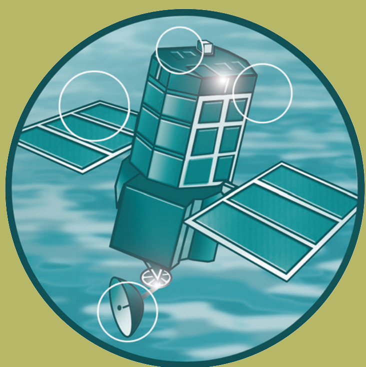
Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

# FD2120: Analysis of historical data sets to look for impacts of land use management change on flood generation

## A1. Technical appendix on drivers of change in rural catchments

R&D Project Record FD2120/PR



Environment Agency

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# A1 TECHNICAL APPENDIX ON DRIVERS OF CHANGE IN RURAL CATCHMENTS

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Since the 1960s, agriculture in the UK has become more intensive, resulting in many changes to the rural landscape. The pre-war landscape with small fields, hedgerows and natural meandering rivers, was transformed into a post-war landscape with larger fields, compacted soils due to machinery, land drains and aligned rivers and channels (O'Connell et al., 2004a). The major drivers of the changes in agriculture over the past 5 decades are briefly reviewed below.

## A1.1 Agricultural change in the UK

There have been a number of gross changes to agriculture in the UK over the past 5 decades, as a result of a set of policy, economic and technological drivers, which are discussed in the following sections.

In general, the total agricultural area has decreased (Figure A1.1), as have the areas of arable and permanent pasture.

There have also been changes in the areas of individual crops grown over this period (Figure A1.2): wheat has increased over the years, but barley decreased after an initial increase. Since the 1980s, oilseed rape has become more common. Changes amongst mixtures of arable crops, for example a switch from spring to winter sown cereals, has led to increased cultivations in the autumn, newly established autumn crops, increase bare soil in early winter and reduced over-wintered stubble in fields . It is possible that such changes could affect the probability of runoff in some conditions.

The livestock sector has not been immune from changes (Figure A3.3). Sheep increased dramatically in numbers in the 1980s, but more recently they have declined in numbers again, as have pigs. Since the mid 1970s there has been a gradual decline in cattle numbers.

