Experiences with three tillage systems on a marine loam soil
I: 1972–1975

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A joint study of the Westmaas Research Group on New Tillage Systems, carried out on the Westmaas Experimental Husbandry Farm

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Abstract

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During 1972–1975 three soil tillage systems were compared in a four-year crop rotation: potatoes – winter wheat + undersown grass – sugar beet – spring barley + undersown grass, on a marine loam soil (22 % clay) at Westmaas Experimental Husbandry Farm. The three tillage systems were characterized as follows: (1) Loose-soil husbandry (System A) in which the main tillage treatment for all crops was ploughing, and due care was taken to preserve the loosening effect by minimizing soil compaction. (2) No-tillage (System B), in which soil tillage was only applied for planting and ridging potatoes and harvesting root crops (System B1) or was totally omitted in an alternative four-year rotation with non-root crops only: seed grass – winter wheat – oil seed rape – spring barley + undersown grass (System B2). (3) Rational tillage (System C) in which the main tillage treatment was ploughing for root crops and fixed-tine cultivation for cereals. To study the effect of tillage-induced changes in soil structure on nitrogen availability in the soil profile and on crop response to nitrogen, three perennial nitrogen levels were established, ranging from 80 to 120 %, and five annual nitrogen levels ranging from 0 to 200 % of the amounts of nitrogen normally applied in practice. In all three soil tillage systems the common chemical weed control was applied. In the no-tillage system one or more additional herbicide treatments were necessary. Systems A and C showed only slight differences in soil structure, nitrogen requirement and crop yield. In the no-tillage system the soil was more compact, all crops demanded more nitrogen and the sugar yield of sugar beet was clearly lower than in Systems A or C. Although System B was more risky than Systems A and C, winter wheat, seed grass and, with sufficient nitrogen also spring barley, mostly gave satisfactory yields. For potatoes System B was less suitable because of the intensive soil tillage required and the generally lower yield of saleable tubers.

Free descriptors: Loose-soil husbandry, no-tillage, rational tillage, soil structure, nitrogen availability, weed control, potatoes, winter wheat, sugar beet, spring barley.

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Foreword

K.B. van Gilst

In the past traditional soil tillage, practised by the farmers in the south-west of the Netherlands and by their colleagues on clay soils in other districts, followed fairly fixed patterns. Although there may have been differences in the tools used for the tillage operations, their aim was essentially the same: ploughing the clay soils well before the winter started so that the freshly ploughed soil would be exposed as long as possible to the weather conditions. Frost and thaw and alternately drying and wetting should then disintegrate the big clods, thus making it easier to prepare a seedbed the following spring. As the remnants of the previous crop and weeds, especially the perennial ones, were ploughed under and the soil surface was levelled, in spring farmers could begin with a clean slate.

In the last three decades this pattern has changed considerably, due to several circumstances.

1. The rapid development of herbicides has decreased the importance of soil tillage as a method of weed control; in theory tillage is not even necessary.

2. Root crops (potatoes, onions and sugar beet) are harvested by increasingly heavy machinery which leaves the fields with countless ruts and a very compacted soil.

3. The percentage of root crops in the crop rotation increased to 50 and over, which results in harvesting late in the season especially when the autumn is wet. Therefore, ploughing generally has to be carried out under unfavourable soil conditions (too wet).

4. Field traffic with tractors of ever increasing weight (fertilizer application, seedbed preparation and sowing, spraying of herbicides and pesticides) has considerably increased and, therefore, compaction is more and more counteracting the loosening effect of the main tillage treatment.

5. With the introduction of equipment driven by power take-off the topsoil can be influenced far more than in the past. However, when this equipment is used under adverse soil conditions it 'takes more than nature gives' and soil structure is ruined.

Considering these trends it is doubtful whether without better adapted tillage systems agricultural production in near future can be maintained at the same high level as today. Therefore, the Board of the Westmaas Experimental Husbandry Farm has always been on the alert with respect to soil tillage and, consequently, since the 1950s several tillage experiments have been carried out on this farm.

In order to anticipate questions which undoubtedly will arise in the next few years, the study of separate parts of the tillage system (e.g. ploughing depths, tillage implements, time of ploughing in autumn) was concluded, to start with the study of tillage systems in crop rotation. Therefore knowledge and experience of research workers of several research institutions, including the Tillage Laboratory of the

Agricultural University, Wageningen, were integrated into the Westmaas Research Group on New Tillage Systems. Under the aegis of this group a first experiment was carried out from 1967–1971 (Bakermans et al., 1974). The second experiment was started in 1972 and was concluded in 1979. Preliminary results (Kuipers & Boone, 1978) have already attracted international interest.

To inform the interested research workers in the Netherlands and abroad this progress report on the first four years of experimentation in the second experiment was written by the investigators involved. Mr F.R. Boone of the Tillage Laboratory fulfilled the laborious and difficult task of editing. We are very thankful to him and we sincerely hope that this publication will contribute to a better understanding of soil tillage problems under present-day conditions.

The finances that the Department of Agricultural Research of the Ministry of Agriculture and Fisheries has provided since 1977 to safeguard the continuation of this research project are gratefully acknowledged.

1 Introduction

F.R. Boone, C. van Ouwerkerk, W.A.P. Bakermans & L.M. Lumkes

1.1 Tillage systems and net returns

Soil structure of arable land changes considerably with time, due to cultural practices and weather conditions. By the main tillage operation, performed in autumn, the whole arable layer is usually loosened considerably. The rate of consolidation of the loose soil during autumn and winter diminishes logarithmically with time and is modified by climatic factors like rainfall, frost and thaw (Kuipers & van Ouwerkerk, 1963a). Often half of the original loosening effect is still present at the time of the first field operation in spring. Due to the intensity of traffic involved in fertilization, seedbed reparation and sowing, during the growing season many soils are nearly as compact as before the main tillage operation in autumn. During the growing season of most crops soil structure of the ploughed layer usually does not change considerably. It can be questioned whether soil density thus maintained is too high to obtain maximum (potential) yields, in wet growing seasons due to poor aeration, and in dry ones due to insufficient root penetration.

There are two ways to increase net returns of the farm over the entire crop rotation (van Ouwerkerk, 1974): increasing crop yield (physically and/or financially) or lowering production costs. In the Netherlands this increase in net returns is achieved by an increase in the proportion of root crops in the rotation (Lumkes, 1976). However, these crops are more demanding with respect to soil structure and, moreover, the chances of deleterious effects of harvesting operations, involving soil working machinery and heavy transport (over 50 t ha^{-1}), soil fumigation, etc., on soil structure are greater. Therefore, to obtain maximum yields in these narrow crop rotations, soil structure requires special attention by adaptation of the tillage system to local conditions of soil type, crop rotation and climate. A modification of the tillage system may also be considered with respect to production costs (van Ouwerkerk, 1976b). However, because in the Netherlands tillage costs are only of the order of 10 % of total production costs, careful economic evaluation of cost and profit aspects is necessary to assess the ultimate effect of tillage systems on the profitability of the farm (Cevaal, 1978).

1.2 Tillage systems and soil density

In general, almost any tillage operation, and especially ploughing, has a loosening effect on soil structure, while traffic over the field has a compacting effect. According to the extent to which loosening effects are incorporated and compacting effects are tolerated, four tillage systems can be distinguished (Kuipers, pers. commun, 1970; Table 1).

Table 1. Tillage systems.

Loosening effects	Compacting effects	Denomination
+	−	loose-soil husbandry
+	+	traditional tillage
−	−	rational tillage
−	+	zero-tillage

In the *traditional system* the whole arable layer is loosened intensively each year. However, in spring the soil is usually compacted to the extent that almost all of the loosening effect is lost.

Loose-soil husbandry tries to improve this situation by maximizing the loosening effect, and by minimizing compaction through reducing field traffic and restricting it to non-vulnerable situations.

In its full sense, *zero-tillage*, means that any tillage whatsoever (seedbed preparation included) is omitted (Bakermans & de Wit, 1970). However, for potatoes this is impractical as mechanical lifting is impossible without proper ridges. Therefore, for this crop a seedbed has to be made by full-width rotovating to a depth of at least 7 cm. Nevertheless, in this system compaction is an overruling factor. In the research reported here this system is denoted as no-tillage.

In the tillage system arbitrarily denoted as *rational*, soil tillage in its broader sense (i.e. including field traffic) is restricted to a rational or reasonable extent, to satisfy the specific demands of the individual crops in the rotation with respect to soil structure and weeds. This may be a reduction to nothing (as for cereals), but also ploughing to 25 cm depth (as for sugar beet). The loosening effect is safeguarded by rationalization of field traffic (combined cultivations, wide implements, etc.).

1.3 Tillage systems studied

A first experiment was conducted on a clay loam soil (27 % clay; 3 % organic matter), on the Westmaas Experimental Husbandry Farm (EHF), 10 km south of Rotterdam, during 1968–1971 (van Ouwerkerk & Boone, 1970; Bakermans et al., 1974). In a fairly wide, five-year rotation: alfalfa (lucerne) or ryegrass – sugar beet – winter wheat + ryegrass – potatoes – barley or oats + ryegrass, rational tillage was compared with traditional tillage and no-tillage. This experiment showed that restricting both loosening and compacting effects as practised in the rational tillage system did not result in a looser soil structure than in the traditional system (Table 2). It was concluded that to obtain a really loose soil structure, it is anyway necessary to plough the whole arable layer (0–25 cm depth) each year, as advocated in the loose-soil husbandry system.

In 1971 a new experiment was started on the Westmaas EHF on a loam soil with 22 % clay and 2.3 % organic matter (van Ouwerkerk, 1976a, 1976b). Here rational tillage is being compared with loose-soil husbandry and no-tillage in a four-year rotation: sugar beet – barley + ryegrass – potatoes – winter wheat + ryegrass. The

Table 2. Westmaas EHF (1968–1971) – Pore space (%, v/v), averaged over 4 years and 5 crops (n = 450).

Depth (cm)	Tillage system		
	traditional	zero	rational
2–7	49.5	45.9	48.9
12–17	46.7	44.0	45.6
22–27	46.3	44.7	45.5

essential features of the experimental site and of the three systems are given in Chapter 2.

In the present report results with respect to soil structure, nitrogen availability, weed control and crop yield obtained during the first four-year crop rotation 1972–1975 are dealt with. Cost and profit aspects are being evaluated now as the experiment was concluded in 1979.

2 Lay-out of the experiment

L.M. Lumkes & C. van Ouwerkerk

2.1 Soil characteristics

The research was carried out on Westmaas Experimental Husbandry Farm which is situated in the southwest of the Netherlands, in the Hoeksewaardpolder. Soils in this district belong to the important group of 'polder' vague soils (de Bakker, 1979), with loam in the plough layer and clay content decreasing with depth. As a rule below 40–60 cm depth the soil changes into sandy loam with a spongy consistency. The topsoil (0–30 cm) of the experimental field has a pH-KCl of 7.3, a fair organic matter content (2.3 %), and a high content of calcium carbonate (8.3 %). The mineral fraction contains 22 % $< 2\mu m$, 33 % $< 16\,\mu m$, 33 % 16–50 μm, 22 % 50–105 μm, and 2 % $> 105\mu m$. Chemically the topsoil is characterized by contents of 19 mg K per 100 g, 65 mg Mg per kg, 10 mg P per 100 g, and 0.14 g N-total per 100 g. From these data it may be concluded that this soil is fertile.

The experimental field is intensively drained: tile drains with a spacing between 7.2 and 9.2 m have been installed at a depth of 1.10 m. The direction of the drains is about perpendicular to the direction of the tillage operations. The texture of the experimental field is fairly uniform. However, due to the former creeks micro-relief is irregular: height differences amount to 50 cm. On several places in the field a rather severe plough pan was found at about 30 cm depth.

2.2 Tillage systems and crop rotations

To study the loosening and compacting effects of soil tillage and their influence on crop growth, three distinct tillage systems were compared. The systems, summarized in Table 3, are further explained below.

A. *Loose-soil husbandry*. The aim was to produce and maintain a much looser soil than normally is found in agricultural practice. We tried to achieve this aim by ploughing the whole arable layer every year and by minimizing the number of passes for fertilizing, seedbed preparation, and drilling. So for instance fertilizing, seedbed preparation, planting and ridging of potatoes, was done in one pass.

B. *No-tillage*. This system was the opposite of System A. Soil tillage was restricted to drilling, planting and ridging for potatoes, and harvesting of root crops, resulting in a very compact soil.

C. *Rational tillage*. This system represents current progressive farming methods, for increasing the efficiency of soil tillage in a technological and economic sense. Loosening by soil tillage was restricted by ploughing sometimes less deeply than in System A or by substituting cultivation with a fixed-tine cultivator for ploughing. Preliminary research (Lumkes & Beukema, 1973) showed that with a fixed-tine cultivator there

Table 3. Tillage systems compared during 1972–1975.

	Loose-soil husbandry (A)	No-tillage (B)	Rational tillage (C)
Potatoes	plough 25 cm N-fert. + seedbed prep. + planting + ridging (1 pass)	– rotovator 7 cm + planting (1 pass) row-rotovating + ridging (1 pass)	plough 20 cm seedbed prep., planting (2 passes) row-rotovating + ridging (1 pass)
Winter wheat	plough 20 cm + sowing (1 pass); no seedbed prep.	cultivator 6 cm + sowing (1 pass); no seedbed prep.	cultivator 15–20 cm + sowing (1 pass); no seedbed prep.
Sugar beet	plough 25 cm seedbed prep. + sowing (1 pass)	– direct drilling	plough 25 cm seedbed prep., sowing (2 passes)
Spring barley	cultivator 8 cm plough 20 cm seedbed prep. + sowing (1 pass)	cultivator 3 cm – direct drilling	cultivator 8 cm cultivator 15–20 cm seedbed prep., sowing (2 passes)

is a better chance for volunteer potatoes to be controlled by frost. In general it might be acceptable to substitute ploughing for cereals. Therefore, in the research reported fixed-tine cultivating was also practised after sugar beet. Thus in System C ploughing and cultivating alternate and cereals were drilled in an unploughed soil.

The main crop rotation in the experiment was potatoes – winter wheat (with undersown grass) – sugar beet – spring barley (with undersown grass), which is representative for the south-western marine clay district of the Netherlands. The grass green manure, as well as tops and leaves of sugar beet and chopped straw, were incorporated into the soil (Systems A and C) or, after treatment with herbicides, left on the surface as a mulch (System B).

In principle the no-tillage system is not suitable for potatoes and sugar beet as seedbed preparation and harvesting operations for these root crops necessitate a fair amount of tillage. The inherent soil disturbance may have negative effects on the soil and prevent soil fauna from realizing a stable soil structure, characteristic for the 'pure' no-tillage system.

Therefore, it was thought wise to split the plots marked out for the no-tillage system in two halves, one with the main crop rotation as described above (B1), and one with a crop rotation with non-root crops only (B2): oil seed rape – winter wheat (with undersown grass) – seed grass – spring barley (with undersown grass).

In 1972 crop rotation B2 did not pose any problem. For all crops the previous crop was spring barley, the regrowth of which had been more or less controlled by intensive stubble cultivation in autumn 1971. However, in autumn 1972, and in spring 1973 mass regrowth of winter wheat developed in the seed grass and quite a lot of regrowth of spring barley in oil seed rape. As it proved to be very difficult to control these volunteer plants chemically, in spring 1973 oil seed rape and seed grass were killed chemically. Afterwards these plots were resown with seed grass and oil seed rape, respectively. Thus the B2 crop rotation became seed grass – winter wheat – oil seed rape – spring barley (with undersown grass), which offers sufficient possibilities for chemical control of regrowth in the next crop. Moreover, it has the advantage that seed grass (underseed) can be sown mixed with spring barley (cover crop) which increases the chances of successful growth of the seed grass considerably. In spring 1975 oil seed rape (sown in 1974) failed. Therefore it was replaced by maize.

2.3 Fertilization

2.3.1 Nitrogen

Crop response to tillage-induced changes in the nitrogen status of the soil was established by applying five amounts of nitrogen (0 kg ha^{-1} included) on plots with the main crops potatoes, sugar beet, winter wheat, and spring barley (Table 4). To prevent residual effects these annual nitrogen levels were realized each year on only one of the three replicates of the experimental field.

To establish to what extent crop response on tillage-induced changes in soil structure can be influenced by the nitrogen fertilization regime, the normal amount of nitrogen (P), as usual in agricultural practice in the southwest of the Netherlands was compared with 20 % higher (P^+), and 20 % lower (P^-) amounts except for spring

Table 4. Annual nitrogen levels (kg ha^{-1}), 1972–1975.

	N1	N2	N3	N4	N5
Potatoes	0	80	160	240	320
Winter wheat	0	40	80	120	160
Sugar beet	0	60	120	180	240
Spring barley	0	20	40	60	80

Table 5. Perennial nitrogen levels (kg ha^{-1}).

	Year	P−	P	P+
Potatoes	1972–1975	190	240	290
Winter wheat	1972	80	100	120
	1973–1975	60	80	100
Sugar beet	1972	120	150	180
	1973–1975	120	160	200
Spring barley	1972	30	40	50
	1973	–	20	40
	1974	20	40	60
	1975	40	60	80

Table 6. Phosphate and potassium fertilization (kg ha^{-1}), 1972–1975.

	P_2O_5	K_2O
Potatoes	200	500
Winter wheat	–	–
Sugar beet	150	150
Spring barley	–	–
Seed grass	50	150
Oil seed rape	100	150
Maize	100	150

barley, where, because of the low amounts, the relative differences were bigger (up to 100 %: Table 5). To enable cumulative effects to appear, this fertilization scheme was reproduced each year on all plots of all three replicates of the experimental field.

Annual and perennial nitrogen levels were supposed to be supplementary, the rate used in practice (P) representing the connecting link (P ≈ N2, N3). On the two replicates where in a certain year no annual nitrogen levels were compared, the parts marked out for this purpose received the amount used in practice (P).

We aimed at applying nitrogen fertilizer in late winter over frozen soil. However, in mild winters this was not always possible, and then nitrogen was applied in early spring, prior to seedbed preparation or in combination with planting, according to the tillage system.

2.3.2 Phosphate and potassium

In all tillage systems the same amounts of phosphate and potassium were applied (Table 6). As usual in the Netherlands in a crop rotation with 50 % root crops and 50 % cereals, phosphate and potassium were not applied to cereals. Phosphate and potassium were always applied in autumn (after cereal harvest) as this causes least damage to soil structure.

2.4 Experimental design

The lay-out of the experiment was fairly complicated (Fig. 1). It was a rotational scheme with four crops rotating in four years over tillage systems with fixed places. Each year all crops of the rotation were present in the experiment. The design had three replicates (I, II and III), each with four crop-blocks grouped into two rows. The four crops corresponded with the four phases of the crop sequence: potatoes – winter wheat – sugar beet – spring barley in Systems A, B1 and C, and with the crop sequence: seed grass – winter wheat – oil seed rape – spring barley in System B2.

In periods of four years the crop-blocks were shifted over four positions on the field. Each separate crop gave a complete block design with the three crop-blocks as replicates. Within the crop-blocks there were three plots with the fixed tillage systems A = loose-soil husbandry, B = no-tillage and C = rational tillage. The plots

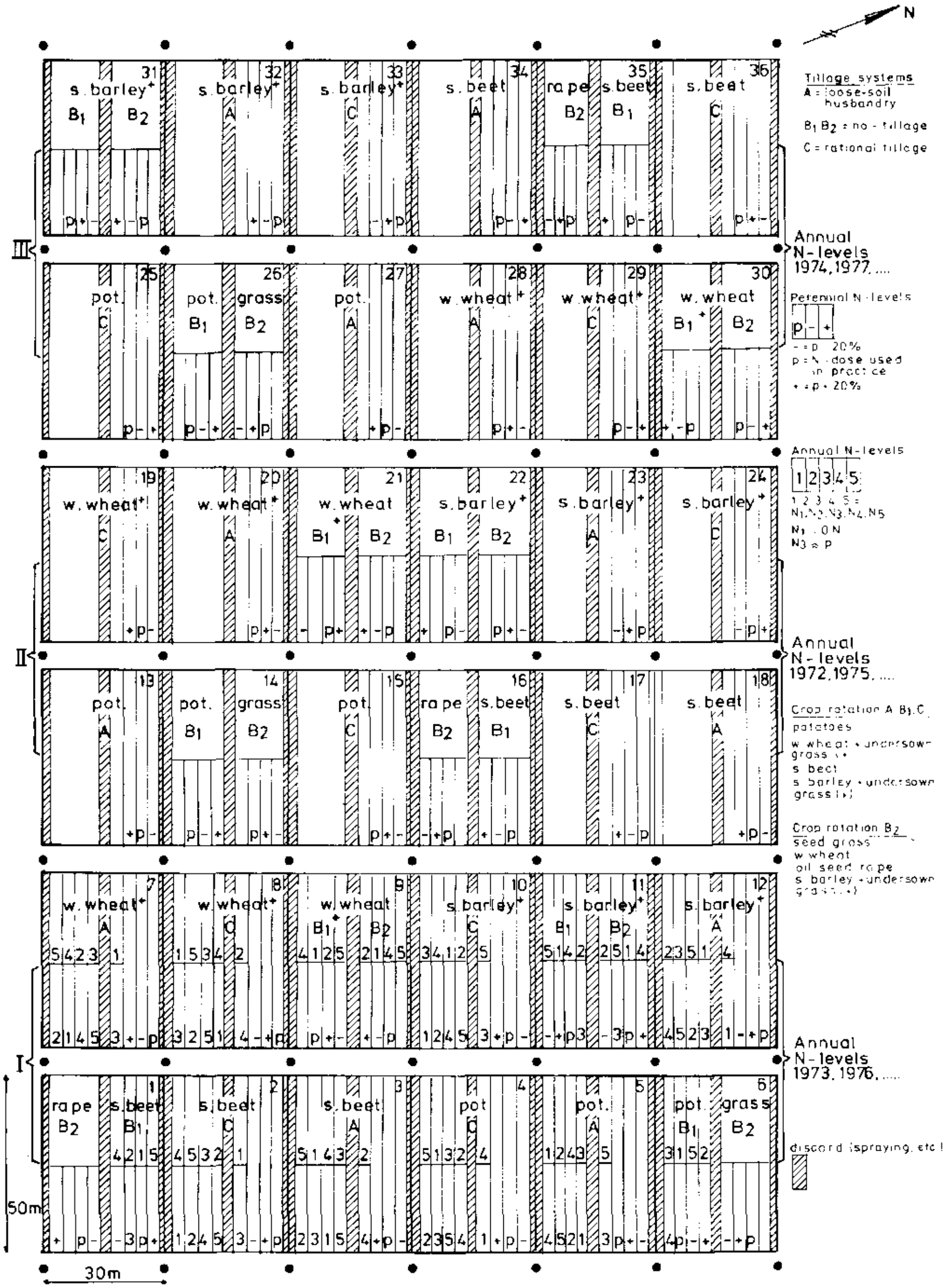


Fig. 1. Lay-out of the experiment.

of System B were split into two halves: B_1 (no-tillage with root crops as in Systems A and C), and B_2 (no-tillage without root crops).

