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SOIL LOOSENING
REQUIREMENTS, IMPLEMENTS AND TECHNIQUES

by

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Soil Loosening. A Review of the Potential Benefits, Techniques and Subsequent Aftercare

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ABSTRACT

This review aims to improve the efficiency of soil loosening operations by presenting to the practitioner, in a readily usable form, information on the many factors which influence the success of these operations.

Background information is provided on the soil conditions required to ensure that all the factors influencing effective crop production are met, namely the needs of the crop and mechanisation operations. Crops need appropriate levels of heat, air, water and nutrients, which can be satisfied with air filled pores of the correct diameter, through which the roots can develop. Achieving these conditions requires good soil structure and drainage. Tractor access, support and traction can best be met by strong compact soils, where water drains from the wheelings. To best meet crop and mechanization requirements, a well structured soil condition is needed comprising a network of continuous drainable pores, in a soil that is not too compact.

Compaction resulting from prolonged wetting, high vehicle loads or wheel slip, or a combination of these factors, causes the essential larger drainable pores to disappear first and if very severe the structural aggregates to break down. Loosening in these situations can create larger fissures to replace the lost drainable pores enabling water, air and root movement to be re-established. Loosening will only be beneficial to the crop and to the timeliness of operations if a soil compaction problem actually exists and providing there

is good sub-surface drainage. Loosening in the absence of these criteria may make conditions worse and excessive loosening should also be avoided, since this not only wastes energy but is detrimental to the support of equipment and traction.

The results of agronomic experiments assessing soil loosening effects show that positive yield benefits from soil loosening are by no means guaranteed. There have been many situations where the response has been zero and a few where it has been negative. Crop response depends on the severity of the compaction problem, the effectiveness of the loosening operation, the weather pattern in the crop growth period, and the subsequent management practices.

The following guidelines should be considered when contemplating and executing loosening operations:

1. Check to ensure a real compaction problem exists and its location. If the problem is marginal there is unlikely to be any benefit for loosening, hence only loosen if problem is likely to become rapidly worse. Compaction problems usually taken one of three forms:

   a. Compaction in upper layers - resulting from weak top soils unable to support heavy surface loads.

   b. Pans - discreet layers of dense soil near equipment working depth.

   c. Compaction at depth, often from natural causes such as glacial action.

2. Subsurface pipe or mole drainage should be adequate.

3. Check to ensure the desired degree of loosening is being achieved; adjust equipment accordingly.

4. Loosening to improve drainage has highest priority on heavy soils and to improve rooting depth on lighter soils.
5. Minimise traffic on loosened soil to avoid rapid recompaction.

The most effective method of identifying problems is to observe the soil and growing crop in the late May to early July period in areas of good and poor crop development. A soil profile pit in these areas will enable soil structure and root development problems to be identified from which, loosening needs and depths can be decided.

The loosening action of the range of soil loosening implements available is reviewed in relation to the ratio of depth of work to width of the implement tip, which is the critical factor governing the effectiveness of the operation. Depth/width ratios of less than five are usually satisfactory, whereas implements with depth/width ratios greater than five tend to form slots or square moles at depth. The attachment of wings or leading shallow tines greatly enhances the ability of an implement to produce effective loosening at greater depths. The correct tine spacing for these operations is specified in relation to the depth of work of the tool. From this review the most suitable equipment to alleviate the various compaction problems is suggested based upon:

1. the working depth range needed;
2. degree and extent of loosening required;
3. surface conditions required;
4. power unit available.

Details are provided allowing implement working depth and number of tines to be matched to tractor size. Operational methods for achieving the desired result with reduced tractor power are also considered by correct tine positioning and depth in relation to tractor wheel spacing. The sequencing of operations where additional surface tillage is required is critical, since a subsequent operations, following deep loosening, can immediately recompact the subsoil. Wherever possible deeper loosening operations should be carried out as late in the sequence as possible.

To maximize the benefits from a loosening operation, the loosened soil needs careful handling to ensure that:

i. The surface layers are not excessively loosened so as to inhibit germination and growth particularly on the light soils.

ii. Excessive recompaction does not occur as a result of high tractor and equipment loadings.

If these objectives can be achieved the benefits will be relatively long lasting.

These risks can be minimized by:

1. keeping the degree of loosening and its depth to the minimum required;

2. consolidating loosened soil at the time of loosening with crumblers/presses;

3. carefully planning the sequence of operations through to crop establishment, to minimize the traffic;
4. keeping loads and pressures to a minimum when working on the loosened soil;

5. concentrating traffic to local traffic lanes;

6. maintaining an adequate subsurface drainage system.

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1. SOIL CONDITIONS REQUIRED FOR EFFICIENT CROP PRODUCTION

The soil conditions needed for efficient crop production must not only satisfy the crop, but also meet mechanisation requirements. Unfortunately, these requirements sometimes conflict and unless a satisfactory compromise condition can be found, adverse soil conditions develop which need rectification through soil loosening. The suitability of a soil for efficient production depends largely upon how the soil is packed and the nature of the spaces or pores between the soil units.

Crop Requirements

Crop roots need adequate quantities of heat, air, water and nutrients for growth and roots must be able to move freely into the soil to exploit the reserves stored there. Roots use oxygen and give out carbon dioxide and so a continual exchange of these gases between the atmosphere and the soil is required. This exchange can only take place through air filled pores, hence the need for drainage. The minimum percentage of air-filled pores needed for good aeration varies from about 5% of the total soil volume in winter, to between 10-15% in summer when demands are higher. Good aeration is therefore dependent upon having a large enough percentage of drainable pores present throughout the soil mass.

The availability of water and nutrients to roots is very dependent upon the roots being able to move to where these elements are stored. Water and nitrate can move through short distances, but phosphate and potash are almost immobile. The deeper and more intensive the root development, the greater the insurance against crop yield reductions through drought or nutrient deficiency. The conversion of nutrients into forms which can be readily taken up by roots is often dependent on soil micro-organism activity. These micro-organisms require similar soil conditions in terms of air, water and temperature to the roots themselves.

The compactness of a soil greatly influences root and plant development. A condition which is too loose is as detrimental as one that is too dense. For rapid root extension pores must be either larger than the root, or the soil weak enough around the pore to allow the root to enlarge it easily. Water and nutrients tend to be taken up most efficiently by relatively young roots and hence soil conditions must allow the continuous development of new roots. A compact soil tends to have fewer larger rootable pores and the small pores present are more difficult to enlarge, slowing down or stopping root movement. If drainage and hence aeration status is poor in a compact soil, roots have even more difficulty in developing into pores smaller than themselves. Although roots can move easily in very loose soils, yields may be low due to the loose soil holding less water.

Mechanisation requirements

The ideal soil condition for tractor and machine operations would be one where there is access to the field at any time, without sinkage and rutting and hence compaction, and where adequate traction can be developed with optimal wheel slip. These requirements can best be met on strong compacted soils, where water drains away from wheelings; loose soil conditions are very inappropriate. These compacted conditions may not suit the plant unless there are an adequate number of large drainable and rootable pores also present. In addition, they will increase power requirements during cultivation operations. Soils are best able to support equipment with minimum compaction when drainage is good. A continuous network of drainable pores is therefore essential for timely mechanisation operations.

Field requirements

To best meet crop and mechanisation requirements, a soil condition is needed comprising a network of continuous drainable pores, in a soil which is not too compact. Providing drainage is good to provide adequate aeration during wet periods, this condition will allow good root development, organism activity and rapid water and nutrient uptake. It will also be satisfactory for supporting light to medium weight equipment under dry or moist conditions, but not under wet, nor for carrying heavy equipment. More compact traffic lanes are required in addition, in the latter situations, to prevent the traffic damaging the soil in the cropped area. The way in which this desired soil condition is achieved and the required soil packing condition, will depend upon the type of soil.

Soil comprises a mixture of individual soil particles and groupings of these particles called structural aggregates. These are packed together leaving a system of pores of different sizes between them. The actual pore sizes present depends upon the tightness of the soil packing and the size of the individual particles and aggregates. The requirement is to obtain the desired combination.

With the exception of coarse sandy soils, the pores between tightly packed individual soil particles and within the structural aggregates, are usually very small, often being less than 0.05 mm in diameter (small pores). On the other hand, pores between the structural aggregates, unless very tightly packed, are usually greater than 0.05 mm diameter (large pores). This pore size of approximately 0.05 mm diameter is a fairly critical one, since it defines the boundary between those pores which will drain and those which will not and it also affects root development. The greater the pore size above this value, the faster the pore will drain and allow air into the soil. Cereal roots vary in size from about 0.1 mm diameter upwards and so they have obvious problems growing through the small pores.

Their root hairs can, however, extract water from them and it is these small pores which hold all the usable water. A good soil structure is therefore essential in most soils, to provide the larger pores between the aggregates for drainage and the smaller ones within aggregates and between individual particles, for holding the usable water.

The type of structure and the stability of the aggregates varies between soils. The best structured soils are those with rounded aggregates less than 15 mm diameter. Poor structured soils can have block-like aggregates up to 100 mm cube or rectangular vertical prisms greater than 150 mm in length. The smaller and more rounded the edges of these aggregates, the easier it is to obtain the desired soil conditions and the less likelihood of the larger drainable pores being lost if the soil is compacted.

The stability of the structural aggregates is important for the preservation of the larger pores. This stability depends on soil type and on maintaining adequate lime, pH and organic matter levels. The higher the organic matter content the more stable the aggregates. Continuous tillage reduces organic matter content and arable soils are less stable than equivalent grassland soils. Arable soils therefore need more careful handling and the less tillage the better. Aggregate stability is often particularly weak on fine sand and silty soils which are low in organic matter. No matter how stable the aggregates in any soil, working the soil severely under wet conditions such as under a slipping wheel, will cause collapse of the aggregates.

In addition to the structural aggregates providing the necessary drainable pores, earthworm activity and natural swelling and shrinkage on clayey soils also creates larger pores and fissures. These frequently persist with time if the soil is left undisturbed, greatly assisting rooting and drainage.

Role of loosening operations in maintaining the desired conditions

When soils become excessively compacted as a result of natural causes such as prolonged wetting, or through high loadings or wheel slip, the first pores to disappear are the larger drainable pores and in some cases the structural aggregates themselves may be destroyed. Loosening operations in these situations can create larger fissures to replace the lost drainable pores, to get water, air and root movement going again.

Loosening operations are frequently limited in what they can do on the different soils. On the lighter and silty soils comprising of smaller structural aggregates and many individual particles, they can with appropriate equipment open up the whole soil mass. The heavier and clayey soils tend to respond differently however, only limited fissure development being usually possible. In the latter case, soil organism and root activity then take over under the improved drainage and aeration conditions to continue the improvement.

When structural aggregates have been destroyed, loosening can reduce to some degree the size of the newly formed compacted units. The main benefit in this case comes from the improvement in drainage, enabling the organisms, roots and wetting and drying cycles to develop and stabilise the structure again. The same process can be beneficial in improving structure within naturally compact poorly structured layers at depth, loosening and drainage starting the process off.

In all situations, loosening will only be beneficial to the crop and to the timeliness of operations if a soil compaction problem actually exists and providing there is good subsurface drainage. Loosening in the absence of these may make conditions worse. Loosening to an unnecessarily excessive degree should also be avoided, since this not only wastes resources but also is detrimental to the support of equipment and traction.

2. SOIL COMPACTION PROBLEMS

Soil compaction problems can arise either from natural causes or from field operations. They differ in nature and location but all have the same effect, namely that of impeding drainage, aeration and root development. The commonest types of compaction problem fall into three categories. These are:

1. Compaction in upper soil layers.
2. Pans.
3. Compaction at depth.

COMPACTION IN UPPER LAYERS

This problem arises when the soil is initially too weak to support the surface load applied. The soil deforms and compacts under the load, increasing in strength until it can support the load without further sinkage. Maximum compaction occurs at a depth below the wheel or track of approximately half their width, and decreases below this depth. The depth to which significant compaction occurs depends upon the soil conditions at the time of loading, the loads and pressures applied, and the extent of any wheel slip. For given loads, the depth of compaction increases as soils become wetter and looser. The higher the pressures, loads and slip, the greater the depth and magnitude of the problem.

Compaction depths with axle loads up to approximately 8 tonnes are generally in the range of 0.20-0.30 m, but can extend to 0.35-0.45 m as weights, pressures and the depth of sinkage increase. With repeated wheelings on the same area, the first wheel pass does the greatest amount of damage, subsequent passes only increase compaction slightly. The extent to which this type of compaction occurs across a field, depends on the quantity of traffic and the positioning of wheels. The compaction can be quite general when there have been numerous random passes, or local if the traffic has been confined to tramlines or traffic lanes.

General compaction will severely restrict root development and water movement in the upper soil layers. It is not uncommon to have water ponded on or near the surface in the more extreme situations. If roots can get through this impeding layer, they will develop satisfactorily below, providing aeration is adequate. The effects of general compaction are usually more severe in spring sown crops, where early establishment and the need for rapid root development are essential for satisfactory production.

Local tramline/traffic lane compaction will not restrict drainage or root development in the field as a whole, but can spread laterally from year to year as tramline positions change until it becomes a general compaction problem.

Soil loosening operations can overcome this problem, providing the loosening implement works just below the compacted zone. In the case of general compaction, the whole field area requires loosening, whereas with tramline and traffic lane problems, the treatment need only be local.

