RESEARCH REVIEW No. 48

REDUCED CULTIVATIONS FOR CEREALS: RESEARCH, DEVELOPMENT AND ADVISORY NEEDS UNDER CHANGING ECONOMIC CIRCUMSTANCES

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REDUCED CULTIVATIONS FOR CEREALS: RESEARCH, DEVELOPMENT AND ADVISORY NEEDS UNDER CHANGING ECONOMIC CIRCUMSTANCES

by

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EXECUTIVE SUMMARY

1. The **objectives** were:

(i) To consult with farmers, research workers, consultants and machinery manufacturers on cultivations for cereals and the related areas of weed and pest control, care of the environment, cost reduction and profitable farming.

(ii) To identify areas which require new initiatives in research, development and/or technology transfer in reduced cultivations for cereals and to suggest priorities for action.

(iii) To propose to HGCA a framework for developing its activity in the subject of cultivations for cereals, and to suggest target areas.

2. We **defined** reduced cultivations as:

"Sustainable cultivation systems which are less expensive than traditional systems; they may be less energy demanding, and/or quicker and/or have a lower labour demand."

3. We consulted widely with individuals and organisations, and reviewed relevant websites, and popular and scientific literature, as listed at Annex I and II.

4. In the **Review of Evidence** we identify the following factors as important:

- labour and machine costs
- yield maintenance
- close management
- soil structure maintenance
- straw and stubble treatment
- grass weed and slug control
- drill design and versatility

5. Our main **conclusions** are as follows:

Larger farm units, less labour and larger machines will of themselves enforce a move away from traditional plough-based cultivation.

Reducing input into cultivations offers real opportunities for improving farmers' returns.

Reduced yields should not and need not be accepted as part of a lower-cost establishment system.

Successful reduced tillage systems are individually suited to soil, site, scale and management of an operation whereas the mouldboard plough is universally applicable.

Climatic, soil and cropping differences within Britain markedly influence suitability for reduced tillage.

The environmental benefits of reduced tillage on farms, as distinct from in experiments, are unclear, sometimes contrary, and far from assured.

6. Finally, our **recommendations** are as follows:

a) The **development of quicker and less expensive tillage systems** should remain one of the six priority topics in the HGCA Research Strategy document, and preferably be raised to first priority among the six. Resources could be effectively channelled through **Agriknowledge** and the **Soil Management Initiative.**

b) We **should not** return to long-term tillage trials in the style of the 1970-1990 period.

No new research on the **ecology and control of grass weeds** should be started until the findings of the current projects are available.

c) **Target areas for research** should be:

- the collection and development of information and standards in support of machinery selection and management
- optimum agronomic inputs for crops established by shallow tillage
- the further development of straw choppers and spreaders, and of cereal drills
- traffic control in cereal production
- reduced tillage to control soil, nutrient and pesticide losses in commercial practice as distinct from experiments
- the role of tillage in flood control

d) The already extensive **exchange of information between practitioners** should be encouraged. Farmers seeking advice on reduced tillage need able and experienced advisers with a comprehensive understanding of machinery, economics, soils and agronomy. Training should be provided.

Leading farmers who practice reduced tillage should be invited, and possibly paid, to have their farms used for long-term demonstration.

e) A working group for **tillage in organic farming** should be established.

INTRODUCTION

1. The HGCA 'R&D strategy for cereals' document of the autumn of 1999 places priority on reducing production costs by optimising labour and machinery use in cereal establishment. Part of this is the maximisation of the speed and efficiency of operations and the use of new technology emerging from developments in precision farming.

An earlier move into reduced tillage and direct drilling was prompted by the need to establish large areas of winter cereals within the time available. At that time paraquat was a recent development and the potential market prompted strong commercial support for reduced tillage and direct drilling, and in addition there were questions over future oil supplies for agriculture. Conditions changed, and the large area of combinable crops established by the newer methods reverted to traditional tillage based on the mouldboard plough.

There is now renewed pressure on cereal growers to reduce crop establishment costs, which in effect means reducing labour and machinery costs, while maintaining maximum winter planted areas and high yields. We have reviewed the technical and economic changes, and the research programmes which have taken place since the earlier developments, and have consulted widely within the industry. We identify some areas where knowledge needs to be updated and where there is need for new research. More importantly we suggest ways in which farmers can benefit from the combined knowledge and expertise of other farmers, consultants and research and commercial interests.

NOMENCLATURE

2. Since some confusion exists in the terms used in reduced tillage and even whether it may refer to reduced depth of work, fewer passes over the land, coarser tilth or reduced energy input, the following terminology is suggested:

> **"Sustainable cultivations systems which are less expensive than traditional systems; they may be less energy demanding, and/or quicker and/or have a lower labour demand."**

In practice reduced tillage as practiced in Europe may be considered as falling into three categories according to the depth of work:

- direct drilling - no cultivation prior to drilling
- shallow tillage - < 100mm without inversion
- deep tillage - > 100mm without inversion

All three with or without chopped straw

In the UK a range of names are used to describe reduced tillage. To most practitioners "Minimum or Minimal tillage' probably signifies the 'Shallow Tillage' category above, but in practice it often includes all three categories. "Lo-Till" and "ECOTillage" are defined more specifically as equivalent to the 'Shallow Tillage' category above. "Conservation Tillage" is a widely used International term describing any non inversion tillage which leaves at least a third of the soil surface covered by crop residues; it includes all three categories above, provided they pass the residue test. "No-Till" and "Zero-Tillage" are equivalents to "Direct Drilling".

As with any technical subject, communication of information is more effective if a few well defined terms are generally understood and accepted. We recommend that the HGCA and other interested parties **reach agreement on such terms and do their best to promote their universal use and acceptance**.

In the Review we use the term "**weatherproofing"** to describe the process whereby newly worked land is protected from the adverse effects of subsequent rainfall. In particular "weatherproofed" land allows further cultivation after rain without a prolonged period of waiting for excess water to drain and evaporate. In practice this is achieved by adequate consolidation either at or soon after the land is worked and then by subsequent drying (hazelling) of the soil.

OBJECTIVES

3. The **objectives** of the current exercise were as follows:

(i) To consult with farmers, research workers, consultants and machinery manufacturers on cultivations for cereals and the related areas of weed and pest control, care of the environment, cost reduction and profitable farming.

(ii) To identify areas which require new initiatives in research, development and/or technology transfer in reduced cultivations for cereals and to suggest priorities for actions.

(iii) To propose to HGCA a framework for developing its activity in the subject of cultivations for cereals, and to suggest target areas.

SUMMARY of HGCA-Research Review No. 5 "Reduced Cultivation for Cereals 1988"

4. Objectives of the Review

- *To collect and report what factual information there was about 'reduced tillage' in the UK at that time,*
- *To recommend where and how 'reduced tillage' systems might be used effectively to reduce the cost per tonne of grain produced and*
- *To recommend what additional information was needed to improve the reliability of reduced tillage, and in particular shallow non inversion tillage, on farms.*

5. Adoption of reduced tillage on farms.

During the 1970's one third of crops grown on cereal growing land in England were established by reduced tillage but by 1988 this figure had fallen to about one tenth. The reasons for this major return to the plough were loss of yield caused by increases in grass weed populations, topsoil compaction and the need to incorporate straw because of restrictions on burning. There was more than adequate tractor power for ploughing available on farms.

The review examined the scenario of widespread re-introduction of shallow (<100mm) non inversion tillage and concluded that because this option entails higher risk than either ploughing or deeper non plough tillage, it was only likely to be attempted 'if the need to reduce indirect costs of production assumes a high priority'!

6. Results of Experiments

Long-term field experiments totalling 200 site years demonstrated that well-managed shallow cultivation or direct drilling usually gave as good or better yields of winter cereals as ploughing, and that the area capacity of these systems was much greater for the same input of labour and fuel. Straw was either burnt or baled in these experiments and grass weeds controlled by overall herbicide applications together with individual plot treatment where necessary. Establishment of spring cereals by reduced tillage tended to be less successful than winter crops except where soil conditions were particularly good.

In those experiments in which reduced tillage gave lower yields, greater populations of grass weeds, and/or topsoil compaction or loss of surface structure were the causes.

7. Machinery

The Review noted that when reduced tillage was first introduced in the late 1960s, drills and shallow cultivation equipment were inadequate. A wide range of more effective equipment was subsequently developed for drilling into undisturbed ground, for shallow primary cultivation and for loosening to the depth of topsoil to remove compaction without lifting many clods. The value of heavy discs and heavy-duty spring tines as fast primary cultivators was noted but their limitations in wet conditions were stressed. Combination implements had been developed but were not widely used on farms. Improvements in tyre design enabled farmers to substantially reduce ground pressures while in traction. However it was noted that compaction of wet land under wheels at harvest was still an important constraint on reduced tillage.

8. Soil Type, Soil Condition and Weather.

Soil types giving the best opportunity for reduced tillage were recognized as those with good drainage, either natural or installed, and naturally stable structure i.e. the ability to retain porosity without regular loosening. High structural stability is a feature of calcareous soils with or without high clay content, thus in the drier areas of Britain clays proved better suited to reduced tillage than many free draining light loams which tended to over-compact. At first the greater density or packing of undisturbed soil was thought to be an adverse feature, but field examination and crop performance showed that often this was not the case. Research showed that that in these cases extra continuity in the coarse pore/fissure system offset the lower total porosity and gave the added benefit of a firmer surface for traffic. In other cases the higher density was not offset in this way, and crops were damaged by root impedance and periodic waterlogging. These problems tended to occur on soils with unstable structure and/or slow drainage.

Climate and weather were seen to play a major role in the success of reduced tillage. In the generally wetter arable areas of Britain only well drained light loams were found to be suitable in contrast to the drier areas. This difference is related to the greater organic matter contents conferring extra stability in soils of the wetter areas. Also the success of reduced tillage was often determined by seasonal rainfall, with wetter seasons, particularly during the period from August to October, causing poorer results.

9. Grass weeds.

At first the build up of blackgrass and brome populations in successive years of reduced tillage was not considered to be a major constraint. However this problem was eventually recognised as one of the major limitations, and substantial research was devoted to providing better understanding of how husbandry changes influenced grass weed pressure. The development of herbicide resistance in blackgrass had been clearly established on some farms but its frequency of occurrence in arable areas was unknown. The susceptibility of reduced tillage systems to resistant blackgrass was already clear and strategies for control of resistant populations had been developed.

In England and Wales straw burning was phased out and finally banned for the 1993 harvest. The adverse effects of this decision for grass weed control were recognised in the Review and some weed scientists considered that with the herbicides available at that time systems of cereal growing that did not include ploughing, at least once during a rotation, were too vulnerable to be viable in the long term.

10. Pest and Disease

By 1988 it had become evident that the anticipated problem of disease carry over from crop debris in reduced tillage was not an important risk except that root disease seemed to be enhanced by shallow incorporation of chopped straw. The risk of slug damage in the fine and well consolidated seedbeds characteristic of reduced tillage systems with straw burning was generally found to be less than in ploughed seedbeds but in wet seasons open drill slots left by direct drills encouraged slugs. It was recognised that where straw was present the risk of slug damage would increase.

11. Strategies for Reduced Tillage

A section of the Review examined situations in which reduced tillage could be adopted with minimum risk and maximum benefit. The better situations were identified as large cereal farms on well drained clays, medium loams and chalk and limestone soils in areas of less than 630 mm average annual rainfall and return to field capacity date (full recharge of soil profile) later than 1 November. In wetter areas only farms on well drained light loams were considered suitable. Cultural measures for grass weed control, low pressure tyres, and soil examination to lessen the risk of soil compaction were considered necessary to avoid failures.

12. Recommendations for Future Work

Six areas were identified as key areas for future funding.

- ***Farm case studies** to encourage uptake of low inflation pressure technology in reduced tillage systems.*
- ***Wide-span Gantries and Permanent Wheelways** were identified as developments which if successful commercially would greatly enhance the viability of reduced tillage.*
- ***Practical Guidelines for Reduced Tillage** were seen as necessary to try to avoid those adopting reduced tillage from repeating earlier mistakes.*
- ***Weed research was recommended to ensure that as** growing systems changed and new herbicides were introduced complementary studies on weeds were made. Specifically the Review argued for examination of the effect of stubble cultivation on the each of the major grass weed species and on volunteer cereals. Research into dormancy in brome species and volunteer cereals were also listed.*
- ***Root diseases** were identified as a risk from straw residues in long term reduced tillage. Studies on common root rot diseases were recommended to provide more information.*
- ***Control of Water Erosion** by the development of cultivation methods designed to maintain infiltration rates, stabilise surface soil and minimise compaction in fields were recommended to meet the concern about the amounts of soil, nutrients and pesticides reaching rivers, reservoirs, roads and houses.*

CHANGES IN FARMING

The current emphasis on reduced tillage is part of a wider response to smaller financial returns in agriculture throughout the EC. However in parallel with this economic downturn, other changes have occurred which have already, or may in the future, influence the practice and value attached to reduced tillage. These various changes are considered in paragraphs 13-26.

