Ecological and agronomic aspects of a pear and vegetable interculture system

Thesis

ECOLOGICAL AND AGRONOMIC ASPECTS OF A PEAR AND VEGETABLE INTERCULTURE SYSTEM

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ABSTRACT

The objectives of this study were to characterise the productivity and resource use efficiency of an experimental interculture system and to develop methods for the evaluation and optimisation of interculture.

The experimental system consisted of a mature pear orchard intercropped with vegetables. The first experiment used a phytometer technique in order to evaluate the response of a range of understorey vegetables (carrot, onion, pea, radish and lemon balm) to the aerial environment created/modified by the trees. The main conclusion was that most vegetables could be intercropped given a suitable soil environment. Some changes in crop morphology were identified in positions directly under the canopy. Radish was selected for further study.

Novel techniques for the measurement of the transmissivity of the tree canopy to photosynthetically active radiation (PAR) were developed and tested. The canopy was found to be around 70% transmissive when averaged over the orchard floor. Areas directly under the canopy received around 50% of the incoming radiation.

The response of radish to various levels of PAR was characterised using a shade experiment. A 50% reduction in PAR resulted and a 65% reduction in yield measured as mean bulb diameter but did not affect the mean total dry weight of the plants. This was due to the plants partitioning proportionately more dry matter to the leaves. A few individual plants, when grown at 30% PAR had bulb diameters equivalent to the 100% mean. This was taken as an indication of the potential for increasing yields by genotype selection.

The land equivalents ratio for the system when calculated indicated that 50-100% more land would be required in order to obtain the same yield from monocultures, depending on the spatial arrangement selected.

The radish component did underyield in positions directly beneath the canopy. Experiments with artificial fertiliser (NPK) and shade indicated that PAR intensity coupled with some soil factor other than NPK concentration were implicated.

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GENERAL INTRODUCTION

Two of the major problems facing the worlds population today and in the future, are the provision of adequate food and high grade energy. All food is derived from the process of photosynthesis. Most of the energy used in the world today is derived from present or past photosynthesis. Man has developed various mechanisms for increasing the efficiency of photosynthesis in terms of yield of a given product per unit area/time. These include :

1. increasing supplies of water and plant nutrients.
2. breeding higher yielding crops.
3. increasing cropping intensity within an area within a year.
4. reducing crop losses to diseases, pests and interference from weeds.

Much of the research on crop production has centred upon monocultures where a single crop is grown within an area within a year. Much applied research has been directed towards environments where the energy and economic costs of using artificial fertilizers, irrigation, herbicides, and pesticides have been considered inexpensive. This economic environment may not continue for long in industrial countries and rarely exists in non-industrial countries.

Research interest is now increasing in the area of mixed cropping. This is a method of increasing cropping intensity where more than one crop species are grown within an area within a year. Several advantages have been reported of mixed cropping relative to monoculture. These include :

1. reduction in land area required to produce a given quantity of each of the component crops when mixed.

2. reduction in the requirement of artificial fertilizers by using mixtures containing leguminous crops.

3. reduction in the incidence of pests, diseases and weeds in crop mixtures.

4. greater stability in the face of drastic changes in the economic and ecological environment of the cropping system.

5. more efficient use of available water.

6. greater yields of total dry matter per unit area.

One philosophy behind the practice of mixed cropping is the fitting of specific crops to environments rather than manipulating the environment to fit the crop by using energy and capital intensive methods.

Mixed cropping is becoming more important in many parts of the world, yet little research has been carried out. Most of the research on mixed cropping has been on mixtures of similar, usually annual crops. Only a few studies have included work on the biological basis of any yield advantage. No information exists in the literature on the yields of interculture systems: mixtures containing tree crops. This study was undertaken in order to characterise the yield of an interculture system containing pear and vegetables, and to develop methods useful in the evaluation and optimisation of these systems.

Aim of study and experimental objectives

The aim of this study is to expand agronomic knowledge on interculture systems; mixtures of crops containing a perennial, usually a tree. The objectives of the study are :

1. to quantify the productivity of an interculture system relative to monocultures of the components.

2. to examine methods for determining the biological basis for any deviations from expected yield and for quantifying interactions.

3. to examine the effects of density, spatial arrangement, the aerial environment and the addition of fertilizer on the yield of an interculture understorey.

4. to examine methods for determining the light use efficiency of an interculture system.

INTERCROPPING: A LITERATURE REVIEW

Chapter 1

INTRODUCTION

A literature review was carried out to find out more about the theory and practice of intercropping, and specifically to provide answers to the following questions:

1.1 What is the range of intercropping systems and how may they be classified?

1.2 How widespread and important is the practice of intercropping?

1.3 What are the advantages and disadvantages of intercropping?

1.4 What is a yield advantage in the context of intercropping and how can it be measured?

1.5 What is the biological basis for yield advantages in crop mixtures?

1.6 What is the extent of research on intercropping and what further research is required?

1.1 The Terminology and Classification of Intercropping Systems

1.1.1 Terminology - A review of the literature shows that the terminology pertaining to the practice of growing more than one crop within a given area within a year is very confused. The following terms have all been used to describe the practice:

(a) intercropping
(b) interplanting
(c) polyculture
(d) multiple cropping
(e) mixed cropping.

Complications arise when authors take one of these synonyms and give it a more specific meaning by taking into account the spatial and temporal arrangement of the cropping system. Examples are:-

(a) Intercropping: Two or more crops grown simultaneously in alternate rows in the same area. (Ruthenberg, 1971).

(b) Mixed cropping: Two or more crops grown simultaneously and intermingled with no row arrangement. (Ruthenberg, 1971; Harwood, 1975).

(c) Interplanting: Long term annual or biennial crops interplanted with short term annual crops during the early stages of plant development. (Ruthenberg, 1971).

The more general definition of intercropping as the growing of more than one crop (species or variety) on a given area of land within a year now appears to be the most widespread in the literature and shall be used in this sense. Other terms associated with intercropping research and their definitions are given below.

Interculture: An intercropping system containing perennial and non-perennial crops, commonly annual crops grown under tree crops. (Ruthenberg, 1971).

Companion planting: Crops, claimed to be mutually beneficial in some way, usually in respect of reduced incidence of pests and diseases. (Philbrick and Gregg, 1966).

Sequential cropping: A series of crops planted in sequence within a year with no overlap. One crop is planted after the harvest of a former crop. Double, Triple and Quadruple cropping refer to the number of crops within the sequence. (Andrews and Kassam, 1976).

Ratoon cropping: The cultivation of crop regrowth after harvest. (Andrews and Kassam, 1976).

Relay cropping: Similar to sequential cropping but crops overlap during part of their growth. (Andrews and Kassam, 1976).

Sole cropping: Synonym of monoculture. One crop grown alone in pure stand. Can be continuous for a number of years.

Nurse crop: A crop usually of minor importance sown to protect the seedling stage of a more economically valuable crop.

Cover crop: A crop sown to improve/maintain soil structure/ fertility.

Catch crop: Usually a crop with a short maturation time, sown between the plantings of major crops.

1.1.2 Classification - Intercropping systems are found throughout the world and contain nearly all known crops. Details of two intercropping systems at the extremes of a scale of complexity are given in Table 1.

Table 1: Contrast of two intercropping systems indicating range of characteristics

Variable	UK Cereal Mixture	Sri Lankan Forest Garden
Number of species	2	17 (+ mixed varieties)
Crop types	Cereals (barley and wheat)	Cereals, fruits, nuts, vegetables, spices
Spatial arrangement	Regular	Highly complex, both laterally and vertically
Temporal arrangement	Simultaneous sowing and harvest	Highly complex, complex intra specific age structure, annuals and perennials
Reasons for intercropping	Reduced disease incidence	Yield stability, provision of total family needs: food, timber, medicine, from a small plot
Ease of mechanisation	Machinery already exists	Harvest mechanisation impossible
Support energy	High	Low
Reference	Burdon and Whitbread (1979)	McConnell and Dharmapala (1973)

No comprehensive classification system was found in the literature. A possible system is outlined below based upon the following variables:

(1) The spatial relations between crops;

(2) The temporal relations between crops;

(3) The type of crops used;

(4) The reasons why the grower adopted the cropping system;

(5) The expected yield reaction.

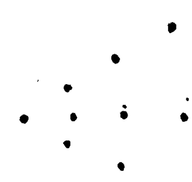
(1) The Spatial relations between crops

By manipulating the planting arrangement, the grower can influence the nature and extent of interference between the crop components. The spatial arrangement of intercropping systems has to be viewed at two levels: a description of the arrangement of the 'holes' that the crops fit into and the way in which the species are allocated to the different holes. There are four possible types of hole arrangement - repetitive, systematic, clumped, and random. These are shown in Figure 1.

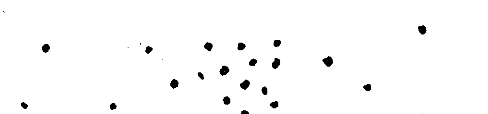
Figure 1: Possible spatial arrangements of holes

Repetitive:

Systematic:



Clumped:

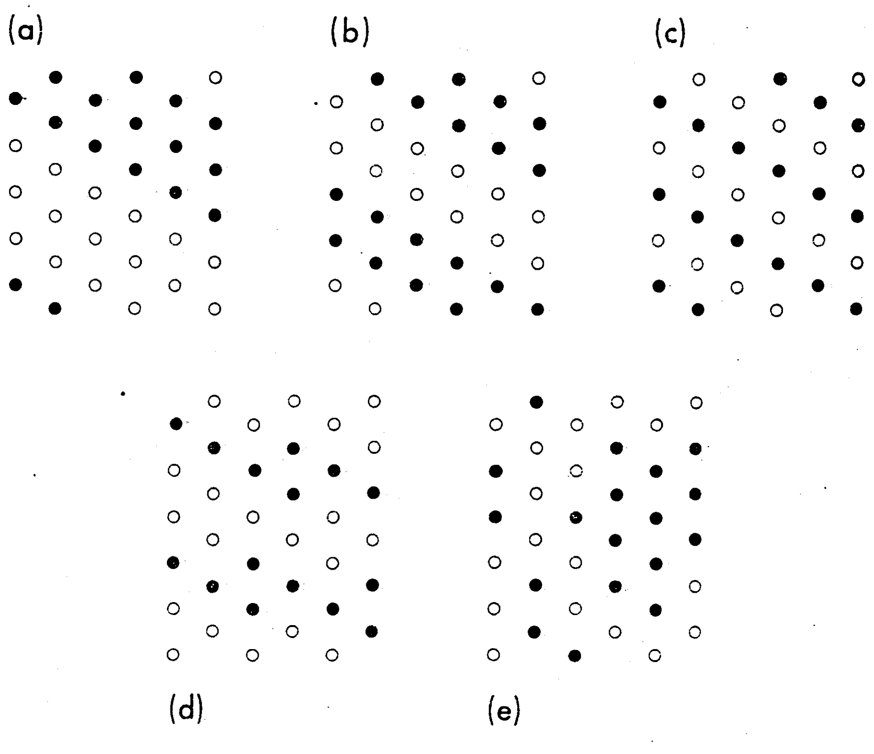


Random:

Random arrangements often occur when seed mixtures are hand broadcast. Clumped arrangements are common in forest garden systems. Systematic arrangements are often used in experimental systems. A variety of spatial arrangements can be generated by altering the proportions and positions allocated to the different crops within the repetitive array.

Figure 2 shows the effects of variable allocation positions within a hexagonal repetitive array (from Harper, 1961). Proportion is constant within the two species mixture. For crops regularly arranged in rows, spatial arrangement can be concisely defined by the rectangularity, which is the ratio of the inter row spacing to the intra row spacing. One other important aspect of spatial arrangement is density of population; this is the number of plants per unit area (Willey, 1979). The distinction must be made between overall and component population. Very little work has been done on the effects of spatial arrangement on yield within mixed cropping systems. Perhaps the simplest way to define the spatial arrangement in complex systems is to draw a scale diagram.

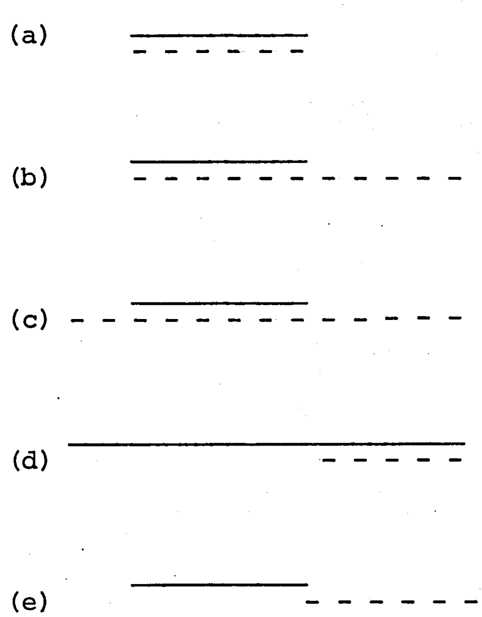
<u>Figure 2:</u> Planting arrangements differing in the frequency of contacts between the two components of 1-1 intercrops. The average number of such contacts (out of 6) in the patterns is:- (a) 1, (b) 2, (c) 4, (d) and (e) 3. This type of intercropping is:- (a) and (b) strip, (c) row, (d) mixed, (e) random (from Harper, 1961).



(2) The temporal relations between crops

Figure 3 shows the five possible combinations of planting and harvesting relationships within a two-crop mixture. Figure 3a represents simultaneous planting and harvesting of a mixture. This is typical of forage and pasture mixtures where separation is not important, only the gross yield of the mixture. Figure 3b shows a form of relay cropping. The crops are planted simultaneously but due to their disparate maturation times are harvested sequentially. A crop such as sugar cane which takes one year to mature is often interplanted with short season maize or soyabeans. Figure 3c shows an interplanted crop sown after and harvested before a crop with a longer maturation time. This often occurs in the interculture of annuals under tree crops. Figure 3d shows simultaneous harvesting of a sequentially sown mixture. I have not found an example of this system. Figure 3e shows a system where there is no overlap within the growing periods of the two crops.

Figure 3: A graphical representation of the five possible permutations of planting and harvesting in a two-crop mixture. (Duration is represented by the length of lines.)



(3) The type of crops used

The crop types used in intercropping systems can be classified in a number of ways. The way in which the crops are classified will depend on whether the system is studied as an ecological, social or economic entity. The following features of crops may be used in developing an ecological classification:-

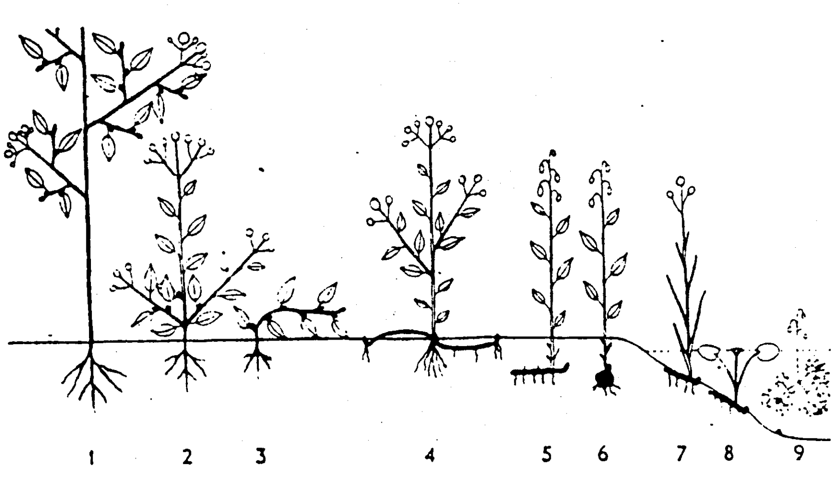
(a) taxonomic

(b) metabolic (e.g. mode of photosynthesis)

(c) phenologic (e.g. annual or perennial)

(d) growth form (e.g. deep rooting, shallow rooting or position of perennating parts). (Figure 4)

Figure 4: The relative positions of the perennating parts of four life forms. (1) Phanerophytes, (2-3) Chamaephytes, (4) Hemicryptophytes and (5-9) Cryptophytes. (From Raunkiaer, 1934).



(4) The reasons why the grower adopted the cropping system

These may be economic, nutritional or social. Tradition may be a strong element in choice. Igbozurike (1978) conducted a survey on the reasons why growers selected a particular polyculture system in villages of Kwara State, Nigeria. The results are presented in Table 2.

Table 2: The frequency of reasons given by growers in villages of Kwara State, Nigeria as to why they selected a particular cropping system (from Igbozurike, 1978) -

	Response	Frequency of Answers
1.	The technique used by our ancestors	100
2.	Greater returns from each piece of land	92
3.	The only hedge against crop failure and thereby starvation	91
4.	Major savings in labour	75
5.	Maximisation of dietary variety	40
6.	The only way to farm successfully	34
7.	The best way to utilise land fully	31
8.	The method our neighbours employ	14

(5) The expected yield reaction

This is dealt with in detail in Section 1.3.

1.2. The ubiquity and importance of intercropping

Intercropping appears to be an appropriate form of production within developing countries. Numerous workers have found the practice to be more profitable and successful in the long term than monoculture (Dalyrimple, 1971; Norman, 1974; Andrews and Kassam, 1976; Igbozurike, 1978). The area intercropped is expanding in India. Between 1968 and 1969, 15 million acres of land in India were used in a programme to intensify agricultural production (Dalyrimple, 1971). The largest area intercropped is present in China, followed by India. The communist party in China have promoted the practice of intercropping, (Dalyrimple, 1971). The main source of data on the ubiquity and importance was the 1960 World Census of Agriculture (FAO, 1973).

Table 3 represents a summary of this data. Francis et al, 1976, report that "98% of cowpeas in Africa and more than 60% of maize and beans in Latin America are in crop mixtures". "93% of the Sokoto area, 83% of the Zaria area, and 53% of the Omo Aran area in Northern Nigeria are intercropped" (Baker and Norman, 1975). It is obvious from these figures that the practice is both widespread and important.

Table 3: Extent of intercropping in selected countries as derived from World Census of Agriculture (FAO, 1973).

Country	Observations made by FAO
Dominican Republic	40% or more maize grown with other crops.
El Salvador	Maize and beans, maize and sorghum, maize and other crops grown in mixtures.
Jamaica	50% of maize mixed with other crops.
Mexico	20% of maize mixed with other crops.
Brazil	6-11% of rice and maize mixed with other crops.
Paraguay	33% of beans, 10% of sweet potatoes, 10% of maize mixed with other crops.
Venezuela	16% of rice, 33% of maize, 20% of beans, 20% of cassava, 50% of cotton mixed with other crops.
India	5-6% of rice and 70-80% of other crops grown in mixtures.
Indonesia	Maize and rice grown in mixtures.
Pakistan	Wheat, barley, cotton and oil seeds frequently grown in mixture.
Central African Republic	25% of cotton, 33% of coffee, 20% of cassava grown in mixtures.
Libya	Considerable part of area of maize and bean mixtures.
Senegal	25% of area in groundnuts and millet grown in mixtures.
Southern Rhodesia	50% of area planted in mixed crops.

Intercropping may also have potential in developed countries. Examples of intercropping in the UK are given below :

(1) Intercropping with annuals

Pastures in the UK generally consist of many species. Dolman and Harris, (quoted in Mead and Riley 1981) list the following potential applications of intercropping to temperate regions :

(i) intercrops grown as animal feed, e.g. maize/kale;
(ii) smallscale unmechanised agriculture, e.g. carrots/ onions;
(iii) intercrops of contrasting varieties of one species, e.g. early/main crop potatoes (see also Schepers and Sibma, 1976; and Chowdhury and Hodgson, 1982).

(2) Mixtures containing perennials (interculture)

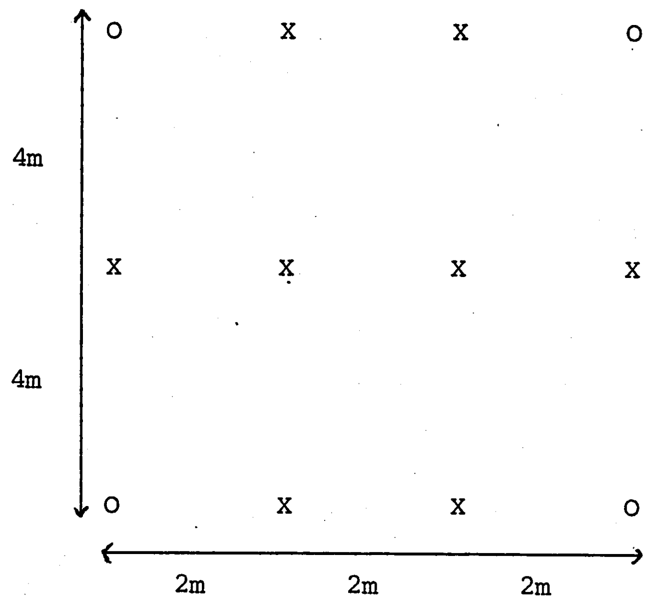
(a) Poplar plantations - Poplars are often undersown to cereals in the first nine years of their growth. After nine years, the ground is then laid to grass, kale and beans. Root crops have also been tried but marketing difficulties have inhibited their incorporation. Poplars are sold, when mature, for matchwood.

(b) Orchard intercropping

(i) Evesham area: Strawberries and wheat are often intercropped in young apple orchards up to five years of age. Apple trees are grown in rows 5 m. apart. The strawberries occupy a 3m strip. Plum orchards are often intercropped with gooseberry, redcurrants, strawberries, cabbage or lettuce, (Fekete, 1958).

(ii) Wisbech area: Plum orchards are often interplanted with gooseberry and sometimes blackcurrants. Bulbs such as daffodils were often catch cropped before the major management operations got under way. Many Bramley orchards containing old trees up to 150 years old are interplanted with gooseberries. Figure 5 shows a typical planting arrangement within a plot.

<u>Figure 5</u>: A typical gooseberry/Bramley system grown in Wisbech.



O = Bramley. X = gooseberry.

Some growers have removed the central row of gooseberries to facilitate spraying. The spraying programme is compatable for both crops. This system is now declining due to the present low price given for gooseberries.

(iii) Kent: The following vegetable crops have been intercropped in orchards -

(1) radish
(2) sprouts
(3) asparagus
(4) early potatoes
(5) maize
(6) courgettes.

The cultivation of the soil for sprouts in Bramley orchards often increased the yield of mature trees. The practice of intercropping vegetables has decreased in recent years. Most orchards are now monocropped. Grass clover leys for sheep were often part of orchard systems in Kent.

1.3. Advantages and disadvantages of intercropping

1.3.1. Integrated land use - This is when various land use activities such as forestry, landscape, agriculture, energy cropping, are carried out on the same piece of land by judicious mixing of appropriate species. Many land use systems have periods in the year with little activity or a spatial pattern with gaps that could be filled by other cropping activities. Agroforestry in developing countries is of increasing importance in providing the diverse needs of local settlements, including food, fuel wood, timber, medicines, etc., (Huxley, 1982).

1.3.2. Complexity: management and mechanisation - Integrated land use achieved through intercropping is by definition more complex than monoculture. This is a disadvantage from a management point of view. The analysis of mixed activities or mixtures of components as a body of knowledge is poorly developed. The ever increasing specialisation found in the developed countries runs counter to the development of mixed cropping systems. Western agriculture has developed along the lines of increased production per person employed by increasing mechanisation. Mechanisation of interculture systems is difficult, but not impossible. Some mixtures such as energy crops, fodder crops, and pastures can be managed as if the crop was a single species in many cases. Separation before or at harvest is not required. Machinery adaptations for multiple cropping systems requiring specialist attention to each of the components are already being developed, (Erbach and Lovely, 1976 ; Crookston 1976). The problems of mechanisation enabling specialist treatments to cropping system components appear meagre relative to those that had to be overcome in machinery such as the combine harvester, where within plant components are dealt with. Even mixtures of dissimilar crops such as poplar and wheat can be dealt with by presently available machinery if the spatial and temporal layout of the system is designed appropriately. The question of mechanisation should also be viewed in a global context. The most important agricultural implement for two thirds of the world's population is still probably the hoe (Buntjer, 197C ; Evans, 1960).

1.3.3 Productivity - Recently several reviewers (Kass, 1978; Willey, 1979; Mead and Riley, 1981) have commented that generally productivity is increased by intercropping in terms of total dry matter and land equivalents ratio.

1.3.4 Resource use - The areas where intercropping systems have evolved and are now widespread and important are characterised by having little access to resources such as artificial fertiliser and pesticides. Systems have been developed to make the maximum use of local growth resources. Mixtures of legumes and non legumes have been used to maintain soil fertility (Kass, 1978). It has been claimed that intercropping may reduce the need for pesticides by the reduced incidence of pests found in intercropping systems (Dempster and Coaker, 1974). Soil erosion may also be reduced by intercropping (Willey, 1979). Increased efficiency of local resources is going to be of increasing importance in developing countries due to the

increased cost of many of the inputs of non local resources such as fossil fuels, artificial fertiliser and pesticides, and the environmental impact caused by the injudicious use of agrochemicals.

1.3.5 Nutritional advantages - In small settlements of subsistence farmers a mixed cropping system is advantageous from the nutritional standpoint in obtaining a balanced diet with sufficient protein, energy, and vitamins.

1.3.6 Labour requirements - It has been shown that while actual labour requirements of intercropping systems may be higher than of monocultures of the component crops, return per unit labour is often higher with intercropping (Kass, 1978). Under traditional agriculture, intercropping appears to equalise labour requirements over the year.

1.4 The Analysis of Yield Advantage in Intercropping Systems

1.4.1 Introduction - The detection of a yield advantage within a cropping system depends on several factors. These are:

(1) Experimental site;
(2) Measures of efficiency selected;
(3) Experimental design/layout.

1.4.2 The importance of the experimental site - Site factors include aspect, orientation, soil type, soil depth and level of management. All of these will effect the biological mechanisms implicated in yield advantages and so affect the results within the site and the reproduceability of the results.

Aspect or orientation, whether a site is north facing, south facing, etc., will affect systems with advantages dependent on asymmetric resource factors such as wind and light. A crop combination designed to make the best use of direct radiation will perform best if it is south facing. A system designed to reduce insect pest incidence by reducing olfactory locational cues will be affected by orientation relative to prevailing winds.

The inclination or slope of a site may affect the efficacy of an intercrop chosen to reduce erosion of the soil. Drainage and insolation will also be affected.

The soil type will affect nutrient and water availability and soil pests. This will affect the results of an experiment, especially legume and non legume mixtures.

The depth of soil will influence the efficacy of a system designed to make use of mixtures with different vertical distributions of roots.

The level of site management is especially important when a system is to be applied in the developing world where the use of pesticides, fertiliser, irrigation and drainage may be difficult, if not impossible.

Fertilisers may mask the effects of legume and non legume mixtures. It is only through the choice of an appropriate, typical site that factors can be dealth with.

The second set of variables pertain to the demands of the grower in terms of yields. There are six possible types of demands made by a grower or an intercropping system.

1.4.3 Measures of yield advantage - The efficacy of various measures of yield advantage has now been assessed in reviews by Kass (1978), Willey (1979) and Mead and Riley (1981). The type of measure selected by investigators has depended upon the types of crop grown, the experimental design and the demands of the grower or experimental aims. There are six possible yield reactions that may be considered desirable within an intercropping system:

(1) The mixture yield must exceed that of the most productive sole crop. If the components of the mixture have equal economic value or form part of a requirement for a homogenous product such as energy, total dry matter, and/or animal/human food, then this demand must be satisfied.

(2) The combined intercrop yield must exceed the combined sole crop yield. This is the commonest requirement in many situations and is usually assessed by using the land equivalents ratio outlined in a later section. It is important to note that a compensation reaction is permissible in this situation. That is where one component overyields to compensate for underyielding by another component.

(3) The system must be more stable. Certain catastrophes that occur within cropping systems are species specific, such as outbreaks of pests and diseases. Mixtures in situations where these problems are widespread, such as in the tropics, provide a form of insurance to growers. Little research has been done on this aspect of mixed cropping, and only qualitative statements have been made.

(4) Nurse cropping: This is where a crop is grown solely for the purpose of increasing the yield of an associated crop. The crop is of little economic value. Examples of this are the leguminous shade trees grown in association with tea and cocoa.

(5) Obtaining some yield of another crop: Intercropping in rubber plantations in Sri Lanka will only be practised if it does not affect the yield of the main crop. Analysis of this cropping system is relatively straightforward.

(6) Synergy: A grower may feel that the added complexity encountered in mixed cropping can only be tolerated if both or all the components outyield monocultural controls.

Most of the research on the analysis of yield advantage in intercropping has been concentrated on situations in which the combined intercrop yield must exceed the combined sole crop yield.

Indices of yield advantage have evolved from two separate experimental designs; additive and replacement series. Additive designs are those in which one crop is set out at optimum density with another crop added to the physical spaces left by the first crop. Early experimenters (Crowther, 1948; Anthony and Willimot, 1957; Grimes, 1963) used this method. In some cases this experiment is appropriate, for instance in existing tree crop systems where it is difficult to manipulate the density and spatial arrangement of existing plantations. In mixed cropping systems containing annuals, it is often inadequate as the optimum overall density for the intercropping system is rarely similar to those of the sole crops or an addition of the two, (Willey, 1979). In additive designs the effects of density are confounded with changes in spatial arrangement and/or overall density. Replacement series designs are based on the competition studies of De Wit (1960) and are an attempt to study competition in a situation where the overall density of both sole crops and intercrops are constant. De Wit used designs with mixtures of two species. The layout of the experiments could be viewed as a monoculture of plants with various individuals replaced by individuals of another species. By replacing more individuals, a continuum of proportions could be generated, viz:

100% species 'A'	75%	50%	25%	0%
0% species 'B'	25%	50%	75%	100%

Figure 6 illustrates the difference between additive and replacement design.

Figure 6 : Additive and replacement experiments, to assess the performance of mixtures compared to monocultures of their components.