The plots had a size of 30 × 50 m = 1500 m^2. They were split in their width, and on the B1 and B2 plots also in their length, to provide room for the different nitrogen levels. The nitrogen sub-plots had a width of 3 m (the working width of the fertilizer drill) and a length of 50 m (or 25 m in Systems B1 and B2). The treatments were assigned randomly. Annual nitrogen levels were established each year on a different replicate, whereas the cumulative nitrogen levels were present each year on all three replicates.

The trial field had a size of 6.3 ha (length 350 m, width 180 m). The general direction of all tillage treatments and of field traffic was in the length. Between the rows of plots there were strips of 10-m wide. These gross strips, which lay in grass, were necessary for turning machinery and especially for the trains of machinery used in System A. There was no room to have these strips also in between the crop sub-plots. Therefore, working across was impossible, and all traffic had to follow the length direction. For each crop and each tillage system one plot was situated on the border of the field. The outside strip of 3 m of the nitrogen sub-plots was always reserved for adjusting the implements.

2.5 Machinery used

2.5.1 Main tillage treatment

The main tillage treatments are summarized in Table 7. They were either ploughing each year (System A), cultivating with a fixed-tine cultivator (Lumkes, 1974) and ploughing alternately (System C), or no tillage (Systems B1 and B2).

Table 7. Main tillage treatment.[1]

	Tillage system	Ware potatoes	Winter wheat	Sugar beet	Spring barley
1972	A	pl 25	pl 20	pl 25	pl 20
	C	pl 20	cult 20	pl 25	cult 20
	B1	–	–	–	–
1973	A	pl 25	pl 20 +	pl 25[2]	pl 20
	C	pl 20	cult 20	pl 25	cult 20
	B1	–	–	–	–
1974	A	pl 25	pl 20 +	pl 25[2]	pl 20
	C	pl 20	cult 20 +	pl 25	cult 20
	B1	–	cult 5 +	–	–
1975	A	pl 25	pl 20 +	pl 25[2]	pl 20
	C	pl 20	cult 15 +	pl 25	cult 15
	B1	–	cult 5 +	–	–

1. Tillage for winter wheat combined with sowing (one pass operation) is indicated by +.
2. Immediately followed by harrowing.

Ploughing was performed with a two furrow reversible plough that cuts furrows 40 cm wide and 20 or 25 cm deep. In the first two years of the experiment the plough used at that time did not give satisfactory results at the shallower depth (20 cm).

In System A, after the first year, ploughing and drilling of winter wheat were done in one pass. The drill with trailing light harrows was mounted on the left side of the tractor (Fig. 2). The drill had a working width of 160 cm and was operated each time two passes of the plough (2 × 80 cm = 160 cm) were completed. Also after the first year, ploughing to a depth of 25 cm for sugar beet in System A was combined with light harrowing in the same pass. Thus, independent of frost action, in spring a level seedbed could be obtained. In System C no such harrowing was performed.

The fixed-tine cultivator was used to a variety of depths: 5, 15, or 20 cm (Table 7). This implement consists in the Dutch version of one beam which is 3 m wide and has two rows of tines (4 or 6 in the front row, and 5 or 7 in the rear row, Fig. 3). Thus tine spacing was 25 cm or 37.5 cm. The tines worked at an angle of about 50° to the horizontal. Either narrow chisel tines or duck feet were used. On the shafts sometimes 10 cm wide, flat plates were mounted to increase upward transport of soil to obtain a coarser tilth.

In System C, after the first two years, fixed-tine cultivating and drilling of winter wheat were combined in one pass, the drill being attached to a three-point implement carrier (bridge-link, Fig. 4).

In System A the fixed-tine cultivator was used to mix the loose soil created at potato harvest with the underlying firm part of the topsoil before ploughing to 20 cm depth for winter wheat.

Fig. 2. Ploughing and drilling of winter wheat in the same pass (System A).

Fig. 3. Dutch version of fixed-tine cultivator with one beam and two rows of tines.

Fig. 4 Combination of fixed-tine cultivating and drilling of winter wheat in one pass (System C).

2.5.2 *Seedbed preparation*

Procedures for seedbed preparation are summarized in Table 8. All implements had a working width of 3 m.

Fixed-tine cultivator In January 1972 in Systems A and C the soil surface was levelled and the soil coarsely crumbled and exposed to further frost action by shallow working with the fixed-tine cultivator, thus facilitating seedbed preparation for sugar beet.

The spring-tine cultivator was used to prepare a seedbed for spring barley. In System A it was followed by the seed drill in the bridge-link in the same pass. In System C, however, the barley and grass seed mixture was usually drilled in a separate pass.

The power rotary harrow was mainly used for seedbed preparation for potatoes in System A. Here nitrogen fertilization, seedbed preparation, potato planting and ridging were done in one pass (Fig. 5), a fertilizer spreader of the seed roll system being used in the adapted front loader of the tractor. Behind the tractor a full width 3-m wide rotary harrow with crumbler-roller prepared the seedbed. It was followed by a bridge-link to which a four-row potato planter, complete with ridgers, was mounted.

In System C a seedbed for potatoes was only prepared when it was thought to be necessary (1974, 1975), and then the rotary harrow was used. However, as the rotational speed was kept lower than normal and the forward speed was increased, the rotary harrow was working much less intensively than in System A. In System C

Table 8. Seedbed preparation[1].

	Tillage system	Ware potatoes	Winter wheat	Sugar beet	Spring barley
1972	A	rotary harrow +	–	cult[2]; harrow +	–
	C	–	–	cult[2]; scrubber	s. tine cult
	B1	rotary cultivator	–	–	–
1973	A	rotary harrow +	–	harrow +	s. tine cult +
	C	–	–	scrubber (2×)	s. tine cult +
	B1	rotary cultivator (2×)	–	–	–
1974	A	rotary harrow +	–	harrow +	s. tine cult +
	C	rotary harrow (extens.)	–	harrow; scrubber	s. tine cult
	B1	rotary cultivator	–	–	–
1975	A	rotary harrow +	–	harrow +	rotary harrow +
	C	rotary harrow (extens.)	–	rotary harrow (2×)	s. tine cult (2×)
	B1	rotary cultivator	–	–	–

1. Seedbed preparation combined with sowing or planting (one pass operation) is indicated by +.
2. On frozen soil, two months before sowing.

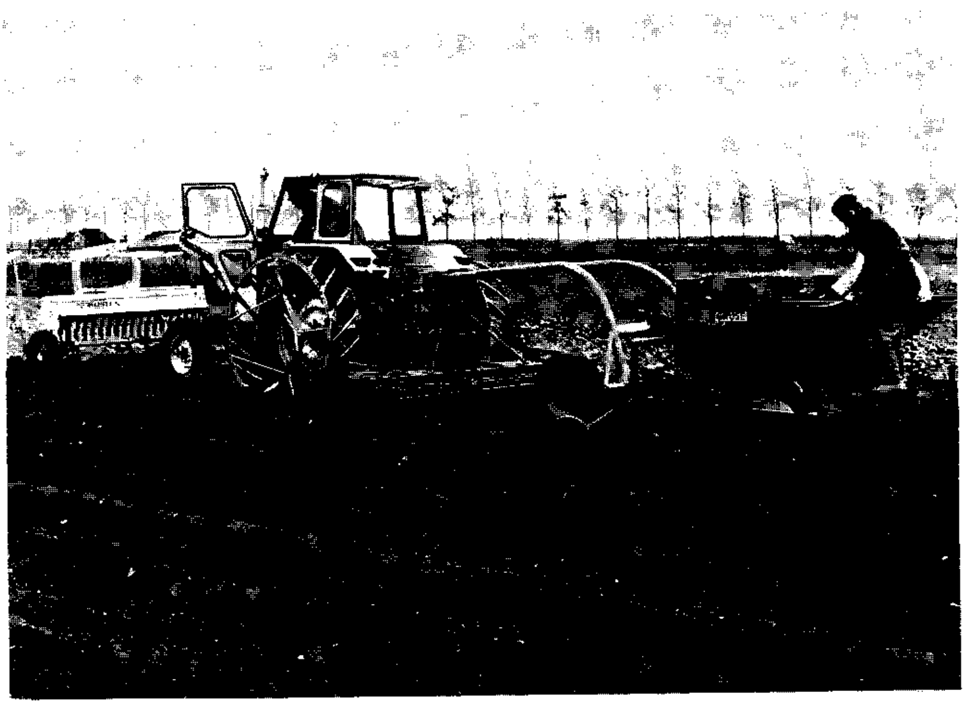


Fig. 5a and 5b. Combination of fertilizer spreader, rotary harrow and four-row potato planter (System A).

the potatoes were planted in a separate pass.

In 1975 when after ploughing to 25 cm depth in System C tilth was very coarse, the rotary harrow had to be used twice to obtain a reasonable seedbed for sugar beet. In this same year the rotary harrow also proved to be indispensable for preparing the seedbed for spring barley in System A.

Power rotary cultivator To prepare a seedbed for potatoes in System B1 the soil was rotovated to a depth of 5 cm. After potato planting and ridging (second pass) an inter-row rotary cultivator with ridgers and a working depth of 3 cm was used to form the final ridges in the third pass.

In System C some time after potato planting the ridges were given their final size and shape by one pass of an inter-row rotary cultivator with ridgers attached.

The scrubber, harrow and, incidentally, *Cambridge roller* were used for the seedbed preparation of sugar beet in Systems A and C (Table 8).

2.5.3 Sowing and planting

As usual in the Netherlands, row distances were 25 cm for cereals, grass and oil seed rape, 50 cm for sugar beet, and 75 cm for potatoes. Therefore in this experiment seed drills and potato planters had a standard working width of 3.00 m.

In Systems A and C drilling of cereals and grass green manure was done with a normal seed drill (nose wheel system). In Systems B1 and B2 cereals usually were drilled with a triple-disc 'roughland' sowing machine (Fig. 6), developed by Bakermans (Bakermans & de Wit, 1970). It cuts through the trash with a front disc (A),

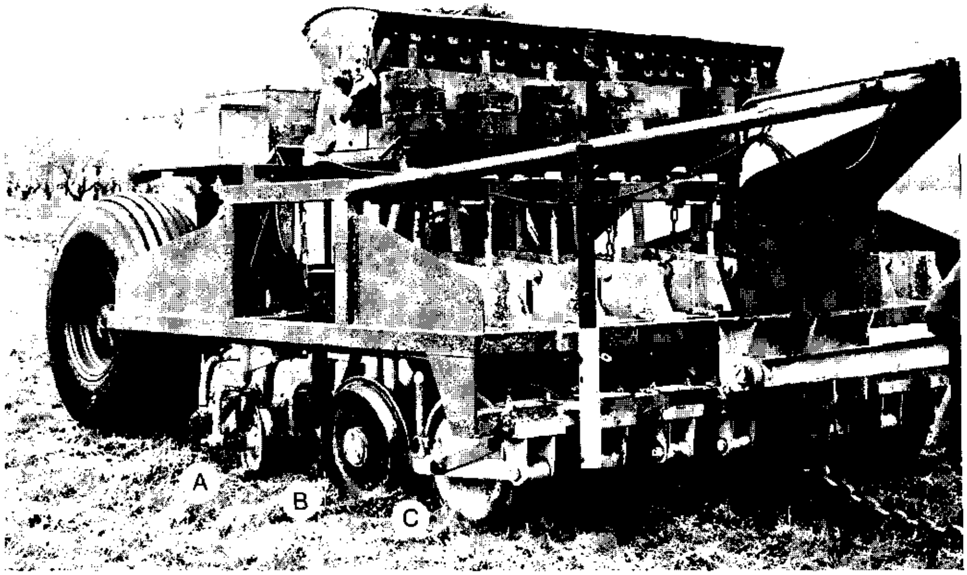


Fig. 6. Experimental triple-disc 'roughland' sowing machine (Systems B1 and B2).

brings the seed into the soil in between the two sowing discs placed in V-position (B) and closes the seed furrow with following small discs (C).

In System B1 after the first two years winter wheat was sown with the normal drill after levelling the surface with the fixed-tine cultivator directly after potato harvest.

Potato planting was done in all three systems with the same four-row potato planter. In System A nitrogen fertilization, seedbed preparation, planting and ridging were combined in one pass.

In Systems A and C sugar beet were sown with a six-row spaced seed drill. In System A sowing was combined with seedbed preparation in one pass, but in System C sowing was performed in a separate pass. In System B1 sugar beet had to be sown with the 'roughland' sowing machine. As this machine is not adapted to spaced seed drilling, more seed than in System A and C was sown and the seedlings had to be singled by hand hoeing.

2.5.4 Field traffic

As a result of the small width of the nitrogen sub-plots (3.00 m), all traffic over the field had to follow the same route, i.e. parallel to the long sides of the field. This resulted in more or less fixed tracks. Only in 1974 and 1975 after harvesting potatoes and sugar beet was the soil levelled by a spring-tine cultivator, working across the plots.

2.6 Timing of field work

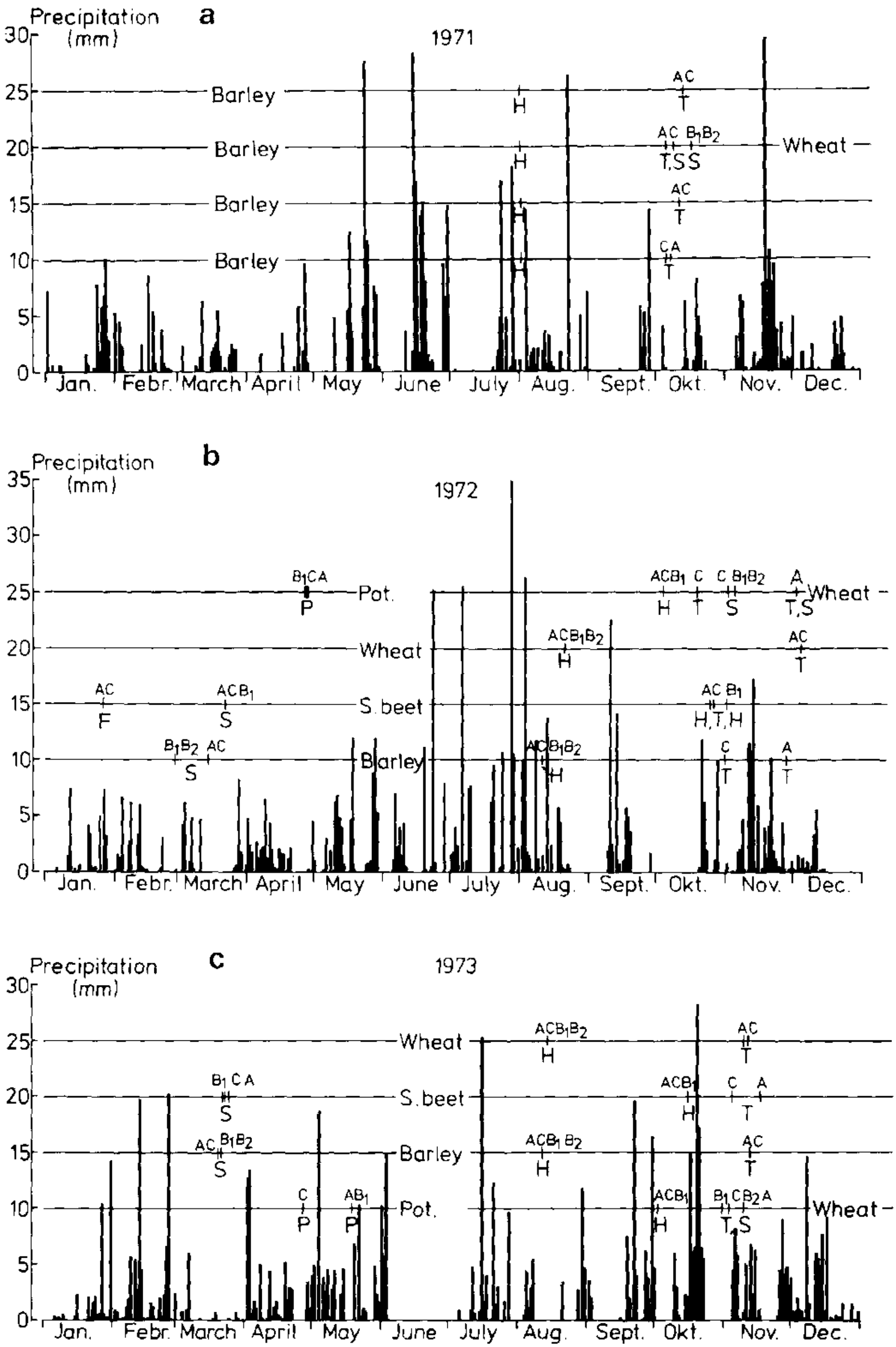
We aimed at carrying out the main tillage treatment in all systems and for all crops by the end of October, or in the beginning of November, and within one week. Thus we had to wait till potatoes and sugar beet had been harvested. However, during this time the grass undersown in cereals developed sufficiently as an effective green manure.

In autumn 1971, after spring barley, we made the most of the favourable conditions and carried out the main tillage treatment early (beginning of October), and also sowed winter wheat well in time (middle of October, Fig. 7a).

In 1972, due to very unfavourable weather conditions, the main tillage treatment for some crops or tillage systems could only be carried out by the end of November or in the beginning of December, under wet conditions. Cultivating for winter wheat (System C) could be carried out at the normal time (end October, beginning November) but ploughing (System A) had to be postponed until 1 December. Therefore there was a one-month difference in time of sowing between System A (1 December) and Systems B1, B2, and C (1 November). (Fig. 7b)

In autumn 1973 weather conditions favoured tillage operations at target time (first half of November), and winter wheat could be sown in the beginning of November.

Autumn 1974 was extremely wet, so that there was serious delay in the harvest of sugar beet and, especially of potatoes (Fig. 7d). Nevertheless, the main tillage treatment for sugar beet, spring barley and potatoes could be carried out more or less in time (beginning of November). However, tillage operations and sowing of winter wheat had to be postponed until the end of December or even to the beginning of January.



Precipitation (mm)
a
1971
Barley
Barley
Barley
Barley
Wheat
Jan. Febr. March April May June July Aug. Sept. Okt. Nov. Dec.
Precipitation (mm)
b
1972
Pot.
Wheat
S. beet
Barley
Wheat
Jan. Febr. March April May June July Aug. Sept. Okt. Nov. Dec.
Precipitation (mm)
c
1973
Wheat
S. beet
Barley
Pot.
Wheat
Jan. Febr. March April May June July Aug. Sept. Okt. Nov. Dec.