13. Farm structure

The long term trend towards increased farm size continues and accelerates. 10% of the farmland in East Anglia is now said to be farmed on behalf of others as part of mixed tenure operations. This would suggest that the actual farming units may be larger than the official statistics indicate, and that they are also fragmented, which adds to the management problems. Larger farm does not necessarily mean a higher standard of farming or higher Net Farm Income per hectare. The Cambridge University Report on Farming in the Eastern Counties 1999/2000 shows, as in earlier reports, (Lang 2001, Murphy 1999, 2000) that there is no clear trend between net farm income per hectare and farm size. This is confirmed by the Deloitte and Touche farm results for 1998/1999 (Deloitte and Touche – RASE 2000), which state that there is no evidence that more hectares farmed means more profit per hectare. In this review, however, we suggest that only the larger farms may be able to afford the cost of re-equipping with large tractors and equipment to make the best use of labour and reduced cultivation techniques. Smaller farms are more likely to practice reduced tillage on an occasional basis using whatever equipment is available. The opportunity is to combine the advantage of scale of the large farm with the close management standards of the small farm for maximum profit.

14. Labour

There has been a rapid decline in labour on farms. For example, in the Eastern Counties total labour has declined from more than 90,000 in the early 1960's to 30,000 in 1997 (Murphy 1999). Hired labour costs have fallen faster than machinery costs have risen. Labour costs have to fall further if farms are to be profitable at current cereal prices.

The rapid increase in the productivity of labour over the longer period has been mainly due to yield increases made possible by crop variety improvement, fertiliser use and disease control. Larger, more reliable, and more effective machines have also been important. In further improvements in productivity lower energy inputs to crop establishment with continuing increase in machine size will be necessary. Total labour on cereal farms in the Eastern Counties on mainly cereal farms of more than 400ha, from the 1999/2000 figures, is 0.91 per 100ha (Lang 2001) Most of the leading cereal growers that we consulted were far below this figure (paragraph 40). There is clearly scope for much further improvement in efficiency of labour use. Three points may be particularly important:

- There is an implication for close management. Managers may be working rather than managing.
- Labour use may be limited in the future by the number of suitable quality people available.
- The weekly working hours required of key staff at busy times may be considered excessive.

15. Machinery investment

Machinery costs account for about 40% of fixed costs on cereal farms. a situation which has not changed markedly since the late 1970's (Murphy 1999). Depreciation charges may be half of total machinery costs, with tractor depreciation being one third of that. Tractor depreciation has been valued at about £5 per tonne of wheat produced. There is an important link between number, size and value of tractors, and the use of skilled labour, in efficient cereal production.

Harvesters are another major item, accounting for about 20% of the total depreciation charges, and there is scope for contract work or machinery sharing on the smaller cereal farms. Over 30 years the commonly accepted combine harvester usage has moved from 125 hours per season to 250 hours, with 300 hours not unusual. On many farms further increases in efficiency will be difficult to find.

Farm vehicles amount to around 10% of the depreciation charges. This level has not changed much over the years, and if the future calls for closer management of larger and more fragmented farms transport must remain vital equipment.

The remaining machinery on the farm, taken together as 'other machinery' amounts for the other one third of the depreciation. Within this are substantial investments in drills and major cultivation equipment which are firmly linked to tractors, labour and method of crop establishment followed. There is greater scope for making the right or wrong choice, with long term consequences, with this equipment than any other on the farm.

Cumulative investment in machinery has declined since 1985, at one stage falling by 31% in 5 years. The market did not respond to the more prosperous years, as it had in earlier decades, with tractor investment falling steadily and vehicle and harvester investment falling more erratically. The most rapid falls were on the largest farms. Depreciation charges fell at similar rates.

There are opportunities for reducing machinery investment through the use of contractors and various forms of machinery sharing. There has been a major increase in the use of contractors in recent years, very often for whole-farm operations. 68% of farmers use contractors in some way (RASE Farmer Members Survey 2000), and 27% share some machines. The top performing farmers in the Cambridge University Report (Lang 2001), however, used virtually no contract work, probably because of their need to have the timing of operations under their own direct control.

16. Agronomy

Reduced tillage has substantial implications for crop management particularly for weed control and crop residue management. In the UK competition from blackgrass and other grass weeds has been a major problem of intensive cereal production for many years but since the previous Review, when the incidence of herbicide resistance in blackgrass was localised at a few sites, it has become widespread. Also since then herbicide resistance in both wild oats and Italian ryegrass has been identified on farms. Although at present resistance in these two species is much less common than in blackgrass, presumably it will continue to increase. At the same time that resistance in grass weeds has been increasing, earlier drilling of winter cereals at lower seed rates, practices which both favour grass weed pressure, have been widely adopted.

Straw burning was still legal during the earlier phase of reduced tillage in the UK, and was considered crucial for direct drilling. Since the burning ban (except in Scotland) dealing with cereal straw has become a major obstacle to reducing tillage, except where baling is an acceptable alternative. Quality of seedbeds has become more difficult to assess in the presence of straw, and the widespread adoption of cultivator drills, which require judgement of seedbed quality in advance of the drill's cultivation, has compounded this difficulty. The positive side is that straw in surface layers offers potential environmental benefits (paragraphs 29 and 60).

17. Environment.

In recent decades pressures on agriculture from environmental issues have increased relentlessly in all EC countries and this trend looks set to continue. The impacts on farmers may be either restrictive e.g. Nitrate Vulnerable Zones or beneficial e.g. Countryside Stewardship Schemes. In the future, it is likely that payment for providing environmental benefits will expand, but irrespective of the net financial effect of schemes on farms, it is important that farmers and consultants are aware of them.

Potentially reduced tillage impacts on several aspects of both the agricultural and the wider environment through the modification of soil behaviour. Current areas of concern are:

- adverse effects on fresh water fisheries of soil transported in runoff from land
- eutrophication (enrichment of surface waters by nutrients leading to excessive production of algae and/or higher plants) mainly due to P losses from land
- contamination of ground and surface waters with nitrate and pesticides
- rapid run off from land in catchments contributing to river flooding

Areas of potential benefit are:

- more insect predators and earthworms
- improved food source and habitat for birds
- enhanced retention of soil organic matter (sequestration of carbon dioxide as soil C)
- less risk of flooding from increased water retention in land

18. Climate Change

Above average rainfall during the August to September period increases the risk of establishment following reduced tillage, particularly on clayland. For the main arable areas of the UK, Table 3 shows the average monthly rainfall during this three month period over the last 70 years, for the decade 1971-80 (when reduced tillage was at its peak in the UK) and for the latest decade

Table 3. Average monthly rainfall (mm) for the 3 month period August – October

	1931-2000	1971-1980	1991-2000
Eastern Scotland	73	61	70
North-East England	70	67	64
Central England	58	53	66
South-East England	66	61	74

The points of interest are that in all areas, apart from the North-East, the latest decade was substantially wetter than the 1971-80 decade, and furthermore, during the latest decade in Central and South-East England, rainfall was well above the 70 year average. These figures indicate that reduced tillage was easier 'last time round'. The Climate Research Unit (CRU), University of East Anglia (see Annex II for website) provides data showing that this trend towards wetter autumns in arable Britain is characterised by more high rainfall events, and points out that these actual trends are consistent with predicted scenarios for Climate Change.

If these trends continue the severe problems encountered during 2000 may occur more frequently.
The substantial trends in increased **winter** rainfall amount and intensity over the 1961-1995 period reported by CRU, are again consistent with climate change predictions and suggest higher incidence of run off, soil erosion and flooding risk.

Machine design

19. The essential elements of the cultivation equipment in use today have been available, and their action has been understood, for several decades. The changes since 1970 have been largely in the scale of the equipment and the combinations in which the various elements are assembled.

20. Tractors
In the 1960's there were single figure numbers of wheeled tractors of 100hp at work in this country. Today the average size sold exceeds 115hp. There are many more 400hp tractors on farms now than there were 100hp tractors in the mid-1960's. At that time large tractors cost more per unit of engine size: today horsepower is generally cheaper in the very large sizes. At that time the discussion concerned the merits and economics of 4-wheel drive tractors. They were more effective but 30% more expensive than 2-wheel drive machines. Today the norm is 4-wheel drive. Tyre sizes have increased to match engine size.

Steel tracks, which were highly efficient but not generally allowable on public roads, have been replaced by rubber track machines. Tyres have become available in very low inflation pressure form (5psi or 0.3 bar) which exert very low ground pressures but may be unsuitable for heavy traction work. In an alternative approach the Kleber Topker tyre has a very large diameter, and therefore a long contact patch, to give good traction and reduced ground pressure in a tyre narrow enough to allow a 205hp tractor to plough in the furrow in the traditional manner. This tyre operates at a range of air pressures which need to matched to the work of the day.

21. Ploughs
While the design of plough mouldboards has not changed markedly, ploughs have evolved to suit present day conditions. All ploughs are now reversible, compared to perhaps one quarter in the 1960's. Ability to vary the width of the furrow is available, and the large ploughs (for example 12 x 16 inch furrows) for use with the largest tractors are articulated for contour-following and ease of manoeuvre. Attempts to introduce shallow ploughs with narrow furrows to provide low energy input work have failed. Current unpublished work at Cranfield University with new mouldboard designs turning wide shallow furrows at comparatively high speeds indicates that the plough can be a fast, low energy input primary cultivator (paragraph 36).

22. Cultivation equipment
Equipment for minimum cultivation today is based on combinations of discs, tines, both forward and backwards inclined, press wheels, and scrubber boards. Some of these may be used separately, particularly discs or presses. The object of the combination machines is primarily to provide a full load for large tractors, but also to provide a logical series of actions. These may be to progress the cultivation downwards in stages, to remove possible disc compaction with a following tine, or to firm the soil between actions and leave it suitable for drilling. In some cases it is difficult to see what the logic may be.

The idea of implement combination was developed at the National Institute of Agricultural Engineering (Patterson et al. 1980) in the 1970's with bridge-links which connected several implements, perhaps discs, tines and drill, in various permutations. They demonstrated that the sum of the energy input for the various elements was the same whether they were separate or combined. The advantage was in providing a full load for the tractor, and avoidance of wheelings over freshly disturbed soil. The idea of the bridge link did not survive, but it may have led to the commercial development of the combination implements in use today.

23. Powered cultivation equipment
The advantage of efficient power transmission through shafts rather than through tyres favours powered cultivation equipment, but the advantage is lost in the action on the soil. Attempts have been made through the years with low rotor speed machines to reach the economy of non-powered equipment, but this has not found favour with the industry. Today cereal farmers are moving away from power harrows and power harrow drills because of their high running costs and comparatively low work rates. Their main use is for emergency work in plough-based systems.

24. Drills

Metering devices and coulters on drills have changed little in a very long time. The main change in drilling has been the inclusion of tines, star wheels, press wheels and other soil working elements to make the drill a combined cultivation and drilling machine. Power requirement is now high, with a tractor of more than 200hp being required for many drills. Because the cost of such a drill is also high farmers would like to see such machines coping with a much wider range of conditions than they do at present (paragraph 45)

Several drills were developed for direct drilling in the 1960's (Outlook on Agriculture 1975). They were generally very robust, heavy and capable of penetration into strong soils, and very largely operated by contractors. All but the Moore Unidrill have been discontinued. A new generation of direct drills are on the market today and are giving a satisfactory performance under some but not all soil conditions.

25. Manufacturers and dealers
The number of farm machinery manufacturers and dealers across Europe and particularly in the United Kingdom has declined sharply over the years. Dealerships have declined in number and the re-shuffle of the reduced volume of business in farm machinery continues between and within the dealerships. There is more selling and servicing directly from manufacturers as communications improve and low-turnover dealers find it increasingly difficult to remain on top of the complexities of present day machines.

26. Consultancy services
During the time of the 1970's developments in direct drilling and reduced cultivations farmers had access to a wide range of general and specialist consultancy and research services, mostly free of charge.
The situation today is that the free-of-charge consultancy services have gone, research programmes on cultivations and crop establishment have been completed or largely discontinued, and commercial organisations, especially machinery manufacturers, are unable to provide the level of support that they did in the past. Important features are:

- ADAS continues to provide consultancy, but on a fee-paying basis.

