



**RESEARCH REVIEW No. 5**

**REDUCED CULTIVATION  
FOR CEREALS**

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## CONTENTS

### Page

1 - 6	Abstract
7	Glossary of Terms
8 - 10	Introduction
11 - 25	Field Experiments
26 - 36	Machinery Aspects
37 - 43	Soil Type, Soil Condition and Weather
44 - 49	Weed Pressure
50 - 53	Pest and Disease
54 - 58	Strategies for Reduced Tillage
59 - 61	Recommendations for Further Study
62	Acknowledgements
63 - 67	References
68 - 70	Appendix I - Yields of Test Crops in English Cultivation Experiments 1969 - 1986:
68	Clays
69	Medium Loams
70	Light Loams
71	Appendix II - Further Reading



## REDUCED CULTIVATION FOR CEREALS

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### ABSTRACT

During the last 15 years fixed costs on cereal farms have increased by about 40% in real terms while output from cereals has only risen by about 15%. Cereal prices are now static or falling and the scope for farmers to increase yield is small. In these circumstances the need to reduce fixed costs is urgent. The purpose of this review is to examine what is known about reduced tillage and to consider the opportunities that safer shallow tillage systems offer in reducing cost per ton of grain produced.

Britain has more recent experience of reduced primary cultivation than any other country and during the 1970's as much as 1/3 of the cereal area was established with these methods and without ploughing, thereby enabling a major switch to winter-sown cereals. This development was supported and encouraged by a very substantial investment in research and development undertaken by ICI, AFRC, ADAS and several universities.

Long-term experiments proved that well-managed shallow cultivation and direct drilling usually gave as good or better yields of winter sown crops as ploughing, and that the area capacity of these systems was much greater for the same input of labour and fuel. For the claylands in particular, straw burning and shallow tillage was successful in giving good quality seedbeds and much faster work rates, leading to uniform early establishment of crops.

However, early in the present decade, the majority of those farmers practising reduced tillage moved back to ploughing. There were probably three main reasons prompting this change: build-up of grass weed pressure - in particular from brome; restrictions on straw burning; and compaction sustained during wet seasons and by repeated

cultivation at one depth. Although these problems were apparent to researchers, results from experiments - other than with surface straw - did not highlight their effects because in general experiments were designed to avoid them.

A great deal of useful information has been gleaned from carefully monitored experiments and also from farm experience. Soil types found to give the best opportunity for reduced tillage were those with good drainage and stable structure, i.e. the ability to retain porosity without mechanical loosening. Thus, to the surprise of many, clay soils in drier areas proved superior to many free-draining light loams which tend to compact. At first the greater density of direct drilled topsoils was assumed to be an adverse feature, but research showed that in many cases extra continuity within the coarse pore/fissure system offset the lower total porosity and gave the added benefit of a better surface for movement of traffic. Climate was seen to play a major role in the success of reduced tillage. In the wetter northern arable areas of Britain only well-drained light loams were found to be suitable, in contrast to the findings in the drier south. This difference is related to the higher organic matter levels conferring extra structural stability in soils of the former areas.

When reduced tillage was first introduced drills and shallow cultivation equipment were inadequate. A wide range of effective equipment was developed - for drilling into undisturbed ground, for shallow cultivation and for loosening to the depth of topsoil without lifting too many clods.

The insidious build-up of grass weeds in reduced tillage was at first dismissed as of minor importance but eventually it was recognised as one of the major limitations. Substantial effort has been invested into studying the dynamics of grass weed species which has led to a quantitative understanding of how husbandry changes influence weed pressure. This has proved useful in providing criteria for avoiding long-term build-up of viable seed.

Initially it was thought that reduced tillage was likely to increase the risk of foliar and root diseases carried over on crop debris. However, in practice few problems have been encountered and although the potential risk is still recognised, it is now evident that this is

not a major risk in cultivation choice. However, the occurrence of cereal root disease is definitely enhanced by shallow incorporation of chopped straw and this is the subject of current studies.

The picture that emerged from more than a decade of research and farm practice is that successful reduced cultivation systems require careful planning and more flexible management than conventional systems. Many farmers did not invest this quality of management and allowed problems to build up to a severity which not only caused a substantial loss of yield but resulted in a permanent change of cultivation method.

### **Recent Developments**

Several recent developments point to the possibility of developing more robust systems of shallow cultivation. Tyre technology has improved so that now some general-purpose radial tyres can be used at recommended air pressure levels low enough to cause only small amounts of damage on wet soils. Research into all-purpose wide-span gantries is well advanced and brings nearer the prospect of economic zero-traffic cereal production. This could extend the opportunity for shallow tillage to a much wider soil and climatic range. The current development of a herbicide effective against brome grasses may overcome a major limitation of non-plough tillage.

There is little doubt that the contribution of shallow tillage to reducing the cost of cereal production could be much larger than at present. In particular, shallow tillage offers the opportunity for 'timeliness' with minimum input of resources. However, this aim would not be achieved were reduced cultivation to be used in the routine and inflexible manner commonly practised in the 1970's. The section of the review entitled 'Strategies for Reduced Tillage' suggests ways in which farmers can take maximum advantage from shallow tillage systems while avoiding or minimising the drawbacks. Those farmers not prepared to invest this level of care are advised to stay with conventional farming methods.

## **Recommendations for Future Study**

Many of the questions and problems encountered through the application of shallow tillage have already been answered by earlier investigations. However, the review has identified a number of key areas needing further studies to take account of changing circumstances and to exploit new developments. These are assembled in the final section of the review and are summarised here:

### **1. 'Low Pressure' Case Studies**

To encourage more effective adoption of low inflation pressure technology on farms and to investigate the problems which restrict uptake, it is recommended that several on-farm case studies are set up.

### **2. Wide-Span Gantries**

The all-purpose gantry offers the prospect of zero-traffic cereal production which would minimise problems of soil and crop damage in wet seasons. It is recommended that continued support should be given to this engineering development. In addition complementary work on the maintenance of permanent wheelways is recommended for contrasting soil types. At a later stage of development case studies to monitor farm application and behaviour of different soils in zero traffic may become necessary.

### **3. Cultivation for Control of Water Erosion**

Concern about the extent of water erosion in Britain has recently increased. Conservation cultivation methods have proved effective for control in several countries and it is recommended that studies to develop similar methods that British farmers will adopt should be supported.

### **4. Practical Guidelines for Reduced Cultivation**

To help those farmers that take up reduced tillage and to avoid the problems encountered in the past, it is recommended that a

complementary effort is needed to develop detailed criteria for making specific on-farm decisions about use of implements, soil management and weed control.

## **5. Weed Studies**

As growing systems change and new herbicides are introduced there is an urgent need for studies on weed behaviour and control methods.

### **i) Stubble Cultivation in the Presence of Chopped Straw**

There is a dearth of information on the effect of stubble cultivation in the presence of straw mulch, and on blackgrass, brome and volunteer cereals. It is recommended that studies are undertaken in a range of situations with detailed monitoring of salient factors.

### **ii) Brome Dormancy**

It is recommended that investigations to identify the factors involved in the apparent dormancy of brome receive continued funding.

### **iii) Volunteer Cereals**

Cereal volunteers are frequently a problem to specialist cereal producers, and it is recommended that studies on dormancy as the basis for improved control measures should continue to receive support.

### **iv) Resistance to Herbicides**

It is recommended that continued support is given to estimating the distribution in Britain of resistant blackgrass - a weed encouraged by reduced tillage. The support should extend to studies providing better understanding of inheritance of resistance in this species.



6.     **Root Diseases**

It is recommended that support be given to studies to provide information on the effect of long-term straw incorporation by reduced cultivation on root rotting diseases which are encouraged by this practice.

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## GLOSSARY OF TERMS

- |                      |  |
|----------------------|--|
| Cultivation          | - Any form of soil disturbance except mouldboard ploughing   |
| Tillage              | - Cultivation and mouldboard ploughing.  |
| Shallow Tillage      | - Shallow cultivation usually no deeper than about 10cm. or shallow ploughing usually no deeper than about 15cm. |
| Reduced Tillage      | - A general term to describe any cultivation using substantially less time and energy than normal ploughing.     |
| Zero Tillage         | - Direct drilling.   |
| Primary Cultivation  | - Cultivation after harvest prior to seedbed cultivation.  |
| Soil Texture         | - Defined in terms of the percentage of clay, silt and sand in a soil.   |
| Soil Structure       | - The units into which the clay, silt and sand of a soil are organised, eg crumb or blocky.                      |
| Structural Stability | - The ease with which soil structure is lost and the soil collapses when wet.                                    |
| Soil Series          | - Soils with similar layers or horizons to depth and formed from similar geological material.                    |
| Weed Pressure        | - A concept combining population density, intrinsic competitiveness and ease of control of a species of weed.    |

## INTRODUCTION

"The syndrome of high cereal yields per hectare associated with profligate expenditure on inputs, in particular fixed inputs, will be the final straw in the saga of cereal growing in the late 1980's and early 1990's;" this is the depressing prospect for UK cereal farmers anticipated by Murphy (1987). He estimates that although real financial output from cereal farms in Eastern England has increased by 10% over the last 15 years, fixed costs - including machinery - have increased by 40% over the same period. Cultivation is a major fixed cost of farming and the purpose of this review is to examine the opportunities for improved and safer reduced tillage systems in achieving the vital objective of reducing the cost per ton of grain produced.

Farmers in Britain have had very extensive recent experience of reduced cultivation for establishing cereals. This experience, backed by comprehensive field research, resulted in the widespread application of reduced cultivation on as much as 1/3 of the cereal growing land in England during the mid 1970's. The move away from mouldboard ploughing to systems with faster output allowed the industry to accommodate a very large increase in winter cereal production at the expense of both grass and spring cropping. In addition the substantial yield advantages of early autumn establishment would not have been possible without the reduced cultivation techniques developed at that time. Thus, during this period adoption of reduced tillage contributed to substantial reductions in unit cost of production. In the 1980's an equally strong trend has taken place; this time at the expense of reduced tillage which has given way to the plough.

Percentage of Crop area established according to tillage system in 1985/86 (after Ball 1987).

	England and Wales	Scotland
Total area of cereals	100	100
Direct drilled	3	0.2
Reduced tillage	12	1
Conventional ploughed	85	98.8

Several reasons have been put forward to account for this reversion. Higher farm incomes resulting, in part at least from the advantages of reduced tillage, encouraged investment in more tractor power and cultivation equipment, and the popularity of 'maximising yield by maximising inputs' - including cultivation - have both played roles. So too have an enforced decline in straw burning and improvements in plough design. However, the greatest disincentive for reduced tillage has undoubtedly been the occurrence of several severe agronomic problems, in particular explosions of grass weed populations and the development of severe soil compaction.

In these circumstances many farmers responded by purchasing extra power and implements to plough much of their farms every year. Was the decision to return to high input cultivation in the best interest of the farming industry or was it an expensive over-reaction? This review examines this question and suggests ways in which low-cost high output cultivation systems, with adequate safety margins, may be integrated into cereal farming.

Shallow ploughing was probably the norm for cereal farmers in Britain before the second world war, but since the 1950's, as power has become more cheaply available, ploughing has become deeper. The shallow working general-purpose mouldboard, designed for inverting grassland, is now rarely seen on farms and its place has been taken by the semi-digger and digger types which are designed to work to a depth of 20cm. or greater.

ICI Plant Protection Ltd. was the first organisation to question the purpose of annual deep inversion following the development of their contact herbicide 'Paraquat'. Early zero tillage trials at Jealott's Hill (Hood et al., 1963) demonstrated that zero tillage was feasible. This finding became the catalyst for a gradual upsurge in interest by both farmers and researchers. Tillage tradition is deeply ingrained and it was only after several years of enthusiastic dedicated field experimentation and demonstration on farms that it became widely accepted by farmers that not **all** soil cultivation is necessary. Zero tillage was the subject of detailed long term experiments by the ARC Letcombe Laboratory and Weed Research Organisation, while the East of Scotland College of Agriculture undertook a field

experiment which started in 1969 and is still running. The largest development project of all was undertaken by ADAS who at their Experimental Centres and on numerous commercial farms tested reduced tillage under a very wide range of conditions and developed guidelines for application. Drayton Experimental Farm developed a shallow cultivation system for the Warwickshire clays which was adopted by large numbers of clayland farmers throughout the Midlands and Eastern England. Plant Protection Ltd. continued to promote direct drilling vigorously during this period and supported the design of seed drills to work in undisturbed soil.

