A STUDY COMPARING A THRESHOLD SYSTEM WITH A REDUCED DOSE APPROACH TO MINIMISE HERBICIDE USE FOR BROADLEAVED WEEDS IN CEREALS IN SCOTLAND

ANDREW JOHN WHITING

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University of Edinburgh
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DECLARATION

I declare that this thesis is entirely written by me and that the majority of the work was carried out by me whilst an employee of SAC (Edinburgh).

ABSTRACT

A field trial programme was started in 1987 covering the main arable areas of the UK, comparing the Long Ashton (LARS) Crop Equivalent system for determining the need for herbicide in cereals against insurance spraying. In Scotland, 4 trials were established in East and West Lothian with both the LARS system and insurance spraying at full and half the recommended rate of chemical against an untreated control. The trials were to last 4 years with each treatment in the same location throughout the period to allow changes in the weed seed bank to be studied.

Cropping years 1988-90 included 4 crops of spring barley, 5 of winter wheat and 3 of winter barley. At all sites there were significant effects of treatments on weed seed numbers in the soil and seedling populations after 3 years of treatments. This was most noticeable in the trial with 3 crops of winter barley at Smiths where *Stellaria media* seed in the soil increased from 156/m^2 of soil in 1988 to 11789/m^2 in 1990. There was a large response to herbicide use for all the winter barley crops, but no clear response for spring barley and winter wheat. The half rate and threshold treatments tended to give the best margins for most crops. In some years, weeds were found to have an economic effect on crop harvesting above that predicted by the LARS threshold system.

Cost of assessment was thought to be a major drawback of the LARS system and an alternative of reducing herbicide dose to suit field conditions was tested from autumn, 1988. This proved successful in finding some of the major factors which affect the optimum dose of herbicide in a given field. Factors included weed species, active ingredient, weed size and weed number.

Because of the difficulty in persuading farmers to use the LARS system and the high cost of assessment, it was concluded that a targeted dose approach provides a more realistic way of minimising herbicide use in cereals.

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1. INTRODUCTION

A change in the pattern of agriculture in the UK in the last fifty years has been brought about by Government intervention through economic support provided initially by the 1947 Agriculture Act and latterly by the Common Agricultural Policy (CAP) of the European Community (EC). Increases in the production of cereals, in particular wheat, have resulted.

One aspect of intensification is the development of herbicides which have increased yield both directly, by removing weed competition, and indirectly, by allowing greater use of winter varieties. The first products developed in the 1930's and 40's, e.g. MCPA, were synthetic plant hormones that disrupted plant growth and controlled many broad-leaved weeds selectively in cereals. With the further development of herbicides, the need for rotations utilising broad-leaved row crops to act as 'cleaning' crops was diminished leading to even more intensive growing of cereals (Orson, 1987). Increased frequency of winter cropping and changes in cultural practices, e.g. direct drilling, led to increased problems with graminaceous weeds especially *Alopecurus myosuroides* and *Avena fatua*. The introduction of effective graminicides starting with barban in 1958 has allowed the growing of winter cereals to continue and expand.

During the 1980's, cereal production in the EC outstripped home demand. Over-production required excess to be exported at below the world price or to be stored. Both options have led to a large increase in the EC budget for cereals. Pressure to reform the CAP and reduce price support has come both from the increasing cost and disquiet about depression of world prices by subsidised exports from the EC. Reform of the CAP began in 1984 and will continue to squeeze farm incomes which have fallen, in real terms, throughout the 1980's (Murphy, 1989).

With more intensive agriculture and an apparent over-supply of many products, there has been a growing movement in Europe against modern agricultural practices, particularly the use of pesticides (e.g. Thonke, 1991). Such concern has no direct economic bearing on the farmer, but political pressure has led to the introduction of environmental policies which can directly limit farming practice.

The two pressures of falling income and environmental concern have led to a re-appraisal of the level of inputs and weed thresholds have been suggested as an objective way to decide on herbicide use in cereals.

2. WEED THRESHOLDS

Weed thresholds were developed to give a spray or no spray decision based on the mathematical relationship between weed number and yield loss.

2.1. COMPETITION - THE BASIS FOR THE MODEL

Zimdahl (1980) gave several definitions of competition amongst plants, the best being a combination of Clements, Weaver and Hanson (1929) who described the situation necessary for competition : "Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors" and Bleasdale (1960) who described the outcome : "Two plants are in competition with each other when the growth of either one or both of them is reduced or their form modified as compared with their growth or form in isolation".

The farmer is only interested in the outcome, e.g. reduction in crop yield, but in order to predict the outcome we must know and be able to describe quantitatively the predisposing factors.

Sagar (1968) quotes a series of questions posed by Friesen (1967) answers to which he claimed were necessary to predict yield loss from weed competition. The most important and the starting point of most models is "What weed densities are necessary to reduce yield?".

2.1.1. YIELD LOSS AND WEED DENSITY

Two main experimental methods have been used to study competition between weeds and crops.

a. Replacement series (de Wit, 1960) in which the crop and weed are grown as monocultures and in a range of mixtures in which the total plant density of the two components remains equal. This method is useful for determining the relative competitiveness of species, but has been criticised by Connolly (1986) because of the practical difficulty in setting up such experiments and the fact that in a field situation, crop population is relatively constant and weed levels are variable so that little of the data is relevant to normal field conditions.

b. Additive series experiments allow crop density to remain constant with variable densities of usually one weed species. Such experiments suffer some of the problems of replacement series in that they apply to a situation of a single weed species and assume even distribution of weeds within the crop (van Groenendael, 1988). Despite these problems, additive series experiments are by far the most widely used method of generating yield loss/weed density relationships.

There are many examples of such experiments (e.g. Scragg and McKelvie, 1976). The majority demonstrate differences in competitive ability between weed species and suggest a relationship between weed density and yield loss, but lack any real predictive value in themselves because they are single site, single year trials. It is only with increased interest in the operational use of thresholds that there has been a concerted approach to produce more robust models.

There is no general agreement as to the form of the yield loss/weed density relationship or even whether one equation can explain all cases. Zimdahl (1980) noted that the relationship was non-linear and from his review of several weed/crop combinations suggested it was sigmoidal. Such a model would suggest a range of weed densities over which no significant yield loss occurs. This is the origin of the critical threshold weed density concept (Moody, 1983). However, in Cousens' (1985) critical review, a rectangular hyperbolic model was proposed and he further suggested (Cousens, 1988) that previous sigmoidal representations resulted because at low weed densities statistically significant yield loss cannot be detected because of high variance. The rectangular hyperbolic and other non-sigmoidal models (e.g. Watkinson, 1981) have now become widely used in predictive modelling (e.g. Lapham, 1987).

The yield loss/weed density curve is only the starting point for a predictive model. Other factors must be included to extend the model to cover the complete range of sites and situations. The outcome of competition between a crop and weed species is a balance between the competitiveness of the crop and that of the weed. Therefore, some understanding of the factors which affect this are necessary.

2.1.2. THE CROP

2.1.2.1. Crop Density and Spatial Arrangement

There is direct experimental evidence for a decline in weed competition with increasing crop density. This has been shown in numerous field and glasshouse experiments (e.g. Lawson and Topham, 1985 with peas; Andersson, 1986 with spring wheat and barley). Connolly (1988) derived a mathematical relationship *(Equation 1)* for the effect of crop and weed density on crop yield :

Equation 1

$$Y = \frac{Dc}{a + b.Dc + d.Dw}$$

where 'Dc' and 'Dw' are crop and weed density (per m^2), 'a' an intercept term, 'b' intra-specific and 'd' inter-specific competition coefficients. From the equation, the effect of a constant weed density declines as crop density increases and an optimum crop density can be suggested for a given weed density.

At a given crop density, spatial arrangement can also affect the ability of the crop to compete with weed plants. The optimum planting arrangement for crop yield is one where the space between rows is the same as that between plants within the row (Donald, 1963). This is because competition between individuals is minimised and use of resources such as light, water and nutrients maximised. In terms of *Equation 1*, there is a reduction in the intra-specific competition coefficient 'b'. Experimental evidence for spatial arrangement affecting weed competition in cereals has been given by Hakansen (1984) who found that yield of cereals increased and weed biomass decreased when row spacing decreased and plant spacing became more even within the row.

An attempt to show how crop density and spatial arrangement can be integrated into yield loss/weed density models was made by Hakansen (1986) who suggested that increased understanding of competition between crop and weed is important for utilising and maximising crop competition as part of a weed control programme, e.g. organic systems, and to improve and adapt weed control measures to suit particular conditions.

2.1.2.2. Crop Cultivar and Species

Differences in weed competitiveness between cereal varieties has been shown in numerous experiments (e.g. Moss, 1985) and has been related to mature crop height (Appleby, Olson and Colbert, 1976), tall varieties being more competitive than short, and tillering ability (Challaiah, Ramsel, Wicks, Burnside and Johnson, 1983).

Differences in competivity between cereal species have also been noted. Bell and Nalewaja (1968) found spring barley to be more competitive than spring wheat when competing with *Avena fatua* and Davies (1988) reporting on weed control trials in Scotland found that yield response was in the order : winter barley > winter wheat > spring barley. Such variation in species response seems not to result from competitive ability *per se*, but reflects more the competitive ability of the weeds and the interaction between sowing date and weed competition.

No attempt has been made to incorporate varietal data into a competition model, although crop growth models do include species characteristics, e.g. rate of development and such models can be used to simulate crop/weed competition by calculating effective leaf area index of the crop and the weed and the proportion of light each intercepts (e.g. Kropff, 1988).

2.1.2.3. Fertiliser and Water

The farmer can manipulate crop growth by irrigation and addition of nutrients. These decisions may favour the crop in competition with weeds.

Soil water status has been shown to affect weed/crop competition, e.g. soybean yield reduced by competition for water by *Alopecurus spp.* (Staniforth, 1958). However, it is unlikely that competition for moisture by weeds plays any part in reducing cereal yields in the UK and water stress may even kill broad-leaved weeds, e.g. *Galium aparine* (Froud-Williams, 1985) which are generally much shallower rooted than the crop.

Competition for nutrients, and in particular nitrogen, is far more important. Some researchers have contended that addition of nitrogen could be used to stimulate crop growth and overcome weed competition. Bell and Nalewaja (1968) did find that addition of nitrogen and phosphate reduced yield loss of spring barley and wheat grown with *A. fatua*. However, Wells (1979) found nitrogen failed to offset the effect of weed competition from five broad-leaved weed species in wheat in Australia. Alkamper (1976) suggested weeds take up fertiliser more quickly and in larger quantities than crops. This was found to be so (Pulcher-Haussling and Hurle, 1986) for *A. myosuroides*, *Fallopia convolvulus* and *Thlapsi arvense* in a winter wheat crop where nitrogen increased dry matter production of the crop and weeds, but to a greater extent in the weeds than the crop.

There are great problems in modelling competition for nutrients and moisture because of the difficulty in studying root systems and separating and defining the effects, which are often inter-related.

2.1.3. THE WEED

2.1.3.1. Weed Species

Much work has highlighted the difference in competitive ability between weed species - Wilson and Wright (1990) found the yield loss of winter wheat to be 1.24% plant^{-1}m^{-2} from *Galium aparine* but only 0.02% for *Viola arvensis*. Numerous yield loss/weed density models have been produced for highly competitive single species such as *Avena fatua* and *A. myosuroides* (e.g. Dew, 1972). Problems arise with modelling mixed populations of individually less competitive species.

2.1.3.2. Weed Emergence and the Onset of Competition

The onset of competition will vary with time of weed emergence relative to the crop and their relative growth rates (Peters, 1984).

Weed species show three patterns of emergence (Roberts, 1982) :

a. all year round restricted only by low winter temperatures, e.g. *Stellaria media*;
b. mainly in autumn, e.g. *Galium aparine* with a smaller peak in spring, e.g. *Viola arvensis*; and
c. mainly in spring, e.g. *Polygonum spp.*

Certain species therefore tend to be associated with winter cereals, e.g. grasses, and others, e.g. *Galeopsis tetrahit*, with spring crops (Scragg, 1974). Competitiveness of spring-emerging weeds in winter cereals will be much less than those which germinate with, or soon after, the crop. Sowing date of winter cereals, more so than spring cereals, can have a great effect on crop yield and yield loss from weeds. Moss (1985) found that weed-free, early-drilled winter cereals outyielded late-drilled ones, but crops with uncontrolled *A. myosuroides* showed a greater yield loss from early drilling than from late. This resulted from a greater *A. myosuroides* density and greater competitive ability of individual *A. myosuroides* plants in the early-drilled crops. Potential increase in weed emergence in crops drilled early in the autumn is largely caused by higher insolation and low soil moisture leading to higher soil temperatures and greater diurnal temperature fluctuations (Thompson and Whatley, 1983). Similarly, individual weed vigour is increased with early emergence as the plant can grow longer and become well established before being stopped by low winter temperatures. A vigorous and dense weed stand also hastens the time of onset of competition. Moss (1987) found that the greater the density of *A. myosuroides* the earlier competition began with winter wheat and a similar result would be expected for increased weed vigour.

2.2. PREDICTIVE MODELS

Models of weed competition fulfil two functions :

a. the prediction of yield loss and the derivation of thresholds;
b. the assessment of long-term consequences of control measures and simulation of the effect of changes in management practices.

Cussans, Cousens and Wilson (1986) give definitions for six threshold types used in predictive models.

a. Competition threshold - a critical weed density below which no yield loss occurs. As already discussed this assumes a sigmoidal relationship between percentage yield loss and weed density and as such is considered incorrect. However, the majority of weed competition studies have concentrated on highly competitive weeds and competition thresholds may well exist for less competitive species. Harvey (1985) could show no yield increase in winter cereals from control of *Poa spp.* despite populations of up to 3,390 panicles /m^2.

b. Statistical threshold - weed density at which yield loss is shown to differ significantly from the weed-free control. This has little value because high variability within weed trials means that yield differences of 10-15% may have to occur before being shown to be significant (Tottman and Bartlett, 1983). The level at which weeds become economically damaging in cereals occurs well below this.

c. Economic threshold - weed density at which the cost of control equals the benefits accruing in a single year. Such a threshold only requires a yield loss/weed density relationship similar to that used by Poole and Gill (1987) to produce a simple model relating *Bromus* species density to yield loss and potential weed-free yield of wheat. Such a model allows a farmer to make an economic decision based upon the weed density and the potential yield of the crop. However, there are several problems with single year economic thresholds.

   Failure to control weeds in one year could lead to serious infestations in subsequent years requiring long-term control measures which are more costly than the saving from omitting control for one year. Weeds which have a potential to build up populations quickly have a short seed life in the soil and little seed dormancy, e.g. *A. fatua, G. aparine and A. myosuroides.* These weeds are also unreliably controlled by cereal herbicides (e.g. Baldwin, 1979) and as such are termed intractable because they persist at a density that is either yield reducing despite control measures or becomes so once weed management is relaxed (Mortimer, 1985).

d. Economic optimum threshold - density above which weeds are controlled to maximise financial return over a number of years (e.g. Murdoch, 1988).

e. Predictive threshold - density at which action should be taken to prevent build up of weeds in future years. Such thresholds are important for grass weeds where head populations just prior to harvest can be used to predict the need to spray in the following crop. Such a method has the advantage that head populations are much easier to count than seedlings which may occur in flushes.

f. Safety threshold - modification of a threshold to take into account the effect of weeds on factors other than yield.

   i. Increase in grain moisture content. Tall green weeds at harvest can increase grain moisture content significantly, e.g. *Elymus repens* (Sheppard, Pascal, Richards and Grant, 1982) and green weed fragments can lead to heating of grain in store (Pertwee, 1968). Effects on grain moisture content are related to weed species and environmental conditions as weeds will often dieback before harvest because of drought. Jensen (1985) found the effect of weeds on grain moisture to be related to soil type and weed number, but this was a reflection of the presence of a particular weed species, *Galeopsis tetrahit*, and its vigour.

ii. Grain contamination by weed seeds. Contamination of harvested grain by weed seeds can lead to rejection for some purposes or a lower price. Strict limits are set for cereal seed production. For other purposes, the quality requirement is less strict, but certain weed seeds will render grain unsuitable for certain quality grades, e.g. any *Allium vineale* in malt samples will lead to rejection (Pertwee, 1968).

Contamination by weed seed will depend on the weed species and the crop. A weed closely related to the cereal plant, e.g. *A. fatua*, will lead to a greater amount of weed seed in the sample (Wellington, 1960). Weed seed of a similar size to that of the grain, e.g. *Galium aparine*, will also cause contamination problems as it will be difficult to clean out. However, the amount of contamination will depend upon the time of harvest of the crop. *A. fatua*, for example, occurs in greater numbers in winter barley than winter wheat because harvesting of the barley coincides more closely to ripening of the wild oat (Tonkin, 1987).

iii. Disease and pests. Weeds can act as host plants for cereal pests and diseases, e.g. *A. myosuroides* can act as a source of spread of ergot (Thurston, 1967), and many weeds allow *Myzus persicae* to overwinter (Broadbent and Heathcote, 1955).

In recent years the positive advantages of weed species increasing insect numbers and diversity has been stressed (Rands, 1985). This may indicate that perhaps herbicide choice and thresholds should be modified to allow weeds of low competivity to remain as has been advocated in the Gamebird Research Project (Boatman and Southerton, 1988).

iv. Grain quality. Although Nakoneshny and Freisen (1961) found *A. fatua* competition reduced protein content of spring wheat, such effects are infrequent (AFRC, 1976). Similarly, the effect of weeds on grain size is variable. Wilson and Peters (1982) noted the proportion of barley grain < 2 mm increased from 13% to 20% with wild oat, but many experiments have failed to show any effect of weeds on thousand seed weight suggesting that most weeds do not compete strongly during grainfill.

Weeds can indirectly affect grain quality by delaying harvesting. Delay in harvesting can lead not only to grain loss (Thomas, Swanston and Taylor, 1987), but also reduction in quality factors such as Hagberg Falling Number (Hayward, 1987).

v. Increase in harvesting costs. The relationship between throughput of matter other than grain (MOG), that is straw and other non-grain components that are harvested, and the amount of grain that is unharvested because of incomplete separation is biphasic (Nyborg, McColly and Hindle, 1969). At a small MOG throughput, grain loss is minimal and any increase in throughput produces only a small increase in grain loss. However, once the straw-walkers become fully loaded, grain is less easily separated from the straw and tends to be carried out of the back of the combine. At this point, any change in MOG throughput has a much larger effect on grain loss. Ideally, throughput should be at the point of inflection where grain loss is minimal and combine output maximised. In practice, such an output is difficult to achieve because any slight change in MOG yield can result in large grain losses and a throughput often far below the optimum is chosen (SAC, 1982).

Weeds increase the amount of MOG without increasing grain yield. Therefore in a weed infested versus a weed-free crop of equivalent yield, the weedy crop will take longer to harvest because speed will have to be reduced in order to maintain a given level of grain loss OR, if speed is held constant, a higher grain loss will result. Such effects have been shown by Nave and Wax (1971) for pigweed in soyabean where threshing and separation losses were 0.68, 2.06 and 4.38% at 1, 2 and 3 mph with pigweed and 0.35, 0.48 and 0.34% at 2, 3 and 4 mph without weed. Again tall growing green weeds will have the most effect on harvesting; Sheppard, Richards and Pascal (1984) found that desiccation of *Elymus repens* could lead to a 10-50% reduction in grain loss or a 11-31% increase in forward speed.

As well as the direct effect of weeds on MOG yield, the high moisture content of some weeds can also increase grain loss. Segler and Wieneke (1961) found that by increasing the amount of green material in wheat and oats by 45%, grain losses increased by a factor of ten and the power requirement of the drum was raised from 3.1 to 19.5 hp. This increase in power requirement is important as it can lead to blocking of elevators and the drum if large quantities are taken in too quickly, thus leading to further harvest delays.

Elliot (1980) attempted to place an economic cost on weeds at harvest. He used the ratio of grain yield to MOG yield (G:MOG) as a measure of the effect of weeds on harvesting. In a clean crop, the ratio would be 1 for a harvest index of 0.5, while a weedy crop would have a ratio of less than 1.

The economic optimum, predictive and safety thresholds have been derived from increasingly more complex competition/population dynamics models produced most notably for *A. fatua* and *A. myosuroides* (e.g. Wilson, Cousens and Cussans, 1984). Each stage in the weed seed cycle is described in the models by a mathematical function which makes a prediction of weed populations in future crops which is then modified to take account of variability in weed control, type of cultivation, method of straw disposal etc. Using such models and introducing sub-models for competitive ability of the weed and economic data with costs and benefits accruing in future years discounted (e.g. Doyle, Oswald, Haggar and Kirkham, 1983), it is possible to produce long-term strategies for weed control and simulate the effect of changes in cultural practice.

Modelling of weed populations of *A. fatua* and *A. myosuroides* has been made easier by extensive research into seed production, seed dormancy etc. carried out over many years because of their economic importance and difficulty of control. Similar basic research for other weeds has been very limited.

The geographic distribution of these two problem weeds in the UK is not uniform and specific regional and crop differences can be found (Makepeace, 1982). In Scotland, *A. myosuroides* is not found and *A. fatua* and *E. repens* are the major grass weeds (Waterson, 1974). In many areas, especially Northern England and Scotland, broad-leaved weeds predominate with specific weed species and populations associated with specific crops. For example, *G. tetrahit* is largely found in spring cereals grown in Scotland (Scragg, 1974). With mixed populations of plants of individually low competitiveness, modelling for the production of thresholds becomes more difficult than for single, aggressive species. Problems are further compounded by lack of information on either competitive ability or population dynamics of many species.

Most common broad-leaved weeds have dormant seeds that persist and remain viable in the soil for many years. Arable soils thus still contain many weed seeds despite up to 40 years of chemical weed control. Roberts and Chancellor (1986) noted 1,500-67,000 weed seeds/m^2 with an average of 4360/m^2 in the top 15 cm of soil from the English Midlands and Warwick (1984) found 0-170,000 weed seeds/m^2 with an average of 16,000/m^2 in the top 20 cm of soil in samples from Scotland. Many plants have the potential to replenish and increase the weed seed bank if uncontrolled, e.g. a single plant of *Papaver rhoeas* can produce over 6,000 viable seeds (Wilson, Peters, Wright and Atkins, 1988).

However, in a single year, the proportion of viable seeds which develop into seedlings is small, Roberts and Rickets (1979) found that even in the most favourable conditions the maximum number of seeds germinating represented only 5-6% of the seed bank. Experiments to look at the change in weed seed bank and weed emergence over a number of years have shown increases in emergence of broad-leaved weeds in untreated plots as time progresses (Dessaint, Chadoeuf and Barralis, 1990), but these changes are often small and variable. Under field conditions, emergence will be greatly affected by the timing of seedbed preparation and environmental conditions and so, despite potentially high levels of weeds in the seed bank, emergence is normally restricted by cultural practice, environmental factors and inate dormancy of the seed.

Brenchley and Warrington (1936) demonstrated the stability of *Veronica hederofila* populations during fallow. This contrasted markedly with rapid population decrease and increase of *A. myosuroides* seeds during and after fallow because of their short dormancy and persistence in the soil. Cussans (1980) commented that the two species exhibited two survival strategies each matching rate of population decline with increase.

It would seem that omission of weed control in one year for the majority of broad-leaved weeds may not have any significant bearing on future populations and their control. A further and perhaps more powerful argument for ignoring weed population dynamics for weeds that are not intractable is the uncertainty of future agricultural production with movement away from support and emphasis on set-aside and extensification. With increased uncertainty it can be argued that future benefits carry less weight and should therefore be discounted at high rates with thresholds for intractable weeds adjusted accordingly and the economic optimum perhaps ignored completely for other species and yearly economic thresholds applied.

2.3. PRACTICAL USE OF THRESHOLDS

Thresholds for the control of weeds have been developed in several countries. Each is based on some form of competition study and attempts to relate weed density or ground cover to economic loss in present and future crops.

2.3.1. FEDERAL REPUBLIC OF GERMANY

So called 'fixed' thresholds for several weeds have been developed (Heitefuss, Gerowitt and Wahmhoff, 1987). These values are based upon experimental results and experience and are adjusted downwards to take into account possible effects of weeds on harvesting etc. Values range from 0.5 plants/m^2 for *Galium aparine* to 40/m^2 for all other dicotyledonous weeds. Accuracy of the system has been sufficiently good to minimise wrong decisions below the threshold (i.e. type II errors), but poorer when predicting yield loss above the threshold (i.e. type I errors). Springer (1985), reporting on a paired plot experiment in which one was sprayed and the other left unsprayed, found that 14% of wrong decisions occurred below the threshold, whereas 48% were wrongly predicted above the threshold. In order to increase the accuracy of the system, a computer model has been developed to produce 'variable' field specific thresholds (Gerowitt, 1988). This model adjusts thresholds for crop species, crop/weed cover etc. and incorporates some of the factors which modify the competitiveness of a given weed density. However, improvements in decision making from using the model have been small and variable. Gerowitt (1987) found wrong decisions in 8.1% and 5.4% of cases below threshold and 33.8% and 28.4% above threshold for 'fixed' and 'variable' thresholds respectively.

2.3.2. Netherlands

The Dutch have developed a computer program to be used by farmers to describe and modify weed thresholds and to select herbicides (Aarts and Visser, 1985). The system uses a standard weed unit (SWU) which is 500 divided by the maximum number of weeds per m^2 that can be tolerated in spring without losing yield. Total SWU for a mixed population is simply the sum of weed density times the SWU for the species. A threshold of 500 SWU/m^2 in early spring and 1000 SWU/m^2 in late spring is used.

2.3.3. United Kingdom

Wilson (1986) highlighted the poor relationship between yield response and total weed density in mixed broad-leaf weed populations. The crop equivalent (CE) threshold was thus developed to allow threshold decisions for mixed populations with individual species weighted for competitive ability. The system depends on 4 assumptions.

a. Yield reduction by weeds is proportional to their biomass.
b. Yield loss is linearly related to weed density, at least at low density. This assumes the yield loss/weed density relationship is not sigmoidal and crop yield does not vary over a wide range of crop densities.
c. The competitiveness of a weed may be expressed by relating dry weight of individual crop plants to individual weed plants :

$$\text{CE of a weed} = \frac{\text{Biomass of a weed plant}}{\text{Biomass of a crop plant}}$$

Total CE of a population = (CE a x d a) + (CE b x d b) + ...

d. Competition is by direct replacement, i.e. crop biomass without weeds = crop + weed biomass. This has been shown to be sometimes true for grass weeds, e.g. *A. fatua* (Baldwin, 1979), but not for *Galium aparine* (Wilson, 1987). This assumption may be better for grass weeds in cereals because Clements *et al.* (1929) stated : "The closeness of competition between plants of different species varies directly with their likeness in vegetation or habit form".

Potential yield loss for any CE value or species combination is thus :

$$\text{Potential yield loss} = \frac{\text{Total CE}}{\text{Total crop CE} + \text{Total CE}}$$

Crop CE = 1, hence total crop CE = crop density.

The CE system was originally developed for use in the Boxworth Project (Hardy, 1986). A threshold of 10 CE/m^2 for broad-leaf weeds other than *G. aparine* was considered acceptable, representing a potential yield loss of 4% for a crop with a density of 240 plants/m^2. However, a 'safety' threshold (Cousens, Wilson and Cussans, 1985) of 5 CE/m^2 was used in practice to allow for risk factors such as variation in herbicide efficacy.

The CE method uses a simple representation of the complex inter- and intra-specific competition which occurs in a mixed weed and crop population. Problems such as growth patterns of weeds and site variation will alter competition with the crop (Wilson and Wright, 1987; Hakansen, 1988). Courtney and Johnson (1988) showed how the CE varied during the season and highlighted the difficulty in choosing a value that reflects the overall competitiveness of a weed. Such problems have led to a reappraisal of the CE system which resulted in Wilson and Wright (1990) concluding that a competitive index based upon percentage yield loss/weed m^{-2} would provide a better threshold value.

2.3.4. PRACTICAL PROBLEMS OF THRESHOLDS

The major problem with practical threshold systems is difficulty of measuring weed density in the field. Marshall (1988) found that population density for three grass species was highly skewed and followed a negative binomial distribution indicative of weeds occurring in patches. Also, the rarer the species, the more quadrats were required to obtain an equivalent error. This has important implications for determination of thresholds since the more competitive the species the lower the threshold and the greater the sample area required to maintain a reasonably accurate measure of population density. Dent, Fawcett and Thornton (1989) measured weed patchiness by aerial photography and produced a set of yield loss functions for *A. fatua* based upon various proportions of weed free area.

Increasing sampling intensity to overcome weed patchiness leads to another major criticism : the amount of time and consequently money that is required to sample a field. Marshall (1987) found that 6 points/ha using 4 x 0.25 m^2 quadrats at each point took 15 minutes and Wilson (1981) suggested 30 minutes per ha to do a whole farm survey for *A. fatua*. Heitefuss *et al.*, (1987) found the time taken for the German system was 12-20 minutes per hectare.

Sampling will also have to be done at least twice a year to assess species that emerge at different times of the year, leading to further time and costs and an impractical workload (Sim, 1987). Costs of £60/hr (SAC, Pers. Comm.) for advisory time suggests costs of £15-£30/ha which is in excess of the herbicide cost of £13/ha (ADAS, 1990) to control broadleaved weeds in cereals.

