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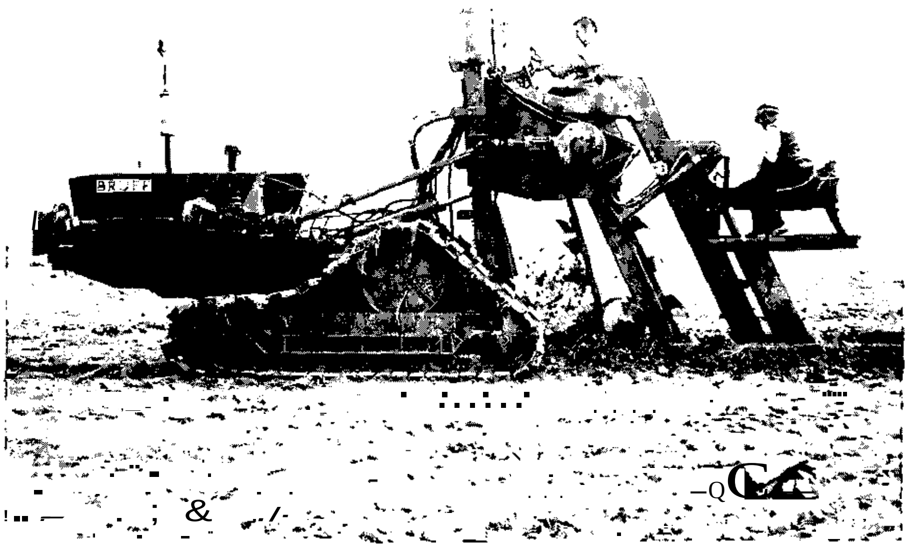
SAWMA VIEWPOINT

In thinking back over the last three months to the Royal Show, a Cereals Demonstration and Information Unit tour to study cereal growing in central France with some top British farmers, a couple of Ministerial reports and various interesting conversations I am of the opinion that the Association's technical dissemination work will become of increasing importance as farmers' minds turn more and more towards soil management.

The indications for this change may perhaps be unrelated at this time but I trust my reasoning is correct. On the cereal tour I had the opportunity of talking to growers and it was obvious that their main obsession was sprays and crop protection. The spraying regimes were impressive by the protectiveness of the policy imposed on the crop yet the crop establishment systems were varied to the point of confusion. Anything from direct drilling to conventional methods were used and even then these men were dissatisfied and convinced that crop yield was not at the maximum.

Is it possible that soil management to produce the right conditions for root growth may be important? Does the absence of waterlogging, the ease of root exploration and good nutrient availability really mean that plants grow better and possibly stay healthier or withstand disease attack longer? The answer must undeniably be YES. Two pointers towards this which immediately occur to me. Firstly, direct drilling, which I am pleased to see Massey Ferguson have now committed themselves to by the



production of the MF130 Drill, (Incidentally this technique was advocated as an important energy saver in the Little NEDO report), shows, by the work Letcombe Laboratory have done and now ADAS are developing to have a beneficial effect on soil structural stability, the earthworm population aids root penetration and that water stress is therefore less likely to occur as roots go deeper.

John Muirhead, a thoughtful and highly successful farmer has arrived at the same or perhaps better root growth conditions after many years of careful work. On his soil type he has developed a machine which stirs soil to depth (see Farmers Weekly July 7th if you missed him at the S.A.W.M.A. Spring Conference) and is achieving some highly impressive results. His method is attracting a lot of attention but I am sure he would be the first to point out that what he is doing is right for his soil type and may not be proper all over the country.

Both direct drilling and deep stirring allow water to move down through the soil more quickly to drain depth. Drainage contractors will certainly be encouraged if these methods are really here to stay as there is nearly always a water surplus between rainfall and evapotranspiration. I also hope that all farmers take a little bit more notice of drainage maintenance and their soils.

It is very pleasing to note that at least one British company is prepared to make a substantial investment in agricultural engineering after the Department of Industry Study 1978 as you will see below.

BRUFF EXPAND

The Bruff expansion programme is in two forms, the product range is being increased to include Trench Diggers which are complementary to the Trenchless Machines, and the first model in this range is the BH3, this being capable of digging a trench 5'9" deep and 5½", 7" or 9" wide.

The second part of the expansion is an enlargement of their manufactur-

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ing facilities. The factory floor-space has been increased by 25% and with the appropriate increase in tooling, this has provided by the production of both Trenching and Trenchless Machines.

Bruff has for many years been recognised as the leading manufacturer of Trenchless Drainage Machines, and, in fact, pioneered this system of land drainage. There is a comprehensive range of Bruff Trenchless Machines offered. The TG1, a low-priced unit drawn by a 10-ton winch which has a working depth of 3'6": the popular TG3 and TG3S models are mounted on a 120 h.p. 4-W.D. tractor and lay land drains to a depth of 5'6". The largest is the TG5 model and this is a tracked machine powered by a 240 h.p. engine. This machine can lay land drains to a depth of 7'0".

In addition to the equipment already mentioned Bruff offer a range of Gravel Trailers provided with a live drive to the trailer axle and the gravel discharge conveyor can deliver to either the right or the left-hand side.

So what is Sodium Bentonite –

I recently had a discussion on this material and its possible uses, which seem quite extensive, during the Royal Show.

Sodium Bentonite is a naturally occurring clay which has some remarkable properties. The most useful one is that by its molecular structure it is able to absorb water up to 15 times its own dry bulk. It is also an inert material. So what, I hear you saying.

Its main use is to seal reservoirs. This is done by mixing the bentonite with material from the reservoir sides and bottom to form a tilth. Add water and the particles separate out and seal all faults, pores and cracks in the reservoir. Because of its inert nature it is also possible to use this in slurry lagoons or wherever a sealing material or liner may have to be used.

SERVICES

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Soil Organic Matter

LIGHT LAND AND SOIL ORGANIC MATTER

A. E. Johnston and G. E. G. Mattingly, Rothamsted Experimental Station, **Harpenden,** Herts., have written this article summarising results which have been obtained during many years of experiments on light land at Woburn Experimental Farm. It describes changes in soil organic matter which have occurred under various **farming** systems and gives yields of both cereal and root crops grown on soils with different amounts of organic matter.

The history of the Woburn farm and the experimental programmes has been described in detail elsewhere'. Experiments were first started in 1876 by the Royal Agricultural Society and since 1926 the farm has been the responsibility of Rothamsted Experimental Station so that both cropping and manuring are well known for a 100 years.

The soils of the **farm** have already been described briefly' and in more detail elsewhere[2,3]. Here we discuss work on the lighter soils of the **Cottenham,** Stackyard and **Flitwick** series. Cottenham soils are freely drained and usually sand or loamy sand throughout the profile. Most of the sandy soils, however, are **classified** as Stackyard series. They are also freely drained but the surface 60 cm or more is usually sandy loam. **Flitwick** soils have the same texture and stone content as Stackyard soils but are less well drained.

Soil organic matter and soil structure

Soil organic matter is beterogeneous group of materials, the chemical and physical properties of which are still only partially understood, particularly the effectiveness of various fractions of soil organic matter in stabilising structure. In addition, soil organic matter releases plant nutrients, especially N, P and S, in forms available to plants as it decomposes. This process is referred to as mineralisation. These nutrients are often well distributed through the plough layer and may be released at times when they can considerably benefit growing crops. Organic matter also affects the water-holding capacity of soil.

The amount of organic matter in soil **depends** on the quantities of organic carbon **compounds** added and the rates of oxidation of these compounds and of existing soil organic matter. Both are affected by the farming systems practiced. When a **farming system** has remained unchanged for a very long period soil organic matter replaces equilibrium values which differ according to farming system, soil type and climate.

The amount of organic matter in soil is determined from the organic carbon content. Percentage organic matter equals %C × 1.72 because organic matter contains about 58% **C.**

Soil structure is a term which cannot be defined simply, nor is there any simple laboratory method of analysis which places soils in a soil structure classification which relates to the structural behaviour of soils in the field.

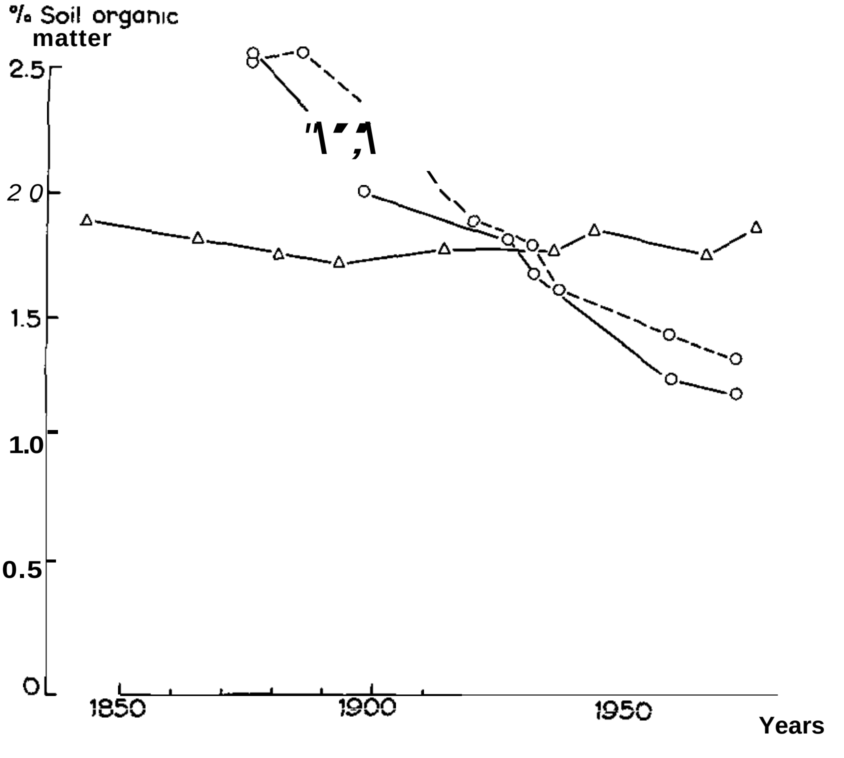
Plant roots need both air and water which both compete for the spaces or pores which exist in most soils. There are two concepts of soil structure. One considers the stability, spatial distribution and size of pores and field descriptions of soils which discuss cracking and root distribution often relate to this concept. The second considers the aggregation of individual particles into recognisable units or crumbs. Many laboratory measurements relate to the stability, especially to water slaking, of these crumbs. These two concepts are not mutually exclusive and soil organic matter helps to stabilise both crumbs and pores. Many aspects of the role of organic matter in soil fertility have been critically reviewed **recently**[4].