Also during this period many implements designed specifically for reduced tillage systems became available; engineers at the NIAE and at Silsoe College played important roles in many of these developments. During this period of intensive work, it became apparent that although reduced cultivation had many advantages over the plough it was very definitely a high risk option. Direct drilling and shallow cultivation worked successfully only within a prescribed range of conditions. On too many farms reduced tillage was adopted inflexibly without sufficient regard to the 'safe' guidelines. Too many advisers and researchers were guilty of over-enthusiastically selling the idea without sufficient regard to the need for the balanced professional interpretation that is always required before experimental results can be safely translated into reliable farm practice.

If shallow cultivation were to be re-introduced on a wide scale, is there any sound reason why the same problems should not occur again? An answer to this very reasonable question is in part the subject matter of this review. Development of efficient brome herbicides, progress in low pressure tyre technology and improved prospects for the commercial development of wide span gantries have enhanced the prospects for more effective shallow tillage systems. However, it would be foolhardy not to recognise that shallow tillage on balance is always likely to involve more risks than conventional systems and will require greater expertise for successful exploitation. In consequence expansion of shallow tillage systems is only likely where the need to reduce fixed costs of production assumes a high priority. Development of strategies to give the best return for these systems and research and development to solve outstanding problems, are the subject matter of latter parts of the review.

## FIELD EXPERIMENTS

Early work at Rothamsted (Russell, 1945) demonstrated the potential for reduced tillage provided weeds were controlled. In the 1960's ICI showed the major role that their contact herbicide 'Paraquat' could play in the absence of ploughing. During the 1970's and early 1980's the potential for shallow and zero cultivation was explored in several large experimental programmes and reduced cultivation widely practised on commercial farms.

The main experimental programmes of this period were:-

Weed Research Organisation/Letcombe Laboratory	1969-1978
Letcombe Laboratory	1974-1984
East of Scotland College of Agriculture and Scottish Institute of Agricultural Engineering	1968-1986
ADAS Eastern Region (MAFF)	1972-1985
Drayton EHF (MAFF)	1972-1976
National Institute of Agricultural Engineering (now AFRC Engineering Silsoe)	1971-1977
Leeds University	1971-1977
Boxworth EHF (MAFF)	1976-1986
Norfolk Agricultural Station	1975-1983

In addition experimental series were conducted on several other MAFF Experimental Stations, including Bridgets, High Mowthorpe and Terrington.

### Nature of Experimentation

The aim behind most of the work was to examine the potential of faster methods for establishing winter cereals. Some of the experiments were fully monitored whereas others, on commercial farms, were less fully recorded but gave a wider representation of site/soil situations. In the majority of projects, limitations, other than soil conditions, were as far as possible kept to a minimum. Thus straw was usually burnt and weeds, diseases and pests controlled by overall treatment together with individual plot treatment if necessary. Cultivation treatments were all drilled on the same day wherever this was

feasible, thus precluding the opportunity to examine any interaction between cultivation type and date of drilling. In general sites with serious drainage problems were either not selected or drained before work started. Most of the experiments compared direct drilling and shallow tine tillage with conventional deeper cultivation, which was normally ploughing.

## **RESULTS**

Short accounts of individual projects are given below with results on pages 16 a-d and in Appendix I

### **Joint Project between WRO/Letcombe Laboratory**

Between 1969 and 1978 these two Institutes worked together on three experimental sites. A deep well-drained sandy loam at Begbroke, a chalk loam at Compton and a calcareous clay at Buckland. It was concluded by Ellis et al. (1979) that on these well-structured soils yields of spring barley and winter wheat were little affected by cultivation method despite differences in soil density.

### **Letcombe Laboratory**

Following its earlier satisfactory experience of reduced cultivation the Laboratory chose three soils with problems for conventional tillage. Ten year experiments were set up on two non-calcareous clays and one silt loam. These sites were farmed by staff from Letcombe and weed, disease and pest control measures were carefully applied and the effects monitored. Crop development, soil conditions and water characteristics were followed in detail.

Apart from improved growth of oilseed rape in the direct drilled clays, there were no large effects of cultivation over the ten year experimental period and particularly in the last five years cereal yields were exceptionally high (Cannell et al., 1980; Goss, 1988). The overall yield response disguises substantial year-to-year effects when weather favoured one or other of the cultivation treatments. At the light-textured Englefield site crops grown under direct drilling, but not shallow tillage, performed poorly in two of the first three

years when wet conditions prevailed (Ellis et al., 1982). However, after this inauspicious start conditions stabilised and results from direct drilling became consistently satisfactory during the remaining years (Goss, 1988). This change was attributed to improvement in stability of the top few centimetres of soil.

#### **East of Scotland College of Agriculture and the Scottish Centre of Agricultural Engineering**

Scottish research workers conducted a large programme on reduced tillage starting in 1968 when the longest surviving tillage experiment in the UK was set up at South Road near Edinburgh. The South Road site contains two soil types differing mainly in natural drainage status. On the less well drained soil reduced tillage proved unsuitable for both spring and winter sown barley, while on the better drained soil it was unsuitable for spring barley but suitable for winter sown barley (Holmes, 1977; Ball, 1988). The free draining sandy loam site at Rosewall responded well to direct drilling over a three year period confirming the view of Ball and O'Sullivan (1987) that free natural drainage is an essential prerequisite for direct drilling in Scotland. Direct drilling of the slow draining soils at Glencorse and at South Road caused reduction in yield of winter barley in the first trial year but similar results to ploughing in three subsequent years.

Scottish workers have consistently shown that shallow rotary tillage of previously broadcast seed is a very effective means of establishing winter barley in their comparatively wet conditions. The system has been compared over eight seasons with direct or conventional drilling in four field experiments by Ball (1986).

#### **ADAS Eastern Region**

Proctor et al. (1988) describe 140 comparisons of deep and shallow cultivations with direct drilling at 35 sites in Eastern Region between 1972 and 1985. A range of soil types was included in these studies. On clays, direct drilling and shallow cultivation performed slightly better than ploughing by 0.6% and 1.8% respectively. On a wide range of medium loams, shallow cultivation and direct drilling performed slightly worse than ploughing (-1.6%



and -0.4% respectively) and direct drilling performed noticeably worse on the light loams (-3.6%) where soil impedance to rooting was the dominant limitation. Substantial depressions from reduced tillage at some sites in some years were attributed to several factors of which poor drainage, weed competition and soil compaction were the most important. Likewise, reduced tillage enhanced yield in several years. The most frequent reason for this was better establishment encouraged by moisture conservation in very dry years; this was particularly noticeable on clay sites.

Indices of crop uniformity were measured on all treatments from 1976 to 1983. Shallow tilled and direct drilled crops were invariably more uniform than ploughed crops. This factor accounted for a substantial amount of the overall yield variation.

#### **Drayton Experimental Husbandry Farm**

Drayton Farm is situated on the Lias Clay of the West Midlands. At this Centre ploughing was recognised as a severe limitation to the yield of winter cereals and to the total area of crop that could be established. Between 1971 and 1976 the Centre developed, a new approach to clayland management. This involved straw burning and encouragement of the summer surface tilth with shallow-working heavy-duty spring tines. Excellent seedbed conditions, avoidance of severe moisture loss and greatly enhanced work rate are the advantages attributed to this system. The 'Drayton system' as it became known was widely practised on clays throughout Midland England and beyond. Unfortunately the long-term build up of weeds and compaction resulted in the eventual failure of the system on many farms. The system was not supported by sufficient long-term critical experimentation, and was applied by farmers with insufficient flexibility. Nevertheless, the principles on which the Drayton system is based are sound and have had a lasting effect on attitudes to farming clays. (Annual Reviews of Drayton EHF for 1978 & 1981).

#### **National Institute of Agricultural Engineering, Silsoe, Bedford**

The performance of a wide range of alternative cultivation techniques was compared over six years on three clay soils in Eastern England. The project measured the substantial savings in time and energy

associated with shallow working implements and direct drilling compared with conventional ploughing (page 23). Yields from these experiments showed no significant effects due to treatment, except a large reduction from direct drilling at two of the sites in some years. This reduction was attributed to wet soil conditions, rutting, presence of straw residues and lack of tilth under dry and hard soil conditions (Patterson, 1987).

### **Leeds University**

Detailed experiments testing spring barley yields established by direct drilling, shallow cultivation and ploughing were made on two soils, a free-draining clay loam and a naturally slow-draining clay. The first experiment showed no real difference due to cultivation apart from a depression from reduced tillage in one out of four years. However, the optimum rates of nitrogen were higher for crops on untilled land. The second experiment on the slow-draining clay resulted in a small grain yield reduction due to reduced tillage. The effect was entirely attributed to one wet spring (Hodgson et al., 1977; Clutterbuck and Hodgson, 1984).

### **Boxworth Experimental Husbandry Farm**

The Hanslope clay formed on chalky boulder clay is one of the most extensive soils and naturally well structured in Eastern England. The Boxworth Centre is on this soil and has practised shallow tillage for many years following a long-term experiment started in 1977. The average yield of winter wheat established after ploughing during the harvest years 1977-86 was 7.41 t/ha with direct-drilled and shallow cultivated yields 2% and 4.5% higher respectively. Very substantial advantages in time and energy saving and better quality seedbeds were recorded in reduced tillage treatments (Annual Reports of Boxworth EHF, 1978-80)

### **Norfolk Agricultural Station**

In 1975 the Norfolk Agricultural Station and ADAS started an ambitious experiment to test the effect of reduced cultivation on a rotation containing sugar beet. The beet was established after strip

tillage in the preceeding cereal stubble. Two experiments were conducted: one on a sandy clay loam and the other on a sandy loam. Winter cereals established after shallow cultivation yielded slightly better than after ploughing on both soils, while direct drilling tended to give lower yields (-1.6%) on the heavier textured site. Sugar beet establishment was generally lower in the strip tillage system at both sites and it was concluded that reduced tillage systems gave no overall advantages in rotations containing sugar beet on loams in Eastern England (Nuttall et al., 1987).

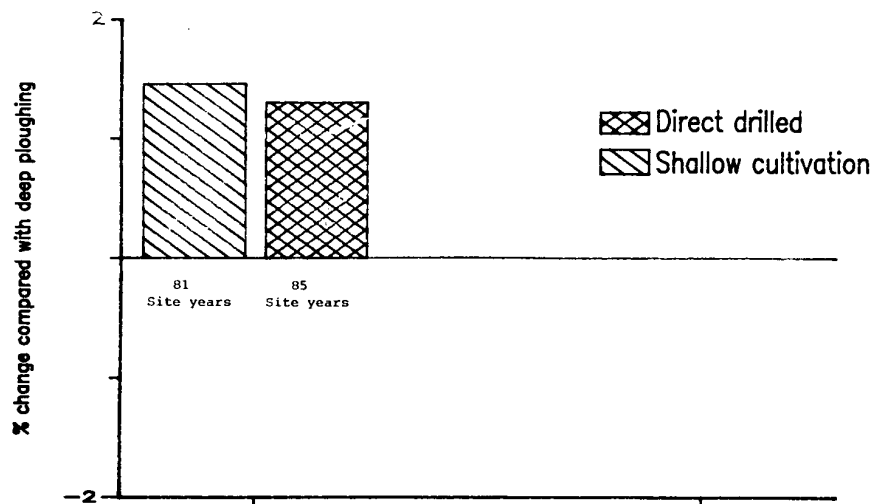
#### **Other Experimental Stations**

Longer term winter wheat growing on medium silts at Terrington EHF showed small advantages from shallow cultivation compared with ploughing (4.5%). Direct drilling gave intermediate results of 2.9% increase. These results were obtained after straw burning and early autumn sowing. Earlier cultivation work at this centre showed substantial depressions in yield of direct-drilled winter wheat when sowing was delayed until winter. (Annual Review for Terrington EHF, 1981).