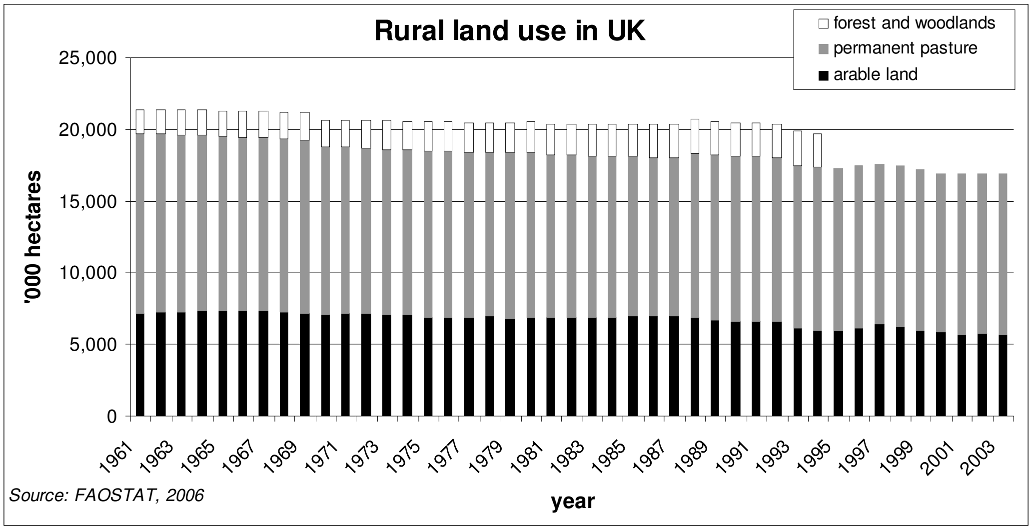



**Figure A1.1 Changing rural land use in UK, 1961-2005**

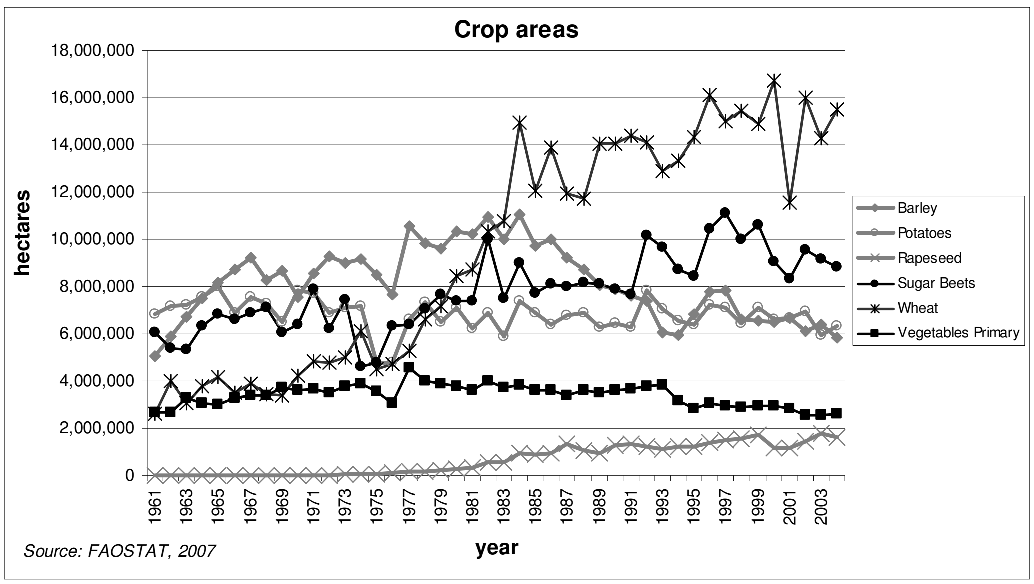



**Figure A1.2 Changing crops in the UK, 1961-2005**

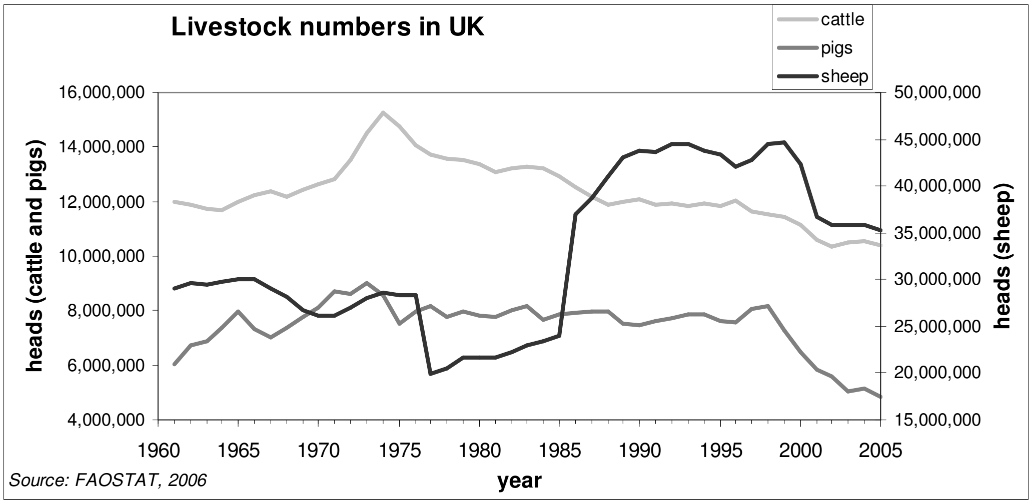



**Figure A1.3 Changing livestock numbers in the UK, 1961-2005**

## A1.2 Changing agricultural policies

Agricultural policy in the UK originates from the collapse of commodity prices and the industrial depression in the 1930s. As the European conflict grew in the late 1930s, there was a massive effort to intensify agricultural production and to convert pasture to arable land to secure sufficient national food supplies. After the Second World War there were clear priorities for domestic food production. Agriculture was viewed as a central role in the protection of the rural environment and the support of the rural economy (Hodge, 2001). The UK government recommitted itself to an intensified and modern agriculture and its policy instruments included price subsidies, ploughing grants and capital grants. Similar policies were put up in place in other European countries, and the policies became more uniform with the initiation of the Common Agricultural Policy (CAP) by the Common Market in 1958 (Dobbs and Pretty, 2004). From the 1960s till the 1980s, European agricultural policy promoted increased production of, and self-sufficiency in, food and fibre, simultaneously supporting farming income through price policies. At the local scale, these policies resulted in removal of hedgerows and woodland, land drainage, and convertion of pasture into arable land (Ogaji, 2005). As agricultural production was intensified through more intensive use of inputs, environmental impacts were generated such as water pollution, land degradation and biodiversity loss (Mayrand et al., 2003). The drive for increased production also led to commodity surpluses, and, of particular concern at the time, a realisation that the EU CAP regime was financially unsustainable.

In the mid 1980s, a substantive change occurred in British agricultural policy as a modification in the CAP allowed the creation of agri-environment schemes. These schemes are policy instruments which provide financial incentives to farmers to adopt practices that protect and enhance the farmland environment and wildlife. These schemes are designed to implement the policy requirements of the EU's CAP Pillar II, which stresses the importance of building effective mechanisms for the delivery of public benefits through land management policy (O'Connell et al., 2004a). The Environmental Sensitive Areas (ESA) and the Countryside Stewardship Scheme (CSS) were the two main agri-environmental interventions, introduced in 1987 and 1991 respectively.

Agri-environmental schemes have become increasingly important due to increasing public demand for environmental-friendly farming and WTO negotiations which aim to reduce producer support for agriculture (Latacz-Lohman and Hodge, 2003; Herzog, 2005). In 2005, a new CAP-reform came into force, decoupling financial support to farmers from their agricultural production. Direct production subsidies were reduced and income support payments, based on historical entitlements, are linked to compliance with standards (Cross Compliance rules) which protect the environment, animal health and welfare. The environmental burden of farming is expected to reduce by the changes of the CAP-reform, through a mixture of extensification of farming, increased compliance, and wider participation in agri-environment schemes (O'Connell et al., 2004a).

However, the impact of agri-environment schemes has been questioned. The main objectives of these schemes include reducing nutrient and pesticide emissions, protecting biodiversity, restoring landscapes and preventing rural depopulation. But uptake of these schemes is the highest in areas of extensive agriculture where biodiversity is still relatively high and lowest in intensively farmed areas where biodiversity is low. There is a lack of robust studies to measures the environmental impact of these schemes (Kleijn and Sutherland, 2003).

### A1.3 Markets, prices and subsidies

The type and amount of agricultural production is strongly influenced by the agricultural markets. To a large extent, prices dictate the amount of agricultural produce. Figure A1.4 for example gives the price trend and production of for wheat in the UK. Until 1995, the price and production follow similar trends. After 1995, the price for wheat declined, but the production stayed of the same order.

In the livestock sector, milk production increased until the early 1980s, but then it declined (Figure A5). However, the milk price continued to rise till the mid 1990s as the introduction of the milk quota system prevented dairy farmers from increasing their milk production.