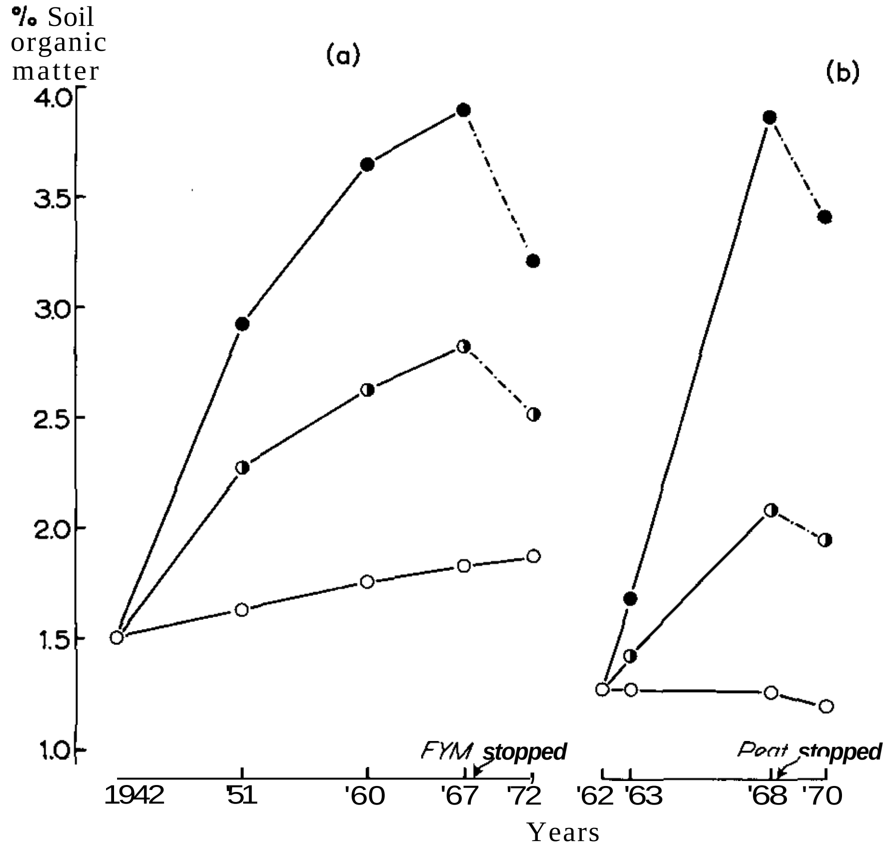
Organic matter and farming systems

The amount of organic matter in roil will always change towards a **steady** (equilibrium) value and some of the factors which affect **this** value have been mentioned above. This effect is well illustrated in *Fig. 1* which shows changes in soil organic matter on silty clay loam soils at Rothamsted and on sandy loam soils at Woburn. At both farms cereals have been grown continuously for more than 100 years on NPK-treated soils. Organic matter in the **silty** clay loam reached its equilibrium value, about 1.8%. by the 1880s and changed little during the next 90 years. In 1876 the sandy loam soil contained more organic matter (2.5%) than the clay loan but, under continuous cereals, organic matter fell steadily to 1.2% so that it is now less than in the clay loam soil. Fig. 1 also shows that farming on a traditional **4-course** rotation failed to prevent a very similar loss of organic matter from the sandy soil. In fact, the increase from organic matter added to soils during rotational cropping rather than continuous cereals was **remarkably** small (less than **0.2%**) on this sandy loam soil.

Effects of bulky organic manures

Appreciable increases in soil **organic** matter can result from applying large dressings of bulky organic manures **(5).** *Fig. 2a* shows the effects of FYM; 25 dressings of 37.5 t **FYM/ha** each year from 1942–1967 increased organic matter from 1.5 to **2.8%.** Doubling the dressing increased organic matter to 3.9%. It is





important to note, however. that once the FYM dressings ceased after 1967 organic matter **began** to decline. In fact, during **1967–1972,** the mean annual rate of decline was larger than the mean annual rate of increase during **1942–1967.** Soils which had received the single and double dressings of FYM lost 0.3 and 0.7% organic matter respectively in 5 years.

Fig. *2b* shows tne effect of adding 6 dressings of either 7.8 or 23.5 **t/ha** peat dry matter, about 23 or 69 **t/ha** fresh peat. Soil organic matter increased from 1.2% to about 2% with the smaller dressing and to 4.2% with the larger. Even with a comparatively inert organic material like peat, soil organic matter started to decline after 1968 when peat dressings ceased.

At the start of the experiment the soil contained 1.75% organic matter and Fig. 3b shows how this changed under the contrasted farming **systems**[7]. With continuous arable cropping about 0.2% organic matter (about 10% of the amount at the start) was lost **during** the first 18 years but **an** equilibrium **value** of **1.5–1.6%** organic matter appears to have been established. Where FYM was given once in **5** years organic matter decreased only a little and remained at about 1.7%; these FYM-treated soils now contain about 0.15% more organic matter than identically cropped soils without FYM dressings. It is important to note that an FYM dressing of 38 **t/ha (15 tons/acre)** once in five years (about as much FYM as might be available on many mixed **farms)** has such a small **effect** on total soil organic matter in sandy loam soils under continuous arable cropping.

Under the sequence of 3 year leys followed by 2 arable crops organic matter was increased by 0.4% (23% of the amount at the start) but it has taken 30 years (6 five-year cycles) to achieve this increase. Where FYM was given to one of the two arable crops in this ley arable system organic matter increased by 0.7% but it took 30 years to achieve this increase.

The increase in organic matter due to FYM in the ley-arable system was **0.3%,** which was double the increase (0.15%) due to the same amount of FYM under continuous arable (Fig. **3b).** This illustrates the fact that there is no standard effect of FYM or leys on soil organic matter. Another example of this is given in Fig. *2a* which shows the effect of annual dressings of 75 t **FYM/ha** from 1942 to 1967. In the first 10 years the average annual increase **in** organic matter was **0.14%,** in the last five years the increase was only **0.05%/**year. This was because the size of the increase diminishes as % organic matter approaches the equilibrium value.

The effect of leys varies in a similar way. A three-year ley once in 5 years increased soil organic matter by 0.4% in 30 years (Fig. 3b) whilst an unploughed ley down for seven consecutive years gave more than half of this increase, 0.26% organic matter (Fig. *3a*).

Large dressings of sewage sludge also increase soil organic matter5 but they may create **problems** by adding toxic metals to. the **soil.**

In an experiment made during 1965–1971 some soils received annual dressings of FYM and straw whilst on others organic matter accumulated under grass **leys**[6]**.** Total amounts of FYM and straw applied were 250 t and 54 **t/ha** respectively. On soils not under leys arable crops were grown except in the first year. The effects of these treatments are shown in Fig 3a. Organic matter declined on soils given fertilisers only although good **crops** were grown throughout the six years. During this period the largest increase in organic matter (0.47%) was from 250 t **FYM/ha.** Straw also gave a **measurable increase in organic matter but the annual dressing, and 9.0 t/ha.** was between 2 and 3 **times** as large as that which would be available for ploughing in after a good cereal crop. After 1970 additions of organic matter as FYM or straw or from leys ceased. Bv 1975–1976 soil **organic** matter had declined most where **it** had accumulated from dressings of FYM.

Effects of ley **arable** farming

In the 1930s much was written about the merits of ley arable farming. The need to increase the arable acreage during the war, and post-war economic pressures, have meant that ley-arable farming as originally conceived **has** never really been practiced on those soils and in those areas where intensive arable cropping is possible. In an experiment at Woburn continuous arable cropping has been compared with a ley and arable system since 1938 on a five-year cycle of three years ley, grazed grass or lucerne, followed by two arable crops. The three-year leys and the arable crops grown in the same years are referred to as treatment crops. Their effects are measured on the two arable crops that follow, usually called the 1st and 2nd test crops. Until 1967 38 t **FYM/ha** was applied to the fourth crop in the five-year cycle on half the plots. The dressings were **cumulative.**

Effects of continuous grass

The equilibrium value for organic matter under continuous grass is larger than that under continuous arable because the input of organic carbon compounds each year is larger. Unfortunately we have no experiments at Woburn in which there has been continuous grass for

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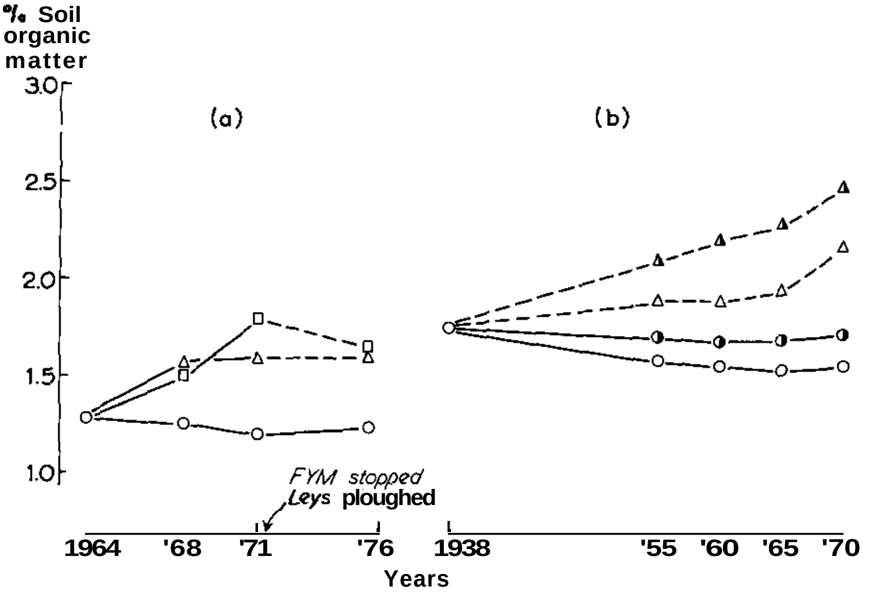
many years. However, soil from a small area of permanent grass on part of the farm now contains 4.6% organic matter; all arable and ley arable soils have much less organic matter than this. Work on Rothamsted soils suggests that it may take more than 100 years to reach the maximum organic matter content under permanent grass after seeding down old arable soils. However the results also show that the organic matter content will increase half-way towards the maximum value in about 25 years, because the rate of accumulation is faster in the earlier rather than the later years.