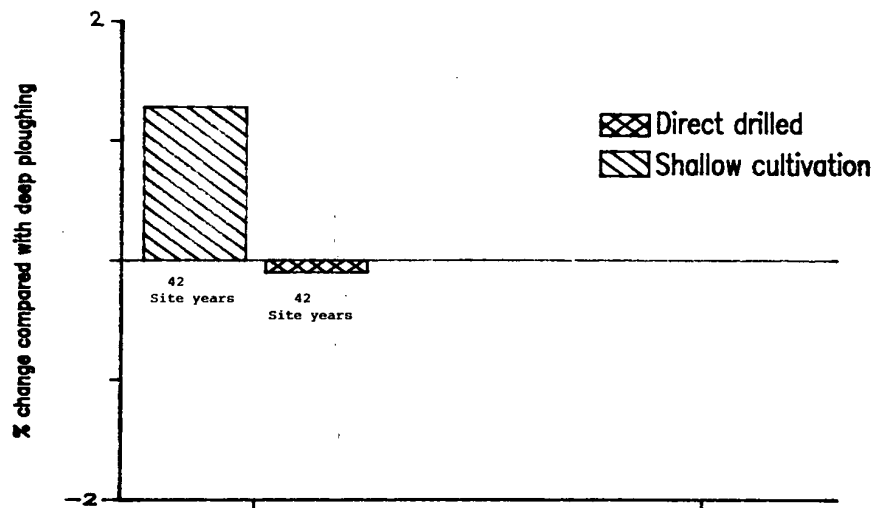
On chalk loams at Bridgets EHF shallow cultivation and zero tillage consistently gave poorer yields than ploughing over a three year period. (Annual Review for Bridgets EHF, 1983). Problems were variously ascribed to surface penetration difficulties, to dry conditions and to weed and trash problems after poor burns. However, it remains to be proven whether an appropriate cultivation system, providing good penetration coupled with better weed control, would have given equivalent yields.

On the chalk loam soil at High Mowthorpe EHF shallow cultivation and direct drilling also gave problems. The cause of the small yield reductions was not clearly identified but was probably due to trash and grass weed problems (Annual Review for High Mowthorpe EHF, 1978).

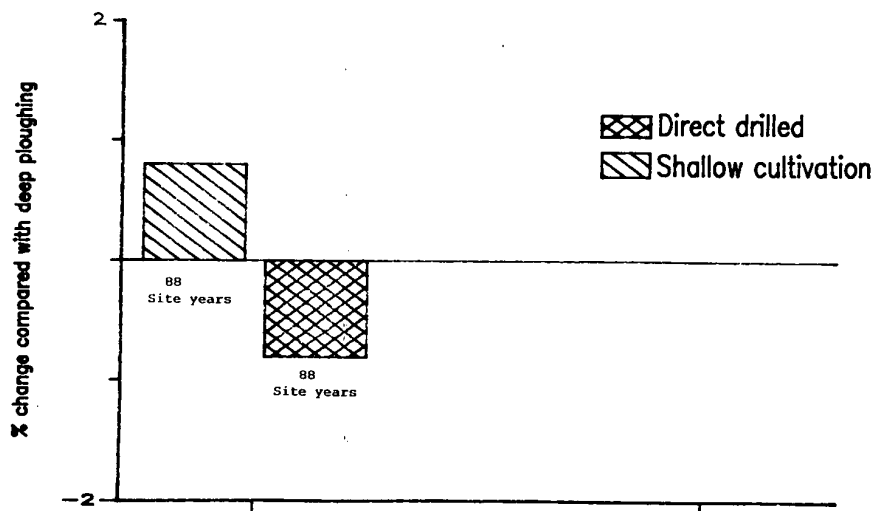
The effect of reduction of tillage compared with deep topsoil cultivation in British field experiments 1969-86  
CLAYS



