Soil Management for Intensive Cereal Production

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Historically, tillage practices have been determined by two factors, the need to kill weeds and the technology available to pull implements through the soil. In humid regions of the world, the need to kill weeds by inversion of the soil ensured the dominance of the moldboard plow. Today's designs are recognisably similar in principle to the implement first brought to Britain around AD 70 by SCIPIO AFRICANUS, although available tractive power has obviously changed. Thus, in Britain successive phases can be traced of shallow plowing by animal power, deeper plowing using steam tackle, shallower plowing using small tractors and then deeper plowing again with larger tractors.

In semi-arid regions the balance between weed pressure and available technology dictated more widespread use of implements less efficient at killing weeds but less demanding of draft power, for example chisels and discs. However, the point remains that tillage implements evolved, rationally enough, in response to the two dominant factors of weed control and draft power availability. Soil structure maintenance and plant root system requirements were little understood. Even today "conventional" tillage practices are often mistakenly rationalised in terms of soil and crop needs.

From the early 1950's onwards the development of herbicides began to mean that weed control could increasingly be achieved without recourse to tillage. Then in the early 1970's the sudden rise in energy costs imposed new limitations, this time economic, on tractive power for tillage. Thus both the dominant factors of weed control and draft power availability that guided the development of conventional tillage implements and systems have become largely outdated. Simultaneously our awareness of both agricultural productivity and environmental hazards of soil erosion has increased and our knowledge of plant root systems' requirements of the soil has developed /RUSSELL, 1977/.

The importance of obtaining good soil physical conditions obviously increases as cereal production is intensified. In a low input/low output system, soil structure is unlikely to be a yield limiting factor. But as inputs are increased, a satisfactory increase in yield will only be obtained if soil physical conditions are adequate to meet the additional demands made.

The purpose of this paper is to try to point out some general principles of a modern approach to soil management and provide some guidance through the maze of conflicting opinions, traditions and vested interests that abound. If this stimulates you to search for improvements in soil management practices for intensive wheat production in Hungary, this paper will have amply served its purpose.

Soil structure requirements for cereal crops

The logical starting point for thinking about soil management for cereals is a multi-disciplinary understanding of crop requirements, particularly those of the root system, in terms of soil physical conditions. Such understanding will not be fully quantitive within the twentieth century, but we do have a growing qualitive knowledge which I have tried to summarise briefly here.

First, plants require a continuous pore system adequate for root development and drainage. WIERSUM /1957/ demonstrated that roots will not grow through a rigid pore system smaller in diameter than the root concerned. More recently work on mechanical impedance of root growth in Britain, the USA and Australia has been reviewed and summarised by RUSSELL /1977/. Both in the field and in laboratory experiments with rigid glass beads in flexible containers, quite small applied pressure /e.g. 2.0 kPa/ were sufficient to reduce the rate of root extension to about half that of the controls.

The range of continuous pore sizes required is thus defined by the range of root diameters. For small grain cereals for example this is from 5 µm for root hairs up to 400 µm for main root axes. The volume of a continuous pore system need not be large since a well developed cereal root system occupies only 5% of the soil volume near the surface and around 0.5% at around 50 cm depth. The pore system should however be evenly distributed through the soil volume in order to maximise access to nutrients and available water /WARKENTIN, 1982/.

Second, a desirable continuous pore system should be combined with adequate bearing strength and aggregate stability that it does not collapse under the compaction from traffic in crop production or from natural processes /e.g. slumping or slaking during wetting/. The importance of bearing strength combined with a suitable pore system has been stressed by PIDGEON /1980/, and of preserving stability by avoiding disruption of natural aggregates by GREENLAND /1981/. Nevertheless, in tillage studies and in practice these strength and stability aspects of soil structure are too often forgotten.

Adequate profile drainage is important as waterlogging will still occur despite a desirable and stable pore system if there is no outlet, either through naturally permeable subsoil or by artificial drainage. In many soils with genetic pans at depth this is a major restriction to productivity. Abrupt changes in soil physical properties with depth may also be detrimental, particularly when a loose layer of soil overlies a hard compacted layer. In these circumstances root distribution can be particularly unfavourably altered /RUSSELL, 1977/ to give shallow dense root systems vulnerable to drought. Finally, an adequate seedbed providing good seed/soil contact and transmission of water and gases is required.

Summarising these plant requirements for soil physical conditions as an adequate size range stable continuous pore system in a soil matrix with good bearing strength and only gradual changes with depth, it is evident, as noted earlier, that most tillage implements and systems have not been designed to meet these criteria.