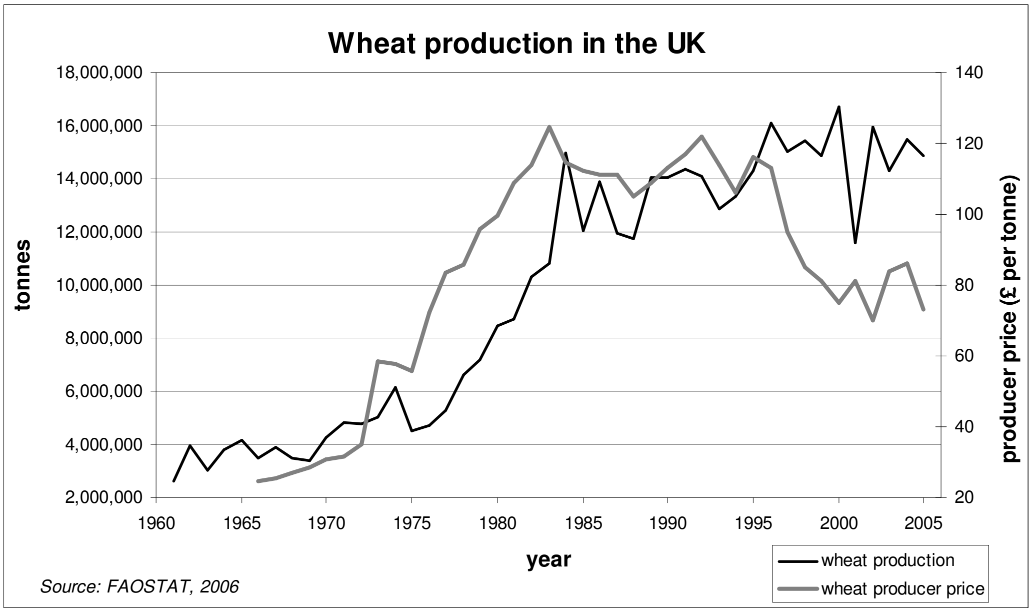



**Figure A1.4 Wheat production and producer price in the UK, 1961-2005**

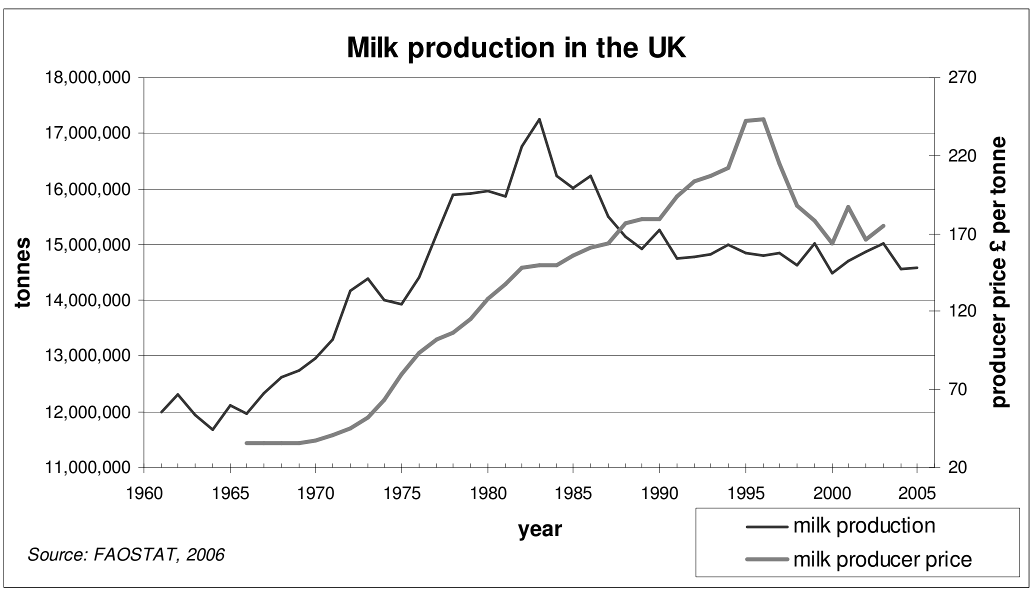



**Figure A1.5 Milk production and producer price in the UK, 1961-2005**

Besides prices, other drivers also define agricultural output. In a perfect competitive market, the price expresses the equilibrium between demand and supply of the good. In practice, however, not all markets are perfect (Colman and Young, 1989). The world market for agricultural commodities has been distorted by economic interventions such as subsidies and trade tariffs. Agricultural subsidies are considered to artificially increase the supply of agricultural products, depress world prices, disrupt world markets, and reduce economic efficiency. Subsidies provide incentives to farmers to intensify agricultural production through more intensive use of inputs, generating environmental impacts such as water pollution, land degradation and biodiversity loss (Mayrand et al., 2003). Environmental externalities are often excluded from the profit and loss accounts of farmers, meaning that environmental damage caused by farming is not paid for by the producers but society. The subsidies encouraging agricultural production thus also increased the associated unpriced environmentally harmful by-products (Lingard, 2002).

In industrialised countries, exchanges of ownership of agricultural produce rarely take place directly between producers and food consumers. The food marketing chain is often simplified by describing five groups of economic agents: producers (i.e. farmers), country dealers, wholesalers/processors, retailers and consumers. These agents are trading with each other through vertically linked markets. In these chains, each stage adds value to the produce of the stage immediately below. Farmers are very dependent upon the performance of other economic agents above them in the marketing chain in terms of the prices they receive and the quality and quantity of products they can sell (Colman and Young, 1989). This is also clearly the case in the UK, where many farmers are dependent on the prices and regulations set by their buyers, predominantly the supermarkets.

Figure A1.6 presents the amount of subsidies provided to UK farmers from 1973 - 2006. Although the subsidies coupled with production increased rapidly in the mid 1990s, the UK agricultural output did not seem to increase during this period (Figure A1.7). But this might also be explained by the declining prices as factor productivity did increase. In 1996, prices for agricultural products declined sharply (Figure A1.8), resulting in a sharp decline of farm income after a short period of income increase (Figure A1.9). It is not known whether this affected land use or land management though. With the reformed CAP in 2005, support payments coupled to production were replaced by decoupled payments (Figure A1.6).

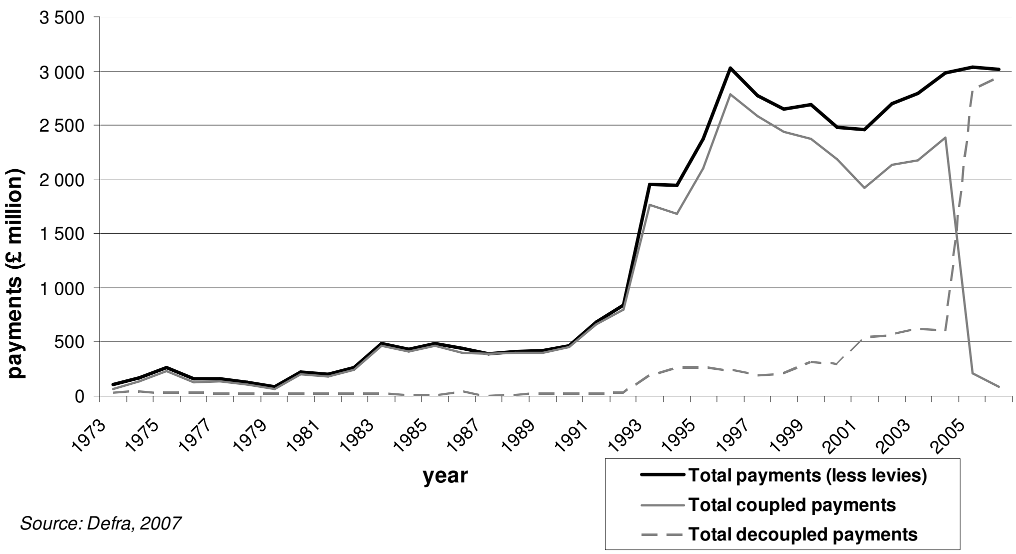
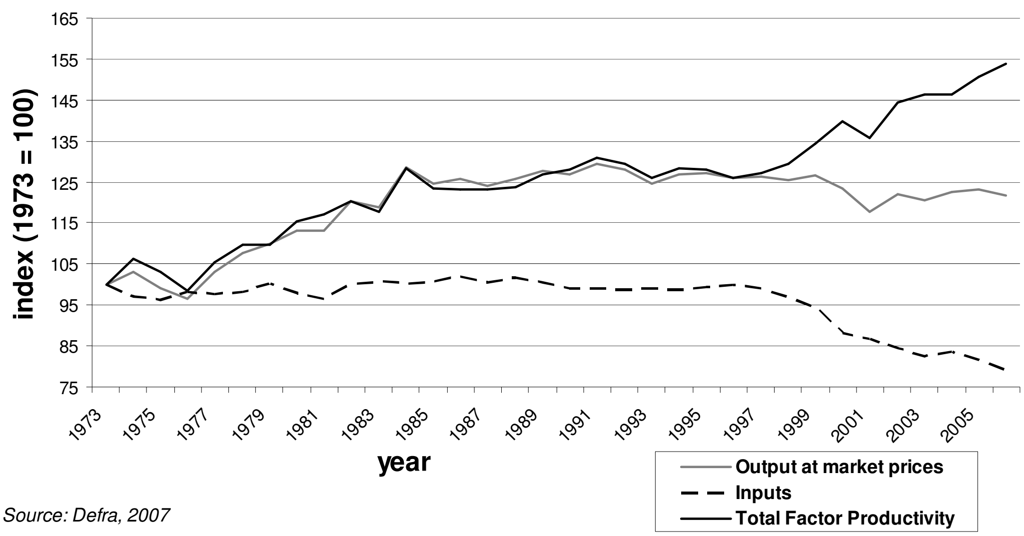
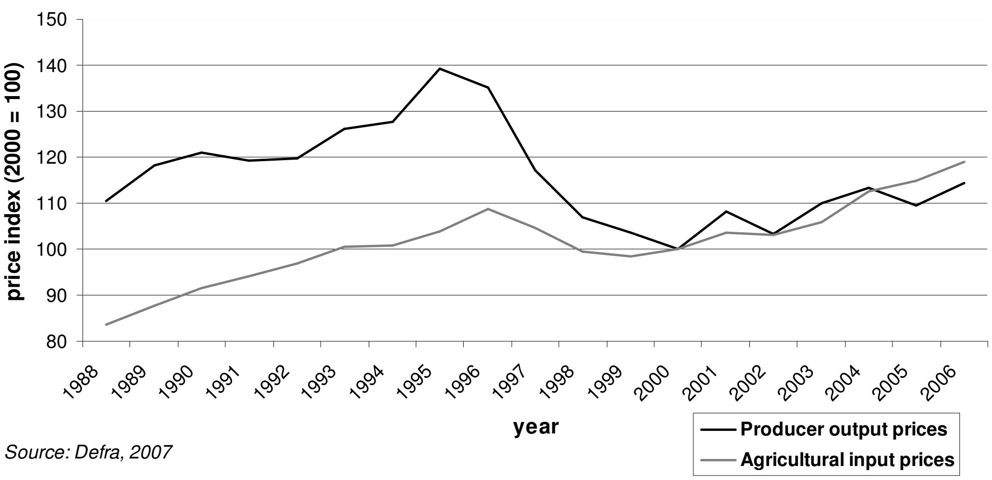