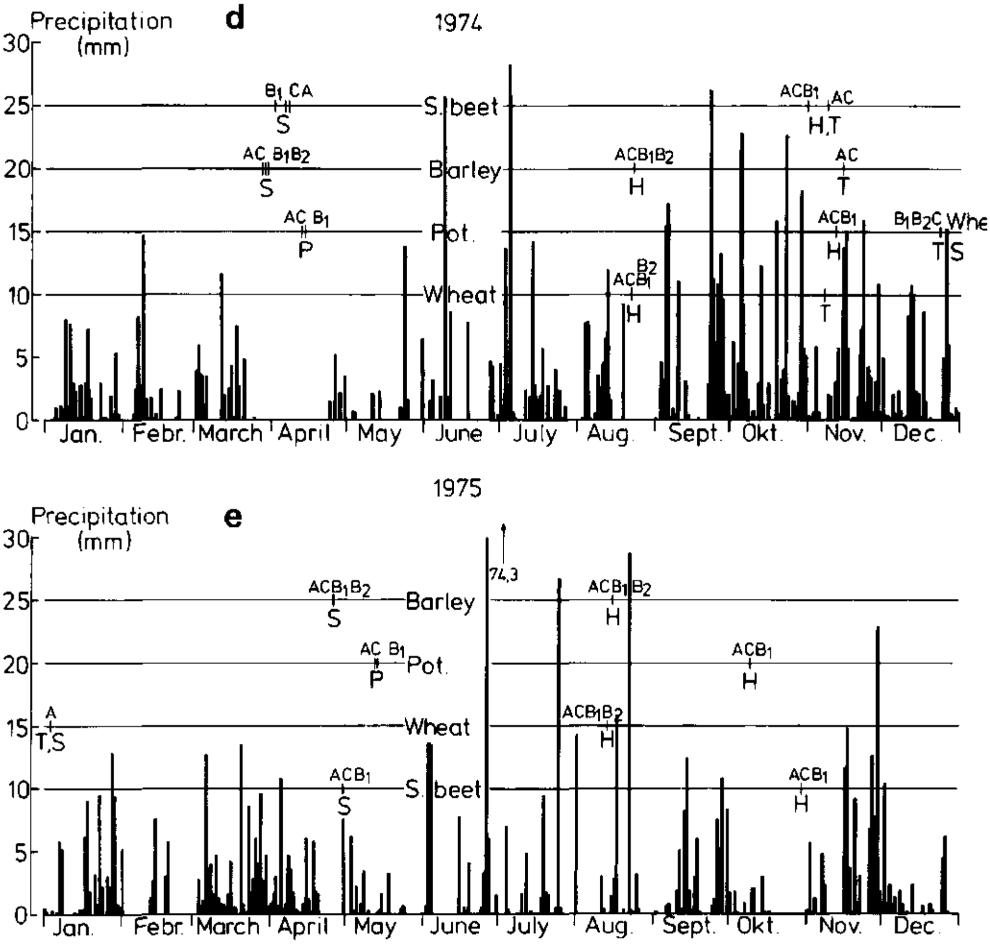


Fig. 7. Timing of field work.
A = loose-soil husbandry; C = rational tillage; B1 = no-tillage with root crops; B2 = no-tillage without root crops; T = main tillage treatment; F = tillage over frozen soil; S = seedbed preparation and/or sowing; P = plantbed preparation and/or planting; H = harvest.

In 1972–1974 spring barley and sugar beet could always be sown in time (middle of March–beginning of April). However, only in 1974 could potatoes be planted in time (middle of April). In 1972 and 1973, due to unfavourable weather conditions, planting had to be postponed to the end of April or even to the third week of May (1973: Systems A and B1).

The months of March and April 1975 were so wet and cold that spring barley and sugar beet could not be sown before the end of April, whereas potatoes could not be planted until the middle of May. Even then the soil was too wet to prepare a seedbed of reasonable quality.

Although we tried to make the most of all possibilities of each tillage system, differences in sowing or planting time between systems generally were rare (Figs.

7a–e). Only in 1972, was spring barley sown 15 days earlier in Systems B1 and B2 as is sometimes possible on non-tilled soil. Omitting the seedbed preparation in 1973 in System C enabled planting potatoes about three weeks earlier, which resulted in a very important increase in the length of the growing period. As already mentioned, in autumn 1972 in System A winter wheat was sown one month later than in Systems B1, B2 and C.

Harvest dates for the same crops were generally similar for all three systems. Harvest of winter wheat and spring barley could always take place under fair to good conditions at the normal time (around the middle of August). Only in 1972 was winter wheat harvested considerably later (11 days) than spring barley.

In 1972, 1973 and 1975 harvest of potatoes (beginning of October) and sugar beet (middle–end of October) could be carried out under good to very good conditions. However, in the extremely wet autumn of 1974 these crops could only be harvested in the beginning of November under very wet conditions.

2.7 Start of the experiment

On the field marked out for the present experiment in 1970 sugar beet was grown and in 1971 spring barley (cv. Delisa), without undersown grass. At harvest, in the beginning of August, field traffic was minimized by using a combine harvester with a mounted straw chopper. However, the spring barley was heavily lodged, and therefore much long stubble remained standing while the mounted chopper could not sufficiently reduce the straw length. Consequently, shortly after harvest straw was insufficiently mixed through the topsoil by a rotary harrow, working to a depth of 5 cm. Therefore, some days later the soil was tilled to 10 cm depth with a stubble plough and thereafter, because the soil still remained too coarse, with a disc harrow.

In this way straw and soil were mixed sufficiently and a reasonably level and fine seedbed was obtained to drill Italian ryegrass on the plots marked out for sugar beet and potatoes (all tillage systems), and for winter wheat and spring barley (tillage systems B1 and B2), and to drill oil seed rape in System B2.

Directly after drilling Italian ryegrass (14 August) and oil seed rape (18 August), an extended drought period started, resulting in only a moderate development of these crops. Moreover, crop development was heavily impeded by mass regrowth of spring barley.

Before drilling English ryegrass in System B2 (31 August) a cultivation with the rotary harrow was necessary to prepare a finely crumbled seedbed but also to control regrowth of spring barley. On plots marked out for winter wheat and spring barley in Systems A and C regrowth of spring barley was controlled with stubble plough and fixed-tine cultivator. Hence, in the beginning of September these plots were bare, while the other plots were green from grass or oil seed rape, both mixed with regrowth of spring barley.

3 Effect of primary and secondary tillage

C. van Ouwerkerk & L.M. Lumkes

The main tillage treatment in System A (loose-soil husbandry) was always ploughing, either to 25 cm depth (sugar beet and potatoes) or to 20 cm depth (winter wheat and spring barley). In System C (rational tillage) ploughing was only done for sugar beet (25 cm) and for potatoes (20 cm), whereas for cereals the soil was tilled with a fixed-tine cultivator to a depth of 15–20 cm.

In order to keep the soil in *System A* as loose as possible, seedbed preparation was omitted, minimized or combined with sowing or planting (one pass operation). This procedure can only give a seedbed of satisfactory quality if the ploughing is done very well. When the quality of the seedbed has to be very high, as for sugar beet, the quality of the work done by ploughing can be improved by harrowing immediately afterwards (1973–1975), or by one pass of the fixed-tine cultivator over frozen soil, well before seedbed preparation (1972). As appears from Table 9 the effect of ploughing was often unsatisfactory. This was partly due to initial difficulties in turning in a lush crop of grass (for sugar beet and potatoes). However, the more or less fixed pattern of the ruts introduced at harvest kept giving trouble. Therefore, on ploughed plots the seedbed was often coarse to very coarse or, for potatoes, sometimes a bit cloddy and shallow (Table 10).

The fixed-tine cultivator usually produced a finer tilth than ploughing to the same depth, especially when the cultivator was used after potatoes. Then only a small amount of the soil sieved out at harvest is transported downwards and not many clods are transported from below. In the first year, after intensive stubble cultivation, the fixed-tine cultivator gave a very fine tilth on the plots marked out for spring barley.

Table 9. Result of main tillage treatment.

	Tillage system	Ware potatoes	Winter wheat	Sugar beet	Spring barley
1972	A	coarse	very coarse	coarse	coarse
	C	coarse	very fine	coarse	too fine
1973	A	coarse, irregular	coarse, irregular	course, irregular	coarse
	C	coarse, irregular	too fine	coarse, irregular	coarse
1974	A	nicely crumbled; even	coarse	coarse, even	coarse
	C	nicely crumbled; even	fine	coarse	coarse
	B1	.	fine	.	.
1975	A	nicely crumbled; even	stiff, irregular	coarse	coarse, irregular
	C	nicely crumbled; even	stiff, irregular	very coarse	coarse
	B1	.	fine	.	.

Table 10. Visual estimation of seedbed quality.

	Tillage system	Ware potatoes	Winter wheat	Sugar beet	Spring barley
1972	A	good	too coarse	good	very coarse
	C	.	too fine	very fine	too fine
	B1	fine	much too fine	.	.
1973	A	good	too coarse	good	good
	C	.	too fine	irregular	a bit coarse
	B1	fine	much too fine	.	.
1974	A	a bit cloddy	coarse	coarse	coarse
	C	shallow, cloddy	very loose	fine	coarse, shallow
	B1	fine	fine	.	.
1975	A	a bit cloddy	coarse, irregular	very coarse	moderately coarse
	C	shallow, cloddy	coarse, irregular	fine	fine
	B1	fine	fine	.	.

However, in later years, when spring barley was preceded by sugar beet, the tilth tended to be coarse, especially when the sugar beet had been harvested under moist conditions.

In *System C* seedbed preparation was not strictly prescribed, the aim being a good seedbed. Therefore, for sugar beet, depending on soil conditions, drawn implements as well as powered implements were used, either once or twice. For spring barley only the spring-tine cultivator was used in 1972, not so much to prepare the seedbed as to destroy weeds and volunteer plants of the preceding barley crop that had grown during winter. In 1972 and 1973, despite a coarse winter furrow it was thought wise to plant potatoes early, without any seedbed preparation. However, in 1974 and 1975, it was thought that preparing a seedbed in an extensive but quick way was the better approach. As in System A, winter wheat was sown directly afterwards (1972) or combined with the main tillage treatment (fixed-tine cultivator 15–20 cm deep), and only harrowed in combination with sowing. As a consequence, seedbed quality in System C differed widely between crops and years, but quite often the seedbed was too fine (Table 10).

In *System B1* tillage for cereals and sugar beet was omitted, except in 1974 and 1975 for winter wheat (after potatoes) when the soil was treated with the fixed-tine cultivator to a depth of 5 cm to restore contact with the dense subsoil and to increase the amount of coarse clods at the surface. Consequently, in 1972 and 1973 the seedbed for winter wheat was much too fine (Table 10). The only seedbed preparation for potatoes was rotovating to a depth of 5 cm, which resulted in a rather finely crumbled seedbed, overlying a dense subsoil.

4 Soil structure

F.R. Boone, B. Kroesbergen, C. van Ouwerkerk & M. Pot

4.1 Methods used for determination of soil structure during the growing season

As a rule soil-physical measurements are carried out twice a year; in spring, after sowing or planting, and in late summer, after harvest of small grains, but before the harvest of potatoes and sugar beet. As soil structure is often quite variable over short distances, the measurements were replicated at least 10 times within the sampling site.

Undisturbed core samples of 100 ml were taken from the 2–7, 12–17 and 22–27 cm layers. Routine laboratory determinations on these samples were usually restricted to total pore space, moisture and air content, both in a field-moist condition and at a pressure potential of −100 cm. Moisture content at this suction represents approximately the equilibrium moisture content in spring of well-drained Dutch loam and clay soils without restricting layers. In the text the term 'moisture content at pF 2.0' will be used. This moisture content was determined by saturating the core sample for one night and placing it on a suction box (very fine sand) for two days. With 10 replicates the standard deviation of the average pore space is usually smaller than 1 % (v/v).

In 1975 air permeability at pF 2.0 was determined according to Kmoch (1961), using commercially available equipment.

A recording penetrometer, with a 60° cone having either a 3.84 or 1.86 cm^2 base, recorded on the same strip of waxed paper the resistance versus depth curves to 35 cm depth of all spots within the sampling site. Through the curves a mean curve was fitted by eye after which the resistance was numerically averaged (MPa) for each different layer (de Boodt et al., 1967).

Visual estimation in the field of total porosity and of 'workability' (ease of crumbling by hand) of dug-up blocks of soil from the 0–10 and 10–20 cm layers gave an indication of gross soil structure. These factors were both rated on a scale from 1 (very poor) to 10 (very good). The scores thus obtained were combined into one figure, characterizing the overall impression of soil structure.

About one month after the last ridging the outer profile of the potato ridges and, after excavation by hand, the boundary between the loose soil in the ridge and the firm soil underneath were determined with a relief meter. At the same time the total amount of loose soil and the percentages by weight of clods > 40 and > 20 mm in diameter were determined by collecting the loose soil of a 20-cm length of ridge and by sieving and weighing it in the field.

In 1972–1974 gravimetric moisture content in the potato ridges (0–5, 5–10, 10–15, 15–20 cm depth) and in the soil underneath the ridges (20–30, 30–60 cm depth) was determined in the period from March to September.

In 1972 soil temperature at planting depth was monitored up to emergence with thermographs.

4.2 Results

4.2.1 Soil structure at the start of the experiment

In August 1971, after harvest of the preceding crop (spring barley) an intensive stubble cultivation was carried on the whole field, to a depth of about 10 cm. Therefore, the 0–10 cm layer was very loose. However, Table 11 shows that the 15–20 cm layer was very dense and hard.

As differences between repetitions were only small we decided to concentrate research on the effect of the three tillage systems on soil structure on Repetition I. Therefore, core sampling, soil temperature measurements and determination of dimensions and quality of potato ridges were only carried out on Repetition I. Periodical sampling of the moisture content of potato ridges was also restricted to one repetition (1972: R I; 1973: R III; 1974: R III). However, resistance to penetration was measured and soil structure was visually estimated on all three repetitions.

4.2.2 The overall effect of tillage

Table 12 shows that there was a considerable positive effect of tillage on pore space. On the average it amounted to 3.4 % (v/v) in the 2–7 and 12–17 cm layers. However, in the 22–27 cm layer it was only 1.9 % (v/v). No-tillage resulted in a very dense soil with the smallest pore space in the 12–17 cm layer. Table 12 also shows a remarkable decline in soil structure in the course of the four years of experimentation. This decline was clearly stronger on non-tilled than on tilled soil and decreased fairly strongly with depth. This phenomenon will be dealt with in greater detail later on.

Ploughing to a depth of 25 cm resulted in a larger pore space in the 22–27 cm layer as compared to ploughing or cultivating to about 20 cm depth (Table 13). The relatively large pore space in the 22–27 cm layer of plots ploughed 20 cm deep led to the supposition that the effective ploughing depth was more than 20 cm. For the relatively small pore space in the 12–17 cm layer of cultivated plots there can be

Table 11. Characteristics of soil structure in the 15–20 cm layer at the start of the experiment (8 September 1971).

Repetition	Pore space	Moisture content		Air content		Resistance to penetration
		field	pF 2.0	field	pF 2.0	
	(%, v/v)	(%, w/w)	(%, w/w)	(%, v/v)	(%, v/v)	(MPa)
I	43.3	20.9	23.1	11.7	8.3	2.1
II	42.4	20.9	22.8	10.3	7.3	2.0
III	42.2	20.5	22.1	10.6	8.1	2.2

Table 12. Effect of tillage and no-tillage on seasonal average pore space (%, v/v).

	Tilled			Non-tilled		
	2–7 cm	12–17 cm	22–27 cm	2–7 cm	12–17 cm	22–27 cm
1972	47.6	46.2	45.0	45.2	43.4	43.5
1973	46.8	45.6	45.0	42.7	41.7	43.3
1974	45.0	44.9	44.6	41.4	41.4	42.3
1975	44.0	43.7	43.5	41.1	40.1	41.5
Mean	45.8	45.1	44.5	42.6	41.6	42.6

Table 13. Effect of tillage depth on pore space (%, v/v), 1972–1975.

	2–7 cm	12–17 cm	22–27 cm
Cultivator (20 cm)	46.2	44.6	43.7
Plough (20 cm)	46.4	45.5	44.7
Plough (25 cm)	45.8	45.5	45.1

Table 14. Effect of plouging for sugar beet and potatoes on pore space (%, v/v), 1972–1975.

	2–7 cm	12–17 cm	22–27 cm
Autumn (after cereal harvest)	45.9	45.1	44.3
Spring (after sowing sugar beet and planting potatoes)	45.6	45.8	45.4
Difference	−0.3	+0.7	+1.1

several reasons: (1) the effective working depth was less than 20 cm; (2) the loosening effect was less intensive than with ploughing; (3) consolidation during the growing season was greater, due to a lower stability of cultivated soil. Reason (1) is the most probable. However, it may be worthwhile to study (2) and (3). The positive effect of ploughing on pore space, as measured after sowing, is understandably only small (Table 14). As a result of the intensive seedbed preparation the effect was completely nullified in the 2–7 cm layer but was still noticeable in the 12–17 cm layer and clearly visible in the 22–27 cm layer.

4.2.3 Overall effects of the three tillage systems

Mean pore space, averaged for all crops and for the four years studied, was only about 0.5 % (v/v), and thus not statistically higher for loose-soil husbandry than for rational tillage (Table 15). Also, visual estimation failed to detect consistent differences in soil structure between these tillage systems (Table 16).

Table 15. Mean ($\overline{X}$)[1] and mean standard deviation ($\overline{S}_x$)[2] of (a) pore space (%, v/v), (b) moisture content at pF 2.0 (%, w/w), and (c) air content at pF 2.0 (% v/v), 1972–1975.

	Depth (cm)	Loose-soil husbandry (A)			Rational tillage (C)			No-tillage with root crops (B1)			No-tillage without root crops (B2)		
		a	b	c	a	b	c	a	b	c	a	b	c
$\overline{X}$	2–7	46.3	23.5	12.7	46.0	23.8	11.8	43.3	23.5	7.8	41.6	22.9	6.1
	12–17	45.6	24.1	10.6	45.1	23.8	10.2	41.6	22.2	7.1	41.4	22.2	6.7
	22–27	45.0	24.5	9.0	44.4	24.1	8.6	42.6	23.0	7.3	42.7	23.0	7.5
$\overline{S}_x$	2–7	2.6	0.9	3.6	2.8	0.9	3.8	2.5	1.0	3.1	1.7	0.9	1.7
	12–17	2.6	1.3	3.3	2.7	1.3	3.4	2.0	1.0	2.3	1.9	1.1	2.0
	22–27	2.3	1.2	2.8	2.6	1.5	3.0	1.9	1.0	2.3	1.7	1.0	2.1

1. n = 320 (4 years × 2 sampling dates × 4 crops × 10 samples).
2. n = 32 (4 years × 2 sampling dates × 4 crops).

Table 16. Mean visual estimation of soil structure, (units in a scale from 1 (very bad) to 10 (very good)),[1] 1972–1975.

Depth (cm)	Loose-soil husbandry (A)	Rational tillage (C)	No-tillage with root crops (B1)	No-tillage without root crops (B2)
0–10[2]	6+	6½	5½	5
10–20	5+	5½	4	4½

1. n = 320 (4 years × 2 sampling dates × 4 crops × 10 samples).
2. In this layer except potatoes.

With no-tillage pore space was significantly smaller than on tilled soil. Loosening the soil twice in four years (potato ridging and sugar beet harvesting; System B1) resulted in a somewhat larger pore space in the top layer than in the rotation without root crops (System B2). From the smaller mean standard deviation of pore space (Table 15) it appears that non-tilled soil, especially in a crop rotation without root crops, is more homogeneous than tilled soil.

Water content at a pressure potential of −100 cm (pF 2.0) in the 12–17 and 22–27 cm layers was clearly lower on the non-tilled than on the tilled plots (Table 15). Moreover, it was closely related to pore space, whereas on the tilled plots there was no such relationship (Fig. 8). Thus the non-tilled plots were seriously compacted (Kuipers, 1961).

Within certain limits, water content at pF 2.0 is also related to water content during a longer period prior to sampling. This explains the observed increase with depth, the higher water contents in spring compared with those in autumn, and the relatively low values for winter wheat in spring. However, on non-tilled soil moisture content at pF 2.0 was invariably higher in the 2–7 cm layer than in the 12–17 cm layer because

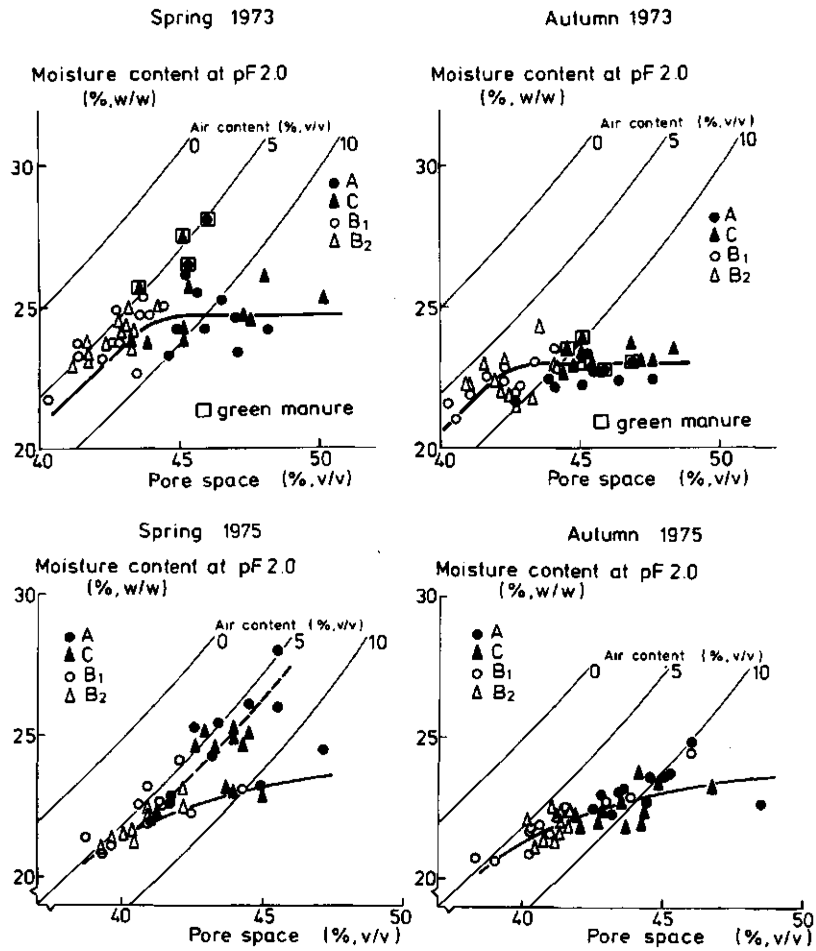


Fig. 8. Relationship between mean pore space and moisture content at pF 2.0 in 1973 and 1975 (n = 10). A = loose-soil husbandry; C = rational tillage; B1, B2 = no-tillage, with and without root crops, respectively.

all remnants of the previous crop remained in this layer and because pore space was here a bit larger.