(a) The additive experiment (compounding density change and specific change).

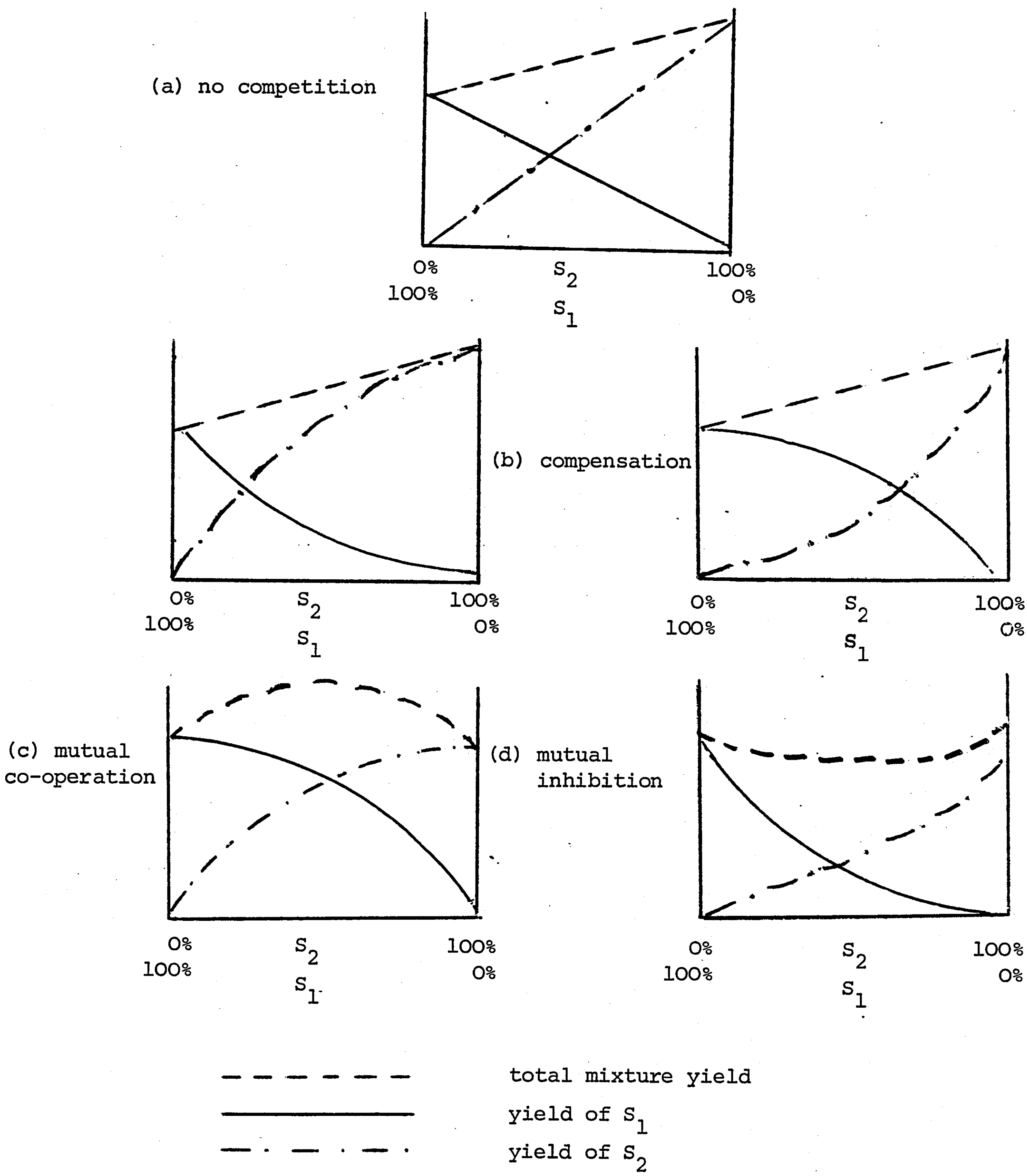
X X X X	O O O O	versus	X O X O X O X O
Z plants of X	Y plants of O		Z + Y plants

(b) The replacement experiment (overall density constant)

X X X X	O O O O	versus	X O O X
Z plants of X	Y plants of O		$\frac{Z}{2} + \frac{Y}{2}$ plants

De Wit used the outcomes of a variety of experiments on mixtures of annuals to generate a mathematical and graphical formalisation of the concept of competition. Two aspects of his work have been used by researchers looking at intercropping systems; mixture performance diagrams and competition functions. Figure 7 illustrates the range of outcomes of competition in binary mixtures as a series of mixture performance diagrams. These diagrams are analogous to those used by physical chemists in studies of the partial vapour pressures of mixtures of liquids at various molar proportions.

<u>Figure 7</u> : Possible results of replacement series experiments where crops are mixed in different proportions at the same overall density.



<u>Competition functions</u>: Four separate functions have been used by workers in intercropping and in competition studies in order to describe the outcome of interspecific interference and the relative contribution of the components to the overall yield. They are:

(a)	The relative yield total, RYT	(De Wit and Van den Bergh, 1965)
(b)	Relative crowding coefficient	(De Wit, 1960)
(c)	Aggressivity	(McGilchrist, 1965)
(d)	Competition index	(Donald, 1963).

The symbols used in these functions have varied a good deal; those used here are:

Yaa = Pure stand yield of species 'a'
Ybb = " " " " " 'b'
Yab = Mixture " " " 'a' in association with 'b'
Yba = " " " " 'b' " " " 'a'
Zab = Sown proportion of species 'a' in mixture with 'b'
Zba = " " " " 'b' " " " 'a'

(a) The relative yield total:

$$RYT = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

This is now more commonly known as the land equivalent ratio and can be defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping.

Advantages of this index are that different crops can be put on a directly comparable basis; it is not confined to replacement series design; it gives a direct measure of yield advantage (a value of 1.2 would indicate a 20% advantage); it illustrates the relative yields of each of the components, and more than two crops can be assessed.

Criticisms of the LER concept include: the sole crop area alternative set by the LER model is based upon harvested yield proportions - this does not indicate to a farmer what the sown alternative is. The highest LER value obtained may not give the appropriate proportions to a farmer. These criticisms, raised by Mead and Willey (1980) refer more to the application of the index rather than any inherent problems. Willey (1979) has extended the LER concept by using the values of combined intercrop yields to achieve an index of monetary advantage.

(b) Relative crowding coefficient:

RCC of species 'a' relative to species 'b'

$$Kab = \frac{Yab \times Zba}{(Yaa - Yab) \times Zab}$$

This measure assumes that mixture treatments form a replacement series. To determine if there has been a yield advantage, the product of the RCCs for both crops is determined, and if greater than one, a yield advantage has occurred. However, the amount that a combined RCC value deviates from unity is not a simple reflection of the magnitude of yield advantage, and it is for this reason that the index has fallen from use.

(c) Aggressivity:

$$A_{ab} = \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times Zba}$$

This measure also assumes a replacement series. An aggressivity value of zero indicates that the components are equally competitive. The bigger the value, the bigger the difference between actual and expected yields.

(d) Competition index:

The basic process is the calculation of 'equivalence factors', one for each species. For species 'a' the equivalence factor is the number of plants of species 'a' which is equally competitive to one plant of species 'b'. The competition index is the product of the two equivalence factors. The problem with this index is that sole crops have to be planted at a wide range of densities so that equivalent plant numbers can be estimated. This estimation is not a very accurate procedure, (Willey, 1979).

1.5 The Biological Basis of Yield Advantage in Intercropping

1.5.1 Introduction - Most of the research papers on intercropping simply report the layout of the experiment and the magnitude of any yield advantage. Few papers attempt to elucidate any of the mechanisms behind a yield advantage. Of those that do, the majority offer observations rather than incorporate methods for the detection of the mechanism into the experimental design. A yield advantage in the context of this section is a system in which the LER value exceeds unity.

1.5.2 Classification of mechanisms put forward in the literature - Biological factors thought to be implicated in the presence of yield advantages can be grouped under three headings; they are:-

(a) synthesis
(b) modulation
(c) partitioning.

(a) Synthesis

Synthesis can be defined as the presence of a chemical change in a crop's environment brought about by the presence of an intercrop. Examples of this are negative allelopathy, nitrogen fixation and the production of 2^{o} plant substances which bring about a favourable change in the incidence of pests, diseases or weeds.

(b) Modulation

Defined as in favourable physical change brought about by an intercrop. This can occur in the form of a change in aerial microclimate or a change in physical properties of the soil. A plant can act as a physical barrier to the movement of pests/diseases or a barrier to detection of the crop by pests. A crop can act as a physical support to an intercrop. The term modulation is used because the physical changes brought about vary in a complex manner. The degree of attenuation of light brought about by a shade crop will vary with time in a complicated way due to leaf angle, growth and the quality/ quantity of incident radiation.

(c) Partitioning

This is the 'dividing up' of the environment/resource by species within ecosystems. In natural ecosystems plants occur in specific places at specific times and make specific demands on their environment. It is postulated that by doing this, species reduce 'competitive stress'. For instance, if a resource is available at a certain rate, competition may be less if demands on that resource were made sequentially rather than simultaneously. If a resource was available at a certain spatial density, the competition would be less if demands were spatially separate rather than in the same place. These are explanations of temporal and spatial partitioning respectively. Demands can be expressed in other dimensions besides space and time and a description based on these demands would, to some extent, characterise the niche of a species. It is postulated that through evolutionary time, competition may have led to niche divergence and eventually to speciation.

Examples of partitioning taken from the literature:

(1) Spatial partitioning - Consider two shallow rooted individuals of a species in a deep soil with a uniform distribution of soil resources. There is more likely to be competition between these plants than the situation arising when one of the plants is replaced by a deeper rooting species. One could say there has been spatial partitioning of the soil resources in the latter case. Nelliat et al,(1974) put this forward as a mechanism in their interculture experiment.

(2) Temporal partitioning - Competition can be avoided by plants taking resources at different times. This can occur in relay intercropping where the different growing seasons give rise to resource depletion at different times or could occur within shorter time periods, for instance, plants with crassulacean acid metabolism take in CO_2 at night

unlike other plants which absorb it during the day. This is an example of diurnal partitioning of a resource. Temporal partitioning of resources is thought to be one of the most important factors behind yield advantages. Very substantial yield advantages have been reported when there has been marked differences in the maturity periods of component crops, (see Table 4).

Table 4: Examples of temporal partitioning in intercrops. Crops of different maturity period shown with yield advantages quoted in the literature (taken from Willey, 1979).

Maturity period	Crop	Yield advantage
85 day 150 day	pearl millet sorghum	80%
80-100 day 180 day	various crops pigeon pea	73%
85 day 120 day	maize ground nut	20-60%
85 day 120 day	beans sorghum	55%
85 day 120 day	beans maize	38%
90 day 160 day	maize rice	30-40%

In reality, spatial and temporal partitioning are often difficult to separate.

(3) Light intensity

C4 crops can use light at higher intensities than C3 crops.

Light is partitioned here on the basis of intensity. There is evidence for partitioning of light quality in some algal species.

(4) Insect pollination: Insect pollinators are partitioned by some crops. Crops with flowers that have different corollae tube lengths partition insects with different probosci lengths.

1.5.3 Light

Donald, 1961, emphasised that light differed from other plant growth resources in that it could not be regarded as a reservoir from which demands could be made as required. Light is 'instantaneously available' and has to be instantaneously intercepted if it is to be used for photosynthesis. Theoretically, light use efficiency could be increased in intercropping by partitioning and modulation.

Partitioning:

Light can be partitioned on the basis of time, wavelength intensity and space.

By simultaneously planting two crops of different maturity periods, one may increase leaf area duration. The rapid maturing crops are, in effect, filling 'gaps' at the beginning of growth of the more slowly maturing crop. Relay planting is an example of temporal partitioning of light. Lakhani (1976) found that leaf area duration increases of 27% were associated with yield advantages of 24%. Chowdhury and Hodgson (1982) found increases in leaf area duration positively correlated with increased yields in mixtures of potato cultivars. Examples of temporal partitioning of light in cropping systems include :

(i) The UK practice of undersowing grass within cereals.

(ii) Mixed pasture crops in the UK.

(iii) Groundnuts and cotton intercropped in South West Sudan: These are planted simultaneously but groundnuts harvested long before the cotton. The groundnuts make use of the light between the young cotton plants and have little adverse effect on them, (Anthony and Willimott, 1957).

(iv) Horticulture in the Vale of Evesham, UK: Strawberries or wheat were intercropped with apple trees in their first five years. Young asparagus beds were intercropped with peas, beans or onions until three years had elapsed. 4% of orchards were intercropped, (Fekete, 1958).

(v) Gram and rice in Burma: Hlaing (1968) reports that gram is planted amongst rice at the 'milk' stage, one month before the rice is harvested. At the rice harvest, the gram is six inches tall, but is not damaged because of its hardiness.

It has been found in mixed algal cultures that different species partition themselves along different parts of the spectra within the photosynthetically active part of electromagnetic radiation. Algae found beneath surface algae are more able to use the radiation at the red and blue ends of the spectra. No analogue of this has been recorded in the literature on mixed cropping and McCree (1976) found a remarkable consistency in the response of most crop species to light at different wavelengths. However, most of the common crop plants had ecological origins in open areas or as pioneer species. McCree's findings might have differed if he included shade crops such as cardamon, parsley and some yams which have their origins on the floor of woods or forests.

Partitioning of light along a gradient of intensity can be illustrated by reference to plants with C4 metabolism which can use light of higher intensities than C3. In regions where there is a large amount of high intensity light with frequent cloud cover, a mixture of C3 and C4 crops may be advantageous, (Crookston, 1976; Paner, 1975). The maize bean and squash plantations of the Mayan Indians are an example of a mixture of C4 and C3 crops.

Theoretically, crop canopies with a better vertical distribution of leaves will use high light intensities more efficiently (Kasanaga and Monsi, 1954). Pendleton and Seif (1962) found no effect on yield when they mixed maize genotypes of different height, yet Osiru (1974) found a 9 per cent increase when sorghum genotypes of different heights were mixed. The height of a cropping system will increase light interception only at its edges. This edge effect is most marked in small interculture systems which often appear as tall islands in a sea of relatively flat land. Examples of interculture systems are listed below :

(a) North African data palm systems - In desert oasis Baldy (1963) reports on a system consisting of three layers constituted by date palm (*Pheonix dactylifera*) citrus and vegetables.

(b) Indian coconut systems - Nelliat et al (1974) studied a system of coconut trees interplanted with pineapple, cinnamon and black pepper.

(c) Arecanut gardens of Mysore, India - Cardamom, peppers and plantains are grown between the trees (Aiyer, 1949).

(d) Burmese plantations - Hlaing (1968) reports that coconuts and rubber are interplanted with pineapples or peas and beans.

(e) Zambian forest clearings - Richards (1939) in Zambia noticed that in forest clearings, maize tends to be planted nearer the centre, while pumpkins tend to be grown nearer the periphery under the shade of trees.

(f) UK intensive horticulture in the Vale of Evesham - Fekete (1958) reports that many crops are interplanted within plum orchards; in fact 100% of the redcurrants, 55% strawberries, 45% radishes, 90% gooseberries and 2% of the cabbages and lettuces grown were intercropped in this manner.

(g) Modified Kandyan Forest gardens - Bavappa and Jacob (1982) have been working on interculture systems in Sri Lanka based upon local forest gardens containing up to 17 different species. A schematic diagram of the canopy architecture of one of the interculture systems studied is given in Figure 8.

(h) Mexican and Costa Rican interculture systems - Ewel et al (1982) studied the vertical distribution of leaves in nine tropical interculture systems found throughout Mexico and Costa Rica. Some of the components were: coffee, cocoa, plantain and maize.

Mixed cropping can often improve light interception by increasing leaf area index. This often occurs in interculture systems where the tree crop forms a discontinuous canopy.

It is thought that combining crops of a roughly similar height with different leaf inclinations may improve light use efficiency, i.e. planting erectophile crops with prostrate ones. One unit of LAl of prostrate white clover Trifolium repens absorbed 50 per cent of the incoming light, whereas the same LAl of erect leaved perennial rye grass Lolium perenne absorbed only 26 per cent (Brougham, 1958), Alcock and Morgan (1966).

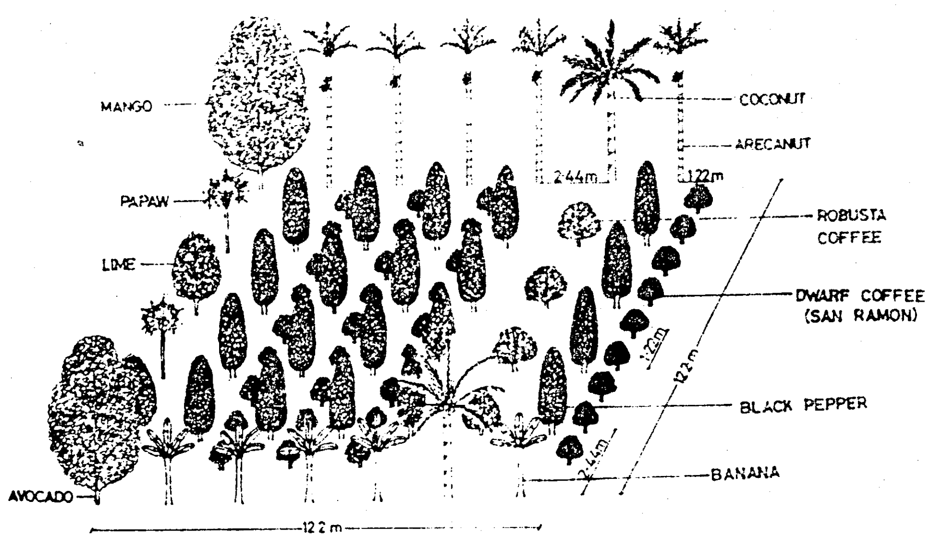


Figure 8 : Schematic diagram of the canopy architecture of a high intensity multi-species crop model.
(From Bavappa and Jacob, 1982.)

Modulation:

Modulation of light occurs when one crop interferes with the physical nature of the light available to an associated intercrop. Light passing through a tree onto an interculture component would be less intense and would also be altered spectrally. There would be proportionally more blue and red light as the leaves act as selective filters, filtering out wavelengths absorbed for photo-synthesis. The variation of intensity of the filtered light over time would be more complex. Fast flickering of light would occur when leaves are blown by the wind.

The question arises: could the light climate altered by a crop be more usable by an associated intercrop than an unmodified light climate?

Some crops such as cocoa and cardamom can suffer photo oxidation of photosynthetic pigments if grown in the open and it is claimed that better growth is obtained if these species are grown in association with shade trees (Purseglove, 1974). Unfortunately, shade trees affect more than just the light climate so little can be said for the advantages of shade per se. Experiments are being carried out on the effect of controlled shade on the growth of cardamom in Sri Lanka, (Bavappa, personal communication). The efficacy of shade trees in tea and cocoa plantations is still controversial, (Hadfield, 1976). No studies have been carried out on light quality within intercropping systems and its effects. The effect of flickering light as opposed to continuous light on plant grown is also controversial. Rabinowitz (1956) illustrated that at interrupt frequencies of one per second or greater, plants may be able to use PAR twice as efficiently as they would with a daily photo period. Recently, Sager and Giger (1981) have re-evaluated this and other work on the effects of intermittent light. Of the 14 experimental studies reviewed, the data of eight supported the hypothesis that the photosynthetic efficiency is no greater for intermittent than for continuous light. One study did not support the hypothesis and five did not provide enough information to make a determination either way. It should be noted that these studies were done on plants grown in conditions in laboratories where the only limiting factor was light. It would be interesting to test these ideas in field conditions under different regimes of soil, water and fertility. The light use efficiency of a C3 crop may be increased if it is cooler. Radiation in crop canopies provides heat as well as light. The light under a tree may be intercepted in a cooler environment. Photosynthesis in the leaves of C3 plants is reduced at higher temperatures due to photorespiration. Could intercropping reduce photorespiration and increase light use efficiency?

1.5.4 Changes in the incidence of pests and diseases brought about by intercropping

This subject has been extensively reviewed by Perrin (1977), Litsinger and Moody (1976), Kass (1978) and Trenbath (1976a). In most cases it appears that intercropping can lead to a decrease in the incidence of pests and diseases but this is not always the case. Kass (1976) outlines situations when an increase has been brought about.

Intercropping may reduce the incidence of insect pests by: reducing the ease with which the pest detects the target crop (olfactory and/or visual cue disturbance); reducing the ease with which the pest moves to within or out of the target crop (influence of spatial heterogeneiety on locomotion), produce a non favourable microclimate for the pest, or a suitable microclimate for predators/ parasites of the pest. Other mechanisms include the intercropping of diversionary hosts or trap crops which attract the pest away from the economic crop and may, by means of 2^o plant substances, kill or suspend development in the pest, (Perrin, 1977).

Mechanisms implicated in disease control include microclimatic change and the physical barrier effects of an adjacent crop (especially with insect vectors). It is now becoming common practice to mix varieties of barley and wheat in order to reduce the incidence of fungal diseases (Burdon and Whitbread, 1979).

1.5.5 Soil Factors

Relatively little work has been carried out on the influence of soil resources and rooting depths on the yield reactions of intercropping systems. This may be due, in part, to the difficulty of separating above and below ground interactions in the field. Willey and Reddy (1981) have developed a field technique for doing this with annual crops. This consisted of a trench lined with a polythene partition. The technique showed that below ground interaction affected the competitive balance between millet and groundnut when intercropped.

Maximum benefits will be observed where the experiment is carried out on soils with low nitrate concentrations. Pot studies in the 1930s established that legumes could excrete nitrate during growth and so benefit an associated non legume (Willey, 1979). The importance and extent of this process on a field scale is far from clear. Singh (1977) obtained greater yields from a non legume (sorghum) when grown with five different legume species than when the non legume was grown as a sole crop. Under rainfed conditions, averaged over two seasons with four spatial arrangements, the sorghum intercrop yield exceeded the sole crop yield with all legumes; increases ranged from 8.4% with soya bean to 34% with cow pea for fodder. Similar experiments in India have been reported (Indian Agricultural Research Institute, 1976) in which the nitrogen contribution of the legumes to maize was estimated to be 40 kg/ha from groundnuts and 25 kg/ha from mung bean.

Martin and Snaydon (1982) found that the yield advantage in a mixture of field beans and barley was due to the use of different N-sources as the relative yield total was decreased with increased applications of N fertilizer.

Willey (1979) observed that pigeon peas appeared to nodulate more readily when intercropped with sorghum. Thompson (1977) noted an apparent increase in nodule weight and number in soya bean when grown with maize.

Residual effects of legume/non legume mixtures have been studied by even fewer workers. Agboola and Fayemi (1972) showed that when maize was intercropped with mung, there was a bigger current transfer of nitrogen than with cow pea; but an examination of the residual effects showed the opposite, with the cow pea having much the greater effect on the yield of the following maize crop.

The increasing cost of artificial fertilizer and the problems associated with its use in the developing world often necessitates the study of long term effects of intercropping on soil fertility. Many workers have shown that there is greater uptake of nutrients in mixtures than monocultures, e.g. for nitrogen (Dalal, 1974 for potassium, and Kassam, 1973; Hall, 1974 for calcium). Increased use of phosphorus and magnesium have also been reported (Kass, 1978; Dalal, 1974). Problems will arise if the rate of export of the nutrients from the system is greater than the rate of import. The amount of crop residues remaining after harvest may affect nutrient availability as the organic matter serves as a substrate for some of the heterotrophic organisms involved in mineralisation/immobilisation, and as the basis of humus which may alter the nutrient retention ability of the soil. Intercropping, if it produces greater biomass, may produce more crop residues. The vital question is: is intercropping removing nutrients that could be used by subsequent crops ? The practice may only be removing nutrients that would be lost due to leaching or erosion. Intercropping, with a deep rooted species, may use nutrients not normally available to shallower rooted crops. There have been few experiments done on the long term effects of intercropping on soil fertility. Brown (1935) however, conducted an experiment with maize in pure stand and interplanted soya beans on a Denham silt loam in Louisiana for five years (1925-1930). Fertilizer (7 lbs/acre of N as $NaNO_3$, 48 lbs/acre of P_2O5 as superphosphate, 30 lbs/acre K as K Cl) was applied each year. In the first two years, maize yields were higher in the pure stand plots, but in the third, fourth and fifth years, maize yields were considerably higher in the plots in which it was intercropped with soya beans. Soil samples taken at the end of the experiment showed total organic matter, percentage of N and soluble K in the mixture greater than in those planted with maize alone. There was no difference in total $P_2 O_5$ or pH. Cotton planted on the plots in the following year, although heavily attacked by boll weevils, was taller and yielded twice as much following the maize soya bean mixture as it did following pure stand maize. There were four replicates in this experiment.

Gautam et al.(1964) ran an experiment for two years in a sandy loam, pH 8.2, medium in N and available P, at the Indian Agricultural Research Institute near New Delhi, in which maize was grown as a pure stand and intercropped with various legumes. The plots were then used to grow wheat. Wheat yields following maize/mung beans and maize sannhemp were significantly higher than following the maize above. From the sparse evidence available, it appears that intercropping does not have a long term deleterious effect on soil fertility.

Allelopathy: Allelopathy is an example of synthesis and can be defined as "any direct or indirect harmful effect that one plant has on another through the production of chemical components that escape into the environment", (Rice, 1974). The wide range of phytotoxins present in plants shows that toxins could possibly be released from many species. Indeed, root leachates from eight commonly associated pasture species chosen without regard to any prior evidence of allelopathic action all caused significant inhibition of growth when applied to plants of the same eight species, (Newman and Rovira, 1975). Some of the species reported to have 'active root' leachates taken from Trenbath, (1976) are : *Juglans nigra*, *Cucumis sativus*, *Grevillea robusta*, *Prunus persica*.

Allelochemicals may be leached from leaves by rain, collected in fogdrip or volatilize. Trenbath (1976) found that the frass of a phytophagous insect (a chrysomelid) feeding on leaves of *Eucalyptus globulus* reduced the germination rate of mustard seeds (*Brassica sp*) to less than one tenth of that in water controls, and was, weight for weight, 13 times more powerful as an inhibitor of germination than the most powerful of 8 preparations involving the original leaves.

The presence of phytotoxins in dead and decaying plant parts may be important in interculture or relay planting and in direct drilling methods.

The controversy around whether allelopathy exists or not, appears to centre around the following problems :-

Replication of results. Many of the experiments showed allelopathic effects but when repeated by other workers they failed to show the effects stated. This could be due to soil differences or intra-specific variation.

Means of extraction. An alcohol extration of macerated plant tissue may extract plant toxins but such a release would not occur in nature. However, the chemical composition of rain/soil water is complex in terms of salt concentration and pH; both these factors will affect the composition of the elluent. Distilled water may be just as artificial as alcohol.

Active concentration: The problem of the means of extraction leads to another problem, that of the appropriate concentration of toxin that would be leached under natural conditions. Workers have been criticized for using too high concentrations.

Live or dead parts? Should workers only consider leaching from live parts? Senescence and the 'sloughing off' of dead tissues is part of plant growth.

Functional allelopathy. If a plant gives out a substance that is used by a soil organism which later excretes a metabolic waste product toxic to plants, can this be described as allelopathy? This has been termed functional allelopathy. In order to test whether allelopathic phenomena were true or functional, workers have sterilized soils. This, however, can profoundly affect the physical/chemical properties of that soil.

The controversy will continue until workers can trace toxins from one plant to another in natural conditions, and show that the presence of the toxin in the target plant caused death or decreased fitness. Allelopathy may be an important factor in intercropping if it suppresses weeds. Crop A grown in monoculture may succumb to weed growth, whereas if crop B is interplanted, allelopathic inhibition of weeds associated with it may give overyielding in A. Negative allelopathy could occur, e.g. through the release of growth stimulating hormones, (Tukey, 1970).

1.5.6 Physical support and protection: Erect growing species may provide support for intercropped climbing species (Aiyer, 1949); the greater vertical separation of the leaves probably improves the photosynthetic effectiveness of the leaf area of the climbers, (Trenbath and Angus, 1975).

Non lodging cereals usually hold up lodging susceptible types if they are intercropped, (Trenbath, 1974). The windbreak effect of crops has been used in barley (Clay and Allard, 1969), citrus and apricots (Trenbath, 1976).

Some of the advantages of using trees as intercrop components may be:-

(1) High LER values due to poor use of resources by tree monocultures;

(2) Deep rooting trees may improve movement of nutrients and help prevent erosion;

(3) Trees may modify microclimate in a favourable way;

(4) Trees may supply non food products, such as timber, firewood, etc.

(5) Tree cropping systems may facilitate integrated land use.

THE DEVELOPMENT OF AN EXPERIMENTAL INTERCULTURE SYSTEM

Chapter 2

INTRODUCTION

It was noted on the literature review that the practice of interculture is, at present, relatively obscure within the UK. No working interculture systems were located within the environs of Milton Keynes.

In order to do experiments and yield determinations, an existing monoculture of a tree crop had to be located into which subsidiary crops could be planted. The tree crop should ideally form a discontinuous canopy as in an orchard or deciduous woodland.

A suitable orchard was found at Middle Claydon in Buckinghamshire.