- Other consultancy and research groups such as the Arable Crop Centres and the Morley Research Centre and Morley Agricultural Consultants Ltd have a strong presence.
- A wide range of consultancy services can be accessed through the British Institute of Agricultural Consultants and the Association of Independent Crop Consultants.
- Some companies, notably Simba, Vaderstad, and Monsanto, make a valuable contribution through customer advice, free publications and support for joint research and promotional projects.
- The Agriknowledge Project (paragraph 81c) offers technical and economic information and performance standards through a website, publications and public seminars.
- The Soil Management Initiative (paragraph 81c) brings together a wide range of commercial and research interests, and provides a basis for the exchange of information within the industry. It has produced a booklet (A Guide to Managing Crop Establishment and accompanying video; Annex II for website). These have been very carefully thought out and incorporate a large amount of the accumulated knowledge and experience of reduced tillage, and have been repeatedly referred to in this document. The booklet contains a number of comprehensive and easily assimilated case studies on farms that have already, or are in the process of changing, from ploughing systems to systems of non inversion tillage.

RESEARCH PROGRAMMES 1988-2001

27. Results of Experiments

The majority UK experiments on reduced tillage were reported in the previous Review (HGCA 1988a). However several important projects mentioned below were either still ongoing in 1988 or started subsequently. Concern for environmental issues has been the motivation for much of this work.

28. Straw Incorporation (ADAS, Letcombe Laboratory/IACR Rothamsted)

Leading up to the straw burning ban in 1992, the effect on cereal test crops of straw incorporation by different methods was investigated in a coordinated series of short and long term field experiments (HGCA 1988b).
Table 1 shows that that incorporation of chopped and spread straw with discs and/or tines gave very similar cereal yields as ploughing on clays but lower yields on lighter soils.

Table 1. The mean overall yield of cereals after straw incorporation with disc and tines as % of ploughed on soils of different texture.

Very heavy	Mod. heavy	Medium	Light	Mean
100.5	98.0	97.5	92.5	96.5

Turley et al. (2002) have reviewed the results of straw incorporation for 11 years at six ADAS sites, three on clays and 3 on lighter soils. The first four years results at these sites are included in HGCA (1988b). The test crops were continuous wheat until break crops were introduced to control brome at three of the sites. On the clays, tine/disc incorporation gave 5-8% less yield compared with ploughing and on the lighter soils the 3-18% less. Much of this yield depression was attributed to competition from *Bromus* spp. But at two shallow stony sites consistent yield losses were attributed to adequate consolidation of the soil straw mix.
A long term experiment on clay conducted by Letcombe and later by Rothamsted at Northfield (Christian et al. 1999) concluded that there are greater risks of losing winter cereal yield from reduced tillage in the presence of chopped straw compared with baling, and that incorporating to deeper than 50mm substantially decreases this risk. This risk was mainly due to lower plant populations leading to greater competition from grass weeds.
Overall these experiments show that shallow straw incorporation with disc/tines is likely to reduce yield compared with ploughing on all soils but more on lighter and very stony soils. This yield depression can be minimised by incorporation to 100mm or deeper, adequate consolidation and satisfactory grass weed and volunteer control. Although not part of the experiments, short chop length and reasonably uniform spreading of straw and chaff are essential to minimise yield loss.
Winter oilseed rape was the test crop at three sites. In the absence of grass weed problems yields were not reduced by disc/tine incorporation. However on the basis of experimental results Jarvis (1988) considered that for oilseed rape ‘there is no consistently satisfactory way of incorporating wheat straw in clays’. This conclusion is probably still valid.

29. Integrated Farming

There have been three major UK projects to compare conventional plough based farming with integrated systems based on shallow non inversion tillage:

- The Less-Intensive Farming and the Environment project (LIFE) at IACR-Long Ashton (Jordan et al. 2000; Jordan 2001)
- The Focus on Farming Practice project at CWS-Stoughton (Leake 2001)

- Integrated Farming Systems/LINK project led by ADAS, (HGCA 2000)

In addition to targeting efficiency of inputs these studies aimed to identify and quantify the effect of soil management on soil structure and fertility, agricultural emissions from land, and to measure effects on soil ecosystems.
Detailed measurements of nitrate leaching, soil and P loss by erosion, P and isoproturon loss in drainage water were made in the LIFE project. A summary of results, including yields are in Annex III. These results show that compared with ploughing, reduced tillage substantially decreased sediment loss in run off, total and soluble P losses, and isoproturon loss in drainage. The Integrated system encouraged larger populations of insect predators and of most species of earthworms than the conventional system. From 1995-2000 the mean yield over all crops was 6.19 & 4.94 t/ha in the two Integrated systems compared with 5.65 t/ha after ploughing, and the cost of crop establishment was reduced by 1/3.
Similar beneficial effects on nitrate leaching, insect predators and earthworms were recorded in the Focus on Farming Project and in addition substantially more birds were found on the 'Integrated' fields. Although reduced tillage was probably responsible for most of these benefits, a contribution from the other components of the Integrated systems cannot be ruled out.

30. Long term control of nitrate leaching (ADAS - Oasby)
Reduced and delayed tillage were tested as part of a 'Protective System' to decrease nitrate leaching on a shallow limestone soil at the Oasby site. The experiment has run through two rotations over ten years and compared with the plough based system the 'protection' continues to give partial control. Average annual N losses were 50, 25 kg N/ha for the Conventional and Protective systems respectively (Johnson & Smith 1996; Johnson et al. 2002). However reduced tillage encouraged both grass weeds and volunteers causing greater outlay on chemical control.

31. South Road, Bush Estate Experiment, SAC Edinburgh
Started in 1961 this long term tillage experiment compared continuous direct drilling and ploughing with straw removed, on a Cambisol (15% clay) and a Gleysol (17% clay). In 1983 it was modified to include short term direct drilling and broadcasting followed by shallow rotavation. These treatments were continued until harvest 1991. Winter barley was the test crop except for one year of oilseed rape. Continuous direct drilling of winter barley gave similar yields to ploughing when the crop established well and survived the winter but in years when wetness curtailed available work days, direct drilled yields were depressed. Because of aeration problems and grass weed competition it was concluded that direct drilling could not be recommended for intensive cereal production (Ball et al. 1994).

32. The Brimstone Experiment (Letcombe Laboratory, IACR Rothamsted/ADAS)
This long term experiment (1979- 88) on a very heavy Denchworth clay soil was designed to compare the effects of ploughing with direct drilling on losses of nitrate, phosphate and several pesticides with and without drainage. Phosphate and pesticide losses were not significantly affected by tillage treatment but there was significantly more nitrate leached from ploughed plots. From 1984-1988 direct d rilling lost 21% less than ploughing (Goss et al. 1993). However subsequent results showed that much of this conserved soil N was subsequently lost by leaching following mineralisation. There was 20% extra mineralisation in plots previously direct drilled for eight years compared with previously ploughed plots, and averaged over five winters the plots previously direct drilled lost 5-57% more nitrate (Catt et al. 2000).

33. Arable Research Centres (ARC)/ IACR Long Ashton/Vaderstad/Montsanto

This group of researchers are three years into an HGCA funded Establishment/Minimum Pass Trial on ARC sites at three locations. The soil types are chalk loam, Hanslope clay, and silt loam over gravel. The cropping is continuous winter wheat drilled with the Vaderstad Rapide into three tillage treatments: plough & press, disc & press once, direct drill. Straw is chopped in all treatments.

Table 2. Mean wheat yield (t/ha) and margins (£) for three sites 1999-2001.

	Chalk loam		Clay		Calc. loam	
	yield	margin	yield	margin	yield	margin
plough	6.54	183	6.79	194	7.20	189
disc	7.51	259	6.64	195	7.11	191
direct drill	6.65	218	5.55	126	7.11	218

At the chalk loam site, disc incorporation yielded significantly better and gave the highest margin; the wheat apparently suffered less from take all than ploughed.
At the clay site direct drilled gave significantly lower yield and margin - in 2001 direct drilled spring wheat gave only half the yield of ploughed; the direct drilled surface remained too wet under the straw mulch.
At the calcareous loam site there were no significant differences between cultivation treatments so the greatest margin was from direct drilled. Resistant blackgrass competed more with the disc treatment especially when establishment was restricted.
Greater levels of Eyespot and Sharp Eyespot were recorded in some ploughed treatments.

34. Morley Research Centre

Sections of fields with replication only over years, have been used to compare tillage and drill type on two soil types in East Anglia. At both farms test crops each year are 1st and 2nd winter wheats. After the 2nd wheat the comparisons are moved to a different field. At both sites discs did as well as ploughing for first wheats but resulted in 0.5 t/ha less from 2nd wheats (straw chopped and spread). Direct drilling depressed yields compared with ploughing in both crops at both sites. Only two of the five drills were able to direct drill the 2nd wheat at the SCL/SC site.

Table 3. Yield of wheat (t/ha) from tillage comparisons on two farms

	Plough		Discs x 1		Direct Drill	
	1st wheat	2nd wheat	1st wheat	2nd wheat	1st wheat	2nd wheat
SCL/SC	10.31	7.85	10.19	7.25	9.50	6.60
SL	9.97	9.39	9.86	8.86	9.24	8.85

2 years results for SCL/SC site; first year at SL site.
SCL/SC- Beccles sandy clay loam/ Ragdale sandy clay; SL- Newport sandy loam

35. IGER/IACR Long Ashton - Control of Soil Erosion in Maize

Run off containing soil and associated pollutants is often a severe problem when maize is harvested late in the season for silage. **The Environment Agency** have funded field experiments at IGER and IACR Long Ashton to examine possible control measures. The results indicate that run off can be substantially reduced by undersowing the maize and by growing a winter cover crop after the maize (Clements and Donaldson, 2001). Chisel ploughing after harvest to leave a rough land surface greatly reduced run off on a well drained sandy clay loam at IGER but increased run off from a silty clay loam at Long Ashton. At the latter site this cultivation was made through wet soil. This contrast in results is a good example of the soil condition rather than the method of cultivation controlling results.

36. Silsoe Research Institute and Cranfield University, Silsoe

Engineering research into reduced energy input for cereal establishment was largely completed with the work of D E Patterson and others at Silsoe Research Institute (Patterson et al 1980). Work on the incorporation of chopped straw (ADAS, Cranfield University and Ransomes Sims and Jefferies, plough manufacturers), beginning in 1984, was aimed at coping with the imminent straw burning ban rather than reduced tillage, but produced basic information on plough draughts related to depth of work, the effect of surface cultivation on later ploughing, plough design and straw and stubble burial, and post-plough pressing (Brassington 1986).

HGCA sponsored work on direct drilling and reduced tillage for cereals and oilseed rape in the presence of surface straw was carried out at Cranfield University over three years (1990-93) (Spoor et al. 1995). The drill coulters used were a triple disc, an angled disc followed by a cast iron press wheel and an inverted T opener followed by a rubber face press wheel. It was concluded that none of the coulters were satisfactory for direct drilling in heavy wet soils. Field treatments were direct drill followed by shallow disturbance, through increasing disturbance to full inversion with the mouldboard plough. The results differed widely in wet and dry years, and showed direct drilling to be unreliable in wet years in clay soils and in the presence of straw. All systems worked well in dry years.

They conclude that very shallow disturbance before direct drilling improved reliability, that broadcasting with shallow incorporation was satisfactory provided there was adequate moisture present, and that the most successful treatment was shallow incorporation with a disc harrow, particularly with following tines to take out any compaction or smearing. It was noted that shorter chopped straw required less tillage for incorporation, 100 mm length being well incorporated with one pass of a disc harrow.

Some drill design work, sponsored by a manufacturer on a confidential basis, continues at Cranfield.

From 1994 work at Silsoe Research Institute into vision guidance led to the development of an autonomous vehicle which followed crop rows and precision sprayed individual brassica plants. This work has been developed to produce a commercially available tractor mounted vision-guided hoe capable of 12 km/hr in the row. It is being used on farms in 18 row form in sugar beet, carrots and parsnips. The hoe has also been used in cereals, and there are possibilities for commercial use in organic crops, control of herbicide resistant grass weeds and overall reduction of herbicide use.

The future of vision guidance may be in conjunction with Real Time Kinematic Global Positioning Systems (RTK-DGPS) to provide ultra-accurate automatic steering in controlled traffic or gantry systems. The work is already well established in Queensland (Chamen 2001; Tullberg 2001).