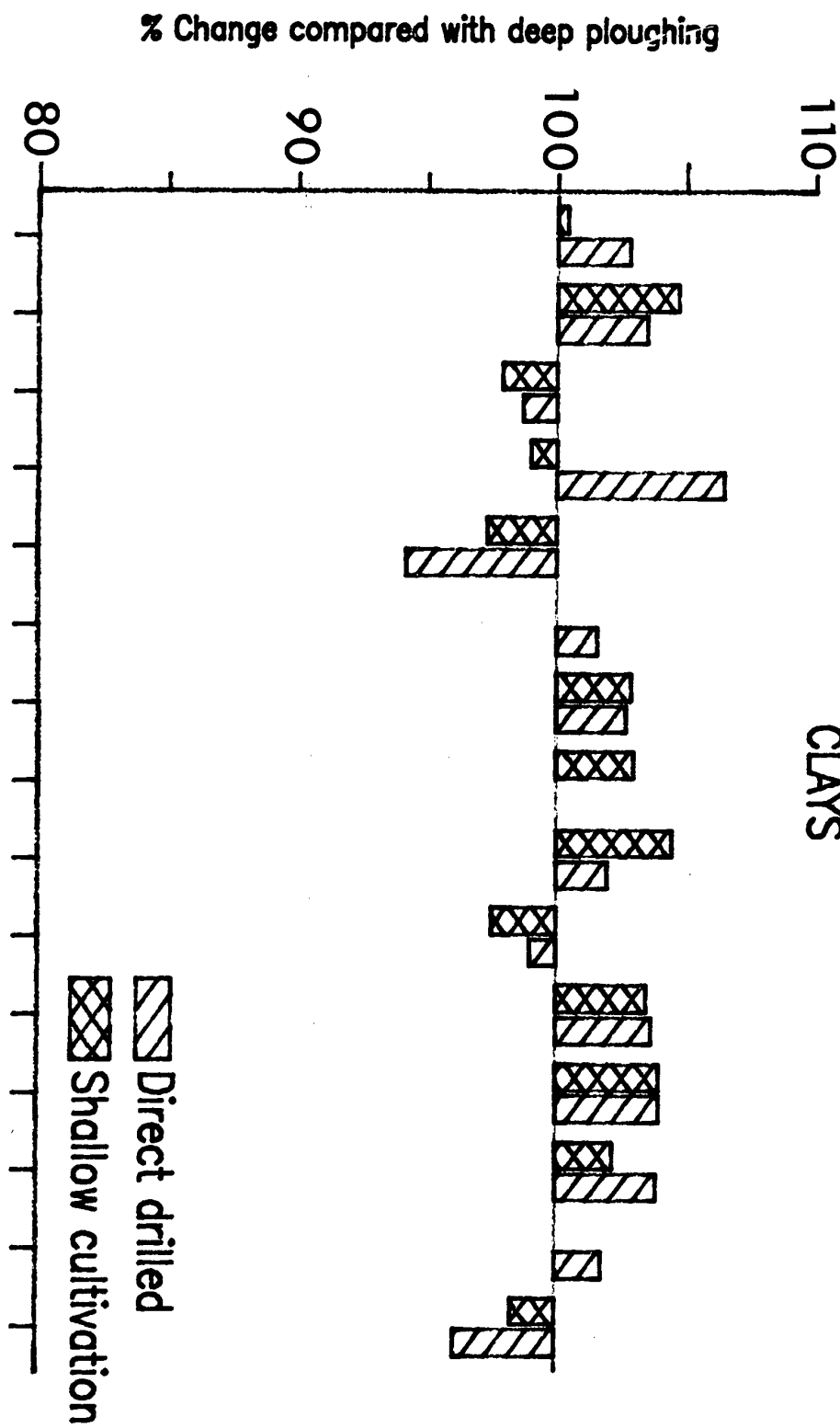
LIGHT LOAMS



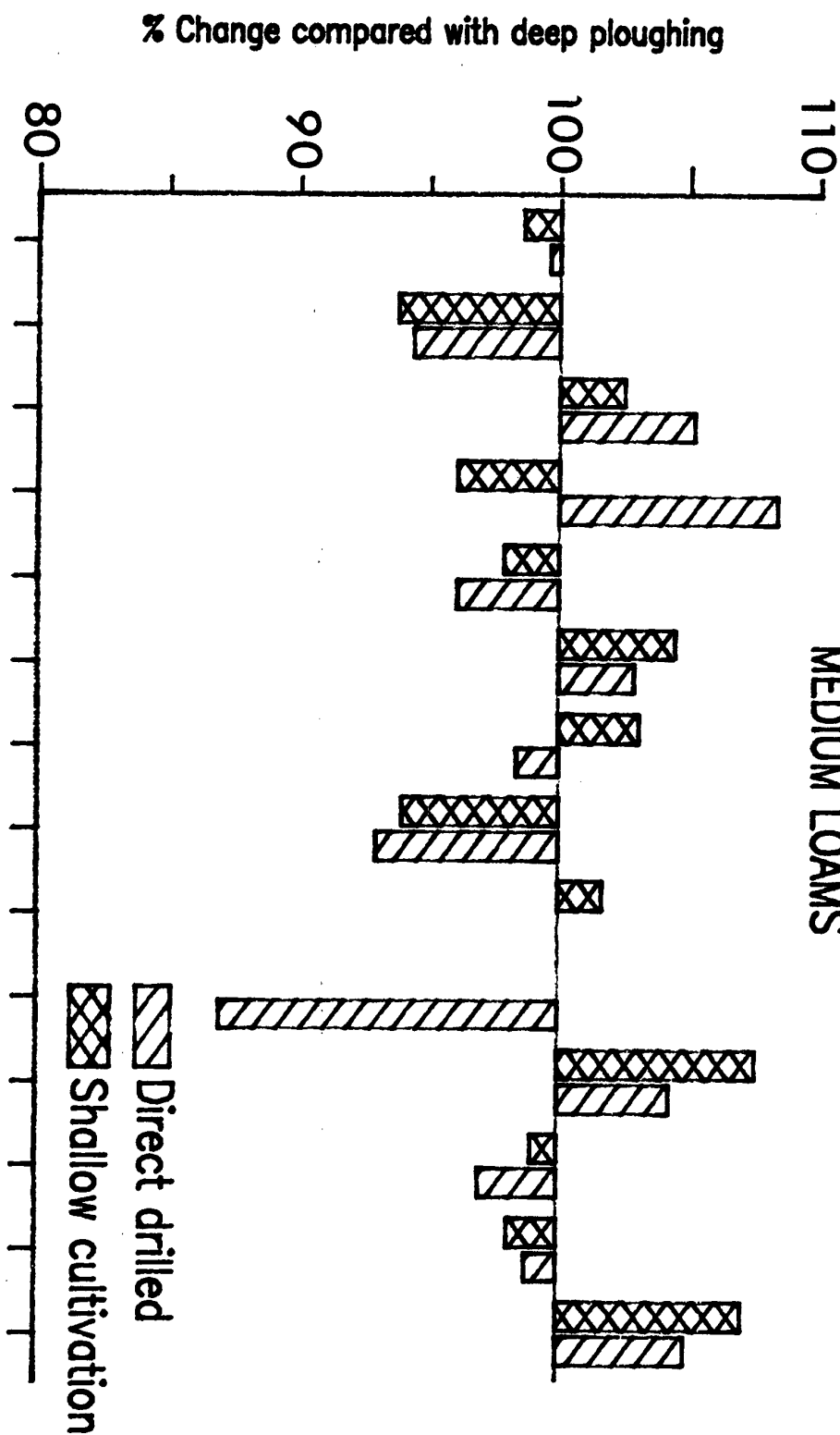
MEDIUM LOAMS



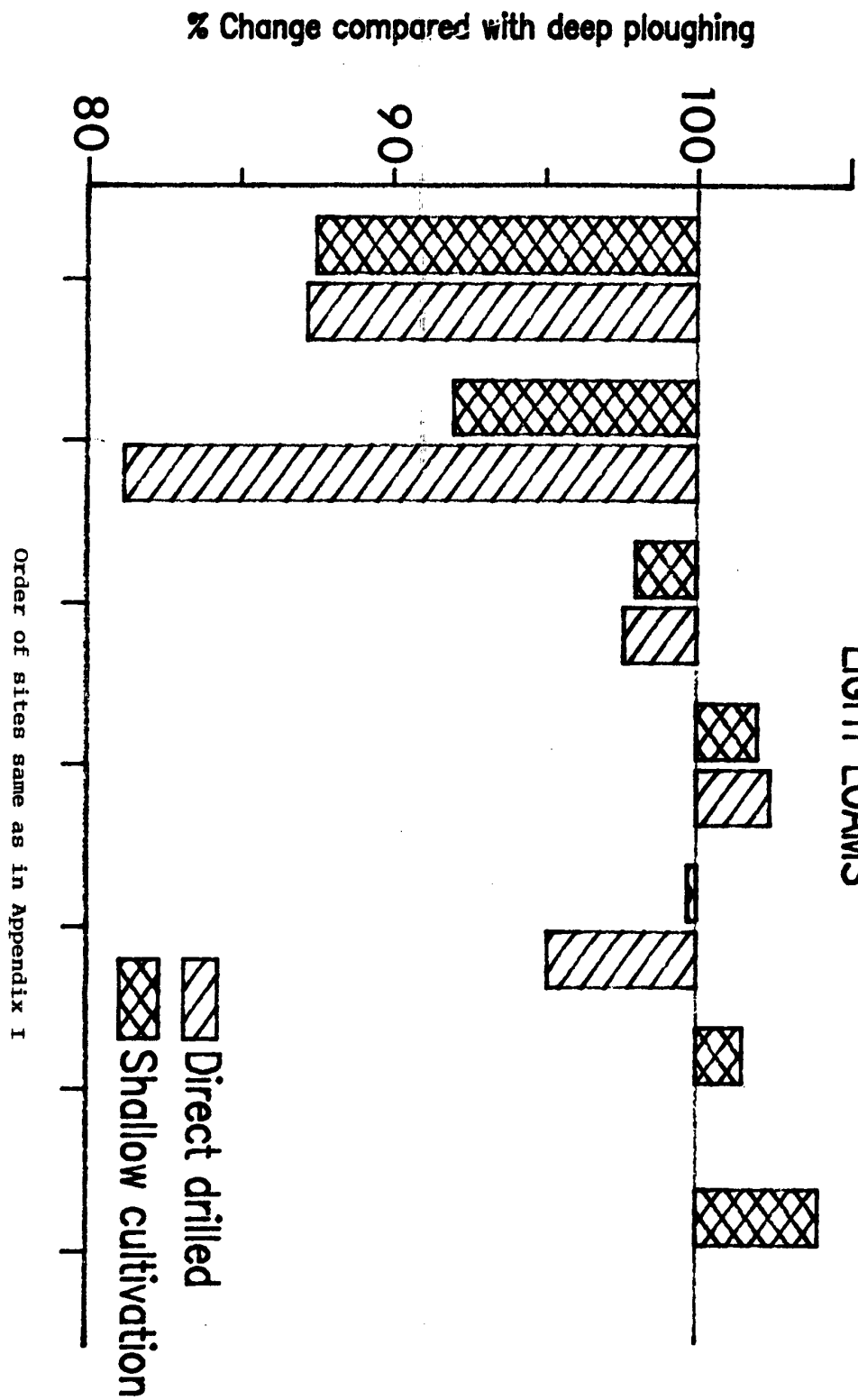
# Yields of test crops in English Cultivation experiments 1969-1986 CLAYS



# Yields of test crops in English Cultivation experiments 1969-1986 MEDIUM LOAMS



# Yields of test crops in English Cultivation experiments 1969-1986 LGHT LOAMS



## Conclusions from Trial Work

The overall conclusions arising from the experiments are:-

1. Direct drilling and shallow cultivation gave very similar yield results to conventional deeper tillage. Note that straw was burnt on the majority of sites.
2. However, yields on clay sites tended to benefit more from reduced tillage than on medium-and lighter-textured soils. The largest depressions in yield occurred on low organic matter sandy loams.
3. Shallow cultivation gave slightly better yields than direct drilling on medium and light loams; this was probably due to easing of surface penetration problems.
4. Results from some long-term sites on unstable light loams, demonstrated a progressive improvement in the performance of direct-drilled crops as soil stability improved after the initial year(s).
5. Spring-sown cereals appeared to be more sensitive to adverse soil conditions than winter-sown crops. This is the most probable explanation for the poor performance of spring cereals at some sites.
6. Indirect evidence from the ADAS trial series indicates that lack of soil disturbance increases crop susceptibility to later autumn drilling and to poorer land drainage. These effects were greater in wetter than average seasons.
7. Populations of a range of earthworm species were increased very significantly by absence of tillage. The improvement in soil conditions resulting from their activities was particularly useful in compacted light loams.



8. Provided establishment of crops in reduced tillage treatments was uniform, soil structural conditions had less influence on crop yield than many of the research workers had initially expected.

These conclusions do not necessarily hold true in commercial farming where the agronomic consequences of greater weed pressure have to be contained economically and where fields, unlike experimental plots include headlands and areas of different soil type.

## **MONITORING SOIL CONDITIONS IN CULTIVATION EXPERIMENTS**

Although reduced tillage does not result in a common predictable set of soil physical conditions there are changes which in the main are similar and have been recorded in many of the experiments recorded.

### **1. Bulk Soil Properties**

Without exception all workers have found that the bulk properties of soil as measured by visual structure scores, bulk density or soil strength are greater in undisturbed land. Initially the consequences of greater bulk density in the topsoil were expected to be adverse. In a few experiments it was possible to identify adverse effects due to severe compaction but in many it was not, this led to more detailed studies of root growth.

### **2. Coarse Porosity and Root Growth**

On sites where zero tillage was successful detailed studies demonstrated that root number and root growth were at least as good in direct drilled treatments and sometimes significantly better in spite of the increased density (Ellis and Barnes, 1980). These findings led to the now accepted view that successful zero tillage on soils containing substantial quantities of clay normally leads to greater continuity of porosity. Thus the growth of roots and movement of drainage water is facilitated by vertically continuous pores and fissures which develop in the soil. Channels left by old roots, shrinkage cracks and earthworm channels tend not to be disrupted and provide a semi permanent architecture of inter-connecting pathways.

In this context the greater numbers of earthworms which are found in shallow-cultivated and direct-drilled land contribute significantly.

### **3. Movement and Retention of Water**

Ponding of water on direct-drilled land during wet weather was commonly noted in a number of experiments whenever subsoil drainage was inadequate or topsoil permeability became limiting. However, in drier years the extra continuity of vertical porosity in direct-drilled plots was clearly demonstrated on clayland sites. Thus in the very dry winter of 1975/1976 rainfall recharged the soil profile to a greater depth than in ploughed/cultivated plots at several of the ADAS sites in East Anglia and on the Letcombe laboratory clay sites near Oxford. This difference resulted in improved yields of 10-20% in direct drilled plots, following the severe drought of 1976 (Goss et al., 1978).

### **4. Stability of Aggregates and Organic Matter**

In the absence of regular mixing of topsoil by cultivation, a gradient of organic matter built up. Such a gradient was recorded at most of the longer-term experimental sites and was associated with greater aggregate stability at all but one of these sites (Douglas and Goss, 1982). Gentle wet sieving proved the most sensitive technique for detecting stability differences. Although humified organic matter is probably responsible for the major increases in measured organic matter, carbon released by straw burning is also a component. All forms of additional carbon, whether from organic matter or burning, play a part in the greater absorption of soil-applied herbicides (page 42).

Extra stability of the soil surface aggregates is probably responsible for the improved performance of direct-drilled crops with time on some weak structured sites (Douglas et al., 1986).

### **5. pH and Soil Nutrient Status**

Absence of soil mixing by cultivation produces concentration gradients of less mobile nutrients. Thus, surface accumulations of phosphate and to a lesser extent potassium were identified after several years at

all sites where monitoring took place. Providing the starting level of nutrients is not deficient these gradients did not appear to influence uptake of nutrients by crops (Ellis and Howse 1980).

Similarly, non-calcareous soils lose calcium from the surface, and after several years of zero tillage acidity may develop. This did not appear to damage any crops in the experiments reviewed although it has caused problems on commercial farms. The change in pH may also reduce the effectiveness of soil-applied residual herbicides.

## **6. Nitrogen Availability and Uptake**

Cultivation encourages mineralisation of organic nitrogen compounds in soil and commonly encourages lusher early growth than in direct drilled treatments (Dowdell et al., 1983). It might be expected therefore that direct-drilled crops would need additional nitrogen to compensate for this smaller nitrogen supply. Davies and Cannell (1975) examining optimum nitrogen levels in cultivation trials produced some evidence for larger N optima in direct drilled treatments but pointed out the inadequacy of much of the available data. Since that review there has been experimental evidence that direct drilled cereals may need seedbed nitrogen to compensate for a reduction in early mineralisation of organic matter (Davies et al., 1979).

The need for differential levels of total fertiliser nitrogen on disturbed and undisturbed land is still not established Letcombe studies and experiments at the Norfolk Agricultural Station show no extra requirement, while Terrington EHF and Leeds University have demonstrated greater optimal rates of nitrogen in reduced tillage treatments. ADAS studies at Cambridge found that direct drilled crops responded to higher fertiliser levels in certain years but not in others. The overall conclusion is that any difference in optimum nitrogen due to cultivation treatment is likely to be inconsistent and for this reason no differences have been made in ADAS recommendations.

## **Criteria for Soil Physical Requirements**

Substantial effort was invested in trying to define soil physical conditions in many of the reviewed experiments, with the objective of

establishing criteria for limiting conditions. It soon became clear that the complex relationship between crop performance and soil condition (page 26) stood in the way of reaching useful objective criteria. Instead qualitative guidelines based on careful soil examination were developed (Allen, 1981; Proctor et al., 1982). It seems unlikely that any further efforts to define better criteria would be rewarding, but better ways of communicating guidelines are needed.

## MACHINERY ASPECTS

Substantial improvements in design of cultivation implements, area capacity and in the means of reducing soil damage under wheels have been made in the last two decades. These improvements have been stimulated to a considerable extent by the development of reduced tillage and are considered in 3 sections:-

1. Cultivation work rates and energy requirements
2. Implements for shallow tillage
3. Reduction of damage under wheels

### Energy Work Rates and Area Capacity

The economy of arable farming without the mouldboard plough has been known and recorded for a very long time. It was mentioned in the Journal of the Royal Agricultural Society in the 1940s and has appeared in various papers at intervals to the present day. The following are the general ranges of energy inputs for cereal establishment as taken from the series of experiments carried out by ADAS in their Eastern Region:

	<u>kwh/ha</u> (h.p.hours/a)	
Direct Drilling	9-23	(5-12)
Reduced Cultivation based on tines and discs	38-66	(20-35)
Traditional Cultivation based on mouldboard plough	57-102	(30-54)

More detailed data from Patterson (1987) working on clay land experiments are given below:-

## Labour, Energy and Area Capability for Cultivation Systems

<u>Cultivation System</u>	<u>Depth of Primary Tillage (mm)</u>	<u>Labour Requirement hr/ha</u>	<u>Net Energy* kwh/ha (h.p hours/a)</u>	<u>Area Capability† ha(ac)</u>
1. Plough, cultivator, drill	220	4.0	89 (48)	88 (217)
2. Shallow plough, combined cultivator/drill	130	2.0	52 (28)	178 (440)
3. Sprayer, direct drill	-	1.0	11 (6)	353 (872)
4. Heavy duty spring tine x 3 drill	50-75	1.9	38 (20)	180 (445)
5. Dynadrive 2 passes, drill	50-75	1.5	33 (18)	235 (580)

1.- 3. from 6 years experiment on clay soil at Boxworth

4.- 5. from 1 years experiment on a clay

\* energy at the implement connection

+ area which can be covered by one man in a season

The area capability of shallow tillage is generally much superior to systems based on the mouldboard plough or rigid tine implements working at or below the normal depth of ploughing. The greater the clay content of the soil the greater the savings due to shallow cultivation. In the past many intended reduced cultivations fell well into the traditional range of energy requirement. The main point in avoiding high power outlay is to avoid bringing up large clods, which are then well nigh impossible to break down without weathering, and seriously impede tractors.

### **Implements for Reduced Tillage**

Attempts to replace ploughs by chisel ploughs and other heavy fixed tine cultivators in the 1960s showed up various limitations in implement design. Although work rates were often improved these cultivators normally left very cloddy uneven surfaces except on soils of low clay content. From this early experience the concept of 'progressive' cultivation was developed, whereby sequential working of soil from the top down retained fine tilth at the surface and loosened

the soil below with minimum clod lift. This process can either be achieved with banks of tines on the same implement working at increasing depth, or with separate implements working sequentially. Severely compacted land is gradually loosened in this way over several years. As compaction is relieved fewer clods are brought to the surface and draught tends to drop from year to year. Eventually a condition is reached when only the surface layer needs working and thus a shallow cultivation system evolves. On clays with well structured subsoils and many medium textured soils a period of deep loosening preceding shallow cultivation is unnecessary.

### **Discs**

Various forms of discs have a place in reduced cultivation. Work rate is high, energy input can be low and they have a good mixing action on surface trash. In addition all the surface is disturbed, but they may cause compaction and localised smearing in moist soils. On hard dry surfaces penetration is often a problem. They are best used on an opportunity basis rather than every year.

### **Tined Implements**

Tine implements show very substantial work rate savings over the mouldboard plough. They are cheaper to buy and do not have severe speed restrictions. Heavy duty spring tines with or without A blades are the most effective for shallow work, provided the surface is not too hard and dry or wet and compact.

Straight tine pressure harrows are useful for increasing the depth of tilth where natural weathering has already started the process and/or where 'Flat Lift' type cultivators have already loosened the topsoil (see later paragraph).