2.1 Site Description and Selection of Overstorey Crop

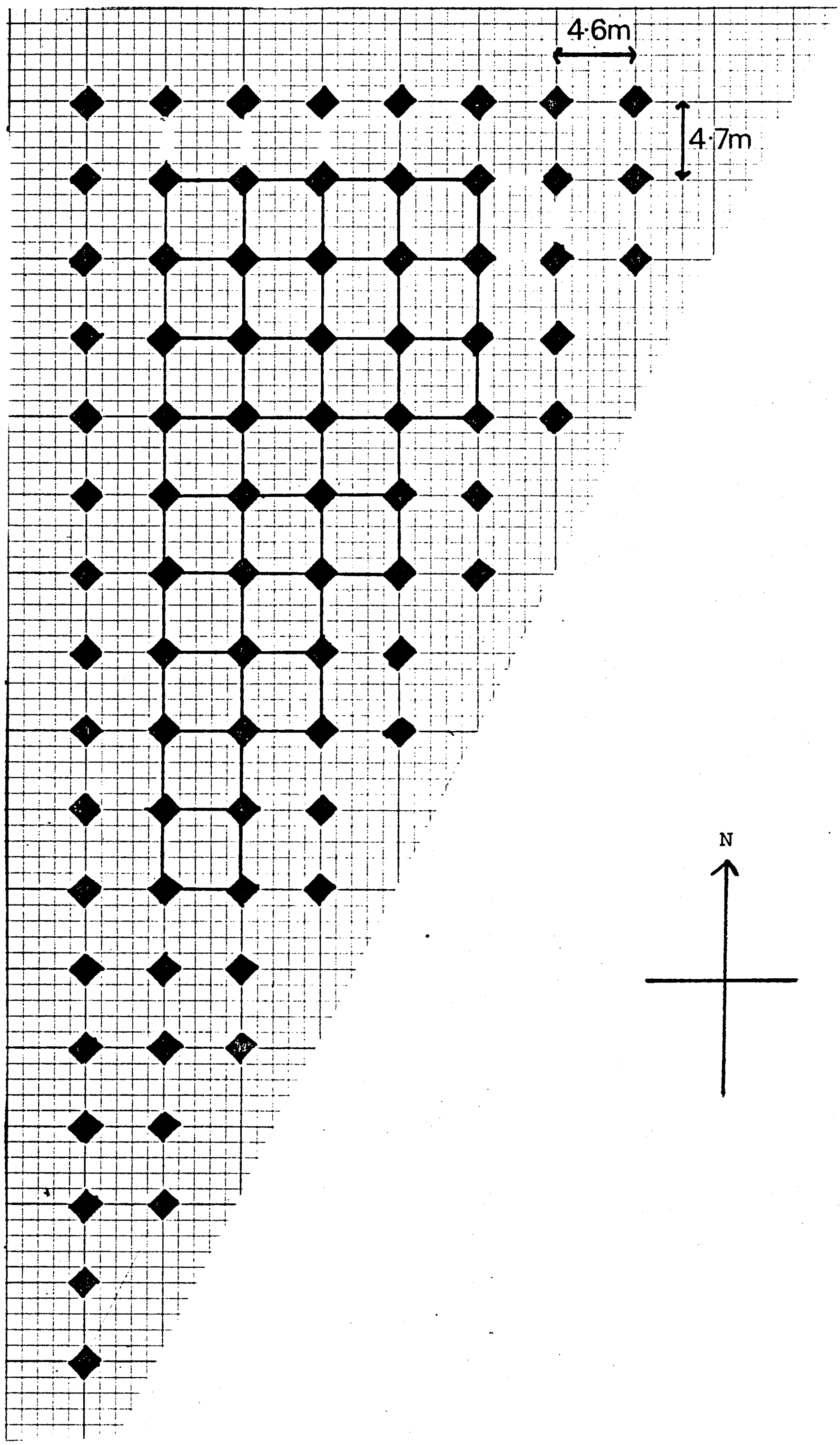
The site was originally a commercial fruit farm occupying an area of about 22 Ha. The farm contained trees of dessert apple and pear. In 1979 the farm had ceased trading as a viable enterprise due to intense competition from the import of French apples. 20 Ha were grubbed up and put down to winter wheat. The remaining 2 Ha contained an orchard of Bramley mixed with Grenadier apples and an orchard of Conference pear.

The pear orchard was selected for study as this was more uniform in terms of tree size and had a more open canopy. The pear orchard was planted on a south facing slope bordered by a screen of *Populus robusta*. The soil is a sandy loam of pH6. The pear plot occupied an area of 0.14 Ha and contained 80 trees. Figure 1 shows the layout of the orchard and how the system was divided into 24 representative plots. Each plot has a tree at each corner surrounded by four trees. A control area of 426 m^2 was located to the north of the pear orchard away from the influence of trees.

The management of the trees, their arrangement and aspect is representative of most UK pear orchards. Conference pear was not selected as the ideal interculture component, and the spatial arrangement of the trees may be far from the ideal for interculture.

Figure 1:

Arrangement of conference pear orchard used in the study, showing spacing and positions of the 24 experimental plots.



2.2 Selection of the understorey crop

Three approaches were used in order to select a suitable understorey crop. They were:-

(1) a literature search on orchard practice;
(2) a literature search on ecological associations containing pear;
(3) a phytometer experiment

A suitable understorey crop would ideally yield more in the orchard environment than as monoculture, and would give rise to increased yields from the fruit trees.

2.2.1 Literature search on orchard practice - Modern orchard practice is geared towards the production of high quality fruits. The number of varieties grown has decreased. Economically, quality can be more important than quantity. The emphasis on quality has led to an intensive management system with a large chemical input in the form of herbicides, insecticides, fungicides, and fertiliser. ADAS now recommends the complete removal of grass cover within orchards.

Nothing is mentioned in modern literature on the growing of subsidiary crops. Fekete (1958) in a survey of horticulture in the Evesham area reported that many crops were interplanted in orchards. These included redcurrants, strawberries, radishes, gooseberries, cabbages and lettuces, planted in plum orchards. This was the only reference on orchard intercropping found. The most useful approach was conversations and meetings with long-standing ADAS officers who specialised in advising fruit growers. Conclusions from talking to these people are as follows:-

(1) There are two types of orchard intercrop system based upon the age of the trees. A catch cropping system where wheat or strawberries are grown during the immature phase of apple, pear or plum trees, and an interculture system where spray/management compatible crops such as fruit bushes are grown in mature orchards.

(2) Almost all vegetables have been intercropped in orchards during the past, but only on a very small scale on smallholdings.

(3) Plum, cherry, apple and pear have been intercropped.

(4) The commonest intercrops in order of importance are:-

(i) blackcurrant
(ii) gooseberry
(iii) redcurrant
(iv) strawberries
(v) vegetables, especially radish, lettuce and cabbage
(vi) rhubarb, blackberries, raspberry
(vii) flowers, especially bulbs such as daffodils
(viii) cereals.

(5) Intercropping is a rare practice in UK orchards. Wisbech in Cambridgeshire is the only place where intercropping with fruit bushes still occurs. This may decline due to decreases in the demand for canned fruit.

(6) There may be a revival of orchard intercropping on small-scale 'pick-your-own' enterprises.

The most suitable understorey crops on the basis of this work appeared to be the blackcurrant, gooseberry, redcurrant or strawberries. Unfortunately, the establishment time for these crops precluded their use in this study.

2.2.2. Literature search on ecological associations - One of the most important techniques in phytosociology, the quantitative analysis of plant communities, is association analysis. Plant communities can be characterised by the likelihood of finding plants of a given species together within an area. Statements such as 'In community X, species Y will nearly always be found growing next to species Z' are based upon this approach. If two species are found in association, this could mean that they had similar environmental requirements or that they were involved in a parasitic, symbiotic or commensalistic relationship.

Hypothetically, if the wild type or ancestors of fruit trees were found in the ecological literature to be associated with the wild types or ancestors of other crops, then this association may be fruitful as an intercropping system. Initial work on the literature to uncover information on these associations was time-consuming as most studies were site specific and no reviews or catalogues of association were found. This approach was abandoned. I have observed that, in many areas where crab apple grows, bramble or wild raspberry grows as an understorey. This is interesting as both raspberry and blackberry have been intercropped with apple.

2.2.3 A phytometer experiment - Eventually it became apparent that management rather than ecological constraints would be more important within a three year study. Cereals and fruit bushes as understorey crops would not be suitable. This left annual vegetables. The most important limiting environmental factors within an interculture system, in terms of the ease in which they can be artificially enhanced, are physical space and the amount of photosynthetically active radiation (PAR). Pruning may increase the amount of PAR but carried out too far could affect fruit yield. Generally, the aerial environment is harder to manipulate than the soil environment. Limitations on soil depth due to tree roots necessitated the use of relatively shallow rooted vegetables. An experiment was designed using a representative range of vegetables grown in pots containing adequate nutrients and water, placed at different positions under the pear canopy and in a control area. Any changes in crop response relative to the controls could be due to variations in aerial environment brought about by the presence of the pear canopy.

These potted crops could be termed phytometers. A phytometer is a plant or population of plants used to detect the importance of various environmental factors in relation to aspects of plant form or process. This can include changes in appearance, composition, process rates, fertility, longevity, etc. The phytometer technique was developed by plant ecologists in the 1920s for determining the environmental limits to the distribution of certain plant species (see Clements, 1924; (a), (b), Harper, 1977).

The aims of the phytometer experiment were to:

(1) Compare the performance of a range of potential understorey crops;

(2) Characterise the type of response that a crop may give to an aerial environment created/modified by a tree crop;

(3) Assess the importance of 'position' within an interculture system;

(4) Assess the efficacy of the technique in providing answers to the above.

Materials and methods

The vegetables chosen were to have the following properties:-

1. Easily grown in pots i.e. small annual plants.
2. Be commercial varieties.
3. Display a wide range of vegetable properties including different economic parts, adaptabilities and taxonomic positions.

Table 1 shows the vegetables chosen and some of their properties.

Table 1 - features of the vegetables selected for experimentation

Species	Variety	Taxonomic family	Economic part	Postulated adaptability
radish	Saxerre	Cruciferae	swollen stem	low
carrot	Early Nantes	Umbelliferae	swollen root	low
pea	Onward	Leguminosae	seed	low
lemon balm	-	Labiatae	leaves	high
celery	Golden self-blanching	Umbelliferae	petiole	low
onion	Rijnsberger heldis	Alliaceae	swollen leaf base	low

480 black polythene horticultural bag pots were filled with equal amounts of John Innes No. 2 compost. When filled, each pot measured 18cm high and was 20cm in diameter. Each of the 6 crops was planted in 80 pots at the recommended depth. 16 pots were placed within each of the 4 experimental plots with another 16 pots placed in the control area away from the influence of trees. Figure 2 shows the layout of a typical experimental plot. Each crop was then planted in one control plot and in four orchard plots. Growth analysis was carried out on each phytometer and the results recorded for each position.

The most important variables measured were those which would act as an index to economic yield, such as radish bulb diameter, dry wt of peas, etc. Other measurements were taken with emphasis on typical plant response to shade. These included the measurement of internode length, and height. Height was measured using a ruler. Internode length and bulb diameter were measured using callipers. Dry weights are determined by drying freshly harvested crops in an oven to constant weight.

Table 2 shows the number of seeds planted, the planting harvest dates, and the dates and details of growth analysis. The plants were thinned to leave a single plant per pot after germination. Each pot received equal amounts of water and remained at field capacity during the duration of the experiment.

Pea and radish appeared to thrive when grown in the pots and were ideal phytometer species. Unfortunately the radish phytometers were lost close to harvest due to attack by rabbits. Carrot and onions were difficult to manage in pots and their growth was less than optimal. Celery and lemon balm were abandoned as repeated attempts to establish the plants in pots failed. The results from the growth analysis on pea, radish, carrot and onion were used in an analysis of variance. The raw data are given in the Appendix Section A.

Figure 2 : The layout of a typical plot showing average dimensions and positions for the 16 phytometers.

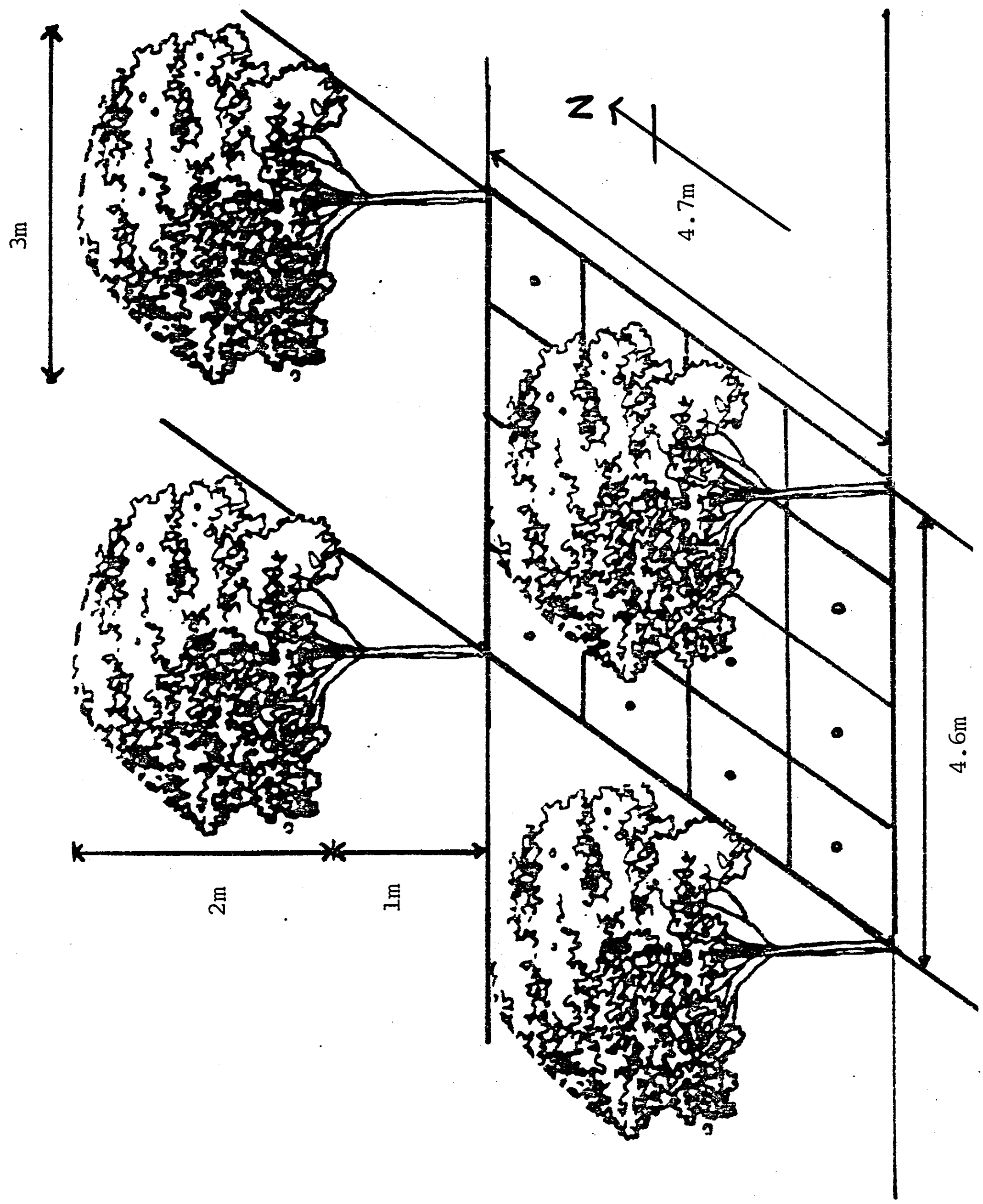


Table 2 : Details of phytometer management and growth analysis

Crop	No. of seeds planted. per pot	Planted	Germinated	Thinned	Harvested	Height recorded	Internode length recorded	Bulb diameter recorded	Dry wt recorded
Pea	4	13.6.80.	23.6.80.	4.7.80.	16.9.80.	25.7.80. 11.8.80. 28.8.80.	28.7.80.	-	16.9.80.
Radish	5	31.7.80.	3.8.80.	10.8.80.	-	-	-	28.8.80.	-
Onion	4 (bulbs)	1.6.80.	-	30.6.80.	2.10.80.	24.7.80. 14.8.80.	-	14.8.80. 2.10.80.	2.10.80.
Carrot	10	3.6.80.	13.6.80.	4.7.80.	10.10.80.	28.8.80.	-	-	10.10.80.

ANALYSIS

14 sets of results were taken during the course of the experiment, one for each growth analysis. Each set of results contained 80 measurements, one for each of the positions within the system. The 16 phytometers grown away from the influence of the trees were taken to be controls. No positional effect should be encountered within the control plot. Each of the 64 phytometers placed in the orchard had two co-ordinates. These were a plot number and a position number, indicating positions within plots. The positional effect within plots was analysed by aggregating the data in an effect known as 'direction' and a separate effect known as 'alphabetical'. Figure 3 shows how this was done. Any effect due to 'direction' may represent asymmetric environmental factors such as prevailing wind, direct solar radiation etc. The alphabetical effect may represent effects of proximity to the trees such as diffuse radiation, spectral changes and temperature etc.

Figure 3:
showing how the positional effect was analysed by aggregation into 'direction' and 'alphabetical' factors. Pots with the same symbol are assumed to encounter similar effects.

Position

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Direction (d)

a	a	b	b
a	a	b	b
c	c	d	d
c	c	d	d

Alphabetical (a)

A	B	B	A
C	D	D	C
C	D	D	C
A	B	B	A

A linear mathematical model was set up combining the various possible sources of variation of each variable for a given species. The total variation T was given as

$$T = D + A + P + DA + DP + AP + (DAP + C)$$

Where T = total variance
D = direction variance
A = alphabetical variance
P = plot variance
DA = direction/alphabetical interaction
DP = direction/plot interaction
AP = alphabetical/plot interaction
DAP + C = residual variation which includes the DAP interaction term if non-significant, pooled with an estimate of variance from the control plot.

An analysis of variance based on this model was carried out which included a test of significance for orchard vs. control pots. Table 3 illustrates the analysis of variance for the effect of position on the height of pea plants grown for a period of 51 days.

The DAP effect was tested for significance and, if found <u>not</u> to be significant was pooled with the control variance as the residual. This pooled residual was then used as the basis for all comparisons.

The complete table of means and results from the analysis of variance is given in Table 3.

Table 3: Results of growth analysis on phytometers placed at different positions relative to the tree crop. The means for the effect of 'direction', 'alphabetical' and plot are presented along with their statistical significance and interaction effects based on an analysis of variance. Statistically significant effects are underlined.

Details of species and growth analysis	Direction means					Alphabet means					Plot means					Interactions				Orchard vs control		
	a	b	c	d	p <	A	B	C	D	p <	1	2	3	4	p <	DA	DP	AP	DAP	ORC	CON	p <
Height of 42 day pea plants (cm)	28	28	26	27	NS	26	27	30	27	NS	26	30	27	27	.05	NS	NS	NS	NS	27	30	.001
Internode length of 45 day pea plants (mm)	39	39	42	40	NS	38	39	42	41	NS	42	43	39	36	.05	NS	NS	NS	NS	40	37	NS
Height of 59 day pea plants (cm)	48	48	51	49	NS	51	47	49	50	NS	48	51	52	45	.001	.001	.001	NS	NS	49	50	NS
Height of 76 day pea plants (cm)	46	46	46	47	NS	46	47	47	47	NS	47	46	49	44	NS	NS	NS	NS	NS	47	51	.01
Dry wt of pods and peas after 95 days (g/10)	52	46	44	48	NS	43	46	49	52	NS	51	49	48	42	NS	NS	.01	NS	NS	47	49	NS
Dry wt of pea plant-pod + peas after 95 days (g/10)	42	45	45	44	NS	47	43	47	44	NS	40	46	45	45	NS	NS	NS	NS	NS	44	52	NS
Height of carrot plants after 28 days (cm)	22	19	22	21	NS	22	20	21	20	NS	19	24	19	22	NS	NS	NS	NS	NS	21	16	.001
Dry wt of carrot tubers after 43 days (g/10)	15	16	15	14	NS	14	15	14	17	NS	15	17	12	15	NS	NS	NS	NS	NS	15	20	NS
Bulb diameter of radish after 28 days (mm)	17	16	16	19	NS	13	15	19	21	.05	15	18	15	19	NS	NS	NS	NS	NS	17	19	NS
Height of 28 day old onion plants (cm)	39	41	44	40	NS	42	41	39	42	NS	40	40	41	44	NS	NS	NS	NS	NS	41	38	NS
Height of onion plants after 50 days (cm)	45	47	48	46	NS	47	47	44	48	NS	46	45	46	49	NS	NS	NS	NS	NS	47	48	NS
Bulb diameter of onion plants after 50 days (mm)	33	34	34	37	NS	35	34	33	36	NS	29	34	37	39	.001	NS	NS	NS	NS	35	32	NS
Dry wt of onion bulbs after 69 days (g/10)	42	48	51	40	NS	34	49	43	55	NS	48	38	45	51	NS	NS	NS	NS	NS	45	60	NS
Bulb diameter of onion plants after 69 days (mm)	42	45	47	43	NS	41	46	43	48	.05	45	42	44	46	NS	NS	NS	NS	NS	44	48	NS

RESULTS AND DISCUSSION

In the analysis of cropping systems there are three distinct levels of analysis required in order to assess the significance of any effect arising out of an experiment. These are statistical, biological and agronomic.

The pea plants, 42 days after planting, were showing statistically significant differences in height between those intercropped in the orchard and the control. There was also a difference between the plot means of plant height but the range in pea height, however, was less than 4 cm. Differences in internode length were detected between plots 45 days after planting. At the 59-day stage, the plot differences were maintained and statistical interactions between direction, alphabetical and direction, plot were significant ($p < 0.01$). This means that the direction effect was more marked in some plots than in others and that the alphabetical effect was also more marked in some directions. After 76 days, these height effects were not significant but a significant difference was detected between the orchard and control mean height of about 4 cm. These effects, however, did not appear to affect the dry weight of the plants and of their economic parts at harvest. There was no significant difference between orchard and control or positions within plots. Minor differences in plant form detected early on in the experiment had no significant effect on final agronomic yield. On the basis of the analysis one may expect shorter plants in the orchard than in the control, but pea appears to be an appropriate intercrop for the pear orchard if soil conditions are suitable. Pea, being a leguminous plant, may also have a beneficial effect on the soil fertility and future yields of pear if intercropped.

The only statistically significant effect detected in the carrot phytometer experiment was between the mean height of the plants grown in the orchard and the control mean. The difference of 5 cm between an orchard mean of 21 cm and a control mean of 16 cm illustrates a typical response to shade. Plants often respond to shade by partitioning a greater proportion of dry matter to leaves, thus increasing light interception. Agronomically, this response could be important if the economic part of the plant was the leaves, such as in parsley. This increased leaf length detected in the orchard carrots did not affect the index of economic yield, tap root dry weight, in any way which was statistically significant.

Radish gave a statistically significant response to the alphabetical effect. Positions A, B, C and D represent a scale of decreasing tree proximity. Bulb diameter means were 13 mm, 15 mm, 19 mm and 21 mm respectively. This again may be a response to shade. On the economic level any radish with a bulb diameter of over 10 mm, if it is not damaged, can be sold.

Onion did not show any statistically significant effects until after a period of 50 days, when a significant plot variation appeared in the bulb diameter. The range of means was 29 mm - 39 mm. The significant differences were not carried through to the final evaluation of bulb diameter after 69 days. An 'alphabetical' effect was detected after this period, but this may not be agronomically significant as the range of means was between 41 mm - 48 mm.

Generally, the results illustrate that the aerial environment created by the tree crop did not have a devastating effect on any of the tested understorey crops. Phytometers place adjacent to the tree trunks in a position where it would be difficult to sow crops due to the presence of large, woody roots did not show symptoms of a chronic shortage of radiation. Results of the direction effect used in the analysis were remarkable in that they did not show a significant result in any of the crops or growth analyses. Light measurements were taken at the phytometer positions in order to gain further understanding of these effects. These are dealt with in chapter three.

COMMENTS ON THE PHYTOMETER TECHNIQUE

Radish appeared to be an ideal phytometer species in that it did not appear to be affected by being grown in pots, and was easily managed. There was no significant difference between orchard and control means for radish bulb diameter, and radish appeared to be typical and, therefore, representative of a range of vegetable species. The short maturation time in radish makes the crop ideal for further experimentation. Phytometers, in the form of potted crops, could be used to provide answers to the following questions often asked during an investigation into the interactions present in mixed cropping systems:

(1) Is there enough light available in system X to support crop growth?

(2) When A was intercropped with B, a deviation from expected yield was encountered; was this due to the aerial or soil environment?

(3) What would be the best spatial arrangement in terms of tree proximity for an understorey crop?

Larger containers or buried polythene sheets may be used in order to improve the design of the technique for specific applications. The use of phytometers in conjunction with standard measuring equipment, such as light meters, could rapidly build up useful information for cropping system design.

CONCLUSIONS

1. Given a suitable soil environment, it appears that it may be possible to intercrop any of the vegetables tested into the pear orchard.

2. The effect of aerial environment with changes in tree proximity was more marked generally than that of direction within the orchard plots.

3. The effects of tree proximity direction and plot should be studied in future experiments.

4. Radish is the most suitable crop for further study, not because it was found to be affected less by the aerial environment of the orchard, but due to the relative ease of handling the crop as an experimental material.

5. Radish was affected by tree proximity but not at an agronomically significant level.

MEASUREMENT OF THE TRANSMISSIVITY OF THE PEAR CANOPY TO PHOTOSYNTHETICALLY ACTIVE RADIATION

Chapter 3

INTRODUCTION

Photosynthetically active radiation (PAR) can be defined as that part of the electromagnetic spectrum containing wavelengths between 400 and 700 nm. PAR is a key environmental factor in any agroecosystem for two reasons: Without it, there would be no plant growth and it can rarely be enhanced by artificial means such as reflective screens or artificial illumination. Knowledge of the way in which the overstorey canopy reduces the amount of radiation available for a potential understorey may be useful in trying to provide answers to the following questions:

1. is there enough PAR available for plant growth at position x and/or time y?

2. was the amount of PAR implicated in any deviations in expected yield?

3. what would be the optimum layout of an interculture system in space and time?

The apparatus described below was designed specifically to provide information on the spatial and temporal variation in the transmissivity of the pear canopy to PAR.

3.2. DESIGN OF A SUITABLE MONITORING SYSTEM

3.2.1 Specification for the PAR sensors

Ideally, any sensor used should have a spectral response similar to most crop species. The sensors should be inexpensive, as many will be needed to cope with the complexity of the light climate found within the discontinuous pear canopy. This complexity arises from the effects of movement of leaves in windy conditions, the growth of the canopy, the movement of sun and clouds, and the variation of tree canopy density and size within the plantation. The high cost of many commercially available devices and the often inadequate information on their angular response necessitated the use of home built sensors. These were constructed from inexpensive readily available components.

The most popular transducers used for sensing PAR are photovoltaic or 'barrier layer' cells. They can be used without a power supply for instantaneous measurements and only cost 1 - 10% of the price of manufactured radiometric instruments. Two types are available: selenium or silicon. Silicon cells are cheaper and give a greater current output but unfortunately require expensive interference filters to limit their spectral response to 400-700 nm. Without these, silicon cells respond to near infra red radiation. Selenium cells respond only to light within the required range, and can be filtered easily with inexpensive optical filters to ensure a relatively flat response over the greater part of this. The major problem with selenium cells is that they may fail suddenly or alter their output characteristics with age, so require frequent checking. Selenium cells can be obtained ready 'potted' in a clear resin. This prevents the problems of damp outlined by Anderson (1964).

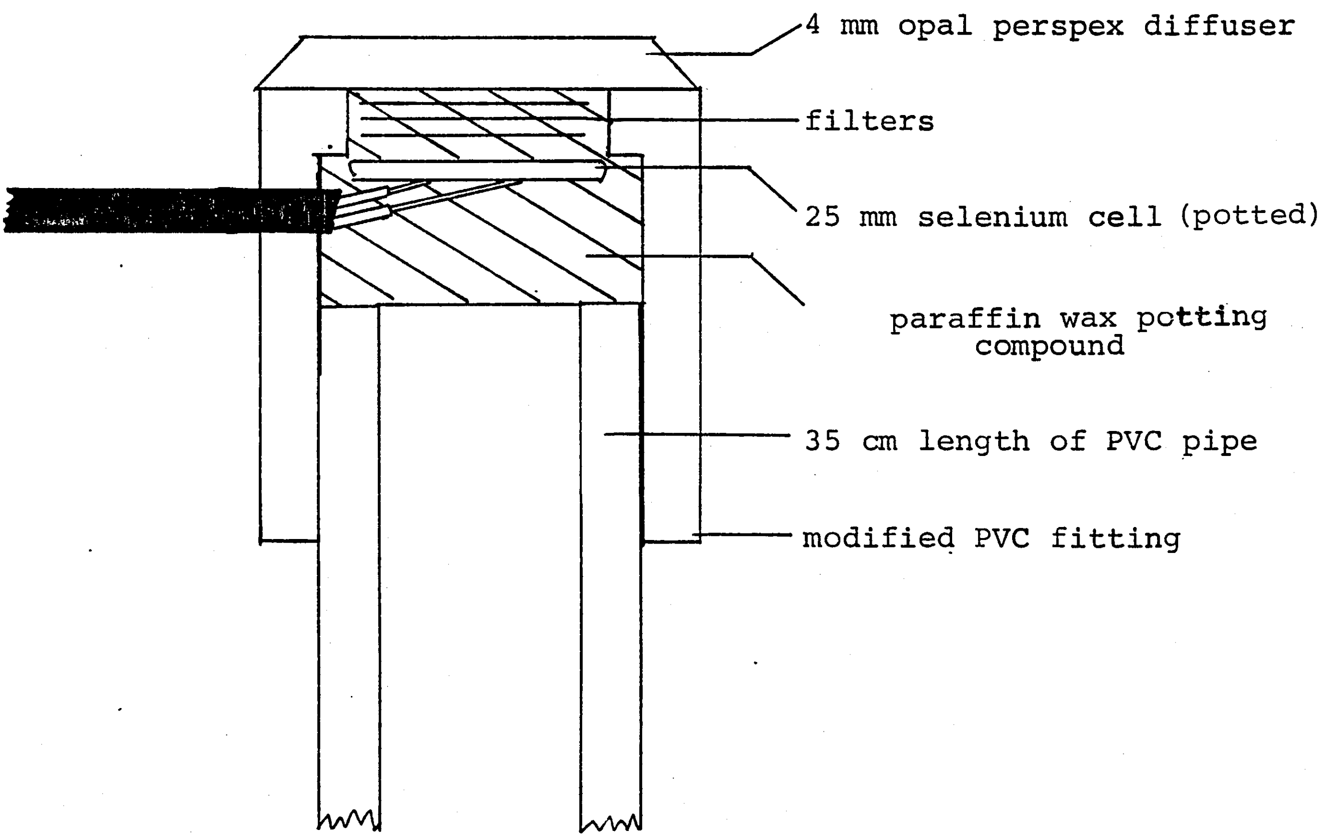
Selenium cells have been used successfully by workers involved in optimising the productivity of orchards. This work is reviewed by Jackson (1980). Selenium cells were used in the construction of the sensor. The angular response of any sensor should conform to the cosine law. This is used as a standard as it can easily be defined in mathematical terms and related to physical models. Plant leaves do not conform to a cosine response; plant leaves and chloroplasts can move and track the sun. However, the actual angular response of plants to light is almost impossible to characterise. The addition of an opal perspex diffuser above the selenium cell improves the cosine response. A sensor was constructed along lines set out in Jackson and Slater (1967).