Organic matter and crop yields

Over 20 years ago, in a review of the importance of organic matter in crop production, Cooke and Garner[8] found little evidence from experiments in Britain that organic manures increased yields by more than the nutrients they contained. Yields of crops produced by fertilisers only, in a six-course all-arable rotation experiment at Woburn between 1930–1948, were above the national average and they stated "It is likely that fertilisers may be used to maintain crop yields at economic levels without organic manuring on similar kinds of light soils. Better crops would no doubt be grown by using organic manures as well where they are available". Cooke and Garner concluded that 'None of the modern experiments in Britain (in 1954) have tested organic manures in the presence of optimum fertilizer dressings, and until this is done the physical effects of the organic manures cannot be measured with certainty'.

It has, however, proved to be more difficult and time-consuming than anticipated to design experiments which provide incontrovertible evidence of the benefits of organic matter on crop yields and even more difficult to establish probable reasons for its value. In part this is because so many factors, (increased fertiliser use, improved varieties and better disease and pest control), interact to control crop growth. These effects are so large that average yields of most crops are now about double those grown in the 1930s and 1940s and best yields (wheat 7–8 t/ha, barley 6–7 t/ha, potatoes 60–80 t/ha) are much larger than those on which Cooke and Garner based their conclusions.

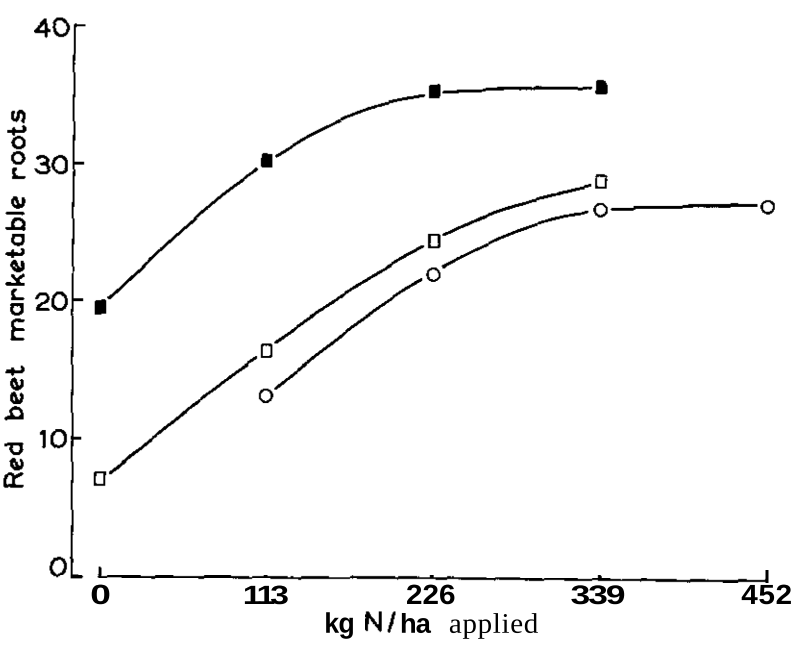
Results from some experiments comparing organic manures at Woburn during the past 30 years are given below together with a brief account of other factors (eg. nematode infestations, soil-borne pathogens, movements of nutrients into, and depletions from, the sub-soil) which complicate the interpretation of the results.

Benefits from bulky organic manures

The value of large dressings (37.5 and 75 t/ha) of farmyard manure, sewage sludge, a vegetable compost and a compost made from sewage sludge and straw were compared with inorganic N, P and K fertilisers in an experiment started in 1942 on market garden crops[8]. This experiment, and others in the late 1930s or early 1940s, were designed before the importance of balancing all major nutrients was appreciated or, indeed, before staff and rapid methods of chemical analysis were available to ensure it was done. At the start of the experiment, the amounts of plant nutrients in the inorganic fertilisers were much smaller than those applied in the bulky organics and, by 1961, the amounts and vertical distribution of available nutrients in the soils given organics or fertilisers were very different (Table 1).

The contrast between the amounts of P and K which move into the sub-soil from heavy dressings of either farmyard manure or sewage sludge are remarkable and make direct comparisons between these organic manures virtually meaningless. Further applications of P and K after 1960 lessened the difference between the amounts of nutrients in soils given many dressings and farmyard manure and *Fig. 4* shows yields of red beet, grown in 1966, on FYM and fertiliser plots.

Johnston and Wedderburn[9] commented that " — even after giving extra P and K to fertilizer plots the bicarbonate-soluble P and exchange-



able K in the soil were still larger on the FYM plots in 1966. Thus we still cannot be certain whether the extra 7.5 t/ha of red beet given by FYM plus most fertiliser N compared to the yield with most fertiliser is due solely to the P and K in the soil. However, it seems probable that some of the difference in yield is due to the extra organic matter in the soils of the FYM plots".

In a more recent experiment, designed to measure the value of farmyard manure, leys and other organic manures for agricultural crops, the same total amounts of P, K and Mg applied annually for 6 years in FYM, were applied, as fertilisers, on control plots[10]. The amounts and vertical ibutio ı of these nutrients in soils ı both FYM anc fertiliser-treated plots were very similar *(Table* I). Maximum yields of potatoes, winter wheat, sugar beet and barley (Fig. 5) were all greater (by 6–17%) in soils containing residues of FYM than on soils growing a sequence of arable crops.

Table 1. Vertical distribution of soluble P and exchangeable K in soils given farmyard manure, sewage sludge or fertilisers.
(Results in mg/kg air-dry soil.)

	Market Garden experiment, 1%1						Organic Manuring experiment, 1972/3			
Depth (cm)	Fertilisers only		Farmyard manure		Sewage sludge		Fertilisers only		Farmyard manure	
	P	K	P	K	P	K	P	K	P	K
0–23	103	111	178	377	166	102	69	253	70	244
23–30	93	101	149	366	150	88	60	282	63	302
30–46	79	93	127	361	97	84	26	202	21	222
46–60	78	83	108	309	78	67	16	127	15	143

Benefits from leys

The ley-arable experiment at Woburn has been described above and Fig. 3b shows % organic matter in these soils. The early results, when the amounts of fertiliser used were small, showed that yields of the test crops were larger after the grazed ley because nutrients applied to the ley were returned to the soil by grazing sheep and benefited the following arable crops. When the amounts of fertilisers were increased (particularly N) the benefit from conserving nutrients by grazing lessened. Yields of potatoes (the first test crop during 1950–1955) were often poorer after lucerne than expected because the amount of fertiliser K applied was less than that removed by the lucerne and so the potatoes were short of K. Fertiliser dressings were, therefore, increased and, before the first test crop is grown, extra fertiliser K is now applied, on the basis of soil analysis, to balance up the soluble K in all soils.

The unambiguous evaluation of benefits from leys in this experiment was further complicated by potato cyst-nematodes which developed in the all-arable cropping sequences. The first test crop was consequently changed to sugar beet and *Table* 2 gives yields of sugar between 1965–1967.

Sugar beet yielded a little more after a 3-year lucerne or sainfoin ley than after a 3-year arable rotation both in the presence and absence of a 38 t/ha dressing of FYM to the beet and even though much more fertiliser N was given to the beet following the arable crops. Table 2 also shows some benefit from FYM which was not obtained by fertilisers alone. Boyd", averaging yields for all amounts of N tested, concluded this effect "was small in the grazed ley and arable (hay) rotations (not given in Table 2) but considerable after lucerne (0.45 t sugar/ha) and after arable (roots) (0.70 t sugar/ha)".

The experiment shows, after more than 30 years of ley and arable farming at Woburn, that three-year leys have had surprisingly little effect on the yields of the arable crops, particularly cereals, that followed them, that cannot be explained by crop nutrition, particularly N supply.

Results from a more recent experiment *(Fig. 3a)* which tests the value of longer leys (7–8 years), suggest that they increase yields of potatoes, winter wheat, sugar beet and barley by 9–18% above the maximum yieids obtained in an all-arable cropping sequence *(Fig. 5)*. The extra organic matter derived from these long leys appears to last longer than expected and both grass-clover and grass with N leys, which behaved similarly, increased maximum yields of potatoes in 1977, 6 years after they were ploughed, by about 10 t/ha more than on soils under continuous arable cropping. It is not yet clear whether the greater benefits from the 7–8 year leys derive from physical effects on soil structure of the larger amounts of organic matter ploughed in, or their greater N content or because yields are poorer than expected on the impoverished soil (1.20% organic matter) which serves as a control in this experiment. The benefits from ley farming on A.D.A.S. Experimental Husbandry farms, which were most apparent in dry summers, have been attributed to a small increase in the available water capacity of soils following 3 year or 9 year leys[12].

Table 2. Effects of leys and farmyard manures (FYM) on sugar beet (1965–1967).
(Sugar yield, t/ha.)

Treatment	Fertilizer N applied, kg N/ha					Mean
	44	88	132	176	220	
Without FYM						
after lucerne	8.33	8.86	8.85	8.95		8.75
after arable		7.43	8.13	8.25	8.33	8.04
With FYM						
after lucerne	9.15	9.29	9.31	9.06		9.20
after arable		8.32	8.72	9.14	8.76	8.74

In 1968–1970 barley replaced sugar beet as the first test crop. Yields averaged less than 4 t grain/ha and were the same after a 3-year ley as after arable cropping when the correct amounts of N were given. Potatoes were again grown as the first test crop from 1971–1975 but this time a test of fumigation to control free-living nematodes, among other pests, was included. This was necessary because there were differences in the numbers of free-living nematodes which had built up under the farming systems tested. Potatoes consistently yielded more when they followed a grass ley or sainfoin than when following arable crops. Fumigation with chloropicrin and granular applications of aldicarb or, in two years, with dichloropropene and aldicarb increased mean yields by 8.7 t/ha. It was, however, impossible to test a range of N dressings so it is uncertain whether yields following arable crops would have increased to those after leys if more N had been given. The second test crop (winter wheat) from 1972–1976 measured any residual effects of fumigants to potatoes and also tested 4 rates of N. There was little benefit from leys or from fumigation.