### **Rotary Implements**

The ground-driven 'Dynadrive', with its twin rotating tines, moves soil to a shallow depth provided the surface is not too strong to penetrate. It is economic and has a fast work rate. Powered rotary cultivators avoid wheelslip and where necessary do a great deal of

cultivation in one pass. However, they are more appropriate for breaking down deeply cultivated land and are rarely used for primary cultivation, where forward speed and economy of effort are needed.

### **Shallow Ploughs**

Several types of plough will work at 10-15cm. with a fast work rate and an energy input of rather more than half that of a plough working at twice the depth. In addition they provide some burial of surface trash. These ploughs often work well in medium loams but tend to be unreliable in hard dry clays with penetration problems. They could play a role in systems with much reduced wheeling.

### **Combination Implements**

Shallow tillage may be achieved with one or more passes of a single implement or with fewer passes of combination implements. Tine/disc combinations are the most common. Farmers have in general opted for the simplicity and greater flexibility of individual implements and have absorbed extra horse-power with wider implements.

### **Implements for Deeper Loosening**

Usually repeated shallow cultivation eventually leads to compaction immediately below the depth of cultivation. The first implements designed to loosen in this situation were the 'Paraplow' and the 'Flat Lift'. Since their development a number of 'Flat Lift' like topsoilers have been marketed, having narrow feet with shallow lifting wings on either side. They are designed to loosen soil in situ without bringing clods to the surface, and work to a maximum depth of about 35 cm. The greater the extent of loosening achieved and the drier the soil, the more clods tend to be brought up.

### **Conclusions**

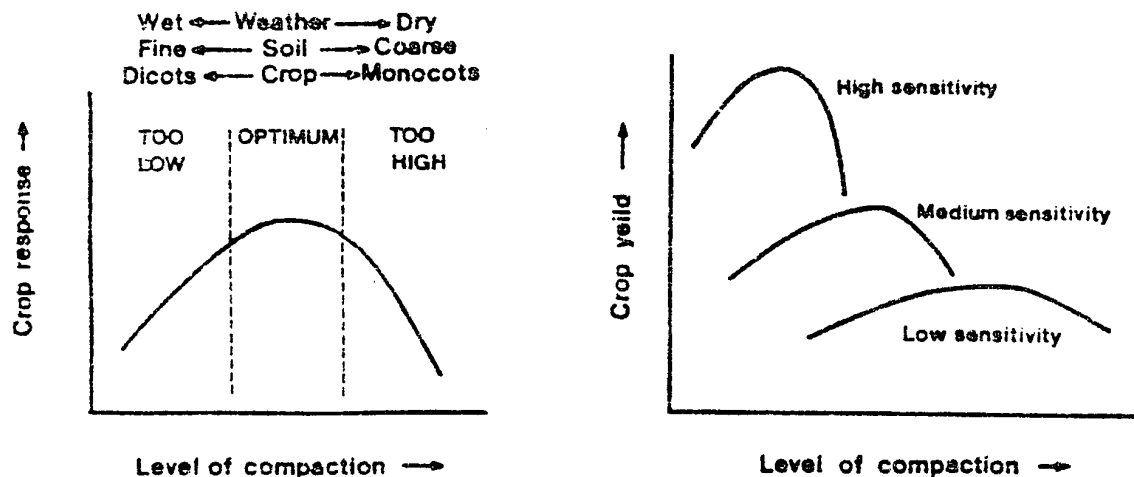
A wide range of effective implements is now available for shallow cultivations which are economical and have fast work rates. Similarly a range of effective implements is available for deeper loosening without excessive surface disturbance. Availability of



effective implements for reduced tillage is no longer a serious restriction to further development.

## REDUCING WHEEL PRESSURE ON CROPPED GROUND

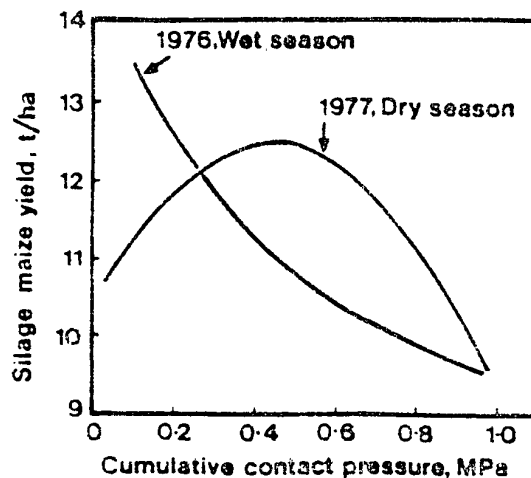
Effects of soil compaction on crop yield are complex and depend upon soil texture, soil moisture and weather during crop growth. Nevertheless generalised relationships of the types shown in the illustrations below are useful (Soane, 1985):



The generalised crop responses to variation in the level of compaction and the factors which influence the position of the optimum.

The left hand diagram shows that, depending on the initial density of the soil, subsequent compaction may increase or decrease yield and that there is an optimum range of packing which will be at a lower density in wetter soil conditions and in the more clayey soils. The right hand diagram illustrates the varying sensitivity of crops to compaction. Thus vegetables and root crops are more sensitive than cereals, and spring cereals are usually more affected than winter cereals.

A quantitative example showing the greater sensitivity of silage maize to wheeling damage in wetter seasons is given below:



The conventional approach to soil damage under wheels is to correct the problem after it has occurred. This is expensive in energy, time consuming, and frequently results in loss of crop because soil conditions may still be unsatisfactory after loosening. Increasingly prevention is seen as preferable to partial cure and two approaches have been pursued: -

- i. Reduced contact pressure under wheels
  - ii. Wide span vehicles to avoid wheeling on cropped land.
- 
- i. **Reduced contact pressure under wheels**

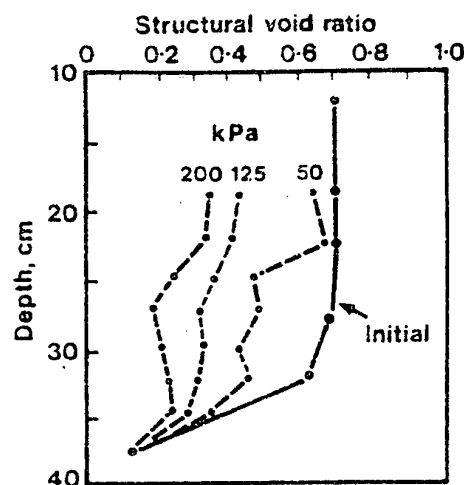
When a soil is wet and easily compacted, reducing the contact pressure under wheels is the most convenient way of minimising rutting and compaction. For a vehicle of a given weight this can be achieved by reducing inflation pressure in the tyres so that the vehicle load is supported by a larger area in contact with the soil. This tactic is satisfactory provided the design criteria for the tyres are not exceeded. However, if the amount of deflation required results in unacceptable deflection then larger tyres and/or dual tyres will be necessary.

The increasing contact area achieved through deflation not only reduces compaction but allows an increase in traction. For

agricultural tractors Zombri (1967) showed that for a constant level of wheelslip the drawbar pull of a tyre normally inflated to 12 p.s.i. could be increased from 100 kg to 220 kg by deflation to 3 p.s.i. However, driven wheels have to support both load forces and the forces caused by generating traction. Thus a tractor in draught requires a larger contact area under its driven wheels than when the wheels are supporting weight alone. Furthermore the development of traction by rubber tyres inevitably results in wheelslip which is more compacting than straight load on wheels (Davies *et al.*, 1973). Reduction of wheelslip to an acceptable level of say 10% or less can be achieved through adding more weight to the wheel, and in most agricultural circumstances the aim should be to obtain the best compromise between weight and slip as alternative ways of achieving high output from tractors. Larger tyres or greater numbers of tyres allow this optimum compromise to be achieved at lower inflation pressures and therefore at a lower level of soil compaction.

Automatic control of inflation pressure would allow farmers to adjust pressures according to the nature of the surface conditions, for example when a vehicle moves from a hard road into work on a soft wet soil. Such control systems are not yet available commercially.

The benefits of deflation in reducing damage on soft wet surfaces are well established, for example the studies of Guerif (1984) illustrated below:-



Change in pore space (void ratio) with depth, when a tractor tyre with different inflation pressures passes over a clay soil with a dry surface (0-7 cm.) overlying a wet sub-surface.

However, results from field experiments testing effects on crops of low and zero pressure production systems compared with conventional systems have been variable.

A four year study at Silsoe (Chamen et al., 1988) compared energy requirements for tine cultivation and winter wheat yields in systems with conventional tyre pressures (up to 38 p.s.i.), low pressures (up to 8 p.s.i.) and a treatment with no wheelings. Results are shown below:-

	<u>High pressure</u>	<u>Low pressure</u>	<u>Unwheeled</u>
Mean grain yields t/ha (1983-86)	7.24	7.46	6.81
Tractor energy for cultivation & drilling MJ/ha (1985 only)	178	182	51

The 'Low Pressure' system did not give consistent improvements in yield or energy saving over conventional systems. Energy requirement of the unwheeled system was much lower, but yield was reduced by manganese deficiency in the first two years before it was controlled by spraying. These results do not necessarily represent what would occur in whole farm situations particularly in wetter seasons and on soils more susceptible to damage. For example, in an experiment in Scotland on a weakly structured sandy clay loam high pressures substantially reduced yield of winter barley compared with lower tyre pressure (Campbell et al., 1984). The two traffic treatments were wheelings across the full width of plots with tyre pressures up to 33 p.s.i., compared with tyre pressures up to 15 p.s.i. It is interesting to note that yields were reduced where land was cultivated before the wheeling treatment but not where land was uncultivated before treatment. The authors concluded that to obtain the maximum benefit from a reduction in tyre pressure, the contribution of carcass stiffness to the ground pressure should be low.

Several manufacturers have now extended the recommended pressure range for their radial tyres down to a level (about 8 p.s.i.) at which

rutting and compaction are minimal even in wet conditions. This approach coupled with tramlines is the common sense choice for farmers who have concluded that a conventional system causes unacceptable damage in wet conditions. The main problems of 'Low Pressure' systems are with high draught vehicles and those carrying heavy loads. Sprayers and fertiliser distributors can be confined to tramlines but no such system has yet been developed for transport trailers. To avoid serious damage during wet harvests, trailers have to be confined to headlands. Obviously there is some scope for pressure reduction in trailer tyres by restricting loads and/or fitting extra wheels but this is normally insufficient to avoid damage. Tractors working at high draught may require dual wheels to carry the load necessary to achieve the required grip and sufficiently low inflation pressures may not be possible in this situation.

The ideal low ground pressure system is one which increases its area of contact by a longer rather than a wider contact patch. The implication of this is that work is needed on more flexible track systems (which also have better draught capability per unit of mass) and/or multiple in-line self-tracking steerable wheels. The alternative, which has limited scope for transport or traction systems, is to reduce vehicle weight.

#### **ii. Zero Traffic with Wide Span Vehicles**

The aim of zero traffic systems is to confine all traffic to lanes and to grow crops between them. For many years vegetable growers have adopted a form of zero traffic in the bed system. However, the width of lanes between the beds represents a substantial proportion of the total area and is too wasteful for narrow row crops like cereals. The ubiquitous tramline is a half way system which takes all the passes after drilling, except at harvest. A wide span vehicle is probably the most practical means of completely removing wheelings from uncropped land.

A 12m. gantry system working on permanent wheelways capable of carrying out all mechanised activities throughout the crop season, is being developed and its effect on soils and crops is being assessed by AFRC Engineering at Silsoe. This machine is the logical development

of the wide span concept already researched for glasshouses by Sharp (1979) and in use by Dowler (1980) on his arable farm in the West Midlands. Observations of the Dowler gantry are reported by Chamen et al (1986) as part of a paper on the development and assessment of wide span vehicles. At the present stage of development the gantry can carry out all operations except cereal harvest for which a conventional combine is required. This is unfortunate because during wet harvests combines and trailers are a major cause of soil damage in cereal fields. Dowler's solution to this problem is to mount his combine on rice tracks. The Silsoe researchers intend to mount a stripping header (Klinner et al., 1987) on the gantry together with its own thresher unit. If this proves successful their gantry should be able to undertake all mechanical operations apart from grain transport. For this purpose they propose a separate gantry running behind the main unit. A crucial element of the gantry system is to have access to land for as much of the year as possible. Spoor of Silsoe College and the AFRC team at Silsoe are jointly developing techniques for making and maintaining permanent wheelways to provide this access. They emphasise the need for:-

- i. a soil side wall to provide lateral support for wheels.
- ii. moving soil into the wheelways to maintain a level firm surface and
- iii. drainage from the wheelways to minimise wheelslip and rutting.