3.2.2 Construction of the sensor

Figure 1 shows the arrangement of the components in the sensor. The sensor consisted of a 'potted' 25 mm type B photovoltaic cell with attached leads (Megatron Ltd., London), housed in a modified ¾" PVC straight coupling (Polyorc Ltd., Leeds). Plumbing fittings have the advantage of being inexpensive and can be placed on other pipes/fittings to give a range of sensor heights and angles. Two sensor housings were made from each plastic fitting by parting the

Figure 1:

- Vertical section through PAR sensor, showing arrangement of components.



fitting on a centre lathe. An opal perspex diffusing disc was cemented into place on the flanged end of the housing. Three cinemoid filters, steel blue, salmon pink and neutral density (Rank Strand Ltd., London) were placed upon the perspex disc in the inverted fitting. The neutral density filter was used to prevent solarisation. The photo cell was then placed on top of the filters and soldered to a screened twin cable entering the housing through a hole drilled above the diffuser. The whole assembly was then waterproofed by pouring in molten paraffin wax (m.p. 45°C), leaving enough room for the insertion of a length of ¾" plastic pipe. This pipe could then be placed in the soil beneath the canopy to hold the sensor at a predetermined height. The screened twin cable terminated in a stereo jack plug. A ¼ Watt 200 Ohms load resistor was soldered across the terminals of the jack plug, in order to give a linear current illuminance relationship. 52 sensors were constructed in this way, in about 8 hours, and each sensor cost about £4 for materials.

3.2.3. Layout of sensors

The minimum area of orchard floor that can be considered representative is the 'repeating unit' of the planting arrangement. This is either a rectangle with a tree at each corner, or an equal area with a tree at the centre. The ideal area will consist of a number of such units sufficient to take into account variations in tree size. Three adjacent units were selected from the pear orchard for study. Having adjacent units meant that some measurements could be checked, as certain positions should have similar readings if placed around the same tree. It also reduced wiring problems. Fig. 2 shows the arrangement of plots and relative tree sizes. Each plot was divided into 16 sub-units as in the phytometer experiment. Sensors were placed on lengths of pipe, sunk into the ground at the centre of each of the 16 sub-units. The 48 understorey sensors were levelled, using a circular spirit level, and adjusted to a height of 30cm which corresponded in the 'growth plane' for the phytometer experiment. Four sensors were placed above the canopy to measure light entering the interculture system. The four sensors were placed next to each other in order to check for any drift in sensor response during sampling. A Kipp and Zonen solarimeter was placed next to the four overstorey sensors to act as a calibration source. This type of solarimeter is a standard meteorological instrument of known performance and accuracy (see Robinson 1966). The amount of PAR could be stated in energy terms as it is known that about half of the short wave radiation monitored by the solarimeter is present as PAR, (Smart, 1974).

3.2.4. Recording the output of the sensors

Daily totals of PAR falling upon each sensor were considered to be the optimum measurement as the information is ultimately to be used in the analysis of crop growth. Periods of less than a day are difficult to interpret, due to changes in solar azimuth. Weekly totals are often difficult to take, and if equipment is faulty, can cost much effort and time. Unfortunately commercial digital integrators are very expensive (around £300-600 each) and often require a mains supply. Each sensor would require its own integrator.

Figure 2:

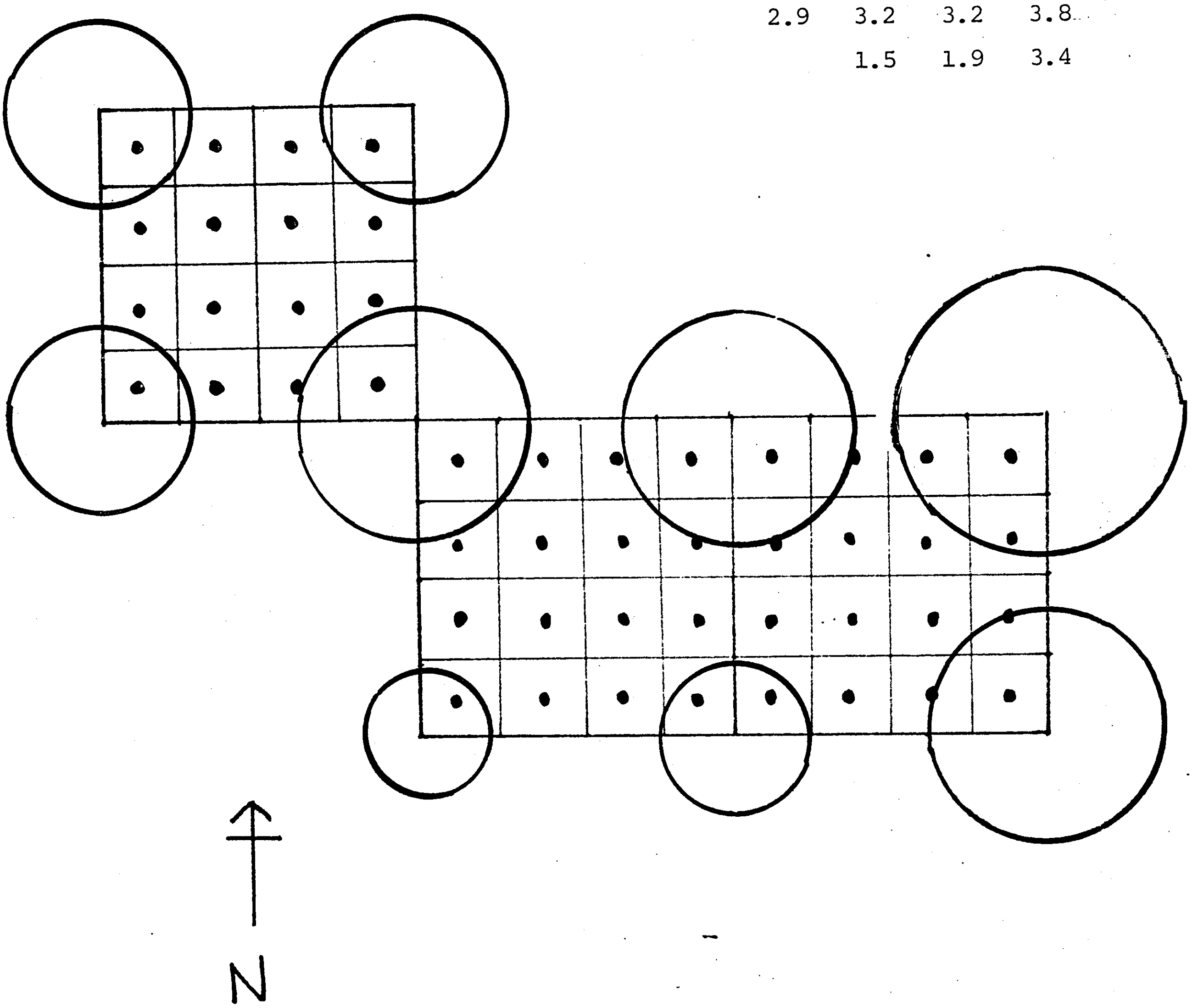
Scale diagram of plots and sensor positions within the orchard with details of tree identification numbers and canopy diameters.

Tree identification numbers

1	2		
6	7	8	9
	12	13	14

Canopy diameters (m)

2.8	2.9		
2.9	3.2	3.2	3.8
	1.5	1.9	3.4



Chemical integrators in the form of mercury coulometers or electrolysis cells consisting of beakers with large electrodes are time consuming and can be inaccurate. The most suitable means of recording data appeared to be using a data logger. A microdata 1600 logger was selected as this had a large number of channels. could be battery powered and was quite flexible in terms of type of analogue input and scan interval. The large magnetic cartridge used in the machine enabled a large quantity of data (around 1 megabyte) to be stored. A 5 minute scan interval was selected based on the information given by Anderson (1971) who used stochastic information theory to optimise sampling rates in assessing light climate. Information recorded on the magnetic cartridge was analysed by replaying the tape via a Perex Sintrom unit to a PDP 11 computer. Several programs were written to error check and format the data. The logger was set up so that each record (5 minute scan) contained a day number, the time of day in hours and minutes, the output of the Kipp, and the output of each of the 52 selenium sensors. Each value is identified by a channel number recorded on the cartridge.

Each sensor was calibrated in the field in order to account for between cell sensitivity. This was done by placing all 52 sensors together under a diffuse sky, setting a scan interval of 10 seconds and recording for a period long enough to include a range of PAR intensities. Correction coefficients were generated using the mean value for each sensor.

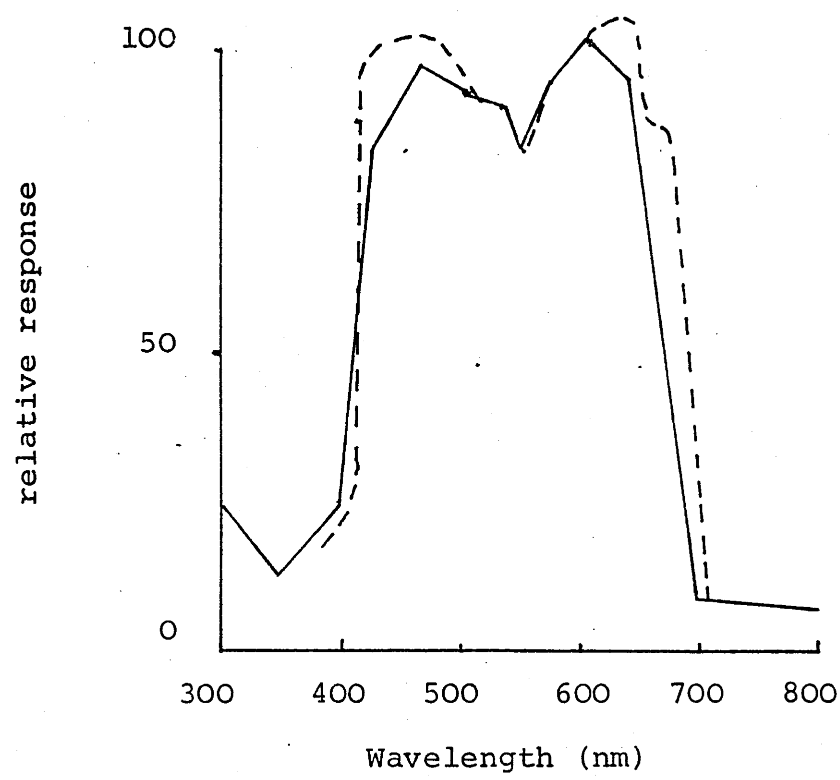
Recording began on 22.10.80.

3.3 THE PERFORMANCE OF THE SYSTEM

3.3.1 Characteristics of the sensor

The spectral response of the sensor was analysed, using a spectrophometer and a voltmeter and assessed in relation to the response for photosynthesis of most crop species McCree (1976). The results of this analysis are shown in Fig. 3. No significant difference was found between the spectral response of a number of sensors.

Figure 3: Spectral response curve for photosynthesis (----) (after McCree, 1976) and a single photosynthetically active radiation sensor (———).



The relationship between short wave irradiance (as measured by the solarimeter) and current output is shown in Table 1.

The azimuthal response of the sensor was about ±1% error over 360° with the incident light beam at an angle of 30°. The cosine response of the sensors is shown in Table 2. These tests were carried out using the specially designed angular response equipment at the National Institute of Agricultural Engineering, Silsoe.

The total error for the system between sensors as assessed for 1 solar day was ±5%.

3.3.2. Performance of the monitoring system 1980

The system ran successfully for one solar day. No effects of solarisation were detected. Unfortunately on the second day of recording, severe problems of damp occurred within about 30 of the sensors during a heavy dew period. Moisture had entered the cells via the leads into the potting media. The system had to be redesigned and monitoring suspended until 1981.

3.4. Results and analysis of 1980 data

Information on the initial calibration, the results for one solar day, and the end calibration was entered into the computer and analysed. Programs were written to give transmissivity values for each of the 48 understorey positions. Transmissivity values should only change as a result of gross canopy changes such as growth, leaf, petal abscission, and fruit fall/harvest. This means that 1 day sampling is often a fair estimate of transmissivity for several weeks. Fig. 4 shows the transmissivity values for the 48 positions (based on information from one solar day of monitoring) within a scale diagram. Effects of tree size based on canopy diameter can be observed.

The mean values of the three plots are also shown in Fig. 4. The overall transmissivity mean for the 48 positions is 71%. The values of 105% and 103% in Fig. 6 could be due to cloud effects during midday. It should also be noted that the values have error limits of ± 5%. The plot means were (reading from left to right) 71%, 85%, 58%

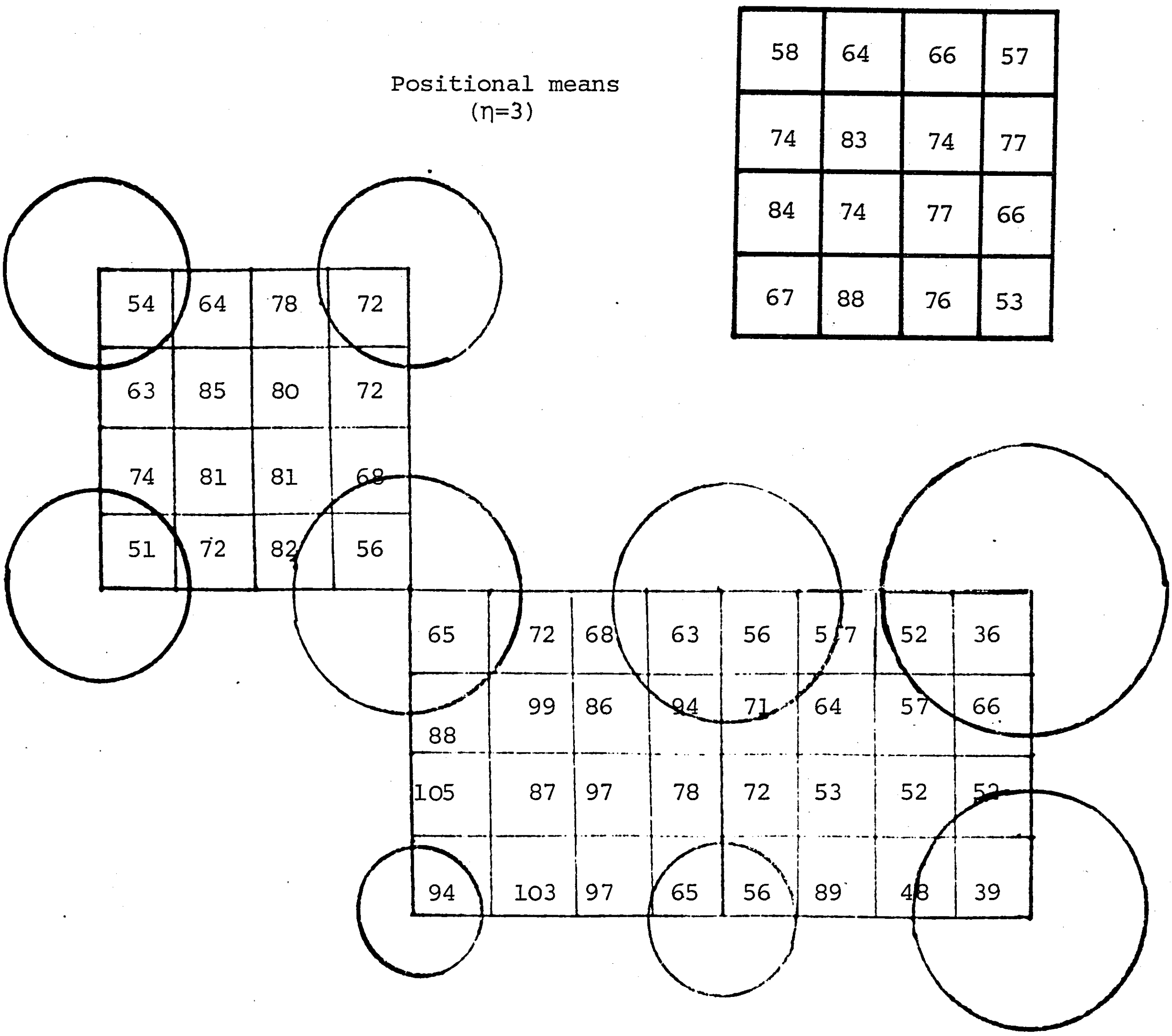
Table 1 - The current output of a sensor in relation to irradiance (at 200 Ω load)

short wave irradiance Wm^{-2}	current output uA
0	0
50	23
275	138
400	180
550	250

Table 2 angular responses of three sensors (unity represents ideal response)

Θ Incidence angle	Cos Θ/relative output A	B	C
0	1.00	1.00	1.00
10	1.00	1.00	1.00
20	1.02	1.03	1.02
30	1.05	1.05	1.05
40	1.07	1.06	1.07
50	1.08	1.08	1.08
60	1.11	1.10	1.10
62	1.12	1.12	1.11
64	1.13	1.13	1.13
68	1.14	1.14	1.14
70	1.16	1.15	1.16
72	1.15	1.16	1.16
74	1.17	1.17	1.17
76	1.20	1.20	1.20
78	1.19	1.19	1.20
80	1.21	1.22	1.21
82	1.11	1.11	1.13
84	1.13	1.13	1.13
86	1.00	1.00	1.00
88	0.50	0.50	0.56
90	0.50	0.50	0.50

<u>Figure 4</u> - Percentage transmissivity of the discontinuous pear canopy to PAR at 48 different positions based upon data for 1 solar day (22.10.80).



3.4.1. Discussion

The operation of the monitoring system and its failure in damp conditions showed that the potted cells and parafin wax sealent are an inadequate combination. A more suitable arrangement may be to use unpotted cells and a different potting compound. The compound could be poured into the mount and the cell suspended until the material sets. Improvements could also be made for work on estimating seasonal changes within canopy transmissivity. Work should be carried out on developing inexpensive integrators to be housed within the sensors. This would remove problems due to wiring and the over-accumulation of data. There may be a more economical way of arranging sensors within a repeating unit.

The overall mean transmissivity value (η=48), of 71% shows that the system is relatively transparent to PAR and the pear trees appear appropriate as an overstorey canopy in a multilayered arrangement. The ideal multilayer arrangement for photosynthesis would be an upper layer which gives a high yield per unit light interception with a lower layer with a high light use efficiency at low light intensities. The range of variation between the plot means (71%, 85%, 58%) was 28%. Analysis of the positional variation of transmissivity showed a range of values between 36%-105%. The alphabetical model used in the phytometer experiment now has support from the PAR work. The alphabetical model rather than the direction model appears most suitable. (See Figure 5).

The differentiation of alphabetical positions B and C however is not supported by the results from the PAR analysis. Three zones would be appropriate.

Figure 5: Means for 'alphabetical' positions used in the anova model for the phytometer experiment.

alphabetical positions

A	B	B	A
C	D	D	C
C	D	D	C
A	B	B	A

positions	mean $\eta = 12$
A	59
B	74
C	75
D	77

3.5 Developments and measurements carried out in 1981

3.5.1. Introduction

The aims of the 1981 seasons work based on the results of 1980 were:

a) to improve the damp resistance of the sensors.

b) to simplify the spatial arrangement of the sensors.

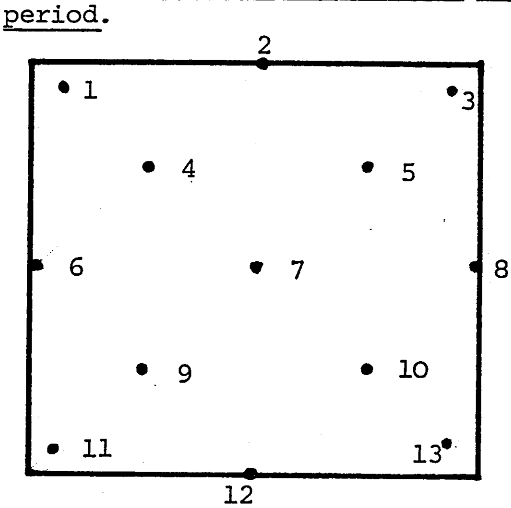
c) to extend the duration of the sampling period in order to assess weekly variation and set up a database useful in optimising the spatial and temporal PAR sampling system.

d) to develop a simplified and less expensive integration system for obtaining daily totals of PAR.

3.5.2. Materials and methods

An improved method of potting was developed using sylgard clear elastomer, obtainable from Farnell Ltd. This involved pouring elastomer into the inverted fitting to a depth of 1mm. This served to seal the glue joint. The filters and unpotted cell were then lowered on to the solidified elastomer, the wires soldered and the level of elastomer topped up in order to completely seal all wires and components. Fig. 6 illustrates the arrangement of sensors within a plot. The number has been reduced from 16 to 13. Only one plot was sampled in 1981. Sampling commenced on 24.7.81. and continued until 24.11.82. An alternative integration system was developed and is described in section 3.7.

Figure 6: Position of sensors within a plot during 1981 sampling period.



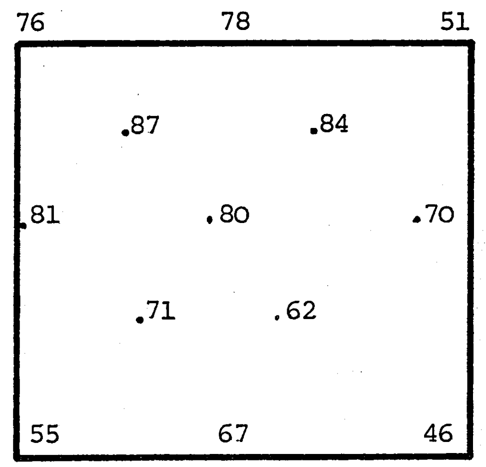
3.5.3. Results and analysis

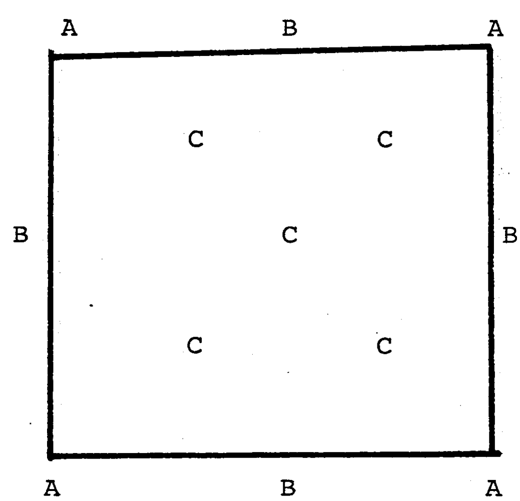
The modified potting method reduced all damp problems effectively. The system ran trouble free for the whole period. All data was successfully filed and error checked in the computer. Unfortunately the operating system on the PDP 11/60 was updated during most of 1981 causing many disruptions and loss of certain system facilities essential for the analysis of the data base. Only the first 5 days of data have been partially analysed and the results are presented here. No work on the optimisation of the sampling pattern has been carried out. Table 3 shows the transmissivity values for the 13 positions over five days and the position means for the five day period. Figure 7 shows the arrangement of the transmissivity positions and their relationship to the three zones.

Table 3 Variation of the transmissivity of the pear canopy in one plot for 13 positions over a period of 5 days with positional means 23.7.81 - 28.7.81.

	Day No.					Mean
Position	1	2	3	4	5	
1	66	73	80	79	81	76
2	72	78	82	78	79	78
3	45	48	60	54	50	51
4	86	88	90	85	85	87
5	78	84	89	85	86	84
6	89	85	72	79	81	81
7	88	85	74	75	77	80
8	78	72	61	66	68	70
9	82	77	62	65	70	71
10	69	63	57	60	59	62
11	60	53	52	53	55	55
12	76	78	59	60	64	67
13	51	43	41	45	48	46
Overall mean						70

Figure 7: Layout of mean transmissivity values for 13 positions based on a sampling period of 5 days and resultant mean values for 3 zones (A, B and C).





A = 57

B = 74

C = 77

3.5.4. Discussion

The information in table 4 indicates that there was little daily variation between the transmissivity values over the 5 days for the 13 points. The information in table 2 indicates that there is a considerable amount of radiation > 70% over most of the area of the plot. Only those sensors directly beneath the canopy (1, 3, 11, 13) are strongly affected, receiving only 57% of the incident radiation. This however is not low enough to preclude crop growth. Crops could be selected to make optimal use of this relatively low PAR level. No clear North South or East West effect is apparent in the data.

3.6 Conclusions

a) The sensors with modified potting performed as expected.

b) The method of data collection and integration proved laborious for obtaining daily totals of PAR transmissivity.

c) No comments can be made on the improvement of the spatial and temporal sampling pattern.

d) The transmissivity data supports the spatial analysis of understorey crop response based on tree proximity rather than aspect. No more than three zones should be required.

e) The pear canopy overall is relatively transparent to PAR (70%) even the densest areas of the canopy adjacent to the tree are not dense enough to preclude crop growth having a transmissivity of around 40-60%.

f) Little change in the transmissivity of the canopy from 24 July to 22 October can be expected, based upon the data from 1980 and 1981.

3.7 The development of an inexpensive integrating par meter

3.7.1. Introduction

The most useful measurement for productivity studies, and estimates of changes in canopy optical density was found to be the daily total of radiation falling on a given point. The major problems with using a data logger based system for obtaining information on seasonal changes are:

1. expense of the system
2. data processing time to derive daily totals
3. problems with rodents chewing the wires
4. power supply problems on field site

Commercial sensors and integrators are very expensive, this means that it is difficult to obtain the replication of readings required to study the light climates of complex biological systems. The financial impact of damage due to rodents or vandalism often precludes the use of these instruments on field sites. The features of the instrument required are:

1. that the integrator, sensor and housing should cost less than £5.00 for materials.
2. that the system can be readily calibrated against existing systems.
3. that the integrators and sensors should require no external power supply and be completely self-contained with no wires.

These requirements meant that conventional electronic integrators were out of the question. Chemical integrators using copper electrodes in silver nitrate electrolyte had been used in the past, but were messy and inaccurate (the quantity of silver deposited on the cathode was measured by weighing the electrode before and after a potential difference was applied via a photocell). Mercury coulometers with a glass housing and vernier scale were difficult to read, and the mercury thread often broke. Fortunately components recently developed by Plessey Limited appeared to solve the problem. These, marketed as E cells, are small, inexpensive, self-contained coulometers that consist of two gold electrodes immersed in silver nitrate solution. When a potential difference is applied, electroplating takes place. When the E cell is taken out of the circuit after plating has taken place, the dissimilar electrodes cause the component to act as a cell. The time taken for this cell to deplate is directly proportional to the number of coulombs put into the cell. The number of coulombs would be directly proportional to the amount of radiation striking the photocell over a given period.

3.7.2. Design and construction of the integrating PAR meter

Figure 8 shows the circuit used in the PAR meter. Resistor B is the load resistor for the selenium photocell. A resistance of 200Ω was found to be optimal for ensuring a linear current illuminance relationship. Resistor D limits the amount of current to the E cell. Optimising the value of this resistor is quite complicated, and depends on a number of factors:

a) Type of E cell used
The 550/560 series E cell was used as this had the greatest maximum current time integral.

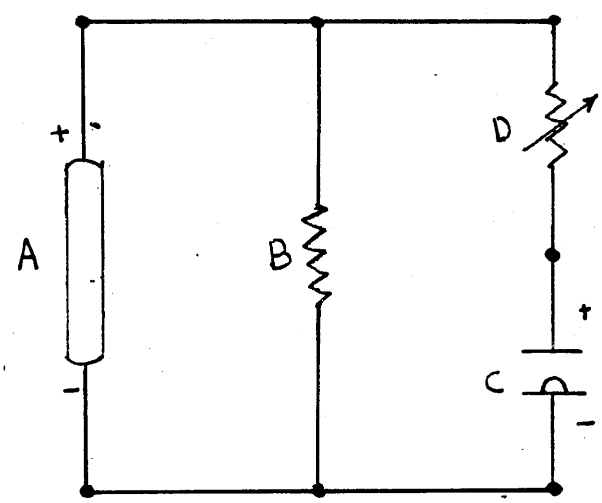
b) Expected life of E cell required
1000 cycles was taken as the minimum life required from the E cells. This gave a maximum current of 70μ A for cycle times under 100 minutes. (using information provided by the manufacturer)

c) Maximum current/number of coulombs
Solar radiation for the UK 1951-1975 obtainable from the Met office was used to determine the brightest day recorded. This was 9502 Whrs M^{-2} day^{-1}. 1KW for 9 hrs on 1 m^2 was taken as the maximum for the design of the circuit. This would give an output of 90.8 mV per hr. from the filtered photocell. A resistance of 1286Ω would be required to give 70μ A.

d) Discharge time required
The maximum discharge time obtained for the system with the lowest resistance on the brightest day would be under 2 hrs for 1 solar day.

