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OPTIMISING ESTABLISHMENT OF WINTER OILSEED RAPE ON CLAYS

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OPTIMISING ESTABLISHMENT OF WINTER OILSEED RAPE ON CLAYS

by

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1 SUMMARY

Establishment of oilseed rape is particularly difficult on clay soils, especially when straw is incorporated. This represents a significant problem to the industry as most oilseed rape (70%) is grown on clay soils. This document reviews the factors which influence the establishment of oilseed rape on clay soils. This is achieved by first detailing the physical and chemical requirements of a rape seed for germination and also the factors which may act to inhibit germination and impede the development of the young seedling.

The ability of clay soils to provide a suitable environment for the germination and subsequent establishment of a rape plant are examined. The important factors for this process are; the underlying soil structure and its ability to produce a natural seedbed by weathering, the soil's amenity to mechanical conditioning to produce a suitable seedbed, previous cropping, moisture supply, pests and diseases. This work indicates that it is impossible to define the seedbed and population of rape which will establish purely on the basis of the type of cultivation machinery used. It is concluded that there is no single engineering solution or simple prescription for obtaining an ideal seedbed.

The interactions between soil type, previous crop, moisture supply and cultivation are examined, both in the context of producing a suitable seedbed and in terms of post-cultivation effects on pests, diseases and the physical environment of the seedling.

These analyses are synthesised into a number of '*Decision Trees*' which plot the likely progress of given options on different soil types under a standard set of conditions (dry, wet, normal, plus straw, without straw) and thus suggest the best strategies for successful establishment under these different scenarios.

The review concludes with a number of R&D recommendations, the principal one being a pressing need to establish a 'testbed' system where all biotic and abiotic factors can be monitored in order to determine the precise effects of different seasonal conditions and cultivation techniques on oilseed rape performance, and thereby to validate the decision trees.

Whilst oilseed rape is grown predominantly as a break crop on clay soils in the east of England, approximately 30% is grown on lighter, better-structured soils. A better understanding of the seed establishment process could allow a) earlier sowing of seed in these soils, and b) precision drilling, which enables reduced seed rates to be used, a particularly important point given the extra cost of new hybrid rape varieties.

2 INTRODUCTION

Oilseed rape is grown because it is arguably the most profitable break crop to cereals on clay soils. Currently, oilseed rape is the third largest combinable crop in the UK (approx 500,000 ha) where it is grown mainly on clay soils (approx 70% of area). In 1993/94, 60% was sown to winter rape. Temperatures greater than 10°C are required for rapid germination and seedling growth, hence, winter oilseed rape typically needs to be sown by mid-September. The process of establishing oilseed rape on clay soils at relatively high temperatures in early autumn is potentially difficult because:-

- the seeds are very small (*c.* 2 mm diameter) and require a moist, fine tilth for water uptake (imbibition), and
- a moist, fine tilth is difficult to achieve on clay soils during a period when loss of moisture by evaporation is normally high, and
- the time available is very restricted, particularly after a late wheat harvest.

Up until the straw-burning ban, farmers made good use of the natural tilth that had developed in the surface 1-3cm of self-mulching clays prior to cereal harvest. In most years, oilseed rape was established either by direct drilling into the natural tilth or drilling after shallow cultivations. In this situation, loss of soil moisture was minimised and establishment became a problem only in very dry seasons.

The introduction of the straw-burning ban in July 1992 made oilseed rape establishment inherently more difficult because of the need to incorporate straw. The implications of this are:-

- substantial amounts of straw on the soil surface or shallowly incorporated; straw inhibits penetration and cause blocking of most conventional seed drills, hence deeper incorporation of straw is required,

- the deeper cultivations cause loss of natural tilth, bring to the surface more cloddy soil and encourage loss of soil moisture,

- therefore, the opportunity to drill oilseed rape into a shallow cultivated natural tilth free of straw, afforded by burning, no longer exists.

Apart from increased time and expense, incorporation of chopped straw into clays does not necessarily cause establishment problems provided there is adequate soil moisture and the soil is friable. However, if the soil is too dry, then tilth loss during straw incorporation exceeds the farmers' ability to create new tilth through cultivations.

The consequences of inadequate tilth in seedbeds are:-

- reduced imbibition, leading to
- reduced germination, and
- delayed and uneven emergence.
- increased risk of slug damage, and
- reduced profitability (particularly if there is a need to plough-out and re-drill).

The process of incorporating straw under warm, dry conditions can cause very high moisture loss and further exacerbate the problem of reduced imbibition. Under very dry conditions, it is virtually impossible to incorporate straw effectively and achieve a suitable, fine tilth for subsequent oilseed rape germination.

Successful establishment of oilseed rape is not just dependent on seedbed preparation and seed germination. Establishment is a more complex process that can be separated into three distinct phases:-

Phase I -	seedbed preparation → sowing → germination,
Phase II -	germination → emergence,
Phase III -	emergence → establishment.

Plant losses occur at each phase, e.g. seed can fail to germinate in phase I if a moist, fine tilth is lacking; in phase II, emerging seedlings can be grazed by slugs or killed-off by disease; and in phase III, small plants can lose out to competition from weeds or be eaten by pigeons. An established plant is defined as one which survives the three phases of establishment and contributes to the final yield of the crop.

2.1 Objectives of the review

The first objective of this review is to identify best practice cultivation methods for incorporating straw and drilling oilseed rape into clays. This is achieved through an improved understanding of how seedbed formation and germination processes are influenced by soil, climatic and agronomic factors during the establishment of oilseed rape. Information from a range of sources is used, including: large-scale comparative field trials where straw incorporation treatments have been taken to yield; in-depth field experiments where there have been detailed measurements of soil structure; laboratory / glasshouse pot studies; and knowledge of the behaviour of clay soils.

This review will consequently act as a synthesis of results from previous experiments concerning the establishment issues (Table 1) and will build on this evidence. On the basis of an improved understanding, a set of best practice guidelines (in the form of a Decision Tree) is presented to enable farmers to make more-informed decisions. The concept of *risk* associated with such decisions is covered.

The other two principal objectives are:

- to identify those factors which detract from achieving satisfactory establishment, in particular the most serious causes of oilseed rape plant loss during the three phases of establishment,
- to indicate areas of high priority for further investigation which will allow farmers to optimise the establishment process and maximise profitability.

The approach taken to achieve these objectives is to first develop, from first principles, an improved understanding of the complex processes involved in seedbed formation and plant establishment when growing oilseed rape on clay soils. The understanding will then be developed by using information from field and laboratory experiments and farm experience (Table 1).

Table 1. Sources of experimental data used in the review.

Experiment, review etc...	Funding body
IACR Rothamsted, Straw disposal before winter rape, 1986-89	MAFF
ADAS, Long-term straw incorporation sites, 1987-1993	MAFF
ADAS, Broadcasting rape seed into standing wheat, 1986-1989	MAFF
IACR, Broadcasting rape seed into standing wheat, 1987-1988	MAFF
ADAS, Establishment of rape in the presence of straw, 1991-1993	HGCA
Silsoe college, Development of direct drilling techniques, 1992-1993	HGCA
University of Nottingham, The relationship between plant establishment and yield of autumn sown oilseed rape, 1991-1993	HGCA
IACR Rothamsted, Weeds in oilseed crops, 1991	HGCA
Velcourt, Straw incorporation, 1991-1993	Velcourt

3 THE PROCESS OF ESTABLISHMENT

Sylvester-Bradley & Makepeace (1984) have divided the phenological development of oilseed rape into seven overlapping stages: germination and emergence, leaf production, stem extension, flower bud development, flowering, pod development and seed development. Overlying this, the *establishment* of a plant must be considered. An established plant can be defined as one which contributes to the economic yield of the crop. Establishment is the culmination of three distinct, yet sequentially linked, phases:

Phase I - seedbed preparation → sowing → germination,
Phase II - germination → emergence,
Phase III - emergence → establishment.

Within each of these phases is a number of factors which can be partially manipulated to affect the final establishment of the plant/crop. Final establishment is affected by many processes which start even before the seed is sown. To understand the ideal requirements for seedbed preparation (phase I), it is first necessary to determine the requirements of an oilseed rape seed for germination and emergence (i.e. phase II). Consequently, this review will consider the phases of establishment in the order II, I, III in Sections 3.1/3.2, 4 and 5 respectively.

3.1 The seeds' requirements for germination

The process of germination lasts from the initiation of metabolic activity in the seed until the emergence of the radicle from the ruptured seed coat. The following four factors influence germination:

- physiological (dormancy/light) requirements of the seed,
- moisture supply,
- temperature,
- oxygen supply.

Successful germination is the result of a satisfactory balance of all four factors. Further factors may operate to prevent germination:

- soil and seed-borne diseases,
- soil-borne toxins,
- slugs.

3.1.1 Physiological requirement of the seed

Oilseed rape seeds sown in the autumn do not appear to demonstrate primary field dormancy, and will germinate as soon as other controlling factors (moisture, oxygen, temperature) are suitable. However, in the absence of sufficient moisture, seeds may become light sensitive, i.e. they become dormant and require light to germinate (Lutman, 1994). It is probable that oilseed rape seeds do not require a period in the dark before they will germinate, as they will germinate on the soil surface. There are genotypic differences in the development of dormancy, and dormant seed can remain viable for at least five years (Lutman, 1994).

3.1.2 Moisture supply

Moisture uptake by seeds (imbibition) is a crucial step in promoting germination. The first stage of germination of the rape seed is the softening of the seed coat (or testa) with the uptake of water under suitable gaseous and thermal conditions. Under controlled laboratory conditions, seeds need to reach a moisture content of approximately 40 per cent to commence germination (S. McWilliam, unpublished). Cotyledon expansion causes the testa to rupture which assists further uptake of water and oxygen.

The quantity of moisture necessary in the soil to achieve 40% imbibition of water in the seed is not well defined, but different soil types require different quantities of water in the soil profile to provide similar amounts of 'available' water (measured as soil matrix potentials, ψ_m, Table 2).
The relationship between soil type, moisture content and "available" moisture is reasonably well understood, and a simple system based on soil series and gravimetric samples (i.e. difference between soil weight before and after drying in an oven) could be developed for the grower.

Table 2. Germination of rape seeds in two contrasting loam soils (adapted from Williams & Shaykewich, 1971).

	silty loam		loam	
ψ_{m^*} (bar)	soil water (%)	time to 60% germination (h)	soil water (%)	time to 60% germination (h)
-0.6	34.2	40	24.9	40
-2.8	23.7	45	17.6	42
-7.8	16.5	160	13.2	140
-10.8	--	280	--	250

* measure of suction required to extract water from soil

A fine seedbed comprising many small aggregates will provide good surface contact with the seed and ensure sufficient moisture transfer (Fig. 1). Conversely, a seedbed comprising only large aggregates will not only dry quickly, but whilst moist will allow only limited water transfer because of poor surface contact with the seed. In wet conditions, soil aggregate size is less important because sufficient direct contact with water will be achieved, but slugs may present a greater problem in wet soil.

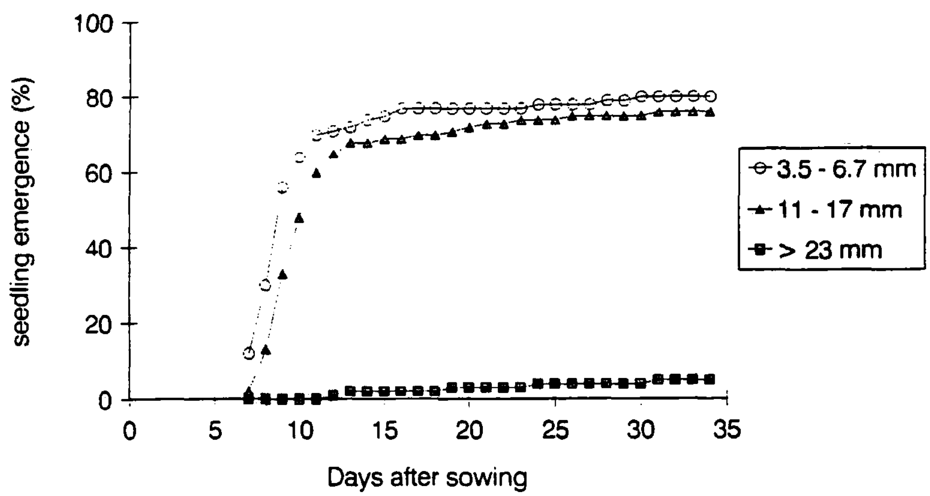


Figure 1. Effect of aggregate size on plant emergence at 12% soil moisture (pot experiment using Evesham clay).

Whilst variation in soil texture and structure will affect moisture supply to the seed, moisture supply to the soil also varies dramatically between seasons. The germination process is sensitive to both over-wet (above field capacity[1]) and over-dry conditions. Conditions of excess moisture, caused by poor drainage in the seed zone, can be deleterious to seed germination by stressing the seeds. This stress may result not only from excess uptake of moisture, but also increased microflora activity resulting in competition for oxygen.

Incorporated straw may form a physical barrier between the seed and soil, limiting water transfer, especially where soil moisture is marginal. However, a surface mulch of straw may aid soil moisture retention in moisture-deficient situations.

3.1.3 Temperature

Germination rate is strongly dependent on temperature; it is not triggered below temperatures of 0°C, and progresses slowly below 10°C. However, as oilseed rape is generally sown during late summer to early autumn when soil temperatures regularly exceed 10°C, this is not a factor which requires consideration unless sowing is delayed or there is prolonged drought. The rate of germination increases up to approximately 25°C. The thermal time (cumulative day degrees above 0°C) between sowing and emergence under non-moisture limiting conditions has been calculated as approximately 140°C days. Depending on the variation in mean daily temperature this translates to between 8-9 days in the field, unless dryness limits development.

3.1.4 Oxygen supply

To meet the respiratory requirements of the seed and germinated seedling, a sufficient supply of oxygen must be available. Oxygen supply to seeds can be limited by ponded water in the seedbed, particularly if decomposing straw is utilising an already restricted supply. Drilling in wet conditions, particularly when compaction is present, may result in soil smearing below the level of the seed leading to anaerobic conditions which restrict germination and/or penetration of the emerging root.

[1] The point at which the soil cannot hold any more water; additional rainfall either runs through the soil profile or causes waterlogging.

3.1.5 Soil and seed-borne diseases

Alternaria spp., *Fusarium* spp., *Pythium* spp, *Phoma lingam* and *Rhizoctonia solani* can all cause damping-off of seeds and early rot of seedlings. Seed-borne infections of *Alternaria* spp. and *Phoma lingam* are generally controlled with fungicidal seed treatments; however, seed treatments do not control post-emergence infections. Moist warm conditions (particularly those encountered under straw mulches) may encourage the development of soil and seed-borne diseases, particularly when oxygen supply is inadequate. In practice, damping-off diseases are only partially controlled by seed treatments; increasing seed rate is likely to be an effective additional measure of securing a good plant stand.

3.1.6 Soil-borne toxins

Microbial decomposition of straw in wet anaerobic seedbeds may cause the release of plant toxins. However, such toxins are usually broken down in the soil relatively quickly and are unlikely to do more than delay establishment and/or restrict seedling vigour of oilseed rape.

Toxins from decomposing cereal residues are sometime held responsible for loss and/or poor seedling growth, particularly but not exclusively during wet conditions. Although it is well documentated that a wide range of organic toxins may be produced during decomposition of cereal straw, the extent to which such toxins could be responsible for damage during establishment of rape is far less clear. Decomposing cereal residues may also interfere with establishment through affecting moisture availability, through excessive immobilization of available N, or through enhancement of slug damage. Thus, possible toxin damage may be masked by one or more of these other effects. For example, the severe N deficiency in seedlings caused by microbial immobilization of N may occur in the presence or absence of toxin production and if toxins are not limiting growth, application of sufficient seedbed N should fully reverse the effects. Furthermore in wet conditions, anaerobic soil produces plant toxins even in the absence of straw.

3.1.7 Slugs

In winter wheat, slugs commonly hollow the seed and shred the leaves of the developing seedling (Glen, Milsom & Wiltshire, 1990), but it is not known whether they attack the much smaller seeds of rape. When cereal seeds imbibe water and start to germinate they produce sugary exudates which make them highly palatable to slugs. Oilseed rape is not thought to become palatable to the slugs until the seedling shoot emerges (A. Lane, pers. comm.). Prior to the straw-burning ban, slugs were considered of minor importance in oilseed rape (Glen, Jones & Fieldsend, 1989), although there was concern over the potential build-up of slug populations in oilseed rape leaf litter. However, since 1992, the incorporation of cereal straw combined with the adoption of low glucosinolate varieties have increased the importance of this pest. The advent of set-aside has also increased the risk of slug damage; slug biomass tends to increase rapidly in undisturbed set-aside placing following oilseed rape crops at increased risk (A. Lane, pers. comm.). Even with a significant increase in the use of molluscicides on oilseed rape (from 16-19 M tonnes of molluscicide in 1992 to 64 M tonnes in 1994), slugs are now a major cause of poor establishment (Garthwaite, Thomas & Hart, 1995).

Thus, the main factor controlling germination is soil moisture and a main potential threat to subsequent emergence is slug damage.

3.2 The seedlings' requirements for emergence

The following factors will influence emergence of the germinated seed:

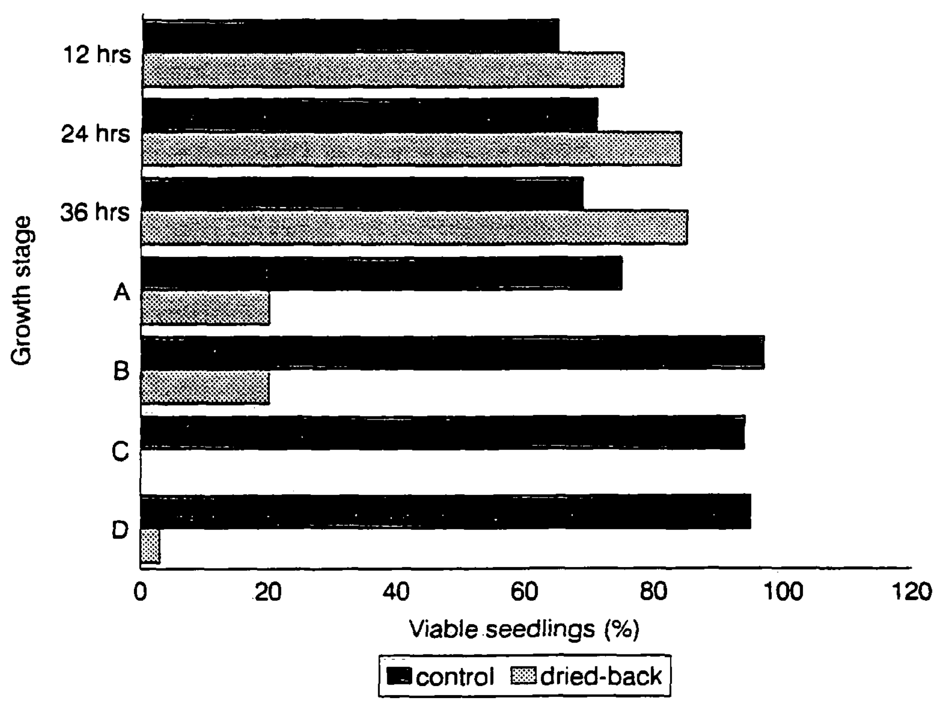
- moisture supply,
- seed size/drilling depth/aggregate size,
- bulk density of soil above seed,
- soil structure below seed,
- temperature,
- toxins and N availability,
- slugs and disease.