PANS

Pans are relatively thin dense restricting layers in the soil, with looser soil conditions both above and below. Some are formed naturally and comprise largely of iron, humus and manganese compounds intermixed with soil, others result from implement action or wheel slip when operations are carried out under moist or wet conditions. Ploughs, discs, sweeps, L-blade rotary cultivators and slipping wheels are the main culprits. Natural pans are located at varying depths across the field, whereas implement and wheel pans are found at a fairly constant depth, corresponding to working depth.

The implement and wheel action breaks down the soil structural aggregates locally, creating a smeared or tight layer containing only very small pores. With time the thickness of this layer increases due to repeated implement/wheel passes at the same depth, further structural collapse due to local waterlogging or to the layer trapping soil particles which move downwards in the soil water. If left undisturbed these pans can build up to thicknesses of 100-150 mm with time.

Water frequently ponds on top of these pans and roots tend to move sideways along the top rather than penetrate through them. Roots can pass through a local fissure in the pan and once through, will develop in the uncompacted soil below, providing aeration is adequate.

For crops such as cereals, more local rather than complete pan shattering may be all that is necessary to re-establish good downward drainage and root development. Complete shattering is necessary, however, for root crops, to avoid problems with root shape. Care needs to be taken when loosening cultivation/wheel pans, not to work too deep below the pan (not more than approximately 50 mm) otherwise little pan shattering will be achieved. Implement positioning to shatter natural pans is more difficult due to variations in their depth.

COMPACTION AT DEPTH

Deep seated compaction problems with looser soil above result largely from natural causes. Glaciers in the past have overcompacted the soil mass and these compact zones have been left at depth. These compacted zones occur at the depth limit of previous cultivation operations and soil weathering action, and can extend to great depths. They frequently severely restrict root and water movement downwards.

Where these zones are relatively close to the surface, rooting depth can be increased and freer water movement achieved by shattering the upper layers of the compacted zone. This should only be done if the subsurface drainage system is adequate to remove the water. In soils where mole drainage is feasible, moling rather than loosening is likely to be more effective. The mole drainage operation will not only produce fissures in the compacted zone, but will also provide a drain to remove free water rapidly, greatly improving aeration.

NATURAL PROCESSES FOR ALLEVIATING COMPACTION

In certain situations, natural processes of wetting and drying and organism and root activity may help alleviate compaction problems. This is particularly so in the case of pans and with compaction in the upper layers. Drying in soils containing clay, tends to create shrinkage cracks in the compacted zone allowing root entry. As the roots move downward, they cause further drying and crack extension to greater depths. Alternate wetting and drying cycles causing swelling and shrinkage also encourage the development of planes of weaknesses and larger pores through compacted areas. The benefits from swelling and shrinkage are greatest on the heavier soils and least on light and silty soils. The burrowing action of earthworms opens up channels through compacted layers, and channels are also left following the decay of old roots which may have been trapped in these layers. Good subsurface drainage encourages all these beneficial natural processes and in many heavy soil situations, this combination of drainage and the natural processes may prevent the build up of serious compaction problems.

3. RESPONSE TO SOIL LOOSENING OPERATIONS

Past experience shows that positive gains from soil loosening operations are by no means guaranteed. There have been many situations where the response has been zero and a few where it has been negative. A review of past loosening experiments will be helpful in identifying both those situations where benefits can be expected and the operating techniques most likely to be successful.

PAST LOOSENING EXPERIMENTS

Soil loosening investigations and experiments, not unexpectedly, have been concentrated largely in periods of "profitable" farming. Some of the first experiments were in the mid 1800's, but these were followed by a large gap, until Russell (1956) initiated some very detailed and extensive trials in the 1940's. Work started again in the 1960's and has continued to the present day.

Work in the Lothians reported by Stephens (1855) from 1848 onwards on the Yester Estates of the Marquis of Tweeddale, showed considerable yield responses to loosening carried out in the furrow bottom during ploughing operations, see Table 3.1. Loosening was extended to depths of up to 0.5m on fields where compact subsoils were identified. Of particular note is the link between deep loosening and drainage, the improved yield being attributed as much to drainage as to increased rooting depth.

Table 3.1. Yield response to loosening and drainage on Yester Estates.

Crop	% Yield Increases	
	Drainage only	Drainage and deep loosening
Cereals	35	95
Turnips	-	100

Russell (1956) investigated crop response to deeper loosening in both shallow (20cm) and deep (35cm) ploughing situations on a wide range of soils. Responses varied widely between sites and years. Table 3.2 shows the average cereal yield increases obtained in 44 experimental fields and Table 3.3 the variation in response between fields when performance was compared with shallow ploughing only.

Table 3.2 The effect on cereal yield of 3 deep loosening treatments compared to ploughing at 20 cm.

Soil type	Number of experiments	Effect on Yield % Shallow ploughing (20 cm) + loosening (42.5 cm)	Deep ploughing (35cm)	Deep ploughing (35 cm) + loosening (42.5 cm)
Clay	12	104	104	106
Loam	14	102	102	104
Light Loam	11	103	103	105
Sand	7	100	97	101

Ploughing at 20 cm = 100%

Table 3.3 Percentage of experimental fields responding to loosening treatments compared with ploughing at 20cm only (44 fields).

Treatment	Response % Positive	None	Negative
Loosening to 40-45cm	50	34	16
Deep ploughing (35cm)	32	41	27
Loosening + deep ploughing	50	39	11

Positive yield responses were only obtained on 50% of the sites, so success was by no means guaranteed and average yield increases were relatively low. On four fields however, yield increases up to 22% were achieved and this was attributed to the loosening operations significantly improving the drainage status of the fields. This large benefit was only obtained in wet years when waterlogging was likely to be a problem; in a dry year the benefit on one site fell to as little as 3%.

Cereal yield responses to deep loosening linked to drainage improvements have been further confirmed in a series of field trials on heavier soils by the Field Drainage Experimental Unit of MAFF. The trial sites were naturally compacted at depth and water movement was restricted. Drainage and crop performance was compared between treatments of drainage pipes only, pipes plus subsoiling to 45cm depth and pipes plus moling to 55cm depth. The subsoiling operations created fissures and a channel, similar to those of the mole plough and hence the major difference between the subsoiling and moling treatments was the depth of the operation. The results from two experimental sites, Drayton Experimental Husbandry Farm and Brooksby Hall, both on clay soils, are presented in Table 3.4 Yield increases ranging from

11-30% were obtained in spring barley and 16-27% in winter wheat at Drayton (Trafford and Oliphant, 1977), as a result of the loosening and drainage treatment. The mean winter wheat yield increase on the moled plots was approximately 1.0t/ha. Increases with winter wheat at Brooksby Hall (Armstrong, 1978) were rather less, up to 8%, equivalent to approximately 0.5t/ha, but nevertheless consistent. In a further trial at the same time at Layer Breton, Essex, yield responses to the drainage and loosening treatments were zero. In one particularly wet autumn, however, on this site, it would have been possible to drill winter wheat on the pipes and moling plot, but not on any of the others. Loosening and drainage in this case meant the difference between a crop and no crop.

Table 3.4 Effect of a combined drainage and soil loosening operation on cereal yields on clay soils.

Site and treatment	% yield increase over untreated area. Winter wheat	Spring Barley
Drayton EHF		
Collector pipes only	16	23
Pipes + subsoiling	14	11
Pipes + moling	27	30
Brooksby Hall		
Collector pipes only	-3	
Pipes + subsoiling	8	
Pipes + moling	6	
Brimstone Farm		
Pipes + moling		
with compaction pan	2	
no compaction pan	11	

The results in Table 3.4 taken from Ellis et al (1984) and Harris et al. (1984), for the Brimstone Farm site, show the effect on the performance of winter wheat of a severe compaction pan in a drained field. During moling, the pan was disrupted locally every 2m, sufficient to allow the mole drains to function, but most of the pan was left largely undisturbed. Despite some drainage, the pan restricted rooting during the winter, largely to the top 20 cm, and there was little improvement in yield compared with the undrained area. Once the pan was shattered, roots developed freely in the top 50 cm during the winter period and significant yield improvements were obtained.

Subsoiling trials at Brooms Barn (Hull and Webb, 1967) on a compact clay loam soil only increased cereal yields by between 1-2%. Loosening was carried out to a depth of 51cm at 1.2m spacing. Waterlogging problems were not serious on this site and it is probable, based on subsequent work by Spoor and Godwin (1978), that the extent of lateral movement and loosening would have been small at this implement spacing and depth.

A review of over 30 North American soil loosening experiments by Burnett and Hauser (1967) and a similar review of other countries by Swain (1975), both indicate varying responses to deep loosening. A major factor influencing response in all the American work was water availability to the crop. In situations where water supply was limiting plant growth, if deep loosening could alleviate this problem, there was a positive response. Where water was not limiting, yield was not usually increased, even in situations where root development had been severely restricted.

The picture on direct drilling sites appears to be similar with only a small proportion of sites giving positive responses. Loosening to depths of approximately 35cm on longer term direct drilling sites (Hipps and Hodgson, 1987) and on some sites not recommended for direct drilling (Davies et al., 1982) did in some cases increase the yield of winter cereals by up to 0.6t/ha. These yield improvements were attributed mainly to improved drainage during wet periods. Yield increases of 12% after loosening in direct drilled spring barley, resulted largely from freer rooting conditions, see Braim et al., (1984).

In the later 1970's, attention turned to investigate the potential benefits of more intensive and complete loosening than was normally achieved with the subsoilers of the day. This work at Wye, Rothamsted, Wellesbourne and Nottingham, looked at whether there were benefits even if no severe compaction problems were present and Rothamsted also looked at responses to the deep placement of P and K fertiliser. The Wye Double Digger was developed at this time as an experimental machine, to allow more intensive loosening treatments to be installed on a larger field scale (Warboys et al., 1976). The results of these experiments are presented in Table 3.5 and demonstrate significant potential for yield increases in cereals and other crops.

The increased yields obtained were associated with even faster rates of root growth, leading to an improved root distribution particularly at depth. The plants were thus better able to exploit water reserves at depth, particularly at times of high water demand and this resulted in improved yields (Rowse and Stone, 1980a, b; Stone, 1982). The increased water availability may not always result in increased yields. Rowse and Stone (1980 a,b) have stated that on the sandy clay loam soils at Wellesbourne, yield increases could only be expected during moderately dry years. In wet years, water is readily available even with poor root systems. In very dry years, the extra water made available by loosening is still insufficient to satisfy the complete crop water demand; hence the yield response is less.

Table 3.5 Crop responses to intensive deep loosening of soils without a compaction problem.

Site/ Soil type	Loosening method	Loosening depth	Crop	% Yield increase
Wye				
silt loam	hand dug	45 cm	Italian ryegrass	89.2
clay			Italian ryegrass	-3.5
silt loam	hand dug	45 cm	barley	14.2
Wellesbourne				
sandy clay loam	excavation and replacement	0.9 m	broad beans	95.2
			potatoes	-3.3
sandy clay loam	Wye Double Digger	45 cm	potatoes	7.9
			broad beans	6.6
			cabbage	15.1
			red beet	27.0
Rothamsted				
sandy loam	hand dug	46 cm		
without deep P and K			wheat	21.0
			barley	24.0
with deep P and K			wheat	21.0
			barley	46.0

Wye: El-Karouri & Gooderham (1977), Fisher *et al.* (1975)
Wellesbourne: Rowse & Stone (1980a), Stone (1982)
Rothamsted: McEwen & Johnston (1979)

At the completion of the Wellesbourne loosening experiment, the soil was ploughed using a single furrow plough with the tractor wheel in the furrow bottom. This wheeling on the previously loosened soil effectively eliminated the previous yield increases, highlighting the need for traffic control after loosening. (NVRS Annual Report 1979). Techniques for minimising the risk of a loosened soil being recompacted by subsequent tractor wheel traffic were investigated by Soane *et al.* (1986). The experiments were carried out on a light loamy soil. Soane examined the effect on the extent of recompaction following loosening, of wheeling with low or high pressure tyres in situations where deep loosening was carried out before, after and simultaneously with ploughing. The only method under those conditions which left a satisfactory final loose subsoil, was simultaneous ploughing and loosening followed by low pressure tyres. Deep loosening followed by ploughing and subsequent random wheelings caused significant recompaction.

Following the success, in terms of yield increase, of the intensive loosening technique in the small scale trials, ADAS and Silsoe College during the 1980's investigated its potential under commercial conditions on 16 sites, examining 42 site years of experience. Crop performance following intensive deep loosening to 45cm depth, with and without deep placement of P and K fertiliser, was compared with an unloosened control. Loosening was achieved using a Wye Double Digger and a winged subsoiler with closely spaced tines to give complete loosening. Yield responses of the crops tested are presented in Table 5.6 (Marks and Soane, 1987).

Table 5.6 Yield response of crops to deep loosening and deep incorporation of P K fertiliser.