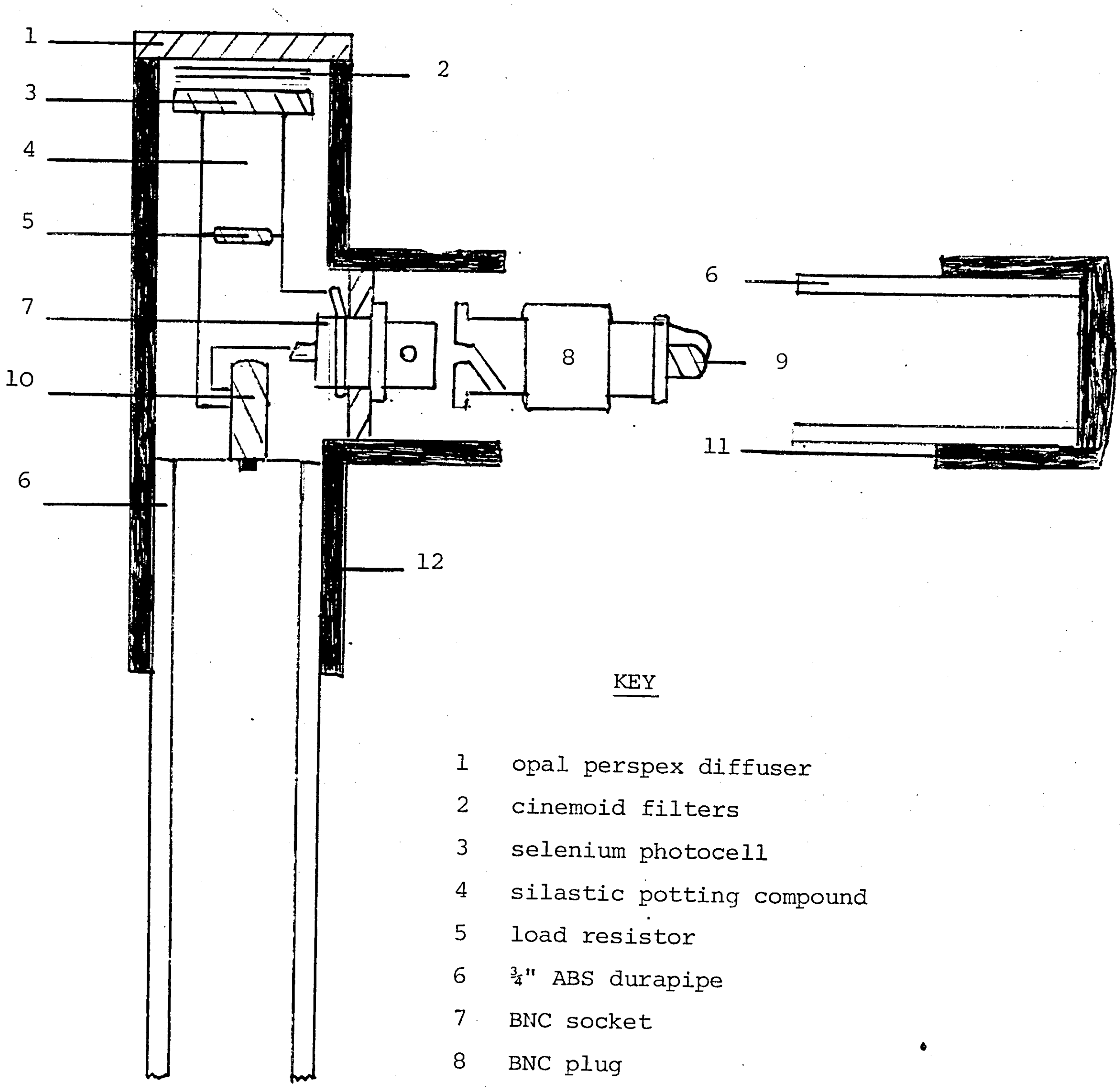
A 1K resistor was used in series with a 500Ω20 turn trim pot. The trim pot would be useful in matching the outputs of a number of selenium cells at a given level of illuminance. The 560 E cell (resistor form) rather than the 550 E cell (bullet with socket) was chosen, as the socket construction was rather flimsy and would not stand up to field conditions. The 560 E cell could be soldered into and protected by a standard BNC plug. BNC plugs and sockets are designed to a high standard for outdoor applications. Figure 9 illustrates the housing of the system in standard plumbing fittings and the positions of the components.

Figure 8 Circuit diagram of PAR meter. A, filtered selenium cell B, load resistor 200 Ω C, E cell D trimpot



The perspex discs were cut from sheets and turned on a centre lathe. Standard durapipe cement was used for all joints. The diffuser joint is sealed by inverting the tee piece and pouring elastomer onto the bottom of the diffuser to a depth of 1mm. The filters and cells are pressed into position, and potted in place with the wires extended for soldering. After soldering, the components are also potted. Plumbing fittings are robust and inexpensive and can be located at any height or angle by the use of other fittings and lengths of pipe.

Figure 9 : Housing and arrangement of components in the PAR meter



KEY

1 opal perspex diffuser
2 cinemoid filters
3 selenium photocell
4 silastic potting compound
5 load resistor
6 ¾" ABS durapipe
7 BNC socket
8 BNC plug
9 coulometer
10 trimpot
11 ¾" stop end
12 ¾" tee

3.7.3. Performance

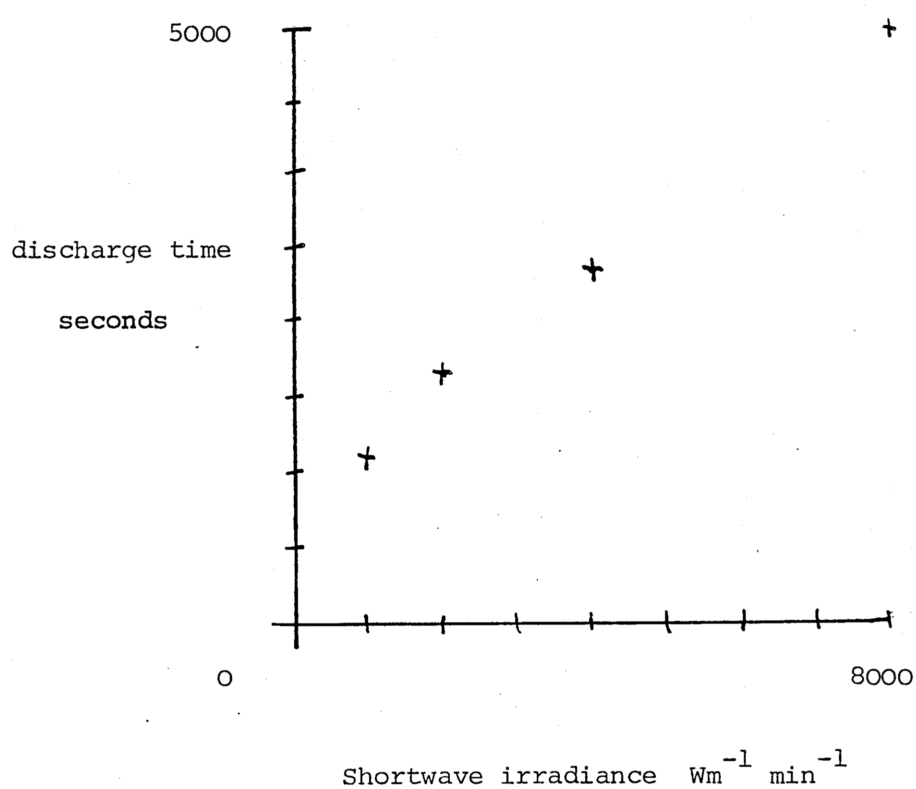
Previous research has indicated that the spectral, azimuthal and cosine response of the sensor assembly are satisfactory. The two most important features of the sensor and integrator are the variation between units and the relationship between the output of the units and a standard meteorological instrument.

10 units were constructed from a random sample of components of no more than 3 batches. The current output of the photocells was matched at 6mV ± .2mV. Each unit was labelled with a number. Unit number 6 contained a faulty photocell that gave out erratic readings and was excluded from the analysis. A Kipp solarimeter and integrator was used to record the amount of shortwave radiation falling upon the PAR cells. The experiment was carried out 27-29 October, when the skies were overcast. One E cell discharge unit = 1.5 seconds. Table 4 contains data used in the estimates of between unit variability. Information on cell 1 was used in order to obtain figure 10. The between unit variability of between 9% and 11% is not acceptable. The origin of this variability is thought to be due mainly to the selenium cells as E cell variability stated by the manufacturers as ± 2%. The nine units were connected to a chart recorder in order to monitor the output that would otherwise have gone to the E cells. It soon became obvious that the variability between the photocells was not linear for different light intensities. Matching the cells at one intensity would be inadequate for integration purposes. The most surprising result in table 4 is the response of cells 1, 7 and 9. These gave identical results for all four quantities of short wave irradiance. This indicates that variability can be considerably reduced by matching the constructed units or by choosing components matched at a number of light intensities. Figure 10 indicates that the relationship between quantity of short wave irradiance and E cell discharge time may be linear at low levels of total irradiance. More results however particularly in bright days must be taken before any regression/calibration analysis can be carried out.

Table 4 : Between unit variability and discharge time irradiance relationships for 10 PAR cells 27-29 October 1982.

Cell No.	Discharge time (x7) in seconds at various levels of short wave irradiance (daylight) Wm^{-1} min^{-1}			
	998	1996	3991	7982
1	215	330	463	748
2	182	260	379	632
3	176	284	398	652
4	174	279	388	628
5	187	292	407	655
6	-	-	-	-
7	215	330	463	748
8	194	330	412	748
9	215	330	463	748
10	182	279	379	632
mean	193	302	417	688
variability ±	10%	9%	11%	9%

Figure 10 : The relationship between short wave irradiance and discharge time for cell number 1.



THE RESPONSE OF RADISH TO VARIOUS LEVELS OF CONTROLLED SHADE

Chapter 4

4.1. Introduction

Previous experiments have outlined the various responses of vegetables to the aerial environment created by a discontinuous canopy of conference pear. Any response found was thought to be due to a complex of factors, not just the attenuation of light intensity. In this experiment, the aims are :-

1. To determine the effect of various levels of controlled shade on the agronomic yield of radish.

2. To evaluate the response of radish to conditions of controlled shade in terms of morphology and light use efficiency.

3. To determine the extent that a 'shade trial' would be a useful tool in the selection of genotypes suitable for interculture, given that the soil environment was 'ideal'.

Possible ways in which the artificial shade differs from tree shade are as follows :-

1. Trees with leaves are selective filters, filtering out relatively more radiation within the 400-700nm region of the spectra. Trees without leaves are neutral density filters. The shades used in this experiment are neutral density filters.

2. Temperature CO_2 humidity, etc., regimes may be different in artificial shade.

3. The spatial and temporal variations in light intensity are far greater in tree shade.

It would be very difficult to make an artificial shade that closely simulated tree shade.

4.2. Methods

A seed bed was prepared of $30m^2$ in an area used for the control in the orchard experiments. The area was marked off into 4 sub-plots each $1m^2$. These 4 plots were randomly assigned different shade treatments.

Six rows of radish var. Saxerre were sown in each of the 4 plots on 3.6.81, and thinned at the seed leaf stage on 24.6.81. to leave a plot arrangement shown in Figure 1. This represents the 'commercial' planting arrangement for radish. Three shade frames were constructed using 1" x 1" timber and 'netlon' garden mesh (plastic). The frames were placed over 3 of the plots, supported by a 'leg' at each corner at a height of 15cm above the radish seedlings. Three different levels of shade were made by overlaying a different number of meshes in the frame. The transmissivity values for the shade were estimated by placing selenium PAR meters above and below the shades on a uniformly overcast day.

The number of 'netlon' sheets and their resultant transmissivity are given below :-

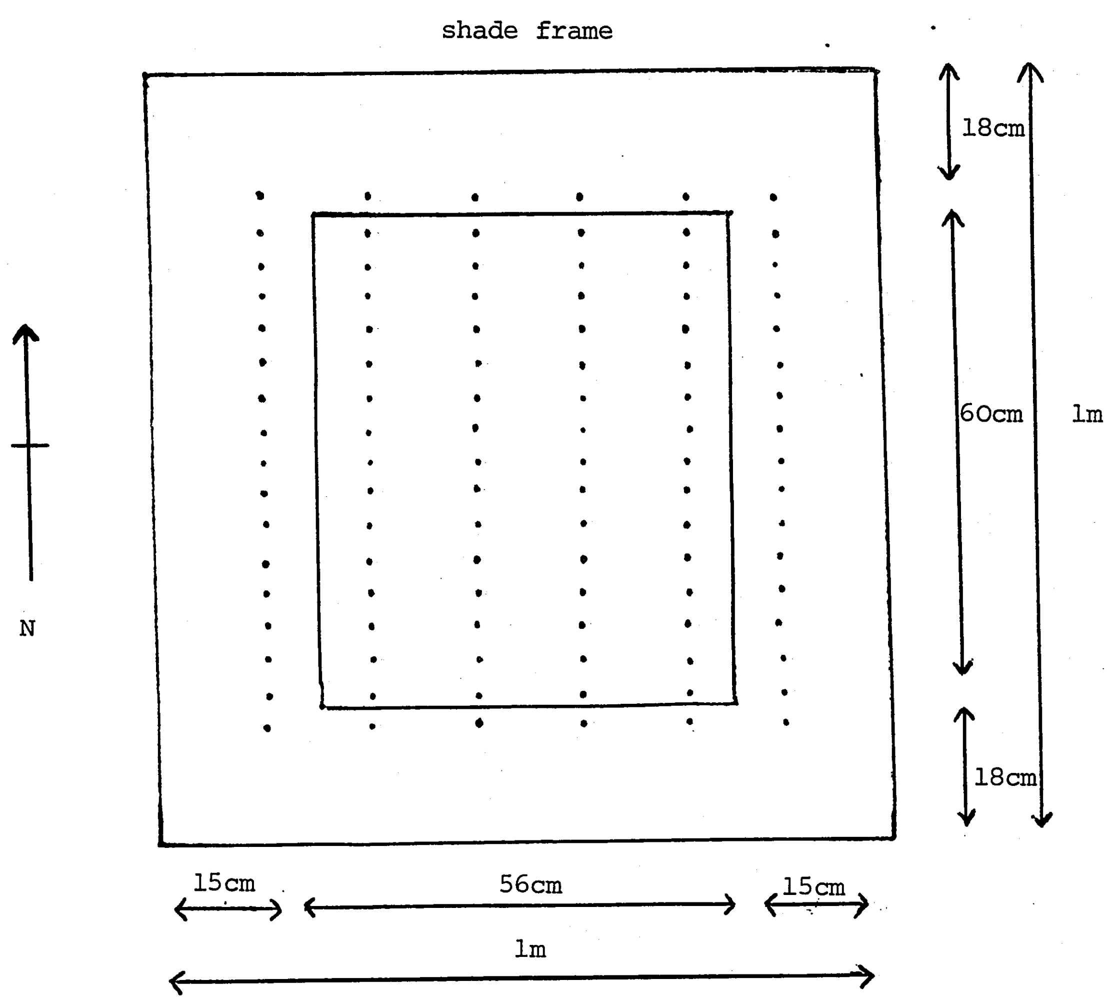
1 sheet = 53% light
2 sheets = 30% light
4 sheets = 10% light

One plot had no shade and acted as a control or 100% light. The radish plants were harvested on 3.7.81. one month after planting. 50 radish were randomly sampled from an area within a guard row containing 60 radish (see Figure 1), for each of the 4 plots. Photographs were taken of the samples and the following growth analysis carried out for each of the 200 harvested radishes :-

(1) Bulb diameter: widest diameter of fresh radish 'bulb' measured using calipers (mm)
(2) leaf length: leangth of longest leaf of fresh radish, measured using a ruler (mm)
(3) Dry weight of bulb: (oven dried to constant weight)
(4) Dry weight of leaves: (oven dried to constant weight)

These data are presented in the Appendix (section B).

FIGURE 1: Arrangement of radish after thinning in a typical plot showing the extent of the shade frame and inner sampling area.



seed spacing = 4 cm within row
14 cm between row

4.3. Results and analysis

Radish under shade frames all appeared to be of a different shade of green from the control, possibly due to the density of chloroplasts within the leaves and or the concentration of chlorophyll. Radish grown under 10% light showed no stem thickening or bulb and did not appear to have developed from the seedling stage. Total dry weight and root: shoot ratio values were calculated for each of the sampled

radish plants using the data on bulb-dry wt and leaf dry wt. This gave 6 variables for the 4 shade treatments, giving a total of 24 data sets. The analysis of the data was carried out in four parts:-

1. Determination of agronomic yields

2. Means and significance testing on morphological response data

3. Calculation of light use efficiency

4. Evaluation of the shade trial as a technique for optimising ecological combining ability in intercuture systems

4.3.1. Determination of agronomic yields

The index of agronomic yield used in the experiment was the number of saleable radish per sample of 50. Radish with a bulb diameter greater than or equal to 10mm were considered saleable based on information given by ADAS. The results are given in Table 1.

Table 1. The effect of controlled shade on the agronomic yield of radish expressed as the number of saleable radish per sample (η = 50)

	100% light	53% light	30% light	10% light
number of saleable radish	46	16	9	0

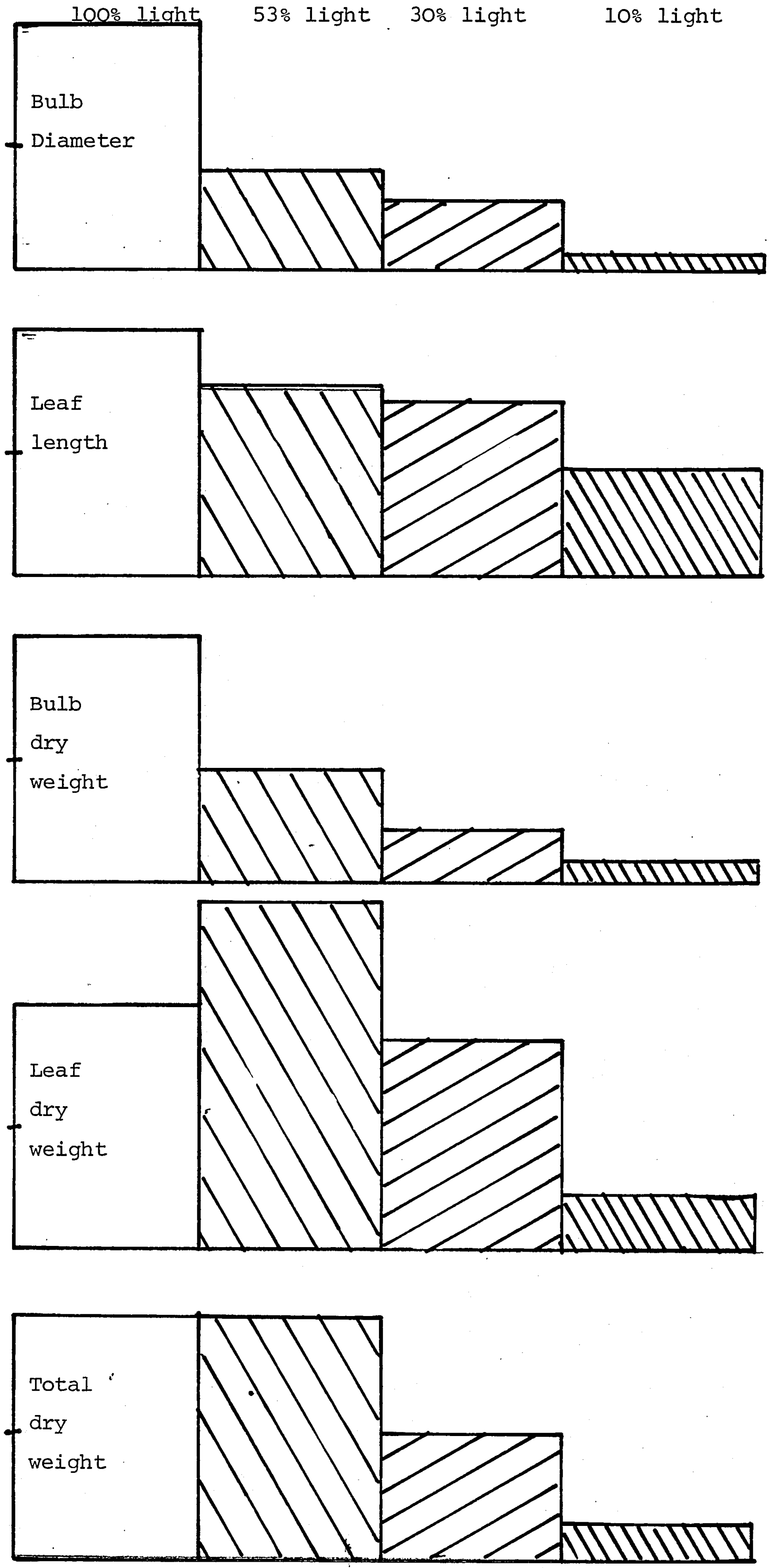
4.3.2. The morphological response of radish to controlled shade

Initial inspection of the 36 data sets showed that many of the distributions were non normal. This had consequences on the way the means should be assessed (graphically or arithmetically) and how significance testing should be carried out (parametric or non parametric methods). Graphical means were used on all non normal data sets. Information on the effects of controlled shade on the distributions, mean values and their statistical significance of the six measures of morphology are presented in table 2. Some of this data is presented in the form of histo grams in figure 2 in order to assess the relative sensitivity of the variables to the various levels of shade. A non parametric significance test known as the Kruskal-Wallis procedure (see Ridgman 1975) was used on the data for bulb diameter, bulb dry wt, total dry wt and root: shoot ratio. One way analysis of variance was used on the leaf length data and on the log transformed data for leaf dry weight.

Table 2. The morphological response of radish to various levels of controlled shade.

Variable	100% light	53% light	30% light	10% light	Significance level (P)
mean bulb diameter (mm)	18	7	5	1	< 0.001
distribution type	normal	truncated normal	truncated normal	single value	
mean leaf length (mm)	71	54	50	30	< 0.001
distribution type	normal	normal	normal	normal	
mean bulb dry wt (g)	0.16	0.07	0.03	0.01	< 0.001
distribution type	log normal	log normal	log normal	single value	
mean leaf dry wt g	0.14	0.20	0.12	0.03	< 0.001
distribution type	log normal	log normal	log normal	log normal	
mean total dry wt g	0.31	0.31	0.15	0.04	< 0.001
distribution type	log normal	normal	log normal	truncated normal	
mean root: shoot ratio	1.39	0.40	0.29	0.50	< 0.001
distribution type	normal	log normal	normal	log normal	

Figure 2. Relative sensitivity of a number of response variables to various levels of controlled shade (100% light taken as unity for each variable).



4.3.3 Calculation of light use efficiency

Interculture systems could be optimised if crops were selcted with appropriate light use characteristics. The overstorey tree crop should have an optimal light use efficiency at high intensities with the understorey having an optimal light use efficiency at lower intensities.

Table 3 Variation in light use efficiency of radish at various levels of controlled shade (calculated as mean total dry wt/% light)

100% light	53% light	30% light	10% light
31%	58%	50%	40%

4.3.4. Evaluation of the shade trial as a technique for optimising ecological combining ability in interculture systems

Besides using shade trials to select species appropriate for the understorey, it may be possible to select varieties and or individuals for further selective breeding to enhance ecological combining ability. Table 4 illustrates the range of response amongst individuals within the populations grown at the various levels of controlled shade.

Table 4 The range of response within different controlled shade treatments

	100% light	53% light	30% light	10% light
mean bulb diameter (mm)	18	7	5	1
maximum bulb diameter (mm)	31	20	18	1
minimum bulb diameter (mm)	7	2	1	1

4.4. Discussion

The shade experiment showed that agronomic yield was drastically reduced by growing radish in controlled shade A reduction in the amount of light by 50% resulted in a yield reduction of 65% relative to the control. Radish did not produce any agronomic yield at the 10% light level. Radish are sold subject to being of the required bulb diameter. If the whole radish plant was eaten as in a fodder crop, then the total dry matter would be an important index of agronomic yield. A reduction of approximately 50% in the light level did not change the mean total dry wt of the radish relative to the control, but did change the allocation of dry matter to the leaves causing a reduction in bulb dry wt.

Figure 2 illustrates the morphological response of radish to controlled shade. Leaf length was least affected by shade. A 50% reduction in light resulted in heavier leaves. At 30% light, the mean leaf length is similar to that at 53% light. Bulb dry wt is about half that at 53% light, so is leaf dry wt. and total dry matter. At 10% light the morphology is similar to the seedling with little development. It is hard to envisage any agronomic potential for radish at 10% light. In order of sensitivity the response of radish to shade is reduction of bulb diameter and bulb dry wt, reduction of total dry wt. reduction of leaf dry wt and reduction of leaf length.

The highest light use efficiency was obtained at 53% light (see table 3) at 58% compared to 31% for the control. This shows that if radish was grown as a fodder or energy crop, then an overstorey could be grown that used 47% of the radiation. It would be useful to repeat the experiment at light levels intermediate to the 53% and 100% in order to find out if yield and light use efficiency would be increased. It would also be useful to repeat the experiment using a 53% light treatment for half of the growth period of the radish to establish if the change in morphology and light use efficiency resulted in a more or less efficient use of 100% light.

Table 4 shows that some of the radish grown at 53% and 30% light had bulb diameters equivalent to the mean bulb diameter of radish grown at 100% light. If this trait of high light use efficiency at low light intensities could be isolated and enhanced by selective breeding, it may be possible to increase the yields of many interculture systems.

4.5. Conclusions

1. Radish, as suspected is not an ideal understorey crop and is very sensitive to levels of light less than 50%.

2. Bulb diameter, a determinant of agronomic yield of radish is the most sensitive aspect of morphological response to shade.

3. Shade produces a severe reduction in bulb diameter and bulb dry weight. At intermediate light (50%) leaf dry weight is increased to give a similar total dry wt. to the control. Leaf length is the least plastic of the responses.

4. Radish does have a higher light use efficiency at 53% light relative to control, but this only has an agronomic consequence if the radish is used as an energy or fodder crop.

5. The shade trial has shown that there may be considerable scope for increases in understorey yields by selective breeding. A few individuals in 30% light had a similar bulb diameter to the mean bulb diameter at 100% light.

6. The shade trial should be repeated using shades between 100 and 53% light and would be more useful if carried out at the same time as radish were intercropped.

THE PRODUCTIVITY OF A PEAR AND RADISH INTERCULTURE SYSTEM: THE EFFECTS OF SPACING POSITION AND CONTROLLED SHADE ON THE UNDERSTOREY RESPONSE

Chapter 5

5.1. Introduction

The general aims of this study are to assess the extent of any yield advantage arising from the interculture of radish within the pear orchard, to analyse the effects of spacing and spatial arrangement on the yield of the understorey and to identify the biological basis for any deviations from expected yield. The land equivalent ratio (LER) appears to be the most useful index for assessing yield advantage in mixed cropping systems. Previous studies on the morphological response of radish to the aerial environment in the orchard and to controlled shade have been based on the assumption that morphological response may be a key to understanding the biological basis of yield deviations. The value of a controlled shade experiment is increased if it is carried out simultaneously with intercropping when environmental conditions are comparable.

The specific aims of this experiment can now be stated as :-

1. To evaluate the effects of spacing and spatial arrangement on the yield of the understorey.

2. To determine a range of LER values for the pear and radish interculture system based upon various assumptions for spatial arrangement.

3. To assess the efficacy of a simultaneous controlled shade trial in analysing the morphological response of the understorey to potential interference factors when intercropped.

5.2. Materials and methods

The orchard and the control area have been described previously.

Glyphosate herbicide was applied to the control area and an area within the orchard (Figure 1), and subsequently rotavated to a depth of $25cm^3$. Seed beds were prepared by hand raking. Seeds of radish, var: Saxerre, were planted in 60cm x 60cm blocks, at a depth of 1cm, at three different spacings in the positions shown in Figure 2 and 3. Three of the 60cm x 60cm sub plots were grown under artificial shades with PAR transmissivities of 65% 53% and 24% light. Unfortunately 65% light

FIGURE 1: LAYOUT OF MANAGEMENT AREAS WITHIN THE 1981 INTERCROPPING EXPERIMENT.