Work has also been carried out at Cranfield on mechanically guided high speed hoeing (D W M Pullen PhD project), on individual tillage tools for manufacturers, and most recently on the Kverneland 'Packomat', a one-pass drilling system which may have a place in low cost cereal establishment on the smaller farm (Cathal Cuinnea MSc 2002)

Current work at Cranfield University concerns the development of shallow, wide furrow, mouldboard ploughing. Results to date indicate that the plough now available competes on cost grounds with disc and tine cultivation up to 300ha when used with one 200hp tractor. (Professor R J Godwin, Christopher Saunders)

REVIEW OF EVIDENCE

FARMERS

37. We visited or otherwise contacted and interviewed leading farmers responsible for more than 25,000 ha of cereals from the Scottish Borders to the South-West of England and from East Anglia to the Welsh border. The pro-forma used as a basis for interview or postal response is at Annex IV. Farm size ranged from less than 200 to more than 3000 ha, and soils ranged from light loams to heavy clay. In addition we considered the 12 case studies set out in the Soil Management Initiative document 'A Guide to Managing Crop Establishment'. The following is a summary of the key points emerging from the discussions, together with our comments.

38. Traditional cultivations
Farms on the lighter soils, with mixed rather than predominantly cereal cropping, which were smaller (perhaps 200ha and less) or had adequate permanent labour, used the mouldboard plough as the basic tillage tool. On lighter land (less than 20% clay) ploughing and drilling with little or no intermediate treatment is as efficient or more efficient in energy and labour terms than tine and disc alternatives. Some clay land farmers had found plough-press-drill, when circumstances were right, their least expensive approach. On larger clay land farms the mouldboard plough had in many but not all cases been retained for occasional use mainly in burying crop residues, relieving compaction or dealing with grass weeds. Some retained a plough solely because of the poor second hand machinery market. These farms for the most part no longer had the labour or the tractor power available to plough the whole farm within the time available for autumn cropping, and reduced cultivation was a well established part of the total operation. In a few cases there was not a plough on the farm.

The decline in the use of power harrows and power harrow-drill combinations was more striking. Farmers in every case were aware that they were energy-demanding and expensive to operate, and every one seen on the farms visited was unused. The general reason for retaining a power harrow was for possible emergency use, and because of poor second hand value .

39. Management
It was agreed by all those consulted that reduced cultivation and direct drilling made increased demands on management, and this has been stressed elsewhere in this report. The need to spread machinery and labour overheads has led to larger and larger farming units spread over considerable distances and farmed for many owners under various operating agreements. One quoted in the Soil Management Initiative booklet was of 2000ha, with 30 owners at distances of up to 32km. A Bedfordshire farmer running a very large and scattered enterprise said that the greatest aid to management would be a ring fence. Labour on cereal farms is in many cases at an astonishingly low level, and the figures, quoted below, include management staff. If reduced cultivation and direct drilling can reduce the number of hours of field work by managers there will be more time available for detailed management. One family farm reported a reduction in tractor time from 2 hours 30 minutes to 42 minutes a hectare, saving 450 man hours a year for outside business interests or recreation. Only one respondent (from France) made the point that field work time saved could raise management standards.

40. Labour

Farm area ranged from 120ha to 450ha per full time person employed. The very approximate median figure would be 200-220ha per person. There was additionally, in almost every case, casual labour at harvest time, and in some cases some labour coming in through contract services. These very low labour levels must indicate that the manager spent long hours during the peak season driving machinery, that the tractor and other machine units were large, and energy per hectare put into cultivation was low. The trend to lower labour input will no doubt continue and will put further pressure on the trend towards more economical cultivation systems and, perhaps, encourage the consolidation of scattered enterprises.

41. Tractors

Total tractor engine power on the farm per acre or per hectare is an approximate guide to the energy efficiency of the operation. It is approximate because it may or may not include items such as forklifts (which may be 120hp – the engine size of a substantial tractor) and self-propelled sprayers, and will normally include 'runabout' tractors which do not feature in the cultivation work. We met an all-ploughed family farm on chalk loam soil at 0.53hp/acre, not counting the forklift. Several large farms on minimal tillage and some direct drilling were in the range 0.21 to 0.28hp/acre, while the 'norm' for the large farms was 0.3-0.4hp/acre. One large farm appeared to register 0.14hp/acre on mainly chalk loam, but the reason for this very low figure, and the extent to which it was supported by hired-in tractors, has not been investigated. The fact is that 0.14hp/acre (0.26 kW/ha), taken over (for example) a 50 day season of 9 hour days at 60% efficiency tractor transmission, delivers 250 MJ/ha at the implement (see Annex VII for conversion factors). This net energy input is known to be sufficient for crop establishment with tine and disc systems (Patterson et al 1980, Smith 1993), but it leaves very little safety margin should the 50 day season of 9 hour days fail. The alternative to very low available tractor power on some farms was the use of large re-built American tractors which came in at low cost, generally worked fairly low hours per year, and provided a safety margin in capacity terms. If roughly one third of the investment in machinery on cereals farms is in tractors, and this incurs one third of the depreciation costs, it is clearly important that tractor purchases are carefully controlled.

Tractors used for cereals work ranged from 125 to 440hp (93-328kW). Those up to 270hp were on rubber tyres, while those above that power were mainly on paired rubber tracks (the Caterpillar/Claas Challenger) or 4 rubber tracks (the Case IH Quadtrac). 'Installed weight' in tractors is of the order of 60 kg/kW of engine power. The largest of these tractors is therefore over 20 tonnes in weight.

42. Working Depth

Within the sample of farms practising reduced tillage there was great variation in the 'normal' depth of working from 20 cm, i.e. the depth of conventional ploughing at one extreme, to 5 cm at the other. By 'normal' depth we exclude remedial topsoil loosening to remove compaction. Irrespective of depth, all claimed some measure of reduced tillage, either in greater area capacity per man or less energy use or both combined. Even when obvious reasons for depth variation, such as shallower work for oilseed rape, were removed much variation remained.

Farmers were asked for their views on the extent of compaction problems and any changes which may have occurred in recent years. In no case did a farmer feel that soil conditions had deteriorated. The large contact areas of modern tyres and especially the rubber track tractors allowed them to work over cultivated land with minimal or no sinkage. Users of the Quadtrac reported reduced compaction problems resulting from its use. Remedial work was mostly shallow (less than 300 mm) lifting with winged subsoil tines, some work at 350 mm or deeper, and some moling. Work was aimed at headlands, tramlines and specific risk parts of the fields, generally amounted to no more than one sixth of the land in any one season, and could on no account be labelled 'recreational'. Moling, where it was practiced, was at about 10 year intervals.

43. Straw chopping and spreading

Without exception farmers rated the chopping and spreading of straw and chaff critical to the success of reduced cultivation and direct drilling. Very few were satisfied with the performance of the equipment they currently own, and would like to change, or are changing, their harvester with the associated chopper and spreader to the firm that appears to have the leading design. The fact that the chopper on the large Claas Lexion harvester can take up to 100hp to drive it was not considered to be a problem. The straw chopping problem is increased to some extent by the perceived need to cut as close to the ground as possible to assist the following reduced cultivation, and therefore passing the maximum quantity of straw through the machine, and the need to operate early and late in the day when extra moisture makes the straw more difficult to chop. All manufacturers of combines should be able to offer choppers and spreaders that work to acceptable standards as new models with larger engines come forward. Farmers consulted said that no straw spreader was capable of uniform spreading under windy conditions.

Farmers we interviewed tended to cut the stubble as short as possible, and made use of the contour-following facility on the harvester. Where minimum cultivation was less than satisfactory it tended to be blamed on a lapse on the part of the combine driver and longer stubble. There were exceptions where farmers found stubble length to be not particularly important.

44. Equipment for reduced cultivation

While many firms offer equipment that may be used for reduced cultivation, the market is dominated by just two (Simba and Vaderstad) who have produced tillage equipment and drills that were developed either from farmers' own ideas or on the basis of a clear understanding of farmers' needs. Both firms support their products with quality technical advice and objective literature. Very few of the larger farmers we consulted did not have equipment from either or both of these firms.

Reduced cultivation equipment is based on discs, tines and presses in various forms and combinations. The geometry and performance of discs and tines has been known and understood for many years, and there have been no major changes. Press wheels attracted little or no attention in the past, but there have been developments in recent times. The outstanding one, in the view of those we consulted, is the Simba 'Double Disc' press wheel which consists of two dished plates of high quality steel pressed together to give a wheel with a sharp edge to break clods and wide 'shoulders' to produce a level finish. A double row of these wheels gives 85% ground cover.

Some 'reduced' cultivation equipment that we saw in use required very large tractors and an energy input per hectare not much less than that of mouldboard ploughing. The implement consisted of tines, presses, and two sets of discs and could be 6m wide. One user had found a 425hp tractor inadequate and had gone up to 525hp. Depth of working was usually said to be 100mm but was often 150mm or more. What was being achieved was complete or near complete cultivation in one pass over the land, very high output from one driver (up to 6 ha/hour) and sufficient depth of cultivation and mixing of straw to allow trouble-free drilling to follow.

Some farmers recognised the very high energy input, and high cost of some of the implements (list price of over £50,000 for a 6m size) and were looking towards lighter and less expensive alternatives. Some used discs, tines and presses as separate units, but this was not generally favoured. One farmer was using a tined implement which gave 50mm depth of complete soil disturbance in one pass which was suitable for drilling without further work. The characteristics of this tool (Kökerling Precision Cultivator) are the length of the frame (10m) and good control of working depth, close overall spacing of tines (131mm) for complete coverage combined with a wide stagger between banks of tines to reduce the risk of blockages. Power requirement compared with the heavier combination implements was roughly proportional to depth of work, that is, about half of that of the combination implements working at 100mm depth.

45. Drills

Farmers would like to have a drill that will work through all kinds of seedbed from traditional cultivation to direct drilling, through large quantities of surface straw, and under both wet and dry soil conditions. This machine does not exist. Some farmers use, for example, a Vaderstad cultivator drill which copes with a wide range of conditions, including direct drilling under ideal circumstances, but they retain an elderly light drill for emergency use. A drill designed for direct-drilling (for example the Kuhn Semis-Direct) will operate well as a direct drill and into 50mm surface tillage, but may not handle deeper cultivation. Therefore a farmer wishing to move towards direct drilling, but still retain the option of some ploughing, needs to retain two drills or have contract services available.

In general the farmers we consulted used large cultivator drills of the Vaderstad, Horsch and Simba type, often needing tractors of 200 hp or more to give the work rate required. One managed the entire 660ha farm with a Kuhn direct drill. There was a general trend away from tine coulters towards discs because of their better trash-handling characteristics.

Oilseed rape is commonly **broadcast directly into the stubble** from the combine with a mounted **'Autocast'** seeder, or if some cultivation is required with a related **'Terracast'** seeder mounted on a cultivator, harrow or ring rolls. Both are sold by G&E Agriculture. One large scale farmer broadcast some cereals when field conditions became difficult for conventional drilling at the end of the autumn season.

46. Spraying

Most farmers were spraying with 24m booms, and even with the high work rates achieved thought that this was the most time-critical operation of the autumn season because of the few safe spray-days available. Spraying was given priority over cultivation work.

47. Timing of cultivation

Cultivation under the minimal tillage systems on the larger farms normally began close behind the combine to take advantage of any remaining soil moisture and to lengthen the season as far as possible. This work is often done by less-skilled casual labour. On the family farm of 220ha of light loam ploughing was started after the harvest season in the confidence that it would be completed with time to spare.

In general it was thought that the large tractors and high work rates associated with reduced tillage would give the manager good control of the situation and result in better yields.

48. Weeds and pests

Without exception black-grass was seen as the most difficult weed and slugs the most expensive pest. Control of black-grass was one reason for retaining a plough on the farm after a change over to minimal tillage. Most farmers felt that the better timing possible with faster cultivation systems gave them more options for destroying weed seedlings in stale seedbeds late in the drilling season.

Slugs were a major problem associated with shallow cereal drilling, direct drilling where the seed slots were poorly closed, and with straw residues. Repeated treatments were effective but expensive.

49. Environmental issues

The farmers interviewed did not see strong links between cultivation systems and environmental issues. Reduced energy input was thought to be to the general benefit of the environment. More residues on the soil surface were thought to be helpful to wildlife over the winter. There was a move away from methiocarb to metaldehyde, being more specific to slugs and less harmful to worms and small animals.

50. Costs of cultivations

Farmers interviewed were well aware that a change to reduced tillage would be profitable only if labour costs per hectare could be reduced. This might mean investment in new implements and larger tractors, which in turn would raise machinery costs in the initial years. Grant Thornton, RASE (Markham and Chapman 2000) and others have published such examples of cash-flow forecasts over the past several years. No one we interviewed costed individual machines and operations, and even the overall cost of crop establishment was considered by a major farming company to be too complicated to be worthwhile calculating. They took a whole-farm view of labour and machinery costs. The Case Studies in the Soil Management Initiative booklet list costs per hectare for various operations which vary widely for the same operation on different farms. For example, cultivator drills range from £20 to £43, direct drill £5 to £43, subsoiling £20 to £40. This may reflect different ages of equipment (new to fully depreciated) or different methods of calculation.
Labour and machinery on the cereal farm usually accounts for around 60% of all fixed costs. The Cambridge University costings for mainly cereal farms in 1999/2000 (Lang 2001) indicated total labour and machinery on all farms to be £335 per hectare, with £303 per hectare for the 'Top ten' on a Net Farm Income basis. The top ten had 39% lower labour costs and 6% higher machinery costs than the average. £303 per hectare is still unsustainably high in the view of John Bailey (Kverneland Training Days 21-22 August 2001) who says the figure needs to be reduced to £200-£250 per hectare as a matter of urgency. See Annex VI for example figures.