**Figure A1.6 Subsidies for UK farming 1973-2006**



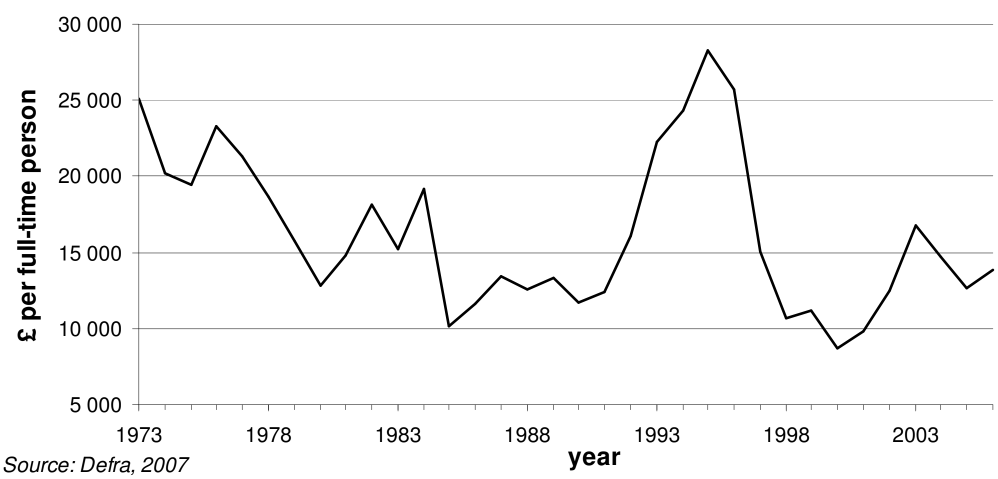

Source: Defra, 2007

**Figure A1.7 UK agricultural production index, 1973-2006**




Source: Defra, 2007

**Figure A1.8 UK price indices for agricultural commodities, 1988-2006**




Source: Defra, 2007

**Figure A1.9 UK total farm income per full-time person at 2006 prices, 1973-2006**

It is expected that removal of trade barriers and subsidies will result in a rise of aggregate world prices of agricultural commodities. A reform of agricultural policies will increase world trade in agricultural commodities, but leaves the level of total agricultural production unchanged. However, the animal product prices are most likely to increase (Diao et al., 2001). This will result in an increased supply of animal products, and thus increased stocking rates.

## A1.4 Demographic drivers

The agricultural sector in the UK consists mainly of family-run businesses. Demographic changes within farm households and the sector as a whole are likely to influence agricultural land use at the farm-scale. Ward et al. (1990) found that changes in agricultural landscapes often occurred when the occupancy changed. Changes in landscape (e.g. loss of field boundaries) conventionally associated with more intensive agriculture have occurred at much faster rates in the lowlands than in the uplands. Resistance to changes in occupancy and the relatively slow-moving agricultural land market are key protective agents for the farmed landscape over this period (Ward et al., 1990).

Recent demographic change in the rural population is likely to change rural land use as well. As net incomes from farming declined (Figure A1.9), the number of farmers declined (Figure A1.10). This trend is likely to continue as many farmers are approaching retirement. It is uncertain what impacts this will have on land use, but this could well lead to decreased stocking rates in upland areas and more intensive arable contract farming in lowland areas.

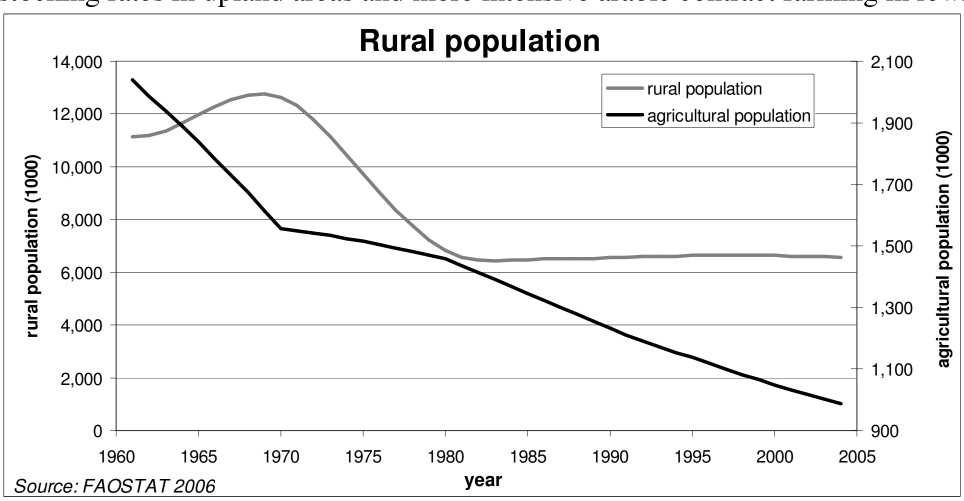



**Figure A1.10 Rural population estimates UK 1961-2004**

Because of the declining profitability of agriculture, many farm households have diversified their income by multiple job-holding by family members. It is expected that the farming community will continue to diversify, ranging from the diversification of income on- or off-farm to the replacement of farmers by 'life-stylers' (Lobley and Potter, 2004). Table A1.1 shows the changes in holdings according to size classes. The number of agricultural holdings has increased, especially in the number of small holdings which are typically occupied by 'life-stylers'. Larger holdings which are potentially viable agricultural holdings have decreased in number. This change in the (financial) relationship between the rural inhabitants and the rural land is likely to cause changes in the use and management of the land as well. However, this diversification process is not uniform across the UK, but differs per region (Wilson and Hart, 2001).