The higher water content at pF 2.0 in the 12–17 cm and 22–27 cm layer of the tilled soil compared with non-tilled soil found in spring might also be attributed to buried organic debris and green manure crops. As these materials decompose fairly rapidly the effect disappeared during the growing season (Fig. 8).

As in the rational tillage system in two out of four years a fixed-tine cultivator was used instead of a plough, more organic matter remained near the surface. Therefore, water content at pF 2.0 in the 2–7 cm layer was here slightly higher and in the 12–17 and 22–27 cm layers slightly lower than on loose-soil husbandry.

Structure deterioration by harvesting root crops and ploughing or cultivating the soil under wet conditions also increased water content at pF 2.0, as appears from the higher than normal water contents at pF 2.0 found in spring 1975. Due to subsequent water extraction by evaporation during summer, water contents at pF 2.0 in autumn were normal again (Fig. 8).

Air content at pF 2.0 generally decreased with depth, due to decreasing pore space and increasing moisture content at pF 2.0. It was significantly lower on non-tilled than on tilled soil. However, due to the lower water content at pF 2.0, the difference was smaller than might be expected from the difference in pore space. In the tilled soil, air content at pF 2.0 in the 2–7 cm layer was higher and in the 22–27 cm layer somewhat lower than 10 % (v/v); on the non-tilled soil it was between 6 and 8 % (v/v).

4.2.4 The effect of tillage systems in different crops

Between *loose-soil* and *rational-tillage* systems there were small, but consistent differences in soil structure, differing for different crops:

Potatoes With loose-soil and rational tillage pore space in the 12–17 and 22–27 cm layers was higher than with other crops (Table 17). This result might be related to the fact that at the time potatoes were planted (three weeks after sugar beet and spring barley) the soil usually is drier and less vulnerable to compaction. However, visual estimation of soil structure did not show this difference. With loose-soil tillage pore space was slightly larger than with rational tillage, especially in the 22–27 cm layer, which was a direct effect of ploughing at a depth of 25 cm instead of 20 cm for potatoes.

Winter wheat Pore space in the 2–7 cm layer of the plots with winter wheat was largest with rational tillage because most of the finely crumbled soil sieved out at potato harvest remained near the surface, whereas with loose-soil tillage this soil was turned in by the plough to about 20 cm depth. In the 12–17 cm layer loose-soil tillage gave a slightly larger pore space than rational tillage, but with visual estimation the reverse was true. The larger pore space in the 22–27 cm layer with loose-soil tillage probably cannot be considered as a residual effect of ploughing at a depth of 25 cm for potatoes; the high water content at pF 2.0 indicates that the ploughing depth was somewhat more than 20 cm.

Sugar beet With sugar beet the 2–7 cm layer had a slightly larger pore space with loose-soil than with rational tillage. This result can be explained by the fact that with loose-soil tillage in spring all field operations were combined. Another reason could be that before ploughing to 25 cm depth the 22–27 cm layer of the preceding winter wheat was clearly more dense with rational tillage. In agreement with the identical ploughing depth (25 cm), pore space in the 12–17 and 22–27 cm layers of Systems A and C was similar.

Spring barley In spring barley pore space in the 2–7 and 12–17 cm layers was largest with loose-soil tillage. Although here again the combination of field traffic in spring could explain this difference, it may be that the loosening effect of the fixed-tine cultivator was not as effective as ploughing to the same depth.

Table 17. Pore space (a), moisture content at pF 2.0 (b), air content at pF 2.0 (c), and visual estimation of soil structure (d), 1972–1975.[1]

	Depth (cm)	Loose-soil husbandry (A)				Rational tillage (C)				No-tillage with root crops (B1)				No-tillage without root crops (B2)			
		a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
Potatoes	2–7	.	.	.	.	.	.	.	.	.	.	.	.	42.1	22.8	6.7	5+
(B2: grass)	12–17	46.7	24.3	12.3	5	46.0	24.0	11.6	5−	41.9	22.2	7.7	4−	41.4	22.0	6.8	4½
	22–27	46.2	24.9	10.5	.	45.2	24.3	9.8	.	42.7	22.7	8.1	.	43.1	23.1	8.2	.
Winter wheat	2–7	45.3	23.5	11.1	6	46.3	24.0	11.9	7−	44.4	23.9	8.9	6−	41.4	23.1	5.5	5
	12–17	45.7	23.9	11.2	5½	45.1	23.4	10.9	6	41.6	22.2	7.0	4+	41.2	22.5	6.0	4+
	22–27	44.7	24.1	9.3	.	43.4	23.2	8.4	.	42.9	23.4	7.3	.	42.2	23.1	6.8	.
Sugar beet	2–7	46.1	23.3	12.7	6½	45.6	23.3	11.7	6	42.4	23.0	7.1	5+	42.1	22.6	6.5	5
(B2: rape seed)	12–17	44.9	23.8	9.8	5½	44.9	24.2	9.4	5+	41.4	22.4	6.5	4+	42.4	22.2	6.5	4½
	22–27	44.6	24.5	8.4	.	44.5	24.6	8.0	.	42.5	23.2	6.9	.	42.9	23.2	7.3	.
Spring barley	2–7	47.3	23.9	13.7	6	46.1	24.3	11.1	6+	43.3	23.6	7.6	5	41.0	22.3	5.8	5
	12–17	44.9	24.2	9.5	5+	44.1	23.8	8.7	5+	41.5	22.1	7.1	4	41.5	22.1	7.2	4+
	22–27	44.3	24.5	7.9	.	44.0	24.1	8.0	.	42.2	22.9	7.0	.	42.5	22.6	8.0	.

1. a: %, v/v; b: %, w/w; c: %, v/v; d = units in a scale from 1 (very bad) to 10 (very good).

With *no-tillage* soil structure in the 12–17 and 22–27 cm layers did not differ much for different crops. Nor did the crop rotation have much effect. However, in the 2–7 cm layer of the plots with winter wheat and spring barley pore space was clearly larger in the crop rotation with root crops (System B1) than in the crop rotation without root crops (System B2). This effect must be attributed to the loosening effect of harvesting the preceding root crops potatoes and sugar beet. The large pore space in the 2–7 cm layer of the plots with winter wheat was also due to shallow cultivating of the fine soil left after potato harvest. This was done to establish a better contact between the very loose top layer and the very dense soil underneath to improve the vertical transport of water and to enrich the fine soil with coarse clods from beneath, thus reducing the risk of the seedbed of winter wheat being slaked.

4.2.5 Soil structure changes in the course of time

Generally, soil structure declined in the course of time (Fig. 9), indicating compactive effects (consolidation, field traffic, harvesting operations) to be stronger than the loosening effect of tillage. Note that in 1975 pore space on tilled plots was the same as in 1972 on non-tilled plots! It can also be concluded that the level of soil structure was more variable between years than between the loose-soil and rational tillage systems.

In the autumn of 1971, prior to starting the experiment, intensive stubble cultivation was carried out. Moreover, ploughing and cultivating were performed early in the season (beginning of October). Therefore, it is not surprising that the loosening effect of tillage was very good and that in spring 1972 high pore spaces were found.

The decrease in pore space during 1972, especially in the 2–7 cm layer, can be explained from compaction at harvesting cereals and from the fairly low stability of this soil (in this year there was serious slaking of plots with sugar beet on loose soil and rational tillage), tending to stabilize pore space at about 46 % (v/v). In 1973 pore space was already somewhat smaller and in 1974 mean pore space decreased further.

The very wet conditions during the sugar beet and potato harvest and subsequent main tillage treatment in the autumn and winter of 1974 resulted in a poor loosening effect. Consequently, pore space in spring 1975 was only about 44 % (v/v). Judged by visual estimation (Table 18), there was a tendency for soil structure to improve

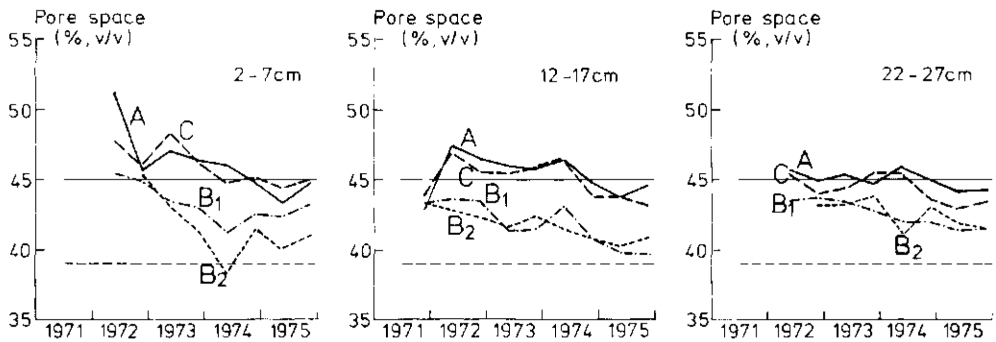


Fig. 9. Pore space during 1972–1975, averaged for all crops. A = loose-soil husbandry; C = rational tillage; B1, B2 = no-tillage, with and without root crops, respectively.

Table 18. Mean visual estimation of soil structure (units in a scale from 1 (very bad) to 10 (very good)),[1] 1975.

	Loose-soil husbandry (A)		Rational tillage (C)		No-tillage with root crops (B1)		No-tillage without root crops (B2)	
	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm
Spring	5−	4	5−	4+	4½	3+	3+	3+
Autumn	6+	4½	6+	5½	6	3½	5	4+

1. n = 40 (4 crops × 10 samples)

Table 19. Soil structure changes during 1975, averaged for all tillage systems.

Depth (cm)	Pore space (%, v/v)		Water content at pF 2.0 (%, w/w)		Air content at pF 2.0 (%, v/v)	
	spring	autumn	spring	autumn	spring	autumn
2–7[1]	42.5	43.5	22.8	22.6	7.5	9.5
12–17	41.9	42.1	23.1	22.1	6.3	8.0
22–27	42.6	42.7	23.8	22.6	6.3	8.1

1. Without potatoes.

during the growing season. This tendency corresponded with an increase in air content at pF 2.0 (on average from 6.7 in spring to 8.5 in autumn), which was due mainly to a decrease in water content at pF 2.0, caused by favourable weather conditions during the growing season (Table 19).

In 1972, no-tillage plots (also intensively stubble cultivated in the autumn of 1971) had a relatively large pore space in the 2–7 and 12–17 cm layers for all crops. However, during the four years of experimentation, harvesting operations and frequent traffic over the field gradually compacted the non-tilled soil seriously. In the fourth year (1975) in the 12–17 cm layer the minimum pore space for this soil, according to van Ouwerkerk (1976a) about 39 % (v/v), was nearly reached. Compacting effects were very weak in the 22–27 cm layer. Therefore, the decline in pore space was here smallest.

Anticipating the report on the development of soil structure in the second (and last) four years of experimentation, we can remark that in 1976 and 1977 pore space on tilled soil could be increased to a level of about 46 % (v/v). However, on non-tilled soil pore space remained at about 40 % (v/v).

4.2.6 *Shape and quality of potato ridges*

Cross-sectional area of the loose soil in the 75-cm spaced ridges (Table 20) generally met requirements, the standard being 600–750 cm² (Kouwenhoven & van Ouwerkerk, 1978). The slightly lower mean value for rational tillage was caused by the small ridges obtained in 1972 when in this system potatoes were planted without previously making a seedbed (Table 21).

External shape of the ridges did not differ much between tillage systems (Fig. 10). On rational tillage and no-tillage plots ridges were slightly steeper, whereas the top was more flattened (Table 20). Within the ridges, however, there were striking differences in shape of the boundary between the loose soil in the ridges and the firm soil underneath. With loose-soil tillage (no inter-row cultivation) this boundary was nearly flat, but with no-tillage and rational tillage a plateau was created by inter-row

Table 20. Mean shape and quality of potato ridges, 1972–1975.

	Depth of loose layer (cm)	Cross-section (cm^2)	Distance top ridge to firm soil (cm)	Width at 5 cm below the top (cm)	Slope halfway up (°)	Clods (%, w/w)	Visual estimation of soil structure (units)[1]
A Loose-soil husbandry	9.6	720	18	27	33	16	7½
C Rational tillage	9.1	680	14	29	37	14	7
B1 No-tillage	9.6	720	16	32	37	10	7+

1. Units in a scale from 1 (very bad)–10 (very good).

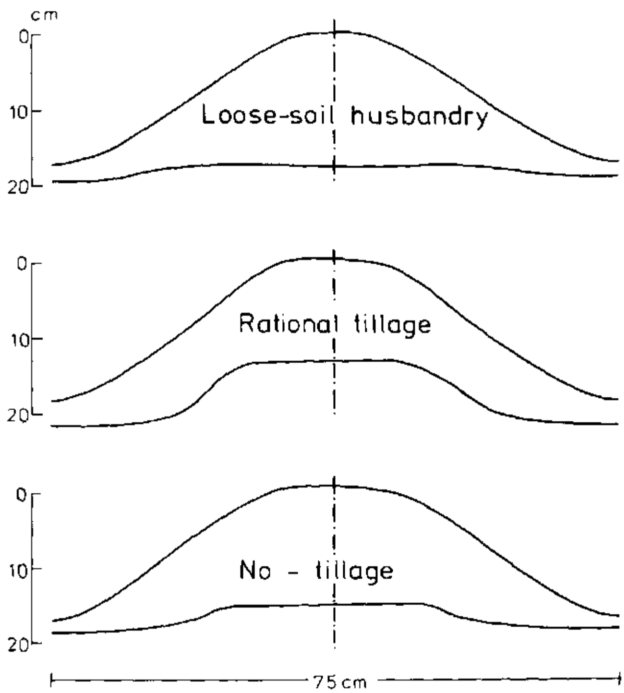


Fig. 10. Mean cross-section of potato ridges, 1972–1975.

Table 21. Characteristics of potato ridges.

	Loose-soil husbandry (A)				Rational tillage (C)				No-tillage (B1)			
	1972	1973	1974	1975	1972	1973	1974	1975	1972	1973	1974	1975
Depth of loose layer (cm)	10.2	9.2	9.1	9.9	7.1	9.2	10.1	10.0	9.3	9.2	9.5	10.5
Cross-section (cm^2)	765	690	683	743	530	690	758	750	700	690	713	788
Distance from top ridge to firm soil (cm)	18	17	20	18	12	14	15	15	16	16	17	16
Clods (%, w/w) > 20 mm	5	11	19	28	6	11	15	26	11	16	1	13
> 40 mm	0	0	4	8	1	0	3	6	0	0	0	1
Visual estimation of soil structure in spring (units)	8–	8½	7½	6–	7½	7½	7	5½	6½	7	8	7–
Mean daily temperature during emergence (°C)[1]	14.9	.	.	.	14.6	.	.	.	13.6	.	.	.
Daily amplitude of the temperature (°C)[1]	4.7	.	.	.	6.5	.	.	.	3.6	.	.	.

1. At planting depth.

rotovating shortly after planting. The plateau was much less pronounced with no-tillage as here the dense and hard subsoil prevented deep penetration of the inter-row rotovator. Consequently, the distance between the seed potatoes (planted at 1 cm above the firm subsoil) and the top of the ridge was largest with loose-soil and smallest with rational tillage. As potatoes normally grow above the plateau and not to the sides, more space is available for growth of harvestable potatoes on loose soil.

In 1972 and 1973 the quality of the potato ridges, as judged by visual estimation of soil structure, and the amount of clods, was a bit less with no-tillage (Table 21). This result can be explained from the fact that a good combination of rotational speed of the full-width rotovator and forward speed of the tractor could not be obtained with the equipment available at that time. In 1974 the soil was dry and hard at seedbed preparation and, therefore, the full-width rotovator, by then well adjusted (operated at a forward speed of only about 800 m h^{-1}) gave an optimum result, whereas the powered harrow, either working intensively (loose-soil) or extensively (rational tillage), gave poorer results. In 1975 at seedbed preparation the soil was moist and stubborn, and again on non-tilled soil far better results were obtained than on tilled soil. However, as could be expected after the dramatic autumn and winter of 1974/1975, a large amount of clods was obtained also with no-tillage. Therefore, visual estimation in 1975 yielded extremely low values. On tilled soil the amount of clods markedly increased in the course of the years, which increase corresponds with the already mentioned gradual decline in soil structure during 1972–1975.

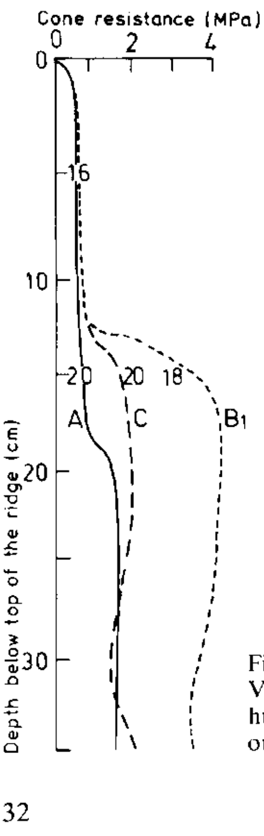


Fig. 11. Resistance to penetration in potato ridges, spring 1974. Values near the curves: moisture content (%, w/w). A = loose-soil husbandry; C = rational tillage; B1, B2 = no-tillage, with and without root crops, respectively.

Resistance to penetration in the loose soil of the ridges did not differ much between tillage systems (Figure 11). With loose-soil and rational tillage resistance to penetration gradually increased with depth and never reached values over 2.5 MPa. However, with no-tillage the dense subsoil caused a very steep increase in resistance to penetration, which under dry conditions easily reached values of up to 4 MPa. In dry springs this high resistance causes considerable difficulties for root penetration.

At planting moisture content of the topsoil (0–5 cm depth) was always higher with no-tillage than with loose-soil and rational tillage (Figure 12). After planting, the loose soil of the ridges dried up to a smaller or larger degree, depending on the rainfall pattern. With rainfall every now and then (1974) the fine ridges of no-tillage remained wetter than the coarse ridges on tilled soil up to the beginning of July. Later on these differences gradually disappeared. During prolonged drought after planting (1973) the ridges with no-tillage became drier than on tilled soil, because with no tillage the roots were restricted largely to the ridge itself, whereas on tilled soil more roots extended to greater depths.

Mean daily soil temperature at planting depth was slightly higher with loose-soil than with rational tillage (Table 21). However, with rational tillage, due to the smaller and slightly drier ridges and to the smaller depth of the seed potato with respect to the top of the ridge, the amplitude was clearly larger than with loose-soil tillage. With no-tillage ridge size was similar but moisture content was 1 % (w/w) higher than on loose-soil. Therefore, both mean daily soil temperature and amplitude were lowest.

4.2.7 Air permeability at pF 2.0

Within the range studied, there was a straight-line relationship between air content at pF 2.0 and the logarithmic intrinsic air permeability (K_i). Variability was often very high, which is reflected by low correlation coefficients (Fig. 13).

In spring 1975, the 12–17 cm layers of all no-tillage plots and the 12–17 cm layer of tilled soil showed nearly the same relationship. The 2–7 cm layer of tilled soil and all samples of System B1 containing fine soil material sieved out at potato harvest, however, had a much lower K_i at corresponding air contents.

In autumn 1975 regression lines had a smaller slope than in spring, especially on tilled soil. Because pore space remained nearly the same, this result must be related primarily to a decrease in water content at pF 2.0 during summer (see Section 4.2.3). Consequently, air content increased significantly. Surprisingly, air permeability increased only slightly. As in the 12–17 cm layer the slope of the curves for the non-tilled soil changed less than on tilled soil, in autumn K_i was here higher on non-tilled than on tilled soil at corresponding air contents. Although pore space and air content at pF 2.0 were significantly lower, it can be assumed that the continuity of the pore system was better on non-tilled soil.