RESEARCHERS AND CONSULTANTS

51. We consulted the major UK research groups concerned in tillage as well as consultants, Government scientists in DEFRA and the Environment Agency. The letter on which personal interviews and written consultations were based is at Annex V. The following is a summary of the responses received with our observations.

52. Successful uptake of reduced tillage

Strong motivation to save costs and to invest the time and attention to detail needed to make reduced tillage work were seen as vital ingredients required of management.

The generally agreed **key site factors** favouring reduced tillage are, in decreasing order of importance:

- **Cropping** – mainly winter sown combinable crops.
- **Climate –** drier arable areas with average field capacity return dates later than mid November
- **Soil Type –** well drained clays, calcareous and other stable loams.
- **Grass weeds –** low populations of grass weeds without herbicide resistance.
- **Cereal Straw** –either a reliable outlet for baled straw or well chopped and evenly spread straw and chaff.

Clearly there are interactions between these factors. Thus freely drained structurally stable soils in wetter areas such as the South West and North East may be satisfactory candidates for reduced tillage. The other important variable is depth of tillage and in general the less suitable the site factors above, the greater the need to avoid very shallow tillage. For example large grass weed populations with herbicide resistance point to avoiding tillage less than 100mm and occasional ploughing. Likewise farms with less suitable soil types (Cannell et al. 1978; Davies et al. 2001; HGCA 1988a; Cranfield University 2001)) or very variable soils types will require deeper tillage. Lodged crops and uneven straw spreading also call for deeper tillage, confirming the view that management for reduced tillage starts with the previous crop.

The key to successful reduced tillage is good seedbed quality, and all the site factors listed above impact directly or indirectly on this requirement. Good seedbeds ensuring uniform timely establishment are important irrespective of type of tillage, but the shallower the tillage and the greater the presence of surface straw, the more difficult it is to ensure uniformity of seedbed quality over large areas of land, particularly in wet seasons. Irregular gappy establishment provides an ideal opportunity for grass weed to exert severe pressure on crops. The seedbed needs of spring sown are more exacting than the requirements of autumn sown crops. It is for this reason that shallow reduced tillage and direct drilling for spring crops has often proved less unsuccessful than for winter crops.

53. Management of reduced tillage

The respondents generally agreed that, although reduced tillage systems have the potential to cut overall farm costs, to be sustainable they require a higher standard of overall management than ploughing. It is only severe financial pressure which is forcing large numbers of farmers to adopt quicker cheaper tillage for their combinable crops, and this fact alone emphasises that reduced tillage is not an easy option. Furthermore the shallower the depth of work, the more the risk involved and the skill required. Adoption of reduced tillage purely because it is widely and persuasively promoted is a recipe for failure. In effect the respondents were suggesting that widespread uptake of reduced tillage may cause as many problems as it solves. Potential disadvantages mentioned were poorer establishment, worse grass weed problems and more topsoil compaction resulting in more runoff containing pollutants.

In more northern parts of the UK, where the climate is less suitable, it was argued that to take advantage of the greater work rates of reduced tillage when conditions allow, whilst retaining the capacity for ploughing if conditions are not suitable, was the best approach. This approach is advocated not only in the north of the UK, but its problem is that overall it may cost more rather than less to establish crops.
There is a paradox in that sites where reduced tillage is often considered more at risk, are often the same time sites where reduced tillage is most needed. To take an example, a slow draining clay site in northern England would be classed as borderline for reduced tillage, but might benefit both from the faster work rate of reduced tillage and by avoiding the difficult task of ploughing this type of clay. The solution may be a combination of flexibility in choice of tillage and deeper rather than shallower reduced tillage.

54. Weed Competition
Satisfactory grass weed control is seen by all practitioners as a key requirement of successful reduced tillage. Weed scientists told us that there are substantial gaps in understanding of grass weed ecology; knowledge that is necessary to provide the reliable predictive advice required on farms. This gap has already been appreciated by funding bodies and two major projects are now underway. One, a multi-site Link project with industry, DEFRA and HGCA funding, majors on cultural control of blackgrass. Treatments include direct drilling, shallow tillage and ploughing and all the sites have substantial blackgrass populations. Gaining a better understanding of weed ecology is a key objective of this work. The other project known as HERMES, examines the effect of the same three tillage treatments on selection pressure for herbicide resistance. The weed specialists we met believed that these two projects should resolve several of the current uncertainties, provided they are run for a sufficient number of years. **We recommend that no additional major project on grass weeds should be started until the findings from these two projects are known.**

55. Pests
We understand that there are only two important pests the severity of whose attacks may be differentially affected by method of tillage. Aphid transmitted Barley Yellow Dwarf Virus and slugs (Young and Oakley 2000).
Work at IACR Long Ashton demonstrated that cereals established by non inversion tillage and direct drilling were less susceptible to the spread of BYDV by aphids, than cereals after ploughing (Kendall et al. 1995). Firstly, fewer aphids settle on non-ploughed land because the presence of surface straw reduces the contrast between seedlings and soil background, which is known to be important for aphid recognition of host plants. Secondly, larger numbers of predator beetles and spiders are present on non-ploughed land in autumn, reducing aphid survival and thus secondary spread of the virus (Kendall 1991).
Slugs are a serious concern to many cereal growers and in contrast to BYDV, we understand, that non-ploughing with straw incorporated may lead to an increase in slug numbers, probably the result of direct mortality due to physical injury incurred during ploughing. However, slug damage does not inevitably increase in fields where more slugs are present and it is possible to counteract the risk of slug damage by good seedbed consolidation and by sowing cereal seeds more deeply than 25mm (Glen et al. 1990, 1992).

56. Disease

In the 1988 Research Review we mentioned that **take-all** in cereals appeared to be worse where straw was shallowly incorporated compared to being ploughed in. Subsequent work did not confirm this finding (Jenkyn et al. 2001) and it was suggested that in the earlier work lack of adequate consolidation in the seedbed had encouraged take-all damage.

A hint in earlier work that the incidence of eyespot may be worse where straw is ploughed in rather than incorporated by reduced tillage has been confirmed

57. Organic Farming

Our contact Dr James Welsh pointed out that the need to reduce costs of production is important for organic farmers but the opportunities to achieve reductions through reduced tillage are probably fewer than in conventional systems because weed competition is the main problem. The potential advantages to soil health and of modifying N mineralisation with reduced tillage (Silgram and Shepherd 1997) are attractive, but little or no work has looked specifically at reduced tillage in organic systems. Dr Welsh **suggests that a soil working group should identify which of current reduced tillage techniques may have potential in organic systems.** This exercise would lead to identification of future research needs and would enlarge on the recommendations made in HGCA (2001).

58. Reduced Tillage in other European Countries

Time restricted us from a comprehensive review of reduced tillage in other countries. ITCF in France reported that about 25% , 40%, 1-2% and 5-10% of winter cereals, winter rape, spring cereals and beet respectively are established by non plough tillage. These percentages are very approximate because results of the next 6 yearly survey is due in 2002. Farmers tend to start deeper and gradually reduce depth in subsequent years as they gain experience. The practice is most widespread on shallow calcareous soils but has also expanded to other loams and to clays.

The main problems reported are grass weeds (blackgrass and ryegrass often resistant to herbicides) and straw management. Shallow tillage is recognised as requiring very careful management particularly in the 'most crucial period between crops'. The main motivation in France was said to be speed of establishment. The motivation to save time is fuelled by the need to devote more time to desk management, to increase the area farmed, to diversify (including off-farm employment), and to take up leisure activities. At present development work is directed towards incorporating cover crops into reduced tillage systems. This is to meet the requirements of the extension of the EC Nitrate Directive to non potable waters. This extension will cover about ½ the arable area of France (this expansion also applies to the UK).

The largest source of information on reduced tillage, including direct drilling, in Europe is contained in a Final Report and the Proceedings of four EC workshops held between 1994 and 1997 (Tebrugge, 1994, 1995, 1996, 1997, 1998). One of the major conclusions from a survey of farmers conducted in all countries as part of this Concerted Action was that farmers lack appropriate advice on reduced tillage.

59. Environmental implications of reduced tillage

The answers we received indicated that differences of opinion exist on the likely benefit to the environment of reduced tillage on farms. The advocates of integrated farming tended to emphasise environmental benefits more strongly than others. Many of those we spoke to, whilst recognising the potential for environmental benefits of reduced tillage, were not convinced that these were, or could be, realised reliably in commercial practice as distinct from in experiments. Successful reduced tillage on farms involves flexible management according to conditions, rather than the set treatment testing characteristic of most experiments. Furthermore the care and timeliness given to experimental treatments cannot be achieved throughout whole farms.

It was pointed out that an advantage in one sector of the environment could be offset by a disadvantage in another. For example whereas continuous shallow tillage may help to control run off and erosion, this is likely to be at the expense of greater herbicide use.

In 1997 the European Commission adopted a package of measures (Agenda 2000) setting out its view on EU common policies beyond 2000. Among the measures anticipated in this reform of the CAP, is a more prominent role of agri-environmental instruments to support sustainable development of rural areas and respond to society's increasing demand for environmental improvements. Tillage has an important role in several such environmental issues and consequently there are implications for farm incomes. These are considered in paragraphs 59-64

60. Runoff and erosion losses

Diffuse losses of soil and accompanying nutrients (N & P) and pesticides to rivers causes deterioration by silting up of spawning grounds in trout and salmon rivers (MAFF, 2000), phosphorus enrichment causes eutrophication in lakes, reservoirs and slow moving rivers (see Environment Agency 2000 for distribution of eutrophic waters in England), and occasional flooding of roads and houses. A recent case at Bishopsteignton in Devon in which a farmer has been successfully prosecuted by Devon County Council for damage caused by soil eroding from his fields, has created an important legal precedence.

Conservation tillage, i.e. shallow non inversion tillage leaving crop residues at the surface, is practised widely in many countries of the world as a cultural rather than an engineering solution for controlling runoff and soil loss from arable land (Carter 1994). The potential for its use in the UK has been assessed by Ball and Dickinson (1998). In the UK conservation tillage for controlling runoff from soils has been assessed in the long term LIFE experiment at Long Ashton (paragraph 29) and in single year experiments in Norfolk (Chambers et al. 2000). In both these cases runoff and losses of soil were substantially reduced compared with ploughed land. In the LIFE project a decade of consecutive shallow cultivation at about 100mm built up humified organic matter and biological activity in the surface layer which resulted in a structure more stable to rain than ploughed seedbeds. In the one year Norfolk experiment the opportunity for build up of soil organic matter was minimal but clearly the combination of root residues and protection of surface straw together gave added stability to rain.

The Environment Agency previously recognised conservation tillage as a 'best farming practice' for controlling runoff and soil loss from fields (Environment Agency 2001). However in our discussions with the Agency they expressed concern that in some recent case studies runoff was not controlled by shallow tillage and they now have misgivings about its general efficacy. In our opinion to expect the general application of shallow tillage to control surface run off in vulnerable catchments is to overlook that reduced tillage has always to be tailored to site and soil condition (paragraph 74).

In the next few years, when the EC Water Framework Directive is in operation, we expect there will be more pressure put on farmers to take effective action to control soil, pesticide and nutrient losses in many vulnerable catchments. At present there are different opinions about the most appropriate tillage for control of these losses **and we recommend that**

attempts should be made to resolve these differences. In particular we recommend that the efficacy of 'conservation tillage' at a range of depths needs to be more widely and carefully assessed. As part of this study, researchers are advised to record the soil condition before and after tillage and not assume that the same piece of equipment always produces the same soil conditions. This apparently obvious but vital requirement is often overlooked.

61. Flood Control

Another high priority concern of the Environment Agency is the role that agricultural land plays in determining risk of river floods. Here we only comment on shedding sites and not on the management of agricultural land in flood plains.