3.2.1 Moisture supply

The imbibed rape seed can tolerate drying to below 40% moisture prior to germination, with the only result that germination is delayed. Drying once the seed has started to germinate results in the loss of the seedling (Fig. 2). Once germinated, the seedling requires a steady moisture supply to ensure emergence.

3.2.2 Seed size/drilling depth/aggregate size

The physical environment in which a rape seed germinates can affect its ability to emerge. All seeds have a limited amount of stored energy for growth in the absence of sunlight; consequently, they need to emerge and expand their cotyledons before these energy reserves are exhausted. Whilst the route to emergence which requires the smallest expenditure in energy is by vertical hypocotyl elongation, the existence of impenetrable objects in the soil profile such as stones, large aggregates and straw, require the hypocotyl to grow around them. The extent of this extra energy expenditure, measured in terms of the additional hypocotyl length on emergence, is presented in Table 3. Thus, at a given depth, seedlings will have a greater chance of emergence if moisture is not limiting, and will emerge faster when covered by small aggregates.



Growth stage key:
12, 24, 36 hrs: drying treatment applied 12,24,36 hours after placing in water
A: drying treatment applied when radicle first emerges from seedcoat
B: drying treatment applied when radicle 1cm long
C: drying treatment applied when cotyledons exposed
D: drying treatment applied cotyledons fully expanded

Figure 2. Response of seeds and seedlings to drying at various stages in growth (S McWilliam, unpublished).

Table 3. Hypothetical path length (mm) required by an oilseed rape seedling to circumvent or grow round aggregates of different sizes following different cultivation treatments (after McWilliam *et al.*, 1995).

	Aggregate size			
Cultivation	>47mm	23-47mm	17-23mm	11-17mm
Disc + straw	56	28	18	12
Disc + burnt	52	27	17	12
Plough + straw	48	26	17	12
Uncultivated	50	28	18	13

This relationship is further complicated when seed size is considered. Larger seed within a seed lot will generally have greater reserves for growth in the absence of light. It follows that there is a limit to the depth at which rape seedlings can emerge (Fig. 3). The deepest sowing depth that resulted in 'viable' seedlings emerging was found by Garrett and Orson (1989) to be 75mm. However, this was under 'ideal' soil moisture conditions in pot experiments. It is generally considered that the optimum drilling depth is 15 mm. It is not possible to consistently achieve this depth of sowing in dry, loose or cloddy seedbeds.

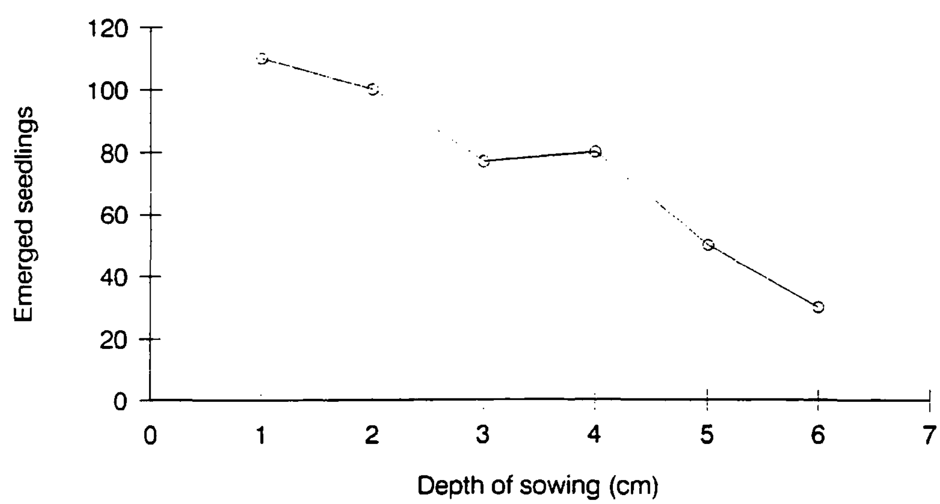


Figure 3. Effect of sowing depth on maximum emergence from 150 seeds in pot experiments (S McWilliam, Thesis in preparation).

3.2.3 Bulk density of soil above the seed

Figs 4 & 5 demonstrate that increased soil compaction (measured as soil bulk density) gives rise to slower rates of emergence and lower total emergence. This is analogous both to situations where trafficking has compacted soil structure and where 'capping' has occurred following heavy rain. There is no difference in emergence rates between large and small seed at low bulk densities (1.1 g cm^{-3}) because both seed groups have enough stored energy to achieve emergence. However, at higher bulk densities (1.2-1.3 g cm^{-3}), large seeds emerge more rapidly and achieve higher final emergence than small seeds because their additional reserves allow them to survive until emergence.

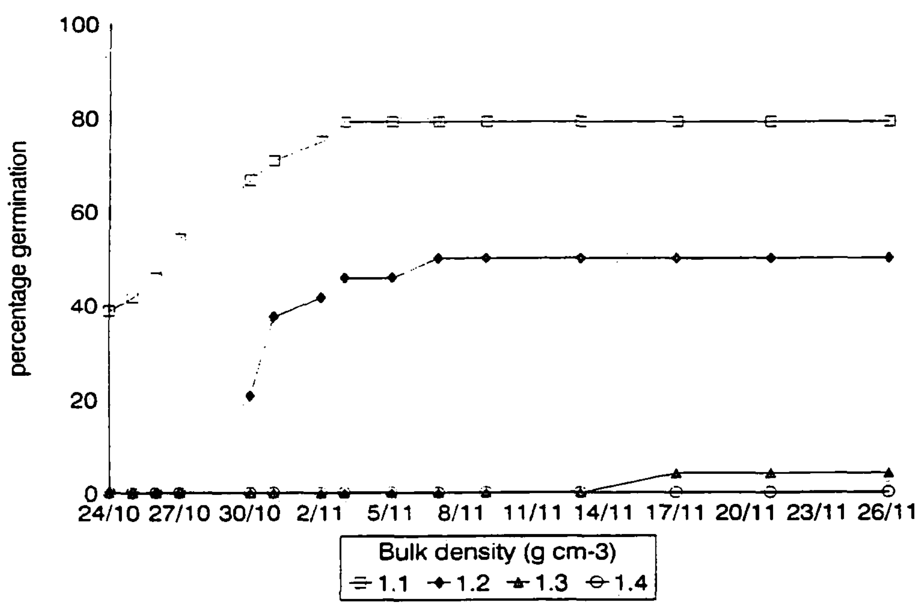


Figure 4. Relationship between soil bulk density (g cm^{-3}) and rate of emergence for ***large*** seed (>2 mm) of oilseed rape grown in laboratory experiments using Fladbury series clay soil (S McWilliam, thesis in preparation).

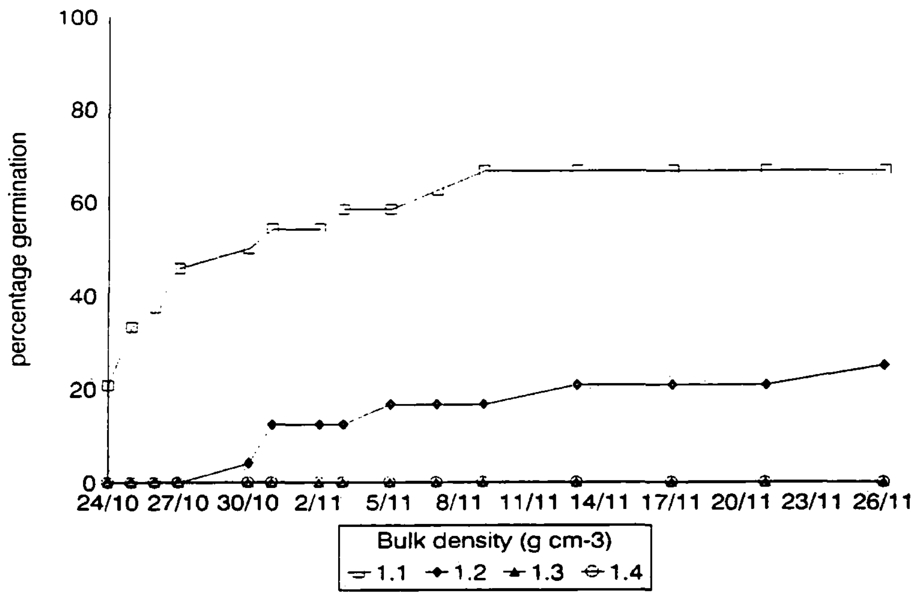


Figure 5. Relationship between soil bulk density (g cm^{-3}) and rate of emergence for ***small*** seed (<2 mm) of oilseed rape grown in laboratory experiments using Fladbury series clay soil (S McWilliam, thesis in preparation).

3.2.4 Soil structure below the seed

The rooting zone for an oilseed rape plant may need to be 1-1.5 m below the soil surface. Throughout this zone a friable, well fissured, oxygenated soil structure with adequate moisture availability will be required for optimal growth. Drilling in wet conditions, even into well-structured seedbeds, may result in soil smearing below the level of the seed. This forms an impenetrable layer to emerging roots and may cause localised anaerobic conditions during periods of heavy rain. These conditions can lead to lower emergence.

3.2.5 Temperature

We have already discussed in detail the temperature, moisture and atmospheric requirements of the seed and seedling. As with any plant, its subsequent development is dependent on these variables. The average thermal time between sowing and emergence (assuming sufficient moisture) is 140°C d (i.e. 9 days at 15°C or 10 days at 14°C; Mendham, 1995). Early sowing under suitable conditions will allow earlier utilisation of radiant energy, and should ensure that the crop achieves a suitable growth stage before the onset of winter, and is therefore more likely to survive to the spring. It is considered desirable to have at least five true leaves and a good root system by early December. The maximum cold tolerance occurs when the rape plants have achieved approximately 8 leaves and a root collar diameter of 8mm.

UK experience suggests that the optimum sowing date, on a variety of soils, is usually early September (Bowerman & Rogers-Lewis, 1980; Mendham, Shipway & Scott, 1981; Anon., 1983; Williams *et al.*, 1991). Slower development caused by sowing in late September or early October often depresses yield and reduces oil content. Occasionally, early sowing results in depression of yield, possibly due to frost damage at the time of flowering.

3.2.6 Toxins and N availability

The same potential problems of damage from toxins apply during emergence as for germination. However, perhaps a more important effect of straw is immobilisation of soil N, thus reducing nitrate supply to the seedling. Symptoms of toxins and N shortage are usually indistinguishable in the field. Such conditions are less likely where rape is established relatively early during good conditions. Except where soil N supply is large, 30 kg/ha N in the seedbed is recommended to ensure N does not limit yield.

3.2.7 Slugs

Seedlings may be killed before or shortly after emergence, but more typically the leaves are holed and shredded, resulting in reduced growth potential. It appears likely that glucosinolates provide some protection against both polyphagous grazing pests such as slugs and also specialist feeders on brassicas (Glen, Jones & Fieldsend, 1989). However, the move towards 'double zero' varieties since 1989 has meant that these varieties may now be more susceptible to damage. The relationship between glucosinolate levels and protection from grazing need to be firmly established as it is possible that seed coatings containing glucosinolates might protect the seed (J. Oakley, pers. comm).

Slug attacks are greater in the presence of surface straw, particularly under conditions where the surface straw forms a damp mulch. In addition, the fungi and algae which decompose straw may act as a secondary food source for the slugs.

It is commonly believed that slugs are a more severe problem in cobbly, under-consolidated seedbeds because these offer a more suitable environment for slugs to shelter and move; slugs require moist conditions, and require fissures to move below ground during the day as they cannot burrow. A seedbed which is moist enough for germination will probably not limit slug activity. Conversely, a high proportion of small aggregates in the seedbed reduces the risk of slug damage. Similarly, deep drilling of seed (to 40mm) reduced slug damage to winter wheat seed and seedlings by rendering the seed inaccessible to the slugs (Glen, Milsom & Wiltshire, 1990). This control option may not be feasible for rape with an optimum drilling depth of 15mm. However, the possibility of using deeper sowing as a control mechanism for slug damage has not been investigated for oilseed rape. The preference for a fine, firm seedbed for the control of slugs in wheat has been questioned by Glen, Milsom & Wiltshire (1989) following an experiment on a Worcester series clay loam. Most slug damage occurred on consolidated seedbeds of fine or medium tilth, least on loose seedbeds of the same aggregate size, with intermediate damage levels occurring on cloddy seedbeds regardless of consolidation level. However, these seemingly anomalous results may have been explained by slug mortality caused by the different soil treatment operations or by differences in sowing depth. For example, results from cultivation trials by McWilliam (unpublished) indirectly indicated that discing achieves greater slug mortality than ploughing because subsequent plant populations were higher following discing (Fig. 6).

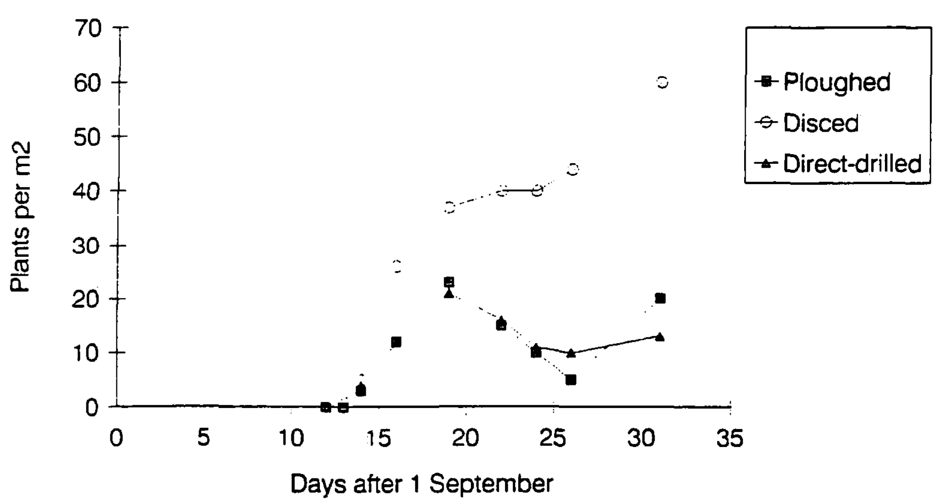


Figure 6. The influence of slugs on plant populations established following three cultivation treatments on a Worcester clay at Kneesall, Nottinghamshire (McWilliam, unpublished).

The key to controlling slug damage on rape will be to understand how different cultivation techniques, different straw incorporation methods and varieties with varying glucosinolate content influence slug populations.

4 SEEDBED PREPARATION

4.1 The seedbed

To recap, the following conditions are required for good germination:

- adequate moisture supply,
- a shallow tilth of suitable aggregate size to ensure sufficient moisture transfer to the seed (the greater the water supply, the less important the tilth dimensions),
- adequate consolidation of tilth to ensure that moisture loss is not excessive, seed imbibition is encouraged and slug activity is reduced,
- adequate soil temperatures (total of 140°C days as rapidly as possible),

and the following conditions are necessary for satisfactory emergence:

- adequate moisture,
- lack of surface capping,
- well fissured topsoil for root growth and drainage of excessive rainfall,
- adequate temperatures,
- freedom from slug damage and damping-off diseases.

On the basis of this information we now can define an ideal seedbed for oilseed rape, and discuss how this can be best achieved on typical rape-growing clay soils.

4.1.1 The ideal seedbed

In the ideal rape seedbed (Fig. 7), seed should be placed at uniform depth on a flat seedbed bottom which has good hydraulic conductivity and hence will allow good root penetration and water movement. Overlying this zone, there should be a layer in which at least 50% of the aggregates are of a similar diameter (c. 2mm) to that of rape seed, or less, (to achieve good contact with the seed for non-limiting imbibition) well packed but not compacted, providing good seed/soil contact, limited evaporation from the seedbed and unimpeded shoot growth. The optimum seed depth of 15 mm requires that this layer only needs to be 2-3 cm deep. Very heavy rain can cause the collapse of the seedbed but the risk of this occurring is minimised by the presence of some larger aggregates in the surface and by not forcing a seedbed when the soil is too moist. Soils dry more quickly in autumn than in the spring so there may be a case for fewer very fine soil particles in spring seedbeds than those produced in the autumn.

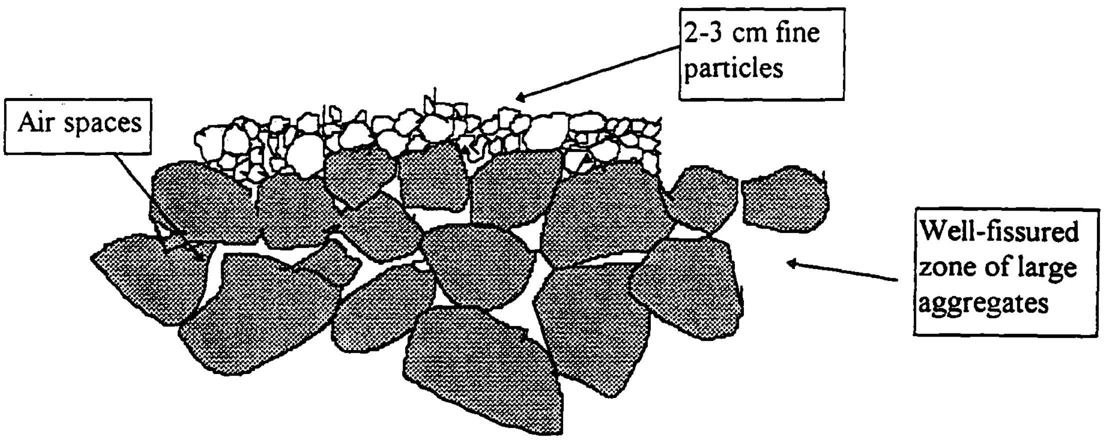


Figure 7. The ideal oilseed rape seedbed.

