SOIL STRUCTURE AND MECHANICAL RESISTANCE DIRECTLY BELOW THE SEEDBED OF CEREALS AND ROOT CROPS IN THREE FIELD EXPERIMENTS IN THE NETHERLANDS

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INTRODUCTION

At seedbed preparation in spring, the workability of the soil surface layer depends on clay content, moisture content, and type of implement used and its adjustment and handling (forward speed, rotational speed, working depth). Moreover, the recent history of the topsoil (kind of primary tillage in autumn, degree of weathering during winter and early spring, speed of superficial drying) affects soil cohesion and, thus, the brittleness of the shallow surface layer to be worked. Therefore, the resultant seedbed quality (aggregate size distrubution, depth) may vary widely from year to year.

Below the shallow, relatively dry surface layer, the soil is often still wet (moisture content about 90%, relative to field capacity), which may cause smearing and compaction by the tools of the tillage implements, especially when powered implements are used, such as reciprocating harrow, rotary harrow and rotary cultivator (in order of increasing tillage intensity). The field traffic which accompanies fertilizer application, seedbed preparation and sowing, may compact not only the top soil, but also deeper soil layers, especially when single, high-pressure tyres are used (Van Ouwerkerk and Van Noordwijk 1989). Therefore, even if the quality of the seedbed itself is satisfactory, the seedbed bottom may be very dense and, thus, may have a very high mechanical resistance.

Seedbed quality is often established only in terms of average depth and aggregate size distribution of the loose layer. However, as the seed preferably should be deposited on or just in the seedbed bottom, it is important to determine the structure of the soil layer directly below the seedbed as well. This should be done at least in terms of total porosity, moisture content and air content, which determine the speed of emergence, and in terms of soil strength, which determines the rate of development of the seedling's roots and their rate of penetration into the subsoil.

METHODS

A spring-loaded hand penetrometer (cone: 30^{0}; base: 25 or 50 mm^2) and a portable shear strength meter (annulus: Ø 70 mm; height of the partitions: 16 mm), which were originally developed to determine the firmness of the top layer of sports turfs (Mes and Pot 1984), were used to characterize the strength of the seedbed bottom. As an objective reference, a third instrument was used, viz., a 90^{0}, 70-mm wide steel wedge, which is forced into the seedbed bottom by means of a 2.5-kg falling weight (Van Ouwerkerk 1989b).

Soil strength of the seedbed bottom was measured on 5 sites per plot. Within each site, 4 determinations of shear strength and wedge penetration and 8 determinations of penetration resistance were made. Total porosity and moisture and air contents in the 2-7-cm layer below the seedbed, both at sampling and at a standard matric water potential of -10 kPa (Kuipers 1961), were determined in 10 intact core samples of 100 cm3 per plot.

In the spring of 1988 and 1989, seedbed quality, mechanical resistance of the seedbed bottom, and soil structure in the 2-7-cm layer below the seedbed, were measured in experimental fields laid out to study field traffic systems, low-input farming, and tillage systems.

RESULTS

Generally, it was found that total pore space and moisture content in the 2-7-cm layer below the seedbed, both at sampling and at a matric water potential of -10 kPa, were positively related to organic matter content which, in turn, was related to long-term organic manuring history or (always positively) to clay content.

Both in 1988 and 1989, the positive effect of primary tillage on soil structure, even if it was performed under favourable conditions (as in the autumn of 1988), was nullified by the negative effect of a winter and early spring with abundant precipitation, but without any frost. In the spring of both years, the soil dried superficially very quickly and a hard, 2-3-cm thick crust developed. Consequently, despite very intensive secondary tillage, only a shallow and very coarse seedbed was obtained. Directly below the crust the soil was still wet which, in many cases, caused the formation of a dense layer directly below the seedbed. Thus, in both years, soil strength directly below the seedbed was generally very high, in spite of the high moisture content.

Table 1 shows soil strength data after seedbed preparation with a spring-tine cultivator, which was preceded by one pass of a heavy float to break the crust. The field experiments concerned are located on the EHF "Dr. H.J. Lovinkhoeve" (Noordoostpolder), where, with respect to clay content, the soil is very homogeneous.