If surface runoff is a major factor in causing flooding, and assuming that the longer that excess rainfall can be retained in fields the less the risk of flooding, there is a need to examine to what extent tillage may assist in maximising temporary storage in soil profiles. Common sense suggests that maintenance of high surface infiltration rates and open porous topsoils are needed to both receive and contain rainfall. These requirements are most likely to be met by coarse and stable surface structures and deep topsoil tillage. Retaining crop residues coupled with deep non inversion tillage appears to be one suitable option. As part of the recommendation in the previous section **we suggest that tillage and other husbandry options should be considered prior to deciding if it is necessary to test measures in river catchments vulnerable to flooding.**

62. Carbon storage

The Intergovernmental Panel on Climate Change (IPCC) has identified three main options for offsetting carbon dioxide emissions to the atmosphere: (a) reduction of agriculturally related emissions, (b) use of biofuels to replace fossil fuels, and (c) the sequestration (storage) of carbon in soil as organic matter. By retaining all crop residues and by minimising tillage, soil organic matter is increased relative to removal of crop residues and to burial of residues by ploughing (Balesdent 2000). Therefore a system of long term shallow tillage, or better still direct drilling, is one option for increasing soil C sequestration. Setting aside practical issues, Smith et al. (1998) estimate that 100% conversion to direct drilling throughout the EC would, through fuel saving and extra soil organic matter, sequester about 23 million tonnes of carbon/year or 4% of the total man made carbon released annually as carbon dioxide.

However we also received evidence (Ball et al. 1999) that direct drilling can in some situations result in greater emissions of another greenhouse gas nitrous oxide, thereby reducing the benefit of carbon sequestration.

Although we cannot rule out that farmers in Britain may in future be paid to sequester carbon by reducing tillage, we believe this is unlikely both because of the uncertainty that the measure would be effective (Powlson & Jenkinson 1981; Smith et al. 1998) and also because the process of carbon storage is easily reversed by deep tillage.

63. Biodiversity

The LIFE and Focus on Farming Projects (paragraph 29) both recorded substantial increases in soil fauna, in particular insect predators and earthworms, in the integrated less intensive systems of farming which include shallow non inversion tillage. The Focus on Farming project confirmed that these extra food sources led to substantial increases in the numbers of skylarks, tree sparrows, linnets, chaffinch and yellowhammers. The UK general public is very aware of the association between arable farming and fewer song birds, and measures that reliably deliver what is generally perceived as an important environmental benefit should be high priorities to receive agri-environmental funding (paragraph 29 and 74)

64. Pesticide and nitrate losses to water by leaching
The effectiveness of greatly reduced autumn tillage in decreasing soil nitrate content and overwinter nitrate leaching has been demonstrated in many field experiments (e.g. paragraphs 30, 32). However in the Nitrate Vulnerable Zones (NVZ) reduced tillage is not one of the required measures. This is probably because of the likely disruption to farm production resulting from its general introduction. It is possible that voluntary and appropriate reduced tillage may attract agri-environment money in the future as a measure to control a combination of run off, soil loss and nitrate leaching in vulnerable catchments.

Information on the influence of reduced tillage on pesticide loss to water is conflicting. The LIFE project showed that leaching of isoproturon was substantially less from the Integrated system than from ploughing (paragraph 29), but the Brimstone experiment (paragraph 32) showed no effect due to tillage treatment. At both sites pesticide leaching was attributed to rapid water movement through macropores so why the difference? A possible explanation is a difference in type of macropores. At the more loamy LIFE site most of the macropores were probably earthworm burrows lined with adsorbant organic material (Stehouwer et al. 1994), whereas in the heavy clay at Brimstone more of the macropores were probably shrinkage fissures less lined by organic coating.

65. Soil Quality
One of the key objectives of the DEFRA draft Soil Strategy (DEFRA 2001) is "to maintain and improve the **quality** of our soils at a level where soil function is not impaired, to ensure we can meet our current and future social, environmental and economic needs." As discussed in paragraphs 60, 62 & 63 reduced tillage has important implications for soil quality and for the sustainable management of soils. The improvements in soil quality resulting from long term reduced tillage described in the Integrated Farming projects (paragraph 29) need to be evaluated on farms to find out to what extent these improvements are achieved in commercial situations.

66. Gaps in Knowledge
Respondents listed as the main R & D needs:

- agronomy of crops established by shallow tillage
- documentation of the experience and knowledge of how best to manage the new systems
- grass weed ecology and control
- traffic control on permanent wheelways to minimise soil compaction

The general view was that, apart from these items of research, the adoption of more profitable tillage systems would be supported best by putting emphasis on the transfer and interpretation of information.
The emphasis on central and southern England as the major source of information on reduced tillage was considered to be a problem by respondents in Scotland and in the south west of England. They stressed the need for more regional emphasis in the information available and in the interpretation of research results and guidelines. It was also considered that there was a need for better informed advice from impartial organisations such as ADAS and SAC.

Weed scientists told us that there are substantial gaps in understanding of grass weed ecology; knowledge necessary to provide the reliable predictive advice required on farms. This gap has already been appreciated by funding bodies and two major projects are now underway. One, a multi-site Link project with industry, DEFRA and HGCA funding, majors on cultural control of blackgrass. Treatments include direct drilling, shallow tillage and ploughing and all the sites have substantial blackgrass populations. Gaining a better understanding of weed ecology is a key objective of this work. The other project known as HERMES, examines the effect of the same three tillage treatments on selection pressure for herbicide resistance. The weed specialists we met believed that these two projects should resolve several of the current uncertainties, provided they are run for a sufficient number of years. **We recommend that no additional major project on grass weeds should be started until the findings from these two projects are known.**

MACHINERY MANUFACTURERS AND SUPPLIERS

67. Responses

Information provided by the manufacturers and suppliers ranged from very full discussions with the Engineering Director and the provision of a great deal of written and video evidence to zero response. For the most part manufacturers were ready to supply well-built cultivation, tractor and tyre equipment, but were not in a position to discuss the agronomy or soil management aspects of reduced tillage.

68. Simba International

Simba International hold a substantial part of the British market for cultivation equipment suited for reduced tillage with their 'Solo' combination tool, the 'Double Disc' press wheels, various disc harrows and the Freeflow drill. They also have a marketing arrangement with Horsch to supply complementary drill equipment. In addition to their own development work the company are involved in agronomic trials with HGCA and others, in the ECOtillage project and the Soil Management Initiative, and have continuing contact with Cranfield University.

The forerunner of the Simba 'Solo', the 'Mono', was made up of a series of discs, tines and press wheels which commonly operated at up to 200mm depth. The energy saving compared with traditional plough-based work was marginal, but it allowed one man with a very large tractor to cover a lot of ground in a short time. The 'Solo' uses lighter tines which can be hydraulically adjusted for depth and the more recently developed DD press wheels. It can be folded to 3m wide for road movement. Draught is lower, depth of operation is normally much less than 200mm, and work-rates are correspondingly high. Philip Wright of Simba was concerned that there is now considerable interest in reducing cultivation depth to 50mm, which could result in a large quantity of straw being mixed with a small quantity of soil, perhaps bringing problems for crop drilling and later growth. He was also concerned about the use of wide sweep tines in shallow cultivation. Where there is risk of smearing and impeded drainage at the cultivation boundary narrower sweeps not giving complete ground coverage may be safer. Related to this problem is the use of cultivator points until they are worn back to a negative rake (a backward slope) when they will cause smearing under moist conditions.

We discussed the problem of smaller farmers wishing to move to reduced tillage when major items of equipment from Simba cost from £11,000 to £60,000. It was confirmed that the various items of **discs, tines and press wheels can be supplied separately** to modify existing cultivators, and in fact are being used by other firms to build new equipment. There is therefore opportunity for low cost conversions.

The question of the performance of **discs in primary cultivation** under wet and possibly compacted soil conditions was raised. It was agreed that as long as there were open drainage channels through the soil, that is, there were no serious compaction problems, discs alone gave satisfactory cultivation. If, however, the upper layers were compacted, or if it is sealed later by fines released in the seedbed, waterlogging problems can occur. Then the combinations of discs, tines and press wheels are superior. Farmer users considered the 'Solo' better than the plough, and better than discs alone, for 'weatherproof' initial cultivation.

There was an awareness of the need to look for further **reductions in energy demand from implements**. This might begin with more information on the energy demand of each element within a combination implement, one example mentioned being the cultivator drill where modifications had produced substantial draught reduction.

At the present time the demand for **satisfactory drilling**, in terms of trouble-free operation and favourable placement of the seed, was seen to be the factor governing depth and degree of cultivation. Tine drills were judged to be simpler, offered a better-draining site for the seed, and could be designed to allow well-chopped straw to flow without blocking problems. The trend for the future would be greater accuracy of depth placement, lower energy demand and below-surface spreading in wider rows.

The company had considered the **precision farming** approach to cultivation, perhaps combining vision guidance and DGPS to routinely assist drivers and to allow targeted remedial treatments within a field. They had also considered controlled traffic on a 3m bed arrangement, with cultivators modified to leave wheelways undisturbed.

(The Amazone 'Centaur' cultivator/disc harrow features tine sections which can be raised or lowered by hydraulic cylinder for **control from soil physical data and GPS position**. It was awarded a Silver Medal at the AGRITECHNICA exhibition in Hanover, November 2001)

Throughout the discussions with Simba the importance of **short chopped and evenly spread straw** in reduced tillage was stressed, as was the need for **close management** of the whole tillage and drilling operation.

69. Vaderstad

Väderstad Ltd, the United Kingdom operation of Väderstad–Verken AB, Sweden, offer a range of cultivation equipment and have a major part of the market for cultivator drills in Britain. The company has commissioned three publications (Vaderstad 1993,1996, 2001) by their own agronomist and senior ADAS consultants on the subject of the agronomy, soil management, mechanisation and economics of cereal establishment. Case studies are included. These publications, in conjunction with a series of seminars run by the company, represent an important contribution to the objective information available to farmers on the choice and management of economical tillage systems.

70. Kverneland

The Kverneland Group, originating in Denmark and with a United Kingdom base since 1976, are the world's largest farm machinery manufacturers outside the tractor companies. They hold the major part of the plough market, and ploughing is thought to still account for more than 70% of our primary tillage. The company is actively involved in developing faster and lower energy input ploughs which should extend the farm area over which ploughing is competitive with the disc and tine approach.

CONCLUSIONS

71. Reducing input into cultivations offers real opportunities for improving farmers' returns

It is clear from our review of evidence that labour and machinery costs of cereal establishment can be reduced without compromising yields. The leading performers ('top ten') in the Eastern Counties report on mainly cereal farms 1999-2000 showed 17% higher gross output and 39% lower labour costs than the average of the group. Machinery costs for the 'top ten' were very similar to the average for the group. Deloitte and Touche Agriculture (Deloitte and Touche 2000) show a greater than 2x factor between the lowest and highest quartile machinery and labour costs (£193 - £426/ha). An achievable target for all-combinable farms is **£200-250 per hectare,** depending on **farm size**. The smaller the farm, the less the scope for saving.

For maximum benefit from reduced tillage techniques, the area farmed needs to be large enough to fully occupy the largest tractor with purpose-built reduced tillage equipment. This suggests **450ha and upwards.**

Smaller farms, say less than **250-300ha,** may operate at their greatest efficiency with the plough, and whenever possible with short-cut plough-press-drill systems. They are unlikely to be able to justify purpose-built reduced tillage equipment, but may be able to take occasional advantage of reduced tillage using existing disc harrows or cultivators. There is no prospect of either group being able to afford to fully equip and staff for both reduced tillage and plough based systems (paragraph 13 refers).

Key factors in restricting labour and machinery costs for cereal establishment are:

- Choice of low energy-input cultivation systems (Patterson et al 1980, Sijtsma et al 1998, Smith 1993) This may involve shallower or less intense cultivation or more efficient equipment. The common range of net energy input is 200-360 MJ/ha for a plough based system, 100-230 MJ/ha for reduced tillage and 80 MJ/ha for direct drilling. The use of fewer larger tractors to deliver the energy per hectare required in a shorter time with less labour input. The usual range of tractor power available is 0.25 – 0.50 hp/acre (0.5 – 0.9 kW/ha). The cost of power in very large tractors need be no more than in smaller ones, and halving the power available to 0.25 hp/acre or less should have an effect on depreciation charges (Annex VI)
- The use of less labour with larger machines to deliver low energy input cultivation at high work rates.

Other factors

- Reduced tillage equipment, particularly discs, may cover some thousands of acres between replacement of wearing parts. Downtime during busy periods is therefore reduced or eliminated.
- Efficient tractor use requires full loading of the tractor and high forward speeds in work. This can easily be provided with tine and disc equipment, but less easily with the mouldboard plough.
- There will be some fuel saving with lower energy inputs. In cash terms it is unlikely to be of importance: a saving of £5 per hectare at present day prices is more than most would achieve.