4.2 How clay soils naturally form a tilth

Under certain circumstances, the soil system will develop an 'ideal' seedbed naturally through the action of weathering[2] and the activity of soil fauna and flora which create tilth. Usually, the seedbed produced at sowing gives rise to an initial tilth. The type of clay soil determines whether the tilth persists or develops further.

Soil can be broken down physically into particles of various sizes (clay, silt, sand), the proportions of which, when mixed with varying amounts of organic matter, determine the soil texture. In field soils these particles, together with organic matter, are combined into aggregates which give the soil its structure. These aggregates vary in size from the smallest crumbs to the largest clods. Between the aggregates are air spaces (pores) of varying sizes. About 50% of a field soil is space; some pores are small enough to hold water, some are larger and these fissures allow water to drain away. In well-structured soil, plant roots can grow freely through the inter-crumb pores to all parts of the soil, in search of water and nutrients. The tap root of oilseed rape may penetrate 1.5m, therefore, the soil must preferably be well-structured to this depth.

[2] a process occurring in the summer months during cyclical wetting and drying of soil

Oilseed rape is grown mainly on clay soils in the UK. Clays are defined as those containing a minimum of 35% clay particles. The microscopically small size of these particles give clays very great surface areas and consequently the clods are strongly cohesive and under dry conditions are very difficult to break into smaller units. In wet conditions, clays swell leading to slow moisture movement and waterlogging unless a drainage system has been installed. However, apart from some sandy clays, most clays naturally form a surface tilth during the wetting and drying that takes place during a growing season; this is termed the self-mulching process and in most seasons provides a shallow seedbed similar to the ideal requirement for rape. There are further divisions within clays caused by the relative proportion of silt, sand and calcium carbonate which modify their behaviour. The structure and stability of clay soils is governed by permanent factors (% silt and sand, % humified organic matter and % calcium carbonate) and temporary factors (soil moisture and type of cultivation). On this basis, clay soils can be divided into one of two agronomically important classes: *poorly-structured, non-calcareous clays* or *well-structured, calcareous clays*. Common clay soil series are classified in this manner (Table 4).

Table 4. Typical examples of clay soil series subdivided according to their agronomically important properties.

Poorly structured non-calcareous clays
Carboniferous shales (Hallsworth, Dale, Dunkeswick)
London Clay (Windsor, Hallsworth)
Oxford Clay (Denchworth)
Keuper Marl (Worcester, Spetchley)
Boulder Clays (Ragdale, Crewe, Foggathorpe, Salop)
Weald Clay (Wickham, Dale, Denchworth)
Alluvial Clays (Compton, Fladbury, Midleney)
Marine alluvium (Wallasea)
Well structured calcareous clays
Chalky Boulder Clay (Hanslope, Stretham)
Oxford Clay (Evesham)
Alluvial Clay (Thames)
Marine Alluvium (Newchurch)

4.2.1. Influence of clay class (calcareous, non-calcareous) on tilth formation

Compared with more loamy soils, all clay soils are more difficult to cultivate and manage and in consequence their cropping is generally restricted to combinable crops or grass. However, in very dry years, rape establishment is a problem on both calcareous and non-calcareous clays. The difficulties associated with cultivation are intensified in the non-calcareous clays by larger proportions of silt or sand-sized particles (silty clays, sandy clays), by an elevated salt content (sometimes present in marine clay) and by a lower content of topsoil organic matter (a characteristic of long-term arable farming). Non-calcareous clays are typically more poorly structured, and do not form seedbeds easily either naturally (self-mulching) or artificially (by cultivation). Once formed, seedbeds are not stable and are more easily destroyed by rain.

However, clay soils containing 5% or more of lime or chalk tend to work more easily than those derived from non-calcareous clays and develop a deeper and more stable natural tilth. In addition, calcareous clays usually have more fissured, better-draining subsoils and their seedbeds are less prone to slaking and capping during rain, i.e. they are more stable.

The class of clay determines the risk of actual poor structure in the field (large, dense clods, compaction or puddled/smeared conditions). Thus, fields of the 'Poorly' structured Group are more likely to be in this adverse condition than fields of the 'Well' structured Group, particularly during or following very wet periods. However, with good farming and dry years, 'Poorly' structured clays are often found in good condition.

The proportion of these two classes of clays in the regions of England and Wales are presented in Table 5. It can be seen that the more difficult clays are well represented in all parts of England. Scotland has only a small percentage of clays in crop-growing areas.

Table 5. Relative proportion (%) of difficult non-calcareous clays in England and Wales (by region).

Region	Poorly structured non-calcareous clays % of region ('000 ha)	Well structured calcareous clays % of region ('000 ha)
South East	22.3 (447)	4.1 (83)
South West	12.7 (305)	6.8 (163)
East	16.6 (455)	16.2 (444)
Midlands & West	15.3 (422)	2.7 (75)
Wales	2.3 (47)	0.4 (7)
North	17.6 (549)	0.4 (12)

4.2.2 Influence of soil moisture on tilth formation

During the months preceding cereal harvest, all clay soils characteristically form a shallow surface tilth by natural weathering but on the non-calcareous clays this tilth is much more likely to be lost in heavy rainfall; they are termed less friable. During and after very wet harvests, the non-calcareous clays are more prone to puddling, smearing and temporary waterlogging induced by traffic and cultivation. Consequently these clays tend to contain more large clods and the clods are less easily broken down.

Once transpiration from the cereal crop ceases at the onset of ripening, most of the rainfall accumulates in the top soil and can be considered useful moisture for seedbed preparation. Consequently, winter barley provides a longer window for moisture accumulation than winter wheat which starts to ripen 3-4 weeks later.

4.3 The need to create a seedbed by cultivating the soil

Most clays are self-mulching i.e. they can form a seedbed naturally through weathering. Up until the straw-burning ban, farmers were able to make good use of the natural tilth that developed in the surface 1-3cm of clay soils prior to cereal harvest. In most years, oilseed rape was established by either direct drilling into the natural tilth or drilling after shallow cultivations (Fig. 8). The principal aim of cultivations was to preserve, or minimise loss of, the natural tilth. In this situation, establishment became a problem only when soils remained dry after drilling and there was insufficient rainfall for germination, or if a natural tilth was absent.

A good natural surface tilth, suitable as a winter oilseed rape seedbed, may not be present if heavy rain has destroyed the tilth, if clays are inherently poorly structured or if farm traffic has caused soil compaction. In the absence of a suitable natural seedbed, a cultivation treatment will be required. The only aim of cultivations here is to create a shallow seedbed in the top few centimeters of the soil surface.

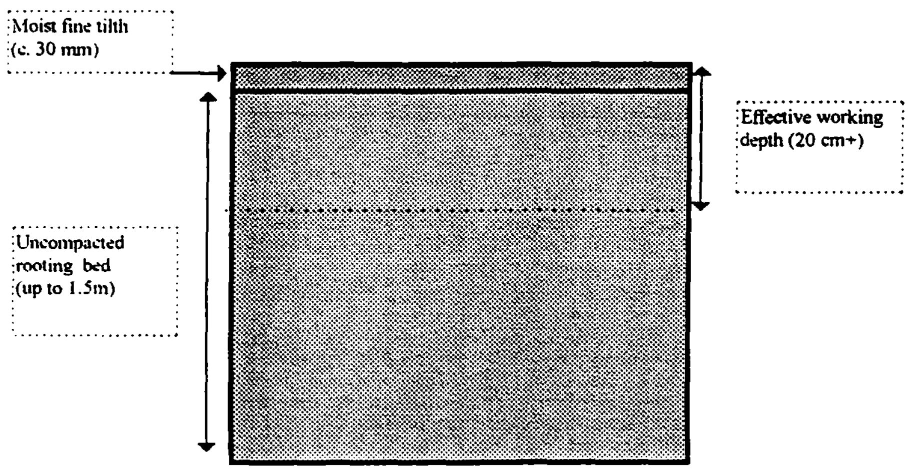


Figure 8. Ideal seedbed required for oilseed rape establishment on clay soils where straw has been burnt.

The introduction of the straw-burning ban made oilseed rape establishment inherently more difficult because of the need to incorporate straw. Substantial amounts of straw on the soil surface or shallowly incorporated, inhibit penetration and cause blocking of most conventional seed drills, hence, deeper incorporation of straw is required (to a minimum of 10 cm, Fig. 9). Deep cultivations which achieve straw incorporation cause loss of natural tilth; the fine soil crumbs become mixed with larger, unweathered clods. In this situation, further cultivations are required to artificially produce an acceptable seedbed in the short time period available.

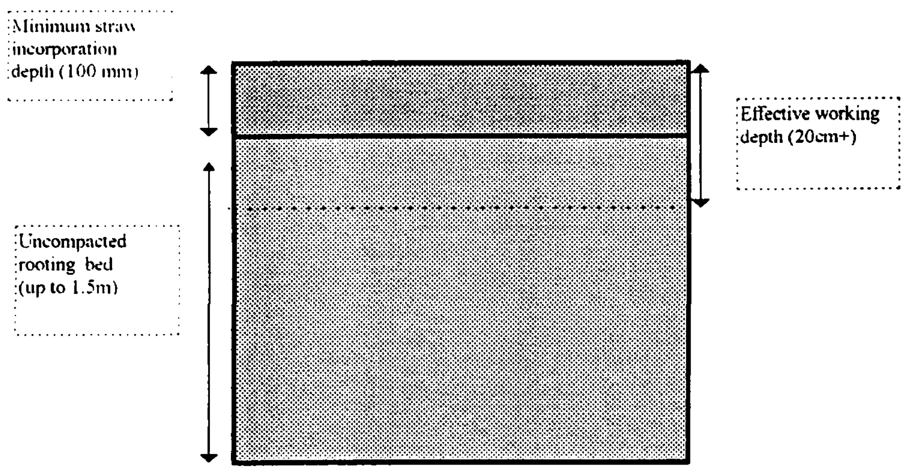


Figure 9. Ideal seedbed required for oilseed rape establishment on clay soils where straw has been incorporated.

4.4 How to create a seedbed by cultivating the soil

Thus, when establishing oilseed rape, appropriate cultivations are required to either preserve the natural tilth or create a suitable seedbed. Choice of an appropriate cultivation method is an important part of the decision process. It is, therefore, necessary to understand the underlying principles of tillage and, in particular, how the likely response of soil influences choice of cultivation equipment.

4.4.1 Type of cultivator

All cultivation equipment can be categorised as having one of three types of action (see Davies, Eagle & Finney, 1993).

- the forward facing tine - these implements lift and loosen soil but do not break clods. These tines will tend to pull up clods; the greater the depth of working, the larger the clods. Tine implements do not mix crop residues well with soil. The plough is an extreme form of this action; as well as lifting and loosening, it completely inverts soil and moves residues to depth without mixing.
- the vertical tine - this has a neutral effect, breaking clods but neither loosening nor compacting soil (e.g. Dutch harrow). Again, vertical tines do not achieve much mixing of residues with soil. An extreme type of this action is the power harrow.
- the backward facing tine - these implements press down on the clods to crush or cut them (e.g. discs, rotary cultivator); consequently, these implements have a tendency to compact and

consolidate soil. The roller is an extreme form of this action. Discs also achieve good incorporation of soil and cereal residues, through the action of the concave which lifts and mixes.

4.4.2 Influence of soil moisture on cultivations

The effect of the three different types of cultivation action described above are influenced by soil moisture, particularly under extreme conditions.

Very wet soils (field capacity and above) exacerbate the consolidating action of the backward facing tine implement (disc, rotary cultivator, roll); this can result in smearing of the soil under the implement and puddling and soil compaction. In such conditions, further rainfall leads to surface waterlogging. Under wet conditions, a forward facing tine action is preferable because it leads to soil drying; under very wet conditions, it is necessary to use the most extreme forward facing tine action, i.e. the plough.

In dry conditions, when preservation of soil moisture is paramount, it is important to avoid any form of soil loosening which exacerbates soil drying. Under these conditions, it is necessary to use a backward facing tine action to consolidate the soil immediately after each mixing operation and thereby retain soil moisture, e.g. disc followed by roll or packer.

4.4.3 Depth of cultivation

Cultivations can also be grouped according to the depth and extent to which they mix soil and incorporate plant residues including straw:-

- Shallow cultivation (e.g., heavy duty flexible tines working to 5 cm),
- Medium depth cultivations (e.g., discing to mix soil and straw to 10 cm),
- Deep cultivations (e.g., ploughing to completely invert soil and residues to 20 cm or more),
- Sub-soiling cultivations (to alleviate sub-surface compaction below the plough layer).

The combination of 'tine type' and working depth will now be considered in the context of either preserving or creating a suitable seedbed on clay soils *in the absence of straw.* Section 4.5, will cover the additional problems caused by the need to incorporate straw.

Shallow cultivation (to 5 cm) by tine, light disc or rotary cultivation

The neutral action of a shallow working, vertical tine maintains any natural tilth which may be present on well structured, friable soils. Where surface tilth has been lost, it does little to improve the seedbed because poorly structured soil remains near the surface. Deeper cultivations are needed to create an improved seedbed, provided soil moisture is adequate.

A greater degree of surface mixing of soil and limited residues can be achieved by the action of shallow discs or rotary cultivations; however, there is risk of smearing and compaction from their backward-facing action if soils are wet.

Medium depth cultivations (e.g. discing to 10 cm)

If the surface tilth has been lost, then discing loosens and 'dilutes' the poorly structured surface soil with more easily broken aggregates from depth, provided soil moisture is adequate. If soils are drier than this, discing will lead to moisture loss and result in large clods brought from depth which will require energetic cultivation to break them down. Under these conditions, heavy rolling after discing will minimise moisture loss. Different weights of disc can be used to cause varying levels of inversion and incorporation but, because of their backward facing tine action, will lead to smearing and compaction beneath the discs under wet conditions.

Where the surface tilth remains intact, discing below the tilth will only serve to mix the fine tilth with larger aggregates brought from depth. Thus, discing is generally an unnecessary, high risk operation if straw residues are small or absent.

Deep cultivation (e.g. ploughing to 20 cm+)

The mouldboard plough is the most effective implement for burying weeds and re-levelling a rutted surface. Where the surface tilth has been lost under predominantly wet conditions, ploughing usually leads to the complete burial of the poorly structured surface soil bringing large but comparatively better structured aggregates to the surface. Because the plough is a 'forward facing tine' implement, it will loosen and dry out the soil without causing compaction.

Ploughing succeeds only in burying an intact surface tilth, replacing it with larger aggregates from depth which can quickly dry; this leads to increased soil strength and a requirement for very energetic secondary cultivations. In many seasons, soil conditions in August are not conducive to ploughing because the dry top soil cannot be penetrated. Where penetration is possible the resulting tilth is frequently cloddy, requiring considerable work to break down the large clods in time for sowing by early September. If soil conditions remain dry, a relatively large amount of rainfall will then be required to trigger germination. For example, after ploughing a Denchworth series soil, 40mm of rain was required to initiate germination (Fig.10); by contrast, only 7mm of rainfall was required to initiate germination after discing.

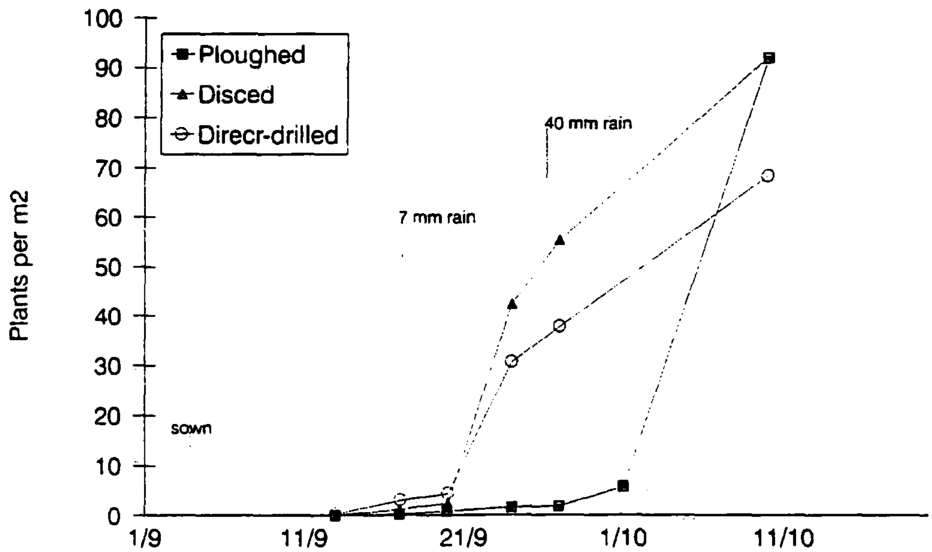


Figure 10. Plant emergence (from 150 seeds) on Denchworth series soil, 1991.

Ploughing can easily result in very rapid drying because it produces a looser, less dense medium encouraging wind to penetrate and remove water. This is exacerbated by the break in capillarity at plough depth which prevents the upward movement of water. Evidence from ADAS Boxworth (unpublished) indicates that during mid-August to mid-September, soil moisture conditions are suitable for ploughing only one year in three. In 2 out of 3 years, the soil is assessed to be too dry and strong.

In the absence of straw, ploughing is only recommended when soil conditions are very wet; under normal moisture conditions, in August/September, is an unnecessarily high risk option unless the soil is in a very good condition structurally.

Sub-soiling

Any sub-soiling required to improve the condition of soil below the top soil should be done before the preceding cereal crop. Sub-soiling immediately prior to rape results in loss of soil tilth, loses moisture and impairs seedbed quality.

4.5 The need to incorporate straw into the seedbed

The introduction of the straw-burning ban in July 1992, made oilseed rape establishment inherently more difficult because of the need to incorporate straw. Straw can be either deleterious or useful depending on its position in the soil profile and on the general soil conditions. Straw remaining on or near the surface is deleterious because it may:-

- reduce drill effectiveness by both blocking coulters and reducing the effective drilling depth, and hinder or even prevent seedling emergence,
- act as a mulch on moist soils producing an environment which is more attractive to slugs,
- in dry conditions, a layer of straw intercepts moderate rainfall keeping the soil dry.