Diagnosis of soil structure problems

Having considered the crop's requirements, i.e. having defined our objectives for soil management, the next step is to examine our soils and diagnose their problems. This is sometimes an area of weakness and too often our approach resembles that of the hypochondriac who rushes to take patent medicines for imaginary or wrongly diagnosed ailments. Proper diagnosis is important. Walking your fields is a good start, but is not sufficient.

It is necessary to use a spade and dig small holes to examine soil structure and drainage, check if pans are present and look at root distribution of the previous crop. With a little training, these skills are easy to acquire and this job should be done by the agronomist responsible for each field, and not be regarded as a task for occasional specialist visits.

Think about soil problems from the bottom of the soil profile upwards. First consider site drainage, then field drainage. Then look at structure of the subsoil, topsoil conditions and finally the seedbed. The reason for this approach is that problems at or near the soil surface often have causes further down the profile. Correcting deeper problems will often improve surface conditions with little extra effort or expense. The converse, that correcting surface problems will somehow take care of problems below, is often hoped for and seldom true.

At this stage, thought should be given to the causes of any soil structure problems that are identified, as prevention rather than cure of such problems is the best long-term strategy. In arable agriculture the two main causes of problems are compaction under wheels of heavy tractors or other vehicles and unwise use of tillage implements in the wrong conditions; or, in a succinct half-truth attributed to Chairman MAO "there is no poor soil, only bad farming".

A rational approach to tillage

Once the cereal crop's requirements in terms of soil structure are understood and soils have been examined, one is then in a position to plan tillage operations rationally on the basis of plant and soil needs. As energy, labour and machinery costs rise and the importance of timeliness increases as cereal production is intensified, a rational approach becomes more necessary. There are two guidelines I would like to stress.

The first guideline is that flexibility of thought and practice is essential. Tillage should only be carried out where it is demonstrably necessary, and the need will vary from field to field and from year to year. Where soil examination shows that structure is satisfactory, the logic of zero or reduced tillage is clear. If the headlands or a part of a field is compacted, an obvious solution is to loosen only that area. If a field has a plough pan or compacted layer, then this must be loosened, but on stable reasonably structured soils loosening only need be carried out when the problem arises, and not routinely every year. Only on poorly structured soils /sand or some silt soils with low organic matter contents, or clay soils with essentially non-expanding clay minerals and hence high subsoil bulk densities and low porosity/ is loosening likely to be necessary every year. Again I stress the logic of avoiding heavy vehicle traffic over the soil and of using herbicides for weed control rather than cultivations where both tractor and implement can give rise to soil damage and unnecessarily create a need for further tillage. This rational approach inevitably makes greater demands on management skills and knowledge of soil than traditional tillage, but the savings in inputs are worthwhile /Table 1/.

Table 1

Workrates, energy and labour requirements for conventional, reduced and zero tillage for cereals on three soil types in Southern England
/Data source: D. E. PATTERSON, W. C. CHAMEN and C. D. RICHARDSON, NIAE, J. agric. Engng. Res. 25. 1-25. 1980/

Cultivation system	Workrate /ha/hr/			Net energy /MJ/ha/			Area capability /ha/		
	B	R	S	B	R	S	B	R	S
Plough, Cultivate, Drill	0.25	0.39	0.24	320	180	324	88	132	99
Chisel plough /x2/, Cultivate, Drill	0.30	0.42	0.30	286	194	308	107	142	137
Shallow plough, Cultivator/drill	0.50	0.63	0.46	187	108	203	178	214	226
Zero tillage /Spray, Direct drill/	0.99	1.09	1.01	38	43	54	353	368	349

B: clay loam soil at Boxworth; R: silty loam soil at Rothamsted; S: silty clay loam soil at Silsoe

The second guideline is a rational approach to tillage for cereals is that when a need for soil loosening is established, a modern implement should be used that has been specifically designed to provide the optimum soil physical conditions discussed earlier. One such implement is the "Paraplow" /PIDGEON, 1982; DAVIES et al., 1982/ developed jointly by HOWARD ROTAVATOR COMPANY and ICI, and others have also become common in the UK over the past two years. SPOOR and GODWIN /1978/ showed that soils have a characteristic critical depth; working deeper than this depth with any tine implement gives no useful loosening and may result in additional compaction at depth, while draft and hence energy consumption increases rapidly below the critical depth. Hence soil loosening implements should be used at a depth suitable to remove an identified soil compaction problem or at critical depth, whichever is the shallower. Soils are most effectively loosened when they are in a slightly moist condition /i.e. around pF 3/. From an implement design point of view, SPOOR and GODWIN's work shows that considerable reductions in specific draft /i.e. draft per unit cross sectional area loosened/ compared to conventional straight leg subsoilers can be achieved by the use of "wings" or slant legs, the correct spacing between legs and by loosening the soil from the top downwards. Correct leg spacing is also of prime importance in achieving a level finish.