**Table A1.1 Number of agricultural holdings in UK according to size classes**

| | 1990 | 1993 | 1995 | 1997 | 2000 | 2003 | 2005 |
|---|---|---|---|---|---|---|---|
| Less than 2 ha | 12430 | 13990 | 11570 | 15100 | 21370 | 34230 | 34770 |
| 2 till 5 ha | 19090 | 20950 | 18960 | 19010 | 21480 | 33220 | 33850 |
| 5 till 10 ha | 30530 | 30270 | 29480 | 28410 | 25670 | 27050 | 28080 |
| 10 till 20 ha | 37350 | 37290 | 36100 | 34720 | 30420 | 29630 | 30620 |
| 20 till 30 ha | 25200 | 24770 | 23740 | 23160 | 19930 | 18770 | 19710 |
| 30 till 50 ha | 35480 | 34120 | 32770 | 32260 | 27900 | 26250 | 27090 |
| 50 till 100 ha | 42510 | 41240 | 40890 | 39900 | 36600 | 35660 | 35720 |
| More than 100 ha | 38470 | 38700 | 39250 | 38550 | 38880 | 39750 | 38570 |
| Total number | 243060 | 243470 | 234500 | 233150 | 233250 | 280630 | 286750 |
| Total 1000 hectares | 16499 | 16383 | 16447 | 16169 | 15799 | 16106 | 15894 |

*Source: EUROSTAT 2006*

## A1.5 Changes in field machinery systems and operations

There have been considerable changes in the type and use of farm machinery for field operations in the last 40 years. Tractors and equipment have almost doubled in size, conventional ploughing systems have been replaced, fully or partially, by reduced tillage systems, and operations have tended to be carried out earlier in the farming calendar. Furthermore, measures have been taken to reduce field travel (through combinations of equipment operating in one pass) and soil damage (through low ground pressure tyres). There is much greater awareness amongst farmers now than in the past of the benefits of avoiding soil compaction as a means of increasing yields and reducing costs.

Changes in mechanisation have been largely driven by increases in the cost of labour, simultaneously facilitated by technological improvements in engineering design and manufacturing, and structural changes in farming towards larger scale, more specialist farm businesses.

Compaction risk from grassland system is extensively reviewed in Clarke et al. (2008).

### A1.5.1 Larger machines and increased work rates

With continued modernisation of agriculture, the unit sizes of farm machinery have increased-tractors are more powerful and work rates have increased significantly.

Figure A1.11 shows that sales of agricultural tractors peaked in 1990, partly reflecting a period of relative profitability. The drop in sales during the 1990s is explained by the declines in real prices and subsidies for agricultural produce and a fall in farm profits during that period. Structural changes during the 1990s led to a fall in farm numbers as farms amalgamated into larger units and the use of machinery sharing and contractors became more common. Throughout the period, the average power per tractor unit increased continuously, so it is now 95kW, although the size of tractor units tends to be greater in the arable compared to the livestock sector, and on the larger arable farms (above 200ha).

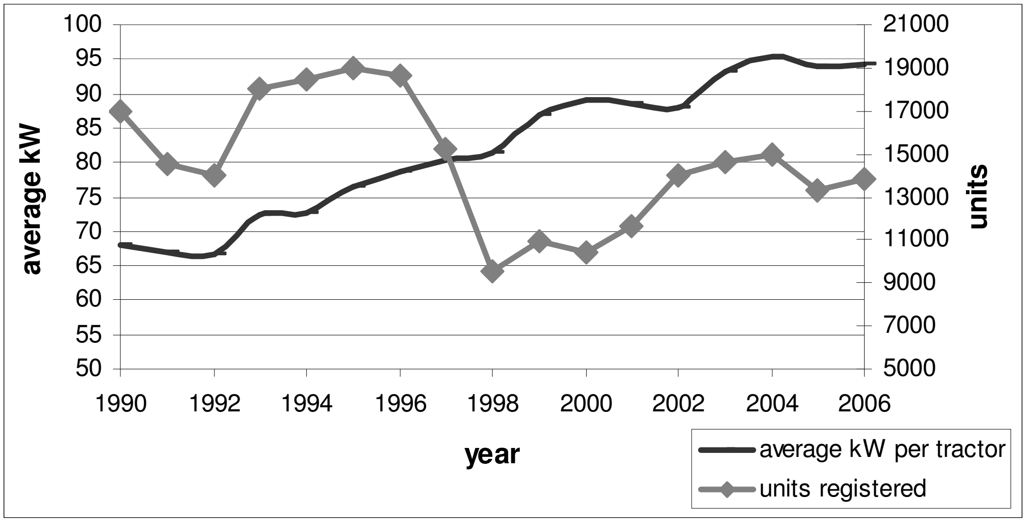



**Figure A1.11 UK Agricultural tractor registration (above 40kW) (Source: Agricultural Engineers Association, 2007)**

Table A1.1 shows the typical engine rating of agricultural tractors and the average working rates for common field operations over a 40 year period . The average work rate (ha/hr) has increased in parallel, typically by a factor of three, for all field operations as technological advances in tractor size and equipment design have facilitated greater working widths and speeds.

**Table A1.1 Changing working rates for standard field operations 1968-2008**

| | 1968 | 1977 | 1987 | 1997 | 2008 |
|---|---|---|---|---|---|
| Typical kW 'ploughing' tractor | 50 | 85 | 95 | 120 | 140 |
| ***Average working rates (ha hr$^{-1}$)*** | | | | | |
| Ploughing | 0.20 | 0.25 | 0.41 | 0.75 | 0.75 |
| Deep ploughing | 0.14 | 0.16 | 0.25 | 0.44 | 0.44 |
| Heavy disc | 0.49 | 0.56 | 1.00 | 1.25 | 1.25 |
| Disc harrowing | 0.49 | 0.69 | 1.38 | 1.50 | 1.50 |
| Power harrowing | 0.81 | 0.81 | 0.75 | 1.13 | 1.25 |
| Rolling – ring | 1.42 | 1.44 | 1.75 | 1.75 | 1.88 |
| Fertilisation | 1.42 | 1.50 | 1.88 | 2.50 | 3.75 |
| Drilling – cereals | 0.81 | 1.25 | 1.50 | 1.50 | 1.75 |
| Spraying | 1.00 | 1.00 | 1.75 | 3.75 | 3.75 |
| Combine harvesting – cereals | 0.57 | 0.88 | 1.00 | 1.00 | 1.00 |
| Sugar beet harvesting | 0.12 | 0.10 | 0.31 | 0.44 | 0.44 |
| Potato harvesting | - | 0.06 | 0.10 | 0.10 | 0.10 |

*Source: Farm management pocketbooks (Nix, 1968; ibid, 1977; ibid, 1987; ibid, 1997; ibid, 2008)*

Table A1.1 and Figure A1.12 show that greatest increases in work rates have been in power-intensive operations such as ploughing and cultivation practices. These operations are now done more quickly (in terms of ha/hr), mainly because of much wider equipment, and to a lesser extent increased working speeds. . In the late 1960s, a reversible plough had 2 to 3, 14'' furrows (350 mm) pulled typically by a 50-60 kW tractor. A semi-mounted plough with 4 to 6 furrows was pulled by 90kW hybrid four wheel drive units (Nix, 1968). Now a reversible plough has typically 5 to 6 furrows pulled by a 130 kW power unit. This is the common ploughing combination for most arable farms. At the largest scale, a semi-mounted plough of 7 to 9 furrows uses a 200 kW tractor (Nix, 2007). Four-wheel drive tractors are now ubiquitous.