Benefits from peat

Sedge peat, which is highly organic, has been used in several experiments

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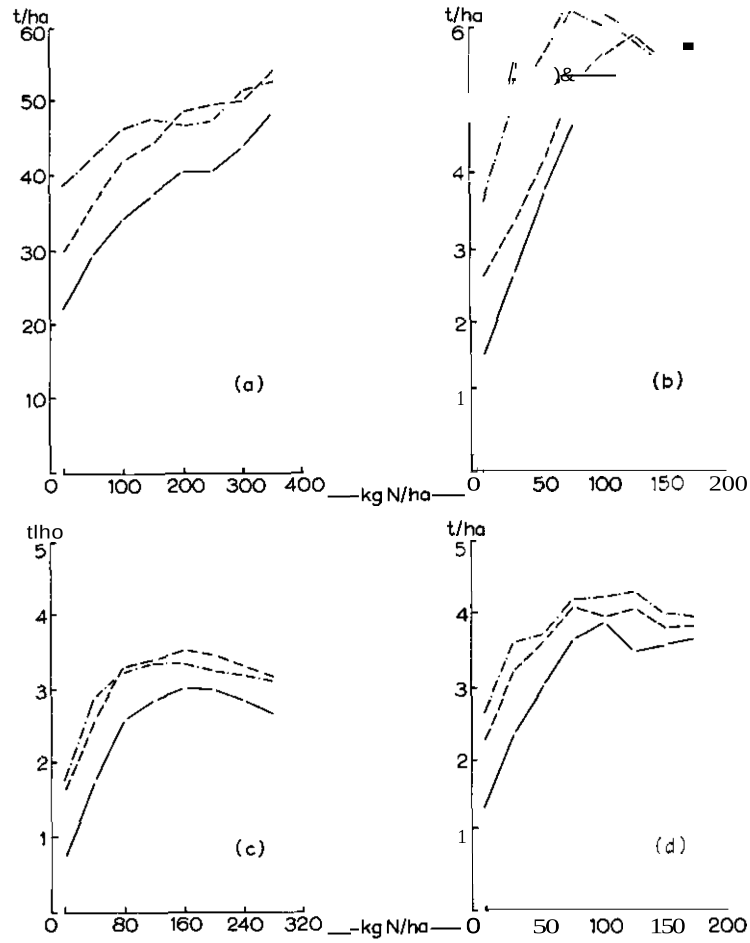

at Woburn to increase organic matter in soils. It contains negligible amounts of P and K (but some Mg) and the nitrogen it contains mineralises very slowly. A micro-plot experiment, started in 1963, tested four rates of application of peat (Fig. 2b). In the early years of the experiment carrots and red beer, grown with uniform N, yielded slightly more on plots containing the most peat than in its absence but the effects were small (5–10% increase). Potatoes grown in 1973 and 1975, with four rates of N manuring, consistently yielded better and used N fertiliser more efficiently on plots containing the most peat (Table 3). Peat appears to have little effect on the structural stability of sandy loam soils but in this, and other experiments, it appears to increase their water holding capacity and the efficiency with which nitrogen is used by crops.

Table 3. Effects of peat and N fertiliser on potato yields. (Means of 1973 and 1975.) (Total tubers, t/ha.)

Peat applied (t/ha)	Fertiliser N applied, kg N/ha			
	0	100	200	300
0	24	33	44	41
8	27	38	40	45
55	28	39	43	57
110	26	41	51	57
165	28	40	50	61

Benefits from green manuring

Dyke, Patterson and Barnes[13] have recently summarized results from many experiments on green manuring at Woburn. In the more recent ones, green manures (trefoil or ryegrass) were taken as catch crops. They were sown after lifting early potatoes to test their effects on following barley or they were undersown in barley before growing potatoes in the following year. *Table 4* shows the effects of short term green manuring of one or two crops of trefoil or ryegrass ploughed down, on yields of barley. Trefoil greatly Increased barley yields in the absence of N fertiliser; its effect declined as fertiliser N dressings increased. Ryegrass had little effect on yield.

Table 4. Effects of short-term green manuring* on yields of barley (1964–1967). (Barley, grain, t/ha, at 85% dry matter.)

Treatment	N applied to barley, kg N/ha				Mean
	0	38	75	113	
No green manures	1.70	2.70	4.01	4.55	3.24
Increase from					
Trefoil	+1.74	+1.58	+0.74	+0.30	+1.09
Ryegrass	+0.04	+0.24	+0.14	+0.26	+0.17

* One or two undersown crops of trefoil or ryegrass

The cumulative effects of long-continued green manuring with ryegrass were considerably greater and they state "although green manures, grown twice in successive years, do little more to improve yields than single green crops, long-continued green manuring has an appreciably greater effect and, when discontinued, leaves residues which increase barley yields for at least five years". Although the direct effects of trefoil (largely the release of nitrogen from the crop by mineralization) are greater than those of ryegrass the residual effect of ryegrass appears to last longer than that of trefoil, presumably because the carbon and nitrogen it contains are more resistant to microbial breakdown in soil.

Unfortunately in this experiment we cannot estimate changes in soil organic matter due to treatments because no soil samples were taken in 1934 at the start of the experiment. However, by 1961, soils with no organic manures contained 0.078% N. At the end of 25 years soils with green manures contained 0.010% more N, equivalent to about 340 kg N/ha, than soils without green manures. During the same period additions of straw (3.8 t/ha) in alternate years after the barley harvest increased soil N by 0.006% N. These increases may be compared with the effect of the-residues of nine dressings of FYM (25 t/ha) applied in alternate years between 1936 and 1953. In 1961 the increase in soil N due to these residues was 0.008%. Green manures therefore increase the organic matter in soil by more than the increases for small, but frequent, dressings of straw. Moreover, green manures, grown in autumn and winter between spring sown cash crops offer farmers a means of maintaining or increasing the stock of organic matter in their soils and of lessening dependence on fertiliser N without loss of production.

In some years, ploughing down green manures has improved yields of the crops which follow them more than can be achieved by any amount of N fertiliser applied as a conventional single dressing. The circumstances under which these large effects are observed. and the reasons for them, have not been fully investigated. It seems likely, however, that trefoil residues decompose slowly in moist soil and release significant amounts of nitrogen late in the season when fertiliser N, especially if applied in early spring, may have been leached from light land. Green manures are more effective in years when the rainfall in May and June is sufficient to keep the soil moist for most or all of the growing season and irrigation (Table 5) has increased barley yields at Woburn somewhat more with trefoil than without.

Table 5. Effects of irrigation (7.0–8.9 cm water) on yield of barley in the presence and absence of green manuring with trefoil.
(Barley, grain, t/ha, at 85% dry matter.)

	No trefoil	Trefoil
No irrigation	2.91	3.24
Irrigated	3.74	4.30

Conclusions and summary

1. Soil organic matter has decreased in all farming systems on light Land at Woburn and has approximately halved since 1876. Land farmed largely in a 4-course rotation contains only 0.2% more organic matter than land growing continuous cereals.

2. Annual additions of about 20–25 t/ha of farmyard manure (two to three times the present average usage in England and Wales) are needed to compensate for these losses.

3. Larger additions (38–75 t/ha) of farmyard manure, sewage sludge or composts have doubled the organic matter content of the soils in 20–25 years.

4. Three-year leys, followed by 2 years arable cropping have increased soil organic matter by about 20% and a three-year lucerne ley by less than 10%. Trefoil and ryegrass, undersown in barley, prevented the decline in organic matter in soils growing alternate crops of cereals over a period of 25 years.

5. Most of the benefits of organic manures can be accounted for by the nutrients they supply. In a few experiments red beet and potatoes appeared to grow better on soils containing more organic matter than on soils given only NPK fertilisers. Potatoes also yielded more on soils enriched with peat and given adequate amounts of N fertiliser than on soils not enriched.

6. Most of the benefits from a sequence of three-year grass or lucerne leys, followed by two arable crops, were accounted for by the nitrogen they released. Ploughing up longer leys (7–8 years in grass (+ N) or grass-clover) consistently increased yields of arable crops which followed them by more (9–18%) than could be attributed to the N they released.

7. Large dressings of peat (up to 165 t/ha) increased the organic matter in the soils and increased potato yields much more in the presence of much N fertiliser than when little or no N was given.

8. Trefoil undersown in a nurse crop and ploughed down in spring sometimes improved yields of following crops more than could be achieved by any amount of N fertiliser applied as a conventional single dressing. Green manuring maintains or slightly increases soil organic matter in soils and lessens the need for, and dependence on, fertiliser nitrogen.

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LIME, FERTILISERS AND THE SOIL

Dr. Dick **Russell** who is the Soil Scientist with A.D.A.S. at Bristol **gave this article as a** paper ***during the Soil Structure and Drainage Conference*** **held in March 1978.** Many **of the topics discussed will be of certain interest to you**

INTRODUCTION

Lime and fertilisers are clearly part of the overall fertility of the soil. At a Conference on Soil Structure and Drainage it is pertinent to enquire whether they have any specific effects on soil structure.

In effect farmers and growers are in business to catch sunlight and convert it into something saleable. Crop plants can be regarded as taking carbon dioxide, mineral nutrients and water, and, using the energy from sunlight, converting them into organic matter of various kinds, some of which can be sold or converted to saleable produce; eg swede and carrot roots, lettuce and cabbage leaves, apples, tomatoes and grain; eggs and bacon from grain, milk and meat from grass and so on.

The carbon dioxide comes into the leaves from the air but the water and mineral nutrients in solution come in through the roots. An efficient root system is therefore a basic requirement. Some horticulturalists grow crops in peat bags or in peat/sand composts and a few are trying the nutrient film technique but most people have to grow their crops in soil and soil conditions must be such that roots can function properly.

ROOTS

Roots have 4 main functions:1-to form an anchorage, 2-take in water, 3-take in nutrients in solution and 4-synthesis of some of the hormones and other compounds which control the growth of the whole plant.

Experimental work with nutrient solutions has shown that a small root system is sufficient for full growth provided the solution is pumped round so that the nutrients are very near the roots. In the field most nutrients move only slowly in the soil and so roots have to explore the soil for nutrients and for water. Soil conditions must be right so that they can do this.

An important factor is the pH of the soil. There is no ideal soil pH. Crops such as lucerne, barley and sugar beet need a pH above 6.5, whereas wheat and potatoes are less sensitive and will grow well when the pH is down towards 5. Similarly with a grass sward. An experiment we have in Devon has over several years shown that grass gives a very good response to nitrogen down to pH 5.5. If grass swards are maintained at a pH just below 6, the herbage will contain more manganese with benefit to stock health.