Crop	Number of sites years	Yield responses to deep loosening			Yield responses to P K placement	
		+ve	0	-ve	topsoil incorporation	deep placement
Winter wheat	10	0	8	2	0	0
Winter barley	3	0	3	0	1	1
Spring barley	10	2	7	1	1	3
Oilseed rape (autumn)	1	0	1	0	0	0
Vegetables (autumn)	3	0	1	2	0	0
Vegetables (spring)	3	0	3	0	0	0
Sugar beet	5	3	1	1	3	3
Potatoes	7	1	4	2	3	3

No yield increases occurred with autumn sown crops, which were grown largely on medium and heavy soils. These crops did not suffer severe drought stress and soil shrinkage on drying created rootable pores through any compacted layers. The major positive responses were on light sandy soils growing spring crops in years of moderate to severe drought. Spring barley yield increases ranged from 4% for the winged subsoiler to between 10-20% for the Double Digger. Yield depressions occurred on the silty soils in wet years. These were associated with instability of the structural aggregates, and the yield depressions were greatest with the double digger (20% with spring barley). A greater response to deep placed than to surface applied P and K, occurred on only one site, a light sandy soil.

The yield increases obtained on this commercial scale were therefore, considerably less than in the smaller scale experiments. It was suggested that part of this difference could be due to the substantially higher nitrogen rates used in the large field trials as compared with applications in the small scale tests. The higher nitrogen application overcame some of the problems associated with compacted soils. Responses only occurred on sites which had easily identifiable compaction problems. Where the problem was only marginal, no positive response was obtained.

The ADAS/Silsoe College experiments also monitored the initial degree of soil compaction and the longevity of the loosening effect (Soane et al, 1987). The rate of recompaction was least with controlled traffic and bed systems and increased with random traffic and with the growing of root crops. On sites subjected to random wheelings, the subsoil density approached that of the unloosened areas in the third season after loosening.

None of the experiments reviewed, quantitatively assessed the possible timeliness benefits achievable through soil loosening, as a result of improved drainage. Many however, mentioned that it would have been possible to carry out operations earlier on the loosened areas.

FACTORS INFLUENCING RESPONSE TO LOOSENING

From the review of past loosening experiments it is very apparent that positive benefits from loosening are by no means guaranteed and in many cases there could be no benefit at all, or even a depression in yield. The following factors can, however, be identified, as having an important influence on the magnitude of any crop response to soil loosening:

1. Magnitude of existing compaction problem.
If no compaction problem exists, there is unlikely to be a positive response to soil loosening. Unless nitrogen status is low, soils with only marginal compaction problems are unlikely to respond.

2. Ability of soils to re-structure naturally.
Compaction problems in clay soils which shrink significantly on drying may be overcome by natural forces in a dry year. Adequate subsurface drainage is a pre-requisite for this re-structuring and loosening may be necessary to help provide this.

3. Efficiency of loosening operation.
If satisfactory loosening is not achieved, a positive response is unlikely. Loosening implement type, adjustment and soil conditions are critical in this respect.

4. Rate of compaction.
Benefits can only be expected in situations where recompaction does not occur. Wheel traffic after loosening is the major cause of recompaction on most soils and needs to be kept to a minimum. Excessive soil disturbance in soils with weak structural aggregates, e.g. low organic matter, fine sands and silts, will encourage slumping and recompaction on wetting. Very severe wetting immediately after loosening may cause slumping and hence compaction, even on soils with fairly stable structural aggregates.

5. Subsurface drainage status.
Good subsurface drainage is needed to maximise the benefits from loosening operations. Loosening without adequate subsurface drainage can cause severe waterlogging, soil slumping and equipment support problems.

6. Subsequent weather conditions.
Unless the subsequent weather conditions are likely to cause damaging waterlogging or significant drought conditions, loosening will be of little value. In situations where drought conditions are very severe, loosening may still be of little benefit if the additional water made available through deeper rooting is still inadequate. These latter conditions are most likely to arise on light sandy soils in dry areas. The conclusion of the work of Cannell et al, (1978) and Goss et al, (1984) at Letcombe Laboratory was that winter wheat yields are unlikely to suffer as a result of drought on clay soils, unless root development is severely restricted. Winter cereals are much more tolerant to the effects of compaction than spring cereals.

7. Timeliness benefits.
Maximum benefit from loosening operations to overcome waterlogging problems will only be achieved if full advantage is taken of the opportunities for more timely operations. Spring crops are likely to benefit most.

GUIDELINES FOR FUTURE LOOSENING OPERATIONS

Past loosening work offers the following guidelines for efficient worthwhile soil loosening operations in the future:

1. Check to ensure a real compaction problem exists before loosening.

2. If the problem is only marginal there is unlikely to be any benefit from loosening, providing nitrogen status is good.

3. Loosening should only be contemplated in a marginal situation, if the problem is likely to become rapidly worse, and weather and soil conditions are currently suitable for the operation. Favourable conditions for loosening may not occur later.

4. Subsurface drainage should be adequate before loosening.

5. Check to ensure the desired degree of loosening is being achieved; adjust the equipment accordingly.

6. Loosening to improve drainage has highest priority on heavy soils and to improve rooting depth on lighter soils.

7. Minimise traffic on loosened soil to avoid rapid recompaction.

4. IDENTIFYING COMPACTION PROBLEMS

Past loosening experiments confirm that unless there is a real compaction problem present, which is impeding water movement and root growth, postive responses to soil loosening are unlikely. Thus to avoid unnecessary loosening operations, confirmation that problems do exist is necessary and this can only be achieved by examining the soil profile itself in the field.

Timing of field investigations

The best time to investigate a field for compaction problems is when the established crop should be rooting at maximum depth and roots should be growing actively. Late May and June are ideal for this with winter sown crops and June and early July for spring ones. At these times, the soils are usually still moist and easily handled and the young actively growing roots can readily be seen. Autumn after harvest is not such a good time for investigation as time is limiting, roots are dying off and hence more difficult to see, and the soil is sometimes dry and hard, which in turn makes the identification of compaction difficult.

Site selection for soil examination

The past traffic, cultivation and harvesting history of a field is often the best indicator as to whether potential compaction problems, justifying investigation, are likely to exist. Problems are most likely to be present if work has been conducted under wet conditions with significant wheel rutting or slip, if drainage has been poor. Investigation is also difficult if the crop has suffered from drought in a dry period.

The sites chosen for investigation in fields where there is thought to be a problem, should be representative of large areas of the field, and gateways, old tracks and hedge lines etc. avoided. If crop variations are present either in patches or strips, choose an area where the crop is good and another where it is poor. Look at both, and if soil conditions and rooting are the same, with good root development, then compaction is not the problem. If they are different, with poor rooting in the bad area, compaction is likely to be one of the factors causing the trouble.

Digging and preparing the pit

Soil pits should be opened up to depths greater than is needed for investigation (40-50 cm), the extra depth catering for soil that will fall in during the observations. The pits can be dug either by hand or machine. If dug by hand, the uniformity, moisture content and strength of the soil as it is dug out should be noted. If the soil is not too stony the ease with which the spade can be pushed into the soil will give an indication of the soil condition and the presence of any compact layers. If a machine is used, it must be remembered that the bucket will disturb soil at the side of the pit. In this case, one vertical face must be cut back about 25-30 cm with a spade, to obtain an undisturbed face. The face to be investigated should then be cleaned up, by flicking off any smeared sections using a knife or spade.

General observations

The prime aim when looking at the soil face is to see whether there is any particular layer which is preventing root or water movement downwards. If any such layer is identified, its depth should be noted, since this will determine the required depth of any subsequent loosening operation. there are two sets of indicators which are helpful in identifying problem areas; one group is associated with the soil itself and the other with plant root behaviour.

The first job is to identify the depths down the face where changes in soil conditions occur. Look particularly for pans at the previous cultivation depth and for conditions where the soil is compacted from the surface layers downwards. Note the development of the roots, their depth, form and distribution down the face and relate this to changes found in the soil conditions. Once the boundaries between the different soil conditions have been identified, each layer should be examined in turn to assess its looseness or tightness and hence its suitability for rooting and water movement.

Soil observations

The soil condition is best assessed by taking out an undisturbed spadeful of soil from each layer. The spadeful should be isolated from the surrounding soil by vertical cuts before being removed. After removal the undisturbed soil block should be broken apart carefully by hand along its weaker planes, to expose the soil units. If a pan is present the looser soil on either side of it will break away easily, as similarly will the looser soil below a compact upper layer.

Where the spadeful can only be broken with difficulty into soil aggregates or, even worse, into smaller sharp cornered units, rooting is likely to be very severely restricted. Soil loosening will be necessary in these situations, unless this tight soil layer contains numerous earthworm channels, old root channels or shrinkage cracks or fissures, down which roots and water can move. The actual rooting in the layer will confirm one way or the other, whether action will be necessary.

Any sudden changes in moisture content down the face are often indicative of a restricting layer. A restricting layer will hold up water and in extreme cases there may be a smell of bad eggs, blue colourations or if straw is present, the straw will remain unrotted. Reddish colourations in recent root channels also indicate waterlogging problems, due to compaction or inadequate drainage.

Root observations

Where it is difficult to decide whether the soil condition is acceptable or not, observations on root development in the different layers will help clarify the situation. Sudden changes in the quantity of root down the face indicate changes in the soil condition. The presence of only a few roots in tight layers, or if the roots are much shallower than would normally be expected, indicates compaction problems that need to be rectified.

Root shape and colour and also helpful. Under good rooting conditions, cereal roots are white in colour and long and slender. Conversely, if their growth is restricted, they will be yellowish and short and stubby. The tap root of crops like sugar beet should go straight down. Any significant sideways movement of fanginess is a clear sign of a restricting layer. Similarly, the sudden horizontal deviation of a large mas of roots indicates that a pan has been encountered. Roots squashed between the faces of soil aggregates as the undisturbed spadeful of soil is opened up, also confirm the presence of a restricting layer.

Decisions of soil loosening requirements

The findings at one site need to be checked in other parts of the field to ensure they are representative. Three of four pits per field are usually appropriate. There is usually most damage in gateways, headlands and tramlines and in some cases loosening operations may only need to be concentrated there. Where a problem needing attention has been identified the depth to which the problem occurs should be noted.

Where there is a delay between the soil investigation and the time for carrying out the loosening operation, further changes in soil condition may occur. Marginal or severely compacted situations at the time of the investigation may improve. This is most likely to occur on swelling and shrinking clayey soils in dry years, when further drying will cause much more cracking, alleviating the compaction problem further. In these situations, in soils where the aggregate faces in the problem layers are rough rather than polished and cracks extend to this depth, the soil will have cured itself and no loosening will be required. Where the aggregate faces are highly polished, however, soil disturbance will still be advisable unless the cracking is severe. Loosening in this situation will cause aggregate re-arrangement so reducing the risk of the soil reswelling into a tight condition. Sandy and silty soils are unlikely to change or improve with time in this way. If soil loosening is needed at the time of observation, it will still be needed after harvest.

Further compaction problems may occur at harvest, depending on the equipment used and the soil conditions. The extent of these problems can be readily identified from the depth of surface rutting, and soil loosening decisions modified accordingly.

This loosening type of movement continues until a certain critical working depth is reached. Once working depth exceeds this critical depth, the soil at depth moves sideways rather than upwards and becomes compacted rather than loosened. For satisfactory soil loosening the tool must work above critical depth.

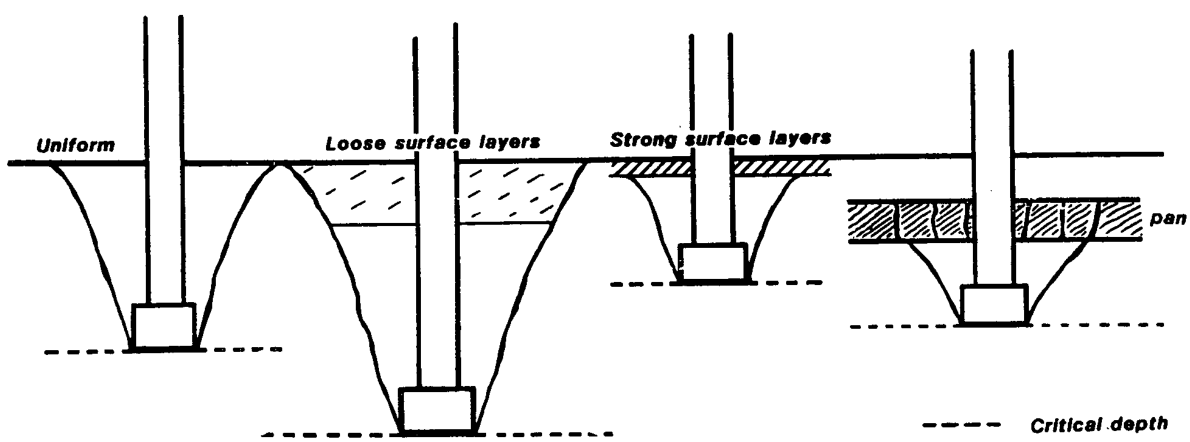
Similar changes in soil disturbance occur with other types of loosening implement when their critical depth is reached (Spoor and Godwin, 1878), (see Fig. 5.2).

FACTORS INFLUENCING THE CRITICAL DEPTH

Unfortunately there is no one critical depth for an implement since it varies with the soil conditions. It can range from near the soil surface to depth of about 0.5m or more. Critical depth tends to increase as soils become drier and more compact, but the condition of the layers above the zone to be loosened also has a major influence. Loose surface layers increase critical depth whereas strong compact surface layers decrease it (see Fig. 5.3).