72. Yield – cost substitution
A lower cost establishment system may be thought to justify acceptance of lower crop yields, Simple examples might be a reduction of one full time worker on 400ha being equivalent to about 1 tonne per hectare of cereal yield, or a saving of £20 per ha in machinery costs being equivalent to a 3% drop in yield, which cannot be detected by eye.
We do not think that this approach is advisable:

- The various university and accountants' costings indicate that the top economic performers, which will have to be equalled by all farmers surviving as cereal growers, produce consistently high yields at lower costs
- The link between tillage system and cereal yield has always been tenuous, and forecasting yield depression resulting from cultivation economies is difficult if not impossible. The possible exception may be estimation of the effect of tillage related grass weed infestations.

73. Machinery selection
Larger farm units, less labour and larger machines are inevitable (paragraph 13 and Executive Summary 5). It is also likely that newer machines will have longer working lives than earlier ones because of quality improvements and shortage of funds to make changes. Some individual machines will represent a substantial part of the machinery depreciation cost on the farm – as, for example, the prime mover tractor, when tractors account for one third of total machinery depreciation (paragraph 15). The single all-purpose drill and the main cultivation implement are similarly important. The **penalty** for making **the wrong decision on machinery purchase** is large and will play havoc with any business plan. Not only will it not do the expected job for the farmer, it will not be attractive to the used machinery trade.

There is no formal farm machinery testing in Britain. A testing scheme of the 1960's failed through lack of support from all sides of the industry. The RASE Machinery Awards provide summaries of extensive user experience of some machines, but there is no laboratory type input and there is no means of arranging 'series' tests, that is, the examination of several makes of one type of machine at one time. As far as we know the only series tests combining both user experience and laboratory measurements are by the Kondinin Project in Australia.

There is no serious prospect of re-establishing machinery testing in Britain, and it is not even certain that the RASE Machinery Awards will continue. The best that can be done is to encourage exchange of information, probably informally, through the network of practitioners described under Recommendations below.

Our review of evidence indicates that the draught of existing cultivation equipment, and of the separate elements within the equipment, is generally not known. **This information would be useful to manufacturers and anyone planning tillage systems, and if funding was available it could be collected at public demonstrations or selected trial sites.**

74. Environmental services as revenue source
We have suggested in the main conclusions (Executive Summary 5) and in paragraph 59 that **the environmental benefits of reduced tillage on farms, as distinct from in experiments, are unclear, sometimes contrary, and far from assured.** There are probably several reasons for this. Firstly, the care and timeliness given to small experimental areas cannot be achieved throughout a whole farm, so that what is described as the same method of tillage achieves very different soil conditions as the end product. Secondly, commercial requirements on farms result in year to year changes in tillage, unlike the continuous tillage treatments tested in long term experiments; for example straw may be baled rather than

incorporated when there is a market for it, or a farmer may decide that severe blackgrass pressure or spring cropping call for occasional ploughing rather than repeated shallow cultivation. If further investigation indicated that certain benefits proven in experiments could be consistently obtained on farms, there may be scope for payments to farmers for adopting reduced tillage practices. The most promising benefits probably derive from repeated reduced tillage with incorporation of crop residues, provided the depth of work is adjusted according to the actual soil condition. The benefits are:

- an enhanced food source for birds
- less run off and associated soil fines, phosphates and pesticides reaching rivers in vulnerable catchments
- increased moisture retention in land resulting in delayed surface run off and less flood risk

75. Successful Reduced Tillage

Conventional farming based on the plough owes its great popularity to its almost universal applicability and reliability. Reduced tillage on the other hand needs to be tailored carefully to site, soil condition and weeds to be successful. The requirement for close field and in-field management means that the risk of compromising yield is greater and that good judgement and strong motivation to make the system work are necessary ingredients of success.
The shallower the reduced tillage the greater the opportunity for cutting costs but in general the greater the risk of losing yield. Having the ability and experience to weigh up the various factors which determine optimum depth of work is important. In the absence of this aptitude managers should err towards working deeper.

76. Site Suitability for Reduced Tillage

Within the arable areas of Britain the suitability of farms for reduced tillage varies widely depending mainly on annual rainfall, soil type and cropping system. Thus the stable structured well drained soils in lower rainfall areas have the best opportunity for saving tillage costs and weakly structured or slow draining soils in wetter areas have less opportunity. However because of the flexibility of reduced tillage, particularly in the depth of working, we believe there is an opportunity for some degree of reduction in almost all situations including mixed arable farms. Growers of root crops and vegetables are unable to adopt as much shallow tillage as those growing all combinable crops, but they still have the opportunity to use deeper reduced tillage instead of ploughing when it is advantageous.

77. Grass weed pressure

Almost without exception the respondents identified grass weeds competition as a major constraint on reduced tillage and on shallow reduced tillage in particular. The magnitude of the problem on farms with large populations of herbicide resistant blackgrass or ryegrass is such that the need for deeper tillage and occasional ploughing inevitably restrict the opportunity for saving tillage costs. At present we understand that the incidence of herbicide resistance is likely to increase rather than decrease. It follows that farms with only minor grass weed populations containing little or no resistance should use reduced tillage with care having regard for long term effects on grass weeds.

78. Larger farm units, less labour and larger machines will of themselves enforce a move away from traditional plough-based cultivation

The trend towards larger farm units, labour reduction and fewer and larger machines can be expected to continue. Farm expansion is giving rise to a larger number of mixed tenure farms at the expense of wholly owned or wholly rented farms, and at the same time to more fragmented farm operations. The requirement is therefore for cultivation equipment that will cover large areas quickly and be capable of rapid, unescorted movement on public roads. This all points towards reduced tillage equipment rather than very large ploughs. It has been suggested that ploughs can compete with reduced tillage up to 250 – 300 ha (paragraph 36), but as this becomes a 'smaller' farm in cereals terms the advantage will be increasingly with reduced tillage.

79. The importance of management in reduced tillage

The importance of and the demands made on management have been clear through the evidence of farmers, consultants and researchers. The success of smaller farmers operating without the benefit of scale, and the occasional loss making by others with the benefit of scale, has to be attributed to management and attention to detail. Managers repeatedly mentioned the problem of managing large and widely scattered enterprises. The answers to the management problem may be:

- greater use of bought-in agronomy services
- further development of reduced input, high speed tillage to allow working managers more time for management
- further development of automation and driver assistance
- eventually, some rationalisation of fragmented holdings

We do not envisage management requirements reversing or slowing the trend towards larger holdings and less labour

80. Advice for farmers and consultants

Replacing one system of tillage by another is a major change, which has repercussions on the whole business. Furthermore the requirements of each farm will be different, depending on the individual financial, labour and technical circumstances. It follows that many of the farmers needing to save costs and contemplating change, would benefit from comprehensive independent advice provided by able and experienced consultants. These consultants need to have a thorough grasp of the economics, mechanisation, soil management and agronomy relating to tillage rather than expertise in a limited area only.

Although we have not attempted to discover the availability of such comprehensive advice, we believe that it is quite limited amongst those consultants who are regularly on farms, and **we recommend that training should be provided to ensure greater availability.**

A major source of experience and knowledge resides with those farmers who have already successfully adapted their farms to reduced tillage. **We propose that ways should be found to tap into this unique resource on a fee paying basis**.

RECOMMENDATIONS

81. Strategic framework for the HGCA cultivations research programme

a) The evidence presented suggests that the clearest opportunity for farmers to reduce the cost of cereal production, and improve profit, is to reduce labour and machinery costs through the adoption of reduced tillage practices.

b) HGCA have already identified the reduction of production costs through low cost establishment techniques and fast and efficient operations as one of six key research areas (HGCA R&D strategy for cereals, autumn 1999). **We recommend** that this be recognised as **first priority** among the six research areas, coupled with similar priority for technology transfer support.

c) Of various groups able to play a part in the dissemination of information and advice to farmers, two are outstanding. They are the Agriknowledge Project (ADAS, HGCA, IACR, Morley Research and the University of Nottingham) and the UK Soil Management Initiative (an association of 16 organisations, with a further 7 in process of joining). The Soil Management Initiative is linked to parallel groups throughout Europe under the coordination of ECAF (European Conservation Agriculture Federation).

- The Agriknowledge Project focuses on farm performance and why more profitable farms are successful, on technical benchmarks for farm performance measurement, and on technical information to enable farmers to reach benchmark performance.
- The Soil Management Initiative places more emphasis on environmental matters, particularly cultivation systems to protect and enhance soil quality, and minimise soil erosion and water pollution.

We recommend that HGCA directs its immediate support primarily to the **Agriknowledge Project,** the aims, objectives and priorities of which coincide exactly with what we see to be the current needs of the industry. At the same time **environmental issues**, which will have an increasing effect on farm income as well as the welfare of the countryside, would be best aided through support for the **Soil Management Initiative.**

82. Target areas for research

a) The negative views are:

- We should not return to **long-term tillage trials** in the style of the 1970-1990 period. They were expensive, slow to produce results, and excessively site-specific.
- No new research on the **ecology and control of grass weeds** should be started until the findings of the current projects are available (paragraph 66)

b) We suggest the following priority topics for research and development:

- **Straw management** (paragraph 43). Combine harvester manufacturers should be encouraged to improve the performance of **straw choppers and spreaders** on the basis of existing technology, and performance data, produced by the manufacturer or independent workers, should be available to farmers. The data required would be energy demand, chop lengths and spread uniformity.

- **Drill development** (paragraph 45). Further development of **cereal drills** is required to cover the wide range of circumstances arising with varying depths of cultivation, differing trash presence, different soils and different moisture conditions.
- **Targets and standards** (paragraph 71) relating to crop establishment operations, and assistance with the calculation of machinery costs, on the lines already introduced by Agriknowledge, should be further developed and refined. This might include tractor power per hectare, labour per 100ha, labour and machinery costs per hectare, energy inputs per hectare, with simple computer programmes for costings and energy input calculations.
- **Energy requirement** (paragraph 73). As a basis for the targets and standards, information is needed on the **energy demand** of common cultivation and drilling machinery, and of the separate elements within combined implements. An example would be the cultivation, packing and coulter sections of a cultivator drill. It should be possible to collect some of this information at public machinery demonstrations, but is more likely to be achieved through specifically planned trial work.
- **Agronomy of crops established by shallow tillage** (paragraph 66). Experimenters have concentrated on comparisons of methods of cultivation. We recommend that the agronomic inputs (e.g. varieties, seed rate, date of drilling, type of drill, weed control) of crops established by reduced tillage alone need to be optimised
- **Traffic control** (paragraph 66) along permanent wheelways for all, or the majority of, field operations reduces traction requirement by as much as 45% by avoiding compaction (Chamen and Audsley 1997; Tullberg 2000, 2001). Such systems have been tested in field experiments, and in Australia controlled traffic has been adopted on many commercial farms. Because the cost benefit of a successful system would be so large, we **strongly** recommend that this area is pursued, starting with a **feasibility study** on traffic control in combinable crops, prior to field development.
- **Appropriate Reduced Tillage including Conservation Tillage** at a range of depths (paragraph 60) should be tested more widely and carefully assessed on commercial farms for the control of soil, pesticide and nutrient losses in vulnerable catchments. The importance of tillage in slowing the release of water to rivers prone to flooding should be assessed (paragraph 61).

83. Nomenclature

In paragraph 2 we suggest that the confusion in terms used to describe reduced tillage detracts from the effectiveness of communication, and that the HGCA and other parties concerned should promote universal use in the UK of an agreed set of terms. Our proposal is to use only three terms to describe reduced non-inversion tillage:

- **Deep reduced tillage** (100-200 mm)
- **Shallow reduced tillage** (less than 100 mm)
- **Direct drilling** (no cultivations prior to drilling)

All three with or without the presence of chopped straw.

84. Working group for Organic Farming (paragraph 57)

Tillage plays a major role in Organic Farming and we recommend that a **soil working group** should be set up to identify current reduced tillage techniques which may have potential in organic systems.

85. Facilitating exchange of information between consultants, researchers and farmers

We have said (paragraph 80) that farmers need help from consultants who have knowledge of the agronomy, soil science, mechanisation and economics of reduced tillage, and have access to successful practitioners. We do not know how many of these consultants exist.

- We suggest that training should be offered to consultants, perhaps in groups from the larger consultancy firms, or through the British Institute of Agricultural Consultants and the Association of Independent Crop Consultants.
- The experience of leading farmers would be vital to such a programme, and we suggest that payment should be made for their services and for access to their farms.

86. The potential for advice to farmers on the basis of existing knowledge
There is a large pool of knowledge of reduced tillage in existence. It is with machinery manufacturers, suppliers of agrochemicals, researchers, consultants, and very much with farmers.

- We suggest that Agriknowledge and others are supported in assembling and publicising, through public lectures, the press, CD's and all means available, proven strategies for reduced tillage, and in providing follow-up support for farmers.