Other criticisms concern the threshold models themselves and include difficulty in allowing for competition between- and within-species. The latter problem can occur because weed populations frequently show hierarchies of plant size, stage of development and thus competitiveness (Mortimer and Manlove, 1983). Such variability arises from weed germination occurring in flushes, with later flushes having poorer competitive ability (Manlove, Mortimer and Putwain, 1982). This could be overcome to some extent by assessing weed ground cover but this adds to further time and cost.

The actual field testing of a threshold system is perhaps more difficult than it first appears. The apparent success claimed for the German system comparing plot pairs +/- herbicide is perhaps an obvious result that should not necessarily be attributed to a threshold system. If there are few weeds, then the probability of a yield response is reduced. Therefore the use of any value, so long as it is conservative, must produce better results than prophylactic spraying. It would seem likely that it would be possible to produce similar results by visual assessment and an educated guess.

2.4. AIMS OF THIS STUDY

a. To compare yield response of cereals to weed control based on prophylactic spraying and a threshold system.
b. To collect data on the effects of weeds on economic factors other than yield and to incorporate these into threshold models. This is not reported in the thesis.
c. To investigate the use of targeted doses as an alternative to threshold spraying.

3. MATERIALS AND METHODS

Field trials were conducted between 1988-90 to look at various aspects of weed control and their relevance to the production of management strategies for broad-leaved weeds in arable systems.

a. Long-term trials testing the Long Ashton Research Station (LARS) threshold system for weed management in cereals against insurance spraying. Particular emphasis was placed on the long-term effects of allowing weeds to remain uncontrolled and the effect of weeds on factors other than crop yield such as harvesting efficiency.
b. A series of trials looking at the effect of reducing herbicide dose as an alternative to simple spray/no spray threshold.

3.1. Comparison of LARS Threshold with Insurance Spraying

Four long-term trials were established in autumn 1987. These trials compared the LARS threshold system with insurance spraying, the use of full versus half dose herbicide and investigated the effect of each management system on build-up of weeds over the trial period. Four locations were chosen representing a range of arable sites in the Lothians.

3.1.1. Site Details

Site details are given in *Table 1* (see next page).

3.1.2. Experimental Design

An incomplete randomised block design with three replicates was used at each site. Each treatment occurred twice within each block to allow comparison of plus and minus pre-harvest glyphosate, although this part of the trial is not reported. Plots were laid out in farmers' crops at right angles to crop tramlines, plot length varying from 4 x 18 m (3 sites) to 4 x 27 m (1 site). All treatments remained in the same position during the three seasons of the trial to allow changes in weed populations to be monitored.

Spraying was carried out with a van der Weij knapsack sprayer using propane gas as a propellant at 210 kPa with a 2 m boom at a water rate of 200 l/ha through Teejet 8003B nozzles producing a medium spray. All other inputs were applied by the farmer.

The five treatments represented four management systems and a control :

a. full insurance spraying to control all broad-leaved and grass weeds using the full dose of herbicide;
b. as (a), but using half dose of herbicide;
c. decision to spray based upon LARS threshold system. Herbicide applied at full dose;
d. as (c), but using half dose of herbicide;
u. untreated/control.

Table 1. Long-Term Site Details 1988-90

Site	**Smiths, Bush Estate**	**Gleghornie, North Berwick**	**Niddry Mains**	**Remote, Pathhead**
Grid Reference	NT 253 657	NT 593 830	NT 096 750	NT 405 652
Elevation	183 m	30 m	76 m	160 m
Soil Series	Darvel	Kilmarnock	Winton	Winton
Soil Type	SL	SL/CL	CL	CL
Previous Cropping				
1987	WB	OSR	OSR	SB
1986	WB	WB	WB	WW
1985	WB	WW	WB	WW
1984	SB	WW	SB	WW
1983	Potatoes	Peas	WW	SB
Trial Crop				
1988	WB/Plaisant	WW/Brock	WW/Mercia	SB/Blenheim
1989	WB/Magie	WW/Apollo	WW/Apollo	SB/Blenheim
1990	WB/Magie	WW/Mercia	SB/Blenheim	SB/Blenheim
Cultivations				
1988	Plough	Chisel Plough	Plough	Plough
1989	Plough	Plough	Plough	Plough
1990	Plough	Plough	Plough	Plough
Sowing Date				
1988	18.09.87	03.10.87	30.09.87	11.03.88
1989	13.09.88	18.10.88	02.11.88	20.03.89
1990	21.09.89	10.10.89	20.03.90	19.03.90

SL - Sandy Loam, CL - Clay Loam, WW - Winter Wheat, WB - Winter Barley, SB - Spring Barley, OSR - Oilseed Rape

3.1.3. LARS SYSTEM

The LARS system requires assessment of weed numbers per square metre and the use of crop equivalents (CE, see *Section 2.3.3.*) to determine whether or not weeds should be controlled.

Table 2. CE Values

	Winter Cereals	Spring Cereals
Galium aparine	7.2	0.1
Avena fatua	2.5	
Papaver rhoeas	0.6	
Matricaria spp.	0.6	0.1
Sinapis arvensis	0.6	0.4
Volunteer rape	0.6	0.4
Stellaria media	0.5	0.2
Veronica persica	0.5	0.1
Lamium purpureum	0.5	
Veronica hederifolia	0.5	
Myosotis arvensis	0.2	0.1
Viola arvensis	0.1	
Poa annua	0.02	0.01
Galeopsis tetrahit		0.6
Polygonum aviculare		0.2
Polygonum convolvulus		0.2
Polygonum persicaria		0.2
Fumaria officinalis	0.3	0.2
Chrysanthemum segetum		0.1
Chenopodium album		0.1
Spergula arvensis		0.01

In winter cereals, weeds were sprayed if the total CE of broad-leaved weeds, excluding *G. aparine*, exceeded 5.0 or if the CE for either *G. aparine* or *A. fatua* exceeded 1.0. For spring cereals the threshold for spraying all broad-leaved weeds, including *G. aparine*, was 10.0 CE.

The crop equivalents recorded in threshold treatments and herbicides applied during the trial period are given in *Appendices 2 and 3.*

3.1.4. ASSESSMENTS

3.1.4.1. Weed Number

Weed numbers were counted in 20 x 0.1 m^2 random quadrats per plot in both autumn and spring for winter cereals, or once in spring for spring cereals.

3.1.4.2. Crop and Weed Ground Cover

Crop and weed ground cover were assessed using ten random point quadrats per plot. The point quadrat had 10 points at 5 cm spacing and was placed at right angles to the cereal rows.

3.1.4.3. **Soil Weed Seed Bank**

Ten to fifteen soil cores to 20 cm depth were randomly taken from each plot before treatments commenced, and again in autumn 1989 and spring 1990 after two years of the various management systems. The soil was bulked for each plot and analysed for weed seed at the Scottish Crops Research Institute.

3.1.4.4. **Measurement of Weed and Crop Above-Ground Biomass**

Crop and weed samples were taken at crop growth stages 30, 39, 65 (Zadoks, Chang and Konzak, 1974) and immediately before harvest for biomass determination. In 1988, 4 x 0.5 m rectangular areas were marked out in the autumn in each plot that was not going to receive pre-harvest glyphosate. From these areas all crop and weed biomass was cut at ground level. Total crop fresh weight from the harvested area was recorded and a sub-sample of approximately 20% of the fresh weight was dried after being split into stem and ears. The crop sub-sample and all weed biomass harvested was dried at 100 ^{o}C for 24 hours and re-weighed. This method proved too time-consuming for the amount of information collected and so in 1989 the method of harvesting samples was modified. At least 100 crop plants were taken at random from each trial plot with the full dose full insurance treatment. Crop plants were not taken from weedy areas to eliminate the effect of weeds on crop biomass. Weed plants, at least 5, were also taken randomly from areas of the trial which had not received herbicide. All crop and weed biomass harvested was weighed, dried at 100 ^{o}C for 24 hours and re-weighed.

3.1.4.5. **Harvesting**

All trials were harvested with a Claas Compact 25 combine harvester. The following measurements were taken.

a. Grain yield from a 2.25 m x 17 m or 26 m swath cut from the centre of each plot.
b. One kg of grain was taken from the combine sample for assessment of :
   i. grain moisture - 100 g of clean grain was dried at 100 ^{o}C for 24 hours;

ii. thousand seed weight - the number of seeds in 15 g of the dried sample from the grain moisture determination were counted. This sample was also retained for nitrogen content determination using the micro Kjeldahl technique (MAFF, 1981);

iii. the bulk of the sample taken at harvest was dried to 15% moisture content by forced air ventilation. From this sample, specific weight was determined using a chondrometer, the amount of screenings in a clean 100 g sample (< 2.2 mm barley, < 2.8 mm wheat) and the amount of weed contamination in a 500 g sample.

c. The effect of weeds on grain loss from a combine harvester was assessed using a method modified from the one described by Pascal and Provan (1967). All straw and chaff (MOG) from the straw walkers and sieves was collected on a canvas sheet over a distance of 8 m whilst the combine harvester was working. The speed of the combine over the 8 m was measured, the amount of MOG collected was weighed and the straw removed to leave the grain that had come over the back of the combine. This grain was thoroughly cleaned using a purpose built winnower, then dried at 100 ^{o}C for 24 hours and weighed. Samples of MOG were also taken and dried at 100 ^{o}C for 24 hours to determine moisture content.

3.2. REDUCED DOSE TRIALS 1989 AND 1990

Trials using reduced herbicide doses in cereals were conducted throughout the main arable areas of eastern Scotland in 1989 and 1990. The main objectives of these trials were to :

a. determine yield response in cereals to level of weed control and herbicide dose;

b. define factors which maximise herbicide efficacy and so minimise herbicide dose;

c. produce simple guidelines to allow farmers and advisers to recognise situations where reduced doses can be used with minimum risk of poor control and yield loss.

3.2.1. <u>1989</u>

3.2.1.1. **Crop and Site Details**

All trials in 1989 were taken to yield and were either drilled with an Oyjord drill at 12 cm row spacing or superimposed onto farmers' crops at right angles to the drilled rows *(Table 3)*.

Table 3. Crop and Site Details

Site	Grid Ref.	Elev. m	Soil Series	Soil Type	Crop	Sowing Date
Bush	NT 249 659	200	Winton	SL	WB/Magie WW/Fortress SB/Camargue	22.09.88 11.10.88 31.03.89
Upper Cairnie	NO 025 193	105	Balrownie	SL	WB/Magie WW/Fortress SB/Camargue	25.09.88 11.10.88 04.04.89
Middlestotts	NT 803 500	80	Whitsome	SCL	WB/Magie WW/Fortress SB/Camargue	20.09.88 18.10.88 31.03.89
Luffness Mains	NT 483 801	10	Dreghorn	SL	WW/Avalon	20.11.88
Markle Mains	NT 561 773	30	Kilmarnock	SCL	WW/Riband	30.09.88
Upper Dalhousie	NT 314 625	110	MacMerry	SL	WW/Riband	14.10.88

3.2.1.2. **Experimental Design**

At all sites, an incomplete randomised block design was used with three replicates and a plot size of 2 x 22 m.

3.2.1.3. **Treatments 1989 - Winter Cereals**

Trials in winter cereals in 1989 compared the use of an autumn with a spring herbicide at reduced dose :

- autumn herbicide DFF/IPU (treatment C *Table 4*) applied at full, half, quarter and one eighth of the recommended dose in winter wheat, but without the full dose in winter barley;
- spring herbicide metsulfuron methyl + CMPP (treatment G *Table 4*) applied at full, half, quarter and one eighth of the recommended dose, but without the full dose in winter barley. All CMPP applied as the potassium salt;

u untreated, one untreated plot per block at all sites except for the winter wheat at Middlestotts where there were three.

At three winter wheat sites (Luffness Mains, Markle Mains and Upper Dalhousie) two timings of the spring herbicide were tested. No autumn herbicide was tested at Luffness Mains.

Table 4. Treatments in Reduced Rate Trials 1990

A	Pendimethalin - 'Stomp 330', Cyanamid (330 g/l pendimethalin EC). Full rate - 1320g/ha pendimethalin applied in autumn.
B	A followed by CMPP in spring (Note 1.).
C	DFF/IPU - 'Panther', Rhone-Poulenc (500g/l IPU / 50g/l DFF SC). Full rate 1000 g/ha IPU / 100 g/ha DFF applied in autumn.
D	C followed by CMPP in spring (Note 1.).
E	Trifluralin - 'Treflan', DowElanco (480 g/l trifluralin EC). Full rate 960 g/ha applied in autumn.
F	E followed by CMPP in spring (Note 1.).
G	Metsulfuron-methyl + CMPP. 'Ally', Du Pont (200g/Kg metsulfuron-methyl WG) + CMPP (Note 1). Full rate 6 g/ha Metsulfuron-methyl + CMPP (Note 1.)
H	Metsulfuron-methyl/thifensulfuron-methyl + CMPP. 'Harmony M', Du Pont (680 g/Kg thifensulfuron-methyl / 70g/Kg Metsulfuron-methyl WG) + CMPP (Note 1). Full rate 4.2 g/ha metsulfuron-methyl / 40.8 g/ha thifensulfuron-methyl + CMPP (Note 1.)
J	MCPA/CMPP/dicamba. 'Banlene Plus', Shering (252 g/l MCPA / 84 g/l CMPP / 18 g/l dicamba SL). Full rate 1008 g/ha MCPA / 336 g/ha CMPP / 72 g/ha dicamba.
K	Cyanazine/clopyralid + MCPA. 'Coupler SC', Shell (350 g/l cyanazine / 60 g/l clopyralid SC) + 'Agritox 50' Rhone-Poulenc (500 g/l MCPA as dimethylamine salt SL). Full rate 245 g/ha cyanazine / 42 g/ha clopyralid + 1500 g/ha MCPA.
L	MCPA/Dichorprop. 'Campbell's Redipon Extra', MTM Agrochemicals (350g/l dichlorprop / 150 g/l MCPA SL). Full rate 1960 g/ha dichlorprop / 840 g/ha MCPA.
M	Metsulfuron-methyl + cyanazine. 'Ally', Du Pont (200g/Kg metsulfuron-methyl WG) + 'Fortrol', Shell (500 g/l cyanazine SC). Full rate 6 g/ha Metsulfuron-methyl + 250 g/ha cyanazine.
N	Isoxaben. 'Flexidor', DowElanco (500 g/l isoxaben SC). Full rate 125 g/ha isoxaben.
P	Trifluralin/IPU. 'Autumn Kite', Schering (300 g/l IPU / 200 g/l trifluralin EC). Full rate 1200 g/ha IPU / 800 g/ha trifluralin.
Q	Isoxaben/IPU. 'Ipso', DowElanco (450g/l IPU / 19 g/l isoxaben SC). Full rate 1575 g/ha IPU / 66.5 g/ha isoxaben.
R	Pendimethalin/IPU. 'Encore', Cyanamid (125 g/l IPU / 250 g/l pendimethalin SC). Full rate 500 g/ha IPU / 1000 g/ha pendimethalin.
S	IPU. 'Hytane 500 FW', Ciba-Geigy (500 g/l IPU SC). Full rate 1500 g/ha IPU.
T	Bifenox/IPU. 'Invicta', Farm Protection (400 g/l IPU / 160 g/l bifenox SC). Full rate 1600 g/ha IPU / 640 g/ha bifenox.
U	Cyanazine. 'Fortrol', Shell (500 g/l cyanazine SC). Full rate 1250 g/ha cyanazine.
V	Fluroxypyr. 'Starane 2', DowElanco (200 g/l Fluroxypyr EC). Full rate 150 g/ha fluroxypyr.
W	CMPP. 'Iso-Cornox 57', Schering (570 g/l CMPP as potassium salt SL). Full rate 2138 g/ha CMPP.
X	Cyanazine/fluroxypyr. 'Spitfire', DowElanco (500 g/l cyanazine / 200 g/1 fluroxypyr KL). Full rate 285 g/ha cyanazine / 150 g/ha fluroxypyr.
Y	Cyanazine/clopyralid + CMPP. 'Coupler SC', Shell (350 g/l cyanazine / 60 g/l clopyralid SC) + 'Iso-Cornox 57', Schering (570 g/l CMPP as potassium salt SL). Full rate 245 g/ha cyanazine / 42 g/ha clopyralid + 2138 g/ha CMPP.
Note 1.	CMPP was either 'Iso-Cornox 57', Schering (570 g/l mecoprop as the potassium salt SL) used in winter wheat and barley trials at Tillycorthie. Or 'Duplosan New System CMPP', BASF (600 g/l mecoprop-P isomer SL) used in all other trials. Full rate - Potassium salt 2138g/ha, P isomer 1200 g/ha.

1 Full recommended rate; 2 Half recommended rate; 3 Quarter recommended rate; 4 Eighth recommended rate.

3.2.1.4. **Treatments 1989 - Spring Cereals**

Full, half, quarter and one eighth of the recommended dose of metsulfuron-methyl plus or minus CMPP as the potassium salt (treatment G *Table 4*) were tested at three sites.

Untreated - one untreated plot per replicate, except at Bush and Middlestotts where there were two.

3.2.2. 1990

In 1990, yielded trials were continued to further study the response of cereal yield to level of weed control. Unyielded screening trials were also begun to look at consistency of control of a range of products against a range of weed species at reduced doses. The trial area was extended to include the major arable areas in Aberdeenshire.

3.2.2.1. **Site Details and Treatments in Yielded Trials 1990**

For treatment codes and site details for yielded trials in 1990, see *Table 5.* Plot size was 2-2.25 m x 20-24 m, in a randomised block with three replicates for each treatment, except the untreated where at some sites there was more than one untreated plot per replicate.

Table 5. Site Details Reduced Rate Yielded Trials 1990

Site	Grid Ref.	Elev. M	Soil Series	Soil Type	Crop	Sowing Date	Treatments (Table 4)
Ploughlands	NT 630 307	76	Kedslie	SL	WB/Magie SB/Camargue	17.09.89 19.03.90	A1-3; B2-4; C1-3; D2-4 G2-4; H2-4; L2-4; K2-4; J2+4
Treaton	NO 324 024	90	Darvel	SL	WW/Fortress SB/Camargue	05.10.89 29.03.90	C1-4; D2-4; G1-4 G2-4; H2-4; L2-4; M2+4
Bush	NT 246 651	190	Darvel	SL	SB/Camargue	30.03.90	GW-4 (T1+T2)
Tillycorthie	NJ 909 235	110	Pitmedden	SL	WB/Magie	26.09.89	A1-3; B1-4; C1-3; D1-4; E1-3; F1-4
Tillycorthie	NJ 915 237	85	Pitmedden	SL	WW/Riband	14.10.89	A1-4; B2-3; C1-4; D2-3; G1-4
Tillycorthie	NJ 912 245	100	Thistleyhill	SL	SB/Golf	21.03.90	G1-4 (T1+T2); H1-4 (T1+T2)
Sunnybrae	NJ 875 115	80	Thistleyhill	SL	SB/Camargue	29.03.90	G2-4 (T1, T2); H2-4; J2-4; K2-4; L2-4; M2-4

3.2.2.2. **Screens 1990**

A series of small plot trials, 2 x 8 m with two replicates, were superimposed onto cereal crops to assess efficacy and crop tolerance of a range of herbicides *(Table 6)*.

Table 6. Site Details Screens 1990

Site	Grid Ref.	Elev. m	Soil Series	Soil Type	Crop	Sowing Date	Treatments
Smiths Holding	NT 253 657	183	Darvel	SL	WB/Magie	21.09.89	Pre A1-3; C1-3; EL-3; N1-3 Post1 C1-3; P1-3; Q1-3; R1-3
Markle Mains	NT 561 773	30	Kilmarn.	SCL	WW/Riband	30.09.89	Pre A1-3; C1-3; EL-3; N1-3 Post1 C1-3; P1-3; Q1-3; R1-3
Carsewell	NT 213 598	229	Darvel	SL	SB/Camargue	01.04.90	G1-4; H1-4; J1-4; K1-4; L1-4; M1-4
Newburgh	NJ 973 224	60	Peterhead	SL	WB/Plaisant	18.09.89	Pre A1-3; C1-3; E1-3; N1-3 Post1 C1-3; P1-3; Q1-3; R1-3 Post 2 C1-3; S1-3; T1-3; U1-3; V1-3; W1-3
Udny	NJ 875 252	95	Tarves	SL	WW/Riband	10.10.89	Pre A1-3; C1-3; E1-3; N1-3 Post1 C1-3; P1-3; Q1-3; R1-3 Post2 G1-3; H1-3; V1-3; W1-3; X1-3; Y1-3

3.2.3. HERBICIDE APPLICATION 1989 AND 1990

All products in all trials were applied as *Section 3.1.2.* and application details are given in *Appendix 4*.

3.2.4. ASSESSMENTS

3.2.4.1. **Weed Density, Weed and Crop Growth**

Weed number, crop/weed ground cover and final harvest assessments were carried out as *Section 3.1.4.* In screens in 1990, 5 random quadrats were used to estimate crop/weed ground cover and weed density.

Crop and weed heights, to the highest point above ground-level, were measured in the winter barley at Bush in 1989 by taking 10 random measurements per plot.

3.2.4.2. Weed Biomass

At Bush, all above-ground weed biomass from a single 0.24 m^2 quadrat was harvested from the centre of all plots in the winter barley trial on 9th May, 1989. This was dried at 100 ^{o}C for 24 hours and weed dry weight determined. *S. media* from all the untreated plots was analysed for nitrogen content by the micro Kjeldahl technique (MAFF, 1981).

3.2.4.3. Fertile Ear Number

Fertile ear number at Bush in winter barley and wheat plots in 1989 was estimated by counting the number of ears in 4 random 0.5 m lengths of row per plot.

3.2.4.4. Crop Damage

A visual assessment of crop vigour, yellowing and scorch were made using a 1-9 scale (9 = High vigour, high level of scorch and yellowing).

3.2.4.5. Harvesting

All yielded sites were harvested with a Claas Compact or Deutz plot combine. A 100 g sample from each plot was dried at 100 ^{o}C for 24 hours to determine moisture content and 15 g dried samples were retained and the number of grains counted to determine thousand seed weight.

3.2.5. ANALYSIS OF RESULTS

Data was analysed using GENSTAT IV and V (Rothamsted Experimental Station). Analysis of variance was performed on trial data with treatment sum of squares partitioned into factors where appropriate (Appendix VII). Linear regression, both single and multiple, was used to further investigate the relationship between variables. Analysis used is outlined at the beginning of each results section.

All yield and thousand seed weight data is expressed at 15% moisture content.

Levels of significance used :	*	- Significant	$p<0.05$
	**	- Significant	$p<0.01$
	***	- Significant	$p<0.001$
	NS	- Not Significant	$p>0.05$

3.2.5.1. **Dose Response Curves and Derivation of Effective Dose**

Control of weed species achieved by herbicides tested in reduced dose trials was characterised by their ED90 - the effective dose (expressed as percentage of the full recommended dose) to control 90% of the population. Weed control figures were derived from ground cover assessments at a standard time (crop GS 39), control expressed relative to the untreated :

% control = 100 x (1 - (% ground cover in treated/% ground cover in untreated))

Problems arose in mixed weed populations because weed competition and differential weed control of species distorted weed growth relative to the untreated. In such circumstances in winter cereals, weed density in the spring was used to determine weed control. For some weeds and for some herbicides which stunt weeds, weed volume (weed height x ground cover) was found to be a better indicator of control.

To all data an equation simplified from the one used by Jensen and Kudsk (1988) was fitted using the 'Logit' link function in Genstat V (see Appendix VII). This transformation produces a straight line fit for the symmetrical sigmoid dose response curve and allows level of control to be determined for any herbicide dose (Streibig, 1988).

General equation fitted :

$$\frac{\%\ \text{Control}}{100} = 1 - \left(\frac{1}{\text{Exp}[-a - b.\text{loge}(\text{dose})] + 1} \right)$$

where 'a' is the constant and 'b' the rate of change term. The equation has been simplified from that of Jensen and Kudsk (1988) by setting a minimum for weed control of 0% and a maximum for dose of 100%.

$$\text{ED90} = \frac{\text{Exp}\ \ \text{loge}(1/9) - a}{b}$$

3.2.5.2. Fitting of Curves to Yield v Herbicide Dose Data

Quadratic curves were fitted to yield data from reduced dose trials conducted in 1989 and 1990. Data were sparse, a minimum of four and maximum of five points, and quadratic equations were fitted using either untransformed or loge(X+1) transformed data.

$$Y = a + b_1X + b_2X^2$$
$$Y = a + b_1.\log e(X+1) + b_2.[\log e(X+1)]^2$$

From these equations, the economic optimum (N) was determined as the point at which the marginal cost was equal to the marginal revenue :

Marginal cost = cost of using 1% more herbicide.
Marginal revenue = value (extra yield) of using 1% more herbicide.
Values used - Average on farm prices 1990 £/1% (100% = full dose) :

DFF/IPU	0.20
DFF/IPU + CMPP	0.25
Trifluralin	0.054
Trifluralin + CMPP	0.10
Pendimethalin	0.22
Pendimethalin + CMPP	0.27
Metsulfuron-methyl	0.13
Metsulfuron-methyl + CMPP	0.18
Th.-methyl + Met.-methyl + CMPP	0.21

Crop prices (1990 ADAS Budget figures) :

	£/t
Winter Wheat (feed)	98
Winter Barley (feed)	92
Spring Barley (malting)	120

A second economic optimum was calculated (2N) based on a herbicide cost twice that of the 1990 price. No other costs, e.g. for spray application, were included.

4. RESULTS

4.1. LONG-TERM TRIALS 1989-90

Data in this section was analysed using ANOVA (Section 3.2.5., Appendix VII - Threshold Trials) and simple linear regression.

4.1.1. YIELD

Significant ($p<0.05$) yield differences between treatments *(Table 7)* were only found for winter barley grown at Smiths in 1988 and 1990 and for winter wheat at Gleghornie in 1990.

Table 7. *Yield Long-Term Trials 1988-90, (t/ha)*

	Insurance Full	Insurance Half	Threshold Full	Threshold Half	Untreated	SED (18 DF)	CV%
Smiths							
WB 1988	7.85	7.07	7.47	6.45	7.79	0.30*	7.1
WB 1989	8.80	8.62	8.71~	8.10~	8.23	0.30	6.2
WB 1990	7.12	6.87	7.09~	6.92~	3.35	0.40**	11.0
Gleghornie							
WW 1988	12.31	12.10	12.40~	12.45~	12.25	0.28	4.0
WW 1989	10.19	10.15	10.23	10.09	9.69	0.29	5.0
WW 1990	8.28	9.01	8.67	8.99	9.45	0.38*	7.3
Remote							
SB 1988	9.30	9.36	9.15	9.27	8.91	0.25	4.0
SB 1989	7.44	7.15	7.36	7.50	7.88	0.43	4.8
SB 1990	7.58	7.63	7.47	7.02	7.39	0.24	2.6
Niddry Mains							
WW 1988	9.30	9.36	9.15~	9.27~	8.91	0.25	4.8
WW 1989	7.44	7.15	7.36	7.50	7.88	0.43	10.0
SB 1990	7.58	7.63	7.47	7.02~	8.39	0.24	5.6

~ Weeds controlled in threshold treatments.

The significant ($p<0.05$) difference at Smiths in 1988 between the half rate threshold and the untreated and full rate threshold, despite all treatments being identical, was the result of differential weed levels between treatments *(Table 8)* and the subsequent effect on plot yields *(Figure 1)*.

Table 8. *S. media m^{-2} Threshold and Untreated, Smiths, Autumn 1987*

Treat.	Threshold (Full)	Threshold (Half)	Untreated	SED (13 DF)
1988	6.3	12.1	4.1	2.9*

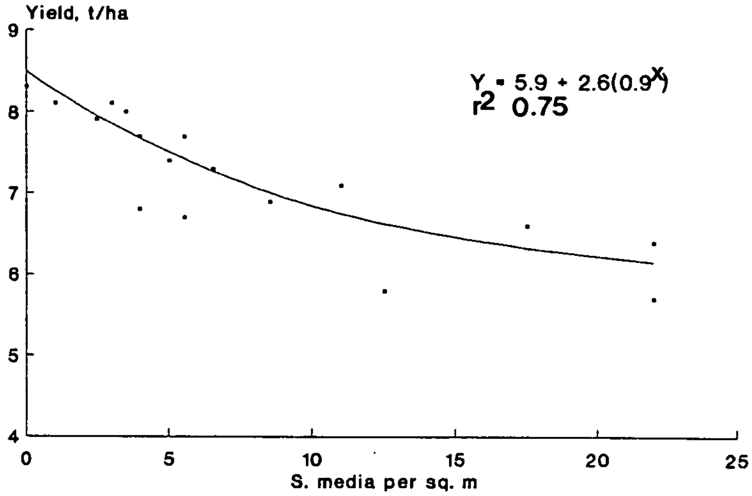


Figure 1. Relationship between Plot Yield and S. Media, Smiths 1988

At Gleghornie in 1990, the full rate full insurance gave a significantly ($p<0.05$) lower yield than the untreated. This would indicate crop damage from the full rate metsulfuron-methyl + Isoproturon applied in the spring. Reduction in yield resulted from a significant reduction in seed number m^{-2} *(Table 9)*.