A strong pan has a similar effect to compact surface layers reducing the critical depth of the implement working below it. (see Fig. 5.3).

Figure 5.3. Effect of surface soil layer condition and subsurface pans on critical depth.



Critical depth is also sensitive to the width and inclination of the working share of an implement. The wider the share and the greater its forward inclination, the deeper the critical depth. As tine share inclination is often 20^{o}-25^{o} and cannot be reduced practically, the critical depth can be increased most easily by:

(1) increasing the width of the leading share on the tine.
(2) loosening the surface layers before deeper loosening.

NARROW TINED IMPLEMENTS

This group comprises of traditional subsoilers and chisel plough and cultivator type implements, all being distinguished by having a relatively narrow (50 - 100mm wide) leading share. The leg may be of similar width to the share as in the case of chisel type tines or narrower as with traditional subsoilers.

The soil disturbance caused by these tines is shown in Figures 5.1 and 5.2. These figures show that when working above critical depth the soil disturbance is progressive with the share disturbing the soil first, followed by the leg splitting the disturbed zone in half causing further disruption. This leg action tends to roll clods out at the surface particularly under drier conditions. Clod production can be reduced and often eliminated in the case of the traditional subsoiler by running a vertical disc ahead of the leg or by inclining the leg backwards. This is not possible with the wider legged chisel/cultivator tined implements. The wider leg on these implements means, however, that the depth of loosening when working below critical depth is greater than with the traditional subsoiler tine (see Fig. 5.2).

SIDEWAYS INCLINED IMPLEMENTS

With these implements, notably the Paraplow, the leg is inclined both sideways and forwards at angles of approximately 45^{o}. This means that the leg does not split the soil loosened by the leading share in half as in the case of the traditional vertical legged subsoiler. Instead, the leg runs in the disturbance crack produced by the share as is shown in Fig. 5.2. This reduces both soil disturbance and the draught force. Rearrangement of the disturbed soil can be increased with this implement by increasing the inclination of the flap at the rear of the leg. This tends to bend the soil as it flows over, placing the soil in tension and increasing the fissuring. A disc at the same inclination and ahead of the leg helps reduce clod production at the surface.

WINGED TINE IMPLEMENTS

Winged or sweep type tined implements come in various forms, but the major differences between them lie in the vertical lift given to the soil as it flows over the wings and the overall width of the wings (see Fig. 5.4).

5. SOIL LOOSENING IMPLEMENTS AND THEIR ACTION

There is a wide range of soil loosening implements available, each type having its own special features which can be important in specific situations. The range can be divided conveniently into implements fitted with the following types of tine:

1. narrow
2. sideways inclined
3. winged
4. shallow leading
5. plough mounted
6. vibrating

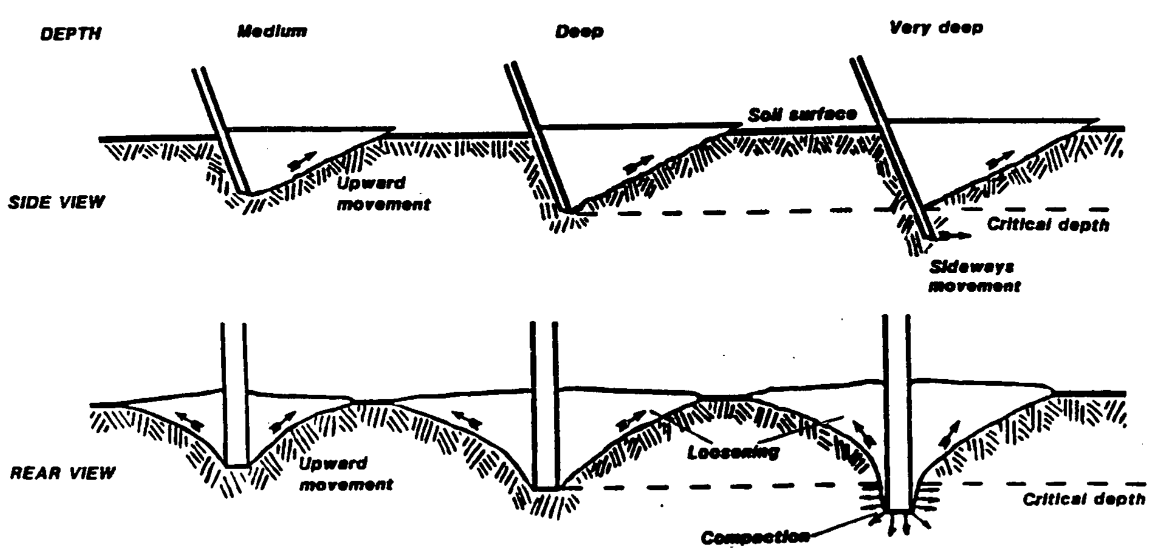
Although differing in detailed design and action, all the implement types have one common and most important feature, namely, if operated at too great a depth, no satisfactory loosening will be achieved. Their maximum useful working depth is dependent upon their "critical depth" (Godwin and Spoor, 1977), under the prevailing conditions.

CRITICAL DEPTH

Before soil can be loosened it must move into a space where it can expand. This usually means moving the soil upwards towards the surface. Unfortunately the same implement does not always deform the soil in this desired way. Two basic types of soil disturbance are possible, one useful, the other useless.

These can best be illustrated by considering the disturbance caused by a chisel tine of uniform width working at different depths (see Fig. 5.1). When the tine is working relatively shallowly, useful upward soil movement occurs both ahead of and at the side of the implement.

Figure 5.1. Types of soil disturbance produced by a chisel plough type tine operating at different working depths.



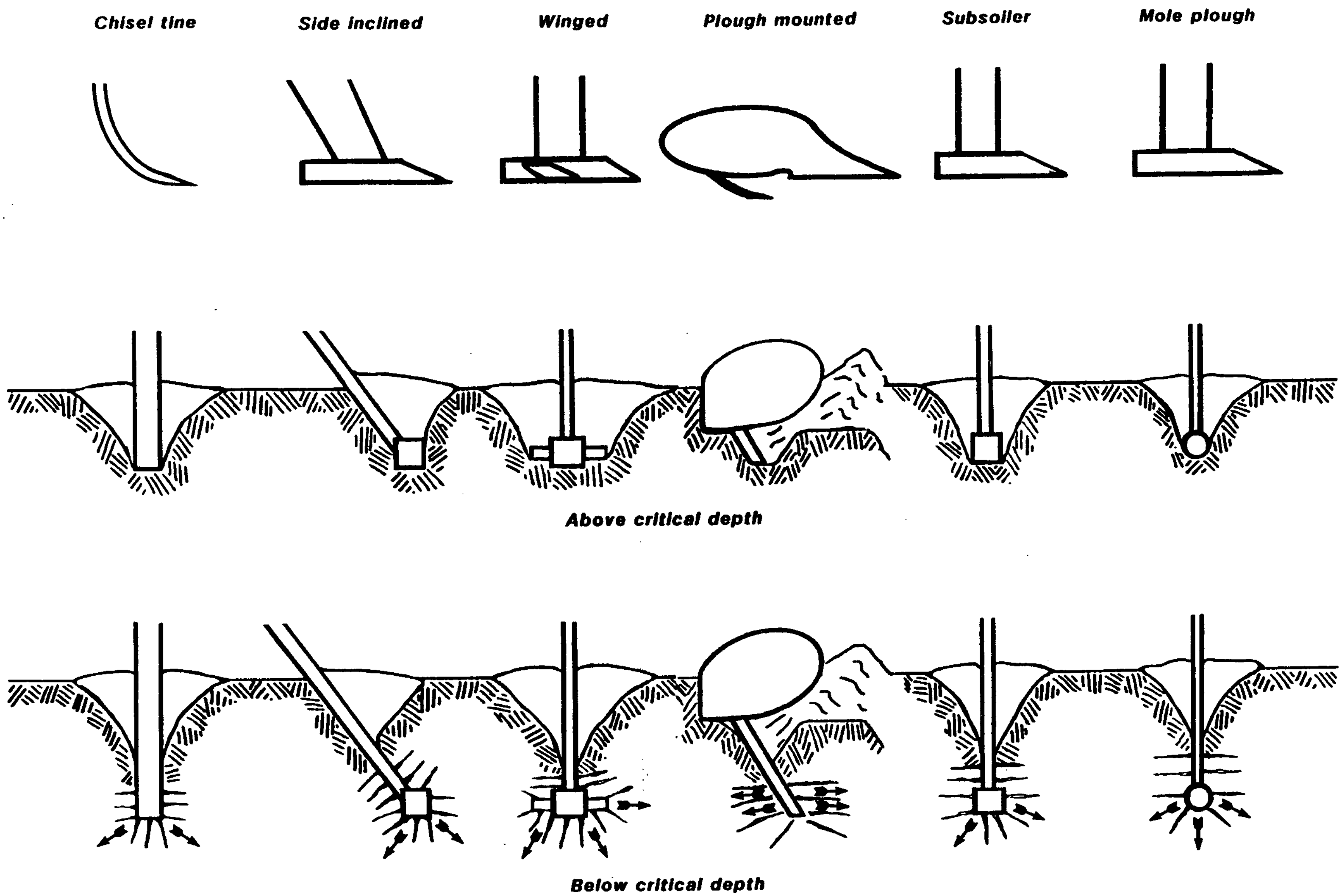
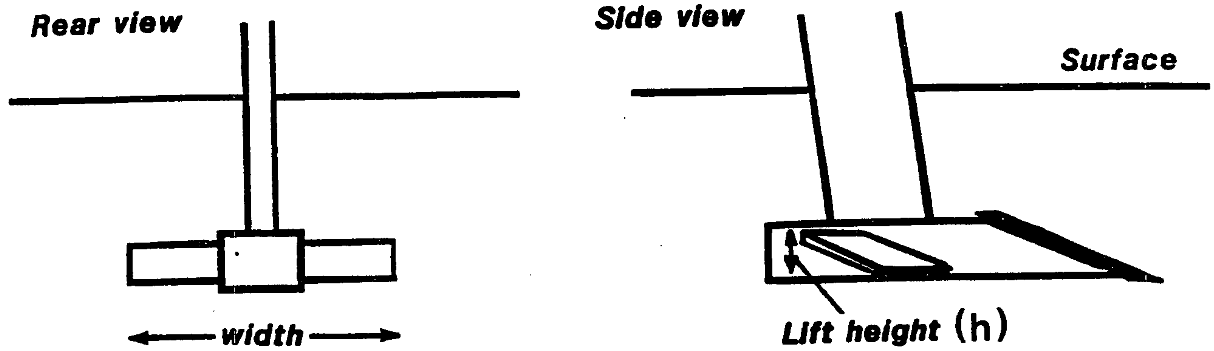


Figure 5.2 Soil disturbance with different types of implement working above and below critical depth.

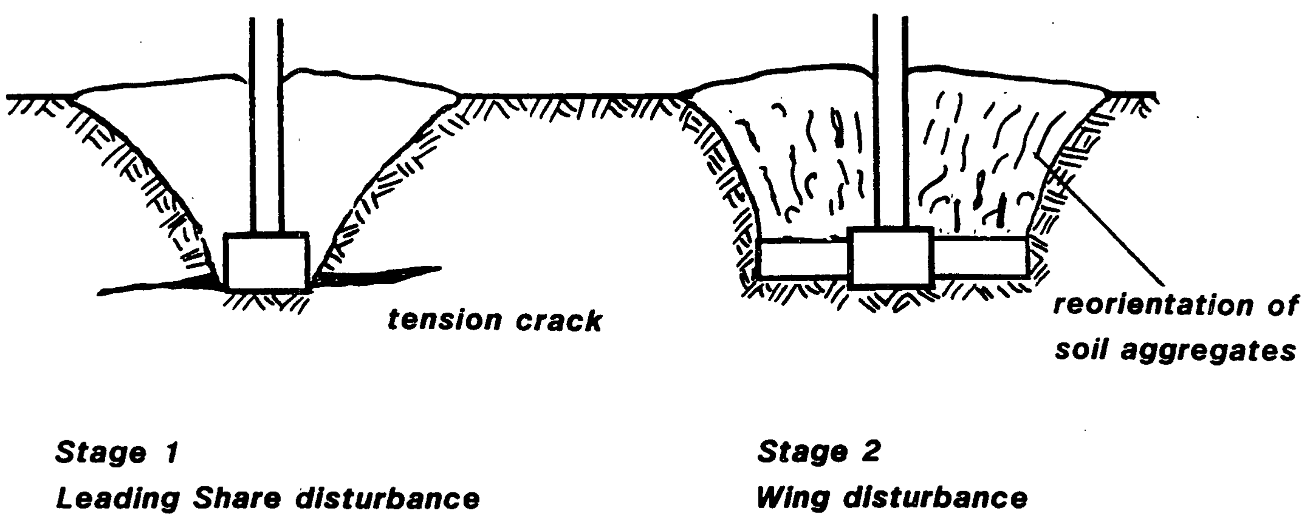
Figure 5.4. Major factors affecting wing performance.



The vertical lift can vary from 150mm down to approximately 25mm and the overall width from approximately 200mm to 350mm. The most common width is 300mm. Some models offer the facility for varying the wing lift height. The optimum position for the wings is when their lower edge is approximately 25mm above the working depth of the leading share.