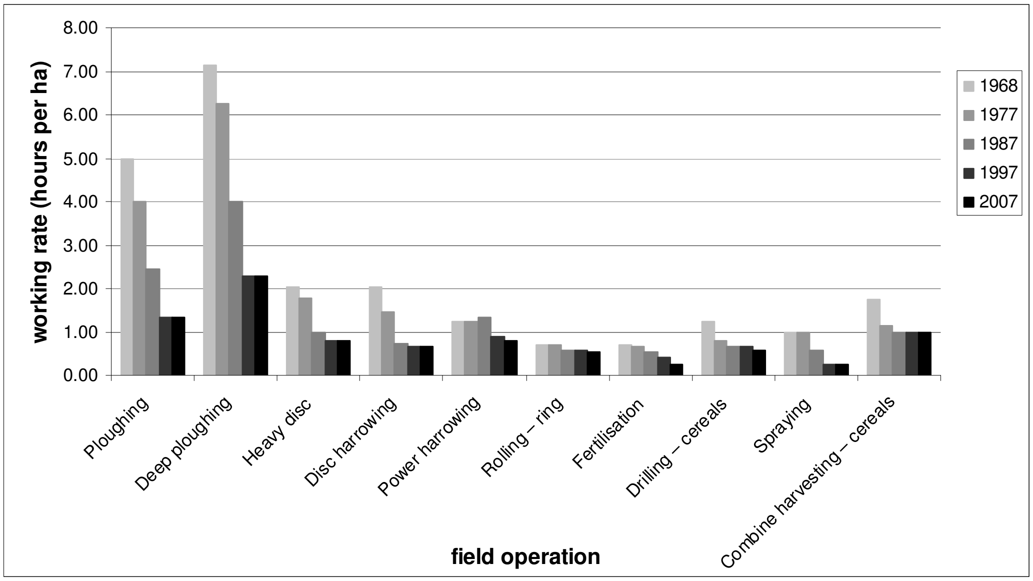



**Figure A1.12 Working rates for common field operations in agriculture, 1968-2007**

### A1.5.2 Machinery size and soil compaction risk

Larger machinery is associated with heavier equipment and an increasing risk of soil compaction (Ansorge and Godwin, 2007), leading to enhanced field runoff. The risk of soil compaction is high when the pressure on the soil surface caused by field travel is greater than the bearing capacity of the soil, as determined by soil type and soil wetness. Compaction can also arise at the surface from wheel slip and the action of animal hooves and, in the subsurface, from ploughing (with the production of plough 'pans').

Heavy equipment, exacerbated by wheel slippage on power units, can increase the risk of soil compaction, especially when soils are wet (Alakukku et al., 2003). Furthermore, additional passes by field equipment can increase compaction risk, including when there is repeat travel on headlands.

However, the relationship between bigger machines and a higher risk of soil compaction and thus reduced infiltration is not straightforward. Firstly, bigger farm machinery tends to have bigger tyres, allowing the increased weight to be spread across a larger surface area such that ground pressures have probably not changed proportionately. Furthermore, the increased width of the machines reduces the amount of travel in the fields. Secondly, increased working speeds, facilitated by greater operator comfort, can enable work to be carried out at the optimum time, avoiding potential soil damage due to untimely operations.

### A1.5.3 Compaction and Timing of operations

Although there has been a decline in total field traffic, in some cases there may be increased risk of soil compaction due to heavier machinery, especially if field operations are timed inappropriately: that is, when field operations coincide with unfavourable weather conditions and/or wet soil conditions. The need to maintain high levels of seasonal machinery usage in order to achieve economies in the use of expensive equipment, may encourage working in less than ideal conditions, especially when contractors are attempting simultaneously to meet the individual demands of many clients.

Some minimum tillage systems are particularly sensitive to soil wetness conditions, especially for generating soil 'tilth' that is suiTable Afor crop establishment. Larger and therefore heavier equipment facilitates higher work rates, but this advantage may be lost if adverse soil conditions require remedial operations to offset compaction.

The move to minimum tillage has generally led to earlier post –harvest cultivations, seed bed preparation and crop establishment, by up to 14 days in the autumn period, and slightly later cultivation of overwintered stubbles in the spring.

### A1.5.4 Use of Contractors

There has been a significant increase in the use of contractors for most field operations as farms seek economies in the use of labour and farm machinery, as well as to complement their own workforce to deal with peak periods of work. Contractors tend to use larger, heavier and in some cases more technologically advanced equipment, including low ground pressure tyre and track systems. Such systems extend the periods for field work, but there may be instances when work is carried out when field conditions are less than ideal, with consequences for compaction risk.

### A1.5.5 Machinery and Field size

The increase in machinery size has been accompanied by an increase in field size and the removal of boundary features such as hedgerows as well as in-field features such as ponds in order to increase the 'field efficiency' of farm machinery, improve work rates and reduce average machinery costs per ha.. Field sizes in mainly arable areas commonly exceed 15 ha, and often 30 ha, whereas in predominantly livestock areas they tend to be around 8 ha or less.

### A1.5.6 Major Field operations

Table A1.2 summarise the main characteristics of farm machinery used for cultivations and for cereals and related combinable crop production in England on mainly arable farms of about 200 ha or more. On smaller farms, tractor and implement sizes are typically about 25% lower than those shown in Table A1.2.

**Table A1.2 Characteristics of farm machinery 2007: Typical farm machinery for cultivations and for cereal and related combinable crop production in England. Based on typical widths, speeds and field efficiencies for farms of 200ha and above. Smaller farms typically have tractors and equipment that are 75% of sizes shown**

| **Operations** | **Tractor - kW** | **Equip Type/brand** | **Equipment Size - m width** | **Work rates ha hr$^{-1}$ (Nix)** | **Typical Work rates ha hr$^{-1}$ *** | **Comment, eg typical ranges of type/size,** |
|---|---|---|---|---|---|---|
| **Cultivations** | | | | | | |
| *Plough based* | 130-140 | Agco, John Deere, New Holland, Case | 1.75 | | | Smaller units: 100 kW and 3 m plough. Large units: 240 kW 7-9 furrows |
| Plough | | Kverneland, Lempkin, Dowdeswell | 4 | 0.63 – 1.13 | 2.04 | |
| Power harrow | 130-140 | Kuhn | 4 | 1.25 – 1.88 | 2.31 | |
| Disc | 130 | Samba, Kverneland | | 1.5 – 2 | | |
| Other | | | | | | Subsoiling every 3-4 years |
| *Reduced tillage* | | | | | | |
| Tine | 140 | Vadestad, Simba | 4 – 4.6 | 1.5 – 2.25 | | Smaller units:: 100kW |
| Disc/tine/press | 140 | Simba | 4 | | | |
| Other | | | | | | |
| **Crop establishment** | | | | | | |
| Drill / broadcast | 100 | Vadestad, Simba | 4 | 1.75 – 2.25 | 1.63 | Smaller units : 75kW |
| Roll/press | 100 | | 5 | | 3.4 | |
| **Crop care** | | | | | | |
| Crop protection – sprays | 100 | Bateman, Horseman, Hardy, Knight | 24 | 3.13 – 9.38 | 12 | |
| Crop fertilisation | 100 | KRM | 24 | 1.88 – 7.5 | 12 | Spinning disc |
| Other | 150 | | 24 | | | Self propelled sprayer |
| **Harvesting** | | | | | | |
| Harvest (combine) | 280 – 420 | Class Medion / Lexion | 5.5 / 7.5 | 0.75 – 3.25 | | Typically 6m |
| Carting | 100 | Ansurge | | | | Up to 15 tonne |
| **Typical Combination operations** | 140 | Tine, disc and press<br>Tine , disc, drill and press | 4 | 1.75 | | |

***Primary Cultivations***

Defra's The Farm Practices Survey (Defra 2001, 2004, 2005) reveals that the mouldboard plough remains the most commonly used implement for primary cultivation of arable land. There was a move towards reduced tillage on medium and light soils in the late 1970s, but this was halted somewhat by the banning of straw burning that encouraged a return to ploughing for straw incorporation. More recently, there has been a decrease in mould board ploughing in favour of tine and disc cultivations, partly associated with a return to straw baling and chopping of straw after combining (Figure A1.13).Recently, more farmers have also adopted reduced tillage as a means of reducing labour and machinery costs compared to conventional tillage, with potential to save on energy consumption.