Table 9. Thousand Seed Weight and Seed No. m^{-2} at Gleghornie 1990

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
Thous. Seed Wt., g	52.6	53.0	50.6	51.9	51.6	0.8*
Seeds m^{-2} x 10^3	15.8	17.0	17.1	17.3	18.4	0.7*

Yield for all years and sites by crop are shown in *Table 10.* Winter barley was the most responsive crop to herbicide treatment producing a net benefit from both insurance and threshold spraying. For both winter wheat and spring barley the benefit from weed control was small or negative. The use of half doses and thresholds tended to minimise economic loss in both winter wheat and spring barley, but the full dose insurance gave the best return for winter barley. However, the results for winter barley, all at Smiths, should be viewed with caution as the half dose insurance had as good weed control as the full dose and difference in yield appeared to be the result of site variation.

Table 10. Mean Yield All Sites and Years

a. Winter Barley (3 trials)

	Yield	Aver. Herbicide Cost	No. Times Sprayed	Margin over Herbicide Cost
	t/ha	£	%~	£
Insurance (Full)	7.92	19.51	100	+114.81
Insurance (Half)	7.52	9.76	100	+87.76
Threshold (Full)	7.76	12.07	66	+107.53
Threshold (Half)	7.16	6.04	66	+58.36
Untreated	6.46			
SED (8 DF)	0.83			

b. Winter Wheat (5 trials)

	Yield	Aver. Herbicide Cost	No. Times Sprayed	Margin over Herbicide Cost
	t/ha	£	%~	£
Insurance (Full)	9.50	33.23	100	-46.95
Insurance (Half)	9.55	16.62	100	-25.44
Threshold (Full)	9.56	16.71	40	-24.55
Threshold (Half)	9.66	8.36	40	-6.40
Untreated	9.64			
SED (16 DF)	0.18			

c. Spring Barley (4 trials)

	Yield	Aver. Herbicide Cost	No. Times Sprayed	Margin over Herbicide Cost
	t/ha	£	%~	£
Insurance (Full)	7.32	18.50	100	-23.30
Insurance (Half)	7.38	9.25	100	-6.85
Threshold (Full)	7.38	0	0	+2.40
Threshold (Half)	7.22	2.58	25	-19.38
Untreated	7.36			
SED (8 DF)	0.10			

~ Sprayed in every year = 100%

4.1.2. EFFECT OF WEEDS ON COMBINE HARVESTER PERFORMANCE

1. Harvest 1988

Grain loss from the straw walkers and sieves was positively linearly related to matter other than grain (MOG) throughput at all sites in 1988 *(Table 11)*. For each site 3 variates : grain yield, straw dry matter percentage and weed level at harvest were fitted to MOG yield *(Table 11)*. Straw dry matter percent was found to be significantly ($p<0.05$) related to MOG yield at 3 sites and weed level only at Remote. A plot of residuals against weed level at Remote showed that the significant effect was heavily influenced by one plot (plot 13,

Table 12) which had a high level of *Polygonum aviculare* at harvest. *Figure 2* shows the significant ($p<0.05$) negative linear relationship between G : MOG ratio and *P. aviculare* ground cover at Remote in 1988.

Table 11. Coefficients and Standard Errors for Variates fitted to MOG Yield and the Linear Relationship between MOG throughput and Grain Loss All Sites 1988

	Grain Yield	DM% of Straw	Weed Level	MOG Throughput (t/hr) versus Grain Loss (kg/ha)
Smiths				
Coeff.	0.16	-0.06*	-	NR
SE.	0.20	0.02	-	
Gleghornie				
Coeff.	0.09	-0.14**	0.02	$Y = -1.2 + 0.8X$; $r^2 = 0.34$
SE.	0.42	0.04	0.05	
Remote				
Coeff.	2.15**	-0.05	0.08*	$Y = -0.5 + 0.4X$; $r^2 = 0.78$
SE.	0.49	0.05	0.02	
Niddry Mains				
Coeff.	0.05	-0.07*	-0.01	$Y = 0.2 + 0.5X$; $r^2 = 0.30$
SE.	0.36	0.02	0.11	

Table 12. Plot Variation in P. aviculare and MOG Yield, Remote 1988

Plot No.	P. aviculare % Ground Cover at Harvest	Grain Yield (t/ha)	MOG Yield (t/ha)	% Yield Loss from Straw Walkers
11	0.0	6.6	7.2	1.4
12	0.0	6.8	6.7	1.8
13	40.0	7.0	9.9	3.0
14	0.0	7.1	7.5	1.5

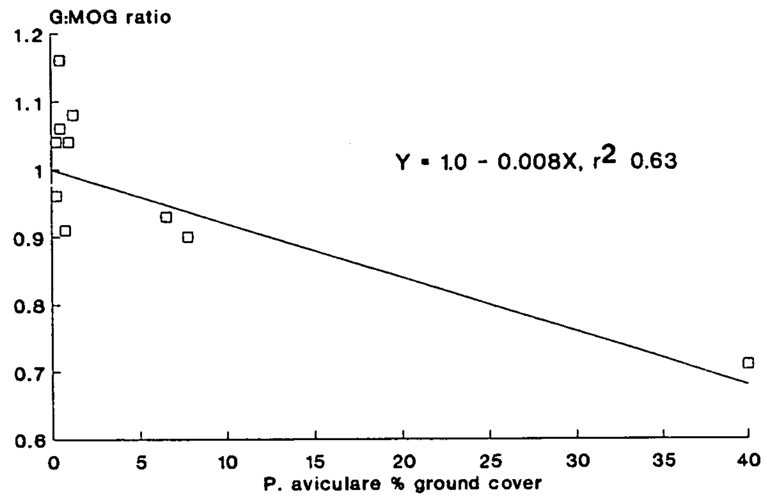


Figure 2. *Relationship between G : MOG Ratio and P. aviculare Ground Cover, Remote 1988*

2. Harvest 1989

In 1989, combine performance was only measured at Smiths, because of the very low weed levels at other sites.

At Smiths, the untreated had a significantly higher MOG yield and significantly lower G : MOG ratio than any treatment in which *S. media* was controlled *(Table 13)*. *Figure 3* shows the relationship between MOG throughput and grain loss from the straw walkers and sieves.

Note : G:MOG ratio is NOT a harvest index. MOG is on a fresh weight basis and represents all matter other than grain that passed through the harvester and includes variables such as cutting height and straw dry matter content.

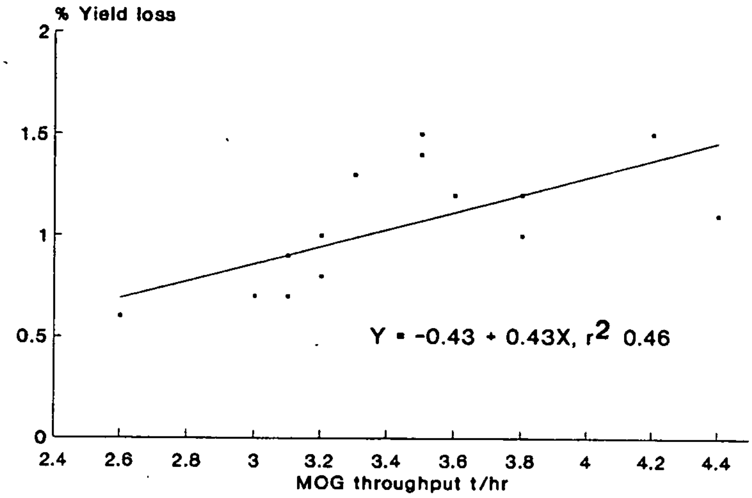


Figure 3. MOG Throughput and Grain Loss, Smiths 1989

Table 13. MOG Yield and Grain : MOG Ratio, Smiths 1989

Treat.	**Ins. (F)**	**Ins. (H)**	**Thr. (F)**	**Thr. (H)**	**Untr.**	**SED (18 DF)**
MOG Yield t/ha	4.2	4.0	4.4	4.0	5.0	0.26**
Grain Yield to MOG Ratio~	2.1	2.2	2.0	2.1	1.7	0.12**

~ G:MOG ratio = Grain yield / MOG yield

3. Harvest 1990

Only at Smiths was weed level sufficient to measure combine performance in 1990. The very high level of *Stellaria media* which caused the large yield loss in untreated plots was still present at harvest. *Figure 4* shows the relationship between % yield loss from the straw walkers and sieves and MOG throughput. It was noticeable that grain loss was greater in untreated plots for any given level of MOG throughput. This reflects the effect of the higher moisture level of the untreated crop *(Table 14)*, caused by the presence of weeds, on grain separation characteristics.

Table 14. *MOG Dry Matter %, Smiths 1990*

Untr.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	SED (18 DF)
43.0	57.1	54.7	55.1	50.6	3.3**

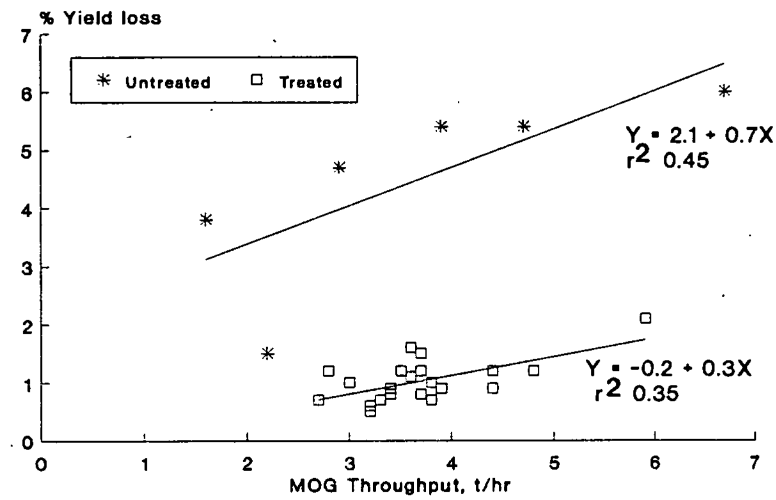


Figure 4. *MOG Throughput and Grain Loss, Smiths 1990*

4.1.3. EFFECT OF WEEDS ON GRAIN QUALITY

At no site in any year was moisture content of the grain found to be significantly affected by treatment.

No management treatment had any significant effect on grain specific weight at any site in any year.

Nitrogen content of winter barley was found to decline with increasing *Stellaria media* density at Smiths in 1988 *(Figure 5)*.

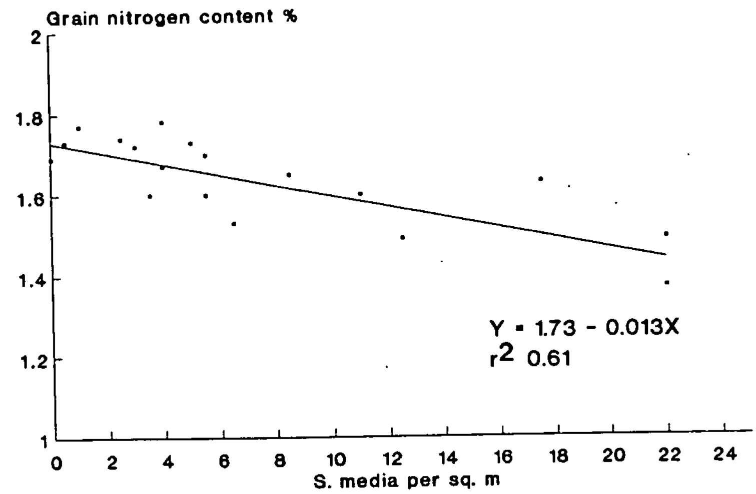


Figure 5. Effect of S. media on Nitrogen Content % in Dry Matter of Winter Barley, Smiths 1988

4.1.4. HERBICIDE DAMAGE

Direct evidence of herbicide damage to the crop was found at Smiths in 1990. Here DFF/IPU sprayed soon after crop emergence was found to have significantly ($p<0.05$) reduced crop ground cover in threshold and insurance treatments compared to the untreated, but there was no response to herbicide dose *(Table 15)*.

Table 15. Crop Ground Cover %, Smiths, 27th November 1989

Untr.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	SED (18 DF)
51.2	45.0	41.3	43.0	43.3	2.9*

4.1.5. WEED SEEDLING POPULATIONS 1988-90

Full weed count data for each site is given in *Appendix 1*. *Tables 16-23* show the weed species whose populations changed over the three years of the trial. Data for insurance treatments in some seasons was taken after herbicide treatment (^). Years in which threshold treatments were sprayed to control the weed species given in the table are denoted by ~. Data collected in 1990 was prior to any herbicide treatment and values for sqrt n+1 transformed data with SED's are given in brackets.

1. Smiths

Table 16. S. media Plant Number m^{-2}, Smiths 1988-90

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
1988	0.3^	0.2^	6.3	12.1	7.3	
1989	0.0^	0.0^	9.6~	37.8~	9.1	
1990	14.4 (3.6)	12.3 (3.6)	129.9~ (11.3)	143.9~ (11.9)	123.4 (10.3)	(1.7)**

Stellaria media plant number in the threshold and untreated showed a large increase in 1990 *(Table 16)*, the result of seed produced in 1988 being ploughed back to the surface. There were approximately ten times as many *S. media* seedlings in the threshold and untreated plots in 1990 as in plots that had received herbicide in the two previous seasons.

2. Gleghornie

Table 17. M. arvensis Plant Number m^{-2}, Gleghornie 1988-90

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
1988	0.0^	0.1^	0.5~	0.7~	1.3	
1989	0.0^	0.0^	0.4	0.1	0.5	
1990	0.3 (1.1)	0.2 (1.1)	0.3 (1.1)	0.5 (1.1)	1.3 (1.6)	(0.1)*

Table 18. S. media Plant Number m^{-2}, Gleghornie 1988-90

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
1988	0.0^	0.0^	3.8~	3.6~	4.4	
1989	0.0^	0.0^	3.1	2.3	3.3	
1990	3.7 (2.2)	4.8 (2.4)	5.2 (2.4)	4.8 (2.3)	9.2 (2.9)	(0.3)*

Table 19. P. annua Plant Number m⁻², *Gleghomie 1988-90*

Treat.	**Ins. (F)**	**Ins. (H)**	**Thr. (F)**	**Thr. (H)**	**Untr.**	**SED (18 DF)**
1988	0.2^	0.7^	9.7	10.7	7.5	
1989	0.1^	0.6^	6.5	4.4	5.8	
1990	7.5 (2.9)	8.4 (3.1)	14.0 (4.3)	17.9 (4.3)	13.0 (3.7)	(0.2)**

Poa annua was not controlled in any year in the threshold and untreated treatments resulting in significantly more *P. annua* seedlings compared to the insurance treatments in 1990 *(Table 19).*

In both insurance and threshold treatments, *Stellaria media* and *Myosotis arvensis* were controlled in 1988 with herbicide and both these treatments had significantly fewer of these seedlings compared to the untreated in 1990 *(Tables 17 and 18).*

3. Niddry Mains

Table 20. S. arvensis Plant Number m^{-2}, Niddry Mains 1988-90

Treat.	**Ins. (F)**	**Ins. (H)**	**Thr. (F)**	**Thr. (H)**	**Untr.**	**SED (18 DF)**
1988	0.2^	0.9^	7.8	6.2	6.4	
1989	0.0^	0.0^	4.3	5.9	5.9	
1990	10.6 (3.3)	12.5 (3.6)	10.6 (3.4)	19.1~ (4.4)	36.3 (6.0)	(0.5)**

Table 21. M. arvensis Plant Number m^{-2}, Niddry Mains 1988-90

Treat.	**Ins. (F)**	**Ins. (H)**	**Thr. (F)**	**Thr. (H)**	**Untr.**	**SED (18 DF)**
1988	0.1^	0.2^	2.3~	2.5~	2.0	
1989	0.0^	0.0^	2.4	2.4	2.3	
1990	2.8 (1.9)	3.4 (2.1)	2.4 (1.8)	2.6~ (1.9)	10.3 (3.3)	(0.3)**

In 1990, *Sinapis arvensis* and *Myosotis arvensis* were present at significantly higher levels in the untreated compared to the full insurance and threshold plots *(Tables 20 and 21).* However, *S. arvensis* was not controlled by the herbicide applied to the threshold plots in 1988 and the data from the weed seed bank *(Section 4.1.7.)* would suggest that *S. arvensis* seeds were present at significantly higher levels in the threshold treatments when compared to the full insurance. Although the herbicide used in threshold treatment in 1988 did not kill *S. arvensis* plants, there was disruption of flowering and abortion of pods which may have affected seed viability and could explain this difference.

4. Remote

Table 22. P. aviculare Plant Number m^{-2}, Remote 1988-90

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
1988	7.5^	2.1^	6.8	2.1	1.8	
1989	2.0^	0.6^	2.5	0.3	0.9	
1990	1.7 (1.5)	0.4 (1.2)	7.3 (2.4)	3.7 (2.0)	4.5 (2.0)	(0.6)

Table 23. S. media Plant Number m^{-2}, Remote 1988-90

Treat.	Ins. (F)	Ins. (H)	Thr. (F)	Thr. (H)	Untr.	SED (18 DF)
1988	2.8	1.7	2.8	1.9	2.6	
1989	1.9	1.1	2.6	3.8	2.2	
1990	1.3 (1.5)	0.8 (1.3)	10.4 (3.2)	13.4 (3.7)	13.7 (3.6)	(0.6)*

Threshold plots remained unsprayed in every year and both these and the untreated had significantly more *Stellaria media* seedlings in 1990 than the insurance *(Table 23)*. Although not significant (p>0.05) *Polygonum aviculare* also showed a similar trend *(Table 22)*.

4.1.6. Weed Growth Patterns 1988 and 1989

The growth of the weeds *(Figures 6a-g)* relative to the crop can be split into three categories :

a. early - weed showing reduction in dry matter before GS 65 of the crop;
b. intermediate - weed showing reduction in dry matter between GS 65 and GS 90;
c. late - weed still increasing in dry matter at GS 90 of the crop.

Variation in weed growth patterns occurred between crop species and years. *Poa annua* in winter barley at Smiths was late in 1988 and intermediate in 1989 compared to *P. annua* in winter wheat at Gleghornie which was intermediate in 1988 and early in 1989. Both the difference between crop species and year is simply a reflection of the effect of season on crop and weed maturity.

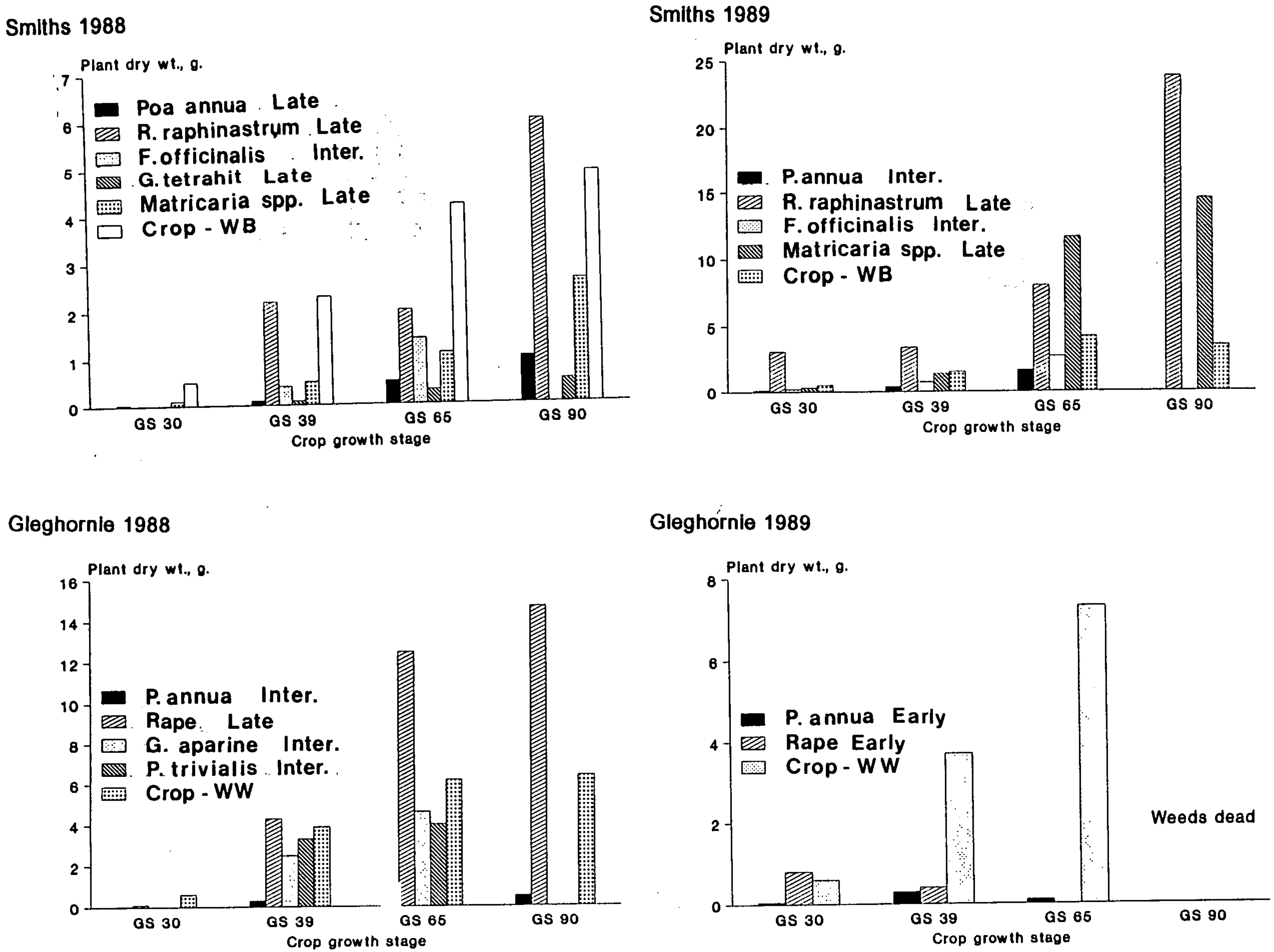
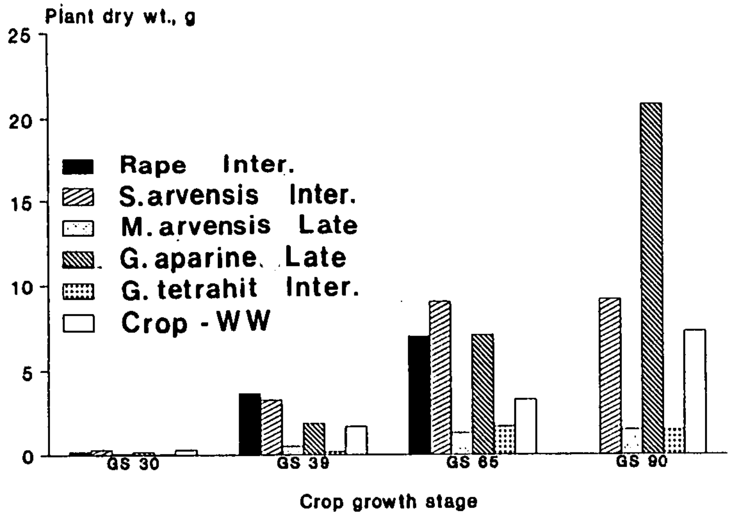
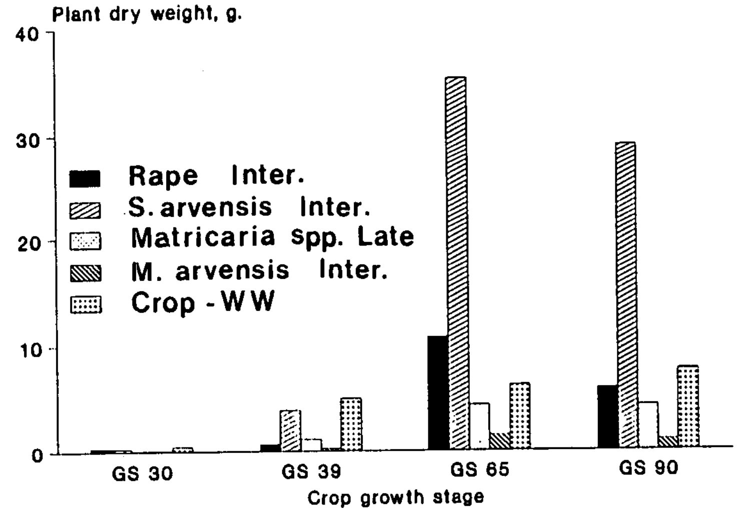


Figure 6. Weed Growth Patterns 1988 and 1989

Niddry Mains 1988



Niddry Mains 1989



Remote 1988

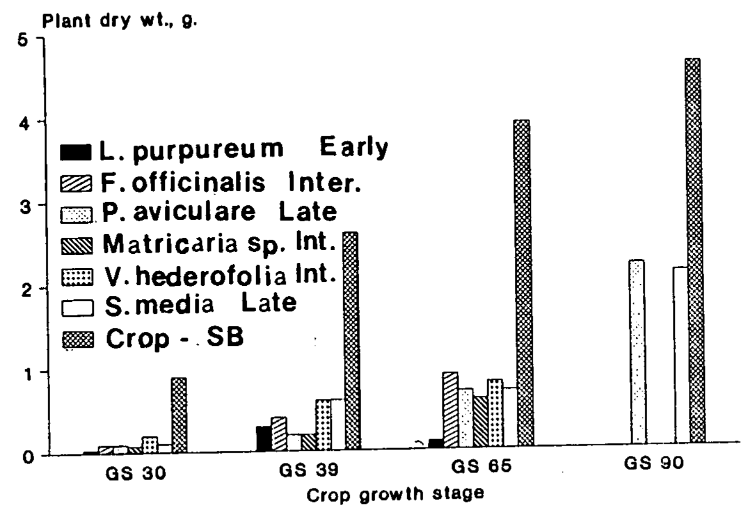


Figure 6. Weed Growth Patterns 1988 and 1989 (continued)

4.1.7. CHANGE IN THE WEED SEED BANK AFTER TWO YEARS OF TREATMENTS

Significant changes in the weed seed bank were found after two years of management treatments *(Table 24)*. Figures in brackets are sqrt n + 1 transformed data and SED's are for comparison between 1988 and 1990. Weed species abbreviations as *Appendix 1*.

Table 24. Number of Weed Seeds in One Square Metre of Soil (20 cm depth) meaned across All Treatments - 1988 and 1990

1. Smiths

Species	S. m	S. a.	C. a.	P. a.	Poa	P. p
Year						
1988	156 (8.9)	600 (19.2)	4944 (68.4)	1967 (43.3)	400 (17.3)	433 (18.9)
1990	11789 (90.8)	56 (4.5)	5467 (72.7)	1233 (33.3)	2033 (42.4)	256 (14.2)
SED (2DF)	(8.9)***	(5.3)	(12.5)	(2.0)*	(2.1)***	(2.9)

2. Remote

Species	S. m	S. a.	C. a.	P. a.	Poa	P. p
Year						
1988	22 (2.6)	33 (3.4)	78 (6.1)	122 (6.4)	1589 (38.8)	267 (15.5)
1990	356 (15.4)	111 (6.7)	167 (10.7)	289 (12.2)	2678 (51.0)	367 (17.4)
SED (2DF)	(1.1)**	(1.0)	(1.2)	(1.3)*	(7.6)	(3.4)

3. Gleghornie

Species	S. m	Poa
Year		
1988	978 (28.3)	1044 (31.1)
1990	533 (18.4)	2767 (49.5)
SED (2DF)	(6.0)	(5.2)

4. Niddry Mains

Species	Br.	S. m	G. a.	M. a.	G. t.	P. a.	B. c.
Year							
1988	33 (3.4)	590 (19.2)	22 (2.6)	1122 (32.4)	133 (8.6)	757 (25.2)	211 (12.0)
1990	478 (19.2)	311 (13.9)	22 (2.6)	411 (19.0)	22 (2.6)	289 (14.8)	144 (8.9)
SED (2DF)	(3.4)*	(5.6)	(1.4)	(4.6)	(1.2)*	(4.1)	(1.3)

Br. - *Brassica spp.* (sinapis arvensis and oilseed rape).

The changes in the weed seed bank from 1988 to 1990 *(Table 24)* have arisen through :

a. Natural loss, e.g. predation, desiccation etc. Seeds which tended to diminish in number across sites were from spring germinating weeds where there had been a sequence of winter cropping, e.g. *Galeopsis tetrahit*, *Polygonum aviculare* and *Polygonum convulvulus* at Niddry Mains and *P. aviculare* and *Polygonum persicaria* at Smiths Holding. The high level of *Chenopodium album* in the seed bank remained unchanged at Smiths Holding despite no spring cropping during the trial period nor since spring barley in 1984.

   In any year the proportion of seeds which gave rise to seedlings was rarely greater than 5% *(Table 25)*, suggesting this was not a major way in which the weed seed bank was depleted.

<u>Table 25</u>. *Proportion (%) of Seeds giving Rise to Seedlings in 1988 and 1990*

	S.m	Br.	G.a.	M.a.	G.t.	P.a.	B.c.	Poa	V.h.	F.o.
Smiths										
1988	4.7									
1990	0.7									
Niddry Mains								-	-	-
1988	0	11.0	0.9	0.2	0.6	0	0	-	-	-
1990	1.6	3.7	0.6	1.3	5.2	0.8	2.2			
Gleghornie										
1988	0.4	1.4	0.0	-	-	-	-	0.8	-	-
1990	1.0	0.0	0.3	-	-	-	-	0.4	-	-
Remote										
1988	10.7	-	-	4.4	-	3.3	-	2.3	0.8	0.4
1990	2.2	-	-	0.5	-	1.1	-	0.1	0.1	0.1

Br. - *Brassica spp.* (sinapis arvensis and oilseed rape).

b. Herbicide treatment. Some changes in weed seed in the soil were found to be significantly related to management treatment *(Table 26)*. At each site the dominant weed that was recorded as seedlings between 1988 and 1990 was present in the soil as seed in lower numbers in full insurance treatments where all weeds were controlled in every year. This reflected the absence of fresh seed production in herbicide treated plots rather than depletion of the seed bank through control of seedlings.