The disturbance caused by winged tines takes place in two stages, the first due to the leading share and the second due to the wings themselves. This is shown in Figure 5.5. The wings increase the soil disturbance at working depth considerably for a relatively small increase in draught (approximately 15-20%), thus increasing the overall efficiency of the loosening operation. In addition, they tend to increase the reorientation of soil aggregates and clods at working depth.

Figure 5.5. Soil disturbance initiated by winged tines.

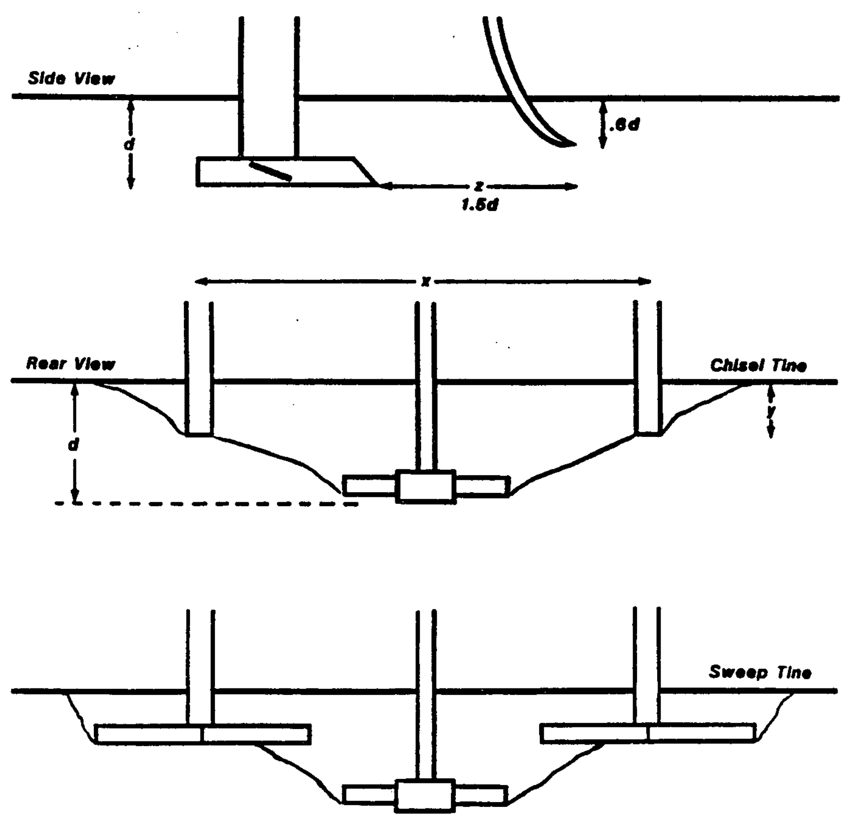


The action of the wings is also to place the soil in tension, which can generate vertical tension cracks as shown in Fig. 5.5. The actual generation and extent of these tension cracks is dependent in given soil conditions on working depth and on the lift height (h) of the wings (Fig. 5.4). The greater wing lift height at a given working depth, the more extensive the crack development and the more open and looser the final soil condition. Conversely, fissuring decreases with increasing working depth or decreasing lift height until critical depth is reached and fissuring ceases. Soil surface disturbance is considerable when an open loose condition is produced and it is frequently associated under dry conditions with a cloddy surface. Minimal fissuring on the other hand with lower lift height wings or increased working depth does not significantly disturb the surface layers or expose clods. The adjustment of wing lift height or working depth therefore enables a wide range of soil surface conditions to be achieved whilst still fissuring the soil mass at depth. The critical depth of winged tine implements increases with increasing wing lift height. The attachment of high lift wings (100mm lift) to a traditional subsoiler would increase the critical depth of the implement by approximately 50mm.

IMPLEMENTS FITTED WITH SHALLOWER WORKING LEADING TINES

Shallower working leading tines are available as both narrow chisel and sweep type tines, working ahead of the deeper tines, which may be winged or non-winged (see Fig. 5.6). The shallower tines loosen the surface soil layers first, making it easier for the deeper layers to move upwards. This increases critical depth, the overall degree of soil loosening and rearrangement, and soil disturbance at the surface.

Figure 5.6. Effect of shallow leading tines on soil disturbance.



The positioning of the shallow chisel tines relative to the deep tines influences the efficiency of the operation. Optimum tine positions are given in Table 5.1. These positions allow maximum soil disturbance for minimum energy input and do not increase overall draught when compared with the draught of deep tines working alone. The wider tine positions are more appropriate under drier soil conditions.

Table 5.1. Tine spacings for deep loosening with leading chisel type tines.

	Tine spacing Conventional subsoiler	Tine spacing Winged subsoiler
Between shallow tines (x)	1.5 - 2.0D	2.0 - 2.5D
Depth of shallow tines (y)	0.5 - 0.7D	0.5 - 0.7D
Forward spacing head of deep tines (z)	at least equal to D	
Spacing between adjacent deep tines	1.5 - 2.0D	2.0 - 2.5D

D = working depth of deep tine
(see Fig. 5.6 for dimensions)

Whilst the extent of soil loosening at depth can be increased by using shallower chisel type tines, this is not the case with shallow sweep type tines (see Fig. 5.6). The main function of the sweep type tines is to loosen the surface layers completely, without bringing clods to the surface or top soil falling into the locally loosened subsoil zone. The degree of surface disturbance depends upon the vertical lift height of the sweeps, their working depth and soil conditions (as discussed in section on winged type tines, page 22).

Shallow and deep tine combinations are most suited to situations where compaction problems are very deep or where strong-dry surface layers overlie weak-moist soil. Shallow chisel tines are not very appropriate where the need is to loosen the soil without exposing significant surface clods.

PLOUGH MOUNTED TINES

These tines, which are fitted to the plough frog, allow loosening below ploughing depth. They operate in the furrow bottom whilst the furrow slice is being inverted and so effectively have a relatively shallow working depth. Adjustments are frequently available for these tines to operate at depths between 50mm and 150mm below ploughing depth. Whilst these adjustments are available, it must be emphasised that the forces when working at depths greater than about 75mm can cause very large bending stresses at the leg and frame which may damage the plough. Tines are not normally fitted to the rear mouldboard, since any loosening there would be recompacted by the tractor furrow wheels on the next bout.

The soil disturbance caused by these tines in shown in Fig. 5.2 and is ideal for the local shattering of a plough pan or for removing any plough share smear when ploughing under wet conditions.

VIBRATING TINE IMPLEMENTS

Two types of vibrating tine implement are available:
(a) where a p.t.o. driven eccentric mass is fitted on to the implement frame inducing vibration into the complete implement e.g. Shakaerator.
(b) where the tine share and sometimes also the leg are positively vibrated during forward travel.

Vibration offers, for an increased power input, the potential to increase the extent and degree of soil disturbance and to reduce the draught. The magnitude of the benefits actually achieved is very dependent upon the power input into the vibrator, soil conditions and implement design. Power inputs into the type (a) implements are relatively small and hence benefits from the vibration are really only noticeable when operating close to the limit of traction. Draught reductions up to 40-50% have been measured with some type (b) machines allowing smaller tractors to be used.

Vibration is more effective in increasing soil disturbance in dry and structured conditions than under moist plastic conditions. The disadvantages of type (b) machines are the initial higher cost, higher maintenance costs and the problems of vibration transmission to the tractor, implement and operator.

INFLUENCE OF TINE SPACINGS ON SOIL DISTURBANCE AT DEPTH AND AT THE SURFACE

The spacing between loosening tines influences the uniformity of soil loosening at depth and the levellness of the final surface condition. A uniform depth of loosening across a field leaves a level surface. At wide spacings, tines act independently, but as their spacing is reduced a more uniform soil disturbance results together with a level surface finish (see Fig. 5.7). This spacing effect is similar for all types of soil loosening tine.

The tine spacing actually chosen will depend on whether complete or local breakout is required at working depth and on whether the final surface condition must be level. Tine spacings for the different types of loosening implement to give almost complete loosening at depth with a level surface are given in Table 5.2.

The narrower spacings in Table 5.2 are more appropriate under wetter soil conditions and the wider under dry. Whilst very close spacings will give complete loosening at depth and level surfaces, the spacings suggested in Table 5.2 are optimal to maximise the disturbance for a given draught.

Figure 5.7. Influence of tine spacing on the uniformity of soil loosening and levellness of surface.

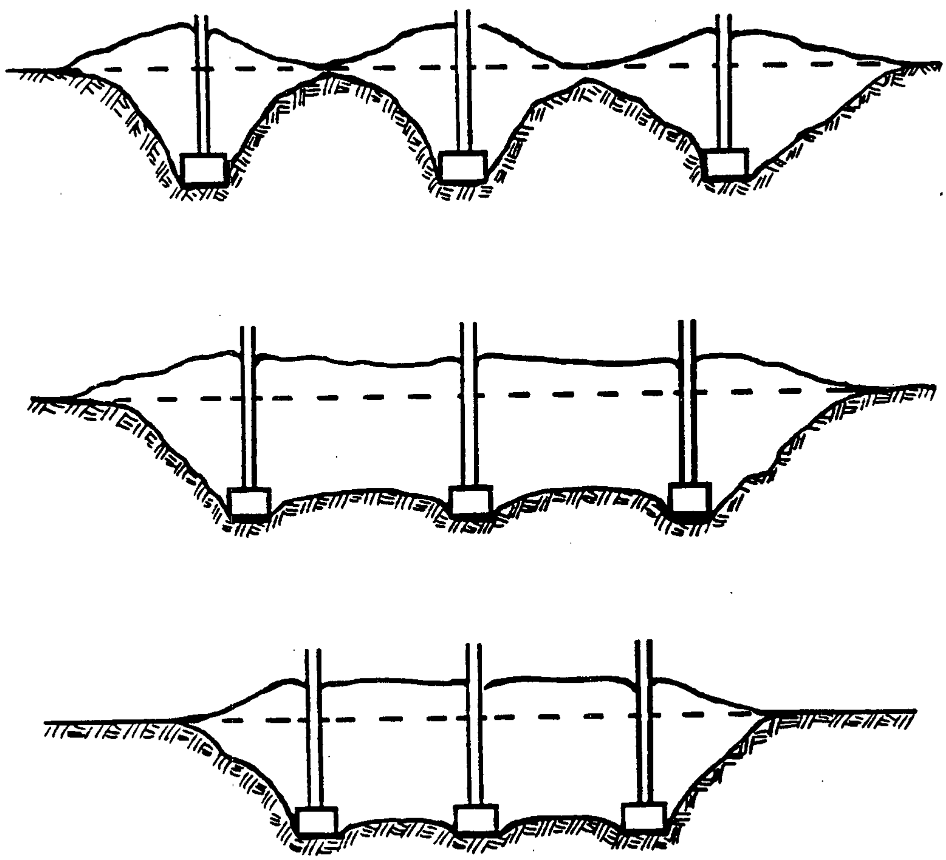


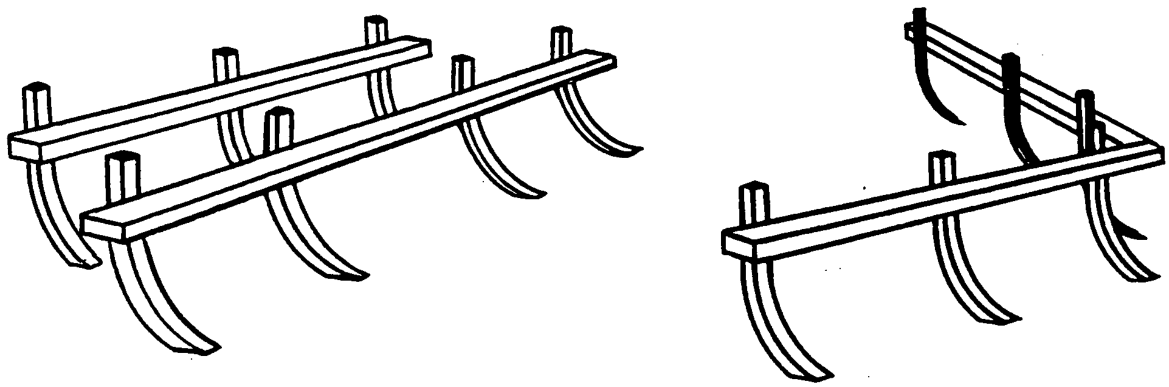
Table 5.2. Tine spacings for complete loosening at depth and level surface conditions.

Type of subsoiler	Tine spacing
Narrow tine	1.0 - 1.5 d
Sideways inclined tines	1.0 - 1.5 d
Winged tine	1.5 - 2.0 d
Vibrating share type	1.5 - 2.0 d
Narrow deep tine with shallow leading chisel type tines	1.5 - 2.0 d
Winged deep tines with shallow leading chisel type tines	2.0 - 2.5 d

d = working depth of deepest tine

Tine stagger on the toolframes is necessary to avoid blockage, help trash flow and avoid the bending of tine legs. Two common stagger patterns are shown in Fig. 5.8. Both are satisfactory and there is little difference in the efficiency of either.