To avoid these limitations and derive a benefit from the additional soil organic matter, it is necessary to incorporate cereal straw residues to depth. However, deeper cultivations to achieve straw incorporation cause loss of the natural tilth; therefore, the opportunity to drill oilseed rape into a shallow cultivated natural tilth previously afforded by burning no longer exists.

Even in the presence of a natural tilth, a non-cultivation strategy is very risky and some form of cultivation is preferable. Under conditions where the surface tilth has been lost, some form of cultivation is definitely required.

Incorporation of chopped straw into clay soils is not necessarily a problem *per se* (apart from increased time and expense), provided soil moisture is adequate (i.e., soil friable). However, if the soil is drier than this, then tilth loss during straw incorporation exceeds the farmers' ability to create new tilth through cultivations.

4.5.1 Choice of cultivation method for incorporating straw

The choice of cultivation equipment/method influences the depth to which straw is mixed. Christian & Bacon (1991) measured the extent to which different cultivation methods incorporated straw to depth (Fig. 11); e.g., tine and disc cultivations incorporate straw to their working depth of 5-15 cm whereas ploughing incorporates to greater depth (20-30 cm).

However, the greater the depth of straw incorporation, the greater the risk of soil moisture loss and the more difficult it is to create a new tilth. Ideally, straw should be incorporated to a minimum of 10 cm. However, in very dry years, oilseed rape seed does not germinate due to the lack of moisture - the presence of shallowly incorporated straw is not, therefore, the limiting factor influencing successful establishment. Under such conditions, ploughing is a higher risk strategy than discing because of the greater risk of moisture loss.

Conversely, as soil conditions become wetter, any backward facing tine, disc or rotary cultivation is at risk of creating a puddled, and smeared seedbed with straw poorly incorporated. In very wet years, ploughing is the only suitable option; it both dries out the soil and effectively incorporates straw at depth.

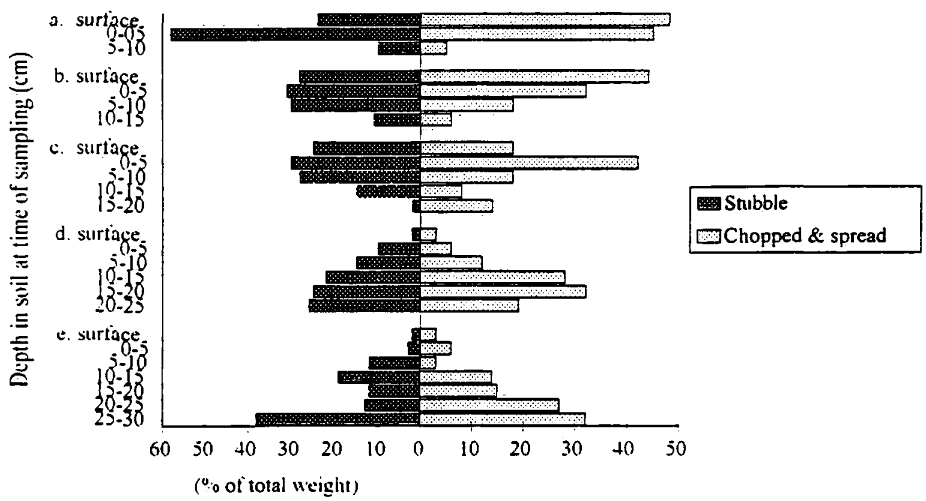


Figure 11. Distribution of stubble and chopped and spread straw in the soil after different methods of incorporation: a - Disc, tine x 2 (5cm); b - Tine x 2, Disc (10cm); c - Tine x 2, Disc (15cm); d - Plough (20cm), disc; e - Plough (30cm), disc (adapted from Christian & Bacon, 1991).

4.6 Influence of season on seedbed preparation

In most situations, cultivations are required to incorporate straw before sowing oilseed rape. Choice of cultivation method will be influenced by soil moisture status which is determined by season. Rainfall and temperature data over the critical period July-September have been obtained for a 28-year period in E England (Appendix 1). From these data, seasons have been placed in one of five categories based on whether the soil is dry (D) or moist (M) in the periods before and after the ideal drilling time of late August to early September:

DD - Dry throughout the 3-month period July-September,

DM - Dry from early July to end August; moist during September,

MM - Moist throughout the 3-month period July-September,

MD - Moist from early July to end August; dry during September,

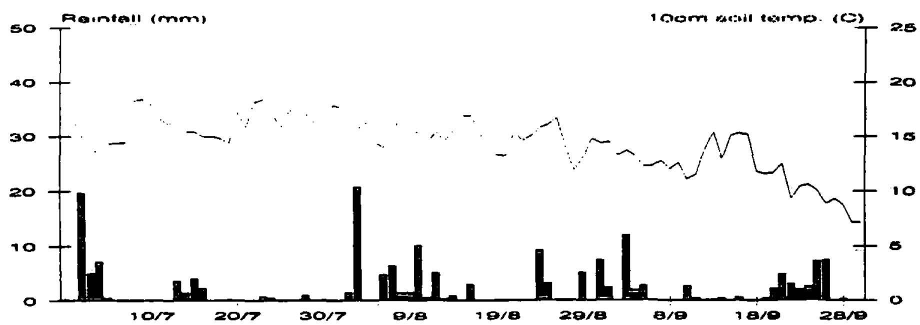
WW - Very wet throughout the 3-month period July-September.

Seasons representing each of these 5 categories are presented in Fig. 12.

Assuming there had been a burning ban throughout this period, and that wheat was the preceding crop, soil moisture would have been adequate for creating good quality seedbeds and for establishment of rape sown in the optimum period (MM) in about 1 year in 3. In about 1 year in 3 (9 of the 28 years) soil moisture was so low as to give a high risk of poor seedbed quality (DD, DM) and in 4 of these years (1972, 1979, 1990 and 1991) it continued dry after sowing and emergence would have been severely delayed.

In about 1 in 3 of the years (10 of the 28 years), rainfall was low after the sowing period (MD) and if seedbed cultivation had not conserved moisture, the risk of emergence being delayed beyond the safe period would have been high.

M/M 1974



D/D 1990

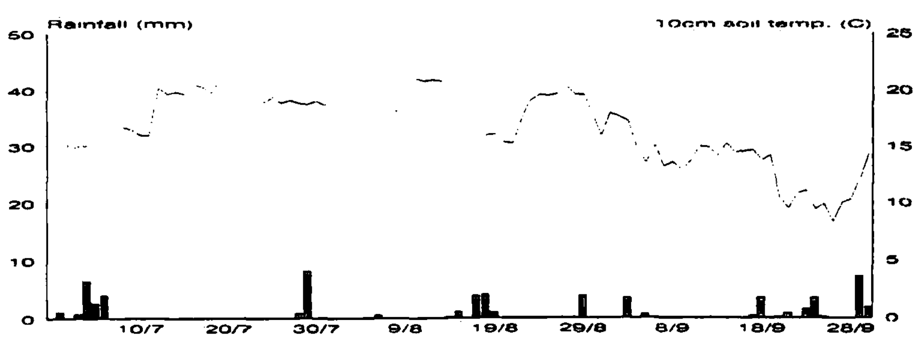
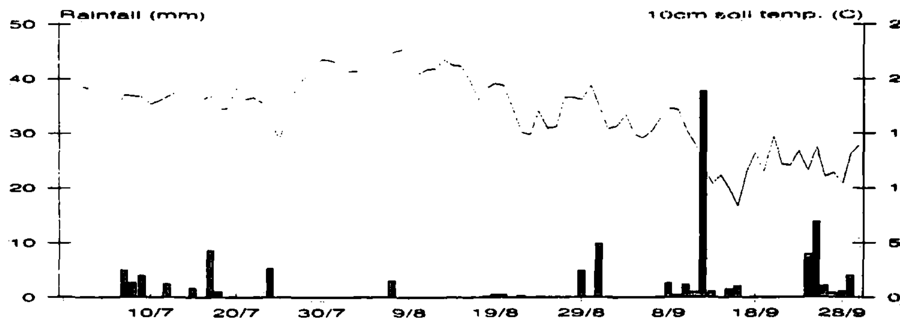
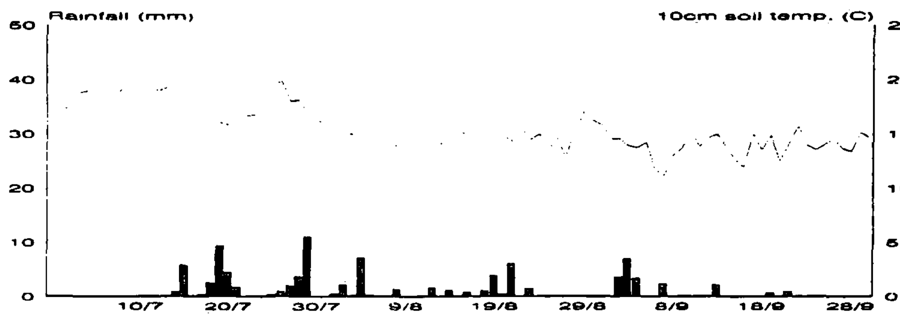


Figure 12. Daily rainfall at ADAS Arthur Rickwood, between the period 1 July (pre-cereal maturity phase) and 30 September (post-oilseed rape drilling window), demonstrating years with distinct rainfall patterns.

D/M 1975



M/D 1985



W/W 1993

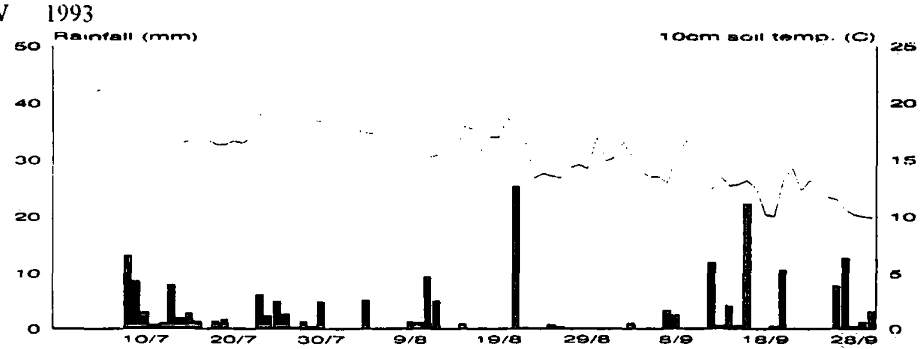


Figure 12. (continued). Daily rainfall at ADAS Arthur Rickwood, between the period 1 July (pre-cereal maturity phase) and 30 September (post-oilseed rape drilling window), demonstrating years with distinct rainfall patterns.

4.7 The decision process

In practice, the optimum cultivation choice reflects the particular combination of soil structure, natural tilth, and weather conditions but is complicated by the presence of straw. Consequently, there is no single engineering solution or simple prescription for obtaining an ideal seedbed.

Instead, we can identify the least risk option associated with a specified combination of factors. This section considers a range of likely scenarios which cover different soil structure and moisture conditions and which include or exclude straw incorporation.

For each scenario, a "least risk cultivation option" is identified.

Whilst the options presented in this section attempt to give appropriate solutions to differing sets of conditions, they are not written in 'tablets of stone'. Rather, these solutions are derived from first principles; consequently, there will be an R&D need to test them under a wide range of appropriate test-bed conditions.

4.7.1 The Decision Tree

Seedbed formation can be optimized through careful choice of cultivation method which takes into consideration soil type and summer rainfall. The aim here is to bring together current knowledge and understanding in the form of a decision tree (Fig. 13) and present a set of best practice guidelines to help farmers in their decision making to select the least risk cultivation options. The decision tree first takes account of previous crop residues:-

- straw chopped and spread,
- straw burnt/baled,
- set-aside.

For each of the first two situations in the decision tree, soil moisture and soil structure assessments are required to reach decisions.

4.7.2 Straw chopped and spread

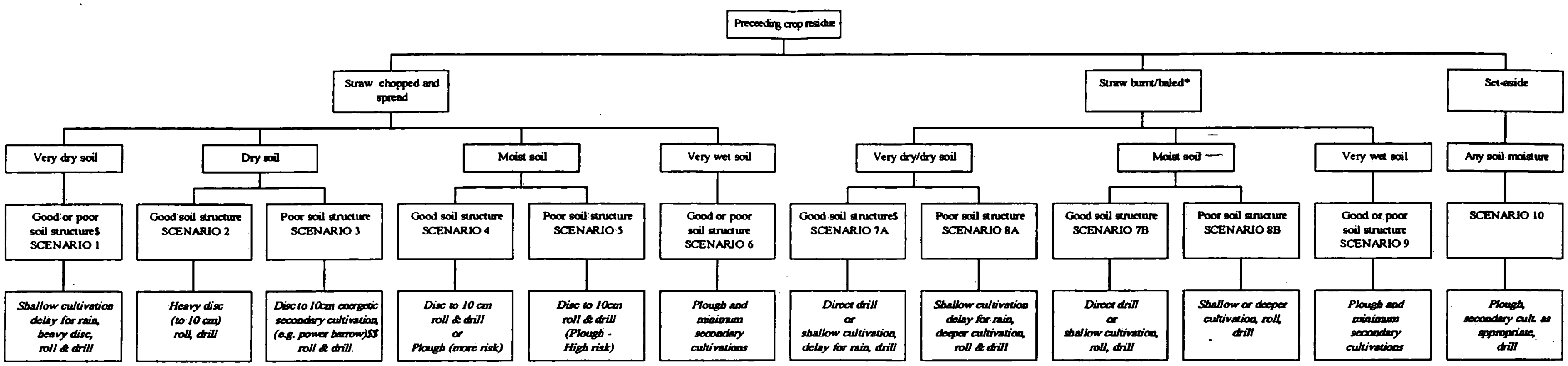
Scenario 1: Insufficient soil moisture to plough or use disc/rigid tine implements effectively

This scenario occurs when the soil is very dry and there is either no rainfall, or limited effective rainfall in the period early-July to early-September (e.g. D/D or D/M). When clay soils are very dry, soil strength is so great that ploughing is not feasible and disc and tine implements are highly inefficient (and costly) at penetrating unweathered soil. The least risk option here is to scarify the surface with a shallow cultivator (e.g. heavy duty flexi-tine or rigid tine) to improve the efficacy of water infiltration when rain arrives. Such cultivation will not effectively mix straw but without effective rainfall (in the order of 25mm+), seedbed cultivation is ineffectual and oilseed rape will not germinate and subsequent emergence will be delayed, protracted and poor (e.g. in 1990 & 1995, Fig. 12 & Appendix 1). In this scenario, the presence of straw is not a complicating factor; without effective rainfall, oilseed rape will not germinate in a dry seedbed with or without straw.

There is little to lose by delaying cultivations in the hope that rain will eventually fall in time for the optimum window for drilling. Most growers did this successfully in 1995 when timely rainfall at the beginning of September ensured good emergence. In 1990, it remained dry leading to poor and protracted emergence..

In the absence of any cultivation, light rain (e.g. <15mm) will be ineffective, i.e., it will wet surface straw but not reach the soil surface. Cultivations can be delayed until mid-September; after that date, there will be insufficient time to fully incorporate straw, re-create a seedbed and obtain germination irrespective of subsequent rainfall. This situation could alter if new varieties with faster development rates were available. There is a need to determine whether there is sufficient genetic variation in seedling development rate for exploitation. Alternatively, turnip rape varieties which are more tolerant of delayed sowing, could be sown. If insufficient rain falls before mid-September, spring cropping becomes the best option.

Figure 13. Decision tree - diagrammatic representation of likely least-risk, best practice cultivation methods for establishing oilseed rape under different conditions of previous crop residue, soil moisture and soil structure (based on first principles).



* Straw burning is no longer an option following the straw -burning ban in 1992

$ Poor soil structure refers to either inherently poorly-structured clays or badly managed, well-structured clays and *vice versa*

$$ 1 or 2 passes with second pass delayed until rain.

Scenario 2: Insufficient moisture to plough but sufficient moisture to work unweathered soil below tilth with non-plough implements - 'GOOD' soil structure (D/D or D/M).

The aim here is to incorporate straw to at least 10 cm but to conserve soil moisture. Forward-facing tine implements are a high risk option because they do not effectively incorporate straw and they bring unweathered colds to the surface and unnecessarily dilute the good surface tilth. Heavy discs and rotary implements are a lower risk option because they effectively mix straw. Heavy rolls immediately after discing break clods and reduce soil moisture loss. Two passes of discs and rolling may be necessary to effectively mix straw to 10 cm.

Scenario 3: Insufficient moisture to plough but sufficient moisture to work unweathered soil below tilth with non-plough implements - 'POOR' soil structure (D/D or D/M)

Once again, up to two passes of discs is the least risk option preceded by a rigid tine to give penetration if needed. However, because of poor soil structure, more less-friable clods may be brought to the surface; additional energetic secondary cultivations (e.g. power harrow) are required to break down clods and create a suitable seedbed. As in Scenario 2, it will be essential to roll after each cultivation to reduce soil moisture loss but inevitably more moisture will be lost. In this scenario, there could be a benefit from delaying the final pass of discs until effective rainfall has occurred.

Scenario 4: Soil sufficiently moist to plough - 'GOOD' soil structure (M/M, M/D)

In this scenario, it is possible to use heavy tine and disc implements or to plough. Heavy tines are the least favoured option because they do not effectively incorporate straw; they loosen and dry out the soil and bring unweathered clods to the surface unless the depth of each pass is progressively increased. This is the highest risk option and is not recommended for incorporating straw into well-structured soils. Ploughing is feasible; it incorporates straw but the good natural surface tilth is completely lost. Consequently, there is a risk of not achieving a satisfactory tilth if conditions subsequently become dry and lead to a cobbly seedbed. Risk from ploughing is reduced if delayed just prior to sowing e.g. use of a cultivation train to minimise moisture loss.

The best, least risk option is to use 1-2 passes of heavy discs which will achieve effective straw incorporation, without loosing all the surface tilth. Again, it will be essential to roll the surface after each pass to reduce soil moisture loss, particularly if it becomes dry after cultivation.

Scenario 5: Soil sufficiently moist to plough - 'POOR' soil structure (M/M, M/D).