TABLE 1
Soil strength directly below the seedbed for spring barley on a loam soil (clay content 22%, w/w) at the EHF "Dr. H.J. Lovinkhoeve", 3 April 1989

Experiment	Tillage system	Organic matter * (%,w/w)	Shear strength (kPa)	Wedge penetration (mm)	Cone index (MPa)
IB 0011	Conventional	2.4	207	26.1	1.0
	Minimum #	2.7	284	21.0	1.3
IB 0029	Conventional	2.7	266	21.2	1.0
		2.2	256	19.4	1.3
	Reduced	2.8	298	18.8	1.3
		2.4	274	21.6	1.2
	Minimum ##	2.4	340	19.4	1.7

* 0-25-cm depth; # Since 20 years; ## Since 3 years.

On experimental field IB 0011, 20 years of minimum tillage (i.e., 7 cm ploughing), resulted in a considerable increase in organic matter content, especially in the top 10 cm (Van Ouwerkerk 1989a). Still, directly below the seedbed, shear strength and cone index were clearly higher and wedge penetration was clearly lower than on the conventional tillage plot, which was always autumn-ploughed to 20-25 cm depth.

On experimental field IB 0029, the differences in organic matter content are caused by long-term (40 years) differences in organic matter application preceding the present experiment, which was started in the autumn of 1984. Differences in soil strength between conventional tillage

(20-25 cm ploughing) and reduced tillage (15 cm ploughing + 5-10 cm subsoiling) are not clear, but minimum tillage (7 cm ploughing) showed a much higher shear strength and cone index than conventional tillage.

The combined effect of clay content and traffic intensity on soil structure below the seedbed is illustrated in Table 2 for a long-term field experiment at the EHF "Oostwaardhoeve" in the Wieringermeerpolder. It consists of 4 blocks of 100 x 200 m^2, each carrying one crop of the intensive, 4-year crop rotation, consisting of ware potatoes - winter wheat + undersown grass - sugar beet - onions. Each block was subdivided into 6 plots where, since 1985, low ground-pressure (L) and high ground-pressure (H) field traffic, and zero-traffic (Z) were practiced all the year round. Soil tillage and all cultural treatments were the same for all three field traffic systems. Soil texture on this experimental field varies strongly among blocks and within blocks, which may make the comparison of the effects of L, H and Z treatments more difficult, but may make it possible to establish differences in magnitude of the effects of field traffic systems on coarse- and fine-textured soils.

TABLE 2
Total pore space, and moisture and air contents at -10 kPa in the 2-7-cm layer below the seedbed at the EHF "Oostwaardhoeve" (1985-1989 average)

	Block	Plot	Clay (%,w/w)	L	H	Z	Mean L,H	Z-L,H
Pore space (%,v/v)	A	1-6	17.7	49.4	47.9	49.6	48.6	1.0
	B	1-3	15.0	46.6	47.0	48.9	46.8	2.1
		4-6	22.6	48.8	48.0	50.8	48.4	2.4
	C	1-6	23.7	48.7	49.5	51.5	49.1	2.4
	D	1-3	23.0	-	49.4	52.4	-	3.0
		4-6	31.8	52.2	-	55.6	-	3.4
Moisture content at -10 kPa (%,w/w)	A	1-6	17.7	23.1	22.4	23.4	22.8	0.6
	B	1-3	15.0	22.1	23.1	23.5	22.6	0.9
		4-6	22.6	25.7	24.6	25.3	25.1	0.2
	C	1-6	23.7	25.4	27.2	25.8	26.3	-0.5
	D	1-3	23.0	-	26.9	26.8	-	-0.1
		4-6	31.8	31.5	-	32.0	-	0.5
Air content at -10 kPa (%,v/v)	A	1-6	17.7	18.7	17.2	18.8	18.0	0.8
	B	1-3	15.0	15.5	14.8	17.4	15.2	2.2
		4-6	22.6	14.2	15.0	17.9	14.6	3.3
	C	1-6	23.7	14.4	13.6	18.7	14.0	4.7
	D	1-3	23.0	-	13.5	18.8	-	5.3
		4-6	31.8	12.6	-	18.2	-	5.6