Figure 5.8. Stagger patterns of tines

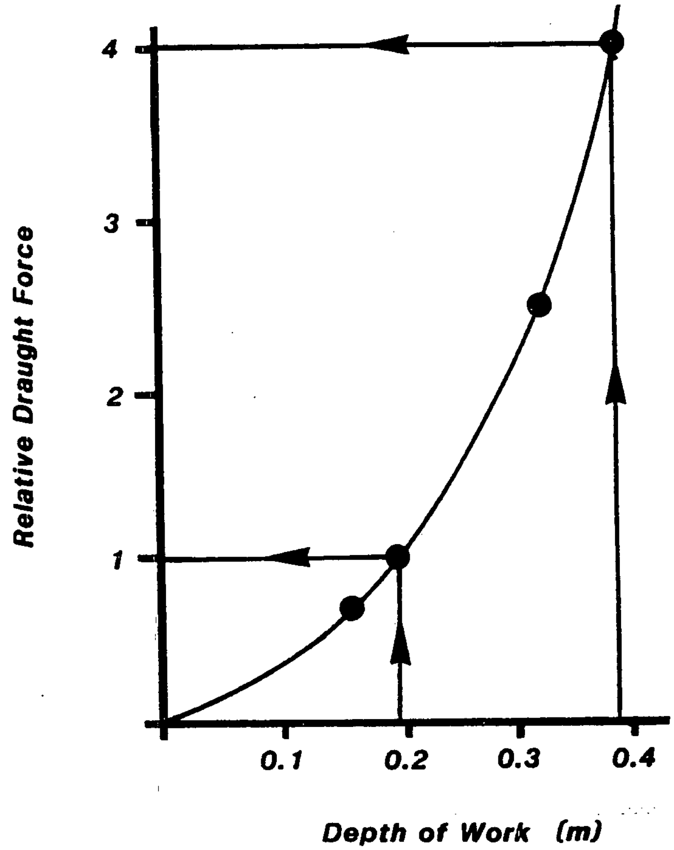


DEPTH CONTROL DURING LOOSENING OPERATIONS

The draught required to operate any given loosening implement is very dependent upon its working depth. Draught increases very rapidly with increasing depth as can be seen in Fig. 5.9; hence the penalties from working deeper than necessary are great. Doubling the working depth increases the draught four times.

The depth of work can be controlled by the tractor hydraulic system, by depth wheels or crumbler rolls. Control by the tractor hydraulics is the most efficient from a traction point of view and hence should be adopted wherever possible. Depth wheels provide good positive control providing they are operating on firm undisturbed soil. Their performance on loosened soil is very poor. When using depth wheels, care must be taken to ensure they are not fitted closely ahead of a deep working tine, or they will tend to hold down the soil which the tine is attempting to lift upwards, increasing draught unnecessarily. Crumbler rolls provide much more positive depth control than depth wheels on loosened surfaces. In addition they assist with clod breaking and firm the surface layers to provide more support for subsequent traffic operations. Their disadvantage is that they are susceptible to blockage when operating under moist soil conditions.

Figure 5.9. Draught requirements at different working depths.



COMPARATIVE PERFORMANCE OF DIFFERENT IMPLEMENT TYPES

All of the equipment available is capable of loosening soil satisfactorily when suitably adjusted and working under appropriate conditions. Nevertheless, differences do exist between the equipment types, influencing their operating efficiency and working range. The most appropriate measure of operating efficiency is the area of soil disturbed for a given draught. Comparisons are made in Figure 5.10 of the actual soil disturbances and relative efficiencies and draught of conventional, sideways inclined, winged and shallow leading tine subsoilers, operating at the same depth and creating a moderate degree of soil loosening.

Other important operating features of the different types of equipment are compared in Table 5.4.

Figure 5.10. Relative efficiency of different types of equipment.

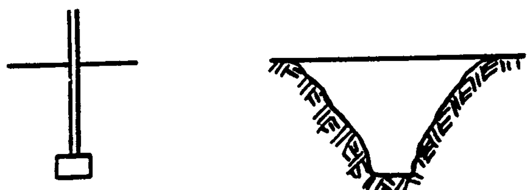
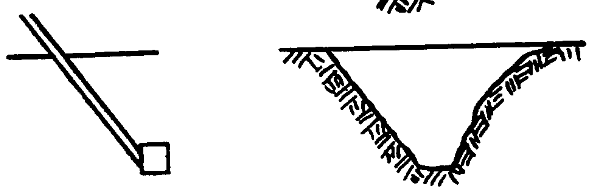
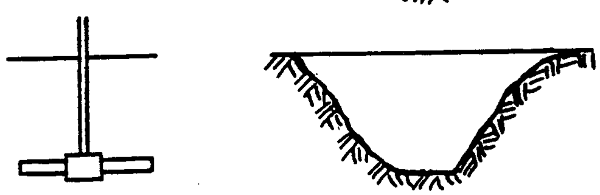
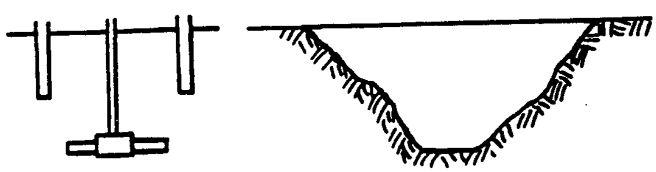
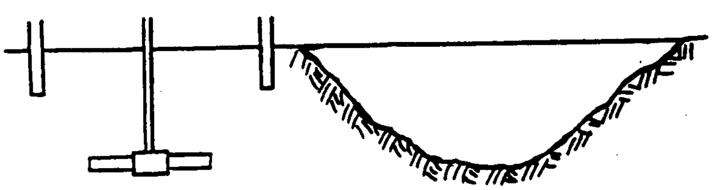
Type of Equipment / Soil Disturbance	Disturbed Area	Draught	Relative Efficiency (Disturbed Area / Draught)
	10	10	1.0
	10	7.5	1.3
	20	12	1.7
	23	10.5	2.2
	36	12	3.0

Table 5.4. Comparison of the operating features of the different types of loosening equipment (particularly advantageous features underlined).

	Narrow chisel and traditional subsoiler tines	Sideways inclined tines	Winged tines tine	Shallow leading tines	Plough mounted tines	Positively vibrated
Critical depth	Shallow	Shallow	Moderate	Deep	Shallow	Moderate
Pull/unit of soil disturbed	High	Moderate	Moderate	Low	Low	Low
Pull	High	High	High	High	High	Low
Power requirement	Moderate	Moderate	Moderate	Moderate	Moderate	High
Maintenance	Low	Moderate	Moderate	Moderate	Moderate	High
Range of operating moisture conditions	Narrow	Moderate	Moderate	Wide	Wide	Moderate

6. SELECTION OF EQUIPMENT FOR THE FARM

There is a wide range of equipment available for deep loosening- hence the need to select the most appropriate type for alleviating the problems likely to occur in the particular farm situation. Four major points need to be considered when deciding upon the type and size of implement required. These are:

(1) working depth range needed
(2) degree and extent of loosening required
(3) surface conditions required
(4) power unit available

The first three considerations influence the type of equipment selected and the latter its size.

WORKING DEPTH RANGE

The working depth range needed will be dependent upon the types of compaction problem existing or likely to arise, and these problems, as discussed in Section 2, tend to fall into the following categories:

1. (a) Compaction caused by traffic running on the soil surface. Here the problems will be in the surface soil layers, frequently within the top 20-30cm, but increasing with higher loads and pressures.

(b) Compaction by surface traffic when excessive wheel sinkage occurs. The compaction depth in this case will be approximately rut depth plus the compaction depth referred to in (a) above.

2. Compaction in the furrow bottom during ploughing, resulting from wheel slip and loads on the furrow wheel. The compacted zone here will be approximately 10-15cm below ploughing depth, the actual depth depending upon tractor weight.

3. Pans formed by the regular working of implements at the same depth. These pans extend to about 5-7cm below the implement working depth and are commonly found after the use of discs, tined implements or ploughs at the same depth over a number of years.

4. Natural compaction at depth in the soil, developed at the time of soil formation. This is common on many clay soils and the compacted zone starts immediately below cultivation depth.

To overcome the first three types of compaction, working depths need to be below compaction depth. Four working depth ranges can therefore be specified:

20 - 30cm for problems 1a and 3
25 - 35cm for 1a, 1b and 2
30 - 40cm for 1b and 4
and below 40cm for 4

DEGREE OF LOOSENING

The degree of loosening achievable can range from considerable loosening and rearrangement of the clods and aggregates, to the creation of only a few cracks and fissures through the compacted area. Greater degrees of loosening and rearrangement are needed in situations where there is a high risk that the soil will be recompacted almost immediately by surface loads or natural forces. These situations include the following:

(a) the loosening of naturally compacted layers at depth
(b) when considerable surface traffic is likely to follow loosening
(c) the lighter soils

In all other situations fissuring the compact layers or pans with minimal rearrangement is acceptable, but care needs to be taken however to minimise subsequent traffic, particularly when the soil is moist.

SOIL SURFACE CONDITION

The soil surface condition produced must as far as possible meet future requirements. Two problems which may arise following loosening operations are excessive clod production and the production of a very open uneven surface conditions. The latter in direct drilling or shallow tillage situations will result in the loss of most of the surface tilth down through the cracks. The openness of the surface after the operation is closely associated with the degree of loosening; minimum surface disturbance and clod production corresponding with minimum loosening. At any particular working depth, the openness of the surface and risk of clod production tends to increase with increasing share width and wing and flap lift height, and through the use of shallow leading tines. Discs ahead of the legs and backward inclined legs significantly reduce surface clod problems and sideways inclined legs tend to produce fewer clods than vertical legs. An increase in the working depth with any tine will reduce the openness of the soil surface and the risk of clod production. The same tine therefore, will produce different degrees of surface disturbance and clod production when used at different working depths.

The levellness of the surface profile after any loosening operation is dependent almost solely on the spacing of the tines and not upon the type of equipment used. All implements are capable of leaving even or uneven surfaces depending upon tine spacing. The wider the tine spacing used, the greater the chance of uneven soil surfaces being left. Single tine implements are not particularly satisfactory for leaving level surfaces. This is due to the need for the tractor wheels to run on previously loosened soil to achieve the desired spacing between tine runs.

SELECTION OF EQUIPMENT TYPE

Current loosening equipment can be classified for selection purposes into the following major groups:

1. Chisel and traditional subsoilers with narrow (5-6 cm wide) shares.

2. Traditional subsoilers with wide (7.5-10 cm) shares.

3. Tines with low lift (4-5 cm lift height) wings or flaps, with either vertical or inclined legs.

4. Tines with high lift (10 cm lift height) wings.

5. Tines with high lift wings and shallower working leading sweep tines.

6. Tines with high lift wings and shallower working leading chisel tines.

7. Positively vibrated tines.

8. Chisel tines fitted to mouldboard plough.

Table 6.1 indicates the implements in the different groups above, which are most suited to producing different degrees of soil loosening and surface disturbance within the different working depth ranges. Assessments in Table 6.1 are provided as a working guide for selection purposes and not as indicators of absolute performance in the field. In the field the actual disturbance will vary with changing soil moisture and packing conditions. At any given depth, the degree of loosening and surface disturbance will tend to be greater under drier conditions and less under wet. Similarly the working depth range may be greater than suggested under drier conditions and less under wet.

Table 6.1. Types of equipment suitable for loosening at different depths to give different degrees of loosening and surface disturbance.

Depth range (cm)	Degree of loosening	Surface disturbance	Groups
20 - 30	moderate	moderate	1,8
	high	high	2,3,4,5,6,7
25 - 35	low	low	3
	moderate	moderate	2,8
	high	high	4,5,6,7
30 - 40	low	low	2
	moderate	moderate	4,7
	high	mod	5
	high	high	6
> 40	low	low	7
	mod	low	5
	mod	mod	6

Whenever it is undesirable to bring any clods to the surface, such as prior to direct drilling or when loosening after drilling into a firm surface condition, flat discs to run ahead of the tine legs will be required. Chisel tines and systems with shallow leading tines are unsatisfactory in these situations.

The extent of soil disturbance both at depth and on the surface is much easier to control with winged tines than with chisel or traditional subsoiler types. The disturbance is quite sensitive to small changes in working depth. They are also capable of inducing fissuring at higher moisture contents than other types. Some tines are available with variable wing lift heights and these offer the widest range of adjustments over a large range of soil conditions and working depths.

Equipment with shallow leading tines is most suitable in heavier soil situations, where the surface layers are dry and strong and conditions at loosening depth are moist. The alternative is to loosen the surface layers in a separate operation, before deep loosening.

SELECTION OF EQUIPMENT SIZE

The power available is the major factor influencing the number of soil loosening tines that can be pulled at a given working depth.

The approximate number of soil loosening tines that can be operated over different working depth ranges by tractors within the 30-250 HP range is given in Table 6.2. The actual number of tines will vary depending upon the soil type, its strength (affected by moisture content and the degree of compaction) and the degree of loosening required. The range given should accommodate these variations, with the shallower depth being associated with strong, heavy clay soils requiring significant soil disturbance, and the deeper figures relating to less severe conditions. The depth range quoted is the "true" depth of tillage, namely that measured from the undisturbed soil surface to the working depth of the tine. In many circumstances surface heave of 5-15 cm, depending upon soil condition and machine type, will be observed. This heave is not included in the depths quoted.