Cultivation choice is even more critical on poorly-structured clays where natural surface tilth is limited or absent. Ploughing gives good straw incorporation but provides an unweathered soil surface with non-friable clods and few fine aggregates. Significant further cultivations (each one causing soil drying) or a long time of weathering will then be required to create a seedbed. This is a very high risk situation. Ideally, 1-2 disc cultivations or rotary tillage at least to 10 cm are recommended to achieve straw incorporation. Again, rolling is essential after each pass to conserve soil moisture.

Scenario 6: Very wet soil conditions

In very wet soil discs, tines and rotary implements either block or cause a muddy mix of straw clumps and smeared clay with risk of smearing and compaction immediately below the working depth. Under these conditions, ploughing is the only feasible option on all clays, irrespective of soil structure. Ploughing removes straw from the surface, accelerates drainage of free-standing surface water and facilitates soil drying. A seedbed can then be created by using light cultivations as the soil dries. If it continues wet, broadcasting of seed should be considered. Ploughing and subsequent cultivations are time consuming and may be impractical on very large acreages.

Summary The decision tree approach indicates that growers have more choice, hence opportunity, to improve chances of successful establishment of oilseed rape under 'normal' rainfall patterns (D/M, M/M, M/D) which occur say 3 years in 4. In practice, there will be a range of soil moistures under normal rainfall conditions. The wetter end will be more suited to ploughing, the drier end more suited to discing. For the better-structured clays, both plough and no plough approaches are likely to work well - *particularly if the soil was ploughed in the previous year.* For the poorer-structured clays, ploughing is less suitable (high risk) because of the large effort required to produce a satisfactory seedbed. Under the more extreme conditions, say 1 year in 7, when it is either very wet (WW) or very dry (DD), farmers have no effective choice in cultivation type; e.g. when it is very dry, clay soils cannot be ploughed; when it is very wet, they must be ploughed.

4.7.3 Straw burnt/baled

Scenario 7: Dry or moist soil with 'GOOD' soil structure

Under these conditions, well-structured soils have a good natural tilth. Prior to the straw-burning ban, it was possible to obtain a satisfactory seedbed for oilseed rape by either direct drilling or shallow cultivations. Now, this option only applies to the straw-baled situation. The only decision required is whether to delay cultivation on very dry soils (Scenario 7a) until after appreciable rainfall.

Scenario 8: Dry or moist soil with 'POOR' soil structure

On poorly-structured soils with limited tilth, there will be a need to create a suitable seedbed by cultivating into the unweathered soil. The least risk scenario is to use a backward-facing shallow tine or disc to break down the surface of the unweathered layer. Under dry conditions, this can be delayed until after rain (Scenario 8a).

Any forward-facing tine action introduces higher risk because large non-friable clods are brought to the surface requiring unnecessary energetic secondary cultivation.

Scenario 9: Very wet soil conditions

Ploughing is the only feasible option for clays irrespective of soil structure and surface residues.

Summary

In the absence of copious amounts of straw, there is no need to cultivate the soil deeper than necessary to create a shallow seedbed. Consequently, the decision-making is less complex.

4.7.4 Set-aside

Scenario 10: Creating a seedbed after set-aside

Oilseed rape following set-aside provides an opportunity to prepare the seedbed well in advance of drilling, and to drill under good, moist, conditions. About 40% of oilseed rape drilled in the autumn of 1994 followed set-aside. The best time to plough-in set-aside is in May/June so that the tilth can be left rough and allowed to break down by weathering followed by a light cultivation before drilling. Less soil moisture is removed during set-aside than during a cereal crop. Early ploughing and the lack of crop cover during the summer means that nitrogen mineralised from the oxidation of soil organic matter encourages extra growth of the rape crop in autumn. Establishing oilseed rape after set-aside is a relatively low risk strategy, at least in the short to medium time scale when set-aside is likely to remain an option.

However, given recent increased export demand for EU-produced grain, the long-term availability of this option must be called into question. Already set-aside area requirements have fallen from 15% to 10% in the last two years.

5 THE SEEDLINGS' REQUIREMENTS FOR SUCCESSFUL ESTABLISHMENT

Having applied the theory of phases I and II (seed germination and seedling emergence requirements) to the preparation of a suitable seedbed, what are the factors which can influence the seedling up to the point at which it is considered established? The decision tree has identified the best, least risk cultivation option to allow plants to germinate and emerge under different circumstances of previous cropping and soil conditions. It has not indicated what target population should be required to optimise final establishment both in terms of yield but also in terms of the ability of the crop to resist the effects of competitors; weeds, invertebrate pests, pigeons, slugs and diseases. These can all be reduced by the production of an evenly spaced, moderately dense crop.

5.1 Seedrate and population density

There is no definitive target density and, therefore, seed rate for oilseed rape. The percentage establishment of plants varies according to variety, season, soil type, soil conditions and quality of seedbed. Crops in the UK are typically sown to achieve 80-100 plants/m^2 in the autumn (i.e. 6-8 kg/ha). Seed yields are not greatly affected by wide ranges of plant population. Under field conditions, between plant populations of about 30 - 100/m^2, final yields will quite possibly be similar due to the compensatory nature of rape growth (e.g. Table 6). Under experimental conditions, evenly-spaced populations as low as 7 plants/m^2 can provide good yields (Scott *et al.*, 1994).

Table 6. Mean number of rape plants per square metre in spring and seed yield (expressed as a percentage of highest seasonal yield). Means of two sites in the ADAS establishment of oilseed rape experiments 1991-93.

Treatment	1990/91		1991/92		1992/93	
	plants/m^2	yield (%)	plants/m^2	yield (%)	plants/m^2	yield (%)
Plough	57	100	73	94	52	93
Tines	56	96	36	100	38	95
Discs	56	96	62	95	58	100
Seed broadcast	44	97	30	89	25	74

This will only occur, however, if establishment is uniform, and if all factors which might act to impede oilseed rape growth are controlled. Any attempt to deliberately establish a plant population as low as 30/m^2 on clay soils would be a high risk approach. A higher target density is set because of the difficulties of predicting percentage establishment. This, in part, has been due to an incomplete understanding of the factors which influence seed germination and emergence. The optimum seed rate depends on how accurately the farmer can predict the influences of soil, seedbed and climatic conditions and to what extent the canopy of low plant populations can be manipulated to produce the ideal seed yielding environment. Yields tend to decline at populations above 130 plants/m^2 because stems of dense crops are thin and weak, predisposing them to lodging and, consequently, increased disease risk to the pods and canopy. Thus, the risk associated with insurance strategies is that in years in which establishment is good, an excessive plant population may develop. The practice of insurance seed rates also becomes less attractive as farmers switch to the more expensive composite hybrid seed mixtures such as Synergy.

In direct contrast to the relatively high seed rate used in the UK, a large number of crops on easier-working loess soils in France and Germany are precision drilled (up to 400 mm between rows) using seed rates to give a spring population of 40-50 plants/m^2. Precision seeding has not been adopted on the less workable, heavier soils in the UK because very fine seedbeds are required; these are difficult to achieve on poorly-structured clays, particularly in dry or wet autumn conditions and in the presence of straw. Seedbeds more suitable for direct drilling or even precision drilling might be possible after set-aside. However, whilst approximately 70% of oilseed rape is grown as a break crop on clay soils in the East of England, the remaining 30% grows on easier working light-textured soils. On these soils, lower target densities are not necessarily a high risk option; a better understanding of the principles which affect rape establishment may enable a) drilling dates to be brought forward and b) the use of precision drilling equipment and much reduced seed rates. This situation would provide a particularly valuable opportunity to establish high cost hybrid seed. Consequently, the most advantageous place for hybrid varieties such as Synergy will probably be on lighter soils with precision drills.

In summary, growers adopt an insurance strategy for seedrate primarily because of the difficulty of predicting establishment. Any attempts to reduce seedrate on clay soils will incur risk; risk can be reduced by improving the decision making associated with seedbed preparation on clay soils or by establishing rape on lighter-textured soils. An insurance seedrate strategy is also adopted to mitigate the competitive effect of pests, diseases and weeds. Patchy crops, sparse crops or over dense crops are to be avoided as they can exacerbate the damaging effects of pests, diseases and weeds.

5.2 Pests

5.2.1 Pigeons

The UK wood pigeon (*Columba polumbus*) population has expanded massively since the introduction of oilseed rape. Indeed, the over-wintering population size of pigeons in any area can be determined by the area of oilseed rape sown the previous autumn (Inglis, pers. comm.). In the late summer/early autumn, pigeons feed off natural food supplies and shed grain in cereal stubbles. As these food supplies are exhausted in late autumn/early winter, pigeons become increasingly hungry and are, therefore, attracted to seedling oilseed rape crops as a main source of food (primarily from December to April). Most economic damage occurs between early February (the onset of spring growth) and the end of March; after this time, the crop has usually become too tall for the pigeons to affect the growing point of the rape plant and are restricted to older, ageing leaves.

At 1979 prices, oilseed rape fields affected by pigeon damage suffered, on average, a yield penalty valued at £52/ha (Inglis, pers comm.). More up-to-date figures will not be available until after publication of a recent NFU survey (Inglis, pers comm.). The results from this survey, suggest that oilseed rape is the crop under most pressure from pigeons; in some instances, farmers are forced out of rape production because local populations are so high. This survey reveals that 45% of farmers consider pigeons to be an increasing problem (on all crops), while less than 5% consider them to be a declining problem. The remaining 50% considered the problem to be static (20%), or are unsure. Unfortunately, this survey did not consider the effects of straw disposal method on pigeon population.

Damage levels within a field may range from undamaged or negligible damage (damage to leaf margins) to severe damage where all foliage and growing tips are removed. It is unlikely that negligible damage affects final yield; more severely grazed plants compensate by producing more secondary stems. However, under these circumstances seed yield, and particularly oil content of the seed, remain depressed. Consequently there is a pronounced economic impact. Grazing also delays phenological development of the crop such that ungrazed plants will produce mature seed before grazed plants. This means that the potential economic yield of the crop is not realized at harvest because of differences in seed maturity. Under extreme circumstances of simulated severe damage in December-April, yield loss is estimated 50% (Inglis, Thearle & Issacson, 1989). It is also be more difficult to make good management decisions for spray applications, based on timing, in crops with variable development.

There is no evidence that the switch to zero or double-zero oilseed rape varieties has made crops more attractive to pigeons, or that industrial rape crops are less susceptible to pigeon damage. Site choice appears to be based more on plant patchiness, density and size. Pigeons prefer to alight on less densely populated regions of fields, for example within tractor wheelings and where establishment has been poor. Pigeon grazing then moves out from these centres. Clearly, once grazing has commenced, the increased patchiness of the crop makes it even more attractive to pigeons, and in this manner entire fields can be devastated. Firm, clean footings are preferred, thus the presence of surface straw may act as an attractant and pigeons will avoid situations where their feathers are wetted by dense foliage. Dense foliage also renders the birds more susceptible to predators so these areas are also avoided. We can now deduce from these points that pigeons will preferentially land and graze in thin crops with small plants which result from poor seedbeds, particularly if surface straw is present. However, there is only annecdotal evidence available on the interaction between straw, its method of incorporation, the quality of the seedbed and pigeon occurrence.

The most effective pigeon control measure is shooting. In the UK, this can be done at any time during the year. However, there is EU pressure to introduce a closed season to pigeon shooting because in the rest of Europe pigeon is a game bird. Any such closed season might have severe implications for rape crops in the UK. Where bird scarers are used, these be moved regularly so that crop damage is not localised in specific areas. Whilst new repellents are under development, these are still some way from the marketplace. (Inglis, pers. comm.)

5.2.2 Invertebrates

Three main invertebrate pests affect oilseed rape during establishment in autumn:-

- cabbage stem flea beetles (*Psylliodes chrysocephala*),
- aphids (e.g. peach-potato aphid, *Myzus persicae* and the mealy cabbage aphid, *Brevicorne brassicae*),
- Slugs.

Cabbage root fly (*Delia radicum*) is not considered to be of economic relevance on oilseed rape.

Cabbage Stem Flea Beetle (CSFB)

Population dynamics and damage/yield loss relationships for this pest are well known. The treatment threshold for insecticide application is triggered at 5 or more larvae per plant. Larvae can cause distortion and disruption of growth and infestations are of most significance in dry conditions, when the crop is already suffering stress. The adult beetles, which cause leaf holing of the seedlings and can lead to plant loss, may need controlling if numbers are high, but treatment is usually directed at larval infestations. Until three years ago, most oilseed rape crops were routinely sprayed in the autumn with a low-cost pyrethroid insecticide. Infestations of, and damage caused by, CSFB remained therefore at very low levels. In recent years, economic pressures to reduce input costs have resulted in much less routine insecticide applications. Consequently, CSFB infestations have recovered, placing more crops at risk. ADAS surveys have demonstrated that CSFB populations are increasing in most areas although few have exceeded the treatment threshold to-date. Populations have also increased because of the trend to earlier sowing (mid-August) of oilseed rape after set-aside. Such early emerging crops attract more adult flea beetles with consequent earlier and larger infestations of larvae in the autumn.

Oilseed rape crops will be at increasing risk from CSFB if current trends (earlier sowing after set-aside and less routine insecticide applications) continue. Poorly established crops need to be monitored carefully and an appropriate spray applied if CSFB numbers exceed the treatment threshold. To achieve more rational use of insecticides and to minimise crop damage, research is needed to develop a method of forecasting adult CSFB attacks together with a more cost-effective in-field assessment of larval infestations.

Aphids

Previously, aphids have not been considered to be a serious pest of oilseed rape. Up until 3 years ago, they were rarely detected in autumn crops of oilseed rape which had been routinely sprayed with pyrethroid insecticides. Following the move away from routine applications, on economic grounds, ADAS survey data have measured an increase in the size of aphid populations in autumn crops.

Infestations of the peach-potato aphid and mealy cabbage aphid are now commonly found on oilseed rape in the autumn; early emerging crops being more prone to attack. Although aphids can cause direct feeding damage in some seasons when numbers are high, concern is mainly over transmission of virus diseases - Beet Western Yellows (BWYV) vectored by the peach-potato aphid, and Cauliflower Mosaic Virus (CaMV) and Turnip Mosaic Virus (TuMV), both vectored by the mealy cabbage aphid. ADAS surveys have shown that incidence of BWYV is widespread in oilseed rape crops whilst CaMV and TuMV infections, which are more damaging, tend to be more prevalent in vegetable brassica growing areas. Early-sown crops after set-aside are more likely to be infected by aphid-borne viruses. Pyrethroid insecticides will give effective control of aphids and reduce incidence of virus infection but timing of application is important as early sprays are more effective. Sprays to control CSFB larvae are generally made too late for effective aphid/virus control. Strategies for controlling aphids in relation to virus transmission are not resolved and require further research along with studies of virus epidemiology.

Slugs

Slug activity associated with crop damage on oilseed rape has increased in recent years because of:-

- the widespread cropping of double low varieties (more susceptible),
- straw incorporation following the straw-burning ban,
- the uptake of set-aside.

These issues are considered in more detail in Sections 3.1.7 and 3.2.7.

Summary

Survey data shows that CAP reform (e.g. input reductions and set-aside) has indirectly led to increased infestations of cabbage stem flea beetle, aphids and slugs in autumn crops of oilseed rape. Establishing crops are, therefore, at increased risk from direct feeding damage and aphid-transmitted virus diseases. Poorly established crops will be at greatest risk. Further research is required to develop cost-effective control strategies against a background of changing pest population dynamics.

5.3 Diseases

Three main diseases affect oilseed rape in autumn/winter:-

- downy mildew (*Peronospora parasitica*),
- phoma canker (*Leptosphaeria maculans*),
- light leaf spot (*Pyrenopeziza brassicae*).

The susceptibility of the emergent seedling to pathogenic attack will be related to:-

- regional and climatic conditions,
- soil conditions, in particular the presence of a mulch of decomposing litter,
- previous cropping,
- proximity of oilseed rape crops,
- varietal susceptibility to disease.

Results from ADAS Disease Surveys have shown that there are large regional differences in disease incidence and severity (Fig. 14).

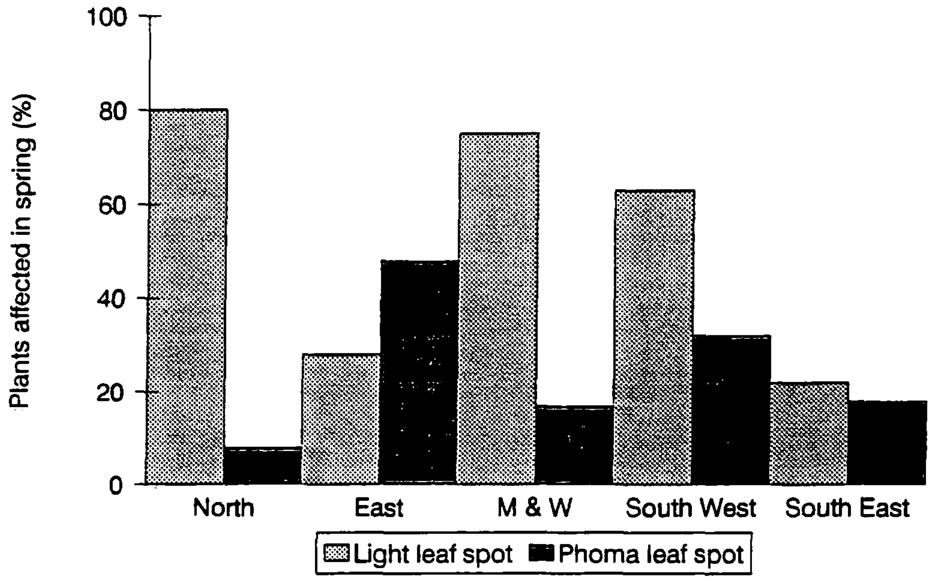


Figure 14. The incidence of phoma leaf spot and light leaf spot on oilseed rape in spring 1995.

There has been a consistent pattern of disease in recent years with the highest light leaf spot and the lowest phoma incidence in the North and the highest phoma and lowest light leaf spot in the East. In 1995, light leaf spot was most prevalent in the north and west Midlands whereas phoma was found most readily in eastern counties and parts of south west (especially Gloucestershire and Cotswolds). Within each area, however, there are large variations from crop to crop and this justifies careful monitoring at critical times.