On L and H plots of similar soil composition, total pore space and moisture and air contents at -10 kPa were similar. On Z plots, total pore space and moisture and air contents at -10 kPa were clearly larger than those on L and H plots, especially on heavier soil. Accordingly, soil strength was similar on L and H plots of similar composition, but on Z plots shear strength and cone index were clearly smaller and wedge penetration was considerably larger (Table 3). However, contrary to pore space and air content at -10 kPa, differences in soil strength among L, H and Z plots were smaller on the heavier soil. This may be caused by the larger pore space on the heavier soil, which counteracts the stronger cohesion.

TABLE 3
Soil strength in the 2-7-cm layer below the seedbed at the EHF "Oostwaardhoeve", spring 1988

	Crop	Block	Plot	Clay (%,w/w)	L	H	Z	Mean L,H	Z-L,H
Shear strength (kPa)	Potato	B	1-3	14.0	306	293	198	300	-102
			4-6	20.7	382	414	320	398	- 78
	S.beet	C	1-6	22.8	262	303	219	282	- 63
	Onion	D	1-3	21.7	-	278	242	-	- 36
			4-6	29.8	269	-	295	-	- 26
Wedge penetration (mm)	Potato	B	1-3	14.0	19.0	18.5	25.7	18.8	6.9
			4-6	20.7	20.2	15.6	20.8	17.9	2.9
	S.beet	C	1-6	22.8	17.6	18.6	27.2	18.1	9.1
	Onion	D	1-3	21.7	-	22.1	25.0	-	2.9
			4-6	29.8	21.2	-	27.6	-	6.4
Cone index (MPa)	Potato	B	1-3	14.0	2.4	2.8	1.4	2.6	-1.2
			4-6	20.7	2.4	2.5	1.7	2.5	-0.8
	S.beet	C	1-6	22.8	0.8	0.8	0.3	0.8	-0.5
	Onion	D	1-3	21.7	-	0.7	0.5	-	-0.2
			4-6	29.8	0.8	-	0.6	-	-0.2

On block B the cone index level was far higher than might be expected on the basis of soil texture or the general relationships among the values of shear strength, wedge penetration and cone index (Fig. 1). Probably, this high level may be considered as the effect of the very intensive seedbed preparation (reciprocating harrow, followed by rotary cultivator) at a fairly high moisture content (on average 92%, relative to the moisture content at field capacity). However, seedbed preparation had been very intensive also on blocks C and D (2x rotary harrow instead of the usual single operation with a reciprocating harrow) and the moisture content on these blocks was not much lower than that on block B (86 and 88%, respectively, relative to the moisture content at field capacity).

Soil strength values on L and H plots were also similar in the spring of 1989; shear strength and cone index on Z plots were clearly lower than those on L and H plots, while wedge penetration was markedly greater (Table 4). The level of soil strength was again very high on potato plots (block D; Fig. 1), which would be consistent with the extremely intensive seedbed preparation (rotary harrow, followed by rotary cultivator). On plot D5 (Z), shear strength values were extremely high and were not consistent with the wedge penetration and cone index values (Fig. 1). This was probably caused by the levelling operation with the rotary harrow, which was performed in autumn to correct the unsatisfactory result of a prototype 2-body plough tested on this plot only. This operation resulted in a too finely crumbled, even surface, which severely slaked during winter and early spring.