Table 26. Effect of Management Treatment after two years on Weed Seeds m^{-2} (20 cm deep) in Soil 1990

	Full Ins. (F)	Full Ins. (H)	Thresh. (F)	Thresh. (H)	Untr.	SED 18 DF
Smiths						
S. media	1278 (32)	1167 (30)	8667 (89)	24555 (155)	28222 (132)	(29)*
P. annua	667 (25)	1167 (32)	3111 (54)	3000 (59)	1667 (37)	(7)*
Remote						
S. media	111 (7)	56 (4)	556 (15)	444 (17)	611 (20)	(8)*
Niddry Mains						
S. arvensis	167 (10)	167 (8)	889 (28)	500 (20)	667 (23)	(6)*
Gleghornie						
P. annua	1278 (34)	1500 (38)	3444 (55)	4167 (62)	3444 (58)	(6)*

( ) Transformed data sqrt n+1

4.2. Reduced Dose Yielded Trials 1989 and 1990

Results of the 1989 and 1990 reduced dose trials are reported by crop and site. Analysis is restricted to the effect of herbicide dose on yield and the amount of variability that could be accounted for by level of weed control (Section 3.2.5., Appendix VII - Reduced Dose Trials).

For the relationship between herbicide dose and yield (Appendix VI) a general equation was fitted to all data :

$$Y = a + b \log_e(X+1) + b [\log_e(X+1)]$$

The effectiveness of herbicides has been characterised by the ED_{90} value for individual weed species and factors which appeared to affect weed control (Section 3.2.5.1). Tables of economic optima have N = herbicide cost, 2N = 2x herbicide cost and Eopt = economic optimum dose (Section 3.2.5.2).

4.2.1. Response of Winter Barley to Herbicide Dose

1. 1989

Only at Bush was there a significant ($p<0.05$) effect of herbicide dose and timing *(Table 27)*. Yield at Bush declined with herbicide dose and was lower from the spring applied herbicide. This response was related to the level of weed control *(Table 27, Figure 7)* of the very high *Stellaria media* population (345 plants/m^2 in the autumn).

Table 27. Yield, t/ha, Reduced Dose Winter Barley Trials 1989

	Bush	Middlestotts	Upper Cairnie
DFF/IPU (Autumn)			
Half	7.35 (3.3)	6.21 (54.0)	5.48 (0)
Quarter	6.51 (36.3)	6.66 (40.7)	5.65 (0)
Eighth	5.05 (81.3)	6.10 (66.7)	5.36 (0)
Mean	6.30	6.32	5.50
Metsulfuron-methyl + CMPP (Spring)			
Half	5.90 (64.0)	5.25 (72.0)	5.26 (0)
Quarter	5.92 (57.7)	5.47 (68.0)	5.33 (0)
Eighth	5.39 (74.0)	5.84 (53.0)	5.56 (0)
Mean	5.74	5.52	5.38
Untreated	4.66 (95.0)	5.61 (63.0)	5.71 (0)
SEDa (12 DF)	0.32*	0.82	0.26
SEDb (12 DF)	0.25*	0.47	0.18
CV%	6.5	17.2	5.8

( ) - Weed level at harvest, Bush = *Stellaria media* ground cover %;
Middlestotts = *Lolium perenne* heads /m²

SEDa - Comparison of any pair
SEDb - Comparison of spring and autumn means

At Middlestotts, a severe *Lolium perenne* infestation caused variation between plot yields *(Figure 8)* and explains most of the yield variation between treatments.

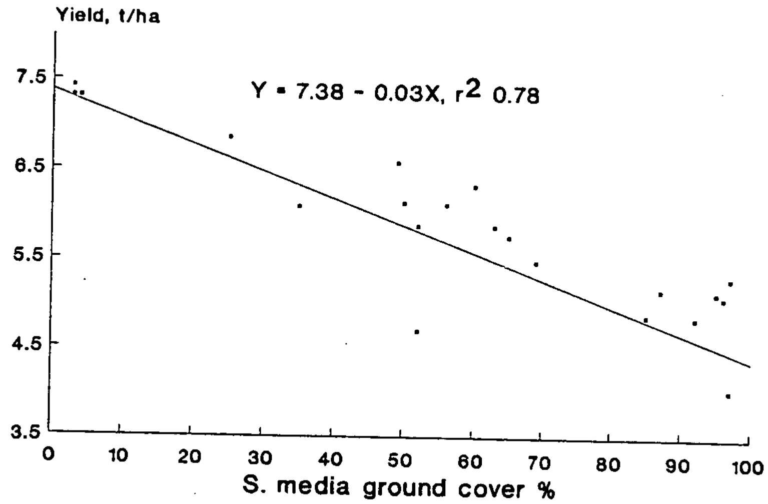


Figure 7. Relationship between S. media Ground Cover at Harvest and Yield, Bush Winter Barley 1989

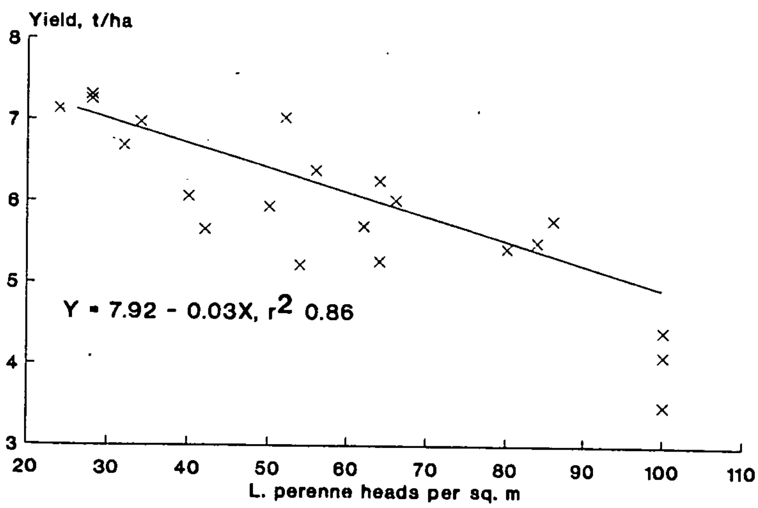


Figure 8. Relationship between L. perenne Heads /m² at Harvest and Yield of Winter Barley at Middlestotts 1989

2. 1990

At Tillycorthie yield differed significantly ($p<0.05$) between treatments and was related to level of *Stellaria media (Table 28, Figure 9).* There was some indication that the use of CMPP in the spring damaged the crop, shown by scorch recorded in April *(Table 28)*, and that this was related to dose.

Table 28. Yield of winter barley reduced dose trials 1990

	Tillycorthie Yield t/ha	Tillycorthie Scorch	Ploughlands Yield t/ha
DFF/IPU			
Full	7.37 (0.0)	2.0	9.85 (0.0)
Half	7.31 (8.7)	2.0	9.84 (0.0)
Quarter	7.07 (50.0)	2.0	9.87 (0.0)
DFF/IPU + CMPP			
Full	7.21 (0.0)	5.0	
Half	7.30 (0.2)	3.7	9.97 (0.0)
Quarter	7.28 (5.3)	3.0	9.69 (0.0)
Eighth	7.23 (11.7)	2.3	9.76 (0.0)
Pendimethalin			
Full	7.47 (0.4)	2.0	9.79 (0.3)
Half	7.08 (19.3)	2.3	9.71 (0.0)
Quarter	6.85 (55.0)	2.0	9.82 (0.0)
Pendimethalin + CMPP			
Full	7.17 (0.0)	5.0	
Half	7.56 (0.7)	3.3	9.71 (0.0)
Quarter	7.42 (3.2)	3.7	9.75 (0.0)
Eighth	7.19 (12.3)	3.0	9.81 (0.0)
Trifluralin			
Full	7.17 (36.7)	2.0	
Half	6.89 (66.7)	2.0	
Quarter	6.62 (73.3)	2.3	
Trifluralin + CMPP			
Full	7.25 (0.7)	5.0	
Half	7.17 (6.3)	3.3	
Quarter	7.43 (7.3)	3.3	
Eighth	7.38 (7.3)	2.7	
Untreated	6.46 (78.9)	1.8	9.87 (7.3)
SED (DF)	0.23** (42)	0.4*** (42)	0.11 (24)
CV%	3.9		1.3

( ) - *Stellaria media* ground cover GS 65 at both sites

Scorch - Score 1-9 (9 = yellow) recorded 14th April 1990

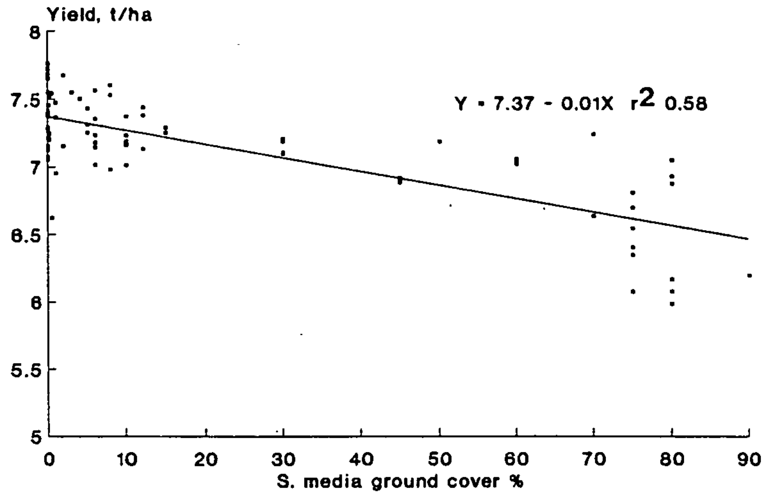


Figure 9. Relationship between Yield and S. media Ground Cover at Harvest, Tillycorthie Winter Barley 1990

4.2.1.1. Yield Response Curves Winter Barley 1989 and 1990

1. Bush, 1989

There was a large yield, and economic, advantage from controlling the high population of *Stellaria media* in the autumn at Bush *(Table 29)*. The high weed pressure did not allow herbicide dose to be reduced below the highest (50%) dose tested *(Figure 10)*.

Table 29. Optimum Herbicide Dose, Bush Winter Barley 1989

	Eopt	Yield t/ha	Herbicide Cost £	Margin Over Herbicide Cost
Autumn - DFF/IPU				
N	50	7.52	10.00	253.85
2N	50	7.52	20.00	243.85
Spring - Metsulfuron-methyl + CMPP				
N	50	5.97	9.00	112.75
2N	50	5.97	18.00	103.75

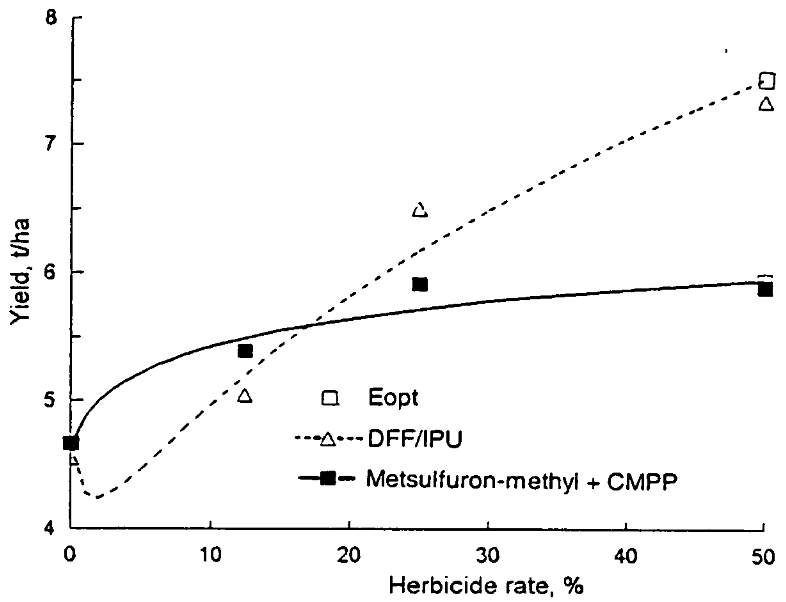


Figure 10. Fitted Curves Bush Winter Barley 1989

2. Tillycorthie 1990

The use of only an autumn residual required a high dose of herbicide to maximise economic return for all herbicides tested *(Table 30, Figure 11)*. This was the result of a combination of a high population of *Stellaria media* and poor weed control as the dose of the autumn herbicides was reduced *(Table 28)*. Poor weed control would seem to have resulted from dry soil conditions when all treatments were applied pre-emergence (see *Section 4.3.2.*).

The follow-up CMPP in spring gave a better economic return than the autumn residual applied alone and allowed the total treatment intensity index (% herbicide dose x number of spray applications) to be reduced. However, high doses of CMPP decreased yield which is consistent with the crop scorch scores recorded in *Table 28*.

Table 30. Economic Optima Tillycorthie Winter Barley 1990

	Eopt	Yield t/ha	Herbicide Cost £	Margin Over Herb. Cost
Autumn - Diflufenican				
N	99	7.39	19.80	66.18
2N	51	7.25	20.40	52.68
Autumn - Diflufencian + Spring - CMPP				
N	21	7.28	5.25	70.11
2N	16	7.26	8.00	65.51
Autumn - Pendimethalin				
N	100	7.46	22.00	69.77
2N	100	7.46	44.00	47.77
Autumn - Pendimethalin + Spring - CMPP				
N	21	7.37	5.67	80.21
2N	16	7.35	8.64	75.25
Autumn - Trifluralin				
N	100	7.18	5.40	60.80
2N	100	7.18	10.80	55.40
Autumn - Trifluralin + Spring - CMPP				
N	20	7.38	2.00	81.33
2N	18	7.38	3.60	79.48

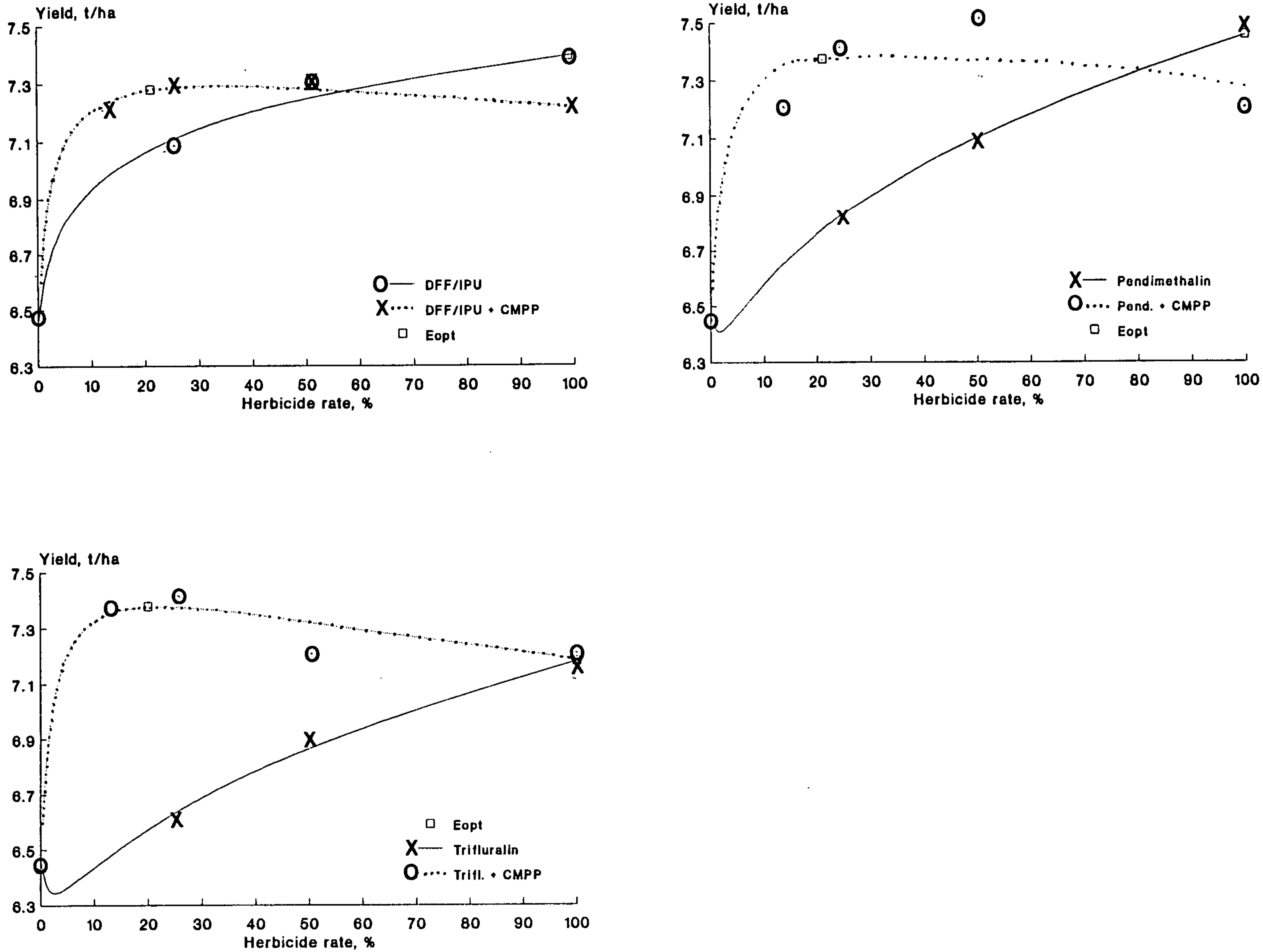


Figure 11. Fitted Curves Tillycorthie Winter Barley 1990

4.2.2. RESPONSE OF SPRING BARLEY TO HERBICIDE DOSE

1. 1989

At no site was yield significantly different between any herbicide treatment or the untreated control *(Table 31).* There was a wide variation in control of polygonous weeds at Middlestotts, but despite this there was a poor correlation between weed levels and yield *(Table 32).*

Table 31. Yield, t/ha, and Weed Cover Spring Barley Reduced Dose Trials 1989

	Bush	G.t.	S.m.	Upper Cairnie	P.a.	Middle-stotts	S.m.	P.sp.	Mean All Sites
Metsulfuron-methyl									
Full	5.99	(1.3)	(0.3)	3.90	(0.5)	4.82	(1.7)	(7.5)	4.90
Half	6.02	(2.3)	(4.0)	3.62	(1.4)	4.75	(3.3)	(14.9)	4.80
Quarter	6.09	(2.5)	(5.5)	3.58	(1.9)	4.67	(8.3)	(35.7)	4.78
Eighth	5.95	(4.7)	(4.7)	3.95	(6.8)	4.97	(0.0)	(32.7)	4.96
Mean	6.01			3.81		4.80			4.86
Metsulfuron-methyl + CMPP									
Full	5.90	(2.0)	(0.0)	3.93	(0.3)	5.01	(1.0)	(1.4)	4.95
Half	5.97	(3.3)	(0.3)	3.80	(0.6)	4.71	(0.0)	(11.5)	4.83
Quarter	6.01	(8.0)	(1.0)	3.55	(6.0)	4.71	(8.3)	(20.0)	4.76
Eighth	5.81	(4.7)	(3.7)	3.96	(2.0)	5.13	(0.0)	(30.8)	4.97
Mean	5.92			3.76		4.89			4.87
Untreated	5.65	(16.0)	(13.0)	3.94	(8.7)	4.72	(28.3)	(53.7)	4.77
SED (19 DF) a	0.19			0.24		0.26			0.13
SED (19 DF) b	0.10			0.12		0.13			0.06
CV%	3.9			7.7		6.6			3.3

SED a-Any pair, b-Metsulfuron-methyl v Metsulfuron-methyl + CMPP

( ) - Ground cover % at GS 39. G.t. = *G. tetrahit*, S. m. = *S. media*, P.a. = *P. aviculare*
P.sp. = Polygonum species

Table 32. Correlation Matrix for Grain Yield and S. media, Polygonum Species and Total Weed Ground Cover % at Crop GS 85, Middlestotts Spring Barley 1989

DF = 28				
Yield	1.00			
S. media	-0.33	1.00		
Polygonous spp.	-0.20	0.71	1.00	
Total weed GC %	-0.22	0.72	0.92	1.00

2. 1990

Generally, there was no clear response to herbicide dose despite large differences in weed control *(Tables 33 and 34)*. At Treaton, there was a high population of transplanted *Stellaria media* which had survived cultivation. This led to a significant yield response to herbicide, c40%. However, at this site the 50% dose MCPA/dichlorprop gave a significantly lower yield than the 25% dose despite better weed control. Similarly at Ploughlands the 50% dose of MCPA/dichlorprop gave a lower yield than either of the two lower doses. This would suggest that MCPA/dichlorprop at the highest dose damaged the crop at these two sites. No visual damage symptoms were recorded at either site.

A comparison of early (crop GS. 13) and late (crop GS. 30/31) applied Metsulfuron-methyl + CMPP and thifensulfuron/metsulfuron-methyl + CMPP at Tillycorthie showed that the earlier timing tended to out-yield the later *(Table 34)*. Assessment of crop damage symptoms showed the later timing significantly reduced crop vigour and that this effect was related to herbicide dose.

Table 33. Yield, t/ha, and Weed Levels Reduced Dose Spring Barley Trials 1990

		Treaton		Ploughlands		Sunnybrae			
Herbicide	Dose	Yld		Yld		Yld T1		Yld T2	
Met.-methyl + CMPP	Half	4.64	(4.3)	7.24	(4.8)	5.94	(0.1)	5.99	(3.9)
	Quarter	4.74	(21.7)	7.09	(10.7)	6.00	(0.5)	5.94	(5.2)
	Eighth	4.25	(25.7)	7.26	(15.3)	5.93	(10.4)	6.08	(6.5)
Thif./Met.-methyl + CMPP	Half	4.77	(9.3)	7.15	(7.8)	6.16	(0.0)		
	Quarter	4.44	(10.0)	7.33	(10.3)	6.20	(0.1)		
	Eighth	4.13	(23.3)	7.26	(16.3)	5.91	(0.1)		
Met.-methyl + cyanazine	Half	4.74	(5.7)	-	-	6.07	(1.3)		
	Quarter	-	-	-	-	6.03	(3.7)		
	Eighth	4.85	(30.0)	-	-	6.11	(6.2)		
MCPA/ CMPP/ dicamba	Half	-	-	7.02	(8.0)	6.08	(0.7)		
	Quarter	-	-	-	-	5.97	(3.8)		
	Eighth	-	-	7.13	(22.3)	5.92	(9.4)		
Cyanazine/ clopyralid + MCPA	Half	-	-	7.31	(6.7)	5.84	(0.0)		
	Quarter	-	-	6.98	(10.7)	5.88	(2.2)		
	Eighth	-	-	7.26	(24.3)	6.00	(7.8)		
MCPA + dichloroprop	Half	3.76	(16.7)	6.97	(2.3)	6.01	(1.3)		
	Quarter	4.41	(26.7)	7.23	(7.7)	5.96	(5.5)		
	Eighth	3.56	(63.3)	7.25	(10.3)	6.10	(6.6)		
Untreated		3.13	(81.7)	6.97	(39.7)	5.88	(25.6)		
SED		0.29**		0.17		0.12			
DF		24		30		46			
CV%		8.3		2.9		2.4			

( ) - Total weed ground cover % at GS 39

Table 34. Yield, t/ha, and Weed Levels Reduced Dose Spring Barley Trials 1990

		Bush		Tillycorthie					
		Yield T1	Yield T2	Yield T1	Sc. T1	Vig. T1	Yield T2	Sc. T2	Vig. T2
Met.-methyl + CMPP	Full	- -	- -	5.99 (2.7)	0.0	8.0	5.27 (6.8)	2.0	6.3
	Half	7.87 (0.0)	7.97 (3.5)	5.47 (4.5)	0.0	8.0	5.42 (8.3)	0.3	7.7
	Quarter	7.98 (0.8)	7.97 (2.7)	5.48 (10.0)	0.0	8.0	5.16 (6.2)	0.0	8.0
	Eighth	7.92 (2.8)	7.89 (11.9)	4.96 (12.7)	0.0	8.0	5.15 (20.5)	0.0	8.0
Thif./Met.-methyl + CMPP	Full	- -	- -	5.28 (1.7)	0.0	8.0	5.27 (2.7)	2.3	6.3
	Half	- -	- -	5.47 (2.3)	0.0	8.0	4.78 (5.7)	0.7	7.0
	Quarter	- -	- -	5.12 (8.5)	0.0	8.0	5.14 (6.5)	0.3	8.0
	Eighth	- -	- -	5.20 (12.2)	0.0	8.0	5.00 (11.9)	0.3	8.0
Untreated		8.04 (23.0)		4.78 (35.8)	0.0	8.0			
SED		0.09		0.35	0.3**	0.2**			
DF		14		34	34	34			
CV%		1.4		8.2					

( ) - Total weed ground cover % at GS 39, SED - comparison of any pair, same untreated for both timings of the herbicides. T1 and T2 are the herbicide timings. Sc. - crop scorch score 34 days after treatment (9 - severely scorched). Vig. - Crop vigour score 34 days after treatment (9 = healthy).

4.2.2.1. Yield Response Curves 1989 and 1990 Spring Barley

1. Bush 1989

The trial at Bush in 1989 showed that yield increased with increasing herbicide dose up to a maximum and then declined; and yield from treatments without mecoprop produced higher yields than those with *(Figure 12)*. Neither at Upper Cairnie, where weed levels were low, nor at Middlestotts was there a similar pattern of yield response and there is no evidence to suggest the response at Bush was a real effect. It should be noted that despite the very poor weed control from the lowest dose at Middlestotts, this treatment gave a better yield than the full dose where weeds were almost totally controlled *(Table 31)*.

Metsulfuron-methyl alone gave the better economic return reflecting the apparently better yield from this treatment *(Table 35)*. Optimum dose for both herbicides was less than 25% reflecting the apparent decline in yield at higher herbicide doses *(Figure 12)*.

Table 35. Economic Optima, Spring Barley Bush 1989

	Eopt %	Yield t/ha	Herbicide Cost £	Margin Over Herb. Cost
Metsulfuron-methyl + CMPP				
N	23	5.92	4.14	29.68
2N	15	5.91	5.40	26.40
Metsulfuron-methyl				
N	23	6.03	2.99	42.49
2N	18	6.01	4.68	39.89

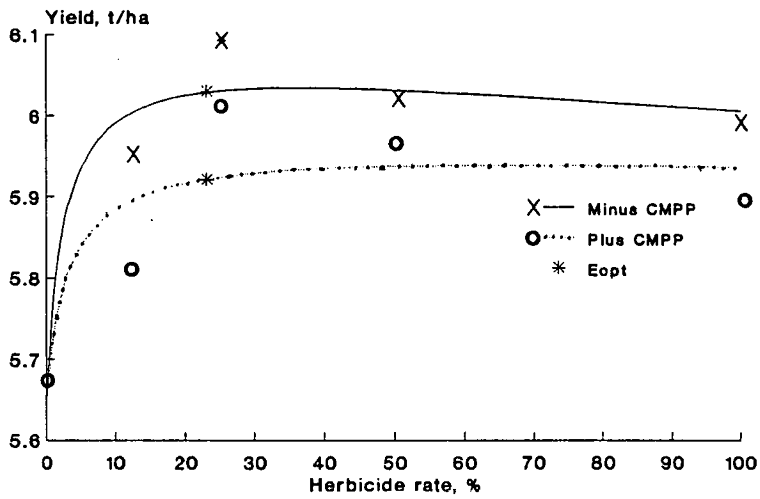


Figure 12. Yield response, Spring Barley Bush 1989

2. All Sites 1990

When yield for metsulfuron-methyl + CMPP and thifensulfuron/metsulfuron-methyl + CMPP was meaned over all sites and timings there was a suggestion that yield was related to herbicide dose *(Figure 13)*. The economic optimum dose was 50% for both herbicides *(Table 36)*.