5.3.1 Downy mildew

Downy mildew is soil or seed borne and can be found in most oilseed rape crops but is rarely severe. Normally, oilseed rape grows and develops at a sufficient rate that new leaf growth compensates for yellowing of older leaves. However, late-drilled thin, poorly-established crops are at greater risk. The timing of drilling is important because the period at which crops are at the cotyledon/1 true-leaf stage is lengthened with later drilling due to lower temperatures; also, plants are most susceptible to disease in cold damp weather. Hence, later drilled crops are more susceptible to disease infection on younger plants. It is possible for downy mildew infection to be severe enough at this stage to kill plants, particularly in periods of frost; such conditions occurred in the unusually cold winter of 1985/86 (Smith & Margot, 1987). In this situation, very thin and backward crops are likely to benefit from a fungicide spray; if frost is threatening and emergence very patchy it is advisable to spray before the 2-leaf stage. Evans *et al.* (1984) demonstrated useful control of downy mildew with a range of autumn fungicide sprays. Under normal conditions, fungicides are unlikely to give a yield benefit; however, an early autumn top dressing application of 30-40 kg/ha N would encourage slow growing crops to 'grow away' from downy mildew disease. The possible link between straw and N immobilisation may mean that higher levels of fertiliser are required following straw incorporation.

5.3.2 Phoma leaf spot

Phoma initially causes leaf spotting on oilseed rape from October onwards. Leaf spotting itself is not that serious but it can lead to stem canker; nevertheless, small plants with significant leaf disease will have their growth impaired. Plants affected with stem canker lesions in early spring can die prematurely. Early canker development in autumn can occasionally occur (as in 1993) and can cause seedling death during autumn and winter. However, this is rarely serious; normally, cankers are not detected until flowering.

Phoma disease development is encouraged by proximity to previous oilseed rape crop stubbles (Gladders & Musa, 1980) and by summer rainfall (in July, August and September); hence, dry soil conditions unfavourable to good establishment will not necessarily increase risk of phoma disease on oilseed rape. If conditions are conducive to phoma development, cost-effective control can be achieved by appropriate application of fungicide in autumn or spring. Priority should be given to small plants (<6 leaves) of susceptible varieties with obvious leaf spotting (>25% plants affected). Susceptible varieties should be avoided in high risk situations. Choice of a seed treatment reducing phoma infection should be considered.

5.3.3 Light leaf spot

Severe light leaf spot can reduce plant stands by half during the winter. Risk of light leaf spot infection is increased when there has been a high incidence of pod disease in the previous oilseed rape crop. Leaf spotting occurs in the period late October-December where infection has been triggered by a 2-3 day period of rain. Symptoms appear 250-300 day degrees later. Susceptible crops benefit from fungicide sprays in autumn or early spring depending on disease development.

5.4 Weeds

It has been estimated that weed control measures cause 15-27% of total variable costs incurred during the production of winter oilseed rape (Whytock, Bingham & Naylor, 1995) even though it is considered to be a strong competitor with weeds (Ward *et al.,* 1985). However, this is mainly post-establishment competitiveness achieved once springtime temperatures rise and stem extension of the crop begins in March/April. Before this stage, the seedlings are susceptible to competition with weeds for moisture, nutrients and light. Competition at this stage is particularly important if the seedlings have been damaged by pigeons, slugs, other pests or diseases and non-vigorous, late-sown or patchy crops will be less capable of tolerating weed competition.

The ideal rape seedbed may also satisfy the requirements of a large number of arable weeds, particularly annual species. However, the move away from minimal cultivations now that there is a need for straw incorporation, may once again provide the necessary conditions for suitable cultural control of weeds such as *Bromus sterilis*, a species which cannot emerge from seed depths in excess of 12 cm, and which consequently benefits from shallow cultivations. Conversely, minimum cultivation techniques reduced the turnover of other species seedbanks (the so-called stale seedbed), and the re-introduction of deep ploughing or heavy discing may increase these weeds once more, although for most weeds the effect is neutral.

The most serious grass weeds are volunteer cereals. These are not only common but also very aggressive competitors. Burning cereal straw was an effective way of reducing viable cereal and some grass weed seeds (Rule, 1991). As a consequence, the ban on burning has resulted in an increase in the densities of volunteer cereals and grass weeds, especially where the soil and straw are not fully inverted (Table 7). Ploughing gives very effective control of volunteer cereals.

Table 7. Annual kill (%) by herbicides needed to maintain a static population of black-grass.

	Straw burnt	Not burnt
Ploughed	50	65
Direct drill	88*	92*

* similar percentages expected for shallow tillage

Whilst there is much evidence of the response of oilseed rape to weed control using herbicides there is very little information published on the precise interactions between rape and weed seedlings. In particular, experiments which vary soil condition whilst keeping the crop and competitor seed bank stable in order to quantify the effect of cultivation treatment have not been made.

In terms of using experimental evidence to help in the construction of the decision process, we are just beginning to understand the complexities of the relationships involved. In some instances, the date of sowing has been correlated with the number of weed plants a crop can tolerate without losing yield. Lutman (1991) found that early-sown crops can tolerate much higher levels of volunteer cereals (110 plants/m^2) than late-sown crops, due to the greater vigour of earlier sown crops. Lutman *et al.* (1993) have found that the numbers of weed plants (sown into the crop) which are required to suppress yield by 5% can vary dramatically. Whilst 1.4 common chickweed plants per square metre were required to reduce yield by this amount at Boxworth, 464 plants were needed at an Aberdeen site. Other site-to-site differences were noted for cleavers. More vigorous rape populations (measured by final plant density) resulted in superior weed suppression. There was no clear relationship between time of drilling and level of competition. Lutman *et al.* (1995) have determined that on the basis of evidence from four field sites, weeds can be graded in terms of their competitive effect on winter oilseed rape:-

Very highly competitive

Galium aparine

Highly competitive

*Papaver rhoeas, Stellaria media, (Sinapis arvensis)**

Moderately competitive

Lamium purpureum, Matricaria perforata, Veronica persicaria, Poa annua, (Sinapis arvensis)

Poorly competitive

Capsella bursa pastoris, Fumaria officinalis

Very poorly competitive

Viola arvensis

* occurs in two positions dependent on whether the plant is an over-wintered biennial or a young plant in its first season.

Thus, regular monitoring of the crop will enable the assessment of the relative value of different control options given competitive or non-competitive weeds at a very early stage before the growth potential of the weed species becomes apparent. Coupled with research work which is showing that earlier-sown crops may be more competitive, and thus require lower herbicide application rates (Whytock, Bingham & Naylor, 1995), we can begin to construct a decision tree, based not on soil type or cultivation method, but on the uniformity and density of establishment, the weed species composition and sowing date (Fig. 15).

As it is estimated that herbicide application to 30-40% of oilseed crops would be uneconomic, the ability to link quality of autumn rape seedling (in terms of competitive ability) to all the climatic, edaphic, biological and pedological factors detailed in this report would provide a better basis for making rational herbicide application judgements. A better knowledge of seedbed structure, moisture supply and development of both the crop and the weed would have provided valuable information on the way establishment stresses can influence susceptibility to weed competition.

Finally, weeds may require control because they can act as hosts for a number of rape pathogenic fungi (e.g., downy mildew, grey mould and stem rot), and can modify the microclimate (increasing humidity at the base of the crop) in favour of the pathogens.

5.5 Canopy compensation

It is important to achieve an adequate plant size during the autumn before inflorescence initiation occurs (Scott *et al.*, 1973), but achieving this will be dependent upon the physical environment of the seed and seedling. The judicial use of fertiliser N may mitigate the effects of poor or delayed emergence and establishment. Autumn N applications can easily double the amount of crop dry matter produced in the autumn. In addition to increasing plant size and root development, autumn N reduces the risk of pigeon damage because it encourages better ground cover. On the basis of results of experiments in 1988-90, ADAS currently recommends that 30 kg/ha N is applied to the seedbed following stubble or straw incorporation (except where soil N supply is large).

Rapid development of the canopy during spring may also be 'managed' to produce the highest possible final yield if the relationship between yield, green canopy and fertiliser input can be ascertained. At present, this sort of information is more anecdotal than empirical; the hypothesis that careful nutrient management of the canopy can maximise yield has yet to be tested under robust field experimentation conditions. Certainly basic physiological knowledge of oilseed rape is some way behind that of cereals.

5.6 The decision process

Whilst the quality of germination and emergence has been linked in the previous chapter to soil structure, cultivation type and seedbed quality, it is more pertinent to classify the decision process for establishment primarily on the patterns of emerging seedlings and their density.

A correct series of decisions in the previous chapter will have produced an evenly emerged crop. Conversely, wrong decisions may have caused patchy or uneven emergence. However, even under the former scenario there may be differences which affect the plants through to establishment. Many of the combinations of climate, previous crop and soil type will have necessitated late cultivation and drilling, producing relatively backward crops. Heavy post-emergence rainfall may have caused localised waterlogging. A particularly hard winter may increase pigeon reliance on secondary food sources such as oilseed rape seedlings. Deep spring frosts may also depress the growth of the seedlings. The easiest of these to classify is sowing date, and many of the following decision trees are sub-divided into 'early' and 'late' sowing options.

5.6.1 Examples

1. **Even establishment of dense crop, early sowing (late August), straw incorporated, 'normal' climatic conditions**

This is in many ways the ideal situation for the establishment of the rape crop. Even establishment and a high count of plants of an advanced growth stage will compete strongly with even the most competitive weeds; herbicide application will be minimal. The evenness of establishment and advanced growth mean that pigeons are unlikely to be attracted to this particular field. The normal weather pattern will not encourage pathogens and the consequential reduction in sprays may reduce trafficking compaction. It is possible that the presence of straw will act as a pathogen reservoir and also encourage slug activity and slugs should consequently be monitored.

2. **Even establishment, sparse crop, late sowing (late September) in the presence or absence of straw, mild and damp climatic conditions**

Even establishment should ensure that, given successful control of pests, pathogens and weeds, the crop should recover to produce acceptable yields. However, the sparse nature of the backward seedlings renders the crop more susceptible to competition from weeds. Additional moisture and high temperatures may encourage pathogens and slugs. Any localised plant failure due to the action of slugs, pathogens or insects may produce landing areas for the pigeons, although their interest in the crop may have been minimised by the favourable winter conditions.

3. **Uneven plant distribution, over-dense patches, late sowing, straw incorporated and normal climatic patterns.**

Patches in the late developing canopy will attract pigeons. Even if these are controlled, the patchiness of the crop means that compensatory growth will not give rise to yields which equal those from evenly spaced crops. The dense areas of vegetation may particularly suit slugs and pathogens, as will the presence of surface straw. Weeds, if uncontrolled, will grow easily between the clumps of crop. Under this scenario heavy remedial action to control all pests, pathogens and weeds will be essential. Even if controlled successfully, variable costs will be higher and yields lower than from an evenly established crop.

The following decision trees set out many possible courses of action separately for weeds (Fig. 15), pigeons (Fig. 16) and slugs (Fig. 17).

Figure 15. Decision tree - diagrammatic representation of likely best practice weed control methods for establishing oilseed rape under different conditions of crop uniformity and density (based on first principles).

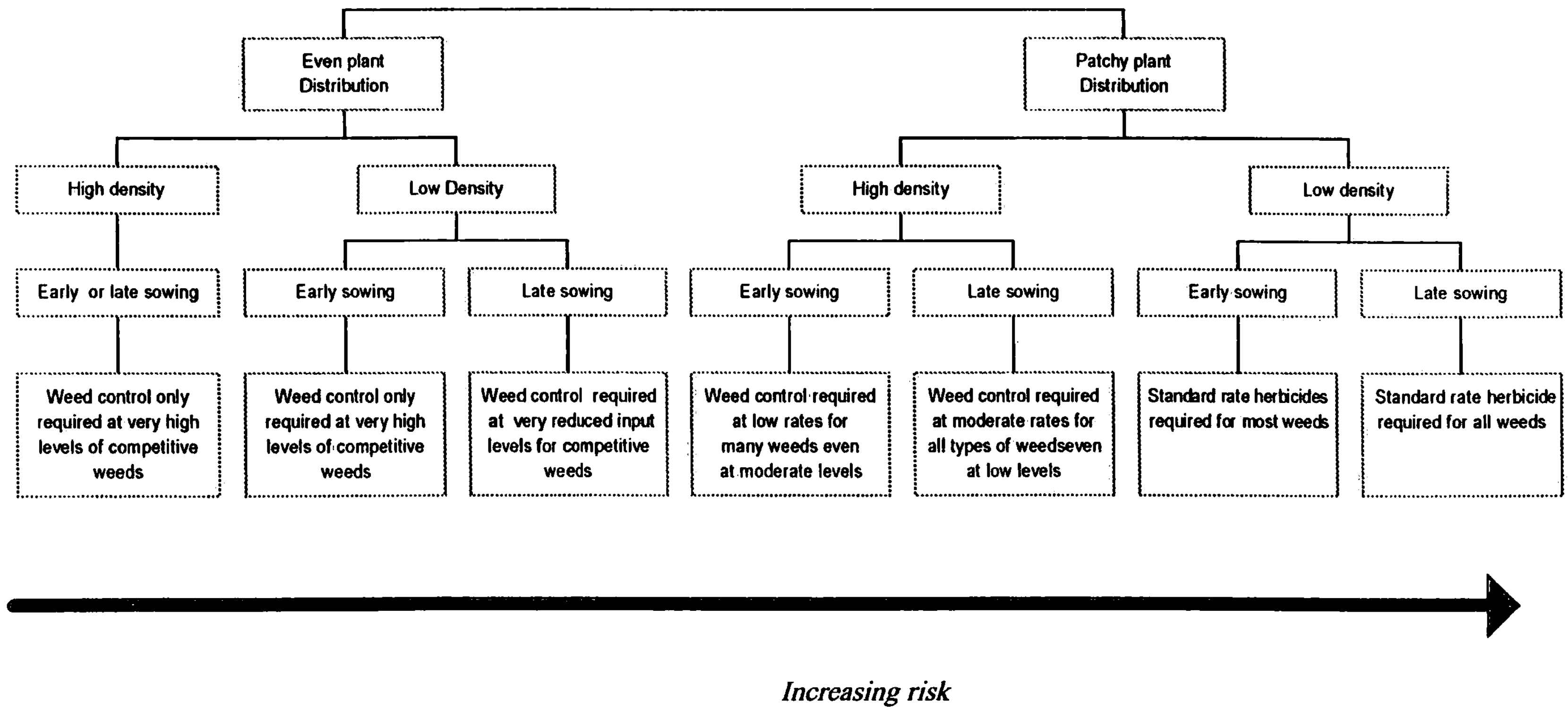


Figure 16. Decision tree - diagrammatic representation of likely best practice pigeon control methods for establishing oilseed rape under different conditions of crop uniformity and presence/absence of straw (based on first principles).

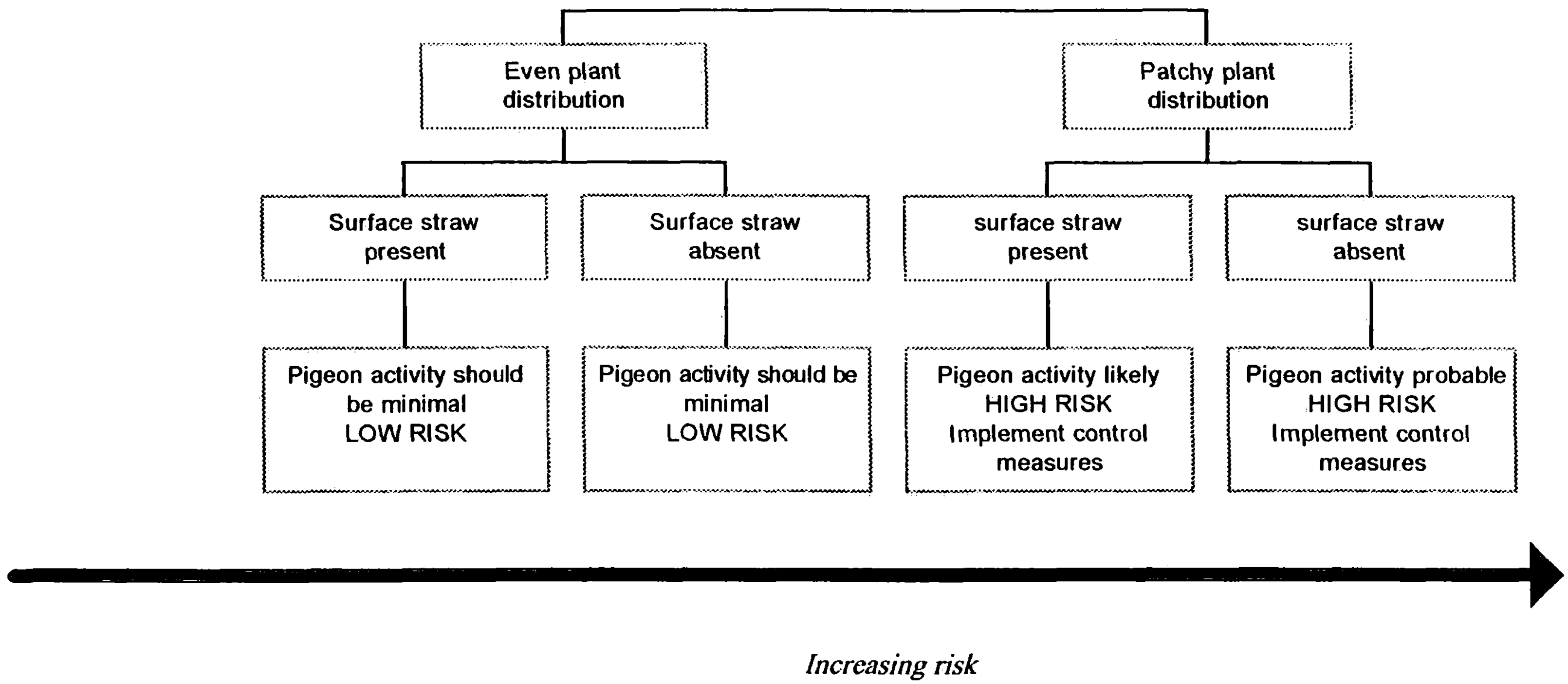
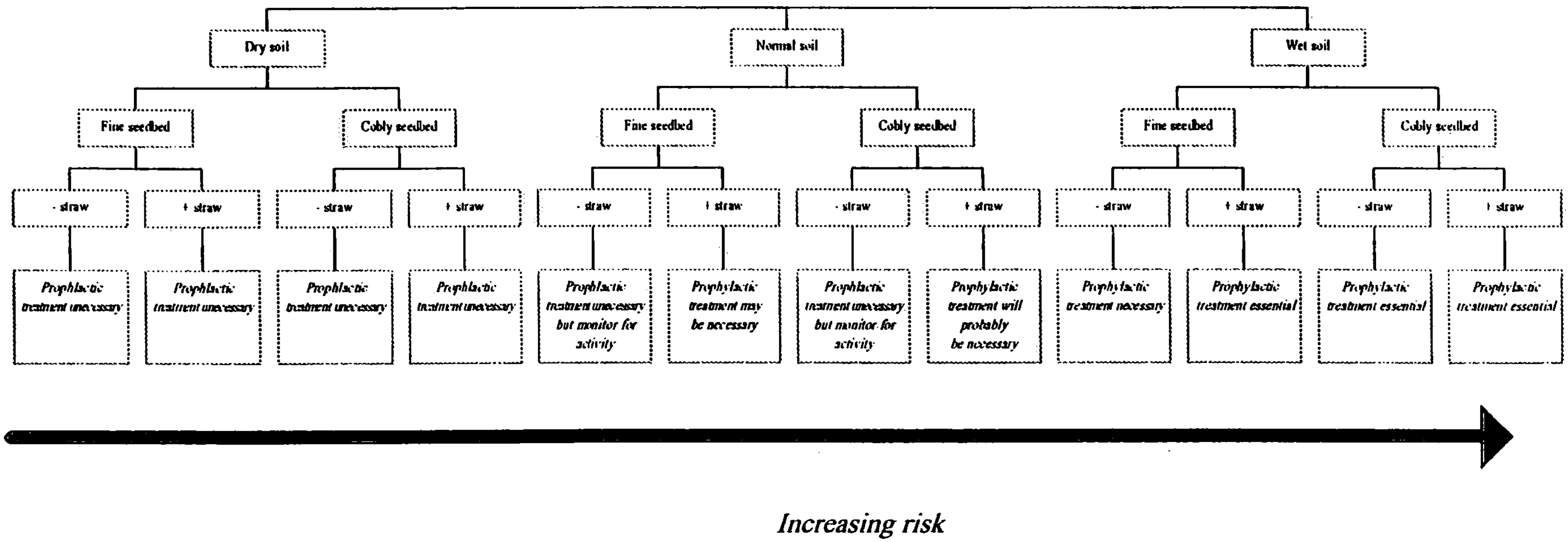


Figure 17. Decision tree - diagrammatic representation of likely best practice slug control methods for establishing oilseed rape under different conditions of crop uniformity and presence/absence of straw (based on first principles).