Crawler tractors of a given horsepower are generally heavier and can transmit their power to the soil more effectively than equivalent horsepower wheeled tractors. This means that they can either:-

i) Pull 50% more tines at the same depth

or

ii) Pull the same number of tines at a 20% greater depth than the equivalent horsepower wheeled tractor.

Crawler tractors perform best at low speeds whilst wheel tractors are able to develop their full power more effectively at higher speeds and lower draughts and will be more effective with fewer tines. Tine draught will increase with forward speed.

The depths suggested in Table 6.2 deliberately 'err' on the conservative side to avoid disappointment when the tractor/implement combination does not meet the specification as a result of overly optimistic performance figures. It is worth remembering that very small reductions in working depth significantly reduce the draught force and power requirement (see Fig. 5.9).

Table 6.2. Wheeled Tractor Capability for operating loosening tines.

Tractor size		Capability	
Engine power (hp/kW)	Ballasted weight (tonnes)	Working depth range (cm)	Number of tines
30/22	1.5	20-30	1
60/45	3.0	30-40	1
75/56	3.75	35-45	1
		25-30	2
100/75	5.0	40-50	1
		30-35	2
		25-30	3
125/95	6.25	45-55	1
		35-40	2
		25-30	3
150/110	7.5	50-60	1
		35-45	2
		30-35	3
		25-30	4
200/150	10.0	40-50	2
		35-40	3
		30-35	4
		25-30	5
250/185	12.5	45-55	2
		40-45	3
		35-40	4
		30-35	5
		25-30	6

For crawler tractor in same horsepower range increase number of tines by 50% or working depth by 20%.

7. FIELD LOOSENING OPERATIONS

The overall success of field loosening operations is very dependent upon good planning, careful setting up of the equipment available to match the conditions and checks to ensure the desired result is being achieved.

PLANNING CONSIDERATIONS

The following general points for consideration at the planning stage can have an important influence on the overall effectivenss and efficiency of any loosening operation.

1. Existing drainage status of field

In well drained situations, few waterlogging problems are likely to arise as a result of loosening and hence any degree of loosening can be contemplated. Where, however, drainage is marginal or poor, excessive loosening can readily create a "bog" condition. Minimal fissuring should be all that is contemplated in this latter situation, aiding water movement to the existing drains without creating a massive reservoir for water ponding.

Wherever possible, loosening operations should be carried out across the line of subsurface drainage systems. This will provide the shortest route for water to the drains and minimise ponding problems. Many old drainage systems are at a relatively shallow depth and care needs to be taken to avoid disturbing these. Loosening operations should not be closer than 100mm to the top of a mole channel, otherwise the risk of channel damage is great.

2. Sequence of operations

One major reason for poor crop response following loosening is rapid recompaction from subsequent traffic. The closer the loosening operation to drilling therefore, the lower the recompaction risk. Fissuring with minimal surface disturbance after drilling is even safer, as is pan breaking during ploughing.

Fissuring after drilling will be feasible with dry surface conditions in situations where the compaction problems are not too deep and where wheel slip can be kept low. Greater rearrangement of the loosened soil units will be necessary as the amount of post-loosening traffic increases, particularly when soil conditions are moist at depth. Sequencing tillage operations so that the soil is loosened from the surface down moves the deeper operations closer to drilling. It also increases loosening efficiency over the widest range of moisture conditions and reduces the risk of severe surface clod problems on the heavier soils in dry years.

If loosening after drilling is not practicable, the prime aims in sequencing must therefore be to:

(i) work towards the final seedbed condition either before or during the loosening operation or both

(ii) combine other operations with deeper loosening to minimise post-loosening traffic.

3. Operating moisture conditions

Unfortunately, effective loosening cannot be achieved under all moisture conditions and decisions have to be taken as to whether the operation should be delayed or, if not, on the best method to use under the prevailing circumstances. No matter what equipment is available, little useful work can be done when the soil is in a plastic mouldable state. Outside this state the efficiency of the operation will vary with the conditions.

Moisture conditions over the complete working depth range must be considered when assessing soil suitability for loosening operations. The ideal state is one where the soil is moist and friable throughout, a condition where clods break fairly easily. Drier conditions than this require greater energy inputs, with a greater risk of clod problems on heavy soils. Dry, hard surface conditions with moist soil at loosening depth need particular care, for the surface layers can prevent the lower layers moving upwards. The reverse situation with a moist top and dry bottom is ideal, providing wheel slip can be kept to a minimum.

When moisture conditions are far from ideal and the need for loosening is only marginal, serious consideration should be given to delaying the operation for a further year. If however, a major problem exists, a technique which will significantly improve the situation without creating many undesirable side effects, is preferable to one which tries to achieve the ideal condition but also causes other secondary problems.

With a hard dry surface and moist bottom conditions, loosening the surface layers first will improve fissuring at depth. This can be achieved with shallow leading tines when available or through a separate shallower loosening operation. Winged tines and positively vibrated tines will fissure at higher moisture contents than chisel and conventional subsoiler tines. Conventional subsoiler tines can readily be modified into winged tines in these circumstances.

Where severe compaction is present on the heavier soils in a plastic mouldable state, a mole drainage operation to alleviate the problem will be much more satisfactory than attempting to fissure with loosening equipment. The moling operation can be shallower and at closer spacings than is normal for drainage purposes, providing it still connects with the permeable backfill above the pipe drains. It may be necessary to reduce the diameter of the mole foot from 75mm to 50mm to ensure a satisfactory channel is formed at the shallower depth.

SETTING UP EQUIPMENT AND WORKING METHOD

The choice of working method is dependent on the type of equipment and power unit available, the depth of the compaction problem, the required levellness of the surface and whether complete or incomplete disturbance is required at depth. Wherever possible, tractors should be operated on undisturbed soil. This gives better traction, reduces sinkage and avoids recompacting the loosened soil.

Field requirements:

1. incomplete disturbance at depth. (only local disruption of compacted zone)

(a) when adequate power is available to pull the desired number of tines

Space tines at the required spacings, ensuring the tractor does not run on loosened soil. It may be possible to select tine spacings which match the width of the following cultivation implement. This enables the undisturbed strips between the loosening runs to be used as traffic lanes for the following operation, hence avoiding recompaction. Figure 7.1 illustrates this for tractors pulling one and two loosening tines prior to a shallower cultivation operation.

(b) when inadequate power is available to pull extra tines

Loosening the surface layers first will help reduce the draught during deeper loosening operations. In many situations this reduction is sufficient to enable an extra deep tine to be fitted.

Either the complete surface can be loosened or, if a tined implement is used for the shallower surface loosening, some tines can be removed to leave an undisturbed traffic lane. The tractor can run in this lane during the deeper loosening operation. Figure 7.2 illustrates such a situation where the tractor could not pull two tines without the initial surface loosening.

Figure 7.1 The effect of loosening followed by shallower cultivation on soil disturbance.

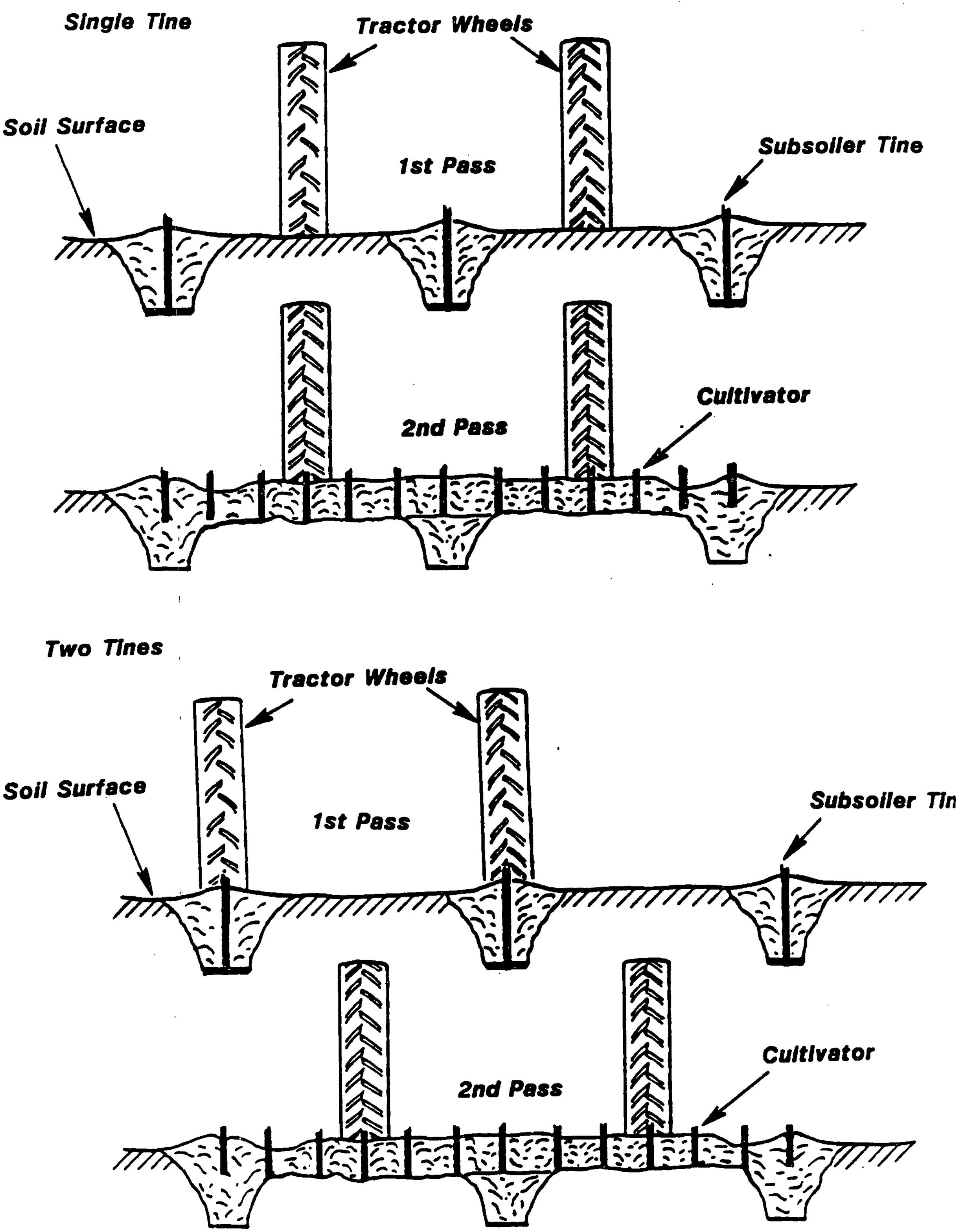
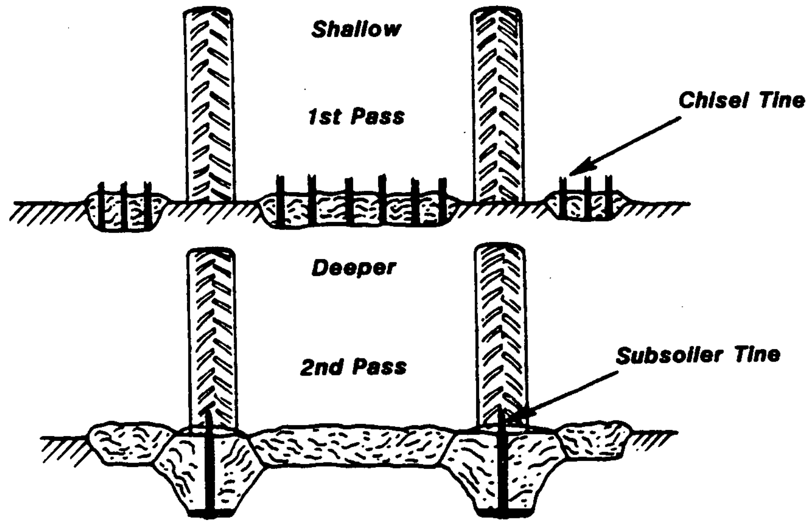


Figure 7.2. Subsoil loosening following a shallower cultivation to reduce draught and clod problems.



2. Complete disturbance at depth and level surfaces.

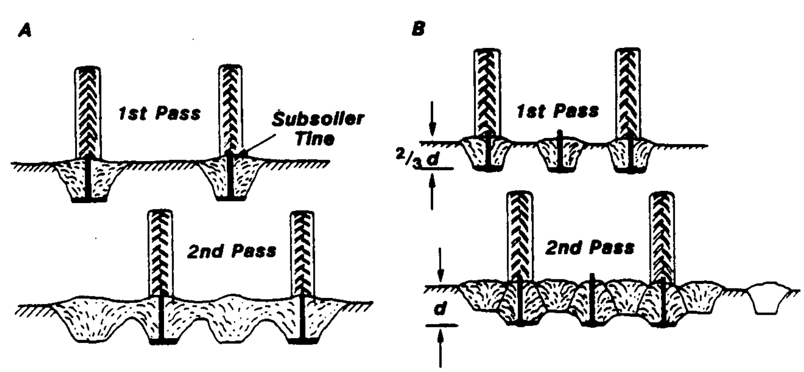
(a) when adequate power available to loosen complete width of tractor.

Arrange tine spacings as suggested in Table 5.2.

(b) where power available is insufficient for tines to loosen across the complete width of the tractor.