LIME USE

When a soil needs liming the amount required to raise the pH from say 5.5 to 6.5 will vary with the soil texture and with the amount of organic matter present. On the other hand more calcium is leached from soil when free lime is present and the rate of loss decreases as the pH and calcium carbonate drop.

So there are difficulties in calculating an overall national lirning need. However the hest estimate is around 3M t per year. From the end of the war until about 1970 more than this was used. Since about 1972 the annual use has not been sufficient to maintain the status quo. Most ADAS laboratories are reporting more acidity problems coming to their attention. Furthermore changing industrial technology is making the situation worse. Until about the middle nineteen sixties it was not possible to distribute pure ammonium nitrate, so such products as 'nitrochalk' and 'nitrashell' were on the market. So there was some lime applied when nitrogen was used. Nowadays a very high proportion of N fertiliser is ammonium- nitrate. Changes in steel making mean that less and less basic slag is available. This phosphate fertiliser does supply some lime.

In 1970 paragraph 242 of "Modern Farming and the Soil" states "We are dissatisfied with the amount of liming that is being done in many parts of England and Wales. Among the causes are lack of manpower and spreading equipment, the limited period in the year when arable land can be limed, and notably a decline in the numbers of contractors in some of the more remote areas. There should be a return to a liming policy on farms and regular testing of soils for acidity."

The situation is worse today and I must wave a large red flag about acidity. Regular soil analysis is surely an essential tool in modern farm management.

LIME AND SOIL STRUCTURE

As well as correcting acidity, calcium carbonate can stabilise soil structure. This is seen naturally in the chalk areas and on the Cotswolds.

In Belgium, workers at the Agricultural State University at Ghent observed that there was less compaction and deterioration of soil structure in their soils (very fine sandy loams, silty loams and silt loams) when calcium carbonate was present. They set up some experiments using sugar beet waste lime at from 50 to 100 t/ha. These treatments had a noticeable effect on soil structure.

In the early nineteen seventies our colleagues in the Eastern region set up a microplot experiment at Anstey Hall, Trumpington, Cambridge. They used 3 soils from different parts of the region and applied by-product gypsum, sugar beet waste lime and polyvinyl alcohol as treatments. The plots were sown with Italian rye grass and yields measured. Various soil structure measurements were also done.

Polyvinyl alcohol and sugar beet waste lime produced benefits in soil structure and grass yields were increased over control. Even though the soils were loosely packed the treatments increased permeability.

At about the same time a field experiment was started at the Norfolk Agricultural Station. This involves a 3 year ley compared with 2 arable rotations of sugar beet, winter wheat, spring barley; and sugar beet, winter wheat, 1 year ley. All these are followed by a test rotation of sugar beet, spring barley, potatoes. ***(Table*** 5). 50 t/ha of FYM is applied to the sugar beet in the treatment and in the testing rotation and 125 t/ha of sugar **beet waste lime is appl** to the sugar **beet in the treatment r** There was a phased entry over 3 years. Varying rates of nitrogen are used.

Sugar beet following the waste lime has been successfully grown in all 3 phases of the treatment rotation. Boron deficiency was a serious problem in 1976 when top growth restarted following the drought. So far the experiment has shown that waste lime from the sugar beet factory can improve the soil structure but it has variable, sometimes positive and sometimes negative, effects on yields. Waste lime also contains some N,P and K.

At present it is only possible to keep an open mind on this. There is some benefit on soil structure but not always on yields. In areas where waste lime is not available treatments could be costly. Furthermore there is always the possibility of induced trace element deficiencies.

My colleagues at Starcross have

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TABLE 5

EXPERIMENT AT NORFOLK AGRICULTURAL STATION

Year	Treatment Rotations		
	1	2	3
I	Ley	Sugar Beet	Sugar Beet
2	Ley	Winter Wheat	Winter Wheat
3	Ley	Spring Barley	I year ley
	Testing Rotation		
4	Sugar Beet		
5	Spring Barley		
6	Potatoes		

done some laboratory work under the auspices of the Regional Soil and Water Management sub-committee. They mixed sub-soil from the Tedburn series containing *47%* clay and *38%* silt with various materials at differing rates. Ground limestone, burnt lime, slaked lime, cement and basic slag were used. Burnt lime, slaked lime and cement produced beneficial effects on soil structural stability as measured by the dispersion ratio technique.

In this method *25* g of soil are dispersed gently in water and another *25* g vigorously treated in a solution of calgon. The ratio of the amount of sediment produced in each case gives a measure of soil structural stability. In general terms the lower the ratio the more stable the structure. Slaked lime is the best material to handle but cement looks attractive on cost grounds. ***(Table*** 6.) The thought behind this work is that it might be possible to incorporate one of the additives while drainage work was in progress and so provide a stable layer above the drains. This could perhaps provide sufficient hydraulic conductivity to avoid the-cost of porous backfill. At present we are searching for a suitable site to follow up this in the field.

TABLE 6

STABILIZING SUB SOIL (STARCROSS)

Materials mixed at M kg per tonne of soil

Material Mixed with Soil	Dispersion Ratio	Approximate cost £ Per Tonne of Soil	Per Metre Run.
Original subsoil	41		
Ground limestone	27	0.19	0.07
Burnt Lime	5	1.92	0.77
Slaked Lime	5	2.11	0.84
Cement	7	1.54	0.62
Basic Slag	25	2.69	*1.08*

'Assuming approx 75 cm depth and 20 – 25 cm width of trench

GYPSUM

At the Anstey Hall experiment gypsum, which is calcium sulphate (Ca $SO_4 2H_2O$) did not benefit soil structure. This material is recommended for use in reclaiming soils which have been flooded by sea water. In this connection the beneficial effects are well known. The calcium from the gypsum replaces sodium in the soil to reform the normal calcium clay-humus complex.

In the mid nineteen fifties a series of experiments was set up in the eastern part of the country testing by product gypsum and *2* rates of gypsum itself on heavy textured soils that had NOT been flooded by sea water. Only transient benefits were observed. During ***1923-1937*** some experiments were run from the Midland Agricultural College using gypsum on various crops. No benefits were observed. Cooke and Williams reported that *25* t/ha of gypsum at Saxmundham, a notoriously difficult soil, reduced bulk density and the force needed to push a penetrometer into the soil 1 year after application. There was doubt as to how long the effect would last. Thus in this country there is no benefit from using gypsum except when reclaiming soils that have been flooded by sea water.

FERTILISERS AND SOIL STRUCTURE

It is not to be expected that fertilisers will have a direct effect on soil structure but there could be indirect ones. Organic carbon is important in soil structure. Carbon is lost from the soil by oxidation to carbon dioxide. Cultivations increase such losses whilst crop residues can increase carbon. Leaf cover from vigorous good crops can protect the soil from the impact of raindrops. Roots grow through the soil searching for nutrients and eventually they die and are decomposed leaving pores in the soil. Organisms breaking down roots produce organic substances which stabilise soil structure. Roots will proliferate in soil regions rich in nutrients and the beneficial effect of phosphorus in particular on root growth is well documented. Nitrogen fertilisers alter the root shoot ratio and most of the effect of nitrogen is seen in the shoot. Roots grow proportionately much less so that there are less roots than one might expect from yields of above ground parts. Grass roots will improve soil structure but they must be vigorous and growing well and this means with adequate nitrogen.

The meadow hay plots in the field "Palace Leas" at Cockle Park to the North of Newcastle are still in being after more than ***80*** years. A single hay crop is taken and then animals are allowed to graze over the whole field. Treatments include FYM, N, P, K, NP, PK and NPK.

Professor Arnold and his colleagues at the University of Newcastle upon Tyne have recently done some more work on the soils of clay loam texture, from the various plots.

The different treatments have produced a range of pH values on the plots. The bulk density of a soil is one measure of its physical properties. The more dense a soil the less easily can roots grow through it. The bulk density of the soil from the plot receiving slag is less than on the control plot and considerably less than soils under some of the other treatments. There is clear visual evidence of variation from plot to plot in drainage of the surface soil. This is probably a reflection of the differences in bulk density. There may be some effect of the lime in the basic slag but in general the effects are indirect as a result of better growth of roots when phosphorus is applied to a soil naturally low in that element.

At Rothamsted over ***130*** wheat crops have been harvested from "Broadbalk" and over ***120*** barley crops from "Hoosfield". Recently workers there including, among others, Mr. A. E. Johnston and Dr. Jenkinson have been looking critically at soils from these plots. During this long period NPK fertilisers ***(Table 7)*** trebled the yield of both grain and straw on Hoosfield but there was very little difference in the amount of organic carbon present in the soil or in the bulk density after more than ***110*** years of differential fertilisers. There were slightly greater differences in Broadbalk ***(Table 8.)***

Thus the use of fertilisers does not seem to have much effect on soil structure. On the other hand they can partially overcome the effects of poor structure. A few years ago we had a nitrogen on barley experiment on an Evesham series soil in Somerset. At one point in the season when the soil

TABLE 7

ROTHAMSTED HOOSFIELD BARLEY

Treatment	Unmanured	PK	NPK	FYM
Mean Yield (t/ha) 1852– 1963				
(a) Grain	0.88	1.32	2.46	2.98
(b) Straw	0.99	1.46	2.84	3.59
Mean Yield (t/ha) 1964 – 1966				
1 Plumage Archer				
(a) Grain	1.03	1.56	3.31	4.59
(b) Straw	0.58	0.87	2.44	3.59
2 Maris Badger				
(a) Grain	1.04	1.18	4.92	5.00
(b) Straw	0.40	0.48	4.09	3.85
Soil Organic Carbon (t/ha 0.23 cm)	26.5	28.8	25.2	86.8
Bulk Density g/ml	1.51	1.50	1.55	1.29

was rather moist some farm equipment was transported several times across the ends of the plots. At harvest time the soil was observed to be compacted and it was possible to harvest the area separately from the rest of the plots. The yields *(Table 9)* show that while extra nitrogen can help overcome the effects of poor soil conditions, there was a much more worthwhile response to nitrogen in the uncompacted soil.

TABLE 8

ROTHAMSTED BROADBALK WHEAT

Treatment	Organic Carbon (t/ha) To 23 cm in soil	Organic Carbon (t/ha) Harvested in crop (grain plus straw) each year
Unmanured	26	1.4
Inorganic Fertilisers	30	3.2

In some experiments done in the Northern region on poorly drained soils our colleagues found some response to nutrients by barley especially to N. However the yields were low and the poor soil conditions were a dominating influence.