6 FUTURE RESEARCH REQUIREMENTS

A number of recommendations for future research is discussed in the body of the review. The three main subject areas warranting further levy funding are:

- validation of decision process for seedbed preparation,
- slug control,
- species selection.

6.1 Best-practice guidelines - Test-bed establishment and the validation of the decision process

Many of the criteria against which different types of cultivation and drilling machinery are tested are poorly resolved. There is no single engineering solution or simple prescription for obtaining an ideal seedbed. Indeed, the emphasis should no longer be on the assessment of pieces of cultivation equipment, but rather on the detailed understanding of soils and seeds and seedlings, and how they can best be manipulated to produce adequate crop establishment. We have given the first definitive list of variables which need to be monitored in order to assess accurately the effect of any individual treatment on oilseed rape establishment, and have provided some indication of the complexity of these relationships. The principal research requirement is to set up a test-bed system on carefully chosen clay soils representing both well-structured and poorly-structured classes, with adequate access to climatic monitoring. Precise measurements of the physical environment before, during and after cultivation and drilling, and extremely detailed monitoring of seed and seedling during development will allow validation of the principles which have been outlined. This will enable more precise data to be collected on the value of specific treatments to farmers under specific conditions.

The ultimate aim of a large-scale, test-bed system should be the development of an easy-to-use Decision Support System/Code of Best Practice which will inform the farmer on the least risk course of action given a certain combination of the factors.

Running parallel to this test-bed system, a comprehensive survey of current practice of rape growers should be made to determine precisely what is current practice, and the degree to which available physiological and climatic data are used in the decision making process. The following areas should be considered:

- Location
- Soil type
- Previous cropping and place in rotation (including set-aside)
- Seedbed quality
- Deduced moisture supply
- Species and variety (*B. napus* or *B. campestris*)
- Method of straw disposal
- Primary and secondary cultivations, and how the decision process is influenced by seasonal factors
- Drill type
- Sowing date and rate
- Autumn post emergence management
- Application of autumn nitrogen
- Risks from slugs, diseases, pigeons and insects
- Risks from pigeon grazing
- Major weeds
- Yield (t/ha & oil content)

For example, it has been shown that there are merits in the utilisation of natural tilth but in order to understand how this knowledge might further benefit the industry we need to know what proportion of growers regularly examine for the presence of a natural tilth in the preceding cereal crops and whether they use this to guide cultivation strategies.

The availability of such data would better guide treatment choice in future experimental programs, and allow more precise assessments of the benefits accruing to the industry from the uptake of ideas resulting from experimental investigations.

6.2 Slugs - Incorporating effective slug control measures within the range of systems required to produce an ideal seedbed

Slug damage to oilseed rape during crop establishment has increased considerably in importance since the introduction of double-low varieties and the ban on straw burning. Glucosinolates derived from the seed of earlier types made seedlings unpalatable to slugs. The relationship between glucosinolate levels and protection from grazing need to be firmly established. It is possible that seed coatings containing glucosinolates might protect the seed - again further work is needed. Slug damage is now a major cause of poor establishment of oilseed rape crops, despite a considerable increase in the amount of molluscicide applied to the crop. The HGCA has funded a study of seedbed preparation which has shown that the method of preparation can exert a significant influence on the amount of slug damage to the crop. The approach to cultivation for rape establishment must remain flexible depending on whether surface tilth exists in the previous crop (or set-aside land) or whether it has been destroyed by trafficking in wet conditions. In the former case, only shallow cultivation to incorporate the straw is necessary, in the latter deep, primary cultivation is essential. The end point must be to achieve an aggregate size distribution which will sustain the supply of water to the seed. The key is to understand the effect that different cultivation strategies have on slug numbers and the effect of seed bed cultivations on slug behaviour.

A better knowledge of how seedbed condition affects the risk of slug damage is necessary to allow exploitation of the findings from the research on seedbed preparation. Lack of understanding of the factors influencing the severity of slug damage to rape establishment currently inhibits the take up of this work by the industry. This knowledge will provide the basis to dovetail measures to control slugs within particular cultivations regimes over the necessary range to produce seedbeds that are ideal for plant establishment. By doing so it may be possible to achieve control of slug damage mainly by cultural methods. The experimental programme should examine the effects of straw incorporation or removal, retention of surface tilth or ploughing, consolidation, autumn nitrogen application and slug control on crop establishment and slug damage. The possibility of using deeper sowing as a control mechanism for slug damage has not been investigated for oilseed rape. Supporting studies under controlled conditions to provide basic information on a range of factors that may influence slug damage, include the effects of variety, depth of sowing and molluscicide choice. An important aim of this work will be to separate the effects of these factors on slug number and biomass from their effects on slug behaviour and the susceptibility of rape seedlings to slug damage.

6.3 Overcoming establishment problems by varietal and species choice

The better understanding of the first principles which influence oilseed rape establishment should be linked with information on varieties and drilling options, particularly on lighter soils. The value of extending the 'window' of drilling opportunity past mid-September by using a combination of improved understanding of the soil/seed relationship and different species and varieties should be investigated.

95% of the oilseed rape grown in Europe is 'swede' rape (*Brassica napus*). The remaining 5% is grown to 'turnip' rape (*B. campestris* & *B. rapa*). Turnip rape yields are, on average, 20% lower than those of swede rape. However, early ripening spring turnip rapes may have value in extreme winter conditions and where short growing seasons preclude the use of autumn sown rape. Therefore, they may be of particular benefit in northerly latitudes. It is not known whether varietal differences extend to improved ability to germinate in dry conditions, or tolerance to poor seedbeds, or indeed to relative growth rate.

6.4 Other Recommendations

Other recommendations for research, e.g. seedrate and plant population for precision drilling on light soils, weed, pest and disease control etc are discussed in the main body of this review.

7 ACKNOWLEDGEMENTS

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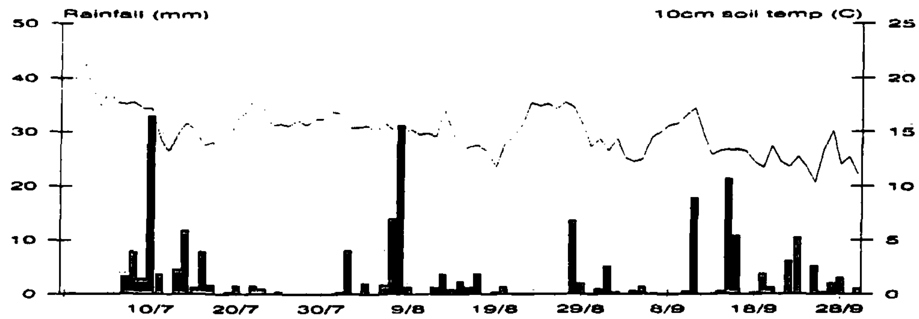
Appendix 1
Rainfall patterns and soil temperatures at ADAS Arthur Rickwood over the critical summer/autumn period for oilseed rape since 1968

1968 - M/M



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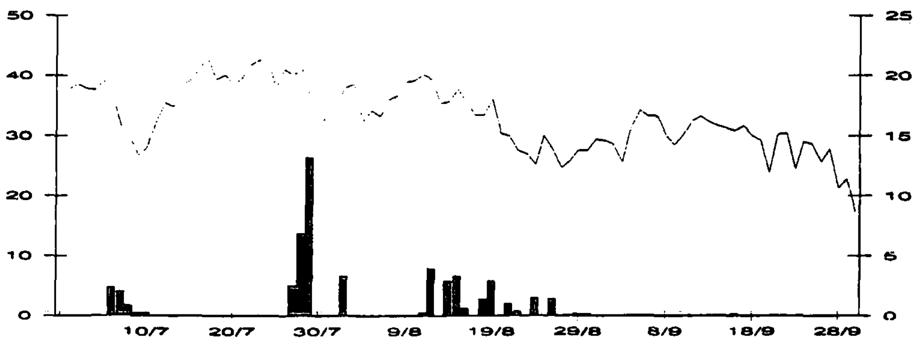

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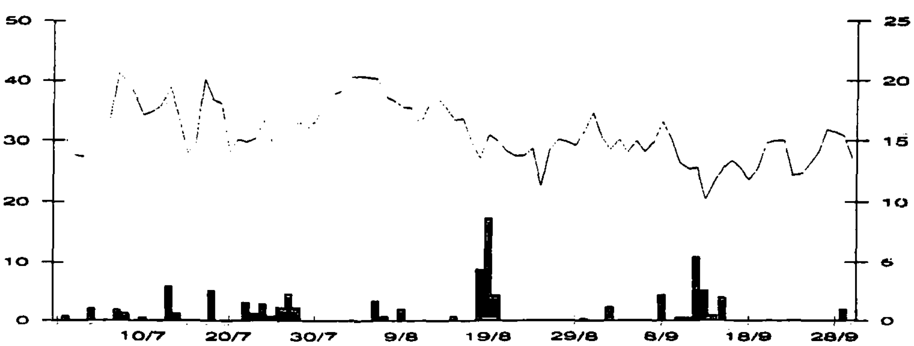

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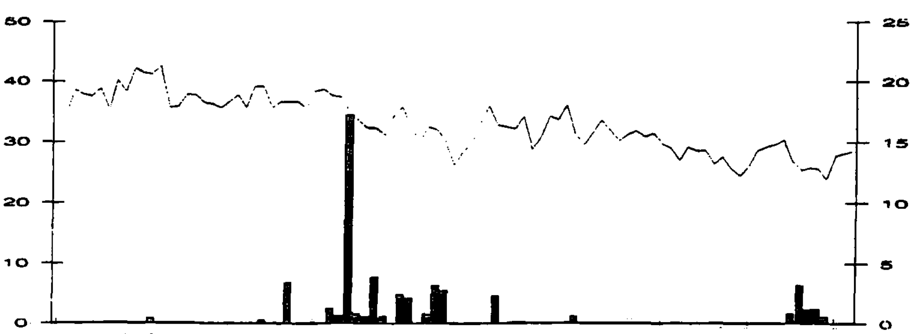

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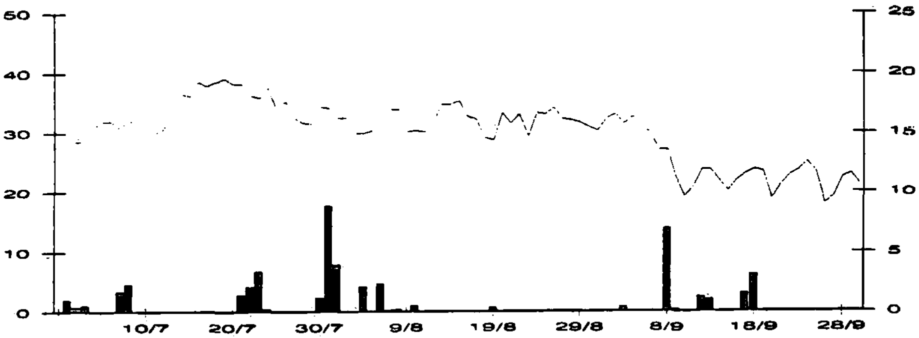

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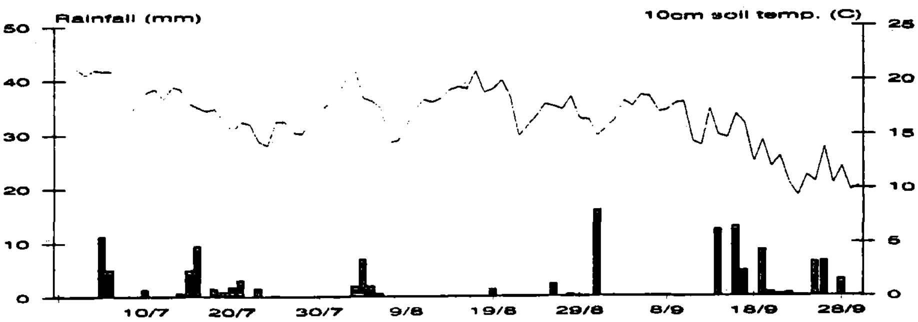

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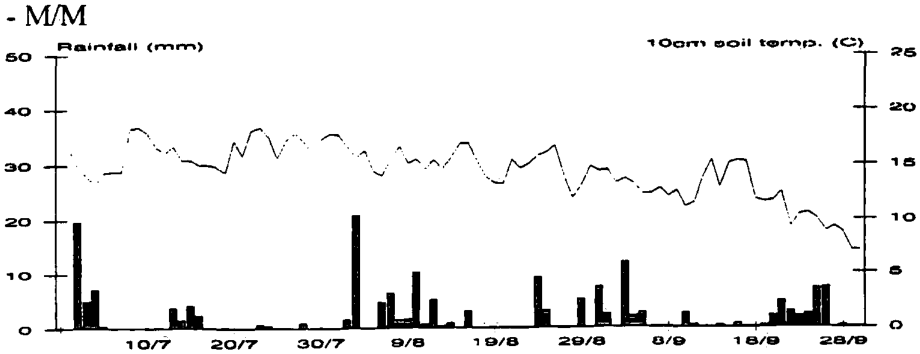

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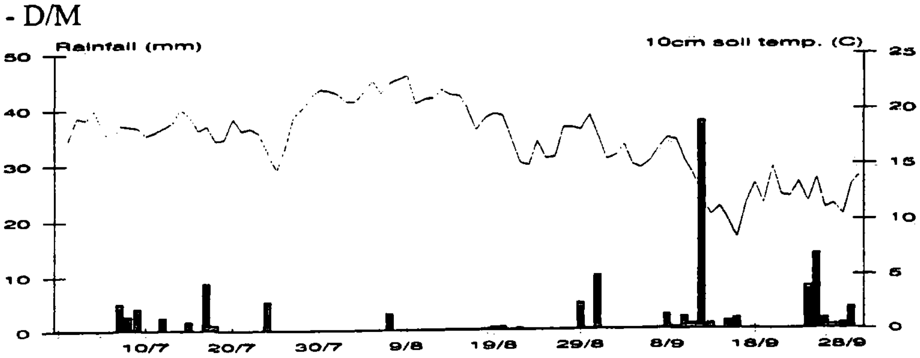

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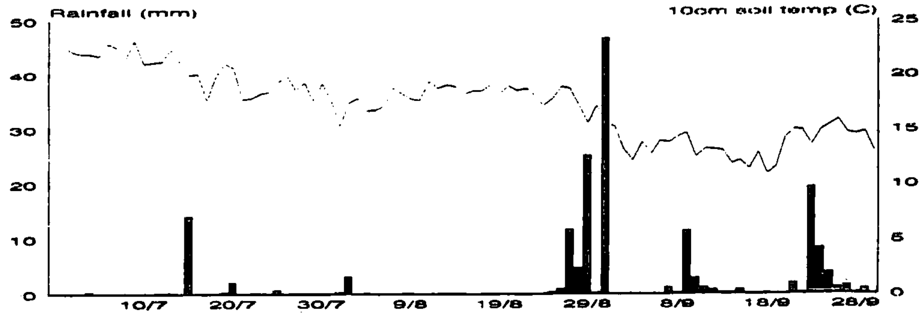

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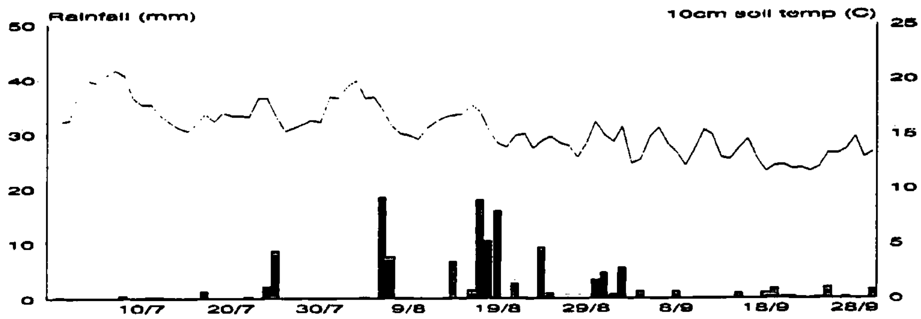