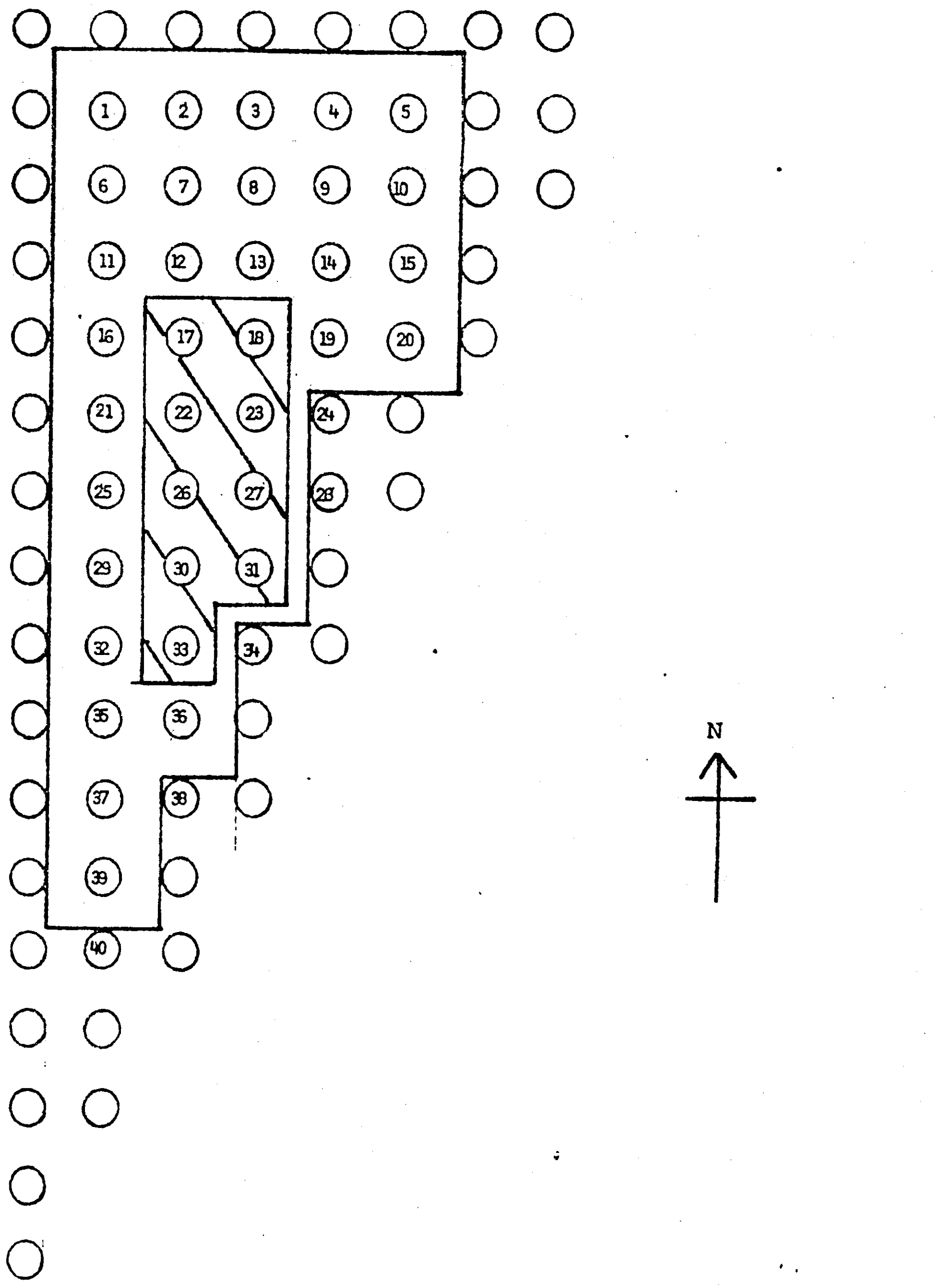


FIGURE 2: SCALE DIAGRAM OF INTERCROPPED AREA SHOWING CANOPY DIMENSIONS, SUB-PLOT POSITIONS AND PLANT SPACINGS

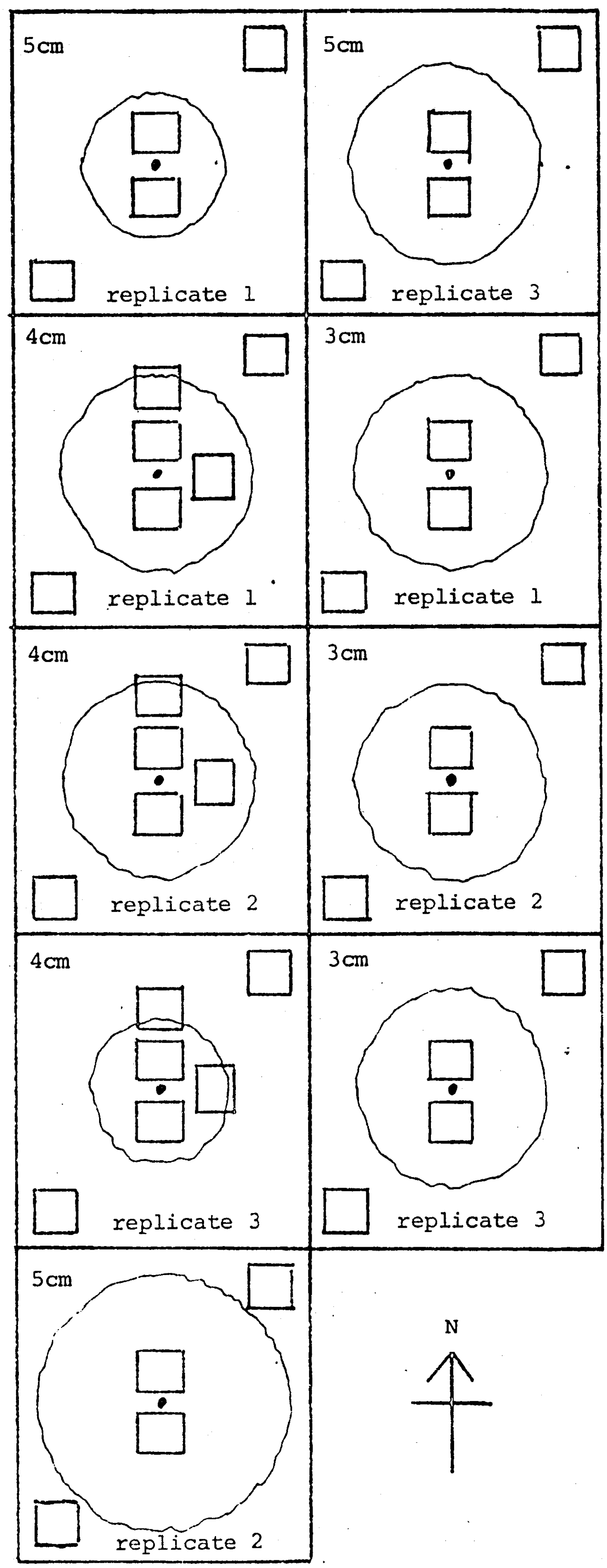
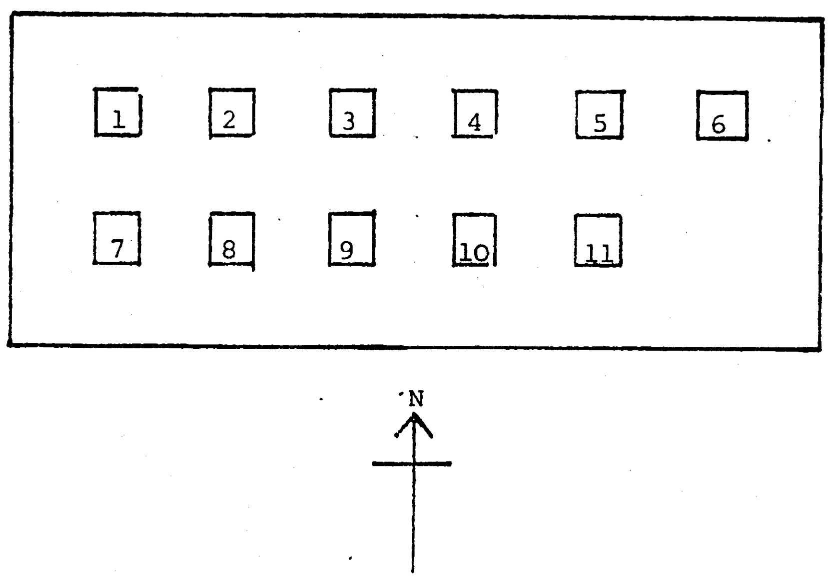


FIGURE 3: SCALE DIAGRAM OF CONTROL AREA FOR RADISH SUB-PLOTS INDICATING THE POSITIONS OF THE VARIOUS TREATMENTS



Key

- 1 — 4cm, 24% light
- 2 — 4cm, replicate no. 1
- 3 — 4cm, 65% light
- 4 — 3cm, replicate no. 1
- 5 — 4cm, 52% light
- 6 — 5cm, replicate no. 1
- 7 — 4cm, replicate no. 2
- 8 — 3cm, replicate no. 2
- 9 — 4cm, replicate no. 1 (13.7.81)
- 10 — 5cm, replicate no. 2
- 11 — 4cm, replicate no. 2 (13.7.81)

was the only shade cloth obtainable that was intermediate between 100% and 53%. 24% was considered a more reasonable representation of the most intense shade in the orchard than the 10% used previously. In the previous shade experiment, the radish were planted at the ADAS recommended - 4cm spacing with between row spacing representing commercial drilling with a precision drill (14cm). In this experiment a square planting pattern was used so that the effects of spacing could be evaluated. 3cm spacing was chosen as a suitable minimum spacing, as bulbs with a diameter >/10mm were required. The arithmetic series of 3, 4 and 5cm spacing should give a geometric increase in area available per plant.

It was assumed that the yield of individual pear trees within an area bound by a guard row would be independent of their position. An inner area of 9 adjacent trees was chosen to facilitate management (figure 1). The trunk circumference, canopy diameter and yield of the trees were measured at the end of the experiment. The position of each tree in the orchard was recorded. Details of the planting and harvesting are given in table 1.50 radish plants were randomly sampled at harvest from an area within each sub plot and the following measurements taken: bulb diameter, number of saleable radishes (i.e. radishes with a bulb diameter >/10mm, leaf length, bulb dry wt, leaf dry wt. The pears were harvested on the 21st September, 1981 and split into economic (saleable) pears and non economic. Fresh weights were taken and dry weights determined using a sub sample of 20 pears.

Table 1: Details of planting and harvesting for 1981 intercropping experiment

	Operating	Dates
(a)	Planting of sub-plots in positions 1, 3, 5 and 6 with controls	10.7.81.
(b)	Planting of 4cm sub-plots in positions 2 and 4, shade sub-plots and controls	13.7.81.
(c)	Harvesting of (a)	10.8.81.
(d)	Harvesting of (b)	13.8.81.
(e)	Harvesting of pears	21.9.81.

5.3. Observations and results

In preparing the plots adjacent to the pear trees, it was evident that in some plots, the presence of large woody roots would reduce the soil volume available to some of the intercropped radish. At harvest, many of the radish adjacent to the pear trees appeared stunted, some showed signs of phosphate deficiency with a reddish purple tinge around the edges of the leaves. The results of the growth analysis for the pears and radish are given in the appendix. (Section C).

5.4. Analysis and discussion

5.4.1. Effects of position and spacing on the yield of intercropped radish

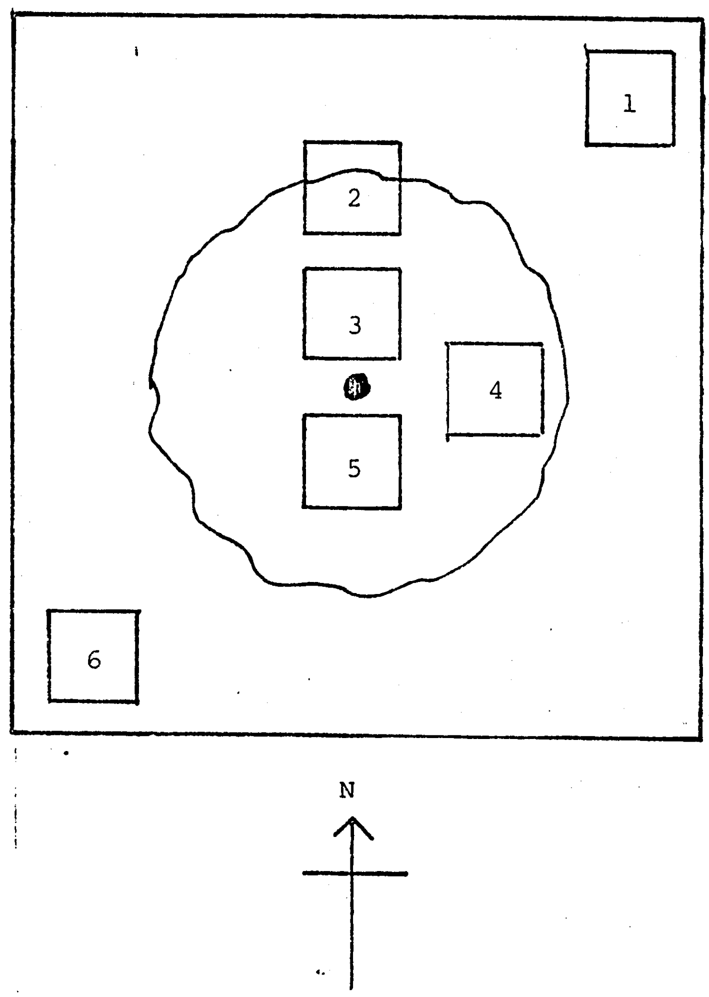
The positions of the sub plots sampled are given in figures 2 and 4. The intermediate positions (2 and 4) for the 4cm spacing were not used in order to balance the experimental design and simplify the analysis. This gave a total of 36 sub plots consisting of 4 sub plots per plot with 3 spacings and 3 replicates. Yield estimates were based upon the mean per plant dry weight and the number of radish with a bulb diameter >/10mm per sample of 50 radish. This information is presented in table 2. The following analysis of variance model was set up to analyse the effects of position and spacing on the yield of radish:-

$$T = D + A + N + DA + DN + AN + RES$$

Where T = total variance
D = spacing variance
A = variance due to alleyway effect
positions 1 + 6 vs 3 + 5
(tree proximity)
N = North South effect
positions 1 + 3 vs 5 + 6
(aspect)
AN,DA,DN = interaction terms
RES = residual.

Initial analysis of the data in table 2 indicated that this model could

FIGURE 4: SCALE DIAGRAM OF A 4cm PLOT INDICATING POSITIONS OF RADISH SUB-PLOTS RELATIVE TO A PEAR TREE. DIMENSIONS ARE: PLOT 4.6m x 4.7m. SUB-PLOT 60cm x 60cm.



be used for the mean total dry weight data, but not for the number of saleable radishes. The large variance found in the inner sub plots (positions 3 + 5) compared to the outer plots (positions 1 + 6) indicated that there may be a replicate effect. On applying Bartlett's test of homogeneity, it was found that the variance of the inner plots was not consistent with that of the outer plots. This necessitated the use of separate ANOVA models for the inner and outer data. The model used is outlined below :-

$$T = D + N + DN + (R + DR) + (RN + DRN)$$

where R + DR = replicate effect
RN + DRN = residual

Table 2 The yield of intercropped radish grown at different spacings and positions within the orchard

spacing (cm)	position	number of radish with a bulb diameter >/10mm (η=50) replicate			mean per plant dry wt (root + shoot) (g) (η=50) replicate		
		1	2	3	1	2	3
3	1	27	31	32	0.27	0.53	0.41
3	3	3	20	10	0.21	0.41	0.19
3	5	2	10	17	0.20	0.23	0.25
3	6	25	25	37	0.30	0.37	0.42
4	1	40	41	39	0.54	0.49	0.52
4	3	31	34	32	0.33	0.33	0.42
4	5	27	6	28	0.45	0.26	0.37
4	6	42	40	44	0.41	0.49	0.53
5	1	50	45	45	0.56	0.48	0.62
5	3	41	16	33	0.63	0.26	0.38
5	5	24	36	9	0.46	0.28	0.23
5	6	45	47	41	0.49	0.58	0.46

The results of using the three anova models are presented in table 3a. The only significant effects appear to be the alleyway effect and the spacing effect in the three models. The means are presented in table 3b. It is necessary to convert the values for the different spacing into yields per unit area in order for the relative yields to be calculated when the LER value is determined. The converted values are presented in table 4 for the different spacings in the outer and inner positions for both indices of yield. The highest yield per unit area in terms of total dry wt would be obtained at the smallest of the 3 spacings used. If 3cm spacing was used in the inner and outer positions the mean yield would be 351 gm^{-2}. For the number of saleable radishes per unit area the highest yield would be obtained by having a 3cm spacing in the outer positions with a 4cm spacing on the inner positions, this would give a yield of 493 radishes per $metre^2$. Using a 3cm spacing throughout would give a yield of 443 per $metre^2$.

Table 3a Results of the analysis of variance models

(1) Total dry matter

SOURCE	CSS	MS	df	F	P
T	5615	-	35		
D	1277	638	2	7.34	< 0.01
A	1849	1849	1	21.26	< 0.001
N	177	177	1	2.04	NS
DA	10	5	2	0.06	NS
DN	40	20	2	0.23	NS
AN	1	1	1	0.01	NS
RES	2261	87	26		

(2) Number of saleable radish (inner plots)

SOURCE	CSS	MS	df	F	P
T	2591		17		
D	1035	517	2	5.0	< .01
N	207	207	1	ns	pooled
DN	85	43	2	ns	pooled
R+DR	441	73	6	ns	pooled
RN+DRN	823	137	6	ns	pooled

(3) Number of saleable radish (outer plots)

SOURCE	CSS	MS	df	F	P
T	988	-	17		
D	817	409	2	11.69	< 0.001
N	1	1	1	ns	pooled
DN	15	8	2	ns	pooled
R+DR	101	17	6	ns	pooled
RN+DRN	54	9	6	ns	pooled

Table 3b: Table of means for the spacing and positional effects used in the analysis of variance
(values underlined have P < 0.05)

Variable	Mean values for major ANOVA variables						
	Spacing			North	South	Alleyway	
	3cm	4cm	5cm	N	S	in	out
Number of saleable radish produced in positions 3 + 5	10	26	26	32	28	-	-
Number of saleable radish produced in positions 1 + 6	30	41	46	32	28	-	-
Mean per plot total dry wt (g)	0.32	0.43	0.45	0.42	0.38	0.33	0.47

Table 4 Yields per unit area of intercropped radish at different spacings at the inner and outer positions in the orchard

Variable	Inner position 3+5 @ 3cm	4cm	5cm	Outer position 1+6 @ 3cm	4cm	5cm
number of saleable radish m^{-2}	230	330	212	655	513	364
total dry wt of radish (root+shoot) $g\ m^{-2}$	276	225	149	426	310	213

5.4.2. The land equivalent ratios for the system

The land equivalent ratio LER is the sum of the relative yields of the components of the mixture

$$LER = \frac{Yir}{Ysr} + \frac{Yip}{Ysp}$$

where Y = yield per unit area
i = intercrop
s = sole crop
p = pear
r = radish

a) The relative yield of radish

A range of relative yield values for the radish component can be generated, based upon different yield indices, spatial arrangements and assumptions. Results for the sole cropped radish are given in table 5. of the 3 spacings used the 3cm is optimal for both yield indices. The simplest equation for the relative yield of radish would be

$$\frac{Yi}{Ys} = \frac{Y1{+}6 + Y3{+}5}{Ys \times 2}$$

where Y1+6 = yield at positions 1 + 6
Y3+5 = " " " 3 + 5
Ys = sole crop yield

The assumptions are that :-

1. The yields were obtained under the same level of management

2. The spacings employed were optimal

3. The area not available for intercropping is negligible, and can be ignored.

4. The ratio of areas represented by positions 3 + 5 : 1 + 6 is equivalent to unity.

Table 5 The yields per unit area of sole cropped radish at different spacings

Variable	Spacing		
	3cm	4cm	5cm
number of saleable radish m^{-2}	889	550	368
total dry wt of radish $g\ m^{-2}$	383	288	248

The yields were obtained from plots under the same level of management in the experiment. Optimal spacings were derived from a range of only 3 within the experiment. The area considered not available for intercropping was the cross sectional area of the tree trunk and the area 15 cm from it. The mean trunk diameter was 12.7cm. This would give a circle of land that would not be available to intercropping with an area of $0.14m^2$. This represents about 0.66% of the area of a plot ($21.62m^2$) and can be ignored in the calculations. A plot in the orchard could be represented as a circle with a tree in the centre with an area of $21.62m^2$ and a radius of 2.62m. Positions 3 and 5 represent an inner circular area with a radius of 1.31m. This would give an area of $5.39m^2$. The area representing the 1 and 6 positions is the total area minus $5.39m^2$ this is $16.23m^2$. Table 6 contains the results of the various equations used to determine the relative yield values. Values for total dry matter range from 0.85 - 1.01 and for saleable radish range from 0.50 - 0.65 depending upon the equation used.

Table 6 Models for determining the relative yield of the radish component

Spacing	Relative yield equation	Value based on number of saleable radish m^{-2}	Value based on total dry matter $g\ m^{-2}$
3cm	$\frac{Y1+6 + Y3+5}{Ys \times 2}$	0.50	0.91
3cm outer 4cm inner	$\frac{Y1+6 + Y3+5}{Ys \times 2}$	0.57	0.85
3cm (area effect)	$\frac{(Y1+6 \times 16.23)+(Y3+5 \times 5.39)}{Ys \times 21.62}$	0.62	1.01
3cm outer 4cm inner (area effect)	$\frac{(Y1+6 \times 16.23)+(Y3+5 \times 5.39)}{Ys \times 21.62}$	0.65	0.98

b) The relative yield of the pear

The yields of the individual pear trees are presented in the appendix (Section C). The mean yields of intercropped and sole cropped trees are given in Table 7, along with details of mean tree dimensions. The yields for the experimental season were poor and can only be taken as an index of the effect of intercropping. In harvesting the fruit, it became obvious that the original assumption that pear tree yield was independant of the trees position within the orchard was false. There appeared to be considerable variation in yield in a NS direction. This positional effect was analysed in a simple analysis of variance model. Position was classified as 'row' and 'column' effects (see Figure 1) row 1 consists of tree numbers 1-5, column 5 consists of tree numbers 5, 10, 15 and 20. Row and column effects reflect variation in North-South and East-West respectively.

The results of the first analysis of variance are given below for fresh wt of saleable pears.

Variable	df	MS	f	p
Total	34	-	-	-
Rows	9	2756.6	3.3	< 0.05
Columns eliminating rows	4	100.8	0.1	NS
Treatment eliminating rows and columns	1	1072.7	1.3	NS
Residual	20	834.0		

The deviations from the overall mean due to row and column effects are given in table 8. It was clear from this analysis that the positional effect due to rows was significant. Further analysis of variance was carried out in order to analyse the effects due to canopy and trunk diameter and test whether the row effect was real. The results of the analysis are shown in Table 9.

Table 7 : Effects of intercropping on the mean yields of pear trees, with details on the mean tree dimensions (trunk and canopy diameter

Variable	Intercropped trees	Control trees
No. of trees in sample	9	26
Mean trunk diameter	13 cm	14 cm
Mean canopy diameter	302 cm	309 cm
Mean fresh wt of saleable pears	1,260 g	893 g
Mean dry wt of saleable and non-saleable pears	720 g	336 g

NB Mean yield values are not disaggregated from row effects.

Table 8 Yield deviations from the overall mean due to positional effects (row and columns)

Row/column number	Yield deviation due to columns	Yield deviation due to rows
1	+ 4.2	- 31.9
2	- 2.7	- 17.3
3	- 6.3	- 22.3
4	+ 1.1	- 11.9
5	+ 4.6	+ 9.4
6		+ 69.4
7		+ 37.4
8		+ 3.6
9		+ 3.1
10 (11+12)		+ 27.6

Table 9 Analysis of variance due to row effect, intercropping and tree dimensions using data on fresh weight of saleable pears

Model: $T_o = R_o + (C+T) + I + Re$

where T_o = total variance

R_o = row effect

C + T = canopy trunk effect

I = intercropping effect

Re = residual

Variable	CSS	df	MS	f	p
R	24809.0	9			
(C+T)-R	43.0	2	21.5	0.03	NS
I-(C+T)+R	1849.1	1	1849.1	2.50	NS
Re	16263.8	22	739.3		
T_o	42965.0	34			
(C+T)	3188.5	2	1594.2	2.16	NS
R-(C+T)	21663.5	9	2407.1	3.26	< 0.05
I-(C+T)+R	1849.1	1	1849.1	2.50	NS
Re	16263.8	22	739.3		
T_o	42965.0	34			
(C+T)	3188.5	2	1594.2	2.16	NS
I-(C+T)	491.9	1	491.9	0.67	NS
R-I+C+T	23020.7	9	2557.9	3.46	< 0.01
Re	16263.8	22	739.3		
T_o	42965.0	34			

The results indicate that canopy and trunk diameter have no significant effect. Intercropping also has no significant effect. The row effect is real and significant ($p < 0.01$) when intercropping and tree dimension effects are disagregated.

The relative yield of the pear component can therefore be taken as unity. A similar result would be expected from the analysis of dry matter yield (saleable + non-saleable pears).

5.4.3. A comparison of the yield and morphological response of radish to controlled shade and position within the interculture system

The comparison consisted of the differences in morphological response, measured as bulb diameter, leaf length, leaf dry weight and bulb dry weight between the following treatments, positions sown at 4cm spacing:

(a) sole crop plots (η=4)
(b) intercrop sub-plots at positions 1-6 (η=18)
(c) 24% 53% and 65% light (η=3)

The original data are presented in the appendix (Section C). It is hoped that the information provided by this experiment could be used to create guidelines for designing an interculture cropping system and to generate hypotheses on the biological basis for any deviations from expected yield. Table 10 contains information of the mean yields for each position/treatment and their rank orders along with the expected transmissivity of the canopy at the various positions. These transmissivity values were based upon the 1981 light data in Chapter 3, Figure 7. Positions 1 + 6 correspond to zone C with a transmissivity of 77%, 2 + 4 = B @ 74%, and 3 + 5 = C @ 57%. The following inferences may be drawn from the information on the mean number of saleable radish:

Table 10 The mean yields of radish grown at 4cm spacings under various levels of controlled shade and positions in the interculture system. Rank orders are also presented along with estimated canopy transmissivities.

Position/treatment (transmissivity estimate)		Mean number of saleable radish per sample of 50	Rank Order	Mean total dry weight (g)	Rank Order
Control	(100%)	45	1	0.48	3
Position 1	(77%)	40	3	0.51	1
Position 6	(77%)	42	2	0.49	2
2	(74%)	40	3	0.45	5
4	(74%)	35	5	0.48	3
65% light		40	3	0.48	3
Position 3	(57%)	32	6	0.36	6
5	(57%)	20	7	0.36	6
53% light		37	4	0.46	4
24% light		0	8	0.14	7

1. Positions 3 + 5 have a yield suppression greater than would be expected from a reduction in the amount of PAR alone.

2. Position 5 has a lower yield than position 3, yet experiences the same degree of shade.

3. Position 4 has a lower yield than position 2, yet experiences the same degree of shade.

4. Positions 1, 2 and 6 share a lower yield than the control and are similar to the 65% light treatment.

For the mean total dry weight, the inferences are :

1. Positions 1 and 6 have a slightly higher yield than the control.

2. Positions 3 and 5 have identical yields that are lower than would be expected from a reduction in the amount of PAR above.

3. Positions 2 and 4 are similar to the control and 65%, 53% controlled shade.

Table 11 contains information on the morphological response of radish to various positions and shade treatments.

The information on bulb diameter again indicate a deviation in positions 3 and 5. The information on leaf length shows that this variable is least affected by position and shade. Position 5 contained radish plants with particularly short leaves. The root: shoot ratio data indicates that all of the radish grown in the orchard tended to be more leafy than the control. Position 5 was the most leafy of the treatments in the orchard.

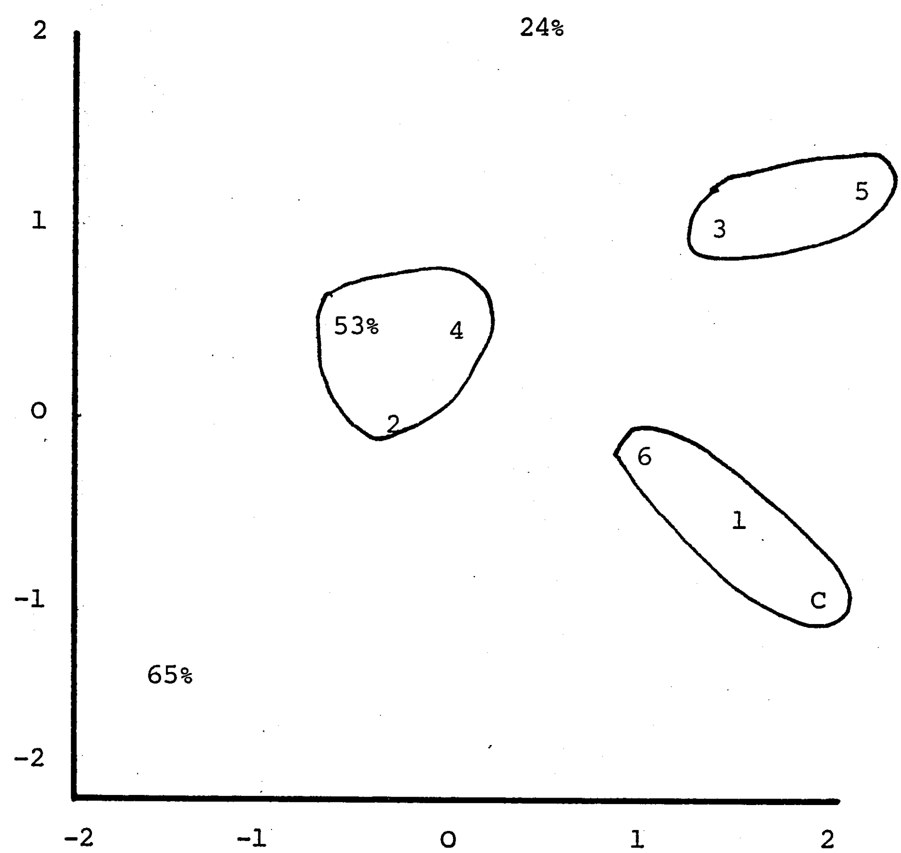
Two multivariate statistical techniques were employed in order to compare the overall morphological response of the radish to controlled shade and position. The aim of these techniques was to find the proximity of the treatments in a given space bound by a number of dimensions. Each dimension would be a particular response variable.

The first technique; discriminant analysis was carried out on bulb diameter, leaf dry weight root dry weight and leaf length data for individual radish plants at each of the plots. This technique was found to be invalid due to different covariance matrices at each plot. A further technique; canonical variates analysis was employed. The proximity of the points on figure 5 is a measure of morphological similarity of radishes in the different plots. The two axes represent the principal components of variation. The results are not clear but suggest that positions 1 + 6 are similar to the control, 3 + 5 are similar but bear little resemblance to what would be expected in shade. Positions 2 + 4 are similar and resemble the response found in 53% light.