Workers from the Field Drainage Experimental Unit found at Layer Breton that an extra **30 kg/ha** of N appeared to compensate for poor drainage. In these conditions roots cannot function fully effectively because of shortage of oxygen in the soil. In general it would seem that extra nitrogen can, to some extent, compensate for poor soil conditions and poor drainage.

On the other hand nitrate can be lost by denitrification in wet conditions. The N in the nitrate is converted to nitrogen gas which goes back to the air. At Layer Breton there was evidence of greater loss of nitrate during the winter from the poorer drained plots in the experiment than from the better drained ones despite the risk of leaching from the latter.

Just after the war combine drilling for cereals was shown to be beneficial. At that time many soils in this country were short of nutrients. The root of a grain which had been combine drilled would develop in a volume rich in nutrients. Subsequent cultivations would spread these nutrients in the soil. Twenty or **30** years of relatively generous fertiliser use together with cultivations means that the top layers of soil in the majority of arable fields are now well supplied with nutrients so that combine drilling is no longer necessary. In our advisory work on individual farms we are finding increasing evidence of potassium deficiency symptoms in spring cereals sown in loose seedbeds. These usually disappear when the crop forms a good root system which can explore the soil. Similarly the transient symptoms of magnesium deficiency when cereals are changing from primary to secondary roots are worse in poor seedbeds.

Phosphorus moves only slowly down the soil profile, it accumulates in the top few cm. If direct drilling is practised for a number of years in a field there is a risk that phosphorus in the root zone may be depleted. However there is little evidence that this is happening yet. It is good to see many drills now used for direct drilling can also place the fertiliser. Evidence is increasing that the rate of release of nitrate from soil organic matter is less in soils where direct drilling is practised and so more than normal fertiliser N is needed.

TABLE 9

NITROGEN AND COMPACTION (SOMERSET)

N Treatment (gk/ha) Seed bed	N Treatment (gk/ha) Top dressing	Yield of barley (t/ha) — 85% DM Compacted soil	Yield of barley (t/ha) — 85% DM Uncompacted soil
0	37.5	1.93	2.89
37.5	75	2.59	4.27

Some advisory observations in Humberside indicate some benefit to yields from sub-soiling and placing phosphate about 45 cms deep in the soil. This needs to be investigated and followed by critical experiments to see if worthwhile benefits can be obtained elsewhere.

FERTILISER USE

The present day nutrient status of many arable soils means that cereals show little response to phosphorus and potassium. It is sometimes thought that extra P and K will result in higher cereal yields. There is no experimental evidence to support this. On the other hand higher yields which can result from other farming techniques mean that more phosphorus and potassium will be removed and so more should be used to prevent a rundown. It must be stressed that the increased use follows, not causes, the higher yields.

Getting the amount of nitrogen right is of overwhelming importance in cereal yields. A great deal of experimental work is being done and the situation is confusing. In general at present, there seems to be no reason for complicating the system. The benefits, if any, from several dressings are not rigorously proven as yet.

Similarly it is sometimes thought that as the recommendations for sugar beet are based on annual experiments there could be yield increases by applying more fertiliser over a rotation. An experiment running at Broom's Barn shows little evidence that recommendations need increasing when *6* years of cropping are considered.

Sugar beet responds to sodium but farmers are sometimes hesitant about using salt because they are worried about the effect on soil structure. Joint work by ADAS Eastern region and Broom's Barn had shown that sodium applied at the recommended rate had negligible effects on soil structure. However, the saline effects can upset germination and produce a gappy crop. The salt should be applied in the autumn or if in the spring several weeks before sowing.

During the last few years ADAS

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Lime, Fertilisers, Soil

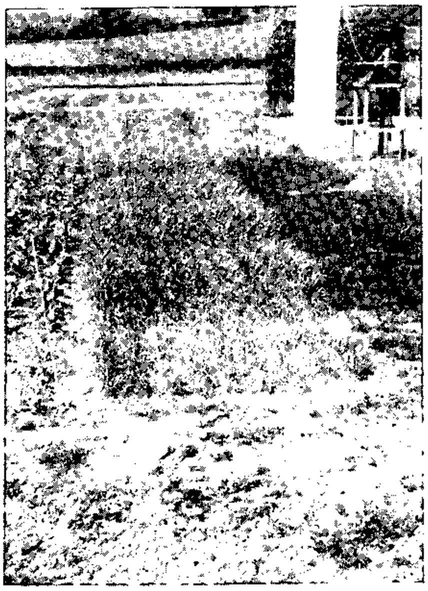
Soil Scientists at Leeds have been running fertiliser experiments on potatoes at Stockbridge House Experimental Horticultural Station following the interest in "blueprint" growing with higher than normal rates of fertilisers. Splitting the nitrogen between seedbed and top dressing was beneficial and 500 kg/ha P_2O_5 was optimum even on index 4 soils but in 1976 there was no difference between placing and broadcasting phosphate. Results in 1975 and 1976 clearly showed the need for adequate water.

ADAS recommendations on fertiliser use are codified in Bulletin 209. These recommendations are based on scrutiny of published information and wide ranging consultation. The Survey of Fertiliser Practise is a joint effort between ADAS, the Fertiliser Manufacture Association and Rothamsted. A stratified sample of farms by size groups are visited and information collected about fertiliser use. Comparison of the data with recommendations show that most arable crops are fertilised at the optimum rate except that sugar beet tends to get too much fertiliser although not to the extent of a few years ago.

With grassland the situation is very different and much permanent grass receives little fertiliser. Much more nitrogen could be used on grass but on the individual farm growing the grass is only the beginning of the story. More grass needs more animals to use it, in turn more animals need more facilities, eg housing and labour and so on. The GM 20 and GM 21 series of experiments were run jointly by ADAS and the ARC and they are at present being written up for publication. There were 28 sites all over England, Scotland and Wales with the same experimental design at each. Although the actual yields and the increase in yields varied from site to site the general picture at each site was very similar in each of the 4 years. At all sites there was a straight line response to N up to about 300 kg/ha.

Grass is not very responsive to phosphorus but it needs some and there must be an adequate amount in the herbage for the grazing animal. Formerly basic slag was widely used to supply P to grassland. ADAS has been running a series of experiments with different materials supplying phosphorus. Of these only basic slag and super phosphate have been satisfactory. Ground Mineral Phosphate is useful where the pH is right but it should not be used on soils containing free lime naturally or on soils that have been recently limed or where the pH is maitrtained above 6 because of certain crops grown in the rotation.

Where slag has been used every 3 or 4 years it is satisfactory to use triplesuper-phosphate in the same way. Triple seems expensive per ton but it is very competitive per kg of P_2O_5.



B.

A & B. Roor deprh control experiments at Starcross using plastic sheers to limit water.

D. Cultivator sliding over soil pan.

C. Fertilizer experiments in the Cotswolds. Foreground plot has not received P_2O_5 for 10 years, plot on right normal P_2O_5.

E. . . . and nothing has been achieved.

TRACE ELEMENTS

In "Modern Farming and the Soil" some comments were made about trace elements on minor nutrients and in paragraph 254 the point is made that annual removals by crops and stock are very small. In this country we are likely to meet

TABLE 10

AMOUNTS OF NUTRIENTS (AS ELEMENTS) APPLIED AS FERTILISER IN THE UK ('000t)

	N	P	K
1874	34	30	3
1913	29	79	19
1939	60	75	62
1948	186	173	147
1958	315	169	289
1965	565	211	340
1968	748	205	366
1970	760	196	316
1972	1128	246	400
1974	1100	216	376
1976	1059	176	331

crop deficiency problems involving boron, copper and manganese. These can be diagnosed and treated. For the individual farmer the problem can be serious but for the whole of agriculture (and horticulture) the effect is a minor one. Manganese deficiency is worse in poorly structured soils.

A great many proprietary materials are on the market and in recent years ADAS has conducted experiments with these over a range of crops. The materials have been applied according to the manufacturer's instructions. So far there has been no evidence of any benefit. If a farmer or grower thinks he has a trace element problem he should get expert advice. If a deficiency is diagnosed it can be treated with the appropriate element.

Too high a level of trace elements and indeed other materials causes toxicity problems. ADAS maintains close liaison with Water Authorities about disposal of sewage sludge on land and can give advice to farmers about the use of animal slurries particularly pig slurry which contains copper.

THOUGHTS FOR THE FUTURE

Farmers must be encouraged to know and understand their soils. This means having samples analysed regularly to check pH and nutrient status; having a spade handy to investigate the soil structure particularly below the surface; and getting advice on problems. Symptoms from various problems are often similar.

From the research and development side it is important to keep up a vigorous effort on improving the effectiveness and advice about nitrogen use on cereals. Placement of fertiliser especially in connection with seed rate inpotatoes needs further investigation and the deep placement by subsoiling methods should be looked at criticallv.

CULTIVATIONS AND SOIL PROBLEMS

Dr. Brian Davies who is the Regional Soil Scientist with A.D.A.S. at Reading is well known for his practical outlook on cultivations and soil problems. This paper was given during the March Soil Structure and Drainage Conference.

The central message of the 'Strutt' report, namely 'know your soil and how to obtain the best from it' is even more relevant today because of the widescale adoption of newer systems of soil management which require different, and often more informed decisions than the traditional techniques. This paper considers some of the new developments in cultivations and comments on their implications for soil physical fertility.

A. Techniques for establishing greater areas of crops in restricted periods of time. In wet autumns the proportion of the national area of winter wheat sown outside the optimum period is higher than in drier years (Table I). By widespread adoption of time saving systems this situation could be much improved.

TABLE I

RAINFALL AND SOWING DATE OF WINTER WHEAT

Harvest Year	Rainfall Sept-Oct % of Avenge	% of Wheat Sown by 1 Dec	Total Area of Wheat in E & W ('000/ha)
1966–69	129	68	878
1970–74	60	87	1087
1975	154	67	1006
1976	90	94	1204
1977	196	89'	1050

'Inflated by very early harvest in 1976.

Reduced Cultivations for Winter Cereals

During the last decade there has been an approximately 50% reduction in the use of the mouldboard plough as a primary cultivation for winter cereals and its replacement mainly by heavy cultivators of various types. Of this cultivated land there has been a significant increase in the area shallow (less than 10 cm) rather than deep cultivated. These trends are at least in part justified by two R & D projects.