#### **Future Potential**

Chamen has examined the economic viability of an all-purpose gantry system for producing combinable crops, compared with conventional methods. Assuming no effect on crop yields, the results suggest that net returns would be £40-£50/ha in favour of a gantry system at current prices. Note that in this study the costs of the gantry and its equipment, are estimates based on current development. If any conventional equipment, e.g. a tractor and plough, were needed to supplement the gantry this would be an additional cost. Obviously the transition from a conventional system to the gantry would require substantial one-off capital investment.

The engineering development of an all-purpose gantry has still some way to go and it would be premature to predict a satisfactory

commercial future at this stage. Nevertheless the system has clear potential advantages for larger cereal farms, and we must remember that Dowler's gantry development has clearly demonstrated its technical viability. The eventual success of the gantry will not be possible without continued funding to ensure:-

- i. engineering development
- ii. further work on techniques for permanent wheelways under a range of soils and sites.
- iii. careful field monitoring and assessment of the performance of gantrys on commercial farms at a later stage of the development.

Complementary studies may be needed to gain the maximum benefit from gantry systems. Thus gantrys will provide access to soil for cultivation when it is wetter than normal and given the loose conditions of unwheeled land it should be possible to cultivate successfully at these higher moisture levels provided suitable implements are available for the purpose. Their design may require special development. The gantry also provides an opportunity for greater precision of pesticide application. Opportunities that this may provide for better target control and reduced chemical rates will require evaluation.

## SOIL TYPE, SOIL CONDITION AND WEATHER

Soil managers have to meet two seemingly irreconcilable requirements: good trafficability and porous soil conditions for crop growth. The first requirement is best met by compact level conditions with surface drainage, i.e. a road! Unfortunately roads are totally unsuitable for crop growth.

Zero tillage by providing both a flat surface and consolidated soil, satisfies the traffic requirement and provided the land retains sufficient coarse porosity crop growth is not limited. In practice, although some soils in favourable conditions are able to retain adequate porosity indefinitely, many soils do not retain sufficient porosity, unless they are regularly loosened. Cannell et al. (1978), guided by results of experiments and farm experience, suggested a soil type and climatic classification which identified areas of soil where sequential direct drilling - and by association shallow tillage - gave similar or better yields of winter cereals than traditional tillage. The criteria identified as characteristic of suitable low risk areas were:

- A) soil types with stable structure and good natural drainage and
- B) areas with sufficiently low rainfall and high evaporation to ensure late dates of return to field capacity.

The classification as simplified by Ball (1988), is:-



Classification of Soil Suitability for Zero Tillage Developed for Use  
in Britain

<u>Class</u>	<u>Soil and Climate</u>
1. Suitable for spring and winter cereals	Stable structure, well drained. Dry climate +
2. Suitable for winter cereals only	Stable structure, moderate drainage. Moist climate
3. Unsuitable	Unstable structure, poor drainage Moist climate.

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+ Mean date of return to field capacity later than 31st October.

Successful cropping requires at least a minimum number of interconnecting coarse pores (greater than 0.5mm) which we recognise as satisfactory soil conditions or satisfactory soil structure. Soils vary in their ability to maintain structure. Some slump and compact easily; others are much more resistant to compaction and tend towards under consolidation. Soils which resist compaction and which recover quickly if they become compacted are more suitable for reduced tillage. In general risk of over compaction is less in drier environments, hence reduced tillage is more widely practised in drier parts of the country. The problems encountered in wetter areas are:

- i) less drying and structural improvement during the growing season.
- ii) more risk of structural damage and rutting during harvest.
- iii) greater risk of surface ponding and waterlogging.
- iv) less opportunity for cultivation in dry soil.
- v) greater risk of slug damage and weed competition.

It is unfortunate that where there is the greatest need for saving time after harvest, conditions are least suited for reduced tillage.

In practice the soils found to be most suitable for reduced tillage are chalk and limestone loams, eg. Sherborne series, and calcareous

clays eg. Hanslope and Evesham series. In practice deeper topsoil loosening is only required infrequently on these soils. The least suitable soils tend to be low organic matter sands, sandy loams and silt loams (Appendix I; North Creak and Hindringham sites). Poorly drained soils are equally unsuitable. Many of these soils need frequent loosening below the depth of shallow cultivation to avoid severe compaction building up and in most cases annual ploughing is the better option.

Ball and O'Sullivan (1987) have developed a classification system which is more appropriate to the wetter northern environments:

#### Tillage grouping for winter barley in Scotland

<u>Cultivation group</u>	<u>Topsoil texture</u>	<u>Subsoil permeability</u>
1. Direct drilling	Sandy loam, loam	Free
2. Reduced tillage	Sandy loam, loam	Moderate
	Loamy sand, silty loam	Free or moderate
3. Conventional	All textures	Slow
tillage	All clay loams and silty clays	Moderate

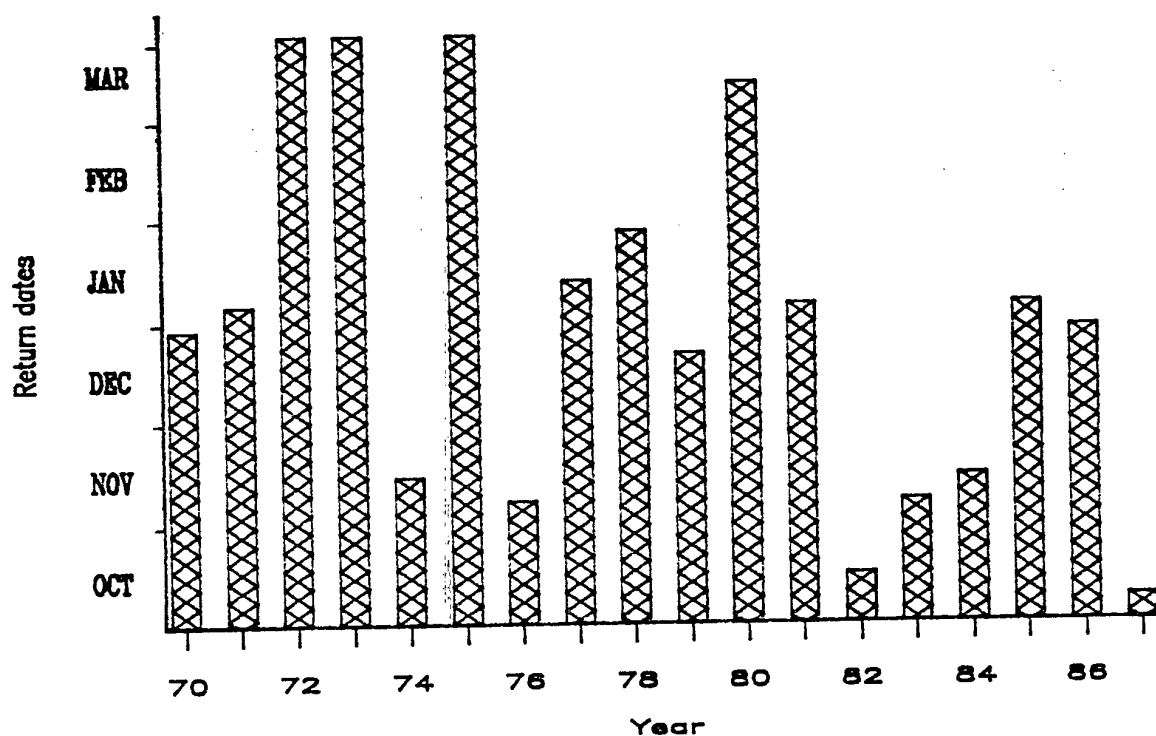
In this scheme the emphasis is almost entirely on rapid movement of drainage water. In the moister environment of Scotland and probably also in arable areas of northern and western England the generally higher organic matter of topsoils enhances structural stability compared with similar soils in drier areas. Note that the same soils that are best for reduced tillage in wetter arable areas are also the soils most easily ploughed.

#### **Weather and Soil Conditions**

Weather, and in particular rainfall, probably has a greater influence on soil conditions than any other single factor. Relative to ploughing shallow cultivation is favoured by drier conditions. Dry conditions at harvest minimise compaction and at sowing favour the moisture conservation and fine tilth attributes of zero tillage; strong drying cycles during the growing season ensure that the soil profile is well cracked - another vital ingredient of reduced tillage.

It has been suggested that the relative popularity of reduced tillage during the period 1970-1980 compared with later years is related to drier seasons in the earlier period. The relative wetness of each year from 1972 to 1987 in terms of return to field capacity under grass is shown below:

Date of return to field capacity at Cambridge between 1970 and 1987



These data lend support to this argument, at least for eastern England. The mean return date for the earlier period was 6 weeks earlier (3rd week January compared with 1st week December) and included 3 years when field capacity was never reached. Conversely in the latter period field capacity was reached in all 7 years and there were 3 years with return dates as early as October (none during the earlier period). The long-term mean return date for Cambridge is early December, which suggests that the 1970's was an abnormally dry decade.

#### **Plant Distribution and Soil Conditions.**

Uniformity of plant distribution depends on accuracy of seed metering (or randomness of broadcasting), seedbed quality (aggregate size distribution and moisture) and seed viability. Ploughing and deep cultivation commonly result in coarse seedbeds that limit uniformity of plant distribution; shallow cultivation normally produces finer more uniform seedbeds in which drill performance is enhanced.

Very uneven distribution and emergence of plants obviously restrict yield but the degree of uniformity required to maximise yield is unresolved. Graham and Ellis (1980), in a review of this topic, concluded that precision drilling offers a yield advantage over good conventional drilling but not for winter cereals. However, Dawson (1984) provides evidence to suggest that winter wheat may not be able to compensate completely for uneven establishment, and he concludes that significant yield improvements might be achieved with improved accuracy of drilling. It is noticeable that most farmers who achieve high cereal yields regularly concentrate on achieving good quality seedbeds and aim for uniformity of emergence. Shallow cultivations provides a marked advantage to this end.

#### **Zero Traffic and Soil Suitability**

The majority of soil problems encountered by farmers practising reduced tillage, are caused by farm traffic. In wet seasons all areas of the country are very susceptible to wheeling damage during harvest and at drilling. Although traditional plough systems are not immune to wet seasons the extra drainage from the top few centimetres of

ploughed land often provides a better environment for seedling growth. Thus steps to reduce surface pressure under wheels of farm traffic or to confine all wheels to uncropped areas, substantially reduces the risks of shallow tillage. If it proves feasible to develop the all-purpose wide-span gantry system into a commercial proposition it is probable that all cereal soils will be suitable for shallow tillage. Similarly careful use of lower tyre inflation pressures will also extend the range of soils suitable for reduced tillage. Developments in both wide span and low pressure technology are considered on pages 27-31.

### **Reduced Cultivation and Water Erosion**

Soil erosion by water appears to be increasing on arable land in Britain and in recent years has attracted increasing attention and concern. Experience outside Britain suggests that those tillage systems that leave more crop residues on the surface and/or enhance infiltration and downward movement of water, reduce the risk of runoff and therefore of soil loss by water erosion.

Individual farmers have adopted several measures to minimise water erosion through trial and error. However, there is now sufficient concern - particularly over the possible nutrient/pesticide pollution side effects - to justify a substantial study of the effectiveness of a range of soil and crop management techniques for minimising soil losses.

### **Future Development**

We now have extensive experience in Britain of the interaction between soil type and tillage system gleaned from long term experiments and from commercial practice. The changes in soil properties which take place in land under reduced or zero tillage are reasonably understood and discussed on pages 18-20. Similarly the suitability of different soil types for reduced tillage have been closely studied and the principles underlying this relationship are recognised albeit qualitatively.

Further studies should be concentrated on:

- i) Studies of the contribution that various reduced cultivation systems can make to the long-term control of soil loss by water erosion.
- ii) Behaviour of contrasting soils under zero traffic with particular emphasis on under-consolidation, clod size distribution, frost heave and root diseases. Complementary studies on maintenance of permanent wheelways in a range of soil types are also required.
- iii) Better ways of communicating to farmers and advisers guidelines on soil conditions suitable for shallow tillage.

## WEED PRESSURE

There is little doubt that one of the main reasons for the shift in popularity from shallow tillage to ploughing in the 1980s has been caused by problems of weed pressure. Promoters of reduced tillage during the 1970's failed to give sufficient emphasis to the serious risk of systems breaking down through excessive weed competition. To be successful any future expansion of shallow tillage must have flexible strategies to deal with weed control. This requires appreciation of the population dynamics of the major weeds of cereals.