- **Successful reduced tillage farmers should be paid** (paragraph 80) to open their farms to visiting groups, and in some cases to accept some plot trials and demonstrations on their farms. These farms would need to be representative of the climatic differences which markedly influence suitability for reduced tillage as well as the main soil types in the cereal growing areas of the country.

Annex 1

List of Institutions and Individuals Contacted

Anderson, Sarah	Deloitte & Touche
Bailey, John	ADAS, Bury St Edmunds
Ball, Dr Bruce	SAC
Barnes, Robert	Farmer, Marston Moreteyne, Bedford
Basford, Bill	ADAS Gleadthorpe
BIAC	British Institute of Agricultural Consultants
Bingham, Dr Ian	SAC
Boughton, Simon	Velcourt, Stamford, Lincolnshire
Carter Dr Andree	ADAS
Chambers, Brian	ADAS
Chamen, Tim	4Ceasons Consultancy, Maulden, Beds
Christian, Dudley	IACR Rothamsted
Clarke, James	ADAS, Boxworth
Cope, Dr Richard	SRI, Silsoe
Costigan Dr Peter	DEFRA
Davidson, Dr Ian	DEFRA
Dickinson, Roger	Farmer, Morpeth, Northumberland
Errington, John	Farmer, Toddington, Bedford
Forsyth, James	Farmer, Butlers Marston, Warwickshire
Freer, Ben	Morley Research Centre
Gaunt, Dr John	IACR Rothamsted
Godwin, Professor R J	Cranfield University, Silsoe
Home, Matt	EngD student, Silsoe Research Institute/Cranfield University
Hulls, Arthur	Agronomist, Somerset
Jenkins, Dr John	IACR Rothamsted
Jordan, Dr Vic	Chief Executive SMI
Johnson, Paddy	ADAS, Gleadthorpe
Kitely, Robert & Russell	Farmers, Steeple Morden, Royston, Herts
Köckerling GmbH	Leamington Spa (machinery supplier)
Koivista, Dr Jason	RAC, Cirencester
Labreuche, Dr Jerome	ITCF, Boignville, France
Leeds Harrison, Dr Peter	Cranfield University, Silsoe
Meakin, Dr Ingrid	DEFRA
Molden, James	Felix Thornley Cobbold Trust, Otley, Suffolk
Moss, Dr Steven	IACR Rothamsted
Nicholson, John	Farmer and manufacturer, Bedale, Yorkshire
Ogilvie, Sue	ADAS High Mowthorpe
Oldfield, Frank	Raynham Farming Company, Norfolk
Peters, Colin	IACR Rothamsted Farm Manager
Payne, Richard	Farmer, Somerset
Poole, Dr Nick	ARC, Gloucs
Powlson, Prof David	IACR Rothamsted
Redrup, Brian	Velcourt, Stamford, Lincolnshire
Robinson, Dr Rob	Environment Agency
Salmon, Robert	Farmer, Dereham, Norfolk
Saunders, Christopher	Cranfield University PhD research

Shepherd, Dr Mark	ADAS Gleadthorpe
Shipley, Ken	Velcourt (Lincolnshire, Yorkshire, NW Norfolk)
Smith, Dr Richard	Environment Agency
Spoor, Professor G	Maulden, Bedford
Stevens, John	Global Drilling (& Seed) Group, New Zealand
Taylor, D	Farmer, Blisworth, Northants
Tillett, Dr Nick	Silsoe Research Institute
Thorne, Ben	FWAG, Somerset
Tullberg, J N	Farm Mechanisation Centre, Queensland
Turley, Dr David	ADAS High Mowthorpe
Watts, Dr Chris	SRI, Silsoe
Welsh, Dr James	Elm Farm Research Centre, Berks
Whitmore, Dr Andy	SRI, Silsoe
Williamson, Richard	Velcourt (Wiltshire, Hants, Dorset)
Wilmott, 'Jock'	ADAS Boxworth
Withers, Paul	ADAS Bridgets
Wright, Philip	Simba International
Young, Dr John	ADAS Boxworth

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Annex III **Research results**

Less Intensive Farming and Environment (LIFE) 1989-2001

Average 1995-2000	Conventional plough	Integrated I milling wheat	Integrated II feed wheat
Yield **all** crops (t/ha)	5.65	6.19	4.94
Net margin (£/ha)	171	263	159
Earthworms (g/m^2)	29	54	44
Grass weeds ($/m^2$)	159	822	459
Broad leaf weeds ($/m^2$)	1247	2447	3041

Oct 1995-April 1997	Conventional Plough	Integrated 100mm reduced
Run off (m^3/ha)	213	110
Sediment loss (t/ha)	2.05	0.65
Total P loss (kg/ha)	2.2	0.5
Available P (g/ha)	30	8
Nitrate-N (mg /sec)[1]	1.28	0.08
Soluble P (mg/sec)[1]	0.72	0.16
Isoproturon (ug/sec)[1]	0.011	not detected

[1] load in drainflow

Focus on Farming 1994-2000

Average (1994-2000)	Conventional	Integrated
winter wheat yields (t/ha)	7.87	7.28
silage yields (t/ha DM)	6.86	5.76
cultivation & application costs (£/ha)	231	191
whole farm margin (£/ha)	114	111
total weight of earthworms (g)	93	48
skylark numbers	125	512
tree sparrow numbers	95	318
linnet numbers	16	102
chaffinch numbers	0	92
yellowhammer numbers	146	392

Annex IV

Format for farmers' evidence

HOME GROWN CEREALS AUTHORITY
Update of HGCA Review No 5 'Reduced Cultivations for Cereals'

Since the publication of this Review in 1988 economic pressures on farming, farm structure, weed and disease problems and environmental concerns over fertiliser and pesticide usage have changed.

The purpose of the update is to identify problem areas which require new initiatives in research, development and/or technology transfer. Of particular concern is the need to identify what problems stand in the way of much more general adoption of faster, low cost tillage systems.

We ask if you would be prepared to provide some information on the following lines:

Name

Address

Telephone

Arable area ha/acres, of which ha/acres is for yourself, ha/acres contracted, ha/acres under other arrangements

Arable land is approximately	**clay**	**%**
	loam	**%**
	sands	**%**

Labour **Management** **Regular** **Casual**

Cereal area is	**winter sown**	**ha/acres**
	spring sown	**ha/acres**

Cereal land is

Ploughed	**%**	**Usual depth of work**	**mm/in**
Disced	**%**	**Usual depth of work**	**mm/in**
Tined			
Combination 'Solo' or similar	**%**	**Usual depth of work**	**mm/in**
Direct seeded	**%**		

Oilseed rape land is

Direct seeded	**%**		
Disced	**%**	**Usual depth of work**	**mm/in**
Tined	**%**	**Usual depth of work**	**mm/in**
Combiantion implement	**%**	**Usual depth of work**	**mm/in**
Ploughed	**%**	**Usual depth of work**	**mm/in**

Other crops grown?

Any livestock?

Equipment

Tractors- number, with models or power as convenient

Ploughs **Average day** **ha/acres**

Discs **Average day** **ha/acres**

Tines/ combination implements such as Simba Mono **Work rates?**

Power harrows **Average day** **ha/acres**

Sprayers **width** **m** **Average day** **ha/acres**

width **m**

Drills- make, model or width **Average day** **ha/acres**

Ploughing

In what situations do you plough rather than use alternative tillage equipmet?

Never **Wet soil** **Grass weed problem** **Excess straw**

Herbicide residues **Others** ***(Please ring)***

Timing

What cultivations do you carry out during the combining season?

When do you expect to finish cultivations and drilling?

<u>Straw</u>

Area of straw incorporated % Area baled and carried off %

Make of combine and straw chopper

Is the length of chop satisfactory? Average length of chop?

Is the evenness of spread of straw and chaff satisfactory?

Is the performance of the straw chopper/spreader critical to your cultivation work?

Do you have problems with straw blockage of cultivation equipment and drills?

<u>Soil Compaction</u>

Any change in your estimate of the extent and severity of compaction in the last 5 years?

Some improvement No change Some deterioration ***(Please ring)***

Reasons for change in compaction level?

Have you seen any evidence in the crops of compaction effect? Yes/No

What remedial measures do you use? Equipment and depth of working –

Make Usual depth Frequency of use

Weeds

Which are your most important weeds? ***Please ring and number in order of importance***
Underline if there is a herbicide resistance problem

Black grass ( ) **Couch ( )** **Wild Oat ( )** **Ryegrass ( )**

Barren brome ( ) **Soft brome ( )** **Meadow grass ( )**

Cleavers ( ) **Mayweed ( )** **Chickweed ( )** **Speedwell ( )**

Others

Any comment on the relationship between cultivation method and these weeds?

Diseases

Have you noted any relationship between disease (foliar or root) and pests and method of cultivation?

Crop yields

Have you noticed any effect of cultivation method on crop yields?
(If so please indicate the circumstances)

Are you aware of any current experimental work on cultivation method and crop yields?

Economy

Can you reduce tillage costs still further? What are the limitations?

Environment **Are any of your tillage systems related to environmental concerns?**

We may ask if we may come back by telephone or a visit to discuss the information you have provided. Your help is greatly appreciated.

Bryan Davies, Old Galewood,
Hinton Way, Great Shelford,
Cambridge CB2 5AN
Telephone 01223 843424 *for HGCA*

Brian Finney, 16 The Oaks,
Silsoe, Bedford MK45 4EL
Telephone 01525 861144

Annex V

Letter sent to Researchers, consultants and Government scientists

Old Galewood
Great Shelford
Cambridge
CB2 5AN
Tel 01223-843424
Fax 01223-843219
e-mail 106531.2643@compuserve.com

Dear

HGCA REVIEW UPDATE – 'Reduced Cultivation for Cereals'

We are seeking information in producing an Update of HGCA Review No 5 **'Reduced Cultivation for Cereals'** and invite you to help us to make the finished document a comprehensive, constructive and realistic account of the role **faster, cheaper cultivation** could play in reducing farm costs and/or in meeting environmental goals.

The agreed Workplan for this Update is enclosed, it covers the purpose and scope of the Update and we hope it will help you to provide us with the relevant information. After reading the Plan, if you consider our approach is in anyway lacking, tell us.

Some of the following general questions may be helpful to you in thinking about your reply but do not feel constrained by them.

1. What tillage related R&D or survey results, produced in the UK or in other temperate countries since 1988, should be included in the Update?
2. What advantages/disadvantages do you consider there might be if shallow non inversion tillage was more widely practiced in the UK?
3. Are there important gaps in our knowledge, which need to be filled, before question 2 can be answered confidently?
4. What do you consider are the main constraints inhibiting uptake of i. low cost fast tillage systems and ii. direct drilling on farms?
5. What information/equipment is lacking that would allow farmers to employ 'low cost' tillage including more widely and effectively?

Bryan Davies, Soil Management Specialist
Brian Finney, Engineering Specialist.

Annex VI

CAN LABOUR AND MACHINERY COSTS BE CUT TO £200 PER HECTARE?

The following material is based on the Cambridge University Reports on Farming in the Eastern Counties of England

Machinery depreciation on all-cereal farms £/ha

	1999-2000[1]	Projected	
Tractors	38 (32%)	19	Halved with reduced input into cultivations
Vehicles	18 (15%)	10	
Harvesters	27 (23%)	20	Extend use to 300 hours
Other equipment	36 (30%)	23	One third reduction
	£119	£72	

Labour and machinery costs on all-cereal farms £/ha

	1999-2000[2]	Projected	
Labour	70[3]	80	250 ha per worker at £20,000 pa
Machinery			
Depreciation	119	72	Detailed above
Repairs	64	40	
Fuel and electricity[4]	35	25	Saving of £5 per ha on cultivation
Tax and insurance	13	13	
Contract	2	2	
	£303	**£232**	

[1] Total depreciation figure is for the Cambridge University 'Top ten' 1999-2000. The percentage breakdown used is from the 1997-98 report.
[2] 'Top ten' figures
[3] Farmer's own labour is not included
[4] This was into a period of high fuel prices. The difference is therefore assumed lower prices plus economy from reduced cultivations.

The conclusion is that labour and machinery costs at or near £200 per hectare are achievable, Labour productivity, made possible by large machines and fast crop establishment systems, being the key factor.

Deloitte & Touche Agriculture Farm Results quote £193/ha for labour and machinery in the lowest cost quartile.

Grant Thornton's harvest 2000 survey shows the top 25% performers spending £252/ha on labour and machinery.

Annex VII

Conversion factors

1 acre = 0.404 hectare

1 horsepower = 0.746 kW

1 kW hour = 3.6 MJ

1 horsepower hour = 2.685 MJ

1 horsepower hour per acre = 6.63 MJ/ha

1 horsepower per acre = 1.85 kW/ha