(i) Patterson's (NIAE) work at 2 clay sites over 6 years has shown no reduction in yield of winter cereals by substituting either the chisel plough (13 cm) or the Rota-digger (10 cm) for the mould boardplough (20 cm). The Rota digger is an implement which works much better than tine cultivators in wet soil conditions.

(ii) Drayton EHF, using shallow surface cultivations achieved with a heavy springtine cultivator have shown that no yield reduction is incurred compared with deeper cultivation on their Lias Clay soil. The Drayton surface cultivation technique has the advantage of avoiding cloddy tilths in dry years and compaction in wet autumns.

Direct drilling of winter cereals

The shift towards shallower cultivations includes 4% of the nations winter cereals which are not direct drilled. This slow trend towards elimination of cultivation is likely to increase as the very substantial time saving of direct drilling and of possible reductions in machinery costs become more widely accepted. However, direct drilling must be adopted with care and attention to detailed guidelines otherwise yield losses will probably result. In addition potential direct drillers should take note of the following points:

(i) A paper entitled 'Soil Suitability for direct drilling' will be published in the June edition of 'Outlook on Agriculture'. The paper is written by representatives of the Agricultural Research Service, ADAS and the Soil Survey. BY examining all the experiments on direct drilling of cereals in the UK since 1969 the authors conclude that in comparison with ploughing:

Direct drilling is more suitable for winter sown crops than for spring sown crops except on calcareous and well drained loamy soils and on sands with moderate to high organic matter.

On clay soils direct drilling of winter crops has generally been satisfactory where grass weeds and drainage water are well controlled.

Cultivations & Soil Problems

TABLE II
TIMING OF NITROGEN FOR DIRECT DRILLED WINTER WHEAT (BOXWORTH EHF)
Mean of varieties Atou snd M. Huntsman

	YIELD INCREASE kg/ha (cwt/acre) due to: Autumn N	Split spring top dressing	Autumn N + split spring top dressing
1975	210 (1.7)	340 (2.7)	400 (3.2)
1976	280 (2.2)	150 (1.2)	650 (5.2)
1977	310 (2.5)	370 (2.9)	540 (4.3)
MEAN	270 (2.2)	290 (2.3)	530 (4.2)

Direct drilling has often incurred yield depression on low organic matter sandy and silty soils, particularly where weakly structured topsoils overlie slow draining clays.

(ii) Absence of soil disturbance invariably alters the pattern of nitrogen release from soil organic matter. During the earlier stages of direct drilled crops nitrogen supply is likely to be too low and advantages will accrue from earlier nitrogen applications than in crops growing on cultivated land. In general no N is needed for cultivated winter cereals until a growth stage 5–6 in Late spring, compare this with data in Table II.
These results indicate the close relationship that exists between soil physical management and chemical fertility of soils.

(iii) In dry years direct drilled crops on clay soils can benefit from increased water storage occurring during early stages of crop growth. In 1976 this effect led to yield increases of between 10–25% compared with ploughed crops in ADAS experiments (Eastern Region) and also in Letcombe Laboratory experiments.

(iv) The surface of direct drilled soils is resistant to wind erosion particularly where crop residues are also present. The flexible application of zero cultivation techniques should make blowing a problem of the past.

(v) With both shallow cultivations and direct drilling we have dispensed with the buffer provided by good loosening operations. In consequence to grow good crops with these systems we must be able to decide whether the soil condition is loose enough for the crop to establish and root satisfactorily. This decision requires field examination of soil and careful interpretation of the soil structure. Most farmers have not acquired this skill and in consequence tend to rely on others for their advice. To this extent minimum cultivation systems are more at risk from poor soil conditions than traditional methods.

Reduced Cultivations for Sugar Beet and Vegetable Crops

In the UK there has been intensive development work on methods of reducing cultivations for small seeded crops as exemplified by sugar beet. The aims of this work have been to save time, improve emergence and to explore the introduction of these crops into direct drilled and minimum cultivated systems of cropping. At the Norfolk Agricultural Station joint work with ADAS has combined these aims with detailed description of cultivation treatments in terms of soil physical condition. Examples of this work are given in (i) and (iii).

(i) ***Influence of reduced seedbed preparation on soil condition and sugar beet development*** following Autumn mouldboard ploughing. (Norfolk Agricultural Station 1974).

Treatments

SUGAR BEET SEEDBED PREPARATION

Traditional Maximum	—	1 Pass Springtine (6 in) 1 Pass Roll, 2 Passes Springtine (4 in) and 2 Passes Roll and Light Harrow
Traditional Minimum	—	1 Pass Springtine (4 in) 1 Pass Roll 1 Pass Springtine (3 in) and 1 Pass Roll and Light Harrow
Dutch Harrow	—	2 Passes (3 in)
Rotary Harrow	—	2 Passes (4 in)

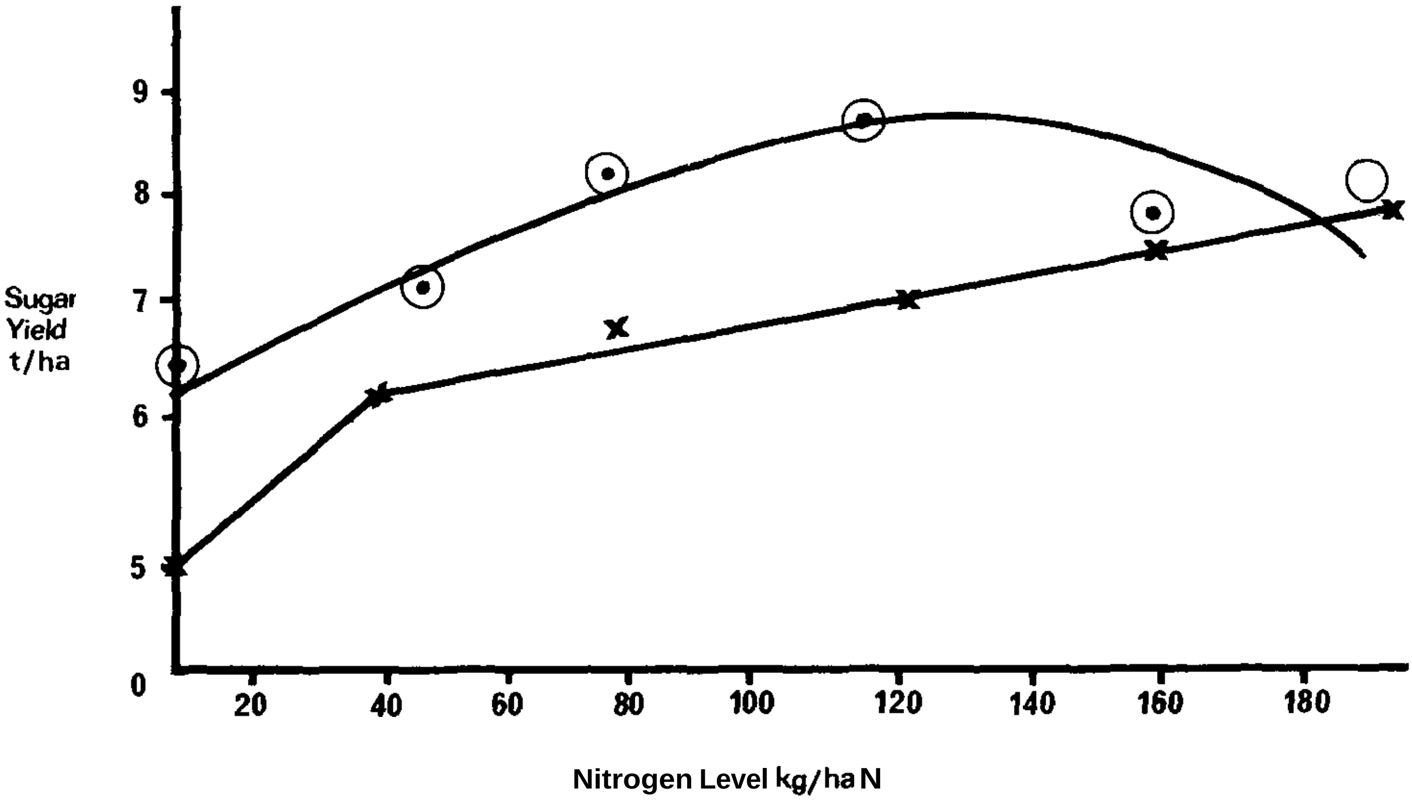
This long term project for which one years results are given has proved that in a range of spring conditions the shallower treatments with no more than two passes give finer seedbeds, better seedling establishment and higher sugar yield. The advantages result from avoiding both deep seedbed cultivation, which unearths larger clods, and the tractor wheel compaction of multi-pass treatments.

(ii) ***The new NIAE vegetable drill*** offers substantial improvements in seedling establishment over existing precision seed drills. This has been achieved by combining very precise seed spacing, minimising 'bounce' as the seeds hit the seedbed and ensuring that seeds are placed firmly into the finer moister tilth of a seedbed.

(iii) ***Strip tillage in cereal stubbles for sugar beet***
At the Norfolk Agricultural Station sugar beet has been grown in cereal stubbles undisturbed by any primary cultivation. Using an ICI/Howard designed machine the seed is precision sown into 15 cm width bands rotavated to 5 cm depth and loosened to 20 cm with narrow tines set in the centre of each band. Problems of smearing by the tines occurred in a wet spring see Fig 1, but enough experience has now been obtained with the technique to hold out a reasonable chance of success for sandy and loamy soils. Fig 1 shows the response in sugar yield to nitrogen level, for crops grown by this and traditional methods. A smeared area adjacent to the tined disturbance reduced root exploration and this plus the possibility of reduced nitrogen supply from soil organic matter probably account for the less effective nitrogen use in the strip tilled treatment. However at the optimum nitrogen levels for each method sugar yields were only 0.6 t/ha lower for the one pass system.

B. *Deep disturbance of Soils*

Parallel to the widespread trend towards reduced cultivation there is work examining the effects of loosening soil sometimes to as deep as 1 metre from the surface. At first sigh: this trend seems at variance with the



move towards reduced cultivation, but closer examination suggests that it is in fact complementary, for irrespective of the degree of surface soil disturbance, land must be free of major compaction at depth if it is to achieve full potential yield. Deep soil disturbance is likely to be beneficial where the natural subsoil is compact and where deep compaction is caused by harvesting crops from wet land eg root crops and winter vegetables. Some soils eg weakly structured slow draining soils are more susceptible to deep compaction than others, and some crops eg as French beans, peas, broad beans, potatoes are worse affected by such compaction than others.