Inextricably linked with the influence of tillage on weeds are the associated issues of straw burning and activity of soil acting herbicides. AFRC weed scientists have examined many of these factors in detail and a brief summary below is taken from their findings (Cussans et al., 1979, 1987; Moss., 1984).

### Seed Longevity

Some weeds can be characterised as 'long cycle' species notably knotgrass, charlock and common poppy. Seeds produced by such species have marked dormancy and great longevity. In any one season, plants can be produced only by the proportion - often small - of the seed bank which has been released from dormancy and is in a suitable position in the upper layers of the soil to germinate successfully. Such 'long cycle' weeds appear to be well adapted to mouldboard ploughing. Annual inversion protects fresh seeds through burial at a time when the seed would be unlikely to germinate. Ploughing in subsequent years brings to the surface older seeds, a proportion of which are released from dormancy each year.

In marked contrast the grass weeds and a few broad-leaved species - notably cleavers - are 'short cycle' species. They produce seed with relatively weak dormancy and a comparatively short life span. Barren brome seed commonly persists only for one year whilst even wild oat and blackgrass have a maximum life span of 6-10 years compared with 50-60 years for long cycle species. Burial of freshly shed seeds by mouldboard ploughing, prevents these short cycle plants from exploiting their seed producing capacity because few seedlings will

establish if seeds germinate at depth. When the land is re-ploughed short cycle species cannot benefit if insufficient seeds remain viable when brought back to the surface. Ploughing at infrequent intervals achieves this aim. However, short cycle species can take advantage of shallow cultivation which allows maximum opportunity for freshly shed seed to germinate and establish.

Some species are intermediate in behaviour between long and short cycle species and appear equally well suited to inversion and shallow tillage. Common chickweed is a good example. Note that some weeds are so easily controlled that they do not create a problem even when favoured by a cultivation system. Other species, notably cleavers, brome and blackgrass are difficult to kill with herbicides, so that they may cause problems in any system and a major threat in reduced tillage.

### **Perennial Weeds**

All the perennial grass weeds eg. Couch grass (Agropyron repens) and Black bent (Agrostis gigantea) and perennial broad leaved weeds eg. Dock and Creeping thistle, are encouraged by reduced tillage and it is advisable to deal with these weeds before embarking on such a system. Since the introduction of glyphosate, the threat of competition from these weeds have become much less important.

### **Straw Disposal**

Straw disposal affects control of weeds directly and indirectly. Straw burning generates very high temperatures which kill many seeds and reduces the dormancy of others. The death of seeds caused by burning is always beneficial to agriculture but the reduction in dormancy by burning may have both beneficial and deleterious effects. When burning is followed by an opportunity for total kill of seedlings ie. delayed drilling, the effects are beneficial. However, when early sown autumn crops follow burning competition from early emerged weeds - for which dormancy has been reduced - can be particularly harmful.



Incorporation of straw inevitably increases the burden of weed seeds in the soil compared with burning. However, if straw is incorporated by ploughing, changes in weed pressure will probably be minor compared with ploughing after burning and indeed may be reduced compared with burning and shallow tillage. Cussans et al., (1987) warn that unless or until improved herbicides are introduced straw incorporation systems which do not involve ploughing - at least on a rotational basis - are too vulnerable to blackgrass and brome to be viable in the long term. They point out that although results in the short term may be satisfactory, these common weeds will inevitably become established in the longer term and are likely to out-strip the capacity of current herbicides to contain them. Volunteer cereals also prosper under non burning shallow cultivation regimes.

### **Effects of Stubble Cultivations**

The need to incorporate straw has revived interest in stubble cultivation both in its effect on subsequent straw breakdown in the soil and more importantly in its effect on weed and volunteer cereal populations. Unpublished information from Moss records the effects of stubble cultivation shortly after harvest with and without burning. His results suggest that shallow tillage, by preventing the loss of blackgrass seeds through natural mortality, may cancel out any enhancement of germination with the result that stubble cultivation has no practical value. However, he points out that the stimulation of germination of shed grain and barren brome seed may be of more practical value. This subject would benefit from further examination.

### **Activity of Soil Applied Herbicides**

Annual grass weed infestations in winter cereal crops tend to be more severe when shallow tillage is employed. Therefore better weed control is required than in systems based on frequent ploughing. Unfortunately the presence of burnt straw residues and in the longer term the development of an organic matter concentration gradient both increase the absorption capacity of the surface layers for some soil

applied herbicides. In soils with inherently high absorption capacity eg. alluvial clays, this process often eventually leads to inadequate weed control and build up of weeds. In other less absorptive soils the process may not precipitate problems, thus Proctor et al., (1988) did not find the control of grass weeds in long term reduced tillage caused unacceptable difficulties on several medium loam and clay sites.

### **Integrated Control**

Cussans et al., 1979, 1987; Moss, 1984 have developed a population model for blackgrass from which it is possible to determine the percentage weed control required to maintain a static weed population:

#### Annual Percentage Kill by Herbicides Needed to Maintain a Static Population of Blackgrass

	<u>Straw Burnt</u>	<u>Not Burnt</u>
Ploughed	50	65
Direct Drill	88*	92*

\* Similar % expected for shallow tillage.

This model emphasises the greatly increased pressures likely to be encountered by adopting sequential reduced tillage, particularly where straw is not burnt. Ploughing every few years to halt the inevitable build up of grass weed populations is a prudent and necessary part of reduced tillage systems. Without periodic inversion the risk of incurring additional herbicide costs and of populations becoming out of hand increases every year. During the 1970's many farmers practising long term reduced tillage discovered this to their cost.

### **Conclusions**

Intensive cereal growing is peculiarly at risk from weed pressure; a risk increased by straw incorporation with shallow tillage. Cereal farmers need to achieve levels of weed control to avoid large population increase from one crop to the next. Some of the most competitive weeds - in particular brome, blackgrass and cleavers -

tend to be the most difficult to control with herbicides. For these species integrated but flexible control measures are necessary where reduced non-plough cultivation is practised. Occasional ploughing, alternation of autumn sowing dates and introduction of occasional spring sown crops, coupled with careful monitoring of weed populations are valuable supplements to herbicide use.

Weed pressure is a cumulative consequence of complex interactions between cropping, type of cultivation, herbicide use and several other factors of husbandry. As growing systems change and new herbicides are introduced there is an urgent need for complementary studies on weeds. Priority areas are:

- i. **Brome.** Dormancy in brome seeds appears to be greater than expected. HGCA is already funding work in this area and its importance coupled with the development of effective herbicides, indicates this to be a priority for future support.
- ii. **Volunteer Cereals.** HGCA is already funding work on variation in the dormancy of cereals, an area about which there is little useful information. Cereal volunteers are frequently a serious problem in non plough cultivation systems and the area deserves continued funding in the future.
- iii. **Stubble Cultivation in the Presence of Chopped Straw**

Few studies have examined in detail effects on grass weeds and volunteer cereals of shallow cultivation in the presence of a mulch of chopped straw. This is of practical significance to many intensive cereal farmers - particularly seed producers and warrants examination in a range of situations.

iv. **Weed Resistance to Herbicides.**

The nature of resistance and strategies for control of resistant plants is already well advanced for blackgrass in the UK. Continued support will be required to estimate the distribution of resistance in blackgrass and perhaps in other species which are encouraged by reduced non-plough tillage. Better understanding of the inheritance of the trait(s) of resistance and cross-resistance are needed to help provide predictions of how quickly resistance may develop in fields where resistant genes occur at low frequency.

## PEST AND DISEASE

The relationship between a crop and pathogens depends on many factors and so it is not unexpected that the effect on cereal diseases of a change from ploughing to reduced cultivation systems is both complex and inconsistent. An analysis of the situation has been made by Yarham (Proctor et al., 1982). He considers the likely effects of a change in cultivation technique on three major groups of disease: those that normally overwinter on living cereal plants, those that survive on dead plant debris, and root diseases particularly take-all.

### Disease normally Overwintering on Living Plants

Brown rust of wheat and barley, yellow rust and mildew are the main diseases in this group. Volunteer cereals tend to be encouraged by shallow cultivation without inversion and the potential risk from these diseases might be expected to be greater where direct drilling and shallow tillage is practised, particularly if they result in earlier autumn drilling. In practice this potential risk has not materialised and Yarham (Proctor et al., 1982) suggests that the abundant production of wind borne spores under favourable conditions which may lead to the very rapid build up of both rusts and mildew during spring and summer, is likely to override differences in amount of over wintering inoculum. Particularly important in determining the final severity of infection in a crop is the susceptibility to infection during periods of rapid growth. Soft lush plants are more easily attacked by leaf infecting pathogens and rusts and mildews are most severe in plots of whichever treatment produces the thickest and most vigorous crop.

### Diseases that Survive on dead Crop Debris

The fungi causing net blotch (Pyrenophora teres) and leaf blotch of barley (Rynchosporium secalis) and leaf spots and glume blotch of wheat (Septoria tritici and Septoria nodorum) are all trash-borne diseases. As might be expected, these diseases tend to be favoured by cultivation techniques which do not invert soil and therefore leave more debris on the surface. Straw incorporation rather than burning intensifies this effect. The effects of cultivation treatment on these diseases tends to be most pronounced early in the year, though

they may sometimes persist throughout the growing season. It should be noted that Rhynchosporium never attacks wheat, Pyrenophora does so very infrequently and Septoria is seldom a problem on barley. The risks of severe attacks of these diseases are therefore increased by not ploughing only where barley follows barley or wheat follows wheat. In practice severe infections due to adoption of shallow tillage have been rare and judicious use of fungicides has sufficed. If problems are encountered with these diseases they are more likely to arise in the moister environments of western cereal growing areas.

Eyespot (Pseudocercospora herpotrichoides) is another important trash-borne disease and it might be expected that it too would be favoured by reduced tillage. Occasional cases have been encountered where non-ploughing does seem to have increased incidence of the disease but this appears to be the exception. In several trials where the disease has been closely monitored overall incidence of eyespot appears to have been less in reduced tillage treatments.

Cephalosporium leaf stripe (C. graminearum) can be aggravated both by minimal cultivation and by straw incorporation. Severe attacks are rare, however, and the disease cannot be seen as a major constraint on the adoption of shallow tillage.

### **Take-all**

The take-all fungus survives between crops on the roots and crowns of dead plants. After harvest it is generally found to be most abundant on root debris in the top few centimetres of soil. We might expect therefore that non-ploughing techniques would aggravate the disease. Early direct drilling experiments carried out by ICI appeared to contradict this hypothesis (Hood et al., 1964). However, since then observations of many trials on sites where straw from the previous crop had been burnt have failed to demonstrate any clear association.

Severity of take-all is encouraged indirectly by a number of factors, in particular early drilling, puffy seed beds, poorly drained compact soil and surface acidity. Where straw is burnt no cultivation method consistently results in one or more of these conditions but if take-all damage is to be minimised it is important to maintain a high standard of soil management irrespective of cultivation method. Where

straw is incorporated, on the other hand, minimal tillage tends consistently to increase take-all as compared to ploughing, probably because of the effects of the incorporated debris on seed bed conditions. These effects tend to disappear during spring and summer.

### **Virus Disease**

Incidence of barley yellow dwarf virus does not appear to be directly affected by cultivation methods, but there is some evidence that spread of barley yellow mosaic virus, which is borne by the fungus Polymyxa graminis, may be favoured by reduced tillage. This moves infected root debris more readily than either mouldboard ploughing or zero tillage.

### **Conclusions**

Yarham's conclusion is that non-plough practices have had less effect on disease severity than plant pathologists originally feared. However, the increase in trashborne leaf diseases that can occur in unploughed fields particularly where straw is unburnt, must be recognised. Up to now these increases have not been consistent or great enough to cause abandonment of a non-plough technique and it seems unlikely that given judicious use of fungicides the situation will change. The increase in take-all levels where straw is incorporated by minimal cultivation techniques, although generally quite small is consistent and well documented. More information is needed on the effect of long term straw incorporation on this and on other root rotting diseases such as those caused by Pythium and Fusarium species.

### **PESTS**

Only two pests appear to have been implicated in crop problems associated with differences in tillage: slugs, an important but rather inconsistent pest of cereals, are influenced by soil conditions and by abundance of crop residues. It is recognised that the loose and cloddy seed beds often characteristic of ploughed land encourage slug activity while the firm fine seed beds characteristic of shallow cultivated land normally provide adequate insurance against damage.