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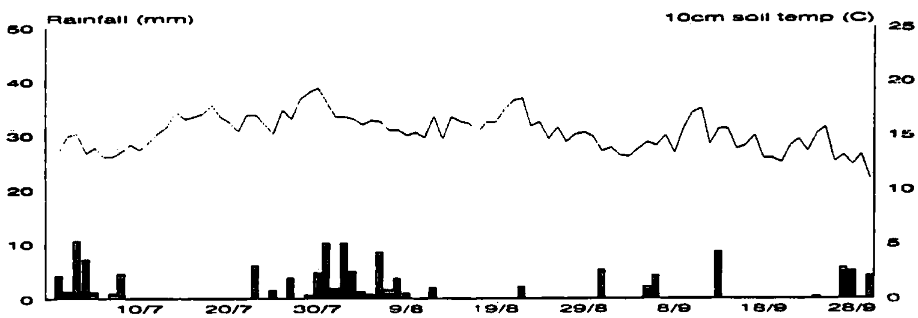

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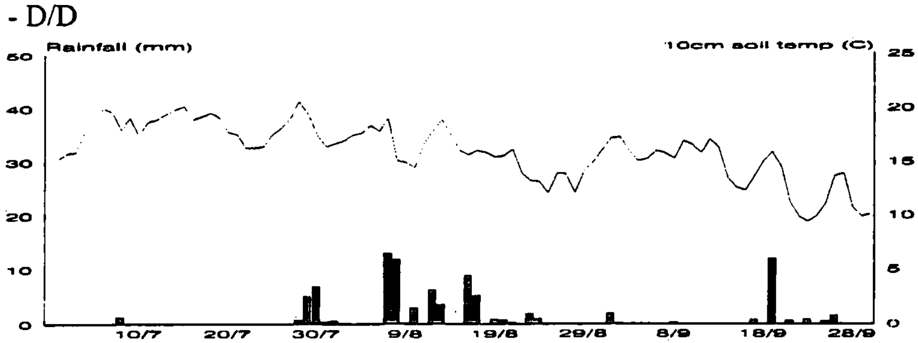

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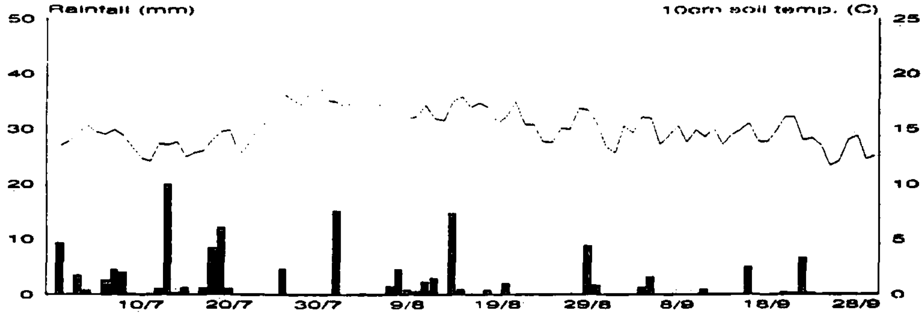

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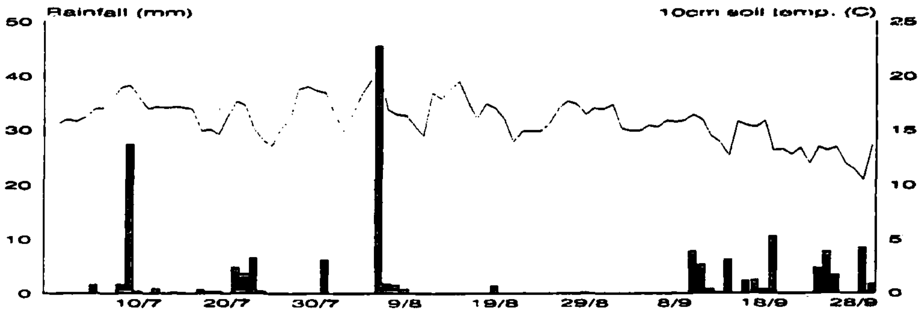

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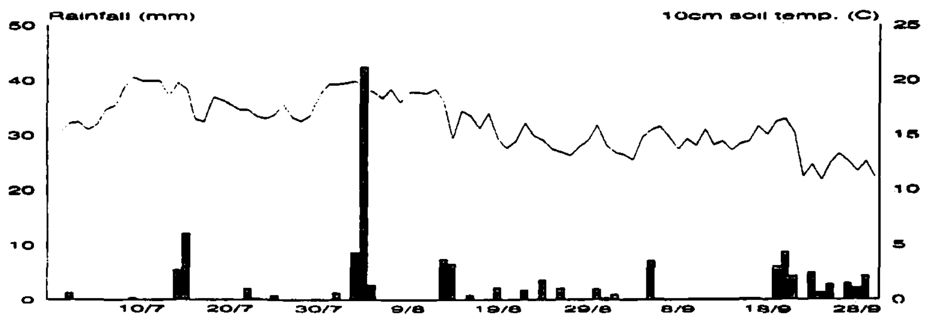

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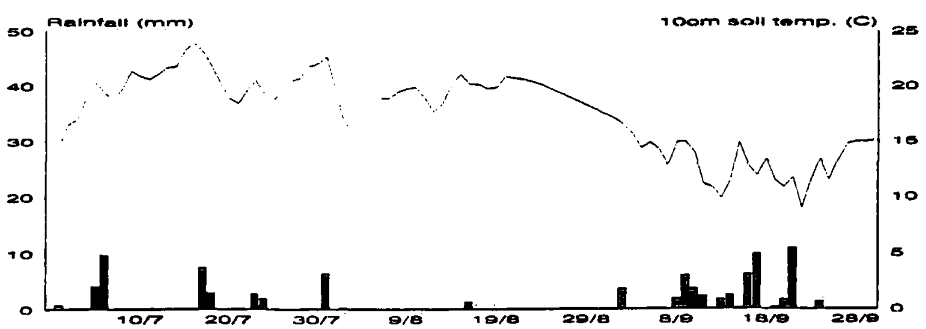

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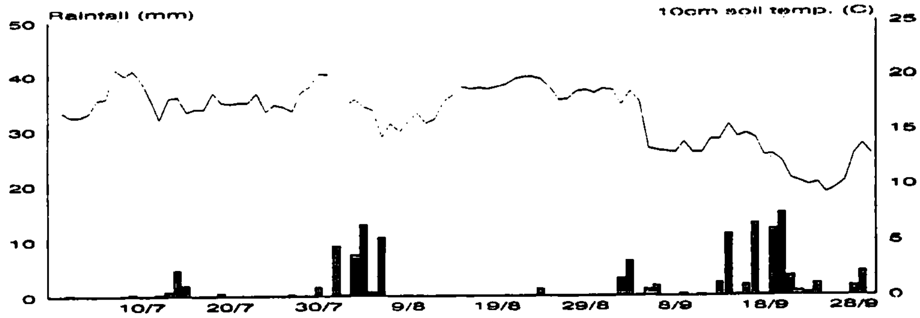

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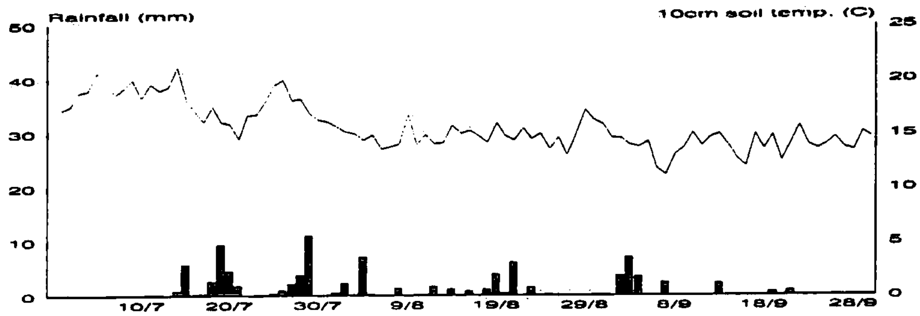

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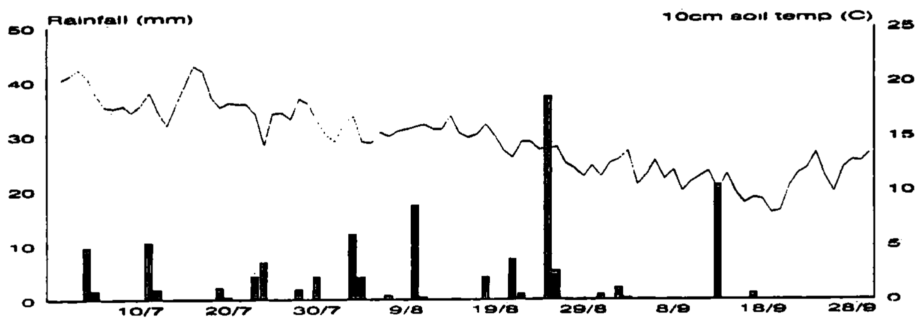

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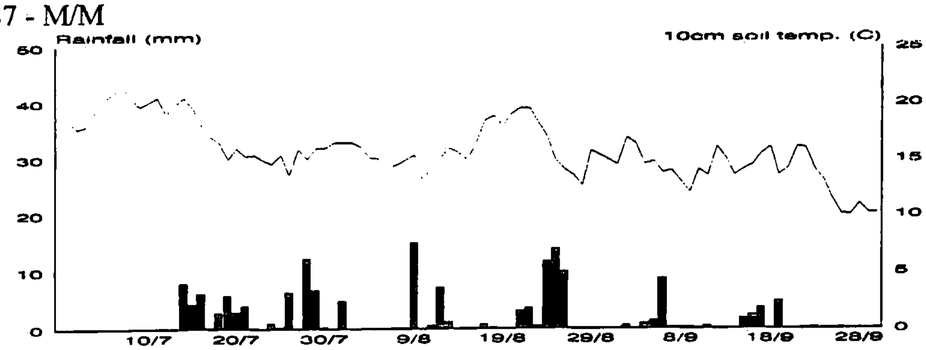

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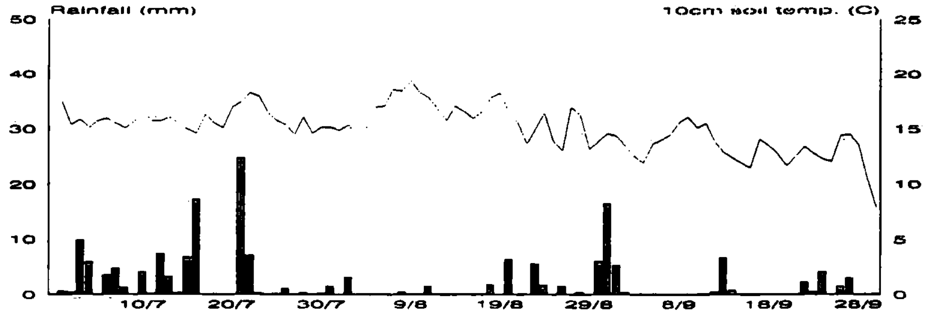

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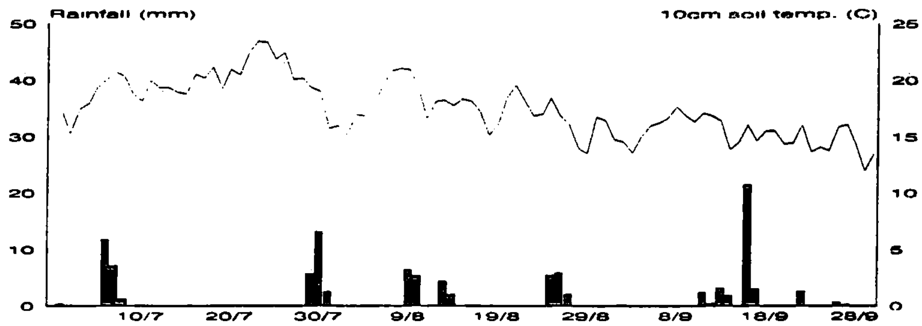

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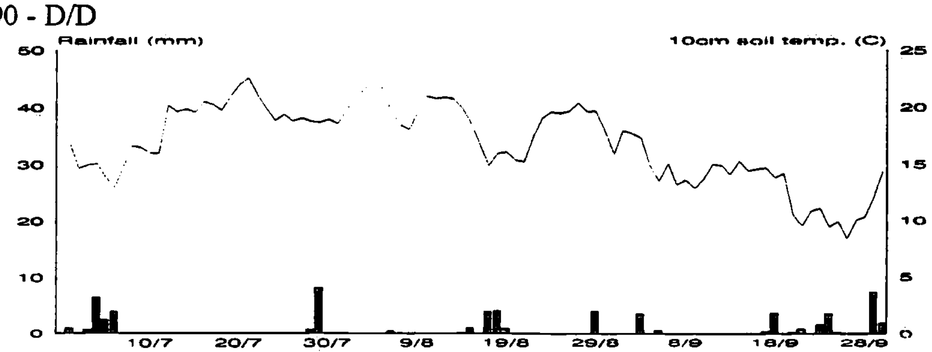

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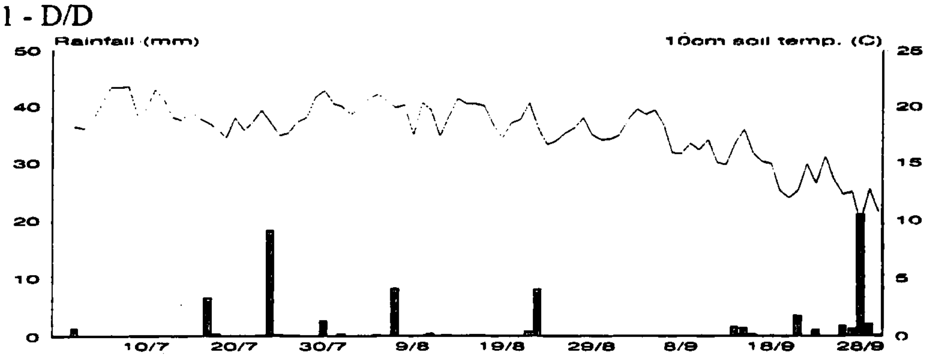

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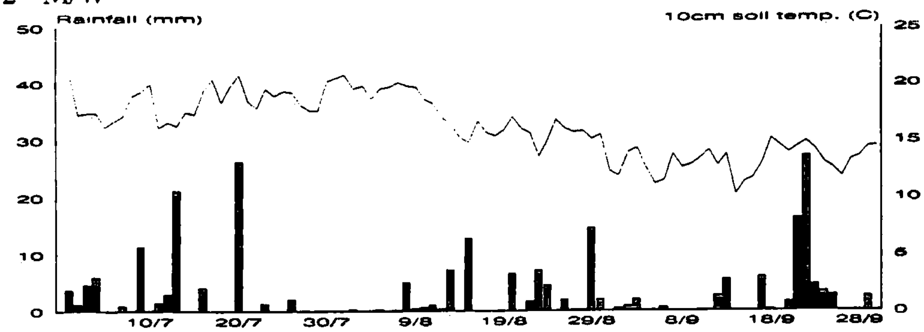

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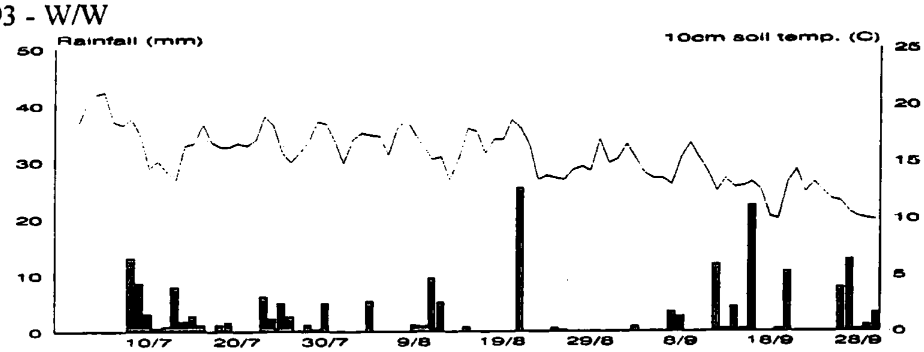

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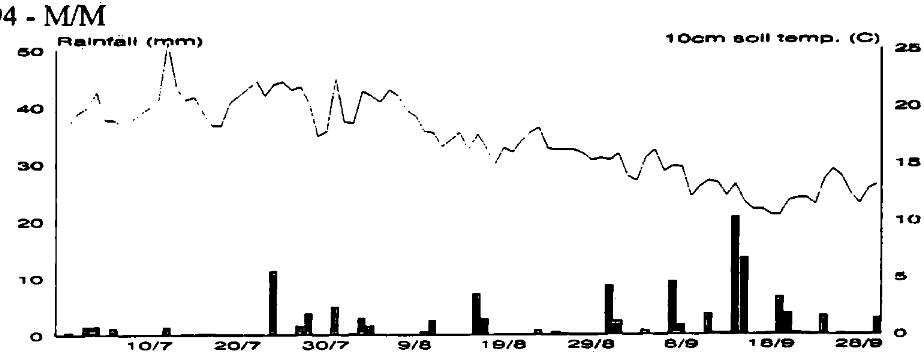

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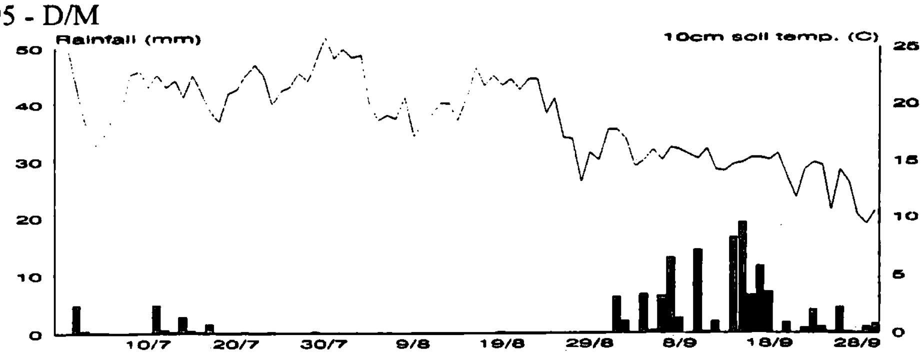

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