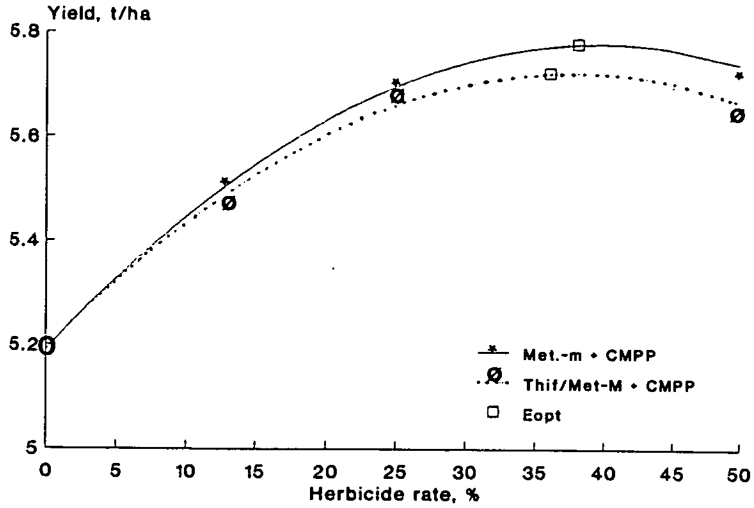


Figure 13. Yield Response Curves Mean 5 Spring Barley Trials in 1990

Table 36. Economic Optima, Mean of 5 Trials Spring Barley 1990

	Eopt %	Yield t/ha	Herbicide Cost £	Margin Over Herb. Cost
Thifensulfuron/metsulfuron methyl + CMPP				
N	50	5.69	10.50	49.28
2N	33	5.64	13.86	40.15
Metsulfuron-methyl + CMPP				
N	50	5.76	9.00	59.21
2N	50	5.76	18.00	50.21

4.2.3. RESPONSE OF WINTER WHEAT TO HERBICIDE DOSE 1989 AND 1990

1. 1989

Table 37. Yield, t/ha, of Reduced Dose Winter Wheat Trials 1989

	Bush	Middle-stotts	Upper Cairnie	Upper Dalhousie	Markle Mains	Luffness Mains
DFF/IPU (Autumn)						
Full	6.37 (0.0)	5.51 (0.0)	7.67 (0.0)	12.11 (0.0)	9.99 (0.0)	
Half	6.65 (1.7)	5.92 (1.3)	7.51 (0.0)	11.99 (0.3)	10.25 (0.0)	
Quarter	6.55 (0.0)	5.46 (0.3)	7.69 (0.0)	11.94 (0.3)	10.18 (0.0)	
Eighth	6.22 (4.7)	5.85 (3.3)	7.70 (0.7)	11.93 (2.3)	10.21 (2.0)	
Mean	6.45	5.69	7.64	11.99	10.16	
Metsulfuron-methyl + CMPP (Spring T1)						
Full	5.79 (0.0)	5.24 (0.0)	7.19 (0.0)	11.67 (0.0)	10.03 (0.0)	10.16 (0.0)
Half	5.67 (0.0)	5.27 (0.0)	7.52 (2.0)	11.14 (9.0)	10.19 (0.7)	10.28 (0.0)
Quarter	5.96 (13.0)	5.76 (5.0)	7.38 (15.0)	11.50 (16.0)	10.00 (3.0)	9.91 (0.0)
Eighth	5.85	6.05 (2.3)	7.40 (11.7)	11.36 (20.3)	9.93 (10.7)	9.98 (2.0)
Mean	5.85	5.58	7.37	11.42	10.04	10.02
Metsulfuron-methyl + CMPP (Spring T2)						
Full				11.54 (0.0)	10.22 (0.0)	9.68 (0.0)
Half				11.69 (2.7)	10.03 (0.0)	9.81 (0.0)
Quarter				11.40 (4.9)	10.30 (0.0)	9.86 (0.3)
Eighth				11.55 (18.3)	10.07 (0.7)	10.45 (1.7)
Mean				11.55	10.16	9.95
Untreated	5.77 (63.7)	5.56 (48.4)	7.63 (18.3)	11.83 (45.3)	9.75 (24.7)	9.68 (24.3)
SED						
a	0.31	0.45	0.13	0.38	0.38	0.38
b	0.16**	0.23	0.06**	0.19*	0.19	0.19
c	0.25**	0.24	0.10**	0.76	0.30	0.30
DF	14	14	14	18	18	14
CV%	6.3	9.8	2.1	4.0	4.6	4.7

( ) Ground cover % of dominant weed at GS 39. *S. media* at all sites except Luffness Mains (*Matricaria* spp.)

SED a - any pair; b - untreated v treated; c - timing means

At Bush, Upper Cairnie and Upper Dalhousie the mean yield of the autumn was significantly higher than that of the spring herbicide *(Table 37)*. When meaned over all sites, excluding Luffness Mains, yield of the autumn herbicide was significantly higher than that of the spring and the untreated *(Table 38)*.

Table 38. Mean winter wheat yields all sites 1989

	Yield t/ha	*S. media* ground cover %
Autumn Herbicide - Dose of DFF/IPU		
Eighth	8.38	2.4
Quarter	8.36	0.2
Half	8.46	0.4
Full	8.33	0.0
Mean	8.39	
Spring Herbicide Dose of Metsulfuron-methyl + CMPP		
Eighth	8.18	10.4
Quarter	8.14	7.8
Half	8.00	1.7
Full	7.99	0.1
Mean	8.08	
Untreated	8.11	37.0
SED (32 DF)		
a	0.14*	
b	0.07***	
CV%	2.1	

a - Any pair, b - Autumn v spring.

At sites where yield components were measured the increase in yield of the autumn herbicide compared to the untreated resulted from an increase in seeds /m^2 *(Table 39).* At the one site where *Matricaria spp.* dominated, Luffness Mains, it was found that thousand seed weight of the untreated was significantly lower than that of herbicide treatments. This would suggest that this weed competed late in the life of the crop.

Table 39. Yield Components Reduced Dose Trials Winter Wheat 1989

TSW is the thousand seed weight and GN is the number of seeds per m2

	Middle-stotts		Upper Dalhousie		Luffness Mains		Bush	
	TSW (9)	GN x 10^3	TSW (9)	GN x 10^3	TSW (9)	GN x 10^3	TSW (9)	GN x 10^3
Autumn								
Full	42.8	12.9	44.5	27.2			47.6	13.4
Half	46.4	12.8	42.9	28.0			50.5	13.1
Quarter	43.6	12.5	43.9	27.2			49.7	13.1
Eighth	46.4	12.6	43.1	27.7			45.8	13.6
Mean	44.8	12.7	43.6	27.5			48.4	13.3
Spring T1								
Full	44.7	11.7	45.7	26.0	51.9	19.6	50.4	11.5
Half	44.7	11.8	42.7	26.1	52.5	19.6	47.4	12.0
Quarter	46.1	12.5	41.4	27.8	51.6	19.2	47.6	12.5
Eighth	48.2	12.5	46.4	24.5	52.0	19.2	48.7	12.3
Mean	47.8	11.6	44.1	26.1	52.0	19.4	48.5	12.0
Spring T2								
Full			44.9	25.3	52.5	18.5		
Half			43.9	26.8	52.7	18.7		
Quarter			44.6	25.5	53.9	18.3		
Eighth			44.9	25.8	53.7	19.5		
Mean			44.6	25.9	53.2	18.7		
Untreated	47.8	11.6	44.9	26.5	50.5	19.2	50.6	11.4
SED								
a	2.1	0.8	1.8	1.0	1.0	0.9	1.9	0.7
b	1.1	0.4	0.9	0.55**	0.5*	0.5	1.0	0.4*
c	1.1	0.4	1.4	0.8	0.8*	0.7	1.5	0.6*
DF	14		18		14		14	

SED a - any pair, b - untreated v treated, c - timing means

2. 1990

Table 40. Winter Wheat Yield Reduced Dose Trials 1990

	Tillycorthie		Treaton			
	Yield	S.m.	Yield	S.m.	V.a.	F.o
DFF/IPU						
Full	12.73		8.72	0.7	0.0	8.0
Half	12.12	0.0	7.41	0.0	0.0	32.0
Quarter	12.61	1.3	7.41	8.7	0.3	28.0
Eighth	12.09	11.0	6.82	34.3	0.7	21.3
DFF/IPU + CMPP						
Half	12.24	0.1	8.39	0.0	0.0	0.7
Quarter	12.52	1.7	8.10	2.0	1.0	0.7
Eighth	11.94	4.7	7.62	15.7	3.3	12.7
Pendimethalin						
Full	12.38	0.2				
Half	12.64	0.3				
Quarter	12.64	2.7				
Eighth	12.30	10.7				
Pendimethalin + CMPP						
Half	12.42	0.0				
Quarter	12.76	0.7				
Eighth	12.68	4.7				
Metsulfuron-methyl + CMPP						
Full	12.73	3.0	8.11	0.0	3.0	0.0
Half	12.43	0.3	7.36	0.0	15.7	0.3
Quarter	12.84	6.0	6.97	0.0	33.7	5.3
Eighth	12.72	11.0	6.49	1.3	49.0	3.7
Untreated	10.92	62.2	4.81	----------	100	----------
SED (Any Pair)	0.31**		0.38**			
DF	36		22			
CV%	3.1		6.3			

S.m. - *Stellaria media* ground cover GS 39
V.a. - *Viola arvensis* ground cover GS 39
F.o. - *Fumaria officinalis* ground cover GS 39

Weed level at Tillycorthie *(Table 40, Figure 14)* and weed level and weed species at Treaton *(Table 40)* were the cause of yield variation between treatments. Correlation matrices *(Table 41)* suggested poor control of *Stellaria media* by DFF/IPU alone, and *S. media* and *Myosotis arvensis* by metsulfuron-methyl + CMPP led to lower yields when herbicide dose was reduced at Treaton.

Table 41. Correlation Matrix, Yield and Weed Species Treaton Winter Wheat 1990

Weed Species	DFF/IPU	DFF/IPU + CMPP	Metsulfuron-methyl + CMPP
	(DF = 10)	(DF = 7)	(DF = 10)
S. media	-0.61*	-0.46	-0.72**
F. officinalis	-0.52	-0.57	-0.49
V. arvensis	-0.48	-0.44	-0.79**

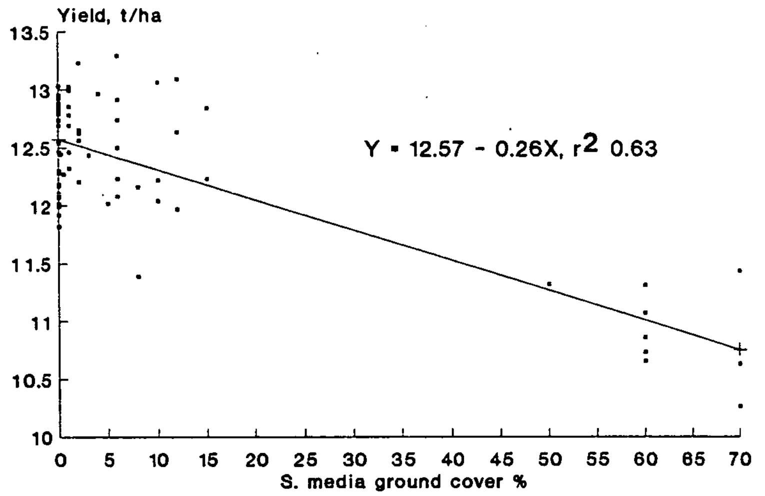


Figure 14. Relationship Between Yield and S. media Ground Cover at GS 65 Tillycorthie Winter Wheat 1990

4.2.3.1. Fitted Response Curves 1989 and 1990 Winter Wheat

1. 1989

Control of *Stellaria media*, the dominant weed, meaned over all sites was poorer with the spring herbicide *(Table 38)*. This poorer control does not, however, explain the lower yield of the spring herbicide treatment. *Figure 15* shows the fitted yield response curves for the meaned data. Dose rate had little effect on yield for the autumn treatment, whereas the spring herbicide treatment tended to decrease yield with increasing herbicide dose; the reverse of weed control. This would suggest that the spring herbicide was damaging to the crop and that this effect was greater than the benefit from controlling *S. media* at the higher doses. Evidence for crop damage was the significantly lower yield from the spring herbicide compared to the untreated at Upper Cairnie *(Table 37).*

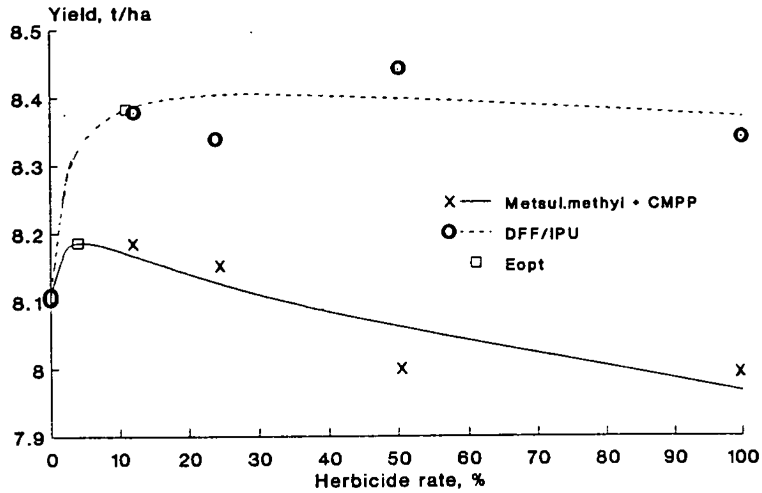


Fig. 15. Yield Response Curves Mean All Sites Winter Wheat 1989

The autumn herbicide gave the better economic return and the optimum dose for both herbicides was less than 20% of the full dose *(Table 42).* This low response to herbicide dose would seem to be the result of low weed pressure (mean of 7.6 /m^2 *Stellaria media* for the five sites) and in the case of the spring herbicide, damage to the crop as herbicide dose increased.

Table 42. Economic Optimum Dose Mean of all Winter Wheat Trials 1989

	Eopt %	Yield t/ha	Herbicide Cost £	Margin Over Herbicide Cost
Autumn - DFF/IPU				
N	15	8.39	3.00	24.90
2N	11	8.38	4.40	22.35
Spring - Metsulfuron-methyl + CMPP				
N	4	8.19	0.72	6.72
2N	3	8.18	1.08	6.11

2. <u>1990</u>

a. Treaton

Economic response to all herbicides was high *(Table 43)*. The mixed population of moderately competitive weeds at moderate to high levels required a high level of herbicide input to maximise yield. The apparent optimum treatment was the DFF + CMPP autumn spring sequence. However, no full dose for this treatment was included in the trial and it is likely, given that virtually all weeds were completely controlled at the 50% dose, that the apparent optimum of 94% was purely an artefact of the curve fitting procedure. Indeed from other trials it would seem that yield may have declined above the 50% dose tested.

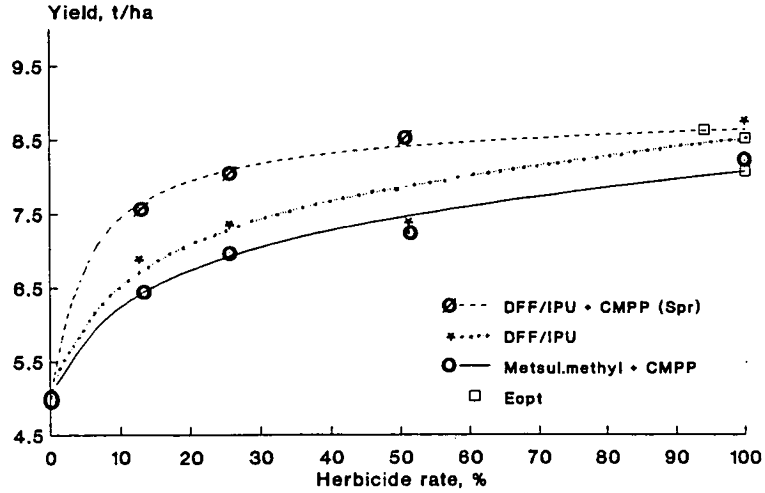


Figure 16. Yield Response Curves Winter Wheat Treaton 1990

Table 43. Economic Optimum Dose Treaton Winter Wheat 1990

	Eopt %	Yield t/ha	Herbicide Cost £	Margin Over Herbicide Cost
Autumn - DFF/IPU				
N	100	8.50	20.00	339.61
2N	100	8.50	40.00	319.61
Autumn - Diflufenican + Spring CMPP				
N	94	8.61	23.50	348.74
2N	65	8.50	32.50	329.49
Spring - Metsulfuron-methyl + CMPP				
N	100	8.05	18.00	298.50
2N	100	8.05	36.00	280.50

b. Tillycorthie

The spring applied metsulfuron-methyl + CMPP gave as good an economic response as any autumn or autumn/spring sequence *(Figure 17, Table 44)*. In terms of treatment intensity index (herbicide dose % x number of spray applications) the autumn/spring sequence did not offer any advantage over the single autumn application.

Herbicide dose to maximise yield was not as high as that for the winter barley at Tillycorthie *(Table 28)*, despite similar levels of *Stellaria media*. This was the result of better weed control from the autumn residual herbicides as dose was reduced - the consequence of greater soil moisture when applied pre-emergence to the later sown wheat *(see Section 4.3.2)*.

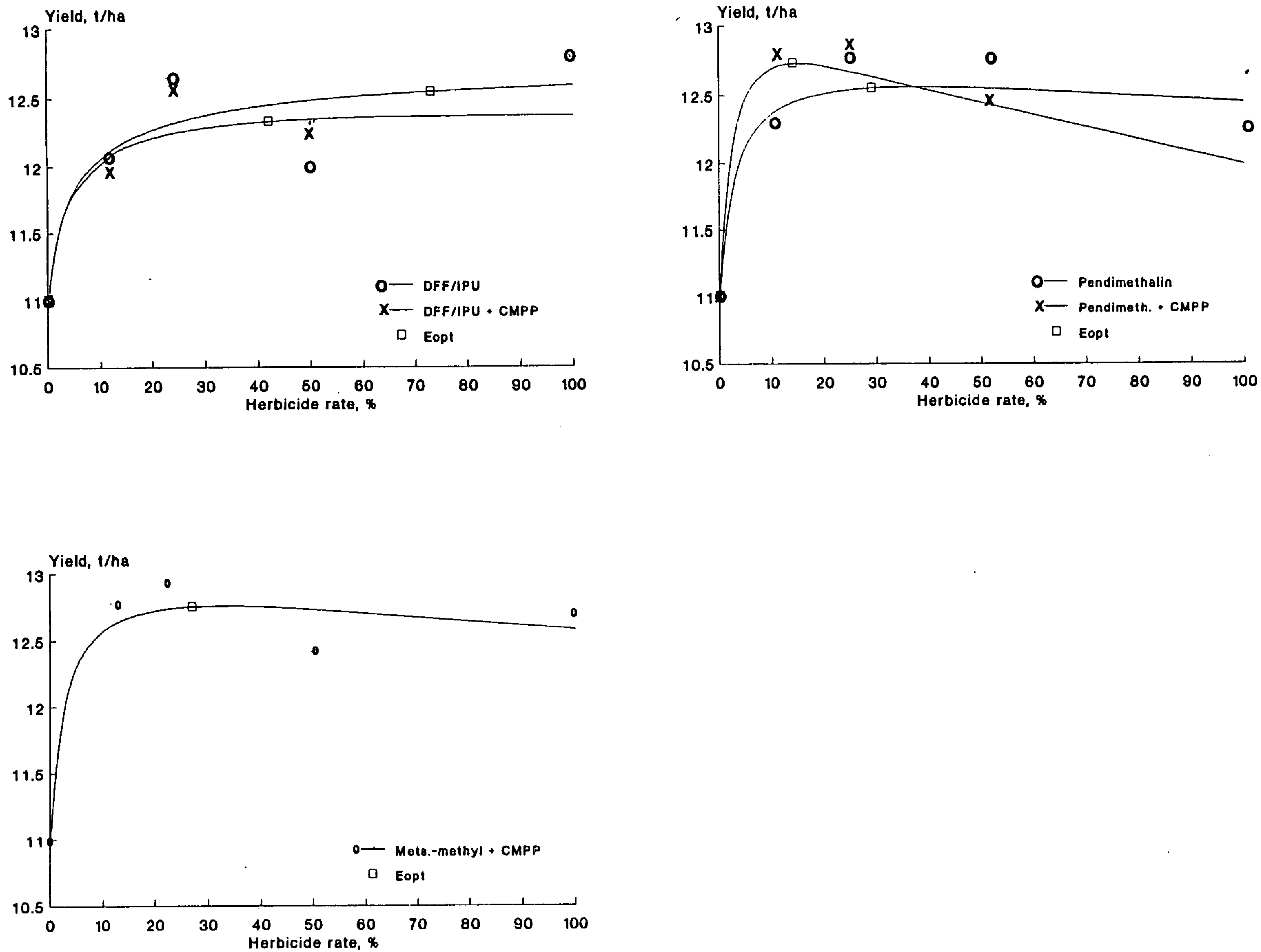


Figure 17. Yield Response Curves Winter Wheat Tillycorthie 1990

Table 44. Economic Optimum Dose Tillycorthie Winter Wheat 1990

	Dose %	Yield t/ha	Herbicide Cost £	Margin Over Herbicide Cost
Autumn - Diflufenican				
N	73	12.55	14.60	144.08
2N	47	12.47	18.80	132.48
Autumn - Diflufenican + Spring CMPP				
N	42	12.33	10.50	128.72
2N	30	12.29	15.00	119.92
Autumn - Pendimethalin				
N	29	12.56	6.38	154.86
2N	24	12.54	10.56	149.14
Autumn - Pendimethalin + Spring CMPP				
N	14	12.73	3.78	173.94
2N	13	12.73	7.02	170.26
Spring - Metsulfuron-methyl + CMPP				
N	27	12.76	4.86	173.10
2N	24	12.75	8.64	168.55

4.2.4. EFFECT OF WEEDS ON GRAIN QUALITY

1. Winter Barley

In Winter barley at Bush and Middlestotts in 1989 weeds at harvest increased grain moisture significantly ($p<0.05$) *(Figures 18 and 19)*.

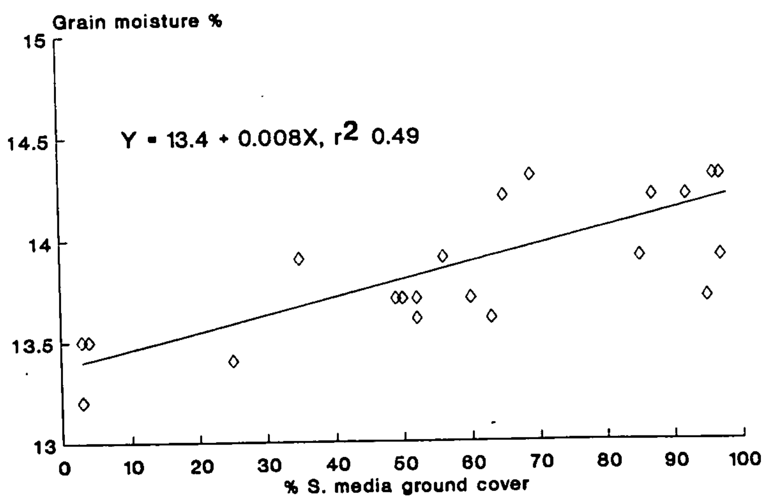


Figure 18. Relationship Between S. media Ground Cover at Harvest and Grain Moisture Bush Winter Barley 1989

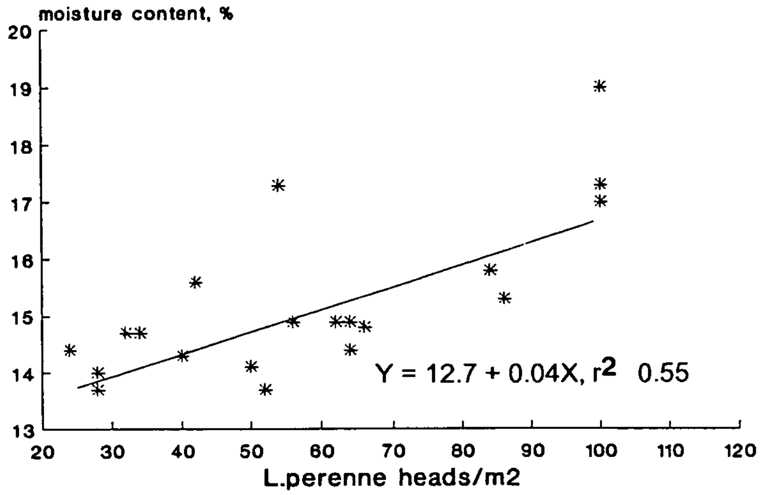


Figure 19. Relationship Between L. perenne heads/m² at Harvest and Grain Moisture Middlestotts Winter Barley 1989

The *Lolium perenne* population at Middlestotts in 1989 also significantly reduced thousand seed weight *(Figure 20)* and significantly increased grain contamination with weed debris *(Figure 21)*.

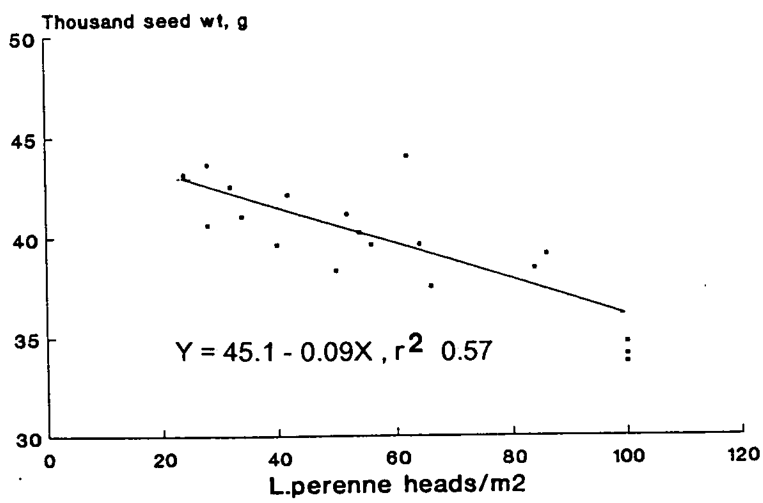


Figure 20. Relationship Between Weed Level and Thousand Seed Weight - Middlestotts Winter Barley 1989

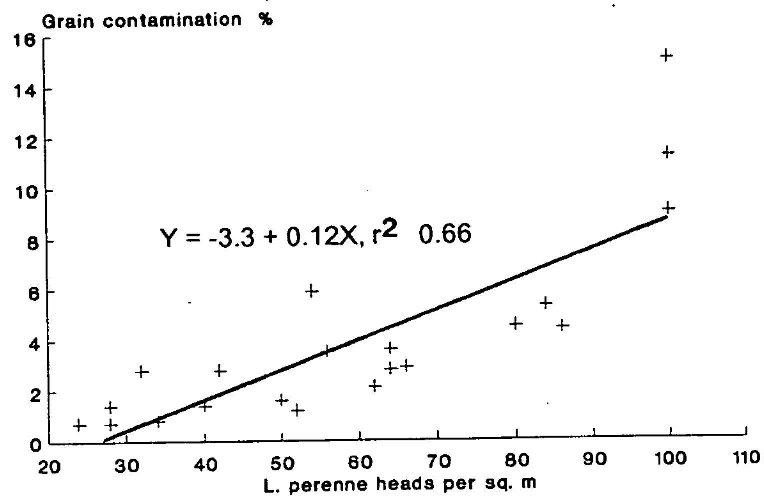


Figure 21. Relationship Between Weed Level and Grain Contamination - Middlestotts Winter Barley 1989

2. Spring Barley

Grain moisture of spring barley at Middlestotts increased as herbicide dose was reduced *(Table 45)*. This was directly attributable to level of Polygonous weed ground cover at harvest *(Figure 22)*.

Table 45. Grain Moisture % - Middlestotts Spring Barley 1989

	Dose	Eighth	Quarter	Half	Full
Metsulfuron-methyl	20.2	20.1	19.9	19.4	19.9
		(58.3)	(50.0)	(40.0)	(14.3)
Metsulfuron-methyl	20.0	19.6	18.7	18.7	19.3
		(39.3)	(26.7)	(13.0)	(3.0)
Untreated	20.3 (79.2)				

SED (19 DF) : comparison of any pair of moisture contents = 0.60 NS
treated and untreated means = 0.37 *

Figures in brackets are the polygonous weed ground cover % at harvest

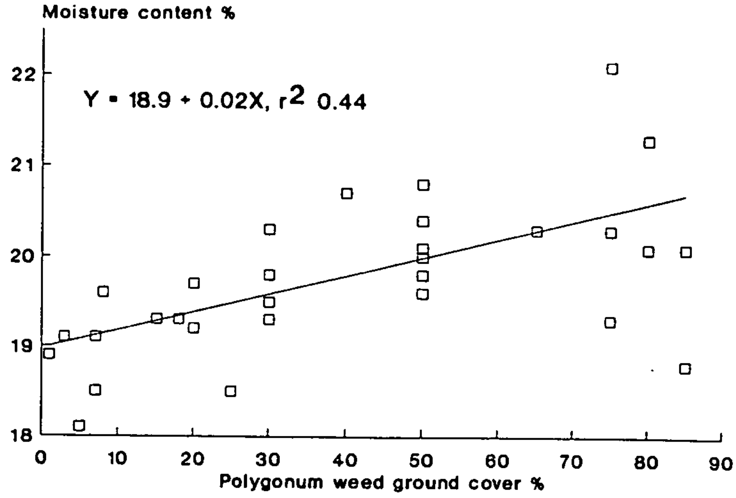


Figure 22. Grain Moisture and Polygonous Weed Ground Cover Middlestotts Spring Barley 1989

4.3. WEED CONTROL REDUCED DOSE TRIALS 1989 AND 1990

Weed control data from yielded and screen trials in 1989 and 1990 was characterised by weed species and ED_{90} value. Factors which seemed to affect dose response curves are presented below, with coefficients for a and b derived from logistic link transformation given in tables and figures (see *Section* 3.2.5.1.