However, where non-plough techniques are practised without straw burning the presence of large amounts of debris in the seedbed tends to encourage slug populations and their activity. Recommendations for studies in this area will appear in the HGCA-funded review on straw.

Frit fly is often a problem when cereals are established after grass with zero or shallow tillage, rather than the mouldboard plough. Larvae from the third generation of frit fly in the autumn remain in newly emerging winter cereal seedlings, eating the centre tiller of young plants. Damage can be at least partially controlled by use of appropriate insecticides.



## STRATEGIES FOR REDUCED TILLAGE

High area capacity tillage systems have failed to maintain their earlier popularity, and on many arable farms have been replaced by a return to ploughing. There appear to be several reasons for this change but in general it seems that farmers perceive that the benefits do not compensate for the risks of losing yield. Shallow tillage is only worthwhile if full advantage is taken of the substantial advantages at the same time as planning flexibly to avoid the problems which we know can occur.

The major potential advantages of shallow tillage are:

### 1. High Output

Greater capacity for establishing winter crops permitting timely sowing in all seasons. Records on some farms suggest a decline in winter wheat yield from sowings after the 25 September at a rate of 30-40 kg/ha of grain per day (Dawson, 1984).

### 2. Better Seedbeds

On soils with appreciable clay content (greater than about 25%) shallow cultivation results in finer tilth and more uniform seedbeds. The greater the clay content the more important this effect. The benefits of this are, earlier emergence in dry years, more uniform establishment - usually leading to some yield increase - in all years and greater efficiency of residual soil acting herbicides. Better seedbeds also result in much less risk of slug damage.

### 3. Lower Machinery Costs

Shallow tillage gives farmers an opportunity to achieve emergence of all their cereal area every year, within a period of minimum penalty for delay, i.e. timeliness. Timeliness can be achieved with any mechanised system, but well planned shallow cultivation achieves it with minimum input of resources. Lower input of resources may be realised either through reduced machinery costs on the same area farmed or by covering additional land area with the same machinery complement.

Actual financial savings can only be realistically calculated in specific farm situations.

Set against these advantages are several drawbacks commonly encountered where shallow tillage is adopted:

1. Pressure from grass weeds tends to increase each year eventually resulting either in loss of yield or greater herbicide use or both. Chopped straw further increases this pressure.
2. Compaction may build up below the depth of cultivation and eventually reduce yield in abnormally dry or wet seasons.
3. In wet years wheeling damage sustained during harvest can only be corrected by ploughing.
4. Chopped straw increases the risks associated with shallow tillage - particularly through greater weed competition.
5. Non-plough systems encourage volunteer cereals which may cause problems for seed and milling wheat production.
6. If rain falls on shallow worked land it takes longer to become fit again for field work.

### **Targeting**

The substantial advantages of shallow tillage systems can only be realised if they are correctly targeted and correctly managed to avoid or minimise the problems listed above.

Plough based cultivation can be routinely employed in nearly all farming situations. Shallow tillage on the other hand is more sensitive to the nature of site and soil. Factors which influence the selection of shallow tillage and improve its chances of success are:

1. **Soil type** - more suitable for clays, medium loams and chalk and limestone soils particularly if organic matter levels are above normal for the soil type. Such soils extend to well over half the cereal growing area of drier England. On farms practising effective 'low inflation pressure' systems the range of suitable soils is extended.
2. **Good soil conditions** - shallow cultivation should never be entertained on soils with severe compaction and/or severe drainage problems until remedial loosening and drainage have been successful. Poorly managed slow draining clays commonly require deep tillage for several years.
3. **Farming type** - more suitable for farmers growing mainly autumn sown combinable crops.
4. **Farm size** - more worthwhile on cereal farms where there is a need for, and an opportunity for, substantial increases in area output from cultivation. Frequently this applies to large cereal farms or to farms that intend to increase their area of cereals rather than to small farms without major bottlenecks in autumn work load.
5. **Climate** - more suitable for areas with annual rainfall less than 630mm. and an average return to field capacity later than 1 November. In wetter areas only free draining light loams are suitable.
6. **Straw disposal** - more suitable where straw can be burnt or baled. However, incorporation with cultivators should not be ruled out on medium loams and clay farms.
7. **Sowing Capacity** - Streamlined cultivation systems are wasted unless matched by high output methods for sowing. Shallow cultivation produces seedbeds which are very suitable for the high output tractor mounted drills now available. Broadcasting of seed is the fastest method but tends to give patchy emergence in dry conditions and is unsuitable for spring sown crops. It is a method well suited to wetter parts of the country.

## Reducing the Risks of Shallow Cultivation

Irrespective of whether shallow tillage is targeted correctly there are a number of ways in which potential problems may be avoided. These require flexible management capable of deciding when to take action before serious problems arise and altering course when conditions change.

### **Weed Control**

Before grass weed populations build up to levels at which 'normal' herbicide use gives insufficient control, action should be taken. Occasional ploughing alternation of autumn sowing dates and introduction of occasional spring sown crops and/or break crops, coupled with careful monitoring of weed populations are useful to supplement herbicide use.

### **Compaction**

Formation of dangerously dense layers below the depth of shallow cultivation can be arrested by occasional deeper loosening before root systems are seriously restricted. Routine soil examination each year is the most appropriate way of deciding when to loosen, but if expertise is not available for this regular deeper loosening every 2-4 years depending on soil type should be practised. To avoid compacting wet soil, contact herbicides should be used in preference to cultivation for cleaning land prior to sowing.

Shallow cultivation should only be practised where tramlines and low inflation pressures - in all wheels not confined to the tramlines - are used as standard practice. The lower the maximum tyre pressure the less the risk of compaction causing problems.

### **Weather Factors**

In dry seasons 'rotational' ploughing should be reduced and cultivation made shallower. Crops will have dried and cracked the soil to depth so that deeper loosening will be unnecessary. Discs are likely to be more effective than tines in these conditions.

In wetter seasons low pressure tyres are necessary for combines and trailers should be confined to headlands if their tyre pressures are too high. The area that needs ploughing will probably be greater than in dry years.

### **New Developments**

There are two developments which, if successful, will benefit shallow cultivation. Introduction of grass weed herbicides which provide satisfactory control of brome will remove one of the main uncertainties of sequential shallow tillage, although it will not remove the need for occasional ploughing.

Introduction on to farms of economic gantry systems capable of both shallow tillage and harvesting would have several important implications. Wheeling damage and soil damage would be eliminated and all soil types would in theory be equally suitable for shallow cultivation. Current work indicates that shallow ploughs can be used on gantrys and that they plough more effectively than on land subjected to the pressures of normal farming. This could open the way for successful incorporation of chopped straw provided adequate consolidation can be achieved. A further advantage of a gantry system would be the large reductions in energy requirement for cultivation.

### Summary of Tillage Requirements in drier areas (Return date after 1st November)

Sands, light loams, light  
and medium silts, peaty soils      - Plough and press

Medium loams and all clays      - Consider shallow tillage unless there  
are weed, trash, compaction or  
drainage problems.

For wetter areas refer to page 35.

## RECOMMENDATIONS FOR FURTHER STUDY

Reduced tillage was intensively researched and developed during the 1970's but recent technical improvements, changing economic circumstances in agriculture and the impact of environmental issues together indicate that a re-examination of the research and development needs is necessary. Areas requiring further study, already mentioned in the text of earlier chapters, are assembled here.

### 1. 'Low Pressure' Case Studies

Increasing the soil contact area under tyres by reducing inflation pressures is a widely understood means of reducing soil damage but is only applied in a comprehensive manner on few farms. In consequence the damage sustained by land in wet years far exceeds what could be achieved if the ideas and materials available were fully exploited. It is recommended that several case studies should be set up on farms adopting reduced cultivation, to work out how best low pressure technology should be applied and what factors restrict uptake. These case studies should be multidisciplinary taking account of rotational requirements, soil behaviour, impact of weather, and financial implications in addition to the mechanical requirements of traction and load carrying.

The studies could be used as demonstration centres to ensure that findings are widely disseminated. More than one case study is needed to cover 'typical' situations; emphasis should be placed on sites where damage from wheels is a substantial problem in wet years.

### 2. Wide-span Gantrys

The ultimate in low pressure is to avoid all wheelings on land growing cereals. An all-purpose gantry system to replace all conventional field equipment is now being developed. The potential advantages of such a system compared with low pressure systems have been discussed on page 30-31. It is premature to predict that this promising development will find widespread application on farms but unless substantial support for high

class engineering development continues to be available a viable system will never evolve. In addition to the basic engineering requirements further complementary work is needed on making and maintaining permanent wheelways on soil types with contrasting physical behaviour. At a later stage of development case studies will be needed to monitor the performance of the system on farms and to solve the problems that arise. An extension of this exercise is the future need to monitor the behaviour of contrasting soils in zero traffic with particular reference to need for consolidation.

### **3. Cultivation for Control of Water Erosion**

Concern about the extent of water erosion in Britain has recently increased. The side effects of this form of erosion, namely nutrient and pesticide movement out of the agricultural environment and soil movement into water courses, reservoirs, roads and houses are probably more damaging than the immediate direct agricultural losses. Conservation cultivation systems are needed which maintain high infiltration rates, stabilise surface soil and minimise compaction in fields. Shallow cultivation with incorporation of chopped straw or direct drilling into undisturbed stubbles need testing, in addition to critical examination of the techniques already used by farmers. This is a very difficult area in which to conduct conventional field experiments and it will require the development of unconventional methods.

### **4. Practical Guidelines for Shallow Cultivation**

In the recent past a major cause of failure of reduced cultivation on farms was the lack of guidance on how to avoid specific problems. Unsuccessful farmers generally applied reduced tillage as an inflexible and routine measure, in the same way as they used the plough. Detailed guidance providing criteria for decision making in specific weed, soil and weather situations are recommended as a contribution towards obtaining the most benefit from shallow tillage systems.

## 5. Weed Investigations

Weed pressure is a cumulative consequence of complex interactions between cropping, type of cultivation, herbicide use and several other factors of husbandry. As growing systems change and new herbicides are introduced there is an urgent need for complementary studies on weeds. Priority areas are:

- i. **Brome.** Dormancy in brome seeds appears to be greater than expected. HGCA is already funding work in this area and its importance coupled with the development of effective herbicides, indicates this to be a priority for future support.
- ii. **Volunteer Cereals.** HGCA is already funding work on variation in the dormancy of cereals, an area about which there is little useful information. Cereal volunteers are frequently a serious problem in non plough cultivation systems and the area deserves continued funding in the future.
- iii. **Stubble Cultivation in the Presence of Chopped Straw**

Few studies have examined in detail effects on grass weeds and volunteer cereals of shallow cultivation in the presence of a mulch of chopped straw. This is of practical significance to many intensive cereal farmers - particularly seed producers and warrants examination in a range of situations.

## 6. Root Disease

There is no suggestion in the literature nor in commercial practice that reduced tillage causes any serious increase in cereal diseases and it seems unlikely that given judicious use of fungicides, the situation will change. However, there is evidence that shallow incorporation of straw encourages root diseases. More information is needed on the effects of long term straw incorporation on this and other root rotting diseases such as those caused by Pythium and Fusarium species.



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## YIELDS OF TEST CROPS IN ENGLISH CULTIVATION EXPERIMENTS 1969-1986

CLAYS

SITE	Plough t/ha	% of Plough		No. of Years
		Shallow Cultivation	Direct Drilled	
ADAS CAMBRIDGE				
5 Short term exp	6.9	100.4	102.8	5
Emneth	7.3	104.7	103.5	9
Bradwell	9.8	97.9	98.7	4
Knapwell	5.7	99	106.5	8
Otley	8.5	97.3	94.2	6
Rawreth	5.8	100	101.6	9
Hundon	6.6	102.9	102.7	12
DRAYTON EHF	4.4 +	103.0	-	5
BOXWORTH EHF	7.4	104.5	102.0	10
NIAE. (Boxworth)	5.8	97.5	99.0	4
LETCOMBE/WRO				
Buckland (w. wh)	4.8	103.5	103.7	4
Buckland (spB)	4.9	104.0	104.0	4
LETCOMBE Northfield	8.7 +1	102.2	103.9	7
C. Beauchamp	8.2 + <sub>1</sub>	-	101.8	9
LEEDS (sp. B)	6.1	98.3	96.1	3

Test crops all winter crops, predominantly winter wheat unless specified otherwise.

+ includes 1 winter bean

+<sub>1</sub> excludes OSR but includes winter oats