEMICAL APPLIED/HR /TANKCAP)
      A1=REFHR*R(JJ)
      A2=REFHR*(T(II)/FERRY)
C A2= TIME FERRYING FROM REFILLING PER HR.
C A2= NO. REFILLINGS/HR. * TIME TAKEN IN FERRYING
      FLDSHR=WRKRATE/(FLDSIZE/10000.)
C FLDSHR= NO. OF FIELDS SPRAYED / HR.
      A3=FLDSHR*(DSTANCE/FERRY)
C A3 = TIME FERRYING BETWEEN FIELDS/HR
C A3 = NO. OF FIELDS SPRAYED/HR *TIME TAKEN IN FERRYING
C        BETWEEN FIELDS
```

```
      TRAVHR=(WRKRATE*10000.)/X(I,2)
C TRAVHR=DISTANCE TRAVELLED IN WORKING IN 1 HOUR
C TRAVHR=WORKRATE/BOOMWIDTH
      TRNSHR=TRAVHR/FLDLNGT
C TRNSHR = NO. OF TIMES TURNED/ HR.
      A4=TRNSHR*TRNTIME
      X(I,3)=((3600-(A1+A2+A3+A4))/3600.)*100.0
C   "X(I.3)" EXPRESSES THIS AS A PERCENTAGE
C  A1=TIME SPENT IN REFILLING/HR (=NO. REFILS/HR.*TIME TO REFIL
      PCSPRAY(K)=X(I,3)+((A4/3600.)*100.)
      PCREFIL(K)=((A1+A2)/3600.)*100.
      PCTRNST(K)=(A3/3600.)*100.
      IF((FLDSIZE/10000.).GE.Z(I,MITS))THEN
      PCREFIL(K)=PCREFIL(K)+PCTRNST(K)
      PCTRNST(K)=0.0
      ELSE
      ENDIF
C
C PCSPRAY(K)=PERCENT TIME SPRAYING AND TURNING
C PCREFIL(K)=  "       "   REFILLING
C PCTRNST(K)=  "       "   IN TRANSIT
   78 CONTINUE
      RIMP=RATE(JJ)/0.0758
      XLACR=A(KK)/2.47
      GACR=XLACR/4.54
      XKPH=3.6*S(LL)
      XMPH=2.237*S(LL)
C CALCULATE WORKRATE  USING RENOLL FORMULA (1981)
      DO 180 IJ=1,ITNS
      SUBA=((10./((S(LL)*3.6)*X(IJ,2))))*FLD
      TURN=((2.8*TRNTIME)/(X(IJ,2)*FLDLNGT))*FLD
      COEFFS=(F4+F5+F6+F7)*SUBA
      U=(A(KK)*(FLDSIZE/10000.))/X(IJ,1)
      DISTANT=(((2.0*(T(II)/FERRY))/60.)*U)/(60.*(FLDSIZE/10000.))
      SUBB=TURN+COEFFS+DISTANT
      TOTAL1=SUBA+SUBB
C CONVERT C(IJ)=HAS/HR TO HAS/DAY: MULT. BY 9
      C(IJ)=(1./TOTAL1)*9
  180 CONTINUE
      WRITE(6,333)T(II),RATE(JJ),RIMP,A(KK),XLACR,GACR,S(LL),XKPH,XMPH
      WRITE(6,268)
      WRITE(6,368)(IX(T),(X(I,J),J=1,2),Z(I,MITS),C(I),
     $      PCSPRAY(I),PCREFIL(I),PCTRNST(I),I=1,ITNS)
   79 CONTINUE
      STOP
   64 FORMAT(I3)
   66 FORMAT(4F10.4)
   67 FORMAT(4F10.4)
   68 FORMAT(A10,2F6.1)
   76 FORMAT(2F6.1)
  368 FORMAT(1X,A10,3X,F6.1,12X,F6.1,6X,F6.2,6X,F6.2,10X,F6.2,
     $       11X,F6.2,9X,F6.2)
  164 FORMAT(1X,20HNO. SPRAYERS TESTED=,I3)
  333 FORMAT(//110("=")///1X,20HDISTANCE TO FILL(M)=,F6.1/
     11X,15HRATE OF REFILL=,1X,F6.2,1X,3HL/S,
     $1X,2HOR,F6.1,1X,9HGALLS/MIN/
     $        1X,18HAPPLIC.RATE(L/HA)=,F10.4,1X,2HOR,1X,F5.1,1X,
     $        6HL/ACRE,1X,2HOR,1X,F6.2,1X,10HGALLS/ACRE/
     $1X,19HFORWARD SPEED(M/S)=,F10.4,1X,2HOR,1X,F4.1,1X,6HKM/HR.,
     $1X,2HOR,1X,F4.1,1X,6HM.P.H.)
  332 FORMAT(//10X,27HASSUME 10 HOUR WORKING DAY,/
     $         10X,35HINCLUDING 30 MINS IDLE AT START AND,
     $            10HEND OF DAY/
     $        10X,24H RELIEF DRIVER AVAILABLE//
     $        1X,19HCONSTANTS IN MODEL:/
     $         1X,36HTIME TO TURN AT END OF SPRAY RUN(S)=,F4.1/
     $         1X,16HFIELD LENGTH(M)=,F6.1/
     $         1X,17HFIELD SIZE(SQ.M)=,F8.1/
     $         1X,27HDISTANCE BETWEEN FIELDS(M)=,F6.1/
     $         1X,20HFERRYING SPEED(M/S)=,F4.1)
  268 FORMAT(/46X,"WORKRATE(HAS/DAY)",11X,"PERCENT OF TIME:"/
     $1X,7HNAME OF,5X,13HTANK CAPACITY,
     $        5X,10HBOOM WIDTH,
     $        3X,"(BALTIN)",2X,"(RENOLL)"/
     $         1X,7HSPRAYER,5X,13H  (LITRES)    ,5X,10H (METRES) ,
     $         23X,18HSPRAYING & TURNING,
     $        4X,9HREFILLING,4X,10HIN TRANSIT/84X,13HAND RETURNING,
     $        3X,14HBETWEEN FIELDS/
     $        62X,50("-")/)
      END
```