On some soils, a 'no till', 'direct-drilled' crop production system may be feasible. A main objectives of no-tillage is the improvement of the soil structure through increased soil organic matter. However, studies so far have shown contradicting results when comparing the effect of no-tillage with conventional tillage on soil compaction (Carof et al., 2007). No-till also has potential to reduce energy consumption, advantageous under current energy prices. It may be necessary to undertake deep ploughing every 4 years or so to alleviate residual compaction.

Minimum and no–till 'Gantry 'systems (12 m) are seen by some as a potentially feasible futuristic approach to energy saving and soil enhancing production. Although commercially launched in the early 1990s, take up was very limited, mainly because they appear incompatible with the dominant, well-established tractor based systems.

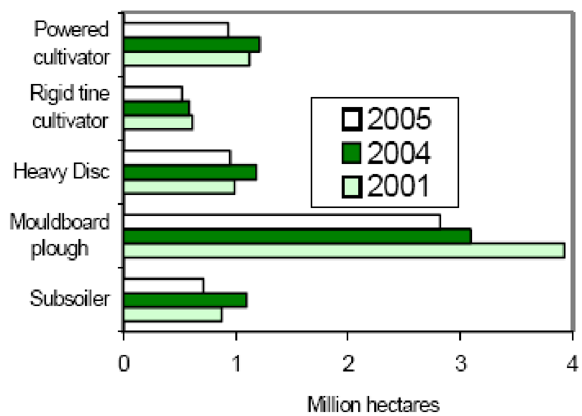



**Figure A1.13 Primary cultivation areas using different implements (Source: Defra, 2006)**

***Secondary Cultivations***

Secondary cultivations usually involve tine and/or disc implements, with power harrows used after mould board ploughing to break soil clods where required (Figure A1.14), typically using two passes but this depends on soil type and weather conditions. There is increasing use of combinations of cultivator/drills and rollers, to save time and expense.

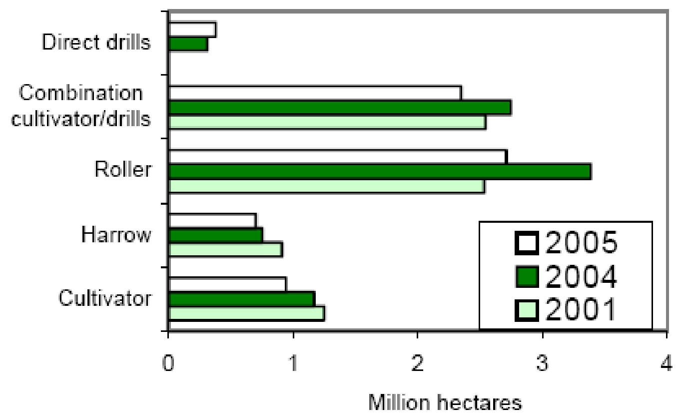



**Figure A1.14 Secondary cultivation areas using different implements (Source: Defra, 2006)**

***Crop establishment***

Crop establishment for cereals usually involves mechanical or pneumatic drills, with a tine or disc coulter to open the seed bed, depending on soil conditions. This operation is very sensitive to soil wetness conditions as they affect drilling and travel in the field. There has been a general tendency to move drilling of autumn sown cereals forward by about 2 weeks. More recently early sowing of oilseed rape has been achieved by broadcasting from the rear of the cereal harvester, followed by minimum cultivation.

Root crops involve deep cultivations, ridging and tuba or seedling placement. Ridges which run down the hillslope are liable to increase runoff and erosion: contour farming and blocking furrows to prevent run off can be practised.

***Crop fertilisation, spraying and tramlines***

There has been a 3 fold increase in work rates of fertilisers and sprayers over the last 40 years, associated with larger equipment and higher speeds. The most common method of fertilisation is the tractor mounted spinner broadcaster with loads of up to 4 tonnes and working width of 24 m to 42 m, operating from tramlines.

Spraying machinery has increased in line with tractor size, involving tractor mounted and trailed tankers, operating along tramlines. Specialist self propelled mobile sprayers are increasingly used by contractors, using pre-established tramlines in order to confine the area of compaction.

***Tramlines***

Tramlines, that is permanent routeways through a standing crop, were first adopted in the 1970s, particularly associated with increase in winter cereal cropping, and are now common place. They usually extend to 24 m and in some cases to 48 m centre spacings. These tramlines concentrate 'wheelings' in the field, reducing overall compaction, although they can provide unimpeded pathways for rapid runoff on hillslopes.

Chambers et al. (2000) found that wheelings contribute to the concentration of surface runoff and this could be reduced by setting up tramlines after winter cereals had emerged and trafficking was delayed or avoided in the autumn (Chamber et al., 2000). Most tramlines are now established at sowing by selectively blocking the spouts of seed drills to give the desired tramline spacings.

Withers et al. (2006) found that tramlines increased runoff by 46% on experimental plots compared with plots without tramlines on ploughed soils. However, tramlines did not result in a significant increase in runoff on soils with reduced cultivation. Establishing tramlines on dry soils reduced the risk of channelled runoff (Withers et al., 2006).

### A1.5.7 Forage machinery

Table A1.2 shows changes in labour and machinery requirements and work rates for forage over the last 40 years. The period saw an almost universal switch from hay making to silage making, involving precision chop and big bale systems. Larger and more sophisticated tractors and forage making and handling equipment, together with increased operating speeds, have reduced labour requirements per ha and tonne of grass forage by about 40%. Increases in tractor and equipment size for forage making are similar to that of arable.

Grass cutting typically involves a 75kW tractor. Precision chopping of silage or large bale (0.5t) machines commonly uses a 130 kW tractor, carried off on 5-8 tonne trailers. Single cut silage is usually taken in mid to late June, compared to early July for hay. Two cut silage usually involves cutting in early June and late July/early August. Harvesting operations require dry weather and ground conditions. Low ground pressure tyres are available for most silage making equipment.