Soil structure deterioration in autumn and winter of 1974/1975 lowered air contents more than K_i. Structure regeneration by water extraction during summer had a larger influence on air content than on K_i. In 1976, soil structure was much better than in 1975 (larger pore space, more friable soil and normal water content at pF 2.0) and 12–17 cm layers of tilled soil gave similar curves (not shown here) as the

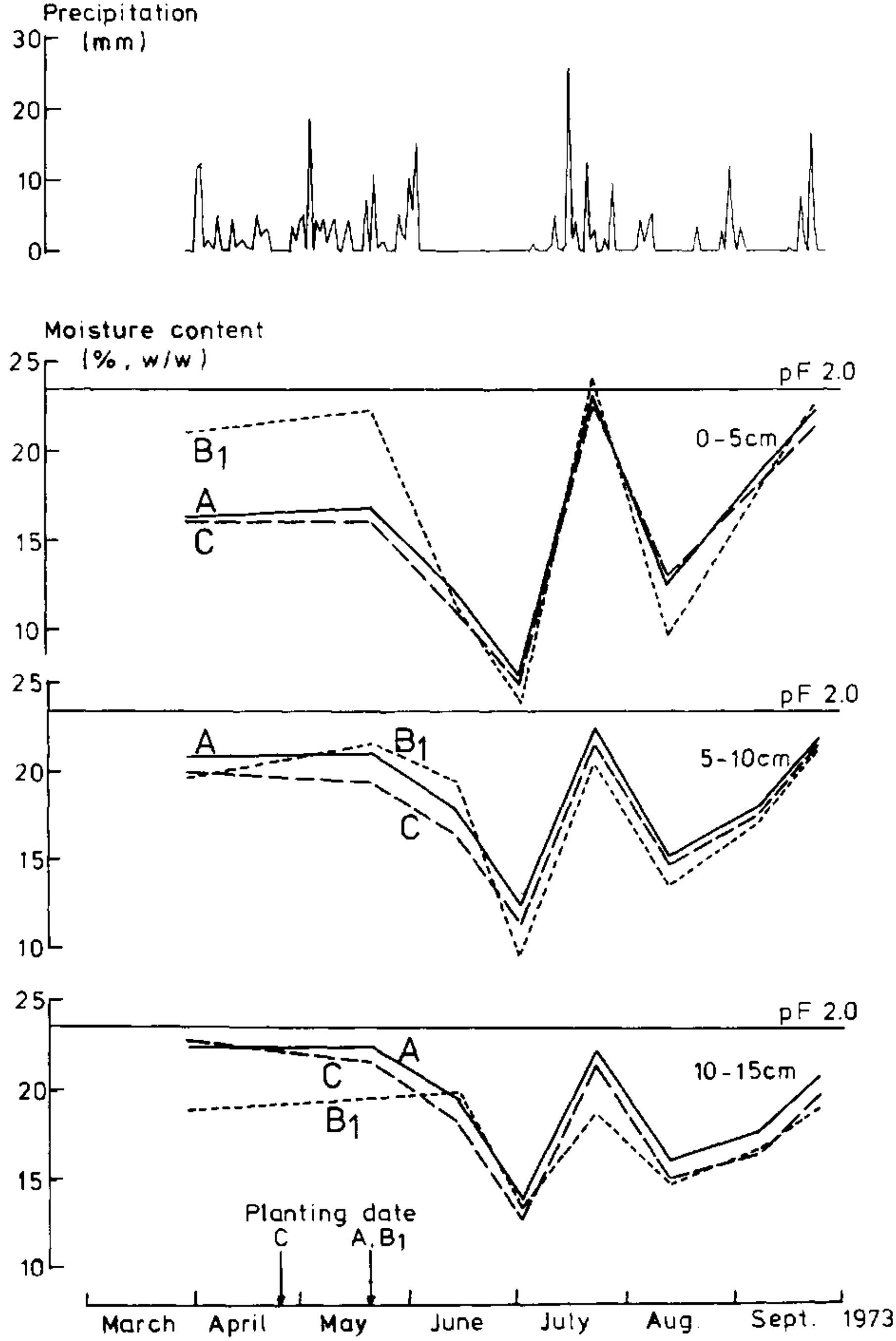
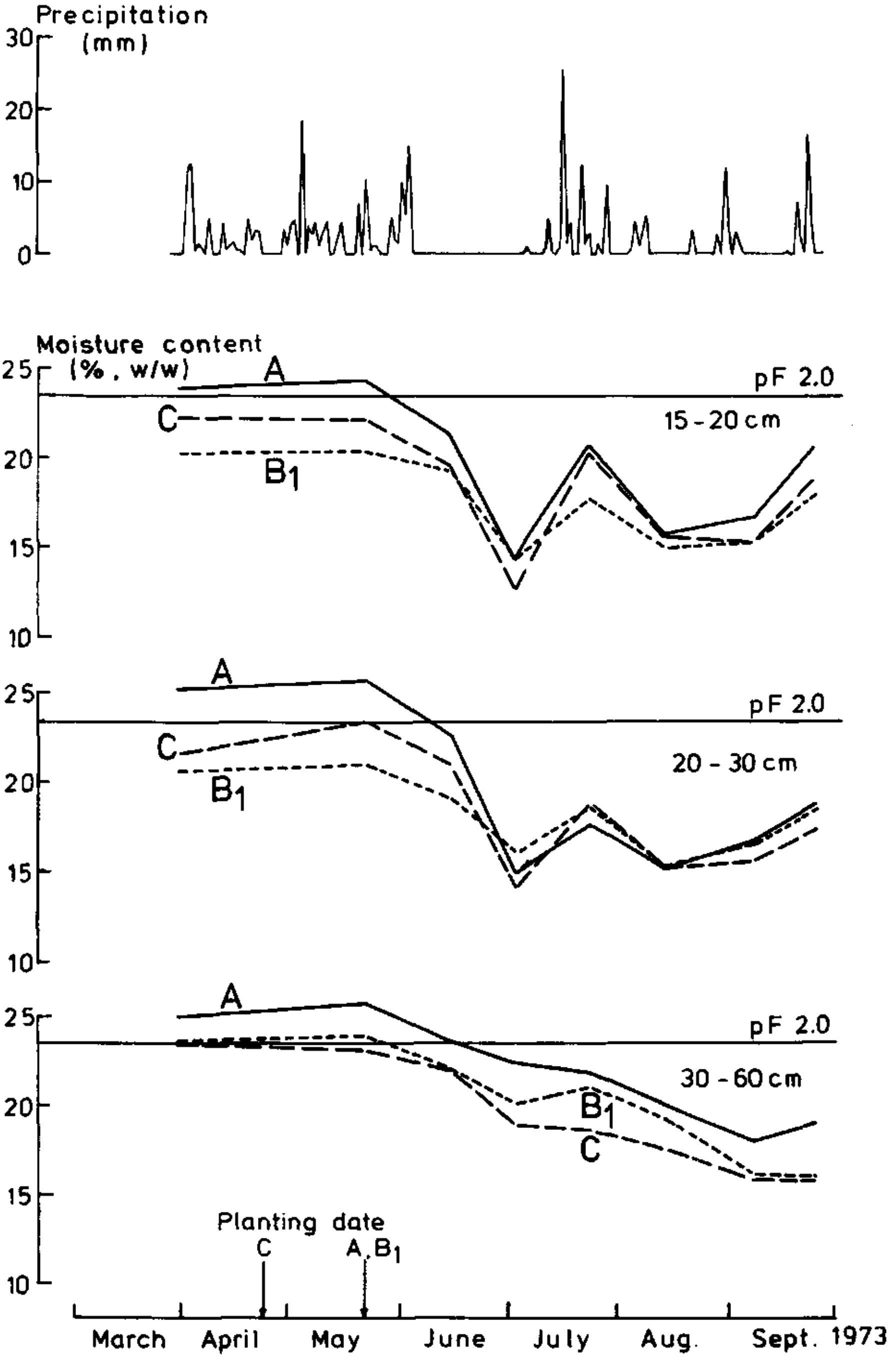


Fig. 12. Precipitation and moisture content of the soil in and below potato ridges, 1973. Until planting date values of depth refer to the soil surface, thereafter to the top of the ridge. A = loose-soil husbandry; C = rational tillage; B1, B2 = no-tillage, with and without root crops, respectively.



Precipitation
(mm)
30
20
10
0
Moisture content
(%, w/w)
25
20
15
10
A
C
B1
pF 2.0
15 - 20 cm
A
C
B1
pF 2.0
20 - 30 cm
A
B1
C
pF 2.0
30 - 60 cm
Planting date
C
A, B1
March
April
May
June
July
Aug.
Sept. 1973

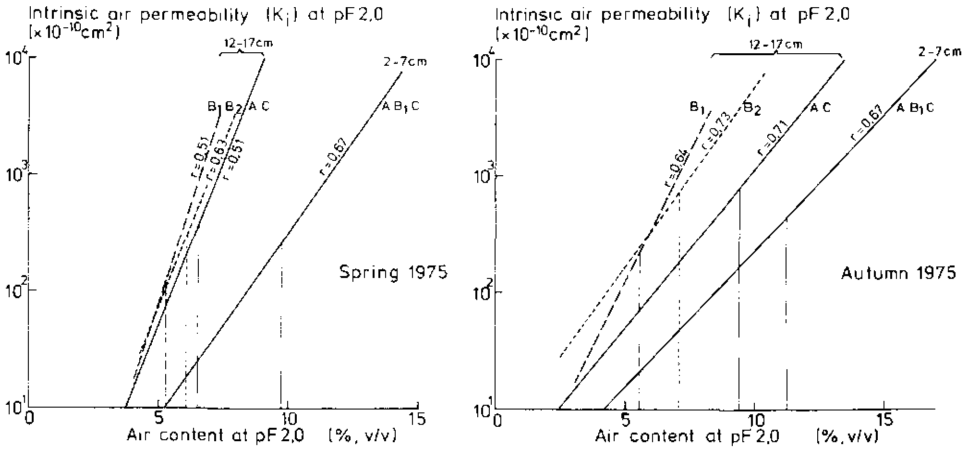


Fig. 13. Relationship between air content and intrinsic air permeability of 100 ml core samples at a pressure potential of −100 cm (pF 2.0) in 1975.

2–7 cm tilled soil in 1975. Because the latter layer was partly below and partly in the seedbed, it might be postulated that although a better soil tilth increases air content considerably, it does not increase K_i correspondingly.

As a K_i of 100×10^{-10} cm² is considered to be at the transition from a fairly low to a medium high permeability (O'Neal, 1949), mean air permeability appeared to be reasonable, even for the untilled soil. The few exceptions are related to the extreme soil and weather conditions during harvest and subsequent main tillage operations in autumn and winter 1974/1975.

4.2.8 Cone resistance

It is well known that cone resistance is dependent on both pore space and moisture content and their interaction. From all of the penetrometer data obtained in this experiment during 1972–1975, the overall relationship could be assessed as illustrated in Fig. 14.

At a total pore space of 46 % (v/v) and a moisture content of 24–25 % (w/w), as characteristic for a tilled soil in spring, cone resistance will be slightly above 1.2 MPa. At this pore space even a decrease of moisture content to 17 % (w/w) did not have much effect on cone resistance. However, after three years of no-tillage pore space was only 41 % (v/v) and moisture content in spring 22 % (w/w), so cone resistance was then already close to 3.0 MPa. During the growing season, due to evapotranspiration, moisture content decreased and, consequently, cone resistance rose steeply, for instance at about 17 % (w/w) up to 4.5 MPa. Even at saturation (moisture content by weight 26 %), a condition which may occur only occasionally and only for a short time, the dense, untilled soil will have a cone resistance higher than 2.0 MPa.

These results indicate that, after a few years of no-tillage, root growth will be hampered seriously unless the amount of large, continuous pores and fissures is still adequate. Further research is required in this respect.

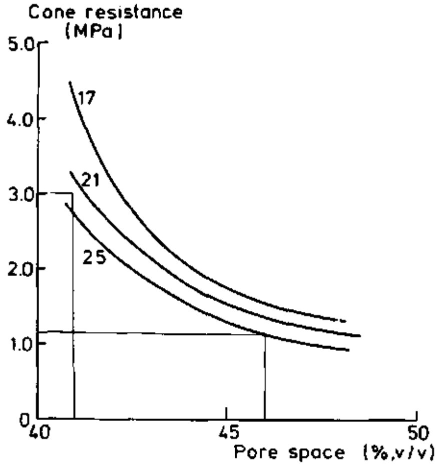


Fig. 14. Relationship between pore space and resistance to penetration at moisture contents of 17, 21 and 25 % (w/w), respectively (1972–1975).

4.2.9 Visual estimation of soil structure

There was a straight-line relationship between visually estimated soil structure and total pore space (Fig. 15). As the visual estimation integrated all aspects of soil structure, amongst which workability, size and shape of aggregates and pore size distribution, it is not surprising that Fig. 15 shows a wide scatter. Nevertheless, the

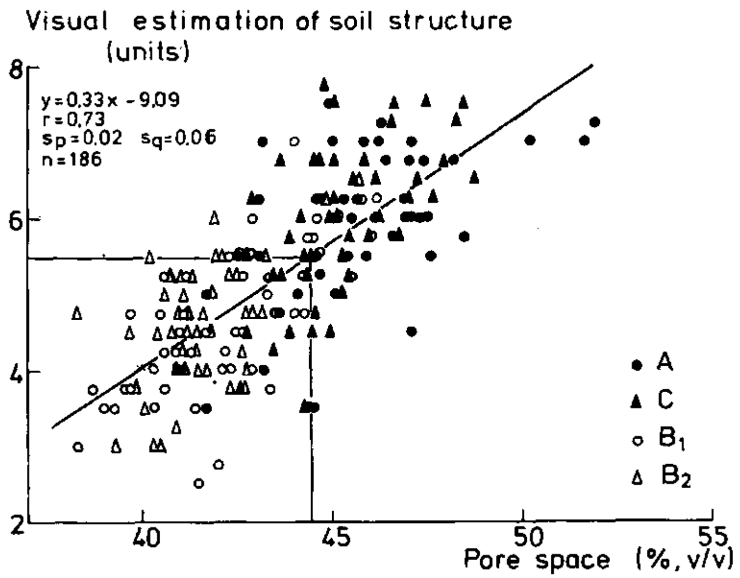


Fig. 15. Relationship between visually estimated soil structure and pore space, 1972–1975. A = loose-soil husbandry; C = rational tillage; B1, B2 = no-tillage, with and without root crops, respectively.

correlation was not too bad (r = 0.70). Moreover, the common standard value 5½ for visual estimation corresponded to a pore space of 44 % (v/v), which in its turn agreed well with the assumed critical air content at pF 2.0 of 10 % (v/v) for this type of soil (Boekel, 1962). Therefore, it may be concluded that visual estimation is a valuable tool for general assessment of the quality of soil structure.

4.3 Discussion

Soil structure encountered in the field depends on many factors as is illustrated in Fig. 16. Actual soil structure is determined by soil, climatic and biological factors, but, to a large extent also by technological factors, of which the tillage system is an integral part.

To explain the effect of tillage on soil structure and development and yield of a particular crop, not only the tillage system applied for that crop, but also the crop rotation and the tillage system of at least the previous crop, have to be taken into account. Although crop rotation and tillage system were fixed in the present experiment, soil structure varied significantly between the four years of experimentation. This stresses the importance of soil conditions at the time subsequent parts of the tillage system were applied.

The strongest indication for this effect occurred in the excessively wet autumn, winter and spring of 1974/1975. Due to not only the high amount of rainfall, but especially to the extraordinarily even distribution of rainfall during September–December (Boels, 1975), sandy loam and clay soils, even when well drained, remained excessively wet. Consequently, many farmers had extreme difficulties with machine harvesting of sugar beet and especially of potatoes, and soil structure was

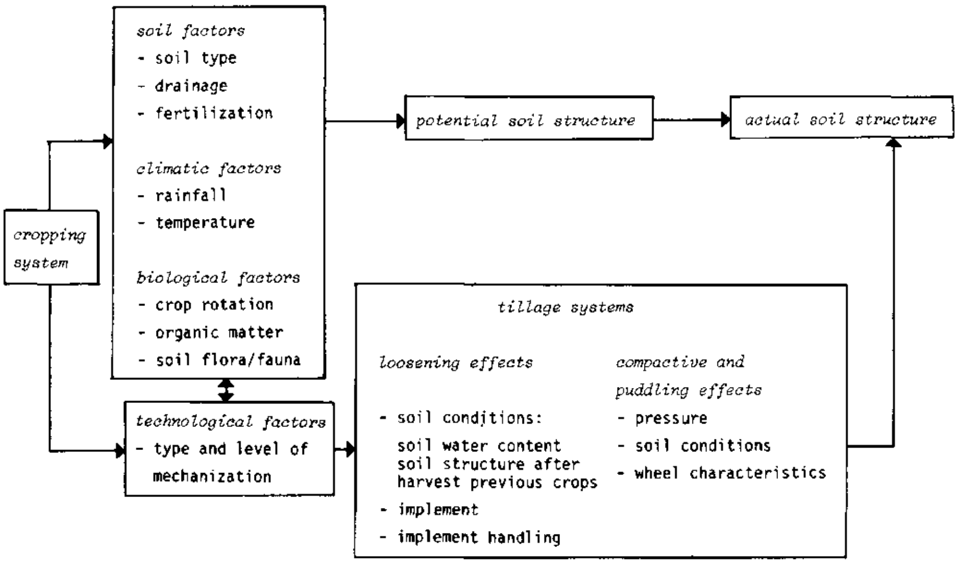


Fig. 16. The tillage system as an integral part of the cropping system and its effect on actual soil structure.

ruined (Boekel, 1977). Because of the extended duration of the wet conditions the main tillage operation had to be carried out very late in the season, but even so soils were still far too wet. As a consequence, soil structure was not improved to the same extent as is usual under more normal, drier conditions. In fact, soil structure in spring 1975 was very bad, especially on plots with winter wheat where seedbed preparation and sowing had caused further damage.

In a three-year experiment on the time of ploughing in autumn on five soil types and including the experimental farm at Westmaas, Kuipers & van Ouwerkerk (1963b) determined the direct effect of ploughing early (good conditions) and ploughing late (bad conditions) on surface relief and the ultimate effect on soil structure. In view of the short duration of the experiment and, still, relatively small differences in soil conditions at the time of tillage, no definite conclusions could be made. However, a clear tendency was found that in the course of time accumulation of small negative effects of ploughing under bad conditions may ultimately have a strong detrimental effect on soil structure.

Further evidence for the paramount importance of soil conditions at the time of harvest and the subsequent main tillage treatment on soil structure was obtained in 1976 in an experiment on double cropping of vegetables for the canning industry on a field adjoining the present experimental field at Westmaas (Boone & Kroesbergen, 1978; van Ouwerkerk & Pot, 1978). By the end of June, during harvest of the first crop (green peas) and subsequent tillage treatments and seedbed preparation for the second crop (French beans), the soil was very dry. Wet conditions at harvest and tillage, on part of the field simulated by sprinkler irrigation, induced a 5 % smaller pore space, irrespective of the tillage system, thus reducing air content at pF 2.0 from 20 to 12 % (v/v).

In the present experiment, soil conditions were seldom ideal at the time of the main tillage operation, seedbed preparation and sowing. Especially in the first 2 years available equipment was not fully suited to effectuate loose-soil husbandry according to intentions. Moreover, not all field operations could be combined (e.g. nitrogen dressing and sowing of winter wheat). Also the difference between the technics used in the no-tillage and rational tillage systems was much larger than between rational tillage and loose-soil husbandry systems.

Consequently, it is not surprising that between loose-soil husbandry and rational tillage differences in soil structure (based on the parameters evaluated) were, on the average, rather small. It is also understandable that these differences were often smaller than the differences in soil structure between years.

In fact, most of the differences in soil structure between loose-soil and rational tillage can be explained by differences in soil structure left behind by the previous crop and by differences in the main tillage operation. Differences in secondary tillage had only minor effects on soil structure of the arable layer. However, the effect on seedbed quality was very strong, with far-reaching consequences for emergence, crop development and crop yield.

Finally, it must be stressed that on the whole of the experimental field traffic was more or less controlled. Although the main plots were 30 m wide, the nitrogen sub-plots had a width of only 3 m, which was the working width of all implements.

Consequently, compactive effects, due to haphazardly driving over the field as is usual on farmers' field (Håkansson, 1965) were largely absent.

Compactive effects at harvest were the same for all three tillage systems as the same harvesting machines were used under comparable conditions. Also, with controlled traffic, it did not make much difference whether seedbed preparation and sowing were combined or carried out in separate passes.

Ploughing was performed with a two-body plough (working width 80 cm), so that every other furrow bottom was compacted. With loose-soil husbandry ploughing was carried out each year, whereas for rational tillage plough and fixed-tine cultivator were used alternately: the cultivator had a working width of 3 m and, moreover, there was no furrow with a wheel running in it.

Consequently and paradoxically then, compactive effects may have been stronger with loose-soil than with rational tillage. The equal and sometimes slightly larger pore space could therefore also be due to a more effective loosening effect of ploughing or a greater stability of ploughed soil compared with cultivated soil. Further research to test this hypothesis is underway.

4.4 Conclusions

1. At the EHF Westmaas soil tillage tended to create a mean pore space of about 45 %, corresponding to an air content at pF 2.0 of about 10 % (v/v), and a visual estimation of soil structure of about 6 in a scale from 1 (very bad) to 10 (very good). For no-tillage the result was a pore space of about 40 %, an air content at pF 2.0 of about 6 % (v/v), and a visual estimation of soil structure of less than 4.

2. Pore space on tilled soil was quite variable between years which could be attributed to different soil conditions at the time of the main tillage operation, seedbed preparation and sowing. Pore space decreased with loose-soil and rational tillage during the experiment, indicating that compacting effects were stronger than the loosening effect of tillage. Without tillage the decrease in pore space was larger but stabilized after three years.

3. The relation between intrinsic air permeability and air content changed during the 1975 growing season which was probably related to changes in water content at pF 2.0 Air permeability on untilled soil was only slightly less than on tilled soil. This result indicates that pore continuity was better on the untilled soil than on the tilled soil.

4. Moisture content at pF 2.0 was higher in spring than in autumn and generally increased with depth but was also positively affected by fresh organic matter, albeit temporarily (depending on the time necessary for decay). At the same effective working depth the plough incorporated organic material deeper than the fixed-tine cultivator did. At 20-cm depth moisture content at pF 2.0 of ploughed soil was often somewhat higher than on soil tilled with a fixed-tine cultivator. At 5-cm depth the reverse was true. In the no-tillage system all crop residues remained at the surface. Hence, moisture content at pF 2.0 was here higher than was expected from pore space.

5. Resistance to penetration on tilled soil never exceeded 2.5 MPa, whereas on untilled soil it was always higher than 2.5 MPa. Thus in a dry growing season on

untilled soil root growth may encounter serious difficulties.

6. Potato ridges with adequate external shape and a sufficiently low amount of big clods could be established in all three tillage systems. However, in the no-tillage system, and especially in the rational-tillage system row rotovating shortly after planting produced a pronounced internal plateau, which may cause extra clod formation at harvest.

In the no-tillage system moisture supply to the crop was often smaller as here the roots were mainly restricted to the loose soil of the ridge itself.

7. In this four-year experiment loose-soil husbandry did not really create a looser soil than rational tillage. This lack of success was first due to the non-sophisticated equipment, available at every farm, used for loose-soil tillage whereas the equipment for the rational system was already quite advanced. Secondly, as the experimental plots and subplots were only narrow (respectively 30 m and 3 m wide), field traffic was more or less fixed along the long axis of the plots. Consequently, in this experiment, soil was not compacted by haphazardly driving over the field as normally occurs.