Consider carrying out the operation in two passes. This method is illustrated for a tractor which can only pull two tines at the required working depth. Using two passes with the two tine arrangement shown in Fig. 7.3a does not loosen the soil completely at depth and an uneven surface is left. If three tines are fitted as shown in Fig. 7.3b considerably more soil is broken out at depth and a level surface is achieved. To enable the tractor to pull the three tines, the first pass should be carried out at two thirds of the final depth required, with the final pass at full depth.

Figure 7.3. A method for complete loosening where the tractor cannot loosen its complete width in one pass.



EVALUATION OF WORK DONE

Whilst the suggested guidelines allow tine spacings and depths and the working method to be selected in advance for the type of loosening required, the settings must be checked in the field to ensure they are correct for the prevailing conditions. Particular points that need to be checked are:

a. working depth relative to the depth of the problem
b. whether equipment is working above critical depth
c. extent of loosening at working depth
d. degree of loosening and rearrangement at working depth
e. levellness of soil surface
f. openness and cloddiness of soil surface
g. extent of fissure development

Some checks require a quick soil excavation; others can be made by observing soil flow and conditions at the surface. To minimise time inputs, the following procedure is recommended.

1. Make a short run with the implement at the required working depth in a representative part of the field. Excavate a trench to working depth across the path of either two tines or a single one, depending upon whether complete or incomplete breakout is required at depth. Observe the limit of disturbance that has been achieved.

If the tines are above critical depth, the trench will be relatively easy to excavate compared with the undisturbed soil. Facing the direction of implement travel, pull away by hand the disturbed soil from the vertical trench face. This will show the limits of disturbance and the ease with which it can be done will indicate the degree of loosening and rearrangement achieved. Assessments of points a, b, c, d and g can be made.

2. Observe the levelness, openness and cloddiness of the soil surface after loosening and note any surface fissure development in situations where loosening is minimal - points e, f and g.

3. Make any necessary tine spacing/depth adjustments to correct deficiencies (described later) and repeat the run. The use of a stout fencing stake to support and change leg position makes spacing adjustments in the field very much easier. Assessment of the changes can now be made from the surface without excavation by noting the following:

(i) surface conditions (as before)

(ii) a level surface and a ridge and furrow surface are indicative of complete and incomplete loosening at depth respectively

(iii) an increase in surface heave and a more open surface condition indicates more loosening and rearrangement at depth

(iv) The depth of penetration of a stick pushed into the loosened profile across the line of travel. This defines the limits of the undisturbed boundary.

4. Stage 3 should be repeated until the required conditions, as defined by surface observations, have been achieved. At this stage make a final check by excavating a trench across the line of work as described previously.

It is well worth remembering that tractor exhaust colour, wheel slip and tine wear are not good indicators of effective, efficient loosening. All these these are achieved unnecessarily when working below critical depth with little effective loosening.

FIELD ADJUSTMENT OF EQUIPMENT TO ACHIEVE DESIRED RESULT

If, on evaluating the work done, it is found that the required type of loosening is not being achieved, the following adjustments can be made:

1. If working below critical depth:

   (a) Fit wider shares to chisel or conventional subsoiler tines.
   (b) Reduce working depth, providing it is still deep enough to overcome the compaction problem.
   (c) Increase wing lift height where feasible.
   (d) Loosen surface layers through a preliminary operation, or by adding shallower leading tines to the deep tine arrangement.

2. If more complete loosening at depth and a more level surface condition is required:

   Reduce tine spacing.

3. If a greater degree of loosening and rearrangement at depth is needed when working with winged tines:

   (a) Increase wing lift height where feasible.
   (b) Reduce working depth.
   (c) Loosen surface layers first.

4. If the extent of fissure development, openness of surface and surface cloddiness needs to be reduced:

   (a) Use discs ahead of tine legs.
   (b) Reduce wing lift height.
   (c) Increase working depth but check to ensure tines do not work below critical depth.

EVALUATING LOOSENING EFFECT FROM EXCAVATED TRENCH PROFILES - AN EXAMPLE

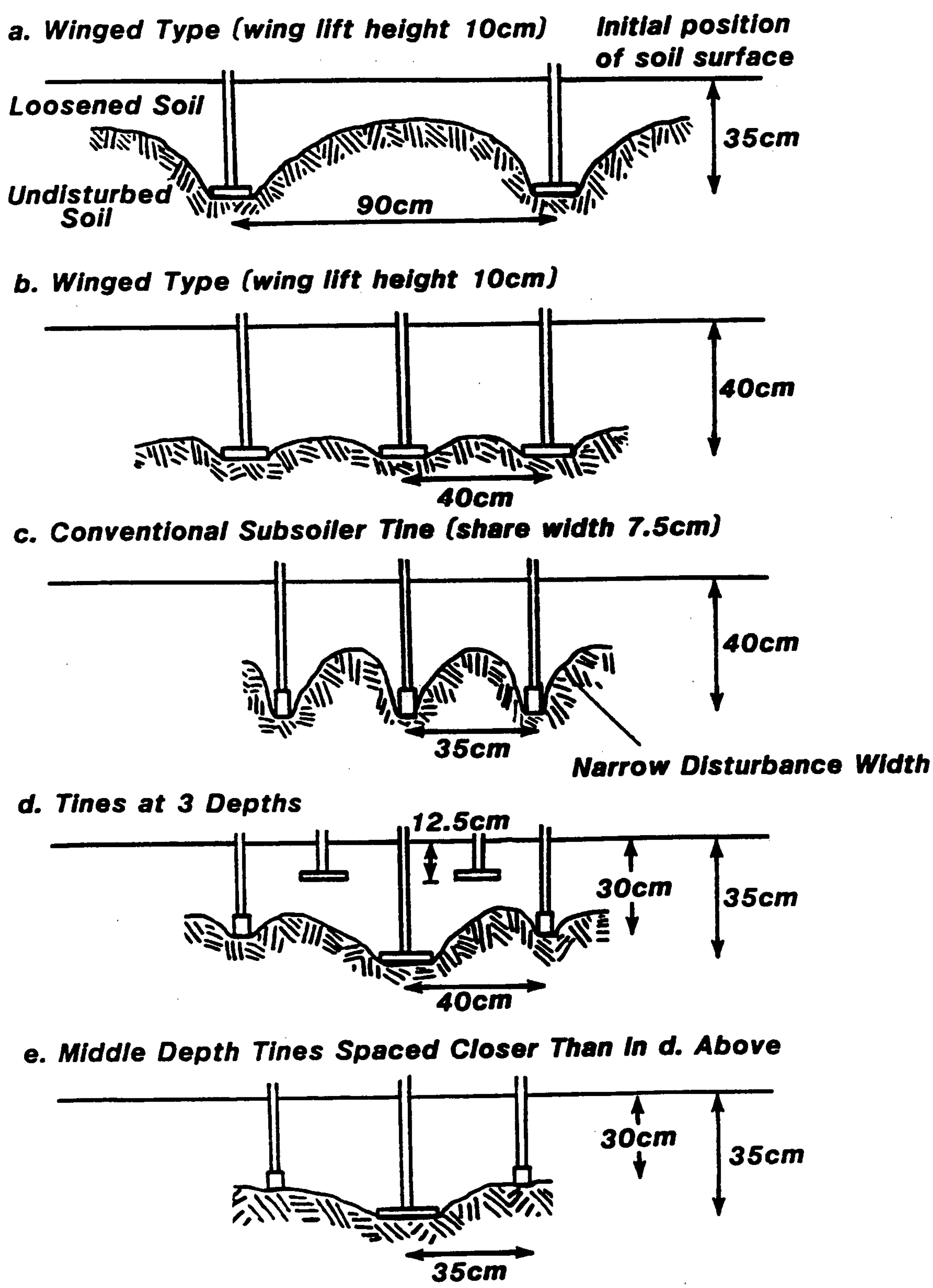
Figure 7.4 shows the disturbance profiles of a number of soil loosening implements at a field demonstration, from which necessary implement adjustments can be identified. The aim on the demonstration site was to achieve as near complete soil breakout at working depth as possible.

In (a) the winged tines (lift height 10cm) working at a spacing of 2.5 times their working depth are producing an incomplete loosening effect. Winged tines of similar dimensions (b), but set at a spacing equal to their working depth are giving complete breakout at depth. The winged tines in (a) need to be spaced closer together and the spacing of those in (b) could most probably be increased without significantly reducing the disturbance at depth.

The conventional subsoiler tines (7.5cm share width) in (c) are also giving incomplete breakout, even though their spacing is less than their working depth. This is because they are working too deep for the prevailing conditions (working below critical depth) and are simply cutting slots at depth (note the narrow disturbance width at depth). It must either be accepted that this implement cannot work effectively at this depth under the prevailing conditions, or that the top 15cm of soil must be loosened first, before working at 40cm with more closely spaced tines. Increasing the share width to 10cm is unlikely to be enough in this case to push critical depth to 40cm.

The implement in (d) has tines mounted at three depths, the deepest tines being widely spaced. In the setting at the demonstration, the spacing of the middle depth tines is too wide relative to the position of the deepest tine, to give complete breakout between then and the deep tine. Figure 7.4 (e) shows the benefit achieved from positioning the middle tines a little closer, to give complete disturbance across the whole field to the depth of the middle tines, with significant disturbance at greater depths.

Figure 7.4 Soil disturbance profiles of a number of soil loosening implements at different field settings.



8. SOIL MANAGEMENT AFTER LOOSENING

To maximise the benefits from a loosening operation, the loosened soil needs careful handling. Two problems can arise, the first being under-consolidation and the second excessive recompaction. Although the latter is by far the most common problem, it is important to firm up excessively loose soil conditions. Under-consolidation is most likely to arise on the lighter soils in situations where the loosening operation is carried out last. Excessive recompaction occurs as a result of high tractor and equipment loadings under moist or wet conditions after the operation.

To increase the chances of long-term loosening benefits, sufficient time is required for the loosened/fissured soil to stabilise. Stabilisation occurs through weathering, organism and root activity and the chance of success is highest under well drained conditions. It is therefore critical that a loosened soil is not subjected to excessive loads before the next crop is fully established and well rooted. If this can be achieved, the benefits will be relatively long lasting.

The risks of excessive recompaction can be minimised by giving due consideration to the following:

1. Keeping the degree of loosening and fissuring and its depth to the minimum required.

2. Consolidating the loosened soil at the time of loosening with crumblers or presses wherever possible, to increase the support capacity for subsequent traffic.

3. Planning the complete sequence of operations through to crop establishment, to ensure the least amount of traffic over the loosened soil after the deeper loosening operation.

4. Keeping loads and pressures to a minimum when working on the loosened soil, making maximum use of vehicles with 4-wheel drive, dual wheels, low pressure tyres, tracks or cage wheels.

5. Concentrating the traffic in local traffic lanes, if operating under high risk conditions with high risk equipment, to confine the excessive recompaction to local areas.

6. Maintaining an adequate subsurface drainage system.

Deeper soil loosening operations are time consuming and expensive and without due after-care, the benefits can very quickly be lost. In addition, in most situations they are effectively reclamation operations following soil damage, and as such, should in many cases be avoidable. Future aims must therefore be to plan and execute all field operations, so that compaction problems can either be avoided or kept shallow, to reduce the need for these expensive deeper reclamation operations.

9. FUTURE RESEARCH REQUIREMENTS

Reviewing the preceeding chapters it can be concluded that the potential response to soil loosening operations and the effectiveness of soil loosening equipment, its selection and field operation, are well understood. The major limitations influencing the success of many deep soil loosening operations are as follows:

i) Lack of a detailed specification of the ideal soil conditions required at depth for cereal production.
ii) Farmer difficulties in identifying soil problems.
iii) Lack of suitable mechanisation techniques for the care of soils once the soil has been loosened.

The detailed specification of the ideal soil condition for cereal production is a complex problem and one that agronomists/soil scientists have attempted to define for many years. Further progress through research in this area is likely to be very slow and in view of the general broad specifications already available and the accomodating nature of the cereal crop, further research in this area must take low priority.

Overcoming the difficulties of identifying of soil management problems is a topic not requiring further research. A major initiative in training through short courses, practical workshops and on-farm advice would however, be extremely valuable and cost effective.

Mechanization management for post-loosening soil care is a critical area requiring future investigation. It is particularly important since current field operation practices whilst suited to relatively light weight equipment, are unsuitable for much of the heavy equipment now being used.

(i) Tillage costs for alleviating soil compaction and breaking clods, the products of compaction, from a significant proportion of cereal production costs.

(ii) More heavily loaded equipment in the form of both combines and trailers is operated in the field producing the difficulties of an acceptable compromise of soil conditions for both cereal production and equipment operation.

Four areas of work requiring further investigation have been identified:

i. The current work on tyre pressure-load relationships to minimize the degree and depth of compaction (to make alleviation easier) requires extension into the design of equipment form (wheel and axle configuration).

ii. Development of field operating systems to confine the spread of heavily compacted areas whilst maintaining or improving field machine operating efficiency (permament or semi-permanent traffic lanes offer considerable potential within this area).

iii. Development of techniques for the preparation of efficient traffic lanes for improved timeliness of field operations and increased support for field equipment with minimum depth and spread of compaction.

iv. Utilising the improved traffic lanes to limit the spread of compaction, develop tillage equipment to extend the working soil moisture limits for efficient soil preparation.

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