**Table A1.2 Labour and Machinery requirements and Work rates for forage crops, 1968-2007**

| | 1968 | 1977 | 1987 | 1997 | 2007 |
|---|---|---|---|---|---|
| *Annual tractor hours per ha* | | | | | |
| Making hay | 15 | 14 | 12 | 12 | 12 |
| Making silage | | | | | |
| 1st cut | 15 | 14 | 12 | 12 | 12 |
| 2nd cut | 15 | 10 | 9 | 9 | 9 |
| *Labour requirements forage crops* | | | | | |
| Grass mowing (hours per ha) | 2.5 | 2.2 | 1.4 | 1.2 | 1.2 |
| Hay yield (tonnes per ha) | 4.0 | 4.0 | 5.5 | 5.5 | 5.5 |
| Total labour hay (hours per ha) | 18.3 | 14.9 | 13.2 | 11.1 | 11.1 |
| Hay labour per tonne (hours) | 4.6 | 3.7 | 2.4 | 2.0 | 2.0 |
| Silage yield (tonnes per ha) | 15 | 15 | 17 | 17 | 17 |
| Total labour silage(hours per ha) | 16.3 | 14.7 | 10.2 | 9.5 | 9.5 |
| Silage labour per tonne (hours) | 1.1 | 1.0 | 0.6 | 0.6 | 0.6 |

*Source: Farm management pocketbooks (Nix, 1968; ibid, 1977; ibid, 1987; ibid, 1997; ibid, 2008)*

### A1.5.8 Machinery, compaction and runoff

There are no automatic links between the observed changes in machinery systems, soil compaction and the probability of runoff from farm land. Larger and heavier equipment can lead to greater compaction, but much depends on the load bearing strength of soils at the time of the operation which is critically influenced by wetness. Wetter soils are weaker and more liable to surface damage and compaction, whether by arable, forage or grazing systems (Photo 1). The risk of compaction by farm operations can be offset by using low ground pressure tyres and changes to the selection (e.g. changes to minimum tillage) and timing of operations. It is not possible to generalise compaction risk, and related soil erosion and run off risk, without reference to contextual factors, especially soil texture, hillslope, and prevailing and antecedent climatic and soil wetness conditions. It is important, therefore, as part of a general appraisal of land use management, to judge whether current mechanisation practices are likely to cause increased damage to soils with consequences for runoff, and whether changes in practices could alleviate such risks.

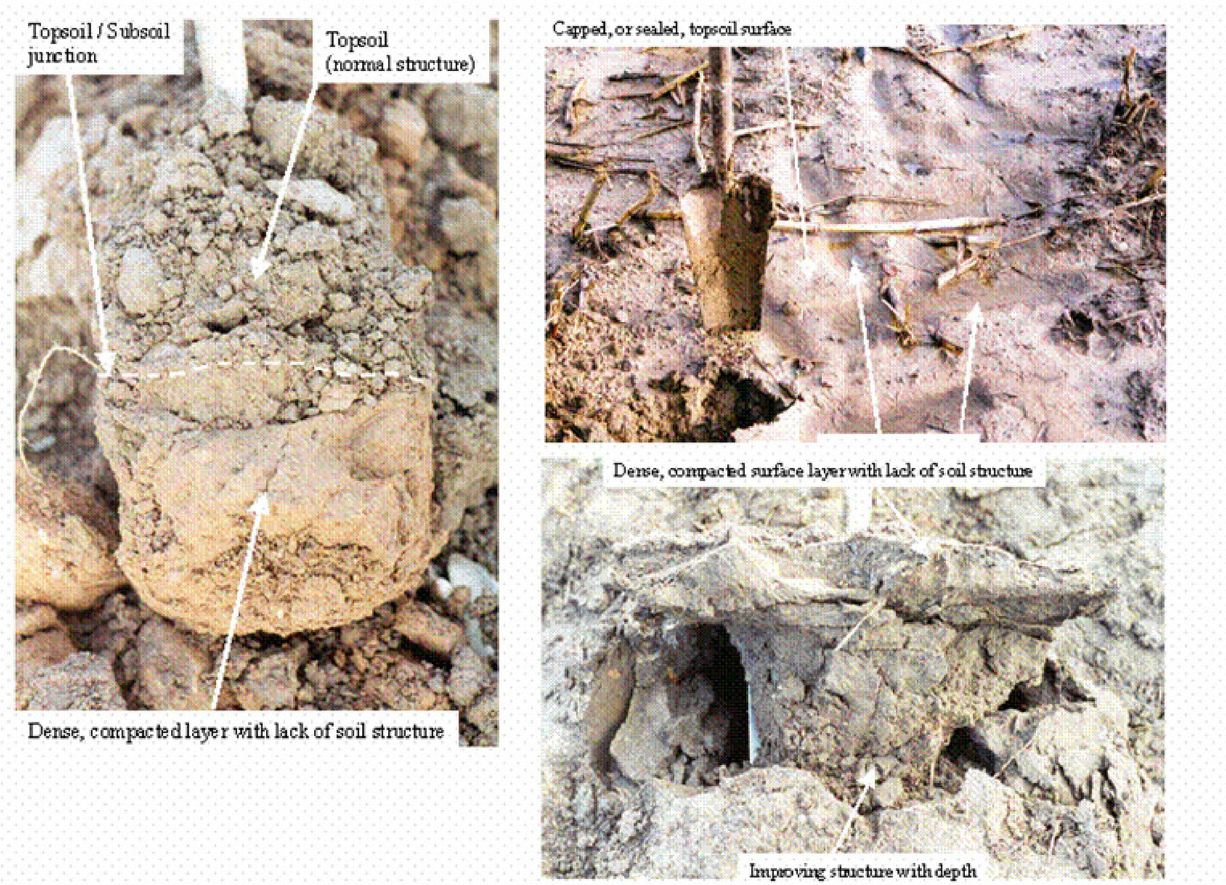



**Photo 1** Examples of changed soil hydrological properties caused by (left) compaction from ploughing, (upper right) capping of bare soil and (lower right) compaction by livestock (from Holman et al., 2002)

Table A1.3 identifies critical operations with a medium to high risk of soil compaction. The machines and equipment used on land under critical conditions can be adjusted to match the actual strength of the soil by controlling wheel or track loads and using low tyre inflation pressures (Alakukku et al., 2003). However, Ball et al. (1997) found that although reduced ground-pressure system successfully minimized compaction in grassland, it was less effective in an arable rotation. Good timing of field operations was thought to be a more effective way of avoiding soil compaction. Low ground pressure tyres do, however, extend the window of time over which operations can be carried out without damage.

**Table A1.3 Critical field operations for arable agriculture in the UK with risk of soil compaction**

| Critical field operation | Crop | Machinery affecting compaction risk | Season: actual timing depending on local conditions |
|---|---|---|---|
| Deep cultivation after subsoiling | All | Tractor | Autumn |
| Ploughing, including plough 'pan' | Sugar beet, potatoes, cereals | Tractor – in furrow | Autumn |
| Harvesting and transport | First cut silage | Harvesters | Spring |
| | Maize, sugar beet, main crop potatoes | Trailers | Autumn |
| Fertilisation and spraying | All | Tractors / tankers | Autumn |
| | All | Self propelled sprayers<br>Lime spreaders | Spring |
| Bed forming / cultivation | Vegetables | Tractor | Winter? Spring |

Adapted from: Chamen et al. 2000, cited in: Alakukku et al., 2003; Holman et al., 2003

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