4.3.1. 1989 TRIALS

a. Weed species. The major difference in control achieved by a product was due to weed species, e.g. DFF/IPU had a greater activity on *Stellaria media* compared to *Veronica hederifolia (Figure 23)*

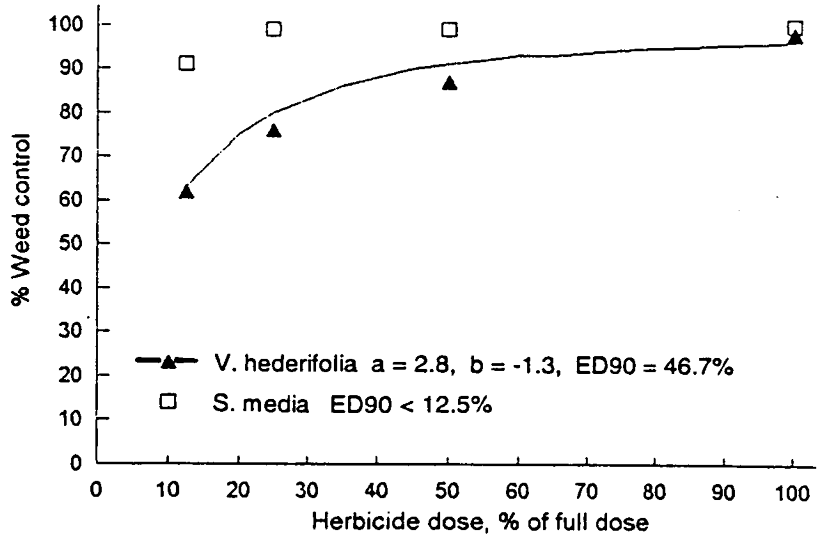


Figure 23. S. media and V. hederifolia Control by DFF/IPU

b. Active ingredient. The dose response for a weed species by a product was in some cases enhanced by the addition of other active ingredients. CMPP alone has no affect on Polygonum weeds and *Figure 24* shows the increase in activity of metsulfuron-methyl in spring barley on *Polygonum convulvulus* by the addition of CMPP, this is in contrast to *Polygonum persicaria* where the addition of CMPP had no effect on dose response. Such results further reflect varying activity of active ingredients on particular weed species.

a.

b.

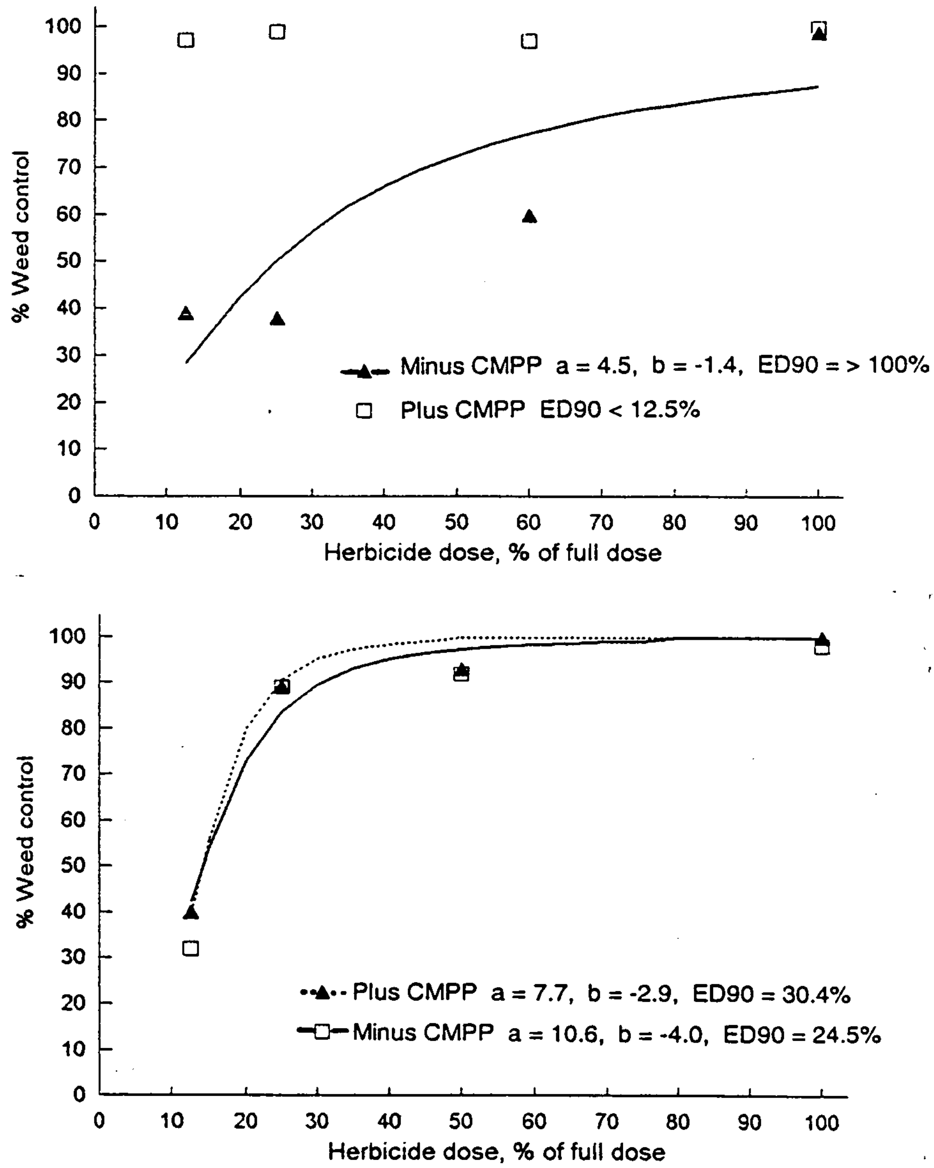


Figure 24. Control of a) P. convulvulus and b) P. persicaria with metsulfuron-methyl +/- CMPP

c. Weed size. Control of *Poa annua* in five winter wheat trials with DFF/IPU showed most variation in control at the one eighth dose. Part of this variation would seem to be accounted for by the proportion of the total *P. annua* population recorded in the trial which had emerged at the time of spraying *(Figure 25)*.

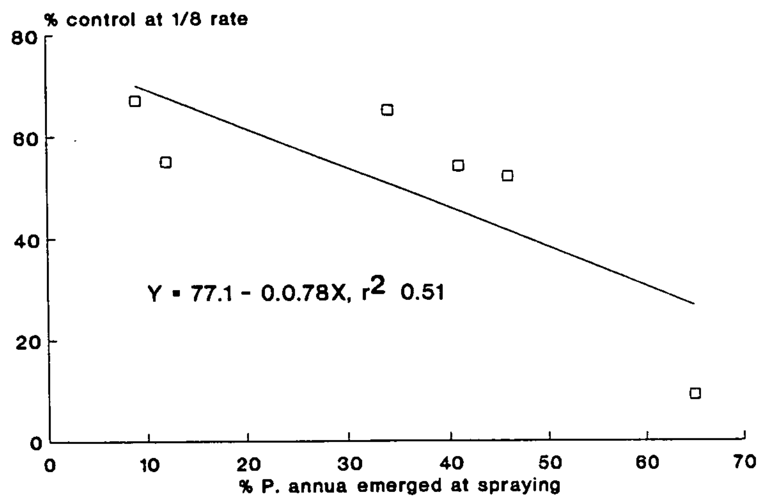


Figure 25. Relationship between Emerged P. annua and Control with Eight Dose DFF/IPU

d. Crop vigour. When the mean ground cover per *Stellaria media* plant in untreated plots in the spring was plotted against crop ground cover in the spring for reduced dose winter wheat and an unreported competition trial there was a significant negative linear relationship *(Figure 26)*. Such crop competition could explain the better control of *S. media* achieved at Markle Mains compared to Upper Dalhousie in the spring at T1 *(Figure 27)*. Both crops were Riband sprayed on 25th March 1989 and crop ground covers at spraying were 75% at Markle Mains and 55% at Upper Dalhousie .

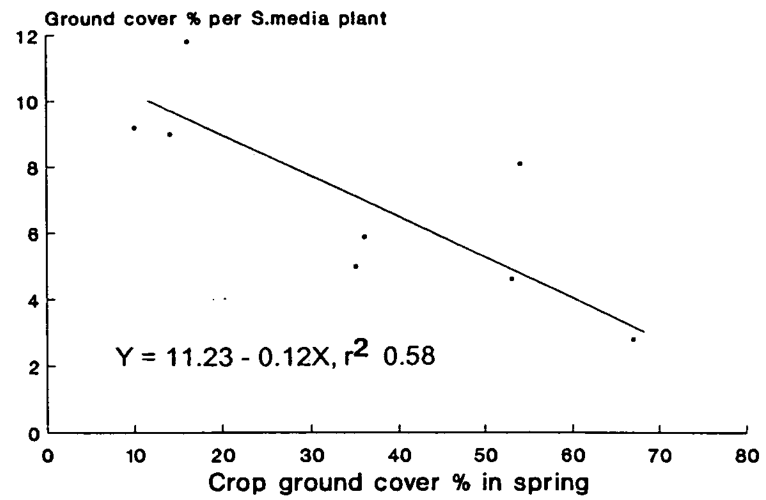


Figure 26. Relationship Between Winter Wheat Ground Cover and S. media Ground Cover in the Spring

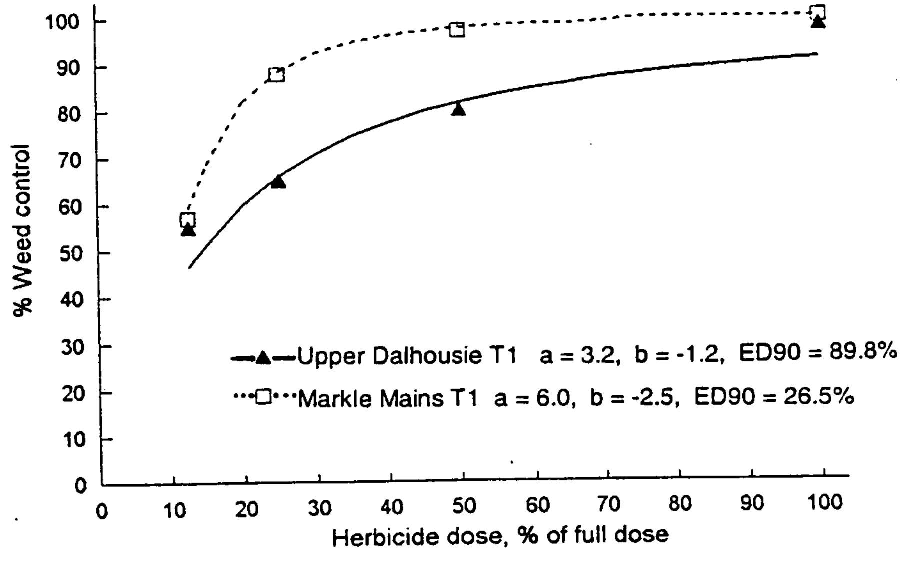


Figure 27. Control of S. media by Metsulfuron-Methyl + CMPP in Two Crops of Differing Competitive Ability

4.3.2. 1990 TRIALS

ED_{90} values for product x weed species for trials in 1990 are shown in *Tables 46 and 47*.

Table 46. % Herbicide Dose Required to give 90% Control, Screen Trials for Winter Wheat and Barley 1990

Figures given in tables refer to percentage of the full recommended dose required to give 90% control of the weed species *(see Section 3.2.)*.

Abbreviations used in tables :
NC - Weed control of more than 90% not achieved by any rate of the herbicide.
<25.0% - 91-100 % control achieved by all herbicide rates tested.
Pre - Herbicide applied pre- crop and weed emergence.
Post - Herbicide applied post- crop emergence at timing 1 or 2 (see Sect. 3.2).
^ - Weed species recorded at Bush (winter barley).
~ - " " " " Newburgh (winter barley).
+ - " " " " Udny (winter wheat).

	WEED SPECIES					
Herbicide	F. officinalis^	P. annua^	S. media^	S. media^	OSR~	S. media+
DFF/IPU	72.4	43.3	25.0	45.6	65.5	<25.0
DFF/IPU Post 1	NC	36.5	<25.0	<25.0	<25.0	<25.0
DFF/IPU Post 2				46.8	NC	
Pendimethalin Pre	25.1	25.0	50.5	100.0	NC	<25.0
Pendimethalin/IPU Post 1	17.2	25.0	21.6	43.5	63.7	<25.0
Trifluralin Pre	NC	50.6	NC	NC	NC	100.0
Trifluralin/IPU Post 1	NC	<25.0	37.8	44.2	100.0	<25.0
Isoxaben Pre	NC	NC	NC	NC	NC	44.0
Isoxaben/IPU Post 1	68.4	23.8	28.3	38.0	72.4	<25.0
IPU Post 2				71.3	NC	
Bifenox/IPU Post 2				87.1	NC	
Cyanazine Post 2				<25.0	NC	
Fluroxypyr Post 2				NC	NC	25.2
CMPP Post 2				59.0	28.8	NC
Metsulfuron-methyl + CMPP Post 2						<25.0
Harmony M + CMPP Post 2						<25.0
Fluroxypyr Cyanazine Post 2						26.2
Cyanazine/Clopyralid + CMPP Post 2						44.0

Table 47. % Herbicide Dose Required to give 90% Control, Mean of all Screen and Yielded Sites Spring Barley 1990

Herbicide	WEED SPECIES S. media	G. tetrahit	P. aviculare	F. officinalis	C. album
Metsulfuron-methyl + CMPP	15.0	24.7	>100.0	67.8	23.9
Thifensulfuron-methyl/ Metsulfuron-methyl + CMPP	20.3	14.8	69.0	>100.0	<12.5
Metsulfuron-methyl + cyanazine	14.0	12.2	74.5	-	<12.5
MCPA/CMPP/dicamba	13.7	25.5	24.2	-	-
Cyanazine/clopyralid + MCPA	13.8	18.4	21.5	65.0	-
MCPA/dichloroprop	31.1	32.1	21.0	39.1	<12.5

a Weed species. Results from the screen and yielded trials would suggest that Pendimethalin and DFF/IPU offer the most reliable control at reduced doses of *Stellaria media*, the most competitive weed in winter cereals in Scotland. Both pendimethalin and DFF/IPU were poor at controlling oilseed rape, and pendimethalin showed better control of *F. officinalis* than DFF/IPU *(Table 48)*.

In spring barley, a major weakness of metsulfuron-methyl + CMPP and to a lesser extent thifensulfuron/metsulfuron-methyl + CMPP was poor control of *Polygonum aviculare* compared to other major weeds such as *Galeopsis tetrahit (Table 47)*. On limited trial data MCPA + dichlorprop, MCPA/CMPP/dicamba, and clopyralid/cyanazine + MCPA appeared to give good control of *P. aviculare* at reduced doses.

Table 48. ED90 Values (% herbicide dose) DFF/IPU and Pendimethalin - Mean of all Trials

	DFF/IPU	Pendimethalin
S. media (13)	29.9	63.3
F. officinalis (2)	>100.0	25.1
Oilseed rape (2)	47.5	>100.0

( ) No. of trials

b Active ingredient. Both isoxaben and trifluralin gave poor control of *Stellaria media* when used pre-emergence *(Table 46)*. The addition of IPU to trifluralin, isoxaben and pendimethalin allowed there use post weed emergence. IPU increased the activity of these herbicides on *S. media*, but activity was still better from DFF/IPU and pendimethalin/IPU indicating the greater activity of DFF and Pendimethalin on *S. media* (*Figure 28*).

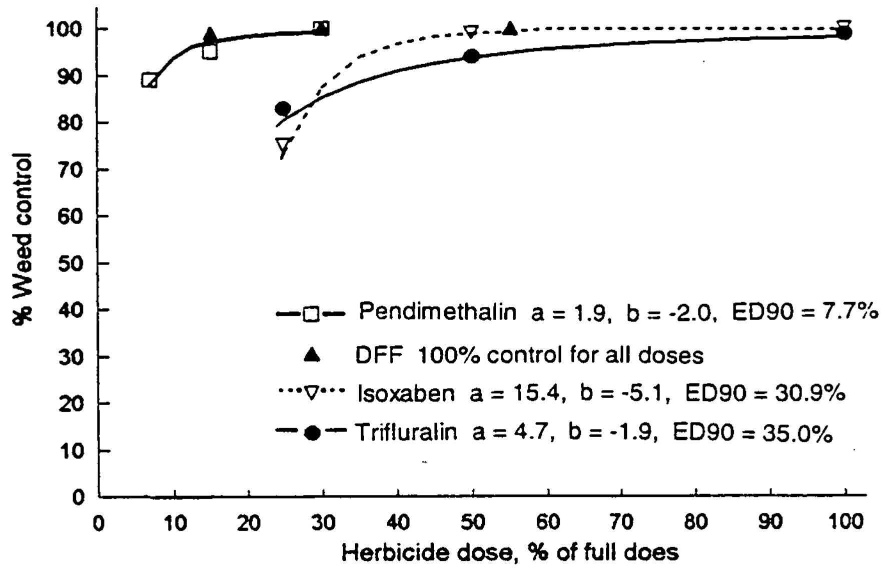


Figure 28. *Control of S. media with Product Combinations Containing Isoproturon*

A dose of 100 % is equivalent to 1800 g a.i. IPU/ha.

c Weed size. Control of *Viola arvensis* in spring barley at Bush by metsulfuron-methyl + CMPP showed poor control of this weed as weed size increased (Table 49).

Table 49. *Control of Viola arvensis with Metsulfuron-Methyl + CMPP at Two Timings Bush 1990*

Date of Spraying	Weed Size	a	b	ED_{90}
11.05.90	2 lf	3.43	-1.52	40.5
25.05.90	4 lf	7.40	-2.22	75.4

d. Soil conditions. There was poor control from several pre-emergence herbicides *(Table 46)*. This would seem the result of dry soil at application and afterwards restricting movement of chemical within the soil to germinating weeds. Soil acting herbicides applied early post-emergence and pre-emergence use after mid-October gave better control, because soils were becoming wetter at the surface as evapotranspiration fell and rainfall had a greater effect on wetting the soil. In the case of early post-emergence applications to small weeds, control may also have been enhanced by the fact that the chemical could act by foliar uptake and did not rely solely upon root absorption.

i. Control of *Stellaria media* by pre-emergence DFF/IPU and Pendimethalin in yielded trials at Tillycorthie *(Table 50)* was poorer in winter barley than winter wheat. This was the result of greater soil moisture from heavy rainfall (20.5 mm) three days before application to the mid-October drilled wheat in comparison to the high soil moisture deficit, higher evapotranspiration rate and low rainfall immediately before and for sixteen days after the application to the mid-September drilled barley *(Figures 29 and 30)*.

ii. A comparison of three timings of DFF/IPU applied to winter barley in the screen trial at Tillycorthie *(Table 51)* showed differences in control of *Stellaria media* and oilseed rape. Pre-emergence (T1) applications to dry soils gave poorer control than application to small weeds and wetter soils in mid-October (T2) *(Figures 29 and 30)*. The mid-November timing (T3) gave the poorest control. Soil moisture was probably no longer a limiting factor at T3, but larger weeds and falling temperatures would have restricted efficacy.

<u>Table 50</u>. Control of S. media in Winter Wheat and Barley with DFF/IPU and Pendimethalin Pre-Emergence Tillycorthie 1990

Herbicide	a	b	ED_{90}
DFF/IPU			
Winter Wheat	7.8	-3.7	14.9
Winter Barley	13.5	-4.0	50.6
Pendimethalin			
Winter Wheat	5.6	-2.8	16.2
Winter Barley	11.5	-3.3	63.5

Table 51. Control of S. media and Oilseed Rape with DFF/IPU at Three Timings - Tillycorthie Screen Trials 1990

Time of Application	Weed Species	a	b	ED_{90}
T1 Pre-Emergence	*S. media*	13.4	-4.1	44.9
27.09.89	Oilseed Rape	12.2	-3.5	61.2
T2 Post-Emergence	*S. media*	-	-	<25.0
12.10.90	Oilseed Rape	49.0	-16.0	<25.0
T3 Post-Emergence	*S. media*	7.2	-2.4	50.2
20.11.89	Oilseed Rape	16.6	-3.4	>100.0

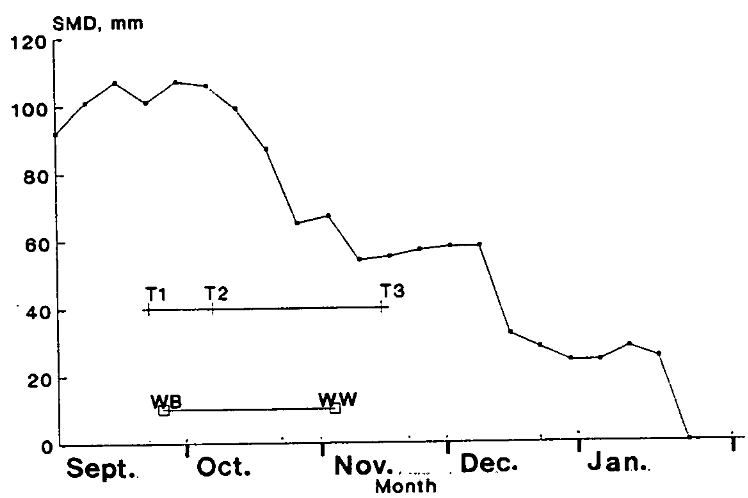


Figure 29. Soil Moisture Deficits Under Grass Dyce Airport 1990

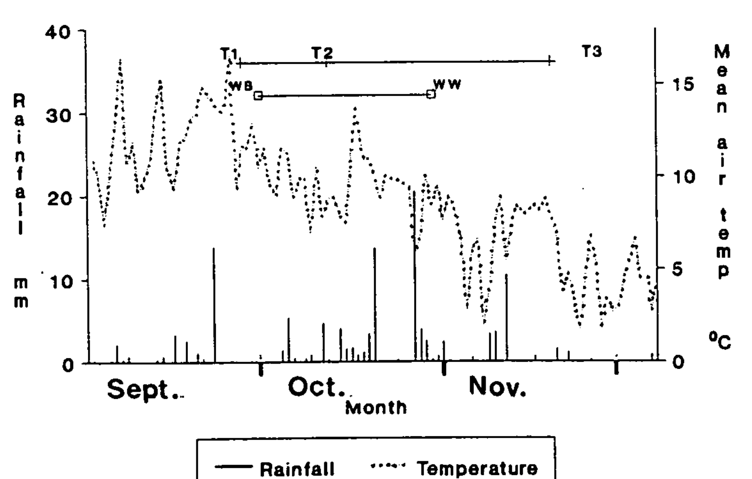


Figure 30. Temperature and Rainfall Data Dyce Airport 1990

4.3.3. CROP EFFECTS IN SCREEN TRIALS 1990

In trials at Smiths and Markle Mains the mean crop ground cover after herbicide treatment was lower than the untreated *(Tables 52 and 53)*. This was significant with post-emergence herbicides at Markle Mains. At both trial sites the post-emergence herbicides gave a lower mean crop ground cover than pre-emergence, but no direct statistical comparison could be made because timing was not randomised within a single trial. There was no consistent effect of herbicide dose on crop ground cover.

In the other screen trials only the second post-emergence spray on winter barley at Tillycorthie was there any visible affect of the herbicide on the crop *(Table 54)*. Here cyanazine had significantly lower vigour than the untreated at both 57 and 156 days after treatment and DFF/IPU, IPU and IPU/Bifenox had significantly reduced vigour 156 days after treatment. These affects were related to herbicide dose, with the greatest vigour reduction at the highest dose.

Table 52. Smiths Holding Winter Barley Crop Ground Cover 29th November 1989

Pre-Emergence	Dose			
	Full	Half	Quarter	Mean
Pendimethalin	43.0	31.0	42.0	38.7
Trifluralin	33.0	38.0	41.0	37.3
Diflufenican/IPU	41.0	43.0	44.0	42.7
Isoxaben	34.0	28.0	41.0	34.3
Mean	37.7^	35.0^	42.0^	38.2$
Untreated	45.0$			

SED (12 DF) a 8.2 Any pair
b 6.0$ Untreated v treated mean
c 4.1^ Comparison between dose means

Post-Emergence				
Pendimethalin/IPU	32.0	35.0	34.0	33.7
Trifluralin/IPU	36.0	31.0	34.0	33.7
Diflufenican/IPU	30.0	37.0	41.0	36.0
Isoxaben/IPU	24.0	35.0	55.0	38.0
Mean	30.5	34.5	41.0	35.3
Untreated	47.0			

SED (12 DF) a 7.7
b 5.7
c 3.9

Table 53. Markle Mains Winter Wheat Crop Ground Cover 7th December 1989

Pre-Emergence	Dose			
	Full	Half	Quarter	Mean
Pendimethalin	22.0	25.0	27.0	24.7
Trifluralin	22.0	21.0	24.0	22.3
Diflufenican/IPU	29.0	20.0	23.0	24.0
Isoxaben	18.0	19.0	22.0	19.7
Mean	22.7	21.2	24.0	22.7
Untreated	31.0			

SED (12 DF) a 6.1
b 4.5
c 3.1

Post-Emergence				
Pendimethalin/IPU	17.0	18.0	19.0	18.0
Trifluralin/IPU	25.0	22.0	16.0	21.0
Diflufenican/IPU	14.0	18.0	19.0	17.0
Isoxaben/IPU	18.0	19.0	18.0	18.3
Mean	18.5	19.3	18.0	18.6
Untreated	27.0			

SED (12 DF) a 4.5
b 3.3*
c 2.6

Table 54. Winter Barley Northern Screen 1990

		Yellowing (57 DAT)	Vigour (57 DAT)	Vigour (156 DAT)
DFF/IPU	Full	2.0	6.0	4.5
	Half	2.0	6.5	4.5
	Quarter	1.5	6.5	5.5
IPU	Full	3.0	6.0	4.0
	Half	2.0	6.0	5.5
	Quarter	2.0	6.5	5.5
IPU/Bifenox	Full	2.0	6.5	4.0
	Half	2.0	6.5	5.5
	Quarter	2.0	6.0	6.0
Cyanazine	Full	4.5	3.5	3.0
	Half	3.5	4.5	3.0
	Quarter	3.0	5.5	4.0
Fluroxypyr	Full	2.0	6.5	6.0
	Half	2.0	6.5	6.0
	Quarter	1.5	7.0	6.0
CMPP	Full	2.0	6.5	6.0
	Half	2.0	6.0	6.0
	Quarter	1.5	7.0	6.0
Untreated		1.8	6.7	6.0
SED (25 DF)		0.46*	0.60*	0.41*

Yellowing and vigour score 1-9, 9 = high vigour, high degree of yellowing.
DAT - Days after treatment.

5. DISCUSSION

5.1. THE LARS THRESHOLD SYSTEM

Results for the first three years of the trials have shown some of the practical weaknesses and the difficulty in determining the possible benefits of a threshold system.

5.1.1. YIELD RESPONSE

The trials did not test the scientific basis of the LARS threshold system. As discussed in *Section 2.3.4.* the threshold simply selects trials in which the probability of yield response is low. So long as the threshold is conservative then any value, irrespective of the scientific basis, will be successful. It would also seem possible that a visual assessment from field walking and an educated guess would be as good as a threshold based on weed counts. However, a subjective visual assessment introduces into the spray decision a major unknown, that of the farmer's/adviser's perception of the value of weed control.

5.1.2. WEED SEED RETURN

By year three, weed numbers had increased at all sites in plots in which herbicide had been withheld for one or more years. The significance of broad-leaved weed seed return for future crops has been poorly studied and the initial results from these trials offer little extra information.

Weed seed return is considered undesirable because this leads to higher weed levels in future crops, hence the oft quoted phrase "one years seeding seven years weeding". Within a conventional farming system relying upon herbicides weed seed return may not be important since if a herbicide is being used anyway it does not matter whether 1 or 100 weeds m^2 need to be controlled. Two cases can be distinguished :

1. Continuous cereals/oilseed rape/grass rotation

Broad-leaved weeds are easy to control in cereals with a wide range of highly effective products available. Therefore allowing broad-leaved weed levels to build-up within cereal/rape/grass rotations does not necessarily lead to yield losses in future crops. This is clearly shown at Smiths Holding where the high *S. media* population in 1990, resulting from not spraying the threshold plots in 1988, was as well controlled by herbicides as the much smaller population in plots that had received a herbicide in every year.

However, if weed density were to increase because of a no spray decision it could limit the use of reduced doses and lead to more herbicide use in the long-term (see *Section 5.2.*). The reverse of this was shown when herbicides were first introduced in the 1940's. Blackman and Roberts (1950) reported the response to weed control in spring cereals over the period 1943-47 to be over 20%. By 1958-64 (Evans, 1966) yield response to weed control in spring barley only exceeded 20% in 4% of trials. This was considered in part the result of reduced weed levels through control in previous years. Gummesson (1988) showed such a decline in weed density in spring cereal trials in Sweden between the years 1950-85 and concluded that it was better to spray prophylactically altering dose to suit weed density and species than allow weed seed return. Results from the long-term trials reported here and from other workers in the UK (e.g. Easson and Courtney, 1989) contradicts this as there is often not a rapid increase in weed numbers in future crops from allowing weeds to remain uncontrolled for a single year. More data from the long-term trial series is required to fully test this.