5 Availability of nitrogen in the soil profile

H.H.H. Titulaer, C. van Ouwerkerk, F.R. Boone & L.M. Lumkes

5.1 Introduction

In the Netherlands, in early spring the content of mineral nitrogen (kg ha^{-1}) of the soil profile (0–100 cm) is determined so that advice can be given on the optimal amount of nitrogen to be applied for arable crops such as cereals, sugar beet and potatoes (Ris, 1976; Titulaer 1978).

To obtain insight in any tillage-induced differences in the nitrogen status of the soil profile, samples were taken from plots on all three tillage systems and analysed for content of mineral nitrogen. These samplings were performed in 1971 and 1972 (preliminary), 1974, 1975 and, at the conclusion of the first four-year crop rotation, in 1976.

5.2 Methods

With an auger samples were taken in 12-fold from 10 cm or 20 cm thick layers up to a depth of 100 cm. The field-moist samples were extracted with a solution of 1 mol l^{-1} sodium chloride. The mineral nitrogen, which consists of the nitrate-N from the soil solution plus a part of the ammonium-N from the cation exchange complex (removed by the sodium ions of the extracting solution), was then determined spectrophotometrically or by titration (Cotte & Kahane, 1946; Novozamski et al., 1974). The mineral-N content of the samples (α) was expressed as mg kg^{-1} oven-dry soil (105°C). The mineral-N content in kg ha^{-1} (0–100 cm) was calculated as: $\Sigma\alpha$ [mg kg^{-1}] × bulk density [t m^{-3}] × 0.1 × depth of the sampled layer [m] = β [kg ha^{-1}]. Bulk densities are shown in Table 22.

The first samplings were performed on 29 December 1971 and 7 March 1972 on plots to be drilled with spring barley. On 27 February 1974 and on 26 May 1975 all perennial nitrogen plots receiving the basic application P (see Chapter 2) of the three repetitions were sampled. To complete the first crop rotation, the P−, P and P+ plots

Table 22. Bulk density (t m^{-3}) in the soil profile (0–100 cm).

Depth (cm)	A	B1	C
0–20	1.40	1.55	1.40
20–40	1.50	1.55	1.55
40–100	1.50	1.50	1.50

of Repetition I and the P– and P+ plots of Repetition II were sampled on 15 January 1976.

As the mineral-N content of the analysed samples was given in mg kg^{-1} soil, in which the amount in mg was given as an integer, variability at low concentrations was high and ranged from 100 % at 1 mg kg^{-1} to 10% at 10 mg kg^{-1}. In our case most concentrations were equal to or higher than 10 mg kg^{-1} so variability was 10 % or less.

5.3 Results

5.3.1 Preliminary research 1971–1972

Results of the first sampling on 29 December 1971 (Table 23) showed that differences between systems were already apparent. As the soil was quite homogeneous and all plots had spring barley as the previous crop, we can ascribe most of these differences to primary tillage in autumn. Compared with System B1 total mineral-N contents in Systems A and C were 1.5 and 2.2 times higher. In the 0–40 cm layer differences between systems were quite small, with a tendency to a higher mineral-N content in System C. The high mineral-N contents in the 40–100 cm soil layer in Systems A and C suggest there was quite a strong leaching of mineral-N in the period between harvest of spring barley and sampling. In System B1 leaching appeared to be much less.

After two months, on 7 March 1972, total mineral contents had increased strongly in System A, somewhat less in System B1 and had remained unaltered in System C. At that time there was no real difference between Systems A and C. Both the total amount and the relative distribution of the mineral-N were the same. This might indicate that mineralization started earlier in System C than in System A. The mineral nitrogen content of the 0–40 cm layer was similar on both sampling dates. On

Table 23. Mineral nitrogen content (kg ha^{-1}) of different soil layers and relative figures of the 0–40 and 40–100 cm layers, respectively, on plots to be drilled with spring barley.

Date of sampling	Depth (cm)	Tillage system					
		A		B1		C	
		kg ha^{-1}	rel.	kg ha^{-1}	rel	kg ha^{-1}	rel.
29–12–71	0–20	21	41	25	67	18	35
	20–40	20		19		33	
	40–100	60	59	22	33	93	65
	Total	101		66		144	
07–03–72	0–20	8	28	23	53	13	27
	20–40	37		28		28	
	40–100	115	72	46	47	111	73
	Total	160		97		152	

the second sampling date mineral nitrogen content in this layer was somewhat higher in System B1 than in System C. Leaching continued in the course of time especially in System A but the amount of mineral-N leached from the 0–40 cm to the 40–100 cm layer was in System B1 only $\frac{1}{3}$ of that in both other systems.

5.3.2 Samples taken on 27 February 1974

Total mineral nitrogen content as a mean of four crops was highest in System A, somewhat lower in System C and clearly lower in System B1 (Table 24). These differences can be explained by differences in the 40–100 cm layer because mineral nitrogen contents in the topsoil were similar for all systems. Therefore, it might be concluded that in System B1 net mineralization (defined as mineralization minus denitrification, immobilization and leaching) was lower than in System A or C. This result might be caused primarily by a higher immobilization of nitrogen in the build-up state of the mulch layer.

Results (Table 25) demonstrate that mulching grass (System B1) grown under previous crops (winter wheat and spring barley), caused a much higher percentage of the mineral nitrogen in the 0–40 cm depth than mixing the grass with soil as was done in Systems A and C. After potatoes and after sugar beet the relative repartition of mineral nitrogen was about the same for all three systems.

From the total amounts of mineral nitrogen in the soil profile it appears that cultivating for winter wheat and spring barley (System C) encouraged nitrogen mineralization less than ploughing (System A), but also reduced leaching from the 0–40 cm layer. The same differences in total and relative amounts of mineral nitrogen were found when comparing ploughing at a depth of 25 cm (System A) and at 20 cm (System C) for potatoes. However, ploughing to 25-cm depth for sugar beet after cultivating the previous year for winter wheat (System C) gave higher values of mineral nitrogen than ploughing to the same depth after ploughing the previous year (System A). This might be explained by a poor grass crop due to an extremely strong developed winter wheat crop in System A.

In all three systems the mineral nitrogen contents of the total soil profile were on average about the same after potatoes, spring barley and sugar beet (System A: 108,

Table 24. Mineral nitrogen content (kg ha^{-1}) of different soil layers and relative values of the 0–40 and 40–100 cm layers, respectively, averaged for all plots (27 February 1974).

Depth (cm)	Tillage system					
	A		B1		C	
	kg ha^{-1}	rel.	kg ha^{-1}	rel.	kg ha^{-1}	rel.
0–20	17	37	21	50	17	46
20–40	18		17		22	
40–100	59	63	38	50	45	54
Total	94		76		84	

Table 25. Mineral nitrogen content (kg ha^{-1}) of different soil layers and relative values of the 0–40 and 40–100 cm layers, respectively (27 February 1974).

Depth (cm)	Tillage system					
	A		B1		C	
	kg ha^{-1}	rel.	kg ha^{-1}	rel.	kg ha^{-1}	rel.
Potatoes → winter wheat						
0–20	14	26	19	35	14	35
20–40	15		15		15	
40–100	81	74	63	65	54	65
Total	110		97		83	
Winter wheat → sugarbeet						
0–20	11	43	22	64	11	44
20–40	12		15		25	
40–100	30	57	21	36	45	56
Total	53		58		81	
Sugar beet → spring barley						
0–20	25	44	19	49	22	54
20–40	24		22		28	
40–100	63	56	42	51	42	46
Total	112		83		92	
Spring barley → potatoes						
0–20	17	38	25	60	20	52
20–40	21		15		22	
40–100	63	62	27	40	39	48
Total	101		67		81	

System B1: 82 and System C: 85 kg ha^{-1}). However, after winter wheat total nitrogen contents were much lower (System A: 53, System B1: 58 kg ha^{-1}) or only slightly lower (System C: 81 kg ha^{-1}). In general uptake of nitrogen from the deeper soil layers was much larger for winter wheat than for the other crops. After potatoes there was a markedly high N-mineral content in the 40–100 cm layer. This was mainly because of the four crops under consideration only potatoes have a very shallow root penetration on this soil type (about 40–50 cm), which limits the uptake of N-mineral from the deeper layers.

5.3.3 Samples taken on 26 May 1975

Against our intentions samples were taken very late and, therefore, results were strongly biased by the nitrogen applications carried out in spring (winter wheat 80, sugar beet 160, spring barley 60 and potatoes 240 kg ha^{-1}). Still, it is interesting to note (Table 26) that when in System C the soil was ploughed (sugar beet, potatoes) total mineral nitrogen contents did not differ much from those in System A. In System B1 mineral nitrogen content was about 25 kg ha^{-1} lower for sugar beet and about 120 kg ha^{-1} lower for potatoes. Especially for potatoes fertilizer nitrogen had been immobilized in the organic matter (stubble and green manure) which was well mixed in the potato ridges. This is also shown by the repartition of the mineral nitrogen in B1, compared with Systems A and C. For the other crops there were no clear differences in repartition between systems.

When in System C the soil was cultivated (cereals) nitrogen content of the total soil profile was less than in System A where the soil was always ploughed, and about the same as in System B1.

Uptake of nitrogen by the already well developed winter wheat was obviously much larger than the uptake by spring barley, which was still in its early stage of development, whereas uptake of nitrogen by the root crops had just started.

Table 26. Mineral nitrogen content (kg ha^{-1}) of different soil layers and relative values of the 0–40 and 40–100 cm layers, respectively (26 May 1975).

Depth (cm)	Tillage system					
	A		B1		C	
	kg ha^{-1}	rel.	kg ha^{-1}	rel.	kg ha^{-1}	rel.
Potatoes → winter wheat						
0–20	14	36	15	44	8	35
20–40	13		12		9	
40–100	47	64	34	56	31	65
Total	74		61		48	
Winter wheat → sugar beet						
0–20	44	52	40	52	45	55
20–40	47		38		51	
40–100	84	48	72	48	77	45
Total	175		150		173	
Sugar beet → spring barley						
0–20	26	52	27	57	20	48
20–40	23		22		22	
40–100	46	48	37	43	46	52
Total	95		86		88	
Spring barley → potatoes						
0–20	252	85	96	62	291	84
20–40	66		69		46	
40–100	57	15	102	38	66	16
Total	375		267		403	

5.3.4 Samples taken on 15 January 1976

This sampling was carried out when the first 4-year crop rotation was completed. The aim was to see whether, besides differences in tillage systems and crops also the cumulative nitrogen levels P^-, P and P^+ had caused differences in the nitrogen status of the soil.

When the mean value of mineral nitrogen content of the P level of all crops and tillage systems is given the relative value of 100 (Table 27), the P^- treatment is 75 and the P^+ treatment 96. Thus diminishing every year the nitrogen dressing by 20% could reduce the nitrogen availability in the fifth year also by 20 %, whereas increasing the nitrogen dressings by 20 % did not alter nitrogen availability. However there was such a large variability within and between tillage systems and crops that the average values mentioned are hardly convincing.

Averaged for P^-, P and P^+ nitrogen levels and all crops, total mineral nitrogen

Table 27. Mineral nitrogen content (kg ha^{-1}) of the 0–100 cm soil layer on P−, P and P+ plots[1], after the first four-year crop rotation (15 January 1976).

Crop		Tillage system								
1975	1976	A			B1			C		
		P−	P	P+	P−	P	P+	P−	P	P+
Potatoes	Winter wheat	79	95	111	100	100	161	81	136	118
Winter wheat	Sugar beet	34	80	36	36	62	32	23	34	36
Sugar beet	Spring barley	43	42	48	44	64	55	52	48	48
Spring barley	Potatoes	49	54	68	38	67	38	53	56	57
Mean (kg ha^{-1})		51	68	66	54	73	72	52	68	65
(%)		76	100	97	74	100	98	76	100	94

1. Yearly nitrogen application on P− and P+ plots was 20% less and 20% higher, respectively, than on P plots.

Table 28. Mean mineral nitrogen content (kg ha^{-1}), averaged for P−, P and P+ nitrogen levels and all crops, and relative values of the 0–40 and 40–100 cm layers, respectively, 15 January, 1976.

Depth (cm)	Tillage system					
	A		B1		C	
	kg ha^{-1}	rel.	kg ha^{-1}	rel.	kg ha^{-1}	rel.
0–20	13	44	16	46	13	45
20–40	14		15		15	
40–100	35	56	36	54	34	55
Total	62		67		62	

Table 29. Mineral nitrogen content (kg ha^{-1}), averaged for P−, P and P+ nitrogen levels and relative values of the 0–40 and 40–100 cm layers, respectively, 15 January 1976.

Depth (cm)	Tillage system					
	A		B1		C	
	kg ha^{-1}	rel.	kg ha^{-1}	rel.	kg ha^{-1}	rel.
Potatoes → winter wheat						
0–20	11	28	17	32	15	32
20–40	15		22		21	
40–100	68	72	82	68	76	68
Total	94		121		112	
Winter wheat → sugarbeet						
0–20	12	47	15	58	9	62
20–40	12		10		11	
40–100	27	53	18	42	12	38
Total	51		43		32	
Sugar beet → spring barley						
0–20	14	52	13	55	13	50
20–40	15		13		15	
40–100	27	48	21	45	28	50
Total	56		47		56	
Spring barley → potatoes						
0–20	13	62	17	56	14	56
20–40	15		14		14	
40–100	17	38	24	44	22	44
Total	45		55		50	

content was the same for all tillage systems while the repartition between topsoil and subsoil is also the same (Table 28).

Considerably higher mineral nitrogen contents were found (Table 29) after potatoes than after other crops, mainly because the 40–100 cm layer contained high amounts of mineral nitrogen. This is in agreement with the 1974 sampling and probably due to shallow rooting of potatoes.

In contradiction to the 1974 sampling no mulching effect of the grass green manure crop could be detected and fixed-tine cultivation (System C) instead of ploughing (System A) encouraged mineralization on plots with winter wheat. In 1976 no differences existed on plots to be drilled with spring barley. After winter wheat total nitrogen content in Systems A and B1 were comparable but in System C the value was much lower. So it can be stated that, in contradiction to the 1974 sampling, ploughing to 25 cm depth for sugar beet after fixed-tine cultivation the previous year (System C) now caused lower amounts of mineral nitrogen than after ploughing the previous year (System A). In general no differences were found after spring barley, winter wheat and sugar beet.

5.4 Discussion

The preliminary 1971–1972 sampling showed that different tillage treatments in autumn had produced different effects. A tillage treatment that mixes the soil encourages mineralization. Fixed-tine cultivation, therefore, was more favourable to early mineralization than ploughing. After winter the ploughed soil, however, showed as much mineralization as the cultivated soil. In the no-tillage system mineralization was much lower. Although the top 0–40 cm layer contained similar amounts of mineral nitrogen, leaching was clearly lower than on tilled soil.

The 1974 sampling clearly showed that both the main tillage treatment in autumn and the previous crop influenced the mineral nitrogen content. A turning or mixing-tillage system encouraged nitrogen mineralization during autumn and winter. No-tillage inhibited mineralization or promoted nitrogen immobilization or denitrification. This generally caused a higher mineral nitrogen content in Systems A and C, which in its turn caused a higher mineral nitrogen content in the deeper soil layers than in System B1. In System B1 the mineral nitrogen was concentrated much more in the topsoil where contents were similar for all tillage systems. Differences between fixed-tine cultivating and ploughing and differences caused by different ploughing depths were not consistent between samplings.

As appears from the low mineral nitrogen content of the deeper layers, winter wheat exhausted the soil nitrogen. Spring barley and sugar beet depleted the soil to a lesser extent whereas potatoes left much nitrogen in the soil, especially in the 60–100 cm layer. This result is in accordance with the limited penetration and development of potatoes roots on this soil type (Boone et al., 1975).

At the end of May 1975 leaching of nitrogen was pronounced for sugar beet. Nitrogen immobilization by micro-organisms can be illustrated by the potato crop in System B1. Here 240 kg of fertilizer nitrogen was applied, but only 267 kg of nitrogen was retained. The rest of the mineralized nitrogen must have been immobilized. On the other hand a large amount of mineralized nitrogen was retrieved from the sugar beet leaves in all systems.

At the conclusion of the first four-year crop rotation no differences in mineral nitrogen content of the 0–100 cm layer between tillage systems could be detected. So it might be concluded that although with no-tillage less nitrogen was available at the start of the experiment, this difference disappeared gradually. This may well mean that in the course of four years a new equilibrium between nitrogen mineralization and immobilization was established.

5.5 Conclusions

1. The influence of soil tillage on the availability of nitrogen was very clear during autumn and winter. However, the differences between Systems A and C usually disappeared in spring. At the beginning of the experiment less nitrogen was available

in System B1, but after one four-year crop rotation nitrogen availability was equal to that in Systems A and C.

2. The samples taken in early spring gave information about the influence of the previous crop on the total amount of mineral nitrogen in the soil. Winter wheat exhausted the soil, spring barley and sugar beet did so to a lesser extent. Primarily due to a relatively superficial rooting pattern on this soil type potatoes left much nitrogen in the 60–100 cm layer.

3. Ploughing, which turns the soil, gave a more homogeneous distribution of the mineral nitrogen than fixed-tine cultivation, which mixes organic debris and soil rather superficially. No-tillage caused nitrogen to accumulate in the topsoil.

6 Crop response

L.M. Lumkes & C. van Ouwerkerk

6.1 Introduction

6.1.1 Length of the growing period

Crop yield may be strongly influenced by the length of the growing period, which during the experiment varied significantly. In the first three years of the experiment the length of the growing period for winter wheat was on average 300 days, for sugar beet on average 215 days and for spring barley on average 145 days (Table 30). For potatoes the length of the growing period ranged in these years between 135 days in 1973 (Systems A and B1) and 215 days in 1974 (all systems) when harvest time, due to unfavourable weather conditions, was one month later than normal.

In 1975, because of sowing and planting late, the growing period was one month (sugar beet, spring barley, potatoes) to two months (winter wheat) shorter than normal.

Table 30. Length of the growing period (days).

	Tillage system	Ware potatoes	Winter wheat	Sugar beet	Spring barley
1972	A	160	314	162[1]	147
	C	161	314	162[1]	147
	B1	162	310	223	163[2]
	B2		310		163[2]
1973	A	135	256[3]	216	143
	C	155[4]	286	216	143
	B1	135	146[1]	216	142
	B2		284		142
1974	A	215	286	211	148
	C	215	292	212	147 (R III: 119)
	B1	214	295	216	146
	B2		292		146
1975	A	150	222	182	111
	C	150	231	182	111
	B1	149	231	187	112
	B2		231		112

1. Resown.
2. Sown two weeks in advance.
3. Sown four weeks later.
4. Planted three weeks in advance.

Of course, re-seeding (1972: sugar beet in Systems A and C; 1973: winter wheat in System B1) caused a strong decrease in the length of the growing period.

6.1.2 Presentation of yield data

Crop response to perennial nitrogen levels often was weak and erratic and very variable between years. Therefore, it had little sense to present graphically results of perennial nitrogen levels (P^-, P, P^+) and the usual graphical comparison with results of annual nitrogen levels (N1–N5) was impossible. The best way out appeared to be to use the mean yield as the common denominator for expressing crop response to nitrogen (Hull & Webb, 1970; Schuurman et al., 1977).

The first step was to calculate for each separate year the mean yield for each tillage system and for each crop by averaging the yields obtained at all nitrogen levels studied. These mean yields were set at 100 % and then the yields obtained at each nitrogen level were expressed as a percentage of the mean yield.

To compare differences between results of tillage systems at the same nitrogen level, yields obtained with different tillage systems at the chosen nitrogen level were averaged and set at 100 %. Then the yield of each tillage system at that nitrogen level was expressed as a percentage of the mean yield.

The 1972–1975 average of the relative yield response was calculated as the arithmetic mean of the relative figures found at the different nitrogen levels in separate years. Results of perennial nitrogen levels are given in tables, whereas results of annual nitrogen levels are presented as graphs.

The advantage of this method is that we can compare the nitrogen reaction of different crops or different yield aspects of the same crop (e.g. roots, leaves, sugar content and sugar yield of sugar beet; grain and straw yield of cereals, etc.), obtained at different yield levels (caused by year-effects, tillage system-effects, or method of harvesting-effects). The reliability of the method is independent of the range of nitrogen levels studied. Therefore, it also allows us to compare crop response to perennial and annual nitrogen levels.

6.2 Potatoes

6.2.1 Introduction

At harvest the straw of the previous barley crop was chopped and spread with a mounted chopper. Stimulated by a nitrogen dressing after cereal harvest the grass green manure (Italian ryegrass) always developed satisfactorily. However, it also tended to grow in strips, caused by the usually uneven distribution of the barley straw and by the negative effect of the wheel tracks.

In System B1 the grass green manure was killed chemically; in Systems A and C it was ploughed in to depths of 25 and 20 cm, respectively. In some years the grass green manure was not sufficiently incorporated by ploughing. Then the regrowth was controlled either full-width (1973) or spot-wise, by spraying with paraquat.

Potatoes (var. Bintje) were planted in rows 75 cm apart, with distances in the row varying between years from 33 cm (40 000 tubers ha^{-1}) to 37 cm (36 000 tubers

ha^{-1}). On the whole emergence was satisfactory, so it was thought unnecessary to count the number of plants.

6.2.2 Crop development

In *1972* crop growth did not show lack of water. Compared with Systems A and C, System B1 had a slower start and development, but died first. In System A the crop looked slightly better than in System C.