Reference to recent work on deep disturbance of soils

1. Spoor's work on subsoiling at National College of Agricultural Engineering. This work has given us a more logical understanding of the processes involved in loosening subsoils. His main findings are:-

(i) There is a critical working depth for all rigid tines below which compaction rather than loosening takes place.

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(ii) Increasing the width of a subsoiler foot with wings and relieving overburden pressure with cultivating tines set in front of a subsoiler allow both deeper and more complete loosening.

(iii) Because of the many factors which influence performance of a subsoiler, digging with a ıde is the onl sure means of assessing results in the field.

TABLE III
SUGAR BEET SEEDBED PREPARATION — SEEDLING ESTABLISHMENT AND SUGAR YIELD

Treatment	Plant Stations '000 per ha 24 April	27 April	2 May	Final	Sugar Yield tonnes/ha	(cwt/acre)
Seedbed Cultivation	43.6	42.9	42.6	41.6	,0. 141	(41.14)
Trad Maximum	35.6	41.9	55.1	51.9	9.4	(74.9)
Trad Minimum	36.5	45.2	55.6	41.5	9.8	(77.6)
Dutch Harrow	56.6	66.4	73.8	79.8	10.4	(83.2)
Rotary Harrow	43.7	50.8	65.9	71.8	10.2	(82.3)

TABLE IV
SUGAR BEET SEEDBED PREPARATION
CLOD DIAMETER (%)

Treatment	Clod Diameter ⅓ 5 mm
Seedbed Cultivations	
Traditional Maximum	30
Traditional Minimum	36
Dutch Harrow	45
Rotary Harrow	37

TABLE V
COMPARISON OF SUBSOILING EFFICIENCY
(SPOOR G. GOODWIN R J, TAYLOR J C)

IMPLEMENT	Mean Draught Force (kN) DEPTH = 42 cm	Loosening achieved Square em. DEPTH = 42 em
Conventional Subsoiler	40	870
Winged subsoiler 30 cm width	M	2500

TABLE VI
Results of deep soil loosening and fertiliser placement at Woburn Experimental Station
MEAN YIELDS 1974–76

	None	Subsailed	Subsoiled* + PK	Topsoil* + PK
WHEAT (Grain @ 85% DM, T/ha)	4.4	5.4	5.2	4.2
SUGAR BEET (Sugar, t/ha)	4.1	4.4	4.7	4.1
BARLEY (Grain @ 85% DM t/ha)	3.5	4.5	5.1	3.4
POTATOES (Total Tubers, t/ha)	48	47	56	49

'Additional PK applied either to the subsoil (25–50 cm) or to the topsoil (0.25 cm).

2. Yield increases have been reported after deep loosening of soils at Woburn, NVRS and Wye College in experiments where conventional subsoiling gave little if any benefit. This work indicates that more work on effective subsoil loosening should be carried out on a selected range of soils.

'In the Rothamsted work at Woburn loosening was achieved by hand digging and working the subsoil with a fork. There were significant benefits from deep placement of P and K in this work:
Greenwood at NVRS has shown a 76% yield increase in broad beans, following full subsoil disturbance to 1 metre depth with an earthmover. Cabbage, a crop with finer roots than broad beans showed negligible benefit. Records indicated that increased bean root extension allowing greater water uptake during stress periods was responsible for the response. Double digging by hand or by machine has given greater rooting depth and higher cereal yields in experiments on Brickearth soil at Wye College.

CONCLUSIONS

1. The traditional viewpoint that it is necessary to regularly loosen topsoil every year for some arable crops has been strongly challenged and in many situations shown to be incorrect. It is important that each farmer should test this finding for his own conditions and where appropriate exploit its implications to the full.

2. Recently there has been much discussion about maximising crop yields. Soil potential sets a ceiling on yield for any crop but this fact is seldom mentioned in the context of maximising yields. Provided the husbandry is not limiting it is the farmer's ability to ensure that his crops fully exploit soil moisture reserves at the appropriate level of N which determine the yield of unirrigated crops. This is true irrespective of whether crops are being grown in completely disturbed topsoils, partially disturbed or in undisturbed topsoils. In effect it puts a responsibility on each farmer to know his soils thoroughly and to understand how to get the best out of them.

THE EFFECT OF STONE REMOVAL, STONE WINDROWING AND STONE CRUSHING ON POTATO YIELD, HARVESTER PERFORMANCE AND TUBER DAMAGE

B. D. Witney, Agricultural Engineering and Mechanisation Department, Edinburgh School of Agriculture, reports on recent work on stone **windrowing.**

Introduction

Following the development of a stone windrower and of a prototype stone crushing machine, a three year investigation into the effect of field stone treatments on potato production systems, was initiated in 1974. The three field trials each contained five replicates of four treatments, namely, control, stone removal, stone windrowing and stone crushing. The plots were six drills wide and the drill width was 75 cm.

Experimental procedure

The Sorensen 'Stonehater' was used for stone removal in all the trials but the single row Scorgie stone windrower was lafer replaced by a two row model and the prototype field stone crusher was later replaced by the Ramsey production version. The equipment and stone treatment techniques are more fully described elsewhere (Witney and Wilson, 1975; Witney, 1976a). Three measurements of the field stone content over 32 mm mesh were taken over an area of $1m^2$, and to the depth of cultivation on the flat before stone treatment and in the ridge after planting for each plot. In the first two trials, the data for the field stone content of the control plots after treatment are incomplete because it was assumed, erroneously, that the measurements on the flat would be the same as in the ridge.

The crop yield was calculated from three assessments per plot immediately prior to harvesting. All the trials were harvested by the same model of manned, single row, complex, trailed potato harvester (Grimme Commander, bunker model). The spot of work was measured over the full length of at least three drills in each plot and 4 tuber samples of approximately 10 kg were taken from the output end of the picking table conveyor on the harvester when lifting the central two drills of each plot.

Experimental results

Irrespective of the initial field stoniness level, the stone content of the drill was consistently reduced to approximately 8 t/ha over 32 mm mesh by stone windrowing (Table 1). Space in the valleys limits the separated material to about 200 t/ha over a 32 mm mesh for a 75 cm wide drill. Stone removal was penalised in the trials because the narrow plots mitigated against cross working the soil and because of machine breakdown in 1974. Whilst stone crushing did make a significant permanent change to the stone population, it was less effective for the immediate crop than the other two treatments. All the two row stone treatment machines, operating at 0.4 ha/hour did not seriously delay planting operations.

Potato yield was not affected by the treatment although there was a significant yield increase for the stone windrowing treatment compared with the control in the unusually dry summer of 1976 (Table 1). Some Norwegian work on the effect of stone removal on potato yield produced equally variable responses (Bohn and Weseth, 1972).

The effect of field stoniness level on the soil environment was investigated by Saini and MacLean, 1967, and their work was related to the present studies (Witney, 1976b). The treatments had no effect on the yield of subsequent crops of either winter wheat or spring barley.

The most significant effect of stone treatment is harvester rate of work and tuber damage (Tables 1 and 2). When the stone content is reduced to a low level as in the case of stone windrowing and to a lesser extent for stone removal, it was possible to operate the tractor in a higher gear at lower engine speed for the harvesting operation. The harvester spot rate of work was increased by 43 per cent on the stone windrowed plots and by 22 per cent on the stone picked plots. The increase in harvester output could be achieved with fewer pickers (three instead of four) and with a reduction in severe damage of 49 per cent for stone windrowing and of 29 per cent for stone removal. The reduction in tuber damage was attributed partly to the absence of stones and partly to the lower web speed to forward speed ratio (Peterson et al., 1975), which was only possible by stone treatment but the significance of each component was not separately identified.

Table 1. Field stone content before and after treatment, crop yield and harvester spot rates of work, 1974–76.

Treatments	Field stone contents (t/ha)					
	before treatment			after treatment		
	1974	1975	1976	1974	1975	1976
Control	138.3	84.4	84.4	—	—	44.5
Windrowing	149.8	97.4	93.2	8.4	7.4	7.7
Crushing	174.9	97.8	8.10	23.0	26.1	42.1
Removal	—	92.8	85.5		16.5	30.0
sed	18.79	8.04	8.93	10.10	4.76	6.13

Treatments	Crop yields (t/ha)			Harvester spot rate of work (ha/h)		
	1974	1975	1976	1974	1975	1976
Control	47.1	68.8	34.3	0.162	0.114	0.136
Windrowing	50.8	71.3	42.7	0.249	0.134	0.206
	53.8	68.4	39.5	0.167	0.115	0.130
Removal	—	65.5	40.3	—	0.137	0.169
sed	3.28	6.23	2.17	0.012	0.003	0.012

Summary

In a three year experiment, potato yield was not affected by either stone removal. stone windrowinn or stone crushing, although in the dry summer of 1976, there was a significant yield

Table 2. Severe tuber damage and damage indices, 1974 – 76.

Treatments	Severe tuber damage (% by wt)			Damage indices		
	1974	1975	1976	1974	1975	1976
Control	31.0	24.9	40.8	301.2	254.6	383.6
Windrowing	16.3	15.4	17.4	184.2	186.2	234.1
Crushing	29.6	21.0	33.0	288.8	234.4	348.4
Removal		15.4	30.1	—	173.9	325.1
sed	5.52	3.36	6.01	39.42	'28.75	35.2

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increase for the stone windrowing treatment compared with the control. There was no yield effect on subsequent cereal crops. Field stoniness levels of up to 200 t/ha of material over 32 mm nominal diameter can be reduced to 7 – 10 t/ha in the ridge by either stone removal or stone windrowing but stone crushing had less effect. Harvester speed was increased by 43 per cent after stone windrowing and by 22 per cent after stone removal, but not after stone crushing. On a manned, single row, complex potato harvester, there was a reduction in severe tuber damage of 13 per cent after stone crushing and of over 30 per cent with the other two treatments. The decrease in tuber damage was due partly to the lower harvester web speeds which were only possible on the areas of low stone content. The combination of higher harvester rates of work or fewer pickers and less tuber damage makes stone windrowing the most economically viable as well as providing an opportunity o att in some of the mechanisation benefits formerly available only to potato growers on stone-free lane. (Witney and Wilson, 1976; Witney, 1977.)

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