2. Cereals/broad-leaved crop

Many broad-leaved crops are highly susceptible to weed competition and the level of weed control achieved by herbicides is unreliable largely because moisture-dependant products are applied in the spring to drying soils. Weed seed return can be shown to be very important for such crops. Using a cereal/fodder swede system :

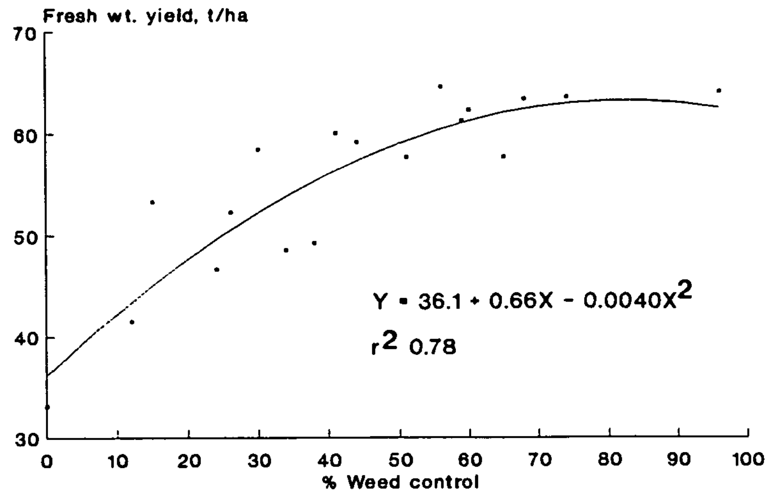


Figure 31. Swede herbicide trial, Aberfeldy 1982

Unpublished data : SAC 1982

Figure 31 shows the relationship between % control of *Polygonum persicaria* and yield of fodder swedes from a herbicide trial at Aberfeldy in 1982. Weed control from the various pre- and post-emergence herbicides varied from 0 to 96% and yield showed a large response to changes in weed control level. A potential increase in weed levels in the swede crop from allowing weed seed return in a cereal crop will obviously alter weed levels after the application of a herbicide to swedes because for any given level of control achieved weeds remaining will be proportional to the initial population. Such an effect could be likened to reducing weed control in *Figure 31* with a consequent reduction in swede yield.

The potential risk of allowing broad-leaved weed seed return in cereals for future broad-leaved crops can be represented by *Equation 2.*

Equation 2.

$$S = \frac{(Y^0 - Y^1).P}{(1 + r)^t}$$

where S = Cost of withholding herbicide in cereal crop in year 0 (£/ha);

Y^0 = Yield of broadleaf crop with control in cereal (t/ha);

Y^1 = Yield of broadleaf crop with no control in cereal (t/ha);

P = Value of broad-leaf crop (£/t);

$(1 + r)^t$ = Discounting factor over t years.

As the value of the crop (P) increases, the cost of withholding the herbicide in the cereal crop in year 0 (S) must also increase. Using fodder swedes (£10 /t fresh weight) with a yield loss of 4 t/ha grown 10 years after herbicide is withheld in the cereal crop and a discount rate of 10% the cost of withholding the herbicide in year 0 would be £15 /ha. If shopping swedes (£84 /t) were grown then the cost would exceed £130 /ha. Such future events are uncertain and Equation 2 can be modified to take this into account by either increasing the discount rate or by introducing a measure of probability *(Equation 3)*.

Equation 3.

$$S = \frac{p[(Y^0 - Y^1).P]}{(1 + r)^t}$$

As Equation 2, p = level of probability, 1.0 = 100% certainty.

If cost of control of cereals in year 0 was £13 /ha (ADAS, 1990) fodder swedes would require $p > 0.87$, compared to only $p > 0.10$ for shopping swedes to justify spraying cereals in year 0 (using the above assumptions).

5.1.3. HARVESTING

The relationship between matter other than grain (MOG) throughput and grain loss was best represented by a straight line at all sites. This relationship varied between sites and years and SAC (1982) showed that the relationship varied between crops, within a crop at different times of the day, between machines etc. Thus the MOG throughput/separation loss relationship for predicting economic loss due to weeds, as used by Sheppard (1984), can lead to error because of the wide variation in the parameters of the relationship.

A better approach is one similar to that used by Elliot (1980). If the cost of harvesting a clean, weed-free crop is £55/ha (SAC, 1990), then increased harvesting costs caused by the presence of weeds is simply determined by the increase in MOG which has to be harvested if it is assumed harvest index remains constant.

Only at Remote in 1988 and Bush in 1989 and 1990 were weed levels shown to effect harvesting. The two sites show contrasting situations.

a. At Bush in 1989 MOG yield was increased by 19% in untreated plots in which *Stellaria media* remained uncontrolled. This would give an increase in harvesting costs of 0.19 x £55 = £10.50. As well as increased harvesting costs, *S. media* also reduced crop yield by an average of 0.47 t/ha compared to treatments in which the weed was controlled from the outset. This is equivalent to £47 /ha for barley priced at £100 /t. Thus the ratio of cost of lost yield to increased harvesting cost is 4.5 : 1. *Figure 32* shows the change in total cost (harvesting + yield cost) and yield cost for any level of harvest cost using the cost ratio of 4.5 : 1. It can be seen that including the increased harvesting cost does not have a large effect on the total cost. It can be argued therefore that for weeds which are competitive and reduce crop yield, the effect on crop yield is proportionately greater than any effect on harvesting and harvesting costs can be ignored in any economic threshold calculation.

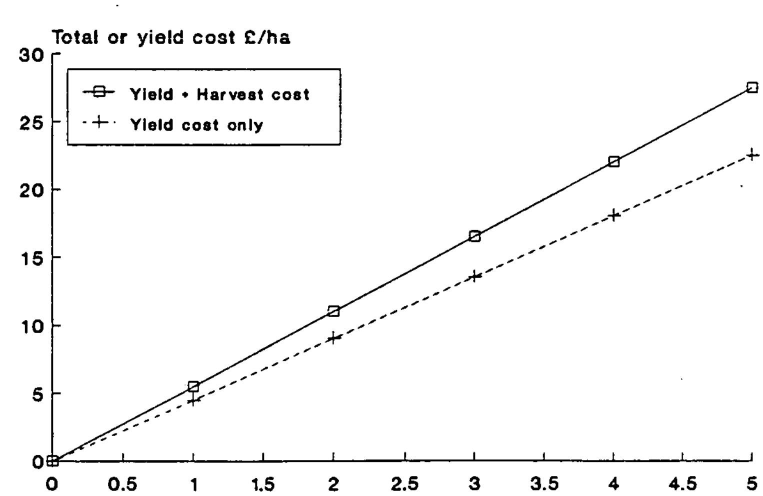


Figure 32. Effect of a 4.5 : 1 Yield : Harvesting Cost Ratio on Total Cost

b. At Remote in 1988 an alternative situation to the one described above occurred. Here the bulk of *Polygonum aviculare* growth occurred after crop GS. 65 and as a consequence crop yield was unaffected.

However, such late growth did increase MOG yield. Using *Figure 2* a ground cover at harvest of 24% *P. aviculare* (G:MOG of 0.81) would have justified spraying costs of £13 /ha.

The effect of weeds on harvesting costs of cereals can justify the cost of control measures independent of any effect on crop yield. Such a situation will most often arise in crops which are very unresponsive to control of broad-leaved weeds, crops with weed species which have a large proportion of their growth late in the life of the crop and with weeds which have the ability to recover from herbicide injury, e.g. *S. media*. Crops in Scotland most at risk of incurring significant harvesting costs if weeds remain uncontrolled are spring barley crops with moderate to high levels of tall growing Polygonous weeds and *S. media*. Such risk will be further heightened by poorly competitive, open crops.

5.1.4. Moisture Content

Weeds at harvest were found to increase the moisture content of harvested grain in spring and winter barley trials in 1989 and 1990. However, in winter barley trials severe yield loss occurred well before the effect of weeds on moisture content became economically important *(Table 55)* and so action would normally have been taken already.

Table 55. Effect of Weeds on Grain Moisture

Site	Crop	Year	Weed	MC	Yield	Yield Cost £	MC Cost £	Ratio
Bush	WB	1989	*S. media*	0.008	-0.03	2.76	0.04	69 : 1
MS	WB	1989	*L. perenne*	0.04	-0.03	2.76	0.22	13 : 1
MS	SB	1989	*Pol. spp.*	0.02	0	-	0.10	-
Till.	WB	1990	*S. media*	0.02	-0.01	1.84	0.11	17 : 1

MC & Yield = change in grain moisture content/yield per 1 % increase in weed ground cover; MC & Yield cost = Cost of 1 % increase in weed ground cover. Values assumed : WB-£92/t and a 7 t/ha yield, SB-£120/t and a 6 t/ha yield, drying costs £0.80/t/1% moisture; Ratio = Yld:MC cost ratio; Pol. spp = *Polygonum* spp.

However, with spring barley at Middlestotts in 1989 there was no correlation between crop yield and weed level, but moisture content was shown to increase by 0.02% for each one per cent increase in weed ground cover at harvest. No direct measurements were made of weed and straw yield at Middlestotts in the spring barley, but using data from Remote in 1988 *(Figure 2)* a harvesting cost of £13/ha was incurred when *Polygonum aviculare* ground cover reached 24%. At this level increased moisture content would cost £2.38/ha, a cost ratio of 1 : 5.4. Therefore, it would seem likely that even when there is no effect of weeds on yield the large bulk of weeds necessary to increase grain moisture will increase harvesting costs to a proportionately greater extent.

5.1.5. Contamination of Grain by Weeds

In all the long-term trials, contamination of grain by weed seed and debris was always at a very low level. In the winter barley reduced dose trial at Middlestotts in 1989 the 2% admixture level for the rejection of the grain was reached at a weed level of 22.2 *Lolium perenne* heads/m^2. However, the lost yield would be equivalent to 0.67 t/ha. Again economically significant effects of weeds on grain contamination require very high levels of weeds at harvest which implies much higher yield and/or harvesting costs.

5.1.6. Effect of Weeds on Grain Quality

At Smiths in 1988 there was a negative linear relationship between grain nitrogen content and *Stellaria media* density in the spring (x). This reduction in grain nitrogen is a direct effect of competition by *S. media* for nitrogen with the crop which was clearly shown in data from other trials not presented in this thesis. The effect of such competition has a much greater effect on crop yield than any possible consequence for grain quality :

Bush Winter Barley 1988

$$\text{Yield} = 5.9 + 2.6(0.9^X)$$

$$\text{Nitrogen \%} = 1.73 - 0.013X$$

At £13/ha control costs and barley at £100/t only 0.5 /m^2 *S. media* would have been required to justify spraying to protect yield. This would only reduce N - content by 0.007%.

Similarly, reductions in thousand seed weight and a potential reduction in specific weight and/or increase in screenings was also found to be coupled with reductions in yield, e.g. Winter Barley reduced dose trial at Middlestotts in 1989 and these yield effects greatly outweighed any effect on grain quality.

The two most important economic factors determining the need for weed control in any one year are yield loss and increased harvesting costs. Other effects such as increased grain moisture can be ignored as they are linked to yield and/or harvesting costs and are proportionately less important.

In the long-term weed seed return can be economically important and it is now considered by some workers that the cereal crop acts as the 'cleaning crop' for broad-leaved weeds in the rotation (Orson, 1987). It was not possible to test fully the long-term effects of weed seed return and other possible failings of a threshold system within the trial series reported. However, three main criticisms of the threshold system show its practical limitations :

a. The saving in herbicide cost of not spraying broad-leaved weeds in one year **potentially** puts far more money at risk from either being wrong and incurring a yield penalty (Streibig, 1989) and/or harvesting costs or by increasing cost or reducing yields in future crops. The farmer would perceive the probability of a type II error as high with the use of thresholds.

b. Thresholds suffer from the requirement to model a complex situation of crop/weed competition that is subject to factors, in particular the environment, which are themselves highly unpredictable in the short- (Orson, 1990) and long-term (Firbank, 1989). A great deal of research would be needed to produce the required data for a system which would be difficult to test under field conditions and so would still be of doubtful accuracy (Streibig, 1989).

c. Assessment of weed populations would have to be done up to three times a year, is time consuming and tedious. Once again the low cost of prophylactic use of broad-leaved herbicides would be small compared to the cost of assessment and management time involved in collecting data.

Some general principles of decision-making and the perception of the value of using herbicides can be represented by a simple model *(Equation 4).*

Equation 4.

$$S = V.P$$

Where S = Cost of control the farmer is willing to pay (£/ha); V = Value to the farmer of control (valued in crop yield, t/ha); P = Crop value (£/t).

i. As crop value falls, the farmer will be willing to spend less on control.

ii. For an individual field, as herbicide cost increases the full cost of control will only be accepted where V is high and the farmer will react by reducing control costs, e.g. using cheaper chemical or lower dose where V is low. Would increased costs of control or fall in cereal prices ever reach a stage where objective weed density thresholds would become an acceptable cost and risk to the farmer? The answer is probably no because with a squeeze on cereal margins farmers generally seek to reduce fixed costs, mainly labour and machinery, by employing family labour, by using contractors and increasing farm size. Such price pressures therefore reduce the time available for crop assessment by the farmer and also his willingness to pay an outside consultant for detailed field walking. The prophylactic use of broad-leaved herbicides, which currently represent less than 2% of gross output (SAC, Pers. Comm.), could be seen as another way of substituting a fixed cost (labour) with a variable cost and the farmer would simply respond to crop and chemical price changes by altering the level of prophylactic use.

5.2. THE TARGETED DOSE APPROACH

An alternative to reduce both chemical usage and cost is the prophylactic use of reduced herbicide doses, or perhaps better described as targeted doses. Such an approach :

a. Reduces, although does not minimise, chemical usage.

b. Minimises risk in both the short- and long-term. It should reduce large fluctuations in the weed seed bank which can be a consequence of a threshold system and may reduce the development of herbicide resistance.

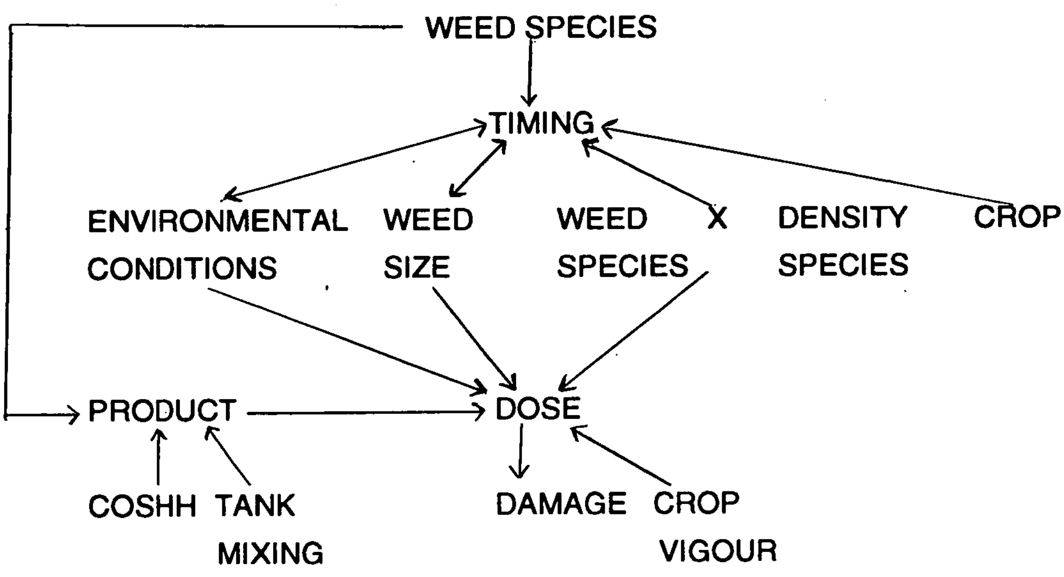
c. Above all it is easy to communicate to the farmer who is often keen to reduce dose, but not willing to withhold weed control completely because he perceives the cost of broad-leaved weed control in cereals as small relative to the perceived cost of allowing weeds to remain uncontrolled.

An advisory computer system to produce recommendations for the use of reduced doses and thresholds in cereals has been developed in Denmark (Baandrup and Ballegaard, 1989). The program selects products that will control the weed spectrum present and adjust dose according to three factors : weed species, weed growth stage and environmental conditions - the last factor is not at present incorporated in the program. The model assumes that the dose response curve of a product is only dependent on its mode of action and that the three factors simply displace the curve parallel to the original (Streibig, 1988).

Results reported in this thesis do not allow for such a sophisticated model to be produced, but initial suggestions for field implementation of reduced herbicide doses for broad-leaved weed control in cereals can be made.

5.2.1. <u>WINTER CEREALS</u>

Herbicide product choice and dose is influenced by several key factors *(Figure 33)*



<u>Figure 33</u>. Diagrammatic Representation of Herbicide Choice and Dose

a. Weed species. In Danish trials (Kudsk, 1989) and in all trials reported in this thesis, weed species was the most important factor determining the success or failure of weed control. If the object is to reduce dose below that recommended, then chemical choice should be limited to those which consistently give good control (> 90%) of weeds present when doses are cut. Such a simple objective enables the number of candidate products to be immediately narrowed down.

The actual level of weed control desired by the farmer will be influenced by the rotation. If high value uncompetitive vegetable crops are grown then the scope for reducing herbicide dose in cereals is less, simply because any weed uncontrolled creates a greater potential threat in subsequent years.

In the majority of trials with both winter wheat and barley the dominant weeds were *Poa annua* and *Stellaria media*, the latter being the most yield reducing. Therefore a broad-leaved weed control strategy should initially be aimed at consistently controlling *S. media* with modifications to strategy dependant upon the importance of other weed species.

b. Timing. With winter cereals there are two broad periods for weed control : autumn or spring.

Advantages of autumn control:

i. Maximise yield by removing weeds early before competition begins. Yield response to early weed control will depend on weed species and weed density and will be modified by environmental conditions. The greater the competitive ability of the weed in the autumn and the greater the weed density the more likely early removal will be necessary. In both the long-term and reduced dose trials, it has been winter barley which has shown consistent yield response to autumn as opposed to spring herbicide. This has been the result of *S. media* at moderate to high density and mild winters, and is consistent with previous results in Scotland (Davies, 1988). This would be expected from the early drilling of winter barley when soil temperatures are still high resulting in increased likelihood of weed emergence and establishment (Thompson and Whatley, 1983) allowing larger plants to enter winter with a decreased risk of winter kill (Debaeke, 1988). Direct beneficial effects of weed removal in the autumn for winter wheat are not clear from results reported or previous trials (Davies, 1988), although as with winter barley early drilled crops with their increased likelihood of weed germination and survival would be considered most at risk from weed competition in the autumn. If pre-emergence herbicides are preferred for management reasons then these should be used in winter barley and early drilled winter wheats, otherwise a decision on need for an autumn herbicide should be left until after weed emergence.

ii. Minimise damage to the crop. In the reduced dose winter wheat trial series in 1989 there was a clear advantage in using an autumn herbicide and this was due to damage to the crop from the spring herbicide. There is increased risk of damage from spring treatments because plants have a shorter time to recover from damage and application in the spring will often coincide with a critical phase of reproductive development (Tottman and Farman, 1983).

iii. Allows a second chance to control weeds. The use of reduced doses increases the risk of poor weed control. *Figure 34* shows the 95% confidence interval calculated for the three doses of DFF/IPU tested in winter cereal trials in 1990 for control of *S. media.* As dose decreases the confidence interval increases, therefore increasing the likelihood of poor control. The major objective for a trialling system to study reduced herbicide doses should be the characterisation of factors which produce this increasing variability as dose is reduced.

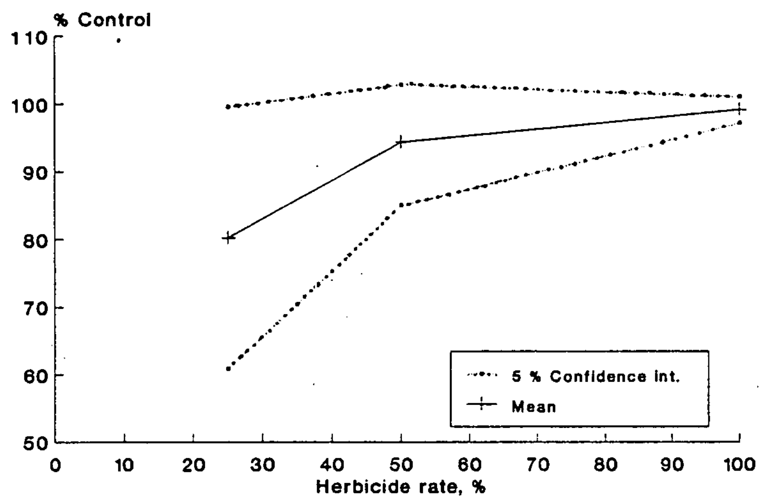


Figure 34. *95% Confidence Interval for Control of S. media with DFF/IPU 1990*

iv. Some weeds are easier to control in the autumn, e.g. *Viola arvensis* (Bradford and Smith, 1982).

v. Poor weather conditions in the spring can limit time available for all field operations and can give poor control by contact and hormonal herbicides. This can also limit the scope to reduce herbicide dose.

vi. Better, more consistent control of most weeds was obtained in reported trials with reduced herbicide doses used in the autumn. This has also been shown in Danish trials (Petersen and Jensen, 1987; Petersen, Jensen and Jorgensen, 1988) and in France (ITCF, 1989). Weeds are smaller in autumn and the herbicide has a heightened effect because of harsh winter conditions.

Advantages of spring herbicide :

i. Delay in spending money. The longer payment is delayed for an input the longer interest accrues on capital or the shorter time interest has to be paid on borrowings. This is of minor importance.

ii. May allow greater scope for tank-mixing. The spraying of cereals with other agrochemicals in the autumn is much less than in the spring, particularly for winter wheat. Tank mixes reduce costs, but the biological activity of compounds can be altered (Sansome, 1989) and crop damage increased.

The apparent advantage in terms of reduced treatment intensity index of an autumn/spring sequence found in some trials may be offset by the increased cost of an extra application in the autumn.

iii. Soil, weather conditions and workload may not allow spraying in the autumn. On some soil types and in very wet seasons spraying in autumn may require a contractor to use a low ground pressure vehicle adding to the cost (c£8.50/ha, SAC 1990) which may offset any advantage in reduced herbicide use in the autumn.

iv. Some weeds are easier to control in the spring, notably those that emerge from depth over a long period, and do not compete with the crop until after crop GS 30 e.g. *Galium aparine* (Froud-Williams, 1985).

Within these broad general timings, environmental conditions and weed size can effect product choice and precise timing. The majority of products used in the autumn will be based upon residual soil-acting chemicals. They therefore require adequate soil moisture to be effective and action is enhanced with fine seedbeds and sometimes with increased temperature and hence transpiration rate (Eagle, 1983). The difference in weed control achieved by DFF/IPU at three timings in the autumn in the screen at Tillycorthie *(Section 4.3.2.)* would suggest that the early post-emergence treatment in mid-October was the optimum timing, the pre-emergence treatment had less effect because of dry soil conditions and the early November timing gave poor control because weeds were larger hence more able to withstand damage and also temperatures were falling and herbicide uptake may have been limited.

In contrast, most herbicides used in the spring are based upon chemicals which have a contact or systemic action. Efficacy of these products will depend upon a complex interaction of factors which include weed size, relative humidity, air temperature, rainfall and light intensity (Gerber, Nyffeler and Green, 1983). In field trials in winter wheat in 1989 there appeared to be poorer control from early spring application of metsulfuron-methyl+ CMPP when weeds were smaller but temperatures lower compared to later timing when weeds were larger, but temperatures were higher. The prediction of herbicide activity based on environmental factors is difficult to study in the field as it is impossible to vary one factor at a time and glasshouse and growth cabinet trials do not adequately reflect field conditions (Blair, 1983). Danish trials have so far only been carried out in growth cabinets, but have shown that relative humidity and temperature can influence optimum herbicide dose (Jensen and Kudsk, 1988). Detailed recommendations for spring herbicides based upon environmental conditions may prove impossible to both study in the field and predict. However, what is clear is that study of consistency of control over a range of environmental conditions can give information useful for product choice. This is best illustrated by the control of *Galium aparine* with fluroxypyr and CMPP. Fluroxypyr has been shown to give better consistency of control than CMPP and that an indicator for herbicide choice is a soil temperature at 10 cm (0900 GMT) of 4 ^{o}C for Fluroxypyr and 8 ^{o}C for mecoprop to control *G. aparine* (Tottman, Steer and Martin, 1988).

Other minor factors :

i. Control of Substances Hazardous to Health (COSHH) regulations require the risk to the user to be minimised. Therefore where there is a choice between products, the product with the greater operator safety should be chosen, e.g. CMPP favoured over HBN because of its lower mammalian toxicity (Fryer and Makepeace, 1977).

ii. Tank-mixing. If tank-mixing is required then the product chosen should be compatible with the other agrochemicals and this may influence product choice.

5.2.1.1. **Choice of Dose**

1. Species x Density

Trial data suggests the probability of reducing herbicide dose is diminished as density or competitive ability of the weed increases. This is the result of increased variation in level of weed control achieved as dose is reduced *(Figure 34)* and a high control rate to reduce populations below yield damaging levels. Simply 90% control of a lot of weeds still leaves a lot!

Yield loss from weeds is a function of weed species and density (Cousens, 1985). Therefore as weed competitiveness and/or density increases the level of control required to prevent yield loss will increase. This was shown by Streibig (1989) who determined net economic return for a range of densities of *Actoptilin repens* after 90% weed control. It was found that there was an optimum beyond which economic return declined as weed density increased, because the control rate of 90% did not reduce the weed population below the economic threshold level. Prediction of herbicide dose to optimise profit from weed control was attempted by Pritchard and Streibig (quoted by Streibig, 1989) who combined dose response curves for clopyralid +/- 2,4 -D and the yield loss/weed density relationship for *Chondrilla juncea*. Streibig (1989) pointed out that such estimations are limited to the conditions under which the two relationships were derived. Work to predict dose response and yield loss could allow dose for a particular weed density and species to be better determined, but again such a goal suffers from the same failings as the threshold system : high research cost and probable impracticality of modelling situations involving complex environmental and plant interactions.

2. Damage

Yield/herbicide dose curves and other data show crop damage to increase with herbicide dose and that this damage can be greater than the benefit from increased weed control resulting in a net economic loss. Such effects strengthen the argument that doses should be minimised, but not necessarily by how much. General suggestions such as the use of autumn residual herbicides in preference to spring herbicides or low dose autumn/spring sequences may minimise this effect.

3. Crop Competition

Weed control is enhanced as the crop becomes more competitive (Whiting, Richards, 1990). Increased crop competition should allow a lower dose to be used, but this reduction is difficult to quantify. The use of more competitive cultivars to limit weed competition in both a conventional and organic crop is not always practicable. Varietal choice will primarily be governed by potential yield in conventional systems (Richards, Morgan, Oskoui and McGregor, 1989) and by disease resistance for organic crops (Richards and Heppel, 1990).

4. Environmental Factors and Weed Size

Both environment, e.g. temperature and weed size can affect herbicide efficacy and determine dose required to give a given level of control (Kudsk, 1989). Such effects are difficult to study and it may only be possible to give general guide-lines to outline situations which minimise the risk of using reduced doses.

5.2.2. SPRING BARLEY

Weed species was the most important factor in determining success of weed control. Yield response to herbicide dose and hence weed control was unclear and generally response to herbicide use was small and often not significant. This is consistent with results both in the UK (Evans, 1966) and in other North European countries (Jensen, 1985). Variable response to weed control has been linked with crop damage from herbicide (Tottman and Bartlett, 1983). Many herbicides used in spring barley are based upon hormonal compounds which are known to damage the crop (e.g. Carpenter and Wilson, 1956). These compounds have very specific recommendation timings which are difficult to comply with because of the rapid growth of spring barley and possible poor spray weather in spring. This often leads to applications outside the recommended 'safe' timings (Tottman and Phillipson, 1974). The rapid growth and short growing season also heightens the effect of any check on crop growth by direct chemical scorch.

In the trials reported here, total weed control was never necessary to maximise yield. However, in spring barley specific weeds at harvest have been shown to be important notably *Polygonous* species and to a lesser extent *Stellaria media*. Initial results would suggest that in many situations the use of full doses is inadvisable. If spraying is delayed because of weather conditions and/or poor conditions persist at spraying then larger weeds may need to be controlled leading to the need for higher doses of herbicide. In such circumstances high doses of herbicide should only be used if there are high levels of weeds generally and in particular *Polygonous* species. Indeed the use of any herbicide at all after GS 30 of spring barley should be carefully considered in view of the weed species present and their density.

Surveys of dicotyledonous weeds in spring barley carried out in the North of Scotland in 1985 (Simpson and Carnegie, 1989) showed regional variation in dominant species. No record was taken of herbicide use, but Salonen and Envio (1988) found in a similar survey in Finland that product choice was often wrong for the weed spectrum. General survey data would be useful as a basis for herbicide selection for extension purposes (Auld, Menz and Tisdell, 1987).

5.2.3. SUMMARY OF YIELD RESPONSE IN REDUCED DOSE TRIALS 1989 AND 1990

Data for yield response in reduced dose trials gives an indication as to the herbicide dose and cost that should be aimed at if prophylactic spraying is used.