1973 was characterized by a wet spring and an extremely dry period in June. The preceding mild and wet winter delayed seedbed preparation. In System C, because the seedbed was not prepared, potatoes could be planted three weeks earlier than in the other systems. During the growing season, System B1 was most adversely affected by the drought. Here, in the fine tilth of a ridge overlying a dense, non-tilled soil the crop grew relatively slowly. Rain in July caused regeneration of the potato crop, but also induced mass secondary growth.

The *1974* growing season was characterized by a dry spring. Therefore, the finely crumbled, rather moist ridge of System B1 resulted in the fastest germination. Germination in System A was next best. The extremely wet autumn delayed harvest until the middle of November.

In *1975* potatoes were planted late. Low temperatures in May and June hampered development. During this period the crop under System B1 developed best. On 24 June 45 mm precipitation fell in one hour, July and August were very warm. By the end of August, however, System A showed the best development, followed by System C, which had fewer stems per plant. At that time the crop in System B1, which had rather few stems per plant, was already dying. It also had fewer troubles from secondary growth of potato tubers.

6.2.3 Crop response to perennial nitrogen levels

Averaged over the three cumulative nitrogen levels P^-, P and P^+, and over the period 1972–1975, System C with 54.8 t ha^{-1} tubers in the grade > 35 mm yielded best (Table 31). The average net yield in System A (53.6 t ha^{-1}) was only 3 % lower. System B1 with 49.8 t ha^{-1} yielded clearly lowest. The average effect of the three perennial nitrogen levels on tuber yield was not clear-cut but very small. For different systems the effects were larger but not consistent between years (Table 32).

In *1972* the slower start of the growth in System B1 and the poorer growth and earlier death resulted in a somewhat lower yield. The reaction to nitrogen was clearly negative. In System A yield was 11 % higher than in System C (46.9 t ha^{-1}) and the percentage of tubers in the grade > 55 mm was markedly higher. In System A the reaction to nitrogen was small, but was clearest in the size > 55 mm. System C reacted positively to nitrogen. The percentage of green and deformed tubers produced in System B1 was low compared with Systems A and C. The percentage of soil clods was highest in System C.

In *1973* System C gave a good saleable yield of 53.4 t ha^{-1} > 35 mm, probably due to the three week earlier planting. When in May the potatoes in Systems A and B1 were planted, those in System C had already germinated. Drought in June adversely

Table 31. 1972–1975 average net tuber yield of potatoes in the grade > 35 mm at three perennial nitrogen levels.

System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
	P^-	P	P^+	t ha^{-1}	rel.	
A	99	96[1]	105	53.6	102	97
B1	98	101	99	49.8	94	91
C	97	102	101	54.8	104	100
Mean	98	100	102	52.7	100	.

1. In 1973 in one replicate 15% lower yield.

Table 32. Net tuber yield of potatoes in the grade > 35 mm at three perennial nitrogen levels.

	System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
		P^-	P	P^+	t ha^{-1}	rel.	
1972	A	98	100	101	52.1	108	111
	B1	109	99	93	45.5	94	97
	C	94	96	110	46.9	98	100
	Mean	100	98	101	48.1	100	.
1973	A	103	93[1]	103	46.3	98	87
	B1	98	103	99	41.9	89	78
	C	96	102	102	53.4	113	100
	Mean	99	99	101	47.2	100	.
1974[2]	A	100	94	106	66.0	100	99
	B1	96	102	103	65.9	100	99
	C	100	105	95	66.5	101	100
	Mean	99	100	101	66.1	100	.
1975	A	96	96	107	49.9	101	95
	B1	98	102	100	45.9	93	88
	C	99	104	97	52.4	106	100
	Mean	98	101	101	49.9	100	.

1. 15 % Lower yield in one replicate, average of the other two replicates 46.9 t ha^{-1}, gross average 43.3 t ha^{-1}.
2. Hand harvest, the soil was too wet to use harvesting machinery.

affected growth, especially in System B1. In July, after heavy rainfall, mass secondary growth appeared. Total yield in System B1 was not much lower than in System A, but more small tubers (8 % of the gross yield), and thus unsaleable were produced. In System A, more tubers were in the size > 55 mm than in Systems B1 and C. In System A also the highest percentage of deformed tubers was found. The highest percentage of green tubers was found in System C. In this system also the highest percentage of clods and loose soil was found in the product. There was no reaction to cumulative nitrogen levels in all systems.

In *1974* potato crop yield was a record (125 % of the average over the four years 1972–1975). In all systems approximately the same yield was reached (System C 66.5 t ha^{-1} > 35 mm). The highest percentage of small tubers was found in System B1, the highest percentage of big tubers in System C. The highest percentage of green tubers and especially of deformed tubers also occurred in System C.

In *1975*, due to the wet spring and the preceding extremely wet autumn, seedbed was too cloddy in Systems A and C whereas in System B1 it was rather fine. Initially the crop developed best in System B1, but it also died first and yielded only 88 % of System C. Although the crop looked better and had more stems per m^2, System A yielded 5 % less than System C, with 54.8 ha^{-1} > 35 mm.

The finely crumbled potato ridge in System B1 induced a crop with a low percentage of green and deformed tubers (especially when compared with System C). In Systems A and C, due to the cloddy ridges, more than three times as much soil was harvested with the crop than in System B1. Only in System A was a positive reaction to the cumulative nitrogen levels found.

6.2.4 *Crop response to annual nitrogen levels*

Crop response to nitrogen fluctuated somewhat between years (Fig. 17). However, it is thought that the average curves for 1972–1975 (Figs. 18 and 19) are fairly

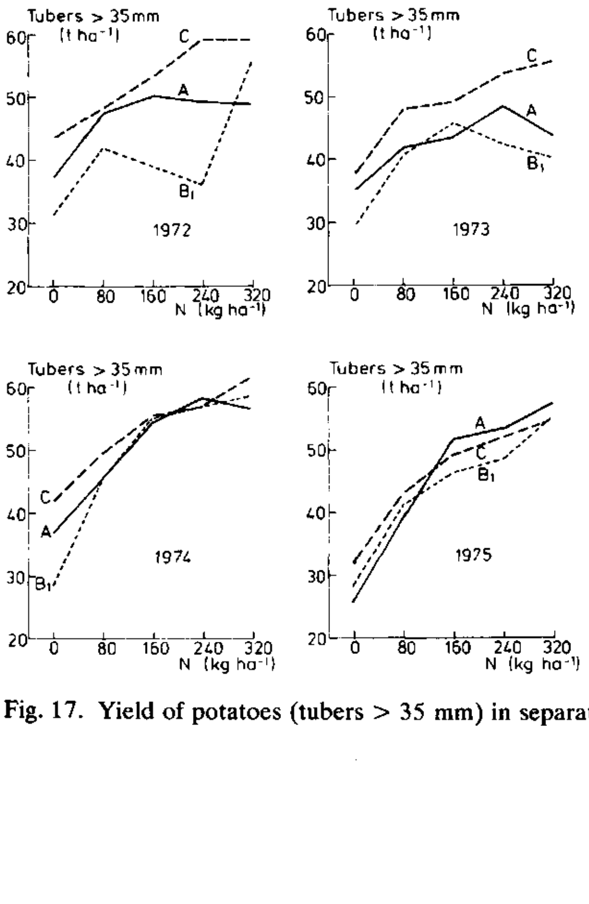


Fig. 17. Yield of potatoes (tubers > 35 mm) in separate years.

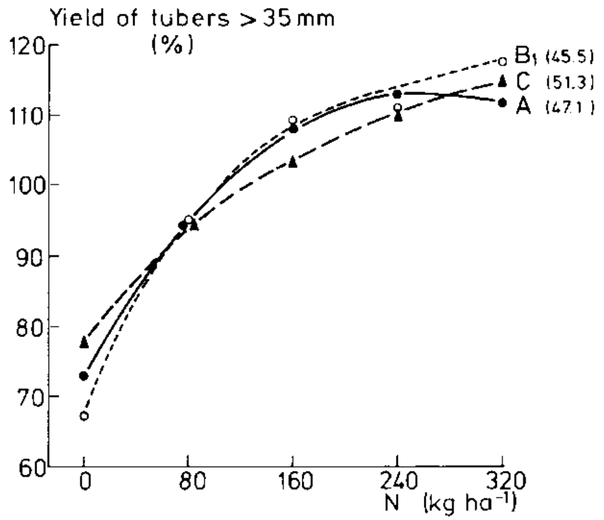


Fig. 18. Yield of potatoes (tubers > 35 mm), relative to the four-year average 1972–1975 per tillage system (in parenthesis; t ha^{-1}).

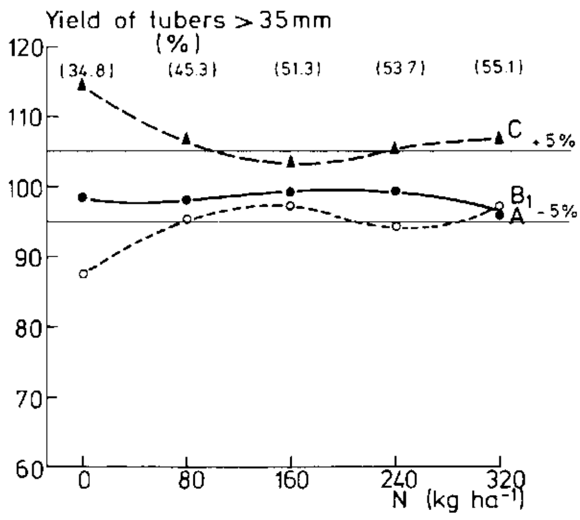


Fig. 19. Yield of potatoes (tubers > 35 mm), relative to the four-year average 1972–1975 per nitrogen level (in parenthesis; t ha^{-1}).

representative. In Systems B1 and C, unlike System A, the nitrogen response curves do not show an optimum (Fig. 18). In System B1 the slope is also slightly steeper.

Yield level in System B1 is only slightly below the yield level in System A (Fig. 19). It is obvious that with respect to tuber yield (> 35 mm) System C performed far better than Systems A and B1.

6.3 Winter wheat

6.3.1 Introduction

Except for the first year the previous crop in Systems A, B1 and C was always potatoes. In System B2 winter wheat was preceded in 1973 by oil seed rape, and in 1974 and 1975 by seed grass.

In Systems A and C after potato harvest the fine soil from the potato ridge left on the field, was always levelled, and mixed with the firm soil underneath by shallow working with a fixed-tine cultivator. In the last two years of the first rotation this was also done in System B1.

Volunteer potatoes (regrowth of potatoes lost at harvest) cause serious problems in following crops, especially when the soil is ploughed as in System A (Lumkes, 1974). In System B1, where volunteer potatoes were kept on or near the surface, they were nearly all killed by frost. In System C, by fixed-tine cultivating, somewhat more potatoes stayed alive.

Winter wheat (var. Manella) was drilled at a seed rate of 160–210 kg ha^{-1}. When problems with respect to emergence were expected the seed rate was increased by approximately 10 % (System A in 1973–1975, Systems B1 and B2 in all years).

6.3.2 Crop development

On the average in Systems A and C emergence and plant number were better and differences between years were smaller than in Systems B1 and B2 (Table 33). Seedbed quality played an important part in the establishment of the crop. However, at tillering these differences disappeared to a large extent.

The ploughed soil in *System A* sometimes remained too coarse and too uneven, which caused unsatisfactory covering of the seed, and sometimes, a too big sowing depth. This was especially so in 1972 when the seedbed preparation was omitted. Therefore in 1973 and 1974 the seed rate was somewhat increased. Nevertheless, sowing in combination with ploughing appeared to be an advantage as in this way ruts were avoided and, hence, slaking was ruled out.

Table 33. Emergence and plant number of winter wheat

	Seed rate (kg ha^{-1})	Emergence (%)				Plants per m^2				Ears per m^2			
		A	C	B1	B2	A	C	B1	B2	A	C	B1	B2
1972	190	32	44	47	47	162	220	236	236	.	.	.	.
1973	180–200[2]	43	34	14	30	225	160	64	144	487	503	.[1]	456
1974	160–165[2]	41	47	55	39	177	198	232	166	391	429	472	435
1975	160	43	38	35	32	181	158	146	134	.	.	.	.
Mean		40	41	38	37	186	184	170	170				

1. Replaced by spring wheat.
2. The highest rate is related to System A.

In *System C*, on the contrary, the soil often remained too fine and too loose, causing a too big sowing depth and severe rutting at sowing. Consequently, in 1973 slaking occurred, resulting in a low percentage of emergence. In 1974 and 1975 results were better because then, just as in System A, the main tillage treatment and sowing were combined by hitching the sowing machine to a bridge-link.

In *System B1*, sowing in a deep layer of loose soil sieved out at potato harvest in autumn 1972, followed by a very wet month had very disappointing results. As the loose soil held much water and pore continuity to the dense subsoil was bad, the topsoil remained wet for too long. This caused slaking and death of the winter wheat by suffocation, especially in dips. Therefore, in March 1973 spring wheat was sown. By shallow working with the fixed-tine cultivator as practised from autumn 1973 onwards, a good seedbed was prepared which allowed sowing with a normal sowing machine. However, if the soil was very wet (autumn 1974), the soil was smeared to such an extent that the positive effect of cultivating was only very small.

In *System B2* emergence was below expectation, probably because at sowing with the roughland sowing machine the walls of the slit were always smeared to some extent. Therefore, in rainy winters (1972; 1973) also in this system the winter wheat could be drowned, especially in dips. When sowing in wet soil (1974) smearing was much more severe and, consequently, emergence was not too good.

In 1972 in Systems A and C irregular, coarse crops developed with a dark green colour whereas in System B1 the crop grew even with much lighter and shorter, sturdier straw. Hence, Mildew and Cercoporella herpotrichoïdes attacked the earlier and heavier developed crops in Systems A and C more than in Systems B1 and B2.

6.3.3 Crop response to perennial nitrogen levels

On average differences in grain yield between years were bigger than differences between Systems (Table 34 and 35). When 1973, with a failure in System B1 and a relative high yield in System A, is excluded, there are only slight differences between systems. Crop response to perennial nitrogen levels was usually small and erratic.

In *1972* System B1 yielded 6 % better than System C (4.9 t ha^{-1}) and 11 % better than System A. In *1973* the yield in System A was 19 % higher than in System C (5.3 t

Table 34. Average grain yield of winter wheat at three perennial nitrogen levels (mean of 1972, 1974 and 1975[1]).

System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
	P−	P	P+	t ha^{-1}	rel.	
A	100	97	103	6.0	97	95
B1[1]	100	96	97	6.2[1]	99	97[1]
B2	97	102	102	6.3	101	99
C	97	97	103	6.3	103	100
Mean	99	98	101	6.2	100	.

1. If 1973 is included, the results of System B1 are much lower.

Table 35. Grain yield of winter wheat at three perennial nitrogen levels.

	System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
		P^-	P	P^+	t ha^{-1}	rel.	
1972	A	105	97	102	4.7	95	96
	B1[1] B2[1]	104	98	98	5.2	106	107
	C	102	99	99	4.9	99	100
	Mean	104	98	100	4.9	100	.
1973	A	103	102	94	6.2	109	119
	B1[2]	.	.	.	.	.	.
	B2	97	107	96	5.7	99	107
	C	108	100	93	5.3	92	100
	Mean	103	103	94	5.7	100	.
1974	A	101	99	100	7.0	100	96
	B1	95	101	104	6.9	97	93
	B2	96	101	101	7.0	99	95
	C	98	101	101	7.4	104	100
	Mean	96	101	102	7.1	100	
1975	A	97	96	108	6.4	98	93
	B1	104	99	97	6.4	98	94
	B2	96	97	107	6.3	98	93
	C	98	99	108	6.8	105	100
	Mean	99	98	105	6.5	100	.

1. First year no difference between B1 and B2. 2. Crop failure.

ha^{-1}). In System B1 the crop failed. In *1974* the average yield was much higher than in other years (115 % of the mean of 1972–1975). System A produced 96 % and System B1 93 % of the yield in System C (7.4 t ha^{-1}). Although soil structure was bad in *1975* the grain yield was very acceptable. System A gave 93 % and System B1 94 % of the yield in System C (6.8 t ha^{-1}).

6.3.4 Crop response to annual nitrogen levels

In *1972* in Systems A and C at the higher nitrogen levels, probably due to mildew attack, crop response was clearly negative (Fig. 20). In System A, due to a lusher growth, yield depression was stronger than in System C. In System B1 the crop had shorter, sturdier straw. Hence, mildew attack was less severe and, consequently, at the higher nitrogen levels crop response was less negative. However, from Table 35 it appears that also in System B1 mildew infestation caused a decrease in yield.

In *1973* nitrogen response curves for Systems A and C showed already at 40 kg ha^{-1} N a marked optimum, whereas for System B2 grain yield was very low at low nitrogen levels, and the optimum was only reached at 120 kg ha^{-1} N. Nitrogen response in Systems A and C was about equal. However, due to the much smaller plant number, maximum yield in System C was much lower. In System B1 the field

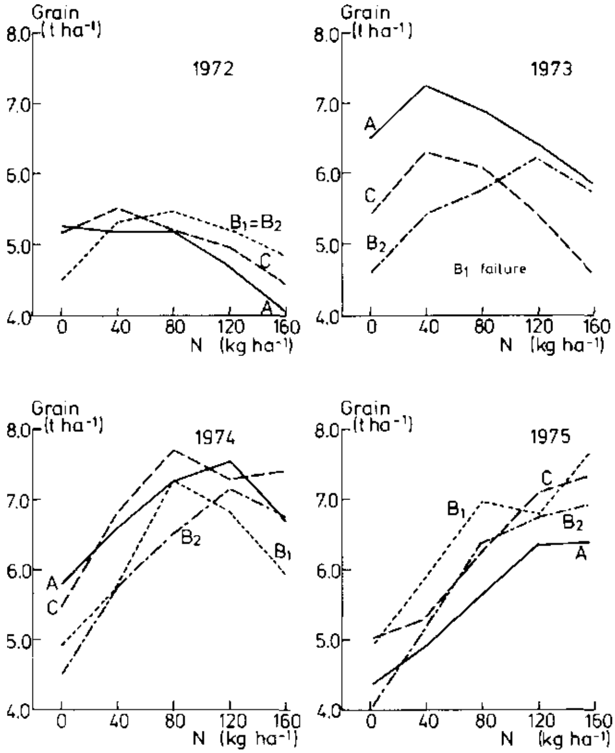


Fig. 20. Grain yield of winter wheat in separate years.

had to be reseeded with spring wheat, so there was no yield of winter wheat. In System B2 winter wheat died to a lesser extent than in System B1. However, the stand was poor and maximum yield was relatively low.

In *1974* emergence was good to very good whereas no slaking occurred. Although weather conditions during the growing season were not particularly favourable, yields were high and about equal for Systems A and C. For Systems B1 and B2 yields were also about equal, but still 10 % lower than in Systems A and C, obviously due to bad soil structure. Crop response to nitrogen did not differ much for Systems A and C. In Systems B1 and B2 nitrogen response was clearly stronger. However, also in these systems optimum yields were obtained at 80 to 120 kg ha^{-1} N.

Especially at low nitrogen levels in *1975* the yield level of Systems A and C was very low. This was due to the fact that harvest operations and primary tillage treatments on tilled soil damaged soil structure to the extent that it became worse than on soil not tilled for four years. This was especially true for System A where soil structure in spring was worse and natural improvement during spring and early summer was less than in System C. Nitrogen response was about the same for all systems. However, due to the bad soil structure, nitrogen requirements of the crop were higher than in any preceding year.

The four-year average of the yield data discussed above (Fig. 21) shows nitrogen

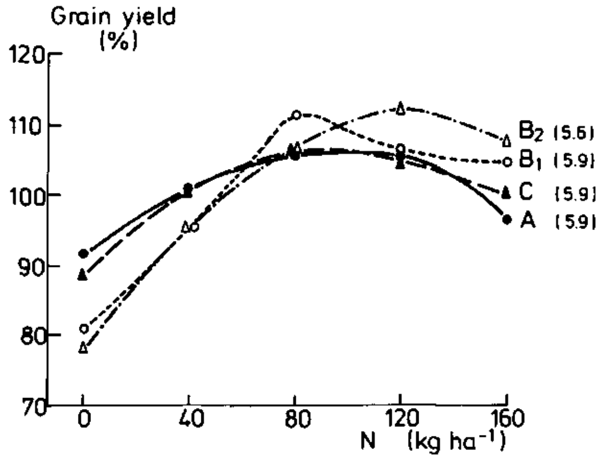


Fig. 21. Grain yield of winter wheat, relative to the four-year average 1972–1975 per tillage system (in parenthesis; t ha^{-1}).

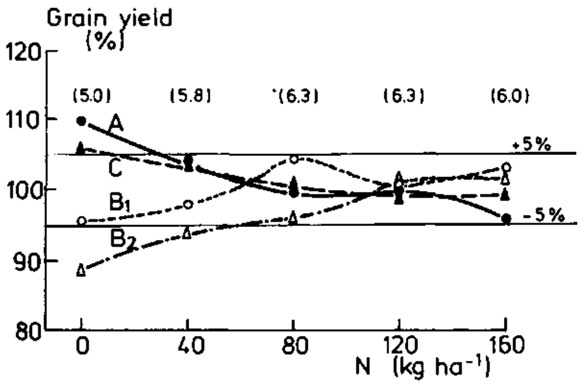


Fig. 22. Grain yield of winter wheat, relative to the four-year average 1972–1975 per nitrogen level (in parenthesis; t ha^{-1}).