The need to avoid recompaction after loosening is increasingly now appreciated. Several workers /RAGHAVAN et al., 1977/ have shown that around 90% of the recompaction possible occurs in the first pass over a recently loosened soil /SOANE et al., 1981/, while PIDGEON and SOANE /1978/ demonstrated that recompaction occurred to the full depth of the previous loosening operation.

The logic in soil physical, as well as economic terms, is thus clear for a one pass soil loosening operation which does only that required for the crop root system and maintains any surface tilth for the seedbed.

Soil management in reduced and zero tillage

Since the intensification of cereal production in Eastern Europe points so strongly in the direction of adopting reduced or zero tillage systems, I conclude this paper with a brief survey of soil management needs of these systems. For both physical and chemical soil fertility, as indeed for weed control, it is essential to begin these systems with the soil in good condition. Careful planning and good management in the year before starting the new system is most important.

In the case of chemical fertility, preparations involve checking for acidity or severe PK deficiencies in the subsoil and if necessary incorporating appropriate amounts of lime or fertilizer to correct any problem. Nutrient stratification, frequently referred to as a potential problem, has been the subject of much research in several countries. It has not however proved to have adverse effects on crop uptake or yields even in semi-arid regions, and can be discounted as a problem.

As far as physical conditions are concerned, the starting point of good soil structure must be attained by careful tillage and management over the previous year. This implies loosening any pans or compacted layers and leaving a firm level surface. This requires careful management of field traffic to avoid rutting and the use of light low ground pressure vehicles whenever possible.

Much can be achieved simply by use of wider tyres and lower inflation pressures, or perhaps modern cage wheels /SOANE et al., 1981/. In the long-term, use of heavy tractors or vehicles is both unnecessary and incompatible with reduced or zero tillage systems for cereals. To emphasise this point I would remind you of the work of HAKANSSON /1979/, who showed that very heavy vehicles weighing 26 tons produce permanent irreversible compaction particularly at 400 mm depth and extending below 500 mm. Such damage is particularly costly to repair as the depths are below the critical depth for loosening with draft tine implements.

Preparations for reduced or zero tillage must also include efficient timely straw residue disposal and weed control, both of which must and can be achieved while leaving a level, unrutted and firm seedbed.

Very brief reference has already been made /Table 1/ to the energy, labour and timeliness advantages of reduced or zero tillage systems. I would like to conclude this paper by highlighting the moisture conservation advantage, which appears particularly relevant to Hungarian conditions. Moisture conservation, due to ground cover of surface residues, reduced surface roughness or smaller number of soil workings has been observed everywhere such studies have been made. Where moisture deficits make this effect relevant, for example in cereal germination and establishment in dry autumns, moisture conservation is beneficial. Table 2 shows selected results for establishment and yield of winter cereals in long-term tillage trials at Letcombe Laboratory, Oxfordshire, England. I have selected the driest years from the last ten at this site with mean annual rainfall of 700 mm as being most relevant to conditions likely to occur most years in the cereal producing areas of Hungary. Under these dry conditions, moisture loss and rough seedbeds after ploughing combined to give significantly lower plant populations and rate of emergence for ploughing compared to reduced and zero tillage. In some cases the effect carried through to crop yield.

Table 2

Effect of tillage on plant population and cereal yield in dry seasons on two soil types in Southern England

/Data source: R. Q. CANNELL and D. G. CHRISTIAN, ARC Letcombe Laboratory/

	1975/1976 Lawford	1978/1979 Lawford	1981/1982 Lawford	1980/1981 Hamble
	W Wheat			W Barley
Rainfall /mm/	304	565	583	608
August-November	164	84	234	248
December-July	140	481	349	360
Emergence /Plants/m^2/				
Direct drill	220	79	291	315
Ploughed	150	11	260	283
Yield /t/ha/ at 15% mc				
Direct drill	5.5	2.8	10.0	8.3
Ploughed	4.9	2.0	8.8	7.9

Soil type: Lawford series clay: 35-40% clay
Hamble series: silt loam

Conclusion

The modern approach to soil management for intensive cereal production calls for greater management skills and understanding of soil/plant relationships than do traditional tillage and low input/low output systems. The savings in energy, labour, timeliness, erosion control and moisture conservation can increase both potential and actual productivity, making it well worthwhile to improve soil management skills.

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