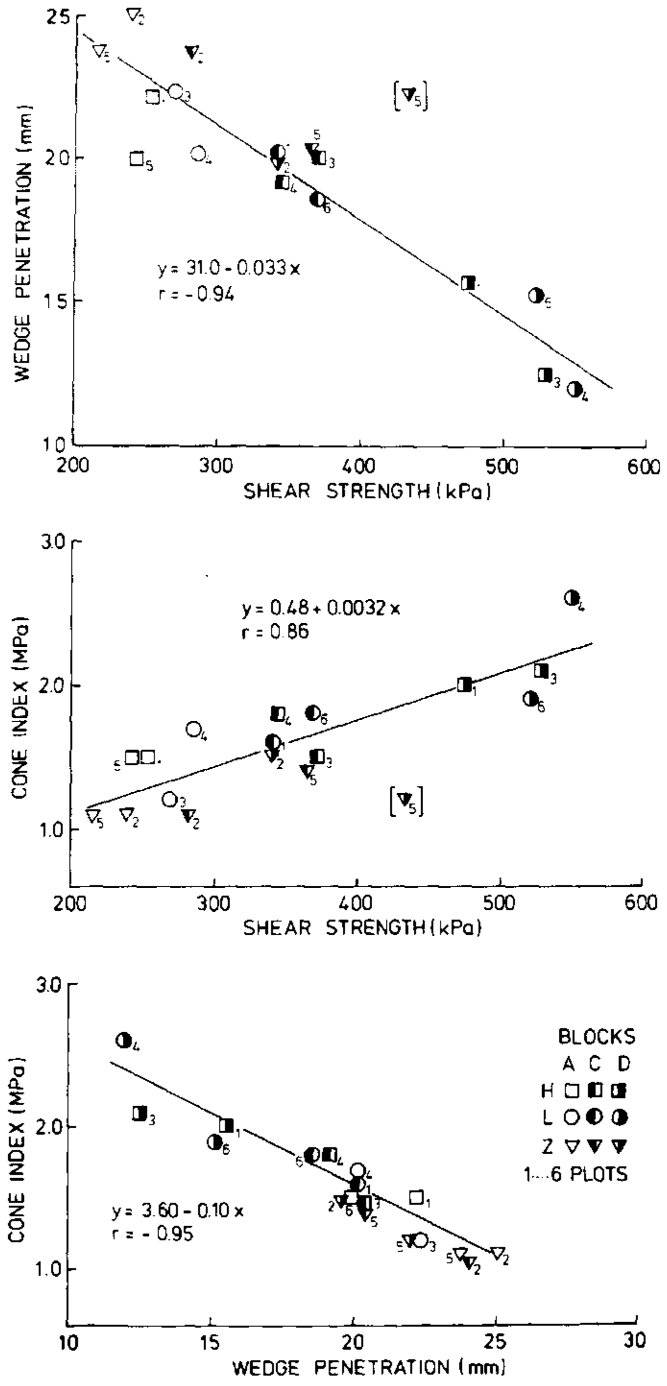

Fig. 1. Relationships among shear strength, wedge penetration and cone index in the 2-7-cm layer below the seedbed, at the EHF "Oostwaardhoeve, in spring 1989.

TABLE 4
Soil strength in the 2-7-cm layer below the seedbed on Z plots, relative to the average values for L and H plots (%), at the EHF "Oostwaardhoeve", in spring 1989

Crop	Block	Plot	Clay (%,w/w)	Shear strength (kPa)	Wedge penetration (mm)	Cone index (MPa)
Sugar beet	A	1-6	16.5	- 13	+ 15	- 27
Onion	C	1-6	22.8	- 9	+ 11	- 29
Potatoes	D	1-3	21.7	- 32*	+ 42*	- 25*
		4-6	29.8	- 19**	+ 63**	- 45**

* Difference Z-H; ** Difference Z-L.

DISCUSSION

As the penetrometer encounters a much smaller soil volume, its readings generally show a much larger coefficient of variation (about 30%) than the readings of the shear annulus and the wedge (15-20%) which encounter similar, much larger soil volumes. However, whether or not the seedling's roots can penetrate the (often compacted) layer directly below the seedbed, probably depends more on the large spatial variation in soil strength as indicated by the penetrometer, than on the overall strength of the bulk soil as indicated by the shear annulus and the wedge.

CONCLUSION

For measuring the mechanical resistance of the soil layer directly below the seedbed of spring-sown crops, the hand penetrometer, the shear annulus and the falling-weight wedge are equally useful. However, the simple, spring-loaded hand penetrometer may well be the best-suited instrument to easily and quickly determine soil strength and its spatial variation directly below the seedbed.

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