Table 56. Economic Optima Based on Yield Mean of all Trials 1989 and 1990

	N		2N		% Change N-2N	
	Dose %	Cost £	Dose %	Cost £	Dose %	Cost £
WB	56.0	(9.60)	48.4	(16.05)	15.7	(67.1)
WW	49.8	(10.53)	41.7	(17.40)	19.4	(65.2)
SB	30.0	(5.38)	25.8	(9.33)	16.3	(73.4)

N - 1990 herbicide cost 2N - 2 x 1990 herbicide cost.

The economic optimum dose for all trials in which there was a response to weed control was c50% for winter cereals compared to only 30% for spring barley *(Table 56)*. The dose would be lower if trials in which there was no yield response were taken into account. When the price of the herbicide was doubled, the optimum dose declined by between 15-20%. However, revenue from herbicides increased by 65-75%. This would suggest that increasing the cost of broad-leaved herbicides in cereals by 100% would : a) encourage a reduction in herbicide use; b) if the increase in price was by taxation the revenue generated could be used to fund research into better herbicide use as in Denmark (Thonke, 1991) where a 3% pesticide sales tax is expected to raise 30-40 million DKr.

6. FUTURE TESTING AND DEVELOPMENT

1. Investigation should continue into the principle factors controlling the use of reduced doses and the relative importance of each :

a. Continued use of simple screening trials to investigate efficacy of a range of herbicides and doses against a range of weed species. This will provide data on species x herbicide dose response and consistency of control.

b. Yielded trials to assess the relationship between yield, weed species, weed density and crop damage. Such trials will provide information on the degree of weed control required to maximise yield for a range of weed species and densities.

c. Investigation of the effect of weed size and environmental conditions presents the difficulty of field testing and this may prove difficult. This should be of low priority.

d. The effect of crop density and vigour on weed control could be measured as part of the screening and yielded trial programme.

Assessment of weed control should be done visually at both crop GS 39 and just before harvest. Such visual assessment is favoured as it introduces a subjective element, namely visual impact of weeds, into the trials which is of great importance to the farmer who judges success or failure by this criteria.

2. Data from the trials outlined above should be incorporated into a concurrent large-scale testing programme.

a. The development of a field walking procedure to identify weed species and a subjective assessment of weed density and any other factors to give choice of product and dose. Such a system could be tested on a small plot and field scale using simple plot pairs, e.g. one at a dose chosen by visual assessment against a full dose.

b. Further investigation into the long-term consequences of varying systems on weed control, particularly the effect of weed seed return on future crops. Modifications to the current trials are suggested :

i. The introduction of crops other than cereals into the rotation, particularly broad-leaved crops with poor competitive ability.

ii. The two doses currently tested, full and half the recommended dose, in all trials have shown no difference in weed control. Instead of a rigid dose, dose should be chosen to suit the weed spectrum etc. with a second treatment half this dose. This variable prophylactic reduced dose could replace the full insurance treatment and be tested against the threshold system, although some problems could arise with differential weed populations which have already been built up between treatments.

iii. Problems have arisen with weed recovery after the use of low doses. Modified harvesting trials should be carried out to investigate the effect of this late growth on harvesting costs.

3. Development of crop protection strategies should take into account the problem of communication of results to the farmer - in particular the farmer's perception of risk.

7. CONCLUSIONS

1. It would seem unlikely that a threshold system requiring detailed weed number counts would be widely adopted under UK conditions.
2. A targeted dose approach offers a more realistic solution to minimising pesticide usage.
3. Initial investigations into the targeted approach demonstrate some of the principles, but more detailed and extensive trials are required.

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APPENDIX I

WEED COUNTS LONG-TERM TRIALS 1988-90

Abbreviations for weed species :

C.a. - *Chenopodium album*
G.a. - *Galium aparine*
L.p. - *Lamium purpureum*
M.a. - *Myosotis arvensis*
P.a. - *Polygonum aviculare*
Poa - *Poa annua*
S.m. - *Stellaria media*
S.v. - *Spergula arvensis*
V.h. - *Veronica hederifolia*
~ Herbicide applied before weed count
Au - Autumn count; Spr - Spring count

F.o. - *Fumaria officinalis*
G.t. - *Galeopsis tetrahit*
M. - *Matricaria* spp.
OSR - Oilseed Rape
P.c. - *Polygonum convolvulus*
S.a. - *Sinapis arvensis*
R.r. - *Rhaphanus raphanistrum*
V.a. - *Viola arvensis*

1. Smiths Holding - weeds/m^2

a. 1988

TREATMENT		WEED SPECIES S.m.	P.a.	F.o.	M.	G.t.	G.a.	R.r.	S.v.
U	Au	7.3	2.0	0.3	0.3	0.0	0.0	0.0	0.0
	Sp	4.1	11.4	0.3	0.3	0.4	0.0	0.3	0.0
1	Au~	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sp~	0.3	1.5	0.0	0.0	0.5	0.2	0.1	0.0
2	Au~	0.8	0.2	0.0	0.0	0.0	0.0	0.1	0.0
	Sp~	0.2	2.3	0.2	0.1	0.5	0.0	0.0	0.0
3	Au	4.9	2.2	0.2	0.0	0.0	0.0	0.3	0.0
	Sp	6.3	14.9	0.8	0.7	0.3	0.1	0.3	0.0
4	Au	16.6	2.7	0.3	0.0	0.0	0.0	0.4	0.0
	Sp	12.1	17.7	0.2	0.5	0.4	0.0	0.2	0.0

b. 1989

TREATMENT		WEED SPECIES S.m.	Poa	F.o.	M.	G.t.	G.a.	R.r.	S.v.
U	Au	9.1	5.0	0.0	0.7	0.0	0.1	0.0	0.3
	Sp	NR	7.8	0.2	0.8	0.3	0.4	0.1	2.6
1	Au~	0.6	0.2	0.0	0.1	0.0	0.2	0.1	0.1
	Sp~	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1
2	Au~	0.5	0.0	0.1	0.2	0.1	0.0	0.1	0.0
	Sp~	0.0	0.3	0.1	0.0	0.6	0.0	0.0	0.1
3	Au	9.6	4.6	0.0	0.4	0.3	0.0	0.0	0.8
	Sp	NR	7.8	0.5	1.4	1.2	0.1	0.0	2.8
4	Au	37.8	7.0	0.3	0.1	0.3	0.1	0.2	0.0
	Sp	NR	7.1	0.3	0.2	0.7	0.0	0.5	1.3

c. 1990

TREATMENT		WEED SPECIES							
		S.m.	Poa	F.o.	M.	G.t.	G.a.	R.r.	S.v.
U	Au	123.4							
	Sp	NR	25.1	0.3	0.5	0.5	0.0	0.1	0.2
1	Au	14.4							
	Sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Au	12.3							
	Sp~	0.0	0.6	1.0	0.0	0.8	0.0	0.0	0.0
3	Au	129.9							
	Sp~	0.0	0.4	0.3	0.0	0.5	0.0	0.0	0.0
4	Au	143.9							
	Sp~	0.0	0.8	1.1	0.1	0.9	0.0	0.0	0.0

2. <u>Niddry Mains</u> - weeds/m^2

a. 1988

TREATMENT		WEED SPECIES							
		S.a.	Poa	S.m.	M.a.	F.o.	G.a.	G.t.	M.
U	Au	6.4	0.0	0.1	0.2	0.0	0.0	0.0	0.0
	Sp	3.2	0.7	0.0	2.0	0.2	0.3	0.9	0.1
1	Au~	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sp~	0.2	0.0	0.0	0.1	0.0	0.0	0.5	0.0
2	Au~	5.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Sp~	0.9	0.0	0.1	0.2	0.4	0.2	0.7	0.3
3	Au	7.8	0.0	0.2	0.0	0.0	0.0	0.0	0.0
	Sp	3.0	0.2	0.1	2.3	0.2	0.3	1.0	0.5
4	Au	6.2	0.0	0.2	0.2	0.0	0.0	0.0	0.0
	Sp	4.9	0.4	0.1	2.5	0.4	0.1	0.5	0.5

b. 1989

TREATMENT		WEED SPECIES							
		S.a.	Poa	S.m.	M.a.	F.o.	G.a.	G.t.	M.
U	Au	5.9	0.0	1.3	2.3	0.3	0.1	0.3	2.0
	Sp	0.8	0.6	0.6	0.8	0.1	0.0	0.0	0.3
1	Au	4.1	0.3	2.3	2.5	0.1	0.0	0.6	2.7
	Sp~	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2	Au	4.9	0.1	1.2	2.3	0.1	0.2	0.0	1.7
	Sp~	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.0
3	Au	4.3	0.1	1.7	2.4	0.0	0.0	0.6	1.7
	Sp	0.3	0.3	0.4	0.4	0.0	0.0	0.1	0.7
4	Au	5.9	0.0	2.0	2.4	0.1	0.2	0.3	1.3
	Sp	0.9	1.0	0.6	0.5	0.3	0.1	0.0	0.3

c. 1990

TREATMENT		WEED SPECIES							
		S.a.	S.m.	M.a.	P.c.	G.a.	G.t.	P.a.	M.
U	Sp	36.3	4.3	10.3	2.7	0.3	1.2	2.3	2.1
1	Sp	10.6	4.3	2.8	2.9	0.1	1.7	2.1	2.0
2	Sp	12.5	4.2	3.4	3.3	0.0	0.9	2.3	1.3
3	Sp	10.6	4.8	2.4	3.4	0.1	1.6	2.1	1.8
4	Sp	19.1	6.1	2.6	3.4	0.3	1.1	2.9	1.5

3. Gleghornie - weeds/m^2

a. 1988

TREATMENT		WEED SPECIES				
		OSR	Poa	S.m.	M.a.	G.a.
U	Au	12.8	0.0	4.4	1.3	0.1
	Sp	5.3	7.5	0.6	0.3	0.2
1	Au~	11.0	0.0	0.7	0.0	0.3
	Sp~	0.0	0.2	0.0	0.0	0.0
2	Au~	8.7	0.0	0.8	0.0	0.0
	Sp~	0.1	0.7	0.0	0.0	0.2
3	Au	10.6	0.0	3.8	0.5	0.0
	Sp	3.8	9.7	1.7	0.1	0.1
4	Au	11.7	0.0	3.6	0.7	0.0
	Sp	5.2	10.7	1.2	0.4	0.1

b. 1989

TREATMENT		WEED SPECIES				
		OSR	Poa	S.m.	M.a.	G.a.
U	Au	0.1	3.4	3.3	0.5	0.1
	Sp	0.1	5.8	0.9	0.1	0.1
1	Au~	0.0	0.4	0.1	0.0	0.0
	Sp~	0.0	0.1	0.0	0.0	0.0
2	Au~	0.1	0.3	0.3	0.0	0.0
	Sp~	0.0	0.6	0.0	0.0	0.1
3	Au	0.4	4.5	3.1	0.4	0.0
	Sp~	0.0	6.6	0.8	0.2	0.0
4	Au	0.1	4.3	2.3	0.1	0.1
	Sp~	0.1	4.4	0.7	0.1	0.0

c. 1990

TREATMENT		WEED SPECIES				
		OSR	Poa	S.m.	M.a.	G.a.
U	Au	0.4	4.6	9.2	1.3	0.1
	Sp	0.0	13.0	2.8	1.7	0.1
1	Au	0.2	2.5	3.7	0.3	0.1
	Sp	0.0	7.5	1.6	0.2	0.1
2	Au	0.4	2.3	4.8	0.2	0.2
	Sp	0.0	8.4	1.4	0.2	0.0
3	Au	0.4	4.6	5.2	0.3	0.1
	Sp	0.0	14.0	0.9	0.3	0.0
4	Au	0.4	5.4	4.8	0.5	0.0
	Sp	0.0	17.9	0.8	0.2	0.1

4. Remote - weeds/m^2

a. 1988

TREATMENT		WEED SPECIES							
		Poa	P.a.	F.o.	V.h.	S.m.	M.a.	L.p.	M.
U	Sp	32.8	1.8	2.1	0.5	2.6	0.7	0.8	0.7
1	Sp	34.0	7.5	0.8	0.7	2.8	3.3	1.0	0.4
2	Sp	35.8	2.1	0.7	0.3	1.7	0.5	0.9	0.1
3	Sp	42.4	6.8	1.2	0.9	2.8	2.0	1.3	0.7
4	Sp	39.8	2.1	1.2	0.7	1.9	0.7	1.3	0.5

b. 1989

TREATMENT		WEED SPECIES							
		Poa	P.a.	F.o.	V.h.	S.m.	M.a.	L.p.	M.
U	Sp	0.5	0.9	0.2	0.2	2.2	0.3	0.5	0.1
1	Sp	0.8	2.0	0.3	0.3	1.9	0.8	0.7	0.0
2	Sp	1.4	0.6	0.1	0.0	1.1	0.4	0.3	0.0
3	Sp	1.3	2.5	0.3	0.3	2.6	0.8	1.1	0.2
4	Sp	0.7	0.3	0.2	0.0	3.8	0.2	3.8	0.0

c. 1990

TREATMENT		WEED SPECIES							
		Poa	P.a.	F.o.	V.h.	S.m.	M.a.	L.p.	M.
U	Sp	0.5	4.5	0.3	0.3	13.7	0.8	0.3	0.0
1	Sp	0.7	1.7	0.0	0.1	1.3	0.3	0.4	0.0
2	Sp	0.3	0.4	0.2	0.1	0.8	0.2	0.3	0.0
3	Sp	1.1	7.3	0.1	0.6	10.4	1.2	0.6	0.0
4	Sp	1.0	3.7	0.3	0.1	13.4	0.3	0.5	0.0

APPENDIX II

CROP EQUIVALENTS FOR THRESHOLD TREATMENTS LONG-TERM TRIALS 1988-90

	Rate	Smiths	Niddry Mains		Gleghornie		Remote
1988	Full	4.1a	2.7a	2.2b	3.4a	0.7b	2.9a
	Half	6.8a	3.8a	0.7b	4.0a	0.7b	1.6a
1989	Full	5.3a	1.3a		0.6a		1.2a
	Half	19.3a	1.3a	0.7a	0.6a		0.9a
1990	Full	65.0a	7.7a		0.8a		3.7a
	Half	72.0a	11.2a		0.8a		3.5a

a - All broadleaved weeds and *Poa annua*, excluding *Galium aparine*.
b - *G. aparine* only.

APPENDIX III

HERBICIDES APPLIED - LONG-TERM TRIALS 1988-90

1. Smiths

	Treatment	Herbicide	Date Applied	Weed GS	Crop GS
1988	1, 2	IPU/DFF(P)	29.09.87	Pre-em.	Pre-em.
1989	1, 2 3, 4	IPU/DFF(P) Fluroxypyr	17.10.88 29.03.89	S.m. Cot. S.m. > 20 cm G.a. > 15 cm	12 30
1990	1, 2, 3, 4	IPU/DFF(P)	30.10.89	S.m. Cot.	13

2. Niddry Mains

	Treatment	Herbicide	Date Applied	Weed GS	Crop GS
1988	1, 2 1, 2, 3, 4	IPU/DFF(J) Fluroxypyr	01.10.87 24.04.88	Pre-em. G.a. 8 cm	Pre-em. 30
1989	1, 2	IPU/DFF(P)	09.02.89	S.m. 4 TL G.a. 1 Wh S.a. 2 TL F.o. Cot.	13/14
1990	1, 2, 4	MM/TM + CMPP	21.05.90	S.a. 10 cm S.m. 5 cm P.c. 1 TL P.a. 2 TL G.t. 1 TL M. 2 TL	22

3. Gleghornie

	Treatment	Herbicide	Date Applied	Weed GS	Crop GS
1988	1, 2 1, 2, 3, 4	IPU/DFF(J) Fluroxypyr	14.10.87 24.04.87	Pre-em. G.a. 8 cm G.a. 10 cm	Pre-em. 31/2
1989	1, 2	IPU/DFF(P)	07.11.88	S.m. Cot	Pre-em.
1990	1, 2	IPU + MM	30.03.90	P.a. 1 TL S.m. 5 cm M.a. 4 TL G.a. 5 cm	30

4. Remote

	Treatment	Herbicide	Date Applied	Weed GS	Crop GS
1988	1, 2	MM + CMPP	15.05.88	P.a. 1 TL S.m. 4 TL F.o. 1 TL	30
1989	1, 2	MM + CMPP	25.05.89	P.a. 2 cm M. 3 TL S.m. 8 cm	30
1990	1, 2	MM + CMPP	13.05.90	P.a. 2 TL	30/1

Herbicides :

IPU/DFF(J) - 'Javelin' Rhone-Poulenc (62.5g/l diflufenican / 500g/l IPU SC). Full rate 187.5g/ha diflufenican / 1500g/ha IPU.

IPU/DFF(P) - 'Panther' Rhone-Poulenc (50g/l diflufenican / 500g/l IPU SC). Full rate 100g/ha diflufenican / 1000g/ha IPU.

Fluroxypyr - 'Starane2' DowElanco (200 g/l Fluroxypyr EC). Full rate 200g/ha Fluroxypyr.

MM - 'Ally' Du Pont (200g/Kg metsulfuron-methyl WG). Full rate 6g/ha metsulfurom-methyl.

MM/TM - 'Harmony M' Du Pont (70g/Kg metsulfuron-methyl / 680g/Kg thifensulfuron-methyl WG). Full rate 4.2g/ha metsulfuron-methyl / 40.8g/ha thifensulfuron-methyl.

CMPP - 'Iso-Cornox 57' (570g/l mecoprop as K salt SL). Full rate 2138g/ha CMPP.

IPU - 'Hytane 500FW' Ciba-Geigy (500g/l IPU SC). Full rate 2100 g/ha IPU.

Weed abbreviations as Appendix I.

APPENDIX IV

SPRAY APPLICATION DETAILS REDUCED DOSE TRIALS 1989-90

Letters in treatment column refer to Table 4 in Materials and Methods.

1. Winter Barley 1989

Site	Treatment	Date Applied	Weed GS	Crop GS
Bush	C	07.11.88	S.m. 1 cm V.h. Cot. Poa 2 LF	13
	G	14.04.89	S.m. 30 cm V.h. 15 cm Poa 8 cm	30/1
Upper Cairnie	C	15.11.88	S.m. Cot.	13
	G	09.05.89	P.a. 2 LF	31
Middlestotts	C	01.11.88	S.m. 1 cm Poa 2 LF S.a. 2 LF	13
	G	14.04.89	S.m. 30 cm Poa 8 cm S.a. 15 cm	31

2. Winter Wheat 1989

Site	Treatment	Date Applied	Weed GS	Crop GS
Bush	C	15.12.88	S.m. 2 cm V.h. 2 LF Poa 2 LF	13
	G	19.04.89	S.m. 30 cm V.h. 10 cm Poa 10 cm	30
Upper Cairnie	C	02.12.88	S.m. Cot.	13
	G	09.05.89	S.m. 25 cm	31
Middlestotts	C	12.12.88	S.m. 1 cm Poa 3 LF	13
	G	14.04.89	S.m. 3 LF	
Luffness Mains	G (T1)	15.04.89	S.m. 8 cm M. 10 cm M.a. 7 TL	31
	G (T2)	29.04.89	S.m. 15 cm M. 10 cm M.a. 10 cm	
Markle Mains	C	02.11.88	S.m. Cot. M.a. Cot. Poa 1 LF	12
	G (T1)	27.03.89	S.m. 10 cm M.a. 7 TL	22
	G (T2)	15.04.89	S.m. 15 cm M.a. 10 cm	31
Upper Dalhousie	C	12.12.88	S.m. 2 TL	12
	G (T1)	27.03.89	S.m. 15 cm	21
	G (T2)	15.04.89	S.m. 15 cm	30

3. Spring Barley 1989

Site	Treatment	Date Applied	Weed GS	Crop GS
Bush	G +/- CMPP	26.05.89	S.m. 25 cm G.t. 8 LF P.a. 5 LF	24/30
Upper Cairnie	G +/- CMPP	17.05.89	S.m. 1 cm P.a. 4 LF M. 5 LF	15/21
Middlestotts	G +/- CMPP	25.05.89	P.a. 10 cm P.c. 5 cm S.m. 8 cm	25/30

4. Winter Barley 1990

Treatment	Date Applied	Weed GS	Crop GS
a. Ploughlands			
A & B	22.09.89	Pre-em.	Pre-em.
C & D	19.10.89	F.o. 2 cm OSR 2 LF S.m. Cot. Poa 2 LF	13-15
B & D	26.03.90	F.o. 15 cm OSR 6 LF S.m. 20 cm Poa 8 cm	30/31
b. Tillycorthie			
A, B, C, D, E, F	30.09.89	Pre-em.	Pre-em.
B, D, F	05.04.90	S.m. 12 cm OSR 15 cm	30/31

5. Winter Wheat 1990

Treatment	Date Applied	Weed GS	Crop GS
a. Treaton			
C & D	16.11.89	S.m. 3 cm S.a. 2 LF Poa 2 LF F.o. 2 LF	12/13
D & G	28.03.90	S.m. 15 cm F.o. 8 cm V.a. 6 LF	30
b. Tillycorthie			
A, B, C, D	30.10.89	Pre-em.	Pre-em.
B, D, G	11.04.90	S.m. 15 cm OSR 8 cm M. 8 LF Poa 2 cm	30

6. **Spring Barley 1990**

Treatment	Date Applied	Weed GS	Crop GS
a. Ploughlands			
G, H, J, K, L	14.05.90	F.o. 15 cm S.m. 15 cm P.c. 2 LF OSR 5 LF	21/22
b. Treaton			
G, H, L, M	17.05.90	S.m. 30 cm M.a. 8 LF P.c. 2 LF	30
c. Bush			
G (T1)	11.05.90	G.t. 4 LF V.a. 2 LF S.m. 10 cm	15/22
G (T2)	25.05.90	G.t. 8 LF V.a. 4 LF S.m. 10 cm	30
d. Tillycorthie			
G (T1), H (T1)	04.05.90	S.m. 6 LF G.t. 2 LF P.a. 2 LF P.c. 1 LF M. 4 LF	13
G (T2), H (T2)	25.05.90	S.m. 10 cm G.t. 8 LF M. 8 LF	30/31
e. Sunnybrae			
G (T1), H, M	13.05.90	S.m. 6 LF G.t. 6 LF P.a. 4 LF M. 4 LF	13
G (T2), J, K, L	25.05.90	S.m. 8 cm G.t. 8 LF P.a. 5 LF M. 6 LF	30

7. Screen Trials 1990

Treatment	Date Applied	Weed GS	Crop GS
a. Smiths- Winter Barley			
A, C, E, N	09.10.89	Pre-em.	Pre-em.
C, P, Q, R	07.11.89	S.m. 2 LF F.o. 2 LF	14/21
b. Newburgh - Winter Barley			
A, C, E, N	27.09.89	Pre-em.	Pre-em.
C, P, Q, R	12.10.89	S.m. 2 LF OSR Cot. Poa 1 LF	11/12
C, S, T, U, V, W	20.11.89	S.m. 6 cm OSR 4 LF Poa 3 LF	14/22
c. Markle Mains - Winter Wheat			
A, C, E, N	10.10.89	Pre-em.	Pre-em.
C, P, Q, R	15.11.89	S.m. 1 cm OSR 2 LF Poa 2 LF	
d. Udny - Winter Wheat			
A, C, E, N	20.10.89	Pre-em.	Pre-em.
C, P, Q, R	01.12.89	S.m. 2 LF OSR 1 LF Poa 1 LF	11/12
G, H, V, W, X, Y	20.04.90	S.m. 10 cm OSR 5 cm	30
e. Spring Barley - Carsewell			
G, H, J, K, L, M	18.05.90	S.m. 7 cm G.t. 6 LF P.c. 2 LF M. 8 LF	16/22

APPENDIX V

METEOROLOGICAL DATA - BUSH, MIDLOTHIAN 1987-90

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1987	a									64.8	120.5	43.4	76.0
	b									11.1	7.2	5.6	4.5
	c									149.5	83.9	54.3	15.9
1988	a	105.0	57.0	76.0	65.0	56.0	18.0	166.0	89.0	91.0	77.0	58.0	43.0
	b	3.3	3.9	4.5	6.7	9.3	12.8	12.9	13.5	11.5	8.4	4.9	6.5
	c	39.2	74.4	97.5	121.7	169.0	181.0	126.0	134.0	121.0	76.0	73.0	32.0
1989	a	75.4	105.8	87.3	35.4	37.6	68.9	15.1	114.0	21.4	64.0	19.7	67.2
	b	6.2	4.3	5.1	5.1	10.5	12.1	14.7	13.8	11.6	9.8	5.2	2.2
	c	36.0	72.0	109.0	126.0	209.0	173.0	232.0	135.0	89.0	91.2	81.0	12.3
1990	a	169.0	162.0	57.0	27.0	39.0	110.0	58.0	67.9	64.0			
	b	4.8	4.9	6.9	7.1	10.2	12.0	13.9	14.7	10.9			
	c	29.0	57.0	97.0	163.0	183.0	131.0	215.0	138.0	85.0			
LT	a	75.5	52.6	66.7	49.2	59.3	60.5	74.1	81.1	76.6	83.5	83.5	82.3
	b	2.2	2.0	4.0	6.8	9.6	12.7	14.3	13.8	12.1	8.9	4.8	3.3
	c	39.6	62.3	93.1	129.9	162.4	160.4	151.3	137.5	107.1	82.3	52.2	29.3

a - rainfall (mm); b - mean air temperature (^{o}C); c - sunshine hours.
LT - long-term average (1955-90)

APPENDIX VI

EQUATION FOR CURVES FITTED TO YIELD AND HERBICIDE RATE DATA

General formula :

$$y = a + b_1 \log e\,(x + 1) + b_2\,[\log e\,(x + 1)]^2$$

Figure No	Herbicide	a	b_1	b_2	r^2
10	DFF/IPU	4.65	-0.80	0.39	0.88
	Metsulfuron-Methyl + CMPP	4.65	0.31	0.006	0.85
11	DFF/IPU	6.46	0.19	0.003	0.97
	DFF/IPU + CMPP	6.46	0.47	-0.07	1.0
	Trifluralin	6.46	-0.19	0.08	0.99
	Trifluralin + CMPP	6.46	0.58	-0.09	0.90
	Pendimethalin	6.46	-0.13	0.08	0.99
	Pendimethalin + CMPP	6.44	0.54	-0.08	0.81
12	Metsulfuron-Methyl	5.65	0.21	-0.03	0.88
	Metsulfuron-Methyl + CMPP	5.64	0.14	-0.02	0.58
13	Thifensulfuron-Methyl/ Metsulfuron-Methyl	5.19	0.14	-0.002	0.94
	Metsulfuron-Methyl	5.19	0.11	0.008	0.94
15	DFF/IPU	8.11	0.17	-0.03	0.79
	Metsulfuron-Methyl + CMPP	8.11	0.09	-0.03	0.70
16	DFF/IPU	4.83	0.64	0.03	0.93
	DFF/IPU + CMPP	4.81	1.43	-0.13	1.0
	Metsulfuron-Methyl + CMPP	4.82	0.5	0.04	0.99
17	DFF/IPU	10.93	0.6	-0.05	0.77
	DFF/IPU + CMPP	10.91	0.65	-0.07	0.78
	Pendimethalin	10.91	0.91	-0.12	0.96
	Pendimethalin + CMPP	10.92	1.29	-0.23	0.99
	Metsulfuron-Methyl + CMPP	10.94	1.04	-0.15	0.90

APPENDIX VII

GENSTAT V Program for Fitting Dose Response Data

```
UNITS [NVALUES = 16]
VARIATE RATE, CONT, LRATE
FACTOR [LEVELS = 4] WEEDK
READ [CHANNEL = 2] WEEDK, RATE, CONT
CALC LRATE = LOG(RATE)
CALC CONT = 100-CONT
VARIATE [VALUES = 16(100)] NSAM
MODEL [DISTRIBUTION = BINOMIAL; LINK = LOGIT] CONT; BINOMIAL = NSAM
FOR WEED = 1...4
RESTRICT LRATE, CONT; COND = WEED.EQ.WEEDK
FIT [PRINT = M, S, E, F] LRATE
ENDFOR
```

Example for the use of the Logistic model :

Figure 27. Upper Dalhousie, a = 3.2, b = -1.2, dose = 50%

$$\frac{\%\ \text{control}}{100} = 1 - \left(\frac{1}{\text{Exp}[-a - b.\log e\ (\text{dose})] + 1} \right)$$

$$= 1 - \left(\frac{1}{\text{Exp}[-3.2 - (-1.2 \times \log e(50))] + 1} \right)$$

$$= 1 - 0.184$$

$$= 0.816$$

$$= 81.6\%$$

Analysis of Variance

1. Threshold Trials

Source of Variation	Degrees of Freedom					
Block	2	Means Compared :				
Management		Untreated	Threshold	Threshold	Insurance	Insurance
Treatment	4		Full	Half	Full	Half
Roundup	1	Plus	Minus			
		Roundup	Roundup			
Residual	22					
Total	29					

2. Reduced Dose Trials

Example with 4 doses, one untreated, two herbicides and 3 blocks :

Source of Variation	Degrees of Freedom					
Block	2	Means Compared :				
Treated versus		Treated	Untreated			
Untreated	1					
Herbicide versus		Herbicide 1	Herbicide 2	Untreated		
Untreated	1					
Herbicide Dose	3	Dose 1	Dose 2	Dose 3	Dose 4	Untreated
Mean of Each			Dose 1	Dose 2	Dose 3	Dose 4
Treatment	3	Herbicide 1				
		Herbicide 2				
Residual	16	Untreated				
Total	26					