Table 11 The morphological response of radish to controlled shade and position within the interculture system. Mean values for bulb diameter leaf length and root:shoot ratio.

Position/ treatment		Mean bulb diameter (mm)	Mean leaf length (ηm)	Mean root: shoot ratio
Control		16	115	1.08
Position	1	15	137	0.65
	2	15	140	0.73
	3	11	135	0.64
	4	12	151	0.50
	5	7	98	0.44
	6	15	155	0.81
65% light		15	172	0.60
53% light		12	156	0.64
24% light		3	139	0.17

Figure 5 Principal components of Canonical variate analysis. The proximity of points is proportional to morphological similarity



5.5. Conclusions

5.5.1. Effects of spacing and position on yield of intercropped radish

Significant yield depressions were found for both yield indices in positions 3 + 5 relative to positions 1 + 6. For total dry matter yield, the best spacing appears to be 3cm at all positions. For number of saleable radish, 3cm was optimal at positions 1+ 6 with 4cm spacing at positions 3 + 5.

5.5.2. Land equivalent ratio for the interculture system

The original assumption that pear yield was independent of tree position was found to be false. When the row position, trunk diameter and canopy diameter of the trees is taken into account, the relative yield of the pear component was found to be unity for both yield estimates.

The relative yield of the radish component will depend on the spacings used and the assumptions made about the area represented in a cropping system by the sub plots. For saleable radish the relative yield range was 0.5 - 0.65. For total dry matter, the range was 0.85 - 1.01. The overall range of LERs for the system can be taken as 1.5 - 2.01, meaning that 50 - 100% more land would be required to achieve the same yields from sole crops. The most important assumption is that the spatial arrangement of the sole crops was optimal.

5.5.3. A comparison of the morphological response of radish to controlled shade and position within the interculture system

The use of a simultaneous controlled shade trial did prove useful in providing clues about the possible biological basis for yield deviations encountered at different positions. Generally the radish plants got more leafy i.e. they had a lower root:shoot ratio as they became closer to the trees. This would be expected from increased shade as would be the observations that the number of saleable radish decreased more than total dry matter with increased shade/tree proximity. Morphologically similar groupings were (positions 1 + 6 and control) (positions 2 and 4 and 53% shade) and (positions 3 + 5). The yield depression found in positions 3 + 5 was far greater than would be expected from shade effects above. Root effects must also be responsible soil nutrients being more likely than soil water. Allelopathic interaction could also be a possibility. The 24% light response was different from anything encountered in the orchard. A 75% light treatment would have been more useful had the shade cloth been available.

THE RESPONSE OF INTERCROPPED RADISH TO THE ADDITION OF ARTIFICIAL FERTILIZER

Chapter 6

6.1 Introduction and Aims

The aims of this experiment were to evaluate the response of intercropped radish to the addition of artificial fertiliser at various dose rates. The specific aims are:

1. To assess the effect of fertiliser on the yield of intercropped radish relative to sole cropped radish
2. To assess the effect of fertiliser on the yield and morphological characteristics of intercropped radish at a range of positions relative to the pear trees

6.2 Materials and Methods

Radish var: saxerre were planted at 3cm spacing in the arrangement outlined in Figure 1. Each plot was divided into 3 sub-plots. The longest edge of the sub-plots was aligned in a north-south direction, corresponding to the slight slope of the orchard. The plots were planted on 21/6/82. Figure 2 shows the layout of the orchard and control plots. The recommended fertiliser dose rate for radish in summer is 70g of 7.20.30 N:P:K per m^2 (MAFF, 1979). Each sub-plot was assigned a fertiliser dose rate of 0g, 70g and 140g).

The fertiliser was applied to the soil surface immediately after planting through a cardboard stencil constructed for the purpose. 20 radish plants were pseudo-randomly sampled for each sub-plot on 23.7.82 and the following measurements taken: bulb diameter, leaf length, dry weight of 20 bulbs and dry wt of leaves of the 20 plants. No irrigation was carried out. Rainfall during the experimental period was heavy.

FIGURE 1: DETAILS ON THE LAYOUT OF AN INDIVIDUAL PLOT SHOWING ARRANGEMENT OF SUB-PLOTS

Area of plot	=	3,600 cm^2 (60 cm x 60 cm)
Number of plants	=	441
Plant spacing	=	3 cm
Density	=	1,225 plants M^{-2}
Area of sub-plot	=	675 cm^2 (15 cm x 45 cm)
Number of plants	=	75
Number of sub-plots	=	3
Planting date	=	21.6.82

Arrangement of sub-plots

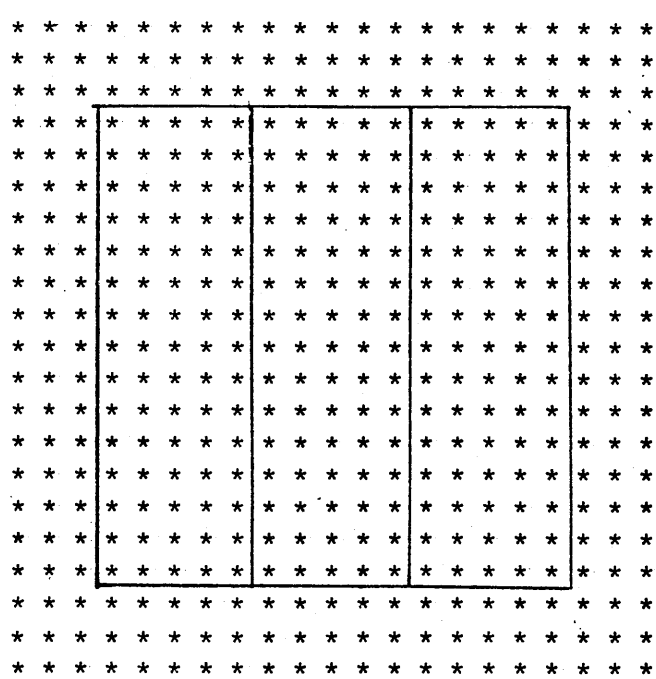
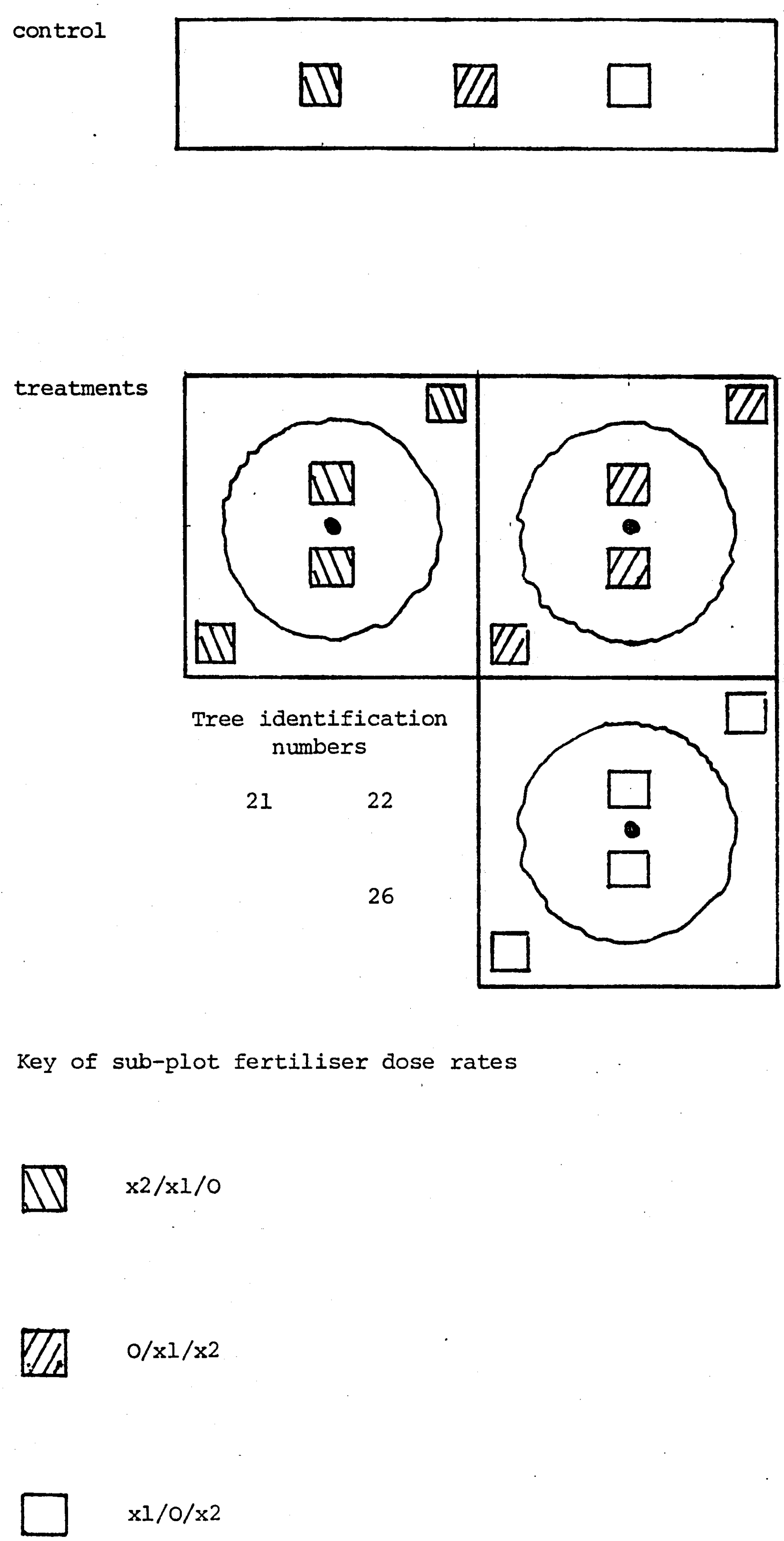


FIGURE 2: LAYOUT OF PLOTS FOR THE FERTILISER EXPERIMENT



6.3 Results and Observations

The mean bulb diameter, leaf length, total dry wt, root:shoot ratio and the number of bulbs 10mm for each sub-plot are given in the Appendix (Section D). There was little variation between the replicates, this facilitated the removal of the plot effect (the effect of the different trees from the analysis .

6.4 Analysis and Discussion

6.4.1 The effect of fertiliser on the yield of intercropped relative to sole cropped radish.

The yield of radish was measured in two ways: the number of saleable radish (bulb diameters $\geqslant$ 10mm) and the total dry wt (root and shoot) of radish per unit area. Table 1 shows the yields of sole cropped versus intercropped radish for the different fertiliser treatments. Addition of fertiliser did not have any agronomically significant effect on the number of saleable radishes grown as sole or intercrops. Fertiliser did however increase the dry matter yield of intercropped and sole cropped radish. Dry matter yield did not increase as dramatically in intercropped radish as sole crop radish with increasing amounts of fertiliser. Both of the yield responses (saleable radish and dry matter) indicate that other factors than soil macronutrients serve to suppress the yield of intercropped radish relative to sole crop raddish.

Table 1. The effect of fertiliser on the yield of intercropped relative to sole cropped radish.

	No. of saleable radish per sample of 20		
	no fertiliser	fertiliser x 1	fertiliser x 2
Sole cropped	16	17	17
intercropped	8	8	9
relative yield	0.50	0.47	0.53

	mean total dry matter (per plant)		
	no fertiliser	fertiliser x 1	fertiliser x 2
sole cropped	0.51	0.57	0.67
intercropped	0.31	0.33	0.38
relative yield	0.61	0.58	0.57

6.4.2 The morphological response of radish to various levels of artificial fertiliser and position within the orchard.

The following variables: mean total dry weight, main root:shoot ratio, mean bulb diameter and mean leaf length were used in the analysis of variance model given below.

T = F + A + N + FA + FN + AN + FAN

where T = Total variance

F = Fertiliser level

A = Alleyway effect (inner vs outer plots)

N = North South effect (upper vs lower plots)

FA, FN, AN = interaction terms

FAN = residual term (FAN effect found not to be significant for all variables)

The results of this analysis are given in Table 2. Significant alleyway and north south effects were apparent for total dry matter. Inner plots produced plants with lower dry matter than outer plots. North plots gave higher dry matter than south plots. The FA interaction term was significant and further analysis showed this to mean that the difference between inner and outer plots was more marked with greater levels of fertiliser, indicating that the level of soil nutrients was not a major factor for producing lower yields adjacent to the trees in the inner plots. The radish plants became more 'leafy' in the inner plots than the outer plots and in the north rather than south plots. This response may be due to effects of PAR intensity. The level of fertiliser did not significantly affect root:shoot ratio or mean bulb diameter. Bulbs were significantly larger in the outer and northern plots. The NS effect was opposite to that found for root:shoot ratio suggesting that the bulbs in the south plots had a greater water content than those on the northern plots. Previous experiments have indicated that a typical leaf length for radish at harvest is around 13 cm. Results from this experiment give values ranging from 17 - 23 cm. This indicates two things. Firstly that there may have been some cross contamination between plots containing different levels of fertiliser in the high rainfall and secondly that the level of fertiliser was too high given the level of soil fertility in the orchard. The response of radish to super optimum levels of fertiliser appears to be to limit storage of carbohydrate in the bulb and to accelerate the process of flowering which starts with increased leaf length. It was observed that some of the harvested radish had the beginnings of the development of a true stem. Leaf length in the northern plots was significantly higher than in the southern plots. The level of fertiliser was not too high if total dry matter was the most important index of yield.

Table 2. Analysis of variance for the morphological response of intercropped radish to various levels of artificial fertiliser and position relative to the pear trees

Variable	fertiliser level				alleyway effect			NS effect			interactions		
	O	x1	x2	p	inner	outer	p	north	south	p	FA	FN	AN
mean total dry weight per plant g	0.31	0.33	0.38	< 0.001	0.30	0.37	<0.001	0.37	0.31	< 0.01	<0.05	NS	NS
mean root: shoot ratio	0.58	0.55	0.56	NS	0.46	0.67	<0.01	0.48	0.65	< 0.01	NS	NS	NS
mean bulb diameter (mm)	9	9	9	NS	7	11	<0.001	9	8	< 0.05	NS	NS	NS
mean leaf length (cm)	18.9	20.5	21.4	< 0.05	20.1	20.4	NS	22.8	17.7	< 0.001	NS	NS	NS

CONCLUSIONS

Chapter 7

7.1 Synthesis and Critique of approach

A review of the literature indicated that past research on mixed cropping was limited given the importance and extent of the practice. Yield advantages have been reported for many, but not all, systems. The magnitude of advantage depends on many things including the species composition and the spatial and temporal arrangement of the crops. The most popular measure of effectiveness for these systems is the land equivalence ratio. This has the advantage of giving the magnitude of any advantage in simple agronomic terms for any number of components within a given system. Partitioning of resources is one mechanism by which interspecific interference can be less than intraspecific interference. The ease with which plants partition resources appears to be related to the degree of dissimilarity of components in terms of taxonomy and morphology. On this basis one would expect the biggest advantages to arise from mixtures of dissimilar crops. Mixtures of tree and non-tree crops known as interculture systems fit into this category. Interculture systems should have high LER values due to the often inefficient use of resources by tree crops, particularly during immaturity. Trees may have many useful properties within a mixed cropping system. Some are leguminous and have deep roots that may serve to increase the availability and dispersion of soil nutrients. Shade from trees may be beneficial in reducing the transpiration and photorespiration of any understorey crop. Tree crops such as coconut, rubber, etc are particularly important in an economic sense in the humid tropics and often serve to reduce soil erosion. Information on interculture systems is virtually absent in the literature: LER's have not yet been determined for any interculture system.

The most useful contribution to work in this field appeared to be to study an interculture system and to develop techniques useful in the evaluation and optimisation of yield responses. The spatial rather than temporal aspects were studied in detail. The amount of photosynthetically active radiation passing through a tree crop canopy was seen as an important determinant of understorey crop yield and was included in the study. An experimental interculture system was set up based upon a commercial pear orchard.

The first experiment using potted vegetables (phytometers), including radish, onion, pea, carrot and onion, indicated that the aerial environment created/modified by the orchard canopy would not have a devastating effect on the yield of an understorey crop. This technique was particularly useful in that it allows a rapid assessment of potential aerial interference. Aerial effects can be far less easy to manage than soil effects in interculture systems. The phytometer technique coupled with analysis of variance facilitated a detailed analysis of the potential response of an understorey to position relative to the trees. The most important conclusions drawn from the work were that tree proximity was a more important factor than aspect in the spatial arrangement of the understorey. This may not be the case however if the experiment were to be repeated at the beginning or end of the growing season during periods of low solar elevation angles. No noted difference was encounted between the response of the different crops used in the experiment. It should be noted here that none of the phytometer species used are considered to be adapted to shade, in fact most temperate crops, with the exception of a few herbs, show the characteristics of pioneer species in having rapid growth and poor tolerance to interference from weeds. Possible generalisations about economic parts and crop families arising from the experiment are that, in areas where shade is a problem within interculture systems, crops of which the leaves or petioles are the economic parts should be used. The family level of classification would not appear to be an appropriate guide in selecting for high 'ecological combining ability' (Harper, 1977) in mixed cropping; the species level is more informative and appropriate for this. The technique was not suited for use with crops requiring a long growth period due to management problems. The effects of intraspecific interference were not included in the experiment due to problems of container size. Buried polythene sheets may improve this as in Willey and Reddy 1981, but their use would be difficult in positions close to tree roots. Radish was selected as an ideal experimental understorey due to ease of management.

Measurements of the transmissivity of the orchard canopy to PAR proved difficult due to the lack of adequate commercially available instrumentation. The most flexible system appeared to be to develop a datalogger based system using specially constructed sensors. Problems were encounted in developing adequate waterproofing for the sensors and software for error checking, formulating and computation of the recorded data.

Constant calibration, achieved by placing all sensors together under a range of irradiances proved to be very laborious. Recordings during 1980 and 1981 indicated that the overal transmissivity of the pear canopy was around 70%. This supported the conclusion that there should be no significant yield depression due to aerial effects. Three important zones were identified based on the transmissivity of the canopy in relation to tree proximity. Moving away from the tree trunk they were 57% 74% and 77%. No significant variation due to aspect effects or daily effects was encountered. The limited amount of data converted to daily totals was inadequate for estimating seasonal variation in detail, however, it did appear that the inter-cropping experiments were carried out during periods of maximum orchard canopy density. The coupling of inexpensive chemical coulometers to the filtered selenum cells to form inexpensive integrating sensors proved particularly useful. The performance of these self-contained units (based upon preliminary tests) should make them suitable for the study of many discontinuous canopies in adequate and terrestrial environments. Further work is required however in order to reduce the cost and increase the flexibility of the discharge unit.

A controlled shade experiment was set up in order to assess the effect of a reduced PAR intensity on the agronomic yield and morphology of radish and to assess the extent to which a shade trial could be useful in genotype selection. Treatments of 100%, 53%, 30% and 10% light were employed. The following measurements of radish morphology and dry weight were used: bulb diameter , length of longest leaf , dry weight of bulb and dry weight of leaves . The most important aspects from an agronomic aspect are bulb diameter and total dry matter. As suspected radish was not an ideal understorey crop in terms of its response to low PAR levels. A 47% reduction in PAR gave a 62% reduction in the mean bulb diameter. Experiments in Russia (Tikhomirov, 1977) have indicated that this linear relationship continues to levels of PAR irradiance greater than would be expected in the field. Shade did not affect total dry weight to such an extent. A 47% reduction in PAR gave a mean total dry weight equivalent to the control, indicating a poor light use efficiency at 100%. This property is ideal in an interculture understorey if total dry matter were required. High total dry matter at 53% light was maintained at the cost of bulb dry weight as indicated by the change from a root: shoot ratio of 1.39 in 100% light to 0.40 in 53% light. This type of response was also reported in Tikomirov 1977. Leaf length was least affected by shade. 10% light gave a drastic response in that the plants did not progress beyond the seedling stage. This treatment was replaced in further studies with light levels more representative of orchard conditions. The presence of individual plants in the 30% light treatment with a bulb diameter equal to the mean bulb diameter of 18mm in the 100% light control indicated the potential for genotype selection. Villareal and Lai (1977) have outlined the importance of screening vegetable varieties for properties of shade tolerance and shallow rooting in order to enhance ecological combining ability with taller associated intercrops. The results of the shade experiment support their suggestions. A shade trial can serve three purposes in the evaluation and optimisation of interculture systems. They are:

(1) to screen suitable genotypes

(2) to characterise the light use efficiency of a potential understorey

(3) to determine the biological basis for any deviations from expected yield.

Point 3 listed above is based upon the assumption that morphological response may be a key in determining operationally important niche variables. For instance if radish plants were grown under a tree canopy with a transmissivity to PAR of 50% and at the same time in a controlled shade trial at 50% PAR, their morphological response of similar would indicate that the quantity of PAR may be implicated.

An experiment was set up in order to quantify the productivity in terms of LER of a pear and radish interculture system. The radish were sown at a number of positions relative to the trees and at a range of spacings. A simultaneous shade experiment was also set up. The yield of the understorey was assessed as total dry matter (tdm) and number of saleable radishes (nsr) per unit area. The optimal sole crop spacing for both nsr and tdm was 3cm. The optimal intercrop spacing for tdm was also 3cm. For nsr the optimal spacing was 3cm in areas away from the tree and 4cm in adjacent areas. At this combined spacing the inner plots gave a yield equivalent to 50% of the outer plots. The inner sub plots represented a smaller cropping area than the outer sub-plots. The aereal effects along with the spacing effects were taken into account when the relative yields of the radish component were calculated. For nsr these values ranged from 0.50-0.65 and for tdm these values ranged from 0.85-1.01. Pear yield was not affected by intercropping (cultivation and presence of radish) for both yield estimates when trunk diameter canopy diameter and position of tree were taken into account. This gives a range of LER values from 1.5-2.01 indicating that 50-100% more land would be required to produce the same yields from sole crops assuming that the sole crops in the experiment were optimally arranged. If one takes the lowest relative yield of radish for total dry matter of 0.85, its productivity would be 3.51 tonnes/ha during the period of maximum canopy density. Assuming it were possible to get 5 crops per year this would give 17.55 tonnes/ha. The average yield of marketable pears for the UK is 20 tonnes/ha this excludes productivity of leaves, branches and non-economic fruit and is stated as fresh weight. The dry weight would be 3.4 tonnes based on my conversion factor of 0.17. The total productivity of pears and radish would be about 21 tonnes/ha/yr.

The biggest problems in assessing LERs for this system were connected with the tree component. The yield of the tree crop was poor during the experimental period and was only determined for one season. The assumption that the tree sole crop was optimally spaced could not be adequately tested. Management rather than yield response is often the major determinant in the spatial arrangements of tree crops. It should also be noted that the intercropped trees had the treatments of rotovation and intercropping compounded. The intercropped radish also did not completely cover the root area of the trees. The analysis of variance on tree yields indicated a strong row effect on tree yields. The position of a tree in the orchard in a NS direction was a more important determinant of yield than whether the tree was intercropped or not. An improved experimental design could now be generated with this information. Information on tree canopy and trunk diameter did not prove to be as useful as expected. Another measure such as height or leaf area may be useful in stratifying the data. Further experimentation is required with a greater cover of intercrops over many seasons.

The light use efficiency of the pear component is high if calculated as yield per unit light interception. In a good year it may be possible to obtain 20 tonnes of fruit for 30% interception. In a commercial orchard the 70% of radiation reaching the ground surface is an expensive problem as herbicides have to be applied to the reduce the growth of unwanted plants. In an interculture system this pattern of light use may be advantageous. Varieties of tree crops selected for interculture would ideally have canopies with erectophile type leaf angles. Significant yield depressions were found in radish sub-plots adjacent to pear trees (positions 3 and 5). A comparison was made between the simultaneous shade experiment and the different positions of sub-plots within the orchard. The yield response variables tdm and nsr were used along with mean bulb diameter, leaf length and root: shoot ratio. The yield depression was greater than would be expected from comparable effects of PAR alone. Discriminent analysis of morphological response indicated that the morphology was significantly different from shade effects. This information along with the previous phytometer analysis led to the hypothesis that root effects were implicated. An experiment using artificial fertilizer was set up in order to investigate whether competition for macronutrients was involved.

An experiment to investigate the effects of the addition of artificial fertilizer was set up the following season. Two levels of fertilizer were used along with a control. Radish was sown at 3 cm spacing in positions 1, 3, 5 and 6. Similar measurements were taken for radish yield and morphology. The results of the analysis indicated that fertilizer did not improve the nbd of radish in the inner positions but did improve tdm. Analysis of the morphological response indicated that some lateral leaching and contamination had occurred during the very damp duration of the experiment. The length of leaves produced by the radish plants at all plots ranged from 17-23 cm where as previous experiments gave values around 13 cm. A change in experimental design is required in order to reduce this contamination in further experiments. This would consist of using tree plots rather than sub-plots for the different treatments and replicates. 9 tree plots would be used (3 replicates of 3 treatments). The main conclusion was that fertilizer would not increase reduced bulb diameters found in the inner positions. The yield suppression found in positions 3 and 5 was probably due to many factors. Previous experiments have shown that the amount of PAR was implicated. Interference for soil water is unlikely as copious rainfall was present throughout the duration of the experiments. One hypothesis that has some support is that soil depth is implicated. The area adjacent to the tree (positions 3 and 5) did have large woody roots near to the soil surface (about 15 cm below). Support for this hypothesis comes from a comparison of yield based on bulb diameter for the three experiments. Results are shown in Table 1. Fertilizer with adequate rainfall did not increase relative yield to the same level as the phytometers. The phytometers were placed under the canopy with the plants growing in a soil depth of over 20 cm. In conclusion there is no clear cut answer to the mechanism involved in yield suppression adjacent to the pear trees. The experimental evidence leads to the hypothesis that the amount of PAR and soil depth are key factors. Selective breeding has an enormous potential for increasing yields-in mixed cropping systems.

Table 1: A comparison of the relative yields of radish grown adjacent to trees in three different experiments measured as mean bulb diameter mm.
(Position A in the phytometer experiment is taken to be equivalent to positions 3 and 5 in the 1981 and 1982 experiments.)

Experimental details	Yield adjacent to tree	Control/sole crop yield	Relative yield
Phytometer experiment	13.0	19.0	0.68
1981 intercropping 3 cm (no fertiliser)	5.7	13.5	0.42
1982 intercropping 3 cm, fertiliser x 2 adequate rainfall. (Sole crop no fertiliser.)	9.0	16.0	0.56

The LER values of 1.5 - 2.0 compare favourably with literature values of 1.1 - 1.4 for field crop mixtures. Values of greater than 2.0 could be expected from interculture systems where the species count is greater than 2.

7.2 Suggestions for further research

1. Other understorey crops where the leaves are the economic part such as lettuce, should be examined in the pear system.

2. Further long term studies are required on the effect of intercropping/cultivation on tree crop yields.

3. Total dry matter and LERs should be determined for more interculture systems.

4. The effects of mulching in order to increase soil depth around the base of trees should be investigated.

5. Further analysis of the 1981 seasons light data would be useful in order to determine optimal spatial and temporal sampling and in order to develop and validate computer models on the PAR transmissivities of a range of idealised discontinuous interculture canopies.

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APPENDICES

SECTION A Results for the phytometer experiment 1980

TABLE 1 Positional variation in the height of pea plants measured in (cm) for phytometer experiment.

Results taken: 25/7/80

Position	Plot 1	2	3	4	CONT.
1	27.00	31.00	27.00	22.00	32.00
2	35.00	26.00	27.00	30.00	31.00
3	28.00	24.00	26.00	32.00	32.00
4	26.00	26.00	30.00	31.00	33.00
5	27.00	36.00	25.00	32.00	32.00
6	29.00	34.00	26.00	18.00	30.00
7	29.00	37.00	34.00	24.00	34.00
8	33.00	25.00	26.00	20.00	22.00
9	26.00	37.00	28.00	34.00	35.00
10	21.00	25.00	26.00	26.00	24.00
11	21.00	30.00	25.00	28.00	27.00
12	22.00	38.00	29.00	34.00	24.00
13	26.00	23.00	25.00	22.00	36.00
14	20.00	25.00	22.00	26.00	29.00
15	21.00	30.00	25.00	28.00	32.00
16	22.00	28.00	26.00	20.00	34.00

TABLE 2 Positional variation in the length of the 5th internode of pea plants (mm) for phytometer experiment.

Results taken: 28/7/80

		Plot				
		1	2	3	4	CONT.
Position	1	23.00	42.00	36.00	26.00	35.00
	2	50.00	51.00	35.00	39.00	48.00
	3	37.00	36.00	34.00	32.00	44.00
	4	51.00	40.00	44.00	38.00	36.00
	5	38.00	53.00	29.00	38.00	35.00
	6	52.00	42.00	38.00	24.00	29.00
	7	52.00	52.00	45.00	27.00	35.00
	8	40.00	40.00	30.00	25.00	35.00
	9	45.00	46.00	50.00	50.00	44.00
	10	35.00	36.00	42.00	56.00	38.00
	11	30.00	45.00	43.00	32.00	35.00
	12	39.00	52.00	45.00	45.00	36.00
	13	54.00	34.00	43.00	35.00	35.00
	14	38.00	45.00	35.00	29.00	30.00
	15	39.00	49.00	30.00	48.00	49.00
	16	51.00	30.00	43.00	25.00	28.00

TABLE 3 Positional variation in the height of pea plants (cm) for phytometer experiment. Results taken: 11/8/80

Position	Plot 1	2	3	4	CONT.
1	48.00	56.00	48.00	48.00	52.00
2	54.00	50.00	54.00	56.00	55.00
3	52.00	53.00	55.00	42.00	49.00
4	49.00	51.00	53.00	47.00	53.00
5	50.00	51.00	42.00	42.00	49.00
6	58.00	46.00	44.00	21.00	49.00
7	50.00	51.00	54.00	45.00	49.00
8	43.00	48.00	40.00	30.00	40.00
9	53.00	52.00	55.00	59.00	55.00
10	49.00	57.00	53.00	63.00	49.00
11	48.00	60.00	54.00	46.00	58.00
12	52.00	54.00	55.00	55.00	45.00
13	52.00	54.00	54.00	52.00	49.00
14	36.00	30.00	49.00	53.00	55.00
15	24.00	54.00	56.00	31.00	51.00
16	51.00	49.00	60.00	37.00	42.00

TABLE 4 Positional variation in the height of pea plants (cm) for the phytometer experiment. Results taken: 28/8/80

Position	Plot 1	2	3	4	CONT.
1	49.00	46.00	49.00	43.50	50.00
2	40.00	33.00	49.00	57.00	61.00
3	52.00	52.00	45.00	50.00	51.00
4	52.00	37.00	48.00	46.00	51.00
5	53.00	39.00	47.00	46.00	48.00
6	55.50	51.00	47.00	38.00	59.00
7	50.00	47.00	46.00	40.00	54.00
8	42.50	52.00	44.00	40.00	49.00
9	48.00	48.00	50.00	41.00	52.00
10	52.00	43.00	49.00	50.00	53.00
11	40.00	49.00	51.00	47.00	48.50
12	53.00	48.00	51.00	52.00	62.00
13	48.00	51.00	45.00	43.00	42.00
14	44.00	40.00	53.00	37.00	43.50
15	35.00	53.00	56.40	35.00	48.50
16	45.00	50.00	46.30	39.00	45.00

TABLE 5 Positional variation in the dry wt. of pods and peas (grams) for phytometer experiment.
Results taken: 17/9/80

Position	Plot 1	2	3	4	CONT.
1	3.52	6.00	4.71	5.31	6.21
2	3.84	4.61	7.35	5.68	6.07
3	6.10	5.74	4.75	4.48	6.71
4	7.15	5.56	2.75	0.09	6.41
5	6.60	5.77	3.05	3.24	5.63
6	7.00	7.11	4.95	4.00	6.83
7	8.31	1.60	5.83	4.60	6.83
8	7.68	1.67	4.67	2.55	3.50
9	6.21	3.08	5.17	5.94	6.30
10	1.82	5.08	4.92	4.71	6.46
11	6.01	6.00	5.18	5.86	3.60
12	5.27	6.75	4.61	6.02	3.75
13	5.00	2.81	4.99	4.88	4.20
14	2.47	2.94	3.87	6.07	3.00
15	2.22	6.60	5.65	0.76	0.89
16	2.76	6.23	3.72	2.45	2.48

TABLE 6 Positioned variation in the weight of pea plants (pods and peas) (grams), for the phytometer experiment
Results taken: 17/9/80

		Plot				
		1	2	3	4	CONT.
Position	1	2.36	4.66	4.13	3.90	5.27
	2	1.81	4.94	4.29	4.45	4.28
	3	5.01	4.26	4.80	4.00	6.72
	4	6.07	3.29	4.75	7.00	4.30
	5	5.55	5.22	4.00	6.06	6.03
	6	3.36	4.22	4.27	3.27	5.08
	7	4.75	2.69	4.17	3.52	5.43
	8	3.69	4.65	6.36	3.42	5.51
	9	5.09	3.55	4.34	4.84	5.39
	10	2.86	5.10	3.42	4.58	3.73
	11	3.79	4.70	3.52	4.30	6.00
	12	4.78	4.48	4.93	4.01	3.75
	13	5.69	5.75	5.95	5.20	4.30
	14	2.22	4.58	4.32	4.79	5.50
	15	5.20	5.76	4.91	3.14	5.50
	16	2.56	4.96	4.09	5.00	6.30

TABLE 7 Positioned variation in carrot plant height the phytometer experiment
Results taken: 28/8/80

		Plot				
		1	2	3	4	CONT.
	1	23.50	18.00	13.00	19.00	19.00
	2	25.00	29.00	19.00	28.00	17.00
	3	15.00	13.00	15.00	15.00	15.00
	4	24.00	24.50	22.00	26.00	19.00
	5	7.00	27.00	26.00	29.00	20.00
	6	16.00	31.00	20.00	17.00	18.00
	7	29.00	10.00	13.00	13.00	6.00
Position	8	16.00	27.00	10.00	25.00	10.00
	9	28.00	24.00	24.00	25.00	12.00
	10	14.50	24.00	23.50	24.50	17.00
	11	18.00	26.00	13.50	26.50	15.00
	12	25.00	28.00	10.00	11.50	19.00
	13	18.00	27.00	23.00	19.50	18.50
	14	21.50	19.00	20.00	22.50	20.50
	15	11.00	23.00	22.00	22.50	18.00
	16	18.00	26.00	23.00	28.00	16.50

TABLE 8 Positional variation in the dry wt. of carrot tubers (grams) for phytometer experiment
Results taken: 10/10/80

		Plot				
		1	2	3	4	CONT.
	1	0.71	0.34	1.14	2.50	2.80
	2	0.57	2.99	1.24	2.10	3.13
	3	2.00	0.80	0.33	0.90	0.98
	4	1.40	2.00	1.49	1.63	1.50
	5	1.80	1.69	1.31	1.65	1.00
	6	1.90	1.14	1.20	1.80	1.30
	7	1.80	3.54	1.42	0.99	2.22
Position	8	2.53	1.29	1.30	1.40	0.67
	9	1.40	1.81	0.55	1.60	3.60
	10	0.94	2.00	3.00	2.50	3.14
	11	0.72	2.76	0.57	0.60	2.75
	12	1.34	0.58	0.85	0.99	2.85
	13	2.07	0.83	1.25	1.30	0.80
	14	0.49	2.02	1.36	1.50	3.13
	15	3.01	2.00	1.30	1.50	0.50
	16	1.42	1.79	1.33	1.40	0.89

TABLE 9 Positional variation in radish bulb diameter measured in (mm) for phytometer experiment
Results taken: 28/8/80

		Plot				
		1	2	3	4	CONT.
Position	1	19.00	15.00	16.00	22.00	23.00
	2	15.00	15.00	3.00	19.00	20.00
	3	3.00	23.00	3.00	21.00	26.00
	4	3.00	24.00	3.00	3.00	3.00
	5	20.00	19.00	14.00	25.00	20.00
	6	9.00	12.00	22.00	26.00	10.00
	7	27.00	21.00	24.00	10.00	15.00
	8	16.00	26.00	25.00	21.00	28.00
	9	10.00	15.00	18.00	25.00	10.00
	10	23.00	14.00	8.00	30.00	27.00
	11	29.00	29.00	19.00	28.00	24.00
	12	25.00	12.00	18.00	10.00	11.00
	13	5.00	2.00	27.00	19.00	18.00
	14	7.00	15.00	22.00	17.00	19.00
	15	9.00	20.00	22.00	29.00	17.00
	16	23.00	19.00	3.00	5.00	27.00

TABLE 10 Positional variation in height of onion plants measured in (cm) for phytometer experiment

Results taken: 24/7/80

	Plot 1	2	3	4	CONT.
Position 1	39.00	38.00	51.00	36.00	34.00
2	25.00	26.00	44.00	49.00	40.00
3	45.00	38.00	41.00	39.00	33.00
4	46.00	38.00	49.00	53.00	37.00
5	36.00	31.00	37.00	38.00	45.00
6	39.00	43.00	49.00	46.00	41.00
7	34.00	43.00	38.00	44.00	41.00
8	37.00	41.00	39.00	37.00	38.00
9	38.00	45.00	45.00	47.00	40.00
10	45.00	39.00	41.00	48.00	44.00
11	45.00	43.00	37.00	41.00	34.00
12	34.00	40.00	30.00	51.00	22.50
13	42.00	48.00	38.00	48.00	29.00
14	39.00	43.00	46.00	44.00	48.20
15	41.00	46.00	48.00	43.00	41.60
16	48.00	25.00	28.00	42.00	34.00

TABLE 11 Positioned variation in height of onion plants for phytometer experiment
Results taken: 14/8/80

		Plot				
		1	2	3	4	CONT.
	1	49.00	44.00	59.00	39.00	36.00
	2	30.00	31.00	47.00	53.00	48.00
	3	60.00	48.00	48.00	44.00	40.00
	4	50.00	39.00	55.00	58.00	45.00
	5	39.00	34.00	39.00	45.00	59.00
	6	56.00	51.00	57.00	52.00	48.00
	7	42.00	46.00	41.00	48.00	51.00
Position	8	38.00	46.00	43.00	45.00	44.00
	9	43.00	47.00	48.00	52.00	51.00
	10	56.00	41.00	44.00	51.00	59.00
	11	49.00	38.00	48.00	44.00	51.00
	12	44.00	49.00	38.00	57.00	48.00
	13	41.00	51.00	39.00	58.00	38.00
	14	45.00	54.00	49.00	44.00	58.00
	15	45.00	56.00	56.00	48.00	48.00
	16	50.00	38.00	32.00	45.00	48.00

TABLE 12 Bulb diameter of onion plants (mm) for phytometer experiment

Results taken: 14/8/80

		Plot				
		1	2	3	4	CONT.
	1	34.00	31.00	34.00	35.00	35.00
	2	7.00	33.00	31.00	31.00	40.00
	3	34.00	36.00	34.00	38.00	32.00
	4	32.00	30.00	50.00	41.00	35.00
	5	40.00	34.00	35.00	40.00	38.00
	6	31.00	40.00	40.00	39.00	43.00
	7	18.00	32.00	42.00	40.00	37.00
Position	8	14.00	36.00	35.00	38.00	33.00
	9	12.00	34.00	39.00	36.00	35.00
	10	32.00	29.00	34.00	45.00	34.00
	11	38.00	40.00	39.00	38.00	10.00
	12	31.00	40.00	30.00	38.00	14.00
	13	33.00	33.00	40.00	42.00	32.00
	14	34.00	35.00	30.00	40.00	28.00
	15	40.00	42.00	42.00	41.00	33.00
	16	40.00	12.00	38.00	39.00	27.00

TABLE 13 Dry wt. of onion plants (g) for phytometer experiment

Results taken: 2/10/80

		Plot				
		1	2	3	4	CONT.
Position	1	3.46	2.79	2.43	1.57	3.00
	2	0.75	1.51	4.28	8.00	9.87
	3	6.23	4.26	7.73	6.10	9.16
	4	4.34	1.61	3.01	5.20	5.08
	5	4.84	4.03	2.39	2.94	5.24
	6	11.20	4.50	4.62	8.15	6.40
	7	4.98	4.39	5.43	2.34	2.87
	8	6.26	5.39	6.24	2.57	5.00
	9	2.18	4.00	7.94	7.72	10.92
	10	7.74	3.12	6.70	8.73	7.47
	11	3.00	3.71	5.24	4.54	1.41
	12	2.50	3.49	0.82	6.17	5.12
	13	3.37	3.79	2.99	3.77	8.89
	14	5.30	3.08	7.01	4.81	3.03
	15	4.69	7.02	2.29	5.41	4.49
	16	6.13	3.45	2.67	3.54	7.43

TABLE 14 Positional variation in the bulb diameter of onion plants (mm) for phytometer experiment
Results taken: 2/10/80

		Plot				
		1	2	3	4	CONT.
Position	1	4.00	3.70	3.90	3.40	4.50
	2	2.30	3.60	4.10	4.90	5.50
	3	5.80	4.60	5.20	5.20	5.10
	4	4.50	3.60	3.70	4.60	4.90
	5	4.90	4.30	3.70	3.90	4.60
	6	5.70	4.40	4.90	5.90	5.20
	7	4.20	4.60	4.90	3.80	4.00
	8	4.80	4.90	4.50	3.70	4.50
	9	3.70	4.10	5.20	5.00	5.70
	10	5.60	3.70	5.20	5.70	5.10
	11	4.20	4.30	4.60	4.50	2.90
	12	3.70	4.40	2.60	5.00	4.80
	13	4.50	4.70	4.10	4.00	5.60
	14	4.70	3.90	5.50	5.00	5.60
	15	4.70	5.10	4.10	5.00	4.50
	16	4.40	3.80	3.60	4.40	4.90

SECTION B Results for the 1981 controlled shade experiment

Table 1: Measurement of bulb diameter, leaf length, bulb dry wt and leaf length for radish grown at 53% light.

Plant identi- fication (no.)	Fresh bulb diameter (mm)	Fresh leaf length (mm)	Bulb dry wt (g)	Leaf dry wt (g)
1	10.	82.	0.10	0.48
2	7.	50.	0.11	0.17
3	4.	50.	0.04	0.17
4	5.	30.	0.07	0.11
5	6.	52.	0.06	0.15
6	10.	80.	0.03	0.40
7	3.	20.	0.01	0.19
8	2.	55.	0.01	0.12
9	16.	45.	0.18	0.21
10	11.	20.	0.14	0.08
11	7.	20.	0.12	0.10
12	10.	60.	0.21	0.27
13	11.	80.	0.07	0.25
14	9.	50.	0.10	0.16
15	6.	60.	0.08	0.20
16	2.	40.	0.01	0.08
17	4.	62.	0.20	0.46
18	6.	90.	0.05	0.57
19	11.	60.	0.11	0.16
20	12.	60.	0.24	0.27
21	4.	60.	0.07	0.12
22	8.	42.	0.06	0.11
23	8.	40.	0.07	0.21
24	13.	60.	0.11	0.27
25	10.	86.	0.15	0.27
26	10.	63.	0.16	0.22
27	19.	54.	0.23	0.26
28	8.	50.	0.08	0.24
29	15.	64.	0.12	0.14
30	20.	85.	0.28	0.38
31	8.	70.	0.06	0.37
32	12.	95.	0.16	0.30
33	2.	48.	0.02	0.16
34	7.	52.	0.02	0.15
35	10.	68.	0.09	0.29
36	5.	35.	0.07	0.41
37	6.	40.	0.09	0.17
38	3.	16.	0.01	0.04
39	6.	68.	0.06	0.19
40	7.	80.	0.06	0.20
41	5.	50.	0.03	0.13
42	3.	40.	0.03	0.27
43	5.	50.	0.02	0.04
44	3.	70.	0.05	0.26
45	9.	55.	0.11	0.33
46	6.	60.	0.02	0.22
47	4.	45.	0.07	0.16
48	3.	25.	0.03	0.16
49	2.	15.	0.03	0.07
50	4.	40.	0.06	0.23

Table 2: Measurement of bulb diameter, leaf length, bulb dry wt and leaf length for radish grown at 100% light.

Plant identification (no.)	Fresh bulb diameter (mm)	Fresh leaf length (mm)	Bulb dry wt (g)	Leaf dry wt (g)
1	25.	90.	0.41	0.23
2	19.	60.	0.25	0.09
3	24.	82.	0.36	0.11
4	20.	41.	0.16	0.11
5	31.	104.	0.90	0.16
6	12.	109.	0.24	0.39
7	24.	95.	0.43	0.30
8	23.	81.	0.26	0.13
9	23.	79.	0.34	0.18
10	18.	61.	0.21	0.16
11	25.	81.	0.32	0.22
12	22.	64.	0.36	0.14
13	23.	76.	0.13	0.12
14	20.	84.	0.13	0.15
15	21.	57.	0.19	0.21
16	19.	65.	0.21	0.11
17	22.	79.	0.37	0.15
18	21.	45.	0.23	0.19
19	19.	92.	0.20	0.29
20	17.	78.	0.19	0.25
21	18.	61.	0.12	0.09
22	26.	75.	0.38	0.17
23	19.	89.	0.25	0.33
24	19.	69.	0.22	0.20
25	19.	61.	0.16	0.10
26	20.	55.	0.19	0.14
27	16.	86.	0.13	0.17
28	17.	67.	0.15	0.17
29	9.	73.	0.06	0.08
30	18.	61.	0.14	0.09
31	17.	60.	0.40	0.15
32	16.	54.	0.12	0.08
33	14.	66.	0.08	0.10
34	19.	74.	0.13	0.07
35	13.	59.	0.11	0.09
36	17.	69.	0.14	0.11
37	10.	80.	0.08	0.12
38	14.	66.	0.13	0.14
39	9.	59.	0.06	0.08
40	18.	78.	0.14	0.11
41	12.	59.	0.18	0.28
42	15.	68.	0.15	0.17
43	12.	61.	0.09	0.11
44	9.	80.	0.11	0.16
45	7.	48.	0.03	0.13
46	16.	90.	0.11	0.12
47	14.	69.	0.09	0.08
48	16.	88.	0.08	0.14
49	15.	55.	0.14	0.09
50	12.	56.	0.09	0.08

Table 3: Measurement of bulb diameter, leaf length, bulb dry wt and leaf length for radish grown at 30% light.

Plant identi-fication (no.)	Fresh bulb diameter (mm)	Fresh leaf length (mm)	Bulb dry wt (g)	Leaf dry wt (g)
1	15.	76.	0.09	0.17
2	2.	60.	0.02	0.12
3	10.	50.	0.07	0.24
4	12.	70.	0.03	0.11
5	8.	60.	0.04	0.12
6	11.	50.	0.06	0.09
7	1.	10.	0.01	0.04
8	5.	12.	0.03	0.14
9	10.	55.	0.07	0.13
10	2.	48.	0.02	0.09
11	8.	28.	0.04	0.08
12	1.	43.	0.02	0.07
13	6.	36.	0.03	0.15
14	18.	12.	0.12	0.25
15	2.	70.	0.03	0.17
16	7.	73.	0.05	0.23
17	12.	82.	0.23	0.23
18	5.	62.	0.02	0.09
19	2.	50.	0.02	0.08
20	2.	50.	0.02	0.10
21	9.	60.	0.07	0.12
22	3.	62.	0.03	0.20
23	8.	60.	0.03	0.19
24	5.	50.	0.03	0.11
25	7.	65.	0.03	0.18
26	12.	20.	0.04	0.11
27	2.	40.	0.01	0.09
28	6.	32.	0.02	0.12
29	6.	50.	0.02	0.11
30	10.	36.	0.07	0.12
31	3.	10.	0.04	0.17
32	7.	62.	0.05	0.17
33	6.	54.	0.04	0.14
34	3.	40.	0.02	0.14
35	5.	58.	0.02	0.08
36	5.	82.	0.04	0.12
37	1.	48.	0.01	0.03
38	4.	60.	0.03	0.38
39	3.	73.	0.04	0.20
40	2.	70.	0.01	0.12
41	4.	80.	0.04	0.17
42	6.	58.	0.03	0.20
43	1.	40.	0.01	0.05
44	2.	35.	0.01	0.10
45	2.	43.	0.05	0.12
46	2.	35.	0.02	0.07
47	2.	42.	0.02	0.08
48	2.	41.	0.01	0.12
49	2.	50.	0.02	0.08
50	2.	44.	0.04	0.06

Table 4: Measurement of bulb diameter, leaf length, bulb dry wt and leaf length for radish grown at 10% light.

Plant identification (no.)	Fresh bulb diameter (mm)	Fresh leaf length (mm)	Bulb dry wt (g)	Leaf dry wt (g)
1	1.	40.	0.01	0.01
2	1.	20.	0.02	0.04
3	1.	41.	0.01	0.03
4	1.	40.	0.01	0.03
5	1.	46.	0.01	0.03
6	1.	23.	0.01	0.02
7	1.	40.	0.03	0.03
8	1.	26.	0.01	0.03
9	1.	65.	0.01	0.03
10	1.	42.	0.01	0.06
11	1.	34.	0.01	0.04
12	1.	24.	0.01	0.02
13	1.	38.	0.01	0.08
14	1.	28.	0.01	0.02
15	1.	30.	0.01	0.01
16	1.	13.	0.01	0.04
17	1.	26.	0.01	0.03
18	1.	23.	0.01	0.05
19	1.	62.	0.01	0.11
20	1.	21.	0.01	0.02
21	1.	18.	0.01	0.02
22	1.	30.	0.01	0.01
23	1.	20.	0.01	0.01
24	1.	31.	0.01	0.06
25	1.	29.	0.01	0.01
26	1.	15.	0.01	0.02
27	1.	25.	0.01	0.01
28	1.	28.	0.01	0.02
29	1.	26.	0.01	0.04
30	1.	18.	0.01	0.01
31	1.	33.	0.01	0.02
32	1.	42.	0.01	0.04
33	1.	36.	0.01	0.06
34	1.	32.	0.01	0.06
35	1.	40.	0.01	0.03
36	1.	35.	0.01	0.04
37	1.	20.	0.01	0.08
38	1.	30.	0.01	0.02
39	1.	23.	0.03	0.03
40	1.	24.	0.02	0.03
41	1.	5.	0.01	0.02
42	1.	38.	0.02	0.01
43	1.	44.	0.01	0.03
44	1.	27.	0.01	0.01
45	1.	20.	0.01	0.01
46	1.	19.	0.01	0.01
47	1.	20.	0.01	0.02
48	1.	25.	0.01	0.01
49	1.	21.	0.01	0.01
50	1.	24.	0.01	0.02

SECTION C Results for the 1981 intercropping experiment with results for simultaneous shade treatments

Table 1: The yields of control pear trees (fresh weight of saleable pears and dry weight of saleable and non-saleable pears for various trees of known canopy and trunk diameter)

Tree Identification No.	Trunk Diameter (cm)	Canopy Diameter (cm)	Fresh weight of saleable pears (g)	Dry weight of saleable and non-saleable pears (g)
1	14	280	454	116
2	13	290	0	10
3	9	225	0	0
4	13	320	0	77
5	17	345	454	270
6	13	285	0	96
7	14	320	1,502	872
8	16	315	0	77
9	14	380	1,021	328
10	18	405	454	386
11	12	265	0	77
12	7	150	0	77
13	8	190	1,361	540
14	14	340	0	77
15	18	425	907	386
16	13	310	0	270
19	15	305	680	289
20	18	435	283	222
21	15	330	1,361	463
25	12	275	3,289	848
29	12	295	3,742	848
32	16	355	1,361	521
35	14	340	680	193
36	8	190	1,701	713
37	14	320	1,814	424
39	15	350	2,155	540

Table 2: The yields of intercropped pear trees (fresh weight of saleable pears and dry weight of saleable and non-saleable pears for various trees of known canopy and trunk diameter)

Tree Identification No.	Trunk Diameter (cm)	Canopy Diameter (cm)	Fresh weight of saleable pears (g)	Dry weight of saleable and non-saleable pears (g)
17	10	210	1,814	704
18	14	325	227	323
22	15	335	0	63
23	15	330	1,814	925
26	13	335	2,948	1,253
27	11	290	2,041	1,152
30	9	185	680	405
31	12	310	1,134	945
33	16	400	680	713

Table 3 : Effects of position and density on performance of radish planted 10.7.81

Spacing cm	Replicate no.	Position	Mean bulb diameter mm	No. of bulbs ≥ 10 mm in dia.	Mean leaf length mm	Mean bulb dry wt. g	Mean leaf dry wt. g	Mean total dry wt. g	Mean root: shoot ratio
3	1	Control	14	43	127	0.17	0.15	0.32	1.13
3	2	Control	13	36	133	0.17	0.20	0.37	0.85
3	1	1	10	27	148	0.10	0.17	0.27	0.59
3	1	3	4	3	99	0.06	0.15	0.21	0.40
3	1	5	3	2	93	0.05	0.15	0.20	0.33
3	1	6	10	25	140	0.10	0.20	0.30	0.50
3	2	1	11	31	150	0.19	0.34	0.53	0.56
3	2	3	9	20	155	0.12	0.29	0.41	0.41
3	2	5	5	10	99	0.07	0.16	0.23	0.44
3	2	6	10	25	154	0.15	0.22	0.37	0.68
3	3	1	11	32	136	0.20	0.21	0.41	0.95
3	3	3	6	10	132	0.04	0.15	0.19	0.27
3	3	5	7	17	133	0.09	0.16	0.25	0.56
3	3	6	15	37	128	0.16	0.26	0.42	0.62
4	1	Control	16	43	127	0.21	0.21	0.42	1.00
4	2	Control	15	44	118	0.25	0.25	0.50	1.00
4	1	1	17	40	149	0.20	0.34	0.54	0.59
4	1	3	11	31	140	0.11	0.22	0.33	0.50
4	1	5	9	27	126	0.14	0.31	0.45	0.45
4	1	6	16	42	152	0.18	0.23	0.41	0.78
4	2	1	14	41	134	0.21	0.28	0.49	0.75
4	2	3	11	34	152	0.12	0.21	0.33	0.57
4	2	5	4	6	76	0.07	0.19	0.26	0.37
4	2	6	15	40	163	0.21	0.28	0.49	0.75
4	3	1	15	39	127	0.20	0.32	0.52	0.63
4	3	3	11	32	113	0.18	0.24	0.42	0.75
4	3	5	9	28	92	0.17	0.20	0.37	0.85
4	3	6	15	44	149	0.23	0.30	0.53	0.77
5	1	Control	17	45	123	0.27	0.32	0.59	0.84
5	2	Control	18	46	109	0.30	0.35	0.65	0.86
5	1	1	17	50	124	0.27	0.29	0.56	0.93
5	1	3	15	41	135	0.25	0.38	0.63	0.66
5	1	5	9	24	139	0.18	0.28	0.46	0.64
5	1	6	17	45	127	0.21	0.28	0.49	0.75
5	2	1	14	45	120	0.19	0.29	0.48	0.66
5	2	3	7	16	111	0.07	0.19	0.26	0.37
5	2	5	12	36	99	0.13	0.15	0.28	0.87
5	2	6	19	47	133	0.31	0.27	0.58	1.15
5	3	1	16	45	134	0.29	0.33	0.62	0.88
5	3	3	11	33	115	0.14	0.24	0.38	0.58
5	3	5	5	9	148	0.07	0.16	0.23	0.44
5	3	6	16	41	128	0.22	0.24	0.46	0.92

Table 4: Effects of position, density and controlled shade on performance of radish planted 13.7.81

Spacing cm	Replicate No.	Position	Mean bulb diameter mm	No. of bulbs ≥ 10 mm in dia.	Mean leaf length mm	Mean bulb dry wt. g	Mean leaf dry wt. g	Mean total dry wt. g	Mean root: shoot ratio
4	1	Control	16	45	96	0.27	0.21	0.48	1.29
4	2	Control	17	48	117	0.26	0.24	0.50	1.08
4	1	2	16	42	131	0.15	0.25	0.40	0.60
4	1	4	14	44	141	0.17	0.38	0.55	0.45
4	2	2	13	38	144	0.15	0.23	0.38	0.65
4	2	4	10	23	161	0.14	0.33	0.47	0.43
4	3	2	16	42	144	0.26	0.29	0.55	0.90
4	3	4	13	38	152	0.16	0.26	0.42	0.62
4	1	65% light	15	40	172	0.18	0.30	0.48	0.38
4	1	53% light	12	37	156	0.18	0.28	0.46	0.64
4	1	24% light	3	2	139	0.02	0.12	0.14	0.17

SECTION D Results for the 1982 Fertilizer Experiment

Table 1 The response of sole crop radish sown at 3 cm spacing to three levels of artificial fertilizer (n=20)

Fertilizer dose rate	Replicate no	$\bar{x}$ bulb dia (mm)	No of bulbs ≥ 10 mm	$\bar{x}$ leaf length mm	$\bar{x}$ bulb dry wt (g)	$\bar{x}$ leaf dry wt (g)
0	1	17	16	151	0.63	0.47
1	1	19	20	174	0.58	0.57
2	1	16	14	199	0.80	0.54
0	2	16	17	150	0.50	0.50
1	2	14	14	182	0.53	0.48
2	2	18	19	190	0.53	0.68
0	3	16	16	156	0.42	0.56
1	3	16	17	163	0.62	0.64
2	3	19	19	173	0.71	0.76

Table 2 The response to intercropped radish sown at 3 cm spacing to three levels of artificial fertilizer at four different positions relating to pear trees.

Position	Fertilizer dose rate	Replicate no	$\bar{x}$ bulb dia(mm)	No of bulbs ≥ 10 mm	$\bar{x}$ leaf length (mm)	$\bar{x}$ bulb dry wt. (g)	$\bar{x}$ leaf dry wt. (g)
1	0	1	9	8	224	0.14	0.32
1	1	1	10	9	230	0.23	0.56
1	2	1	10	11	220	0.44	0.48
3	0	1	7	5	189	0.22	0.41
3	1	1	9	6	204	0.16	0.47
3	2	1	9	8	213	0.25	0.51
5	0	1	8	10	171	0.24	0.37
5	1	1	6	5	218	0.21	0.41
5	2	1	6	4	211	0.19	0.37
6	0	1	10	12	176	0.19	0.32
6	1	1	9	7	221	0.19	0.49
6	2	1	9	8	208	0.27	0.44
1	0	2	11	11	236	0.30	0.45
1	1	2	11	11	262	0.29	0.62
1	2	2	12	10	278	0.48	0.72
3	0	2	10	8	230	0.21	0.56
3	1	2	5	3	252	0.12	0.43
3	2	2	7	5	247	0.14	0.47
5	0	2	5	3	174	0.22	0.38
5	1	2	6	16	211	0.18	0.41
5	2	2	7	3	227	0.22	0.52
6	0	2	10	11	122	0.26	0.23
6	1	2	9	8	167	0.23	0.29
6	2	2	15	17	200	0.37	0.48
1	0	3	12	13	232	0.23	0.57
1	1	3	13	14	209	0.38	0.50
1	2	3	13	15	239	0.29	0.55
3	0	3	7	3	235	0.18	0.46
3	1	2	8	5	208	0.18	0.40
3	2	3	6	4	201	0.13	0.4
5	0	3	3	0	138	0.12	0.23
5	1	3	7	1	138	0.25	0.27
5	2	3	6	4	157	0.15	0.37
6	0	3	10	9	135	0.28	0.33
6	1	3	9	8	135	0.26	0.30
6	2	3	12	15	191	0.43	0.52