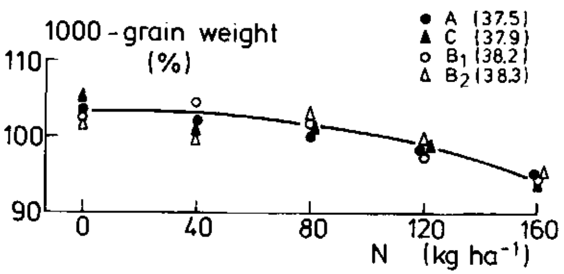


Fig. 23. 1000-grain weight of winter wheat, relative to the four-year average 1972–1975 per tillage system (in parenthesis; g).

response to be much stronger in Systems B1 and B2 than in Systems A and C. Although differences in yield averaged over four years were only small, it is interesting to note that at higher nitrogen levels in Systems B1 and B2 slightly higher yields were obtained than in Systems A and C (Fig. 22).

On average 1000-grain weight did not differ much between systems. Increasing nitrogen fertilization had a clear negative effect on 1000-grain weight (Fig. 23).

6.4 Sugar beet

6.4.1 Introduction

The straw of the previous winter wheat was always chopped, but straw distribution was not ideal. Contrary to the grass sown under spring barley, the grass sown under winter wheat usually developed rather poorly and unevenly, even though nitrogen was applied after cereal harvest. This poor development was not only due to inadequate straw distribution, but also to wheel tracks made at phosphate and potassium application.

6.4.2 Crop development

In *Systems A and C* the sugar beet were drilled to a predetermined distance in the row (ranging between years from 7 to 11 cm, Table 36) with a normal precision drill. In *System B1* no seedbed was prepared, so the roughland sowing machine had to be used which is not adapted to precision drilling. Therefore, the calculated number of seeds sown per ha in System B1 usually was much higher than in Systems A and C. As a result, in all systems the number of plants after emergence usually was satisfactory (Table 37). However, as may be seen from the percentage emergence (Table 38) environmental conditions around the seed in System B1 were bad, except in the first year of the experiment (1972) when the topsoil, due to intensive stubble cultivation in the autumn of 1971, still was relatively loose and there was no layer of chopped straw on the surface. In 1973 a thick layer of dead above-ground parts of grass and chopped straw of winter wheat made it impossible to sow at a regular rate and depth. Moreover, emergence was strongly impeded by the mulch. In spite of additional

Table 36. Calculated number of sugar beet seeds (× 1000) sown per ha.

	A, C		B1		B1/A, C
	distance in the row (cm)	number of seeds per ha	seed per ha (kg)[1]	number of seeds per ha	
1972	11.0	182	4.25	340	1.87
1973	7.0	286	4.00	320	1.12
1974	8.0	250	4.50	360	1.44
1975	11.0	182	5.00	400	2.20

1. 1000-grain weight approx. 12.5 g (80 000 seeds per kg).

Table 37. Number of sugar beet plants per ha (× 1000).

	After emergence[1]			At harvest[2]		
	A	C	B1	A	C	B1
1972	30	38	210	.[3]	.[3]	76.5
1973	180	220	95[4]	67.3	74.1	53.0
1974	63	147	99	71.2	76.6	66.5
1975	112	134	174	72.6	78.6	71.4

1. Average of three replicates.
2. One replicate.
3. After reseeding (9 cm in the row) no counts performed.
4. Directly after counting additionally sown by hand.

Table 38. Emergence (%) of sugar beet plants.[1]

	A	C	B1
1972	16	21	62
1973	63	77	30
1974	25	59	28
1975	62	74	44

1. Calculated from plant number after emergence and calculated number of seeds sown.

sowing by hand there were at harvest only 53 000 plants per ha, i.e. about 30 % less than standard (75 000 plants per ha). In 1974 and 1975 straw of winter wheat was removed and the dead grass was burnt. Nevertheless, plant population density in System B1 was unsatisfactory (66 500 and 71 400 plants per ha, respectively). Averaged over 1973–1975 population density in System B1 was 63 600 plants per ha, i.e. about 15 % below standard.

In *System C* emergence was always better than in *System A*, due to a finer seedbed. Especially in 1974, when after sowing there was no rain for about three weeks, the coarse seedbed of System A proved to be very risky. In 1972, due to an extra cultivation on frozen soil well before seedbed preparation, the seedbed in Systems A and C was much finer than in the following years. Moreover, after sowing temperatures remained low and it rained every day for almost four weeks. Consequently, in these systems serious slaking occurred, followed by crust formation. Emergence was so bad and damage by spring-tails so severe that two months after sowing the sugar beet had to be resown, which was done without renewed seedbed preparation.

In System B1, and when required also in Systems A and C, the sugar beet were singled, aiming at a stand of about 80 000 plants per ha. As appears from the number of plants counted at harvest (Table 37), this target number was never reached, undoubtedly due to the often very irregular distribution of the plants over the field.

Only in System C was the number of plants, about 75 000 per ha, satisfactory at harvest. In System A it was, on the average, 6 % lower and in System B1, except in the first year, the number of plants was 15 % lower.

In System A the coarse and uneven seedbed gave rise to problems with mechanical weed control: quite a number of young beet plants was covered with soil. In System B1 singling and mechanical weed control were impeded by mulch and by the hard, stiff soil.

Crop growth has not been examined in great detail. However, the trend was always the same, viz. a well developed, rapid growing crop in Systems A and C, and an irregular, slowly growing, meagre crop in System B1.

6.4.3 Crop response to perennial nitrogen levels

Averaged over the three perennial nitrogen levels and excluding 1972 (crop failure in Systems A and C) System A yielded somewhat less (4 % roots and 6 % sugar) whereas System B1 yielded much less (17 % roots and 21 % sugar) than System C (Table 39 and 40). This trend was observed in all years (Table 41 and 42). On average the effect of the three perennial nitrogen levels on crop yield was not clear cut, but very small.

In *1972*, as a result of the difference in sowing time caused by crop failure and redrilling in Systems A and C, the yields of both these systems were not comparable with that of System B1, which yielded 52.6 t ha^{-1} roots and 9.3 t ha^{-1} sugar (sugar

Table 39. 1973–1975 average sugar beet yield and sugar percentage at three perennial nitrogen levels.

System	Yield relative to mean at nitrogen level			Mean yield		Sugar (%)	Yield relative to System C
	P^-	P	P^+	t ha^{-1}	rel.		
A	94	102	104	60.5	103	16.5	96
B1	102	107	91	52.4	89	16.0	83
C	101	96	103	62.9	107	16.9	100
Mean	99	102	99	58.6	100	.	.

Table 40. 1973–1975 average sugar yield at three perennial nitrogen levels.

System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
	P^-	P	P^+	t ha^{-1}	rel.	
A	96	101	101	10.0	104	94
B1	104	107	89	8.4	87	79
C	102	95	102	10.7	110	100
Mean	101	101	97	9.7	100	.

Table 41. Root yield of sugar beet and sugar percentage at three perennial nitrogen levels.

	System	Yield relative to mean at nitrogen level			Mean yield		Sugar (%)	Yield relative to System C
		P−	P	P+	t ha^{-1}	rel.		
1972	A[1]	.	.	.	39.1	.	17.1	.
	B1	101	96	103	52.6	.	17.7	.
	C[1]	.	.	.	40.8	.	17.2	.
	Mean	.	.	.	.	.	.	.
1973	A	96	97	107	63	107	16.4	95
	B1	97	105	98	49	83	14.9	74
	C	97	101	102	66	112	16.8	100
	Mean	97	101	102	59	100	.	.
1974	A	90	107	103	61.0	99	16.3	93
	B1	104	122	74	58.6	95	15.9	89
	C	107	87	106	65.5	106	16.7	100
	Mean	100	105	94	61.7	100	.	.
1975	A	98	102	101	57.6	105	16.8	101
	B1	104	92[2]	103	49.6	91	17.2	87
	C	99	99	101	57.2	105	17.3	100
	Mean	100	98	102	54.8	100	.	.

Table 42. Sugar yield of sugar beet at three perennial nitrogen levels.

	System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
		P−	P	P+	t ha^{-1}	rel.	
1972	A[1]	.	.	.	6.7	.	.
	B1	102	96	103	9.3	.	.
	C[1]	.	.	.	7.0	.	.
	Mean	.	.	.	.	.	.
1973	A	98	96	106	10.3	108	93
	B1	100	105	95	7.3	76	66
	C	99	100	100	11.0	116	100
	Mean	99	100	100	9.6	100	.
1974	A	92	108	101	9.9	98	91
	B1	104	123	72	9.4	93	86
	C	108	87	106	10.9	108	100
	Mean	101	106	93	10.1	100	.
1975	A	99	103	98	9.7	103	98
	B1	94	93[2]	102	8.5	90	86
	C	100	100	100	9.9	105	100
	Mean	98	99	100	9.4	100	.

1. Crop failure; resown 16/5.
2. Partly explained by the occurrence of a large area of thistles.

Table 43. Soil tare of sugar beet (% of gross yield).

	Tillage system		
	A	B1	C
1972	.	.	.
1973	17.7	22.5	17.3
1974	32.8	49.4	37.8
1975	11.3	14.4	10.0
1973–1975	20.6	28.8	21.7

content 17.7 %). In Systems A and C the yields were only 39.1 and 40.8 t ha^{-1}, respectively.

In *1973*, System C yielded 66 t roots per ha and 11.1 t sugar per ha. This was approximately 5 % better than in System A. Compared with System C, System B1 yielded only 74 % roots and 66 % sugar. System B1 also had clearly more soil tare. Another problem was that in the compacted soil in System B1 the tips of the beet broke off easily.

The extremely wet autumn of *1974* made it almost impossible to harvest root crops. However, the average yield of all systems was the highest of the reported period. In System C root yield amounted to 65.6 t ha^{-1} and sugar yield to 10.9 t ha^{-1}. Systems A and B1 attained 93 % and 89 % of the root yield of System C, respectively. The bad soil conditions caused a high percentage of soil tare: 38 % in System C, 49 % in System B1 and 33 % in System A (Table 43).

The yield in *1975* was about the same in Systems A and C (in System C 57.2 t roots per ha and 9.9 t sugar per ha. System B1 produced only 87 % of this root yield and 86 % of the sugar yield. In System B1 root size was irregular, which made harvest difficult. The higher percentage of soil tare in System B1 (44 % higher than in System C) made harvesting also more expensive.

6.4.4 Crop response to annual nitrogen levels

Leaving out the first year of experimentation when the crop in Systems A and C failed, we found that sugar yield in System C was slightly higher than in System A. Both yields were much higher than in System B1 (Fig. 24). In 1973 the lower number of plants may have contributed to the low sugar yield.

Due to the reverse effects of nitrogen on root yield and on sugar content, the effect of nitrogen on sugar yield is, as a rule, only small. However, in 1975, due to the bad soil structure, there was a marked positive effect of nitrogen on the sugar yield. This effect, of course, dominates the 1973–1975 average nitrogen response curves (Fig. 25). Nevertheless, it is clear that the nitrogen effect as such does not differ much for the three tillage systems. The 1973–1975 average yield level was clearly lowest in System B1, and highest in System C (Fig. 26).

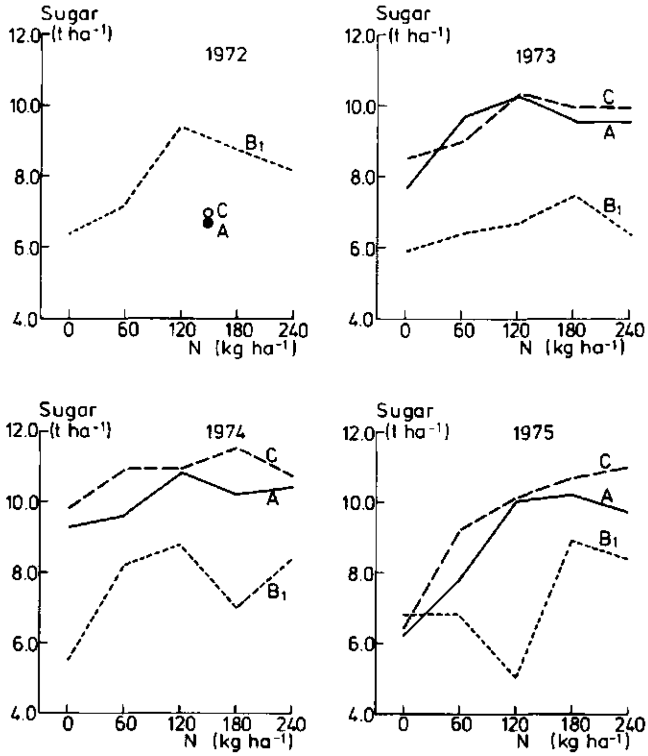


Fig. 24. Sugar yield of sugar beet in separate years.

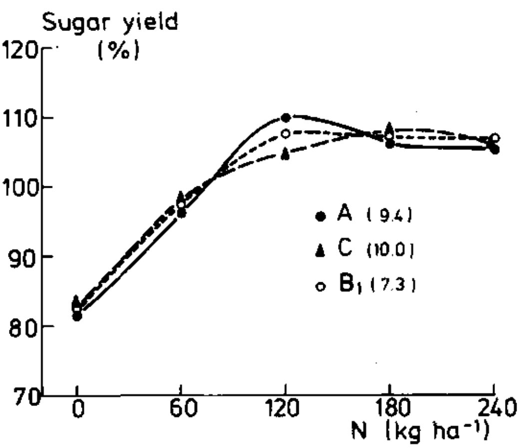


Fig. 25. Sugar yield of sugar beet, relative to the three-year average 1973–1975 per tillage system (in parenthesis; t ha^{-1}).

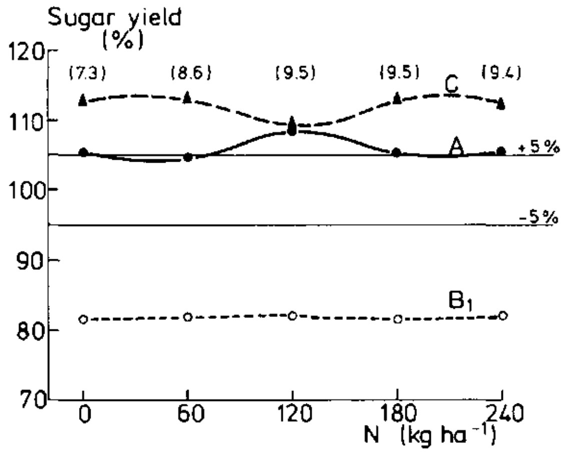


Fig. 26. Sugar yield of sugar beet, relative to the three-year average 1973–1975 per nitrogen level (in parenthesis; t ha^{-1}).

6.5 Spring barley

6.5.1 Introduction

In Systems A, B1 and C the previous crop in 1973–1975 was sugar beet. The tops and leaves of the beet crop were always left on the field at harvest. They never caused problems when the harvest was followed by ploughing (System A), but were troublesome when it was followed by fixed-tine cultivating (System C) or no-tillage (System B1). The beet tops sprouted again, especially after mild winters in System C, where the tops were only partly buried.

Spring barley, var. Berac in 1972, and var. Aramir in 1973 and subsequent years, was alway drilled, mixed with 20 kg ha^{-1} English ryegrass, var. Terhoy. In Systems B1 and B2 direct drilling was always practised.

6.5.2 Crop development

Seedbed quality had a marked effect on emergence and early growth of spring barley. On the average, emergence was better in *System A* than in *System C* (Table 44), mainly because in 1973 and 1974 the result of the identical seedbed preparation (spring-tine cultivator) was better in System A (ploughed) than in System C (cultivated), and because in these years sowing was followed by a long dry period. In 1974 the very coarse and shallow seedbed in System C initiated damage by birds to the extent that in one replicate the crop had to be resown. However, the low plant number was largely compensated for by a strongly increased tillering.

In 1972 omitting seedbed preparation in System A yielded a very coarse seedbed, whereas with the spring-tine cultivator in System C a seedbed of reasonable quality could be prepared. In Systems A and C crop growth was depressed due to mildew infestation, whereas in Systems B1 and B2, the crop having shorter, sturdier straw,

Table 44. Emergence, plant number and ears per plant at harvest of spring barley.

	Seed-rate (kg ha^{-1})	Emergence (%)				Plants per m^2				Ears per plant at harvest			
		A	C	B1	B2	A	C	B1	B2	A	C	B1	B2
1972	100	36	37	38	38	120	122	128	128	.	.	.	.
1973	85	49	31	36	27	104	67	77	57	5.1	7.0	3.5	.
1974	75	45	28[1]	40	42	84	52	75	79	6.8	9.5	7.0	7.0
1975	75	65	62	58	47	122	116	108	89	.	.	.	.
Mean	.	49	40	43	38	108	89	97	88	.	.	.	.

1. Mean of repetition I and II; repetition III had to be resown.

was hardly affected.

In 1975 the seedbed was very coarse in System A (in spite of seedbed preparation with a rotary harrow), and nicely crumbled in System C (spring-tine cultivator used twice). However, due to favourable weather conditions after sowing with occasionally light showers of rain, these differences in seedbed quality did not affect emergence. In 1975 emergence was far better than in 1972, presumably because sowing was very late in the season (end of April) and weather conditions after sowing were still more favourable than in 1972.

In *Systems B1 and B2* emergence was on average only slightly less than in Systems A and C. In 1973 and 1975 there was a marked difference in favour of System B1 because here no mulch was present as it was in System B2. However, the low number of ears/plant in System B1 (Table 44) in 1973 shows that crop development was unsatisfactory, presumably caused by the compact soil. In 1973 unsatisfactory emergence in System B2 was followed by abundant regrowth of grass which so badly affected crop growth that yield determinations did not seem to make much sense. The influence of year-effects on these systems was less than in Systems A and C. Nevertheless, also here in 1975 emergence was much better than in preceding years.

6.5.3 Crop response to perennial nitrogen levels

The average barley grain yield produced in System C over the four-year period was 4.9 t ha^{-1} (Table 45). If this amount is taken to be 100 %, then by comparison the yields of Systems A and B1 were 106 and 83 %, respectively. No-tillage is therefore not recommended in a rotation with root crops. System B2 gave significant higher yields (Table 46), although still clearly lower than in System A. Compared with potatoes, winter wheat and sugar beet, spring barley responded much more strongly to perennial nitrogen levels and unlike these crops its response was nearly always clearly positive (Tables 46 and 47).

In the first year *1972* the barley crop produced similar grain yields in all systems, i.e. approximately 4.8 t ha^{-1} (Table 47). If the yield from System C is taken as being 100 %, then by comparison the yields from Systems A and B were 102 and 96 %, respectively.

The *1973* barley crop was the best yielding of 1973–1975. In System C it reached

Table 45. 1972–1975 average grain yield of spring barley at three perennial nitrogen levels.

System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
	P^-	P	P^+	t ha^{-1}	rel.	
A	96	98	106	5.2	110	106
B1	92	101	106	4.1	86	83
C	98	100	101	4.9	104	100
Mean	96	100	105	4.7	100	.

Table 46. 1974, 1975 average grain yield of spring barley at three perennial nitrogen levels.

System	Yield relative to mean at nitrogen level			Mean yield	
	P^-	P	P^+	t ha^{-1}	rel.
B1	92	106	102	3.9	95
B2	91	98	110	4.3	105
Mean	92	102	107	4.1	100

5.6 t ha^{-1}; System A yielded 5.9 t ha^{-1} and System B1 3.9 t ha^{-1}, which means 105 %, and only 69 % compared with System C. In System B2 the crop failed.

In *1974* the yield of System C was lower because of bad germination; it yielded only 4.3 t ha^{-1}. The yields from Systems A and B1 were 115 and 90 %, respectively, compared with System C. System B2 yielded 102 % of System C; compared with System B1 the yield was 114 %.

The yield in *1975* was influenced by a bad soil structure, introduced at sugar-beet harvest in 1974. System A produced the best yield (5.0 t ha^{-1}). System B1 gave 3.9 t ha^{-1} which means 80 % of System C (4.9 t ha^{-1}). System B2 yielded 108 % of System B1, but when compared with System C only 87 %.

6.5.4 Crop response to annual nitrogen levels

In *1972* grain yields in Systems A and C (Fig. 27) were depressed, due to mildew infestation, and therefore, nitrogen response was only very small. In Systems B1 and B2, having shorter and sturdier straw, the crop was hardly affected.

In *1973* unsatisfactory emergence in System B2 was followed by abundant regrowth of grass, which so badly affected crop growth, that yield determinations did not seem to make much sense. In Systems A and C typical nitrogen response curves were obtained, showing System B1 to yield much lower than Systems A and C, which did not differ much.

In *1974* the very coarse and shallow seedbed of System C initiated severe damage

Table 47. Grain yield of spring barley at three perennial nitrogen levels.

	System	Yield relative to mean at nitrogen level			Mean yield		Yield relative to System C
		P⁻	P	P⁺	t ha⁻¹	rel.	
1972	A	96	101	103	5.0	102	102
	B1[1] } B2[1]	94	100	106	4.7	97	96
	C	101	101	98	4.9	101	100
	Mean	97	101	102	4.8	100	.
1973	A	96	100	105	5.9	115	105
	B1	90	99	111	3.9	76	69
	B2[2]	.	.	.	.	.	.
	C	96	101	103	5.6	109	100
	Mean	94	100	106	5.2	100	.
1974	A	94	95	110	5.0	113	115
	B1	96	103	101	3.9	88	90
	B2	92	100	107	4.4	100	102
	C	106	98	97	4.3	98	100
	Mean	97	99	104	4.4	100	.
1975	A	96	96	108	5.0	111	103
	B1	88	109	103	3.9	87	80
	B2	91	96	114	4.2	94	87
	C	91	101	107	4.9	108	100
	Mean	92	101	108	4.5	100	.

1. First year no difference between B1 and B2.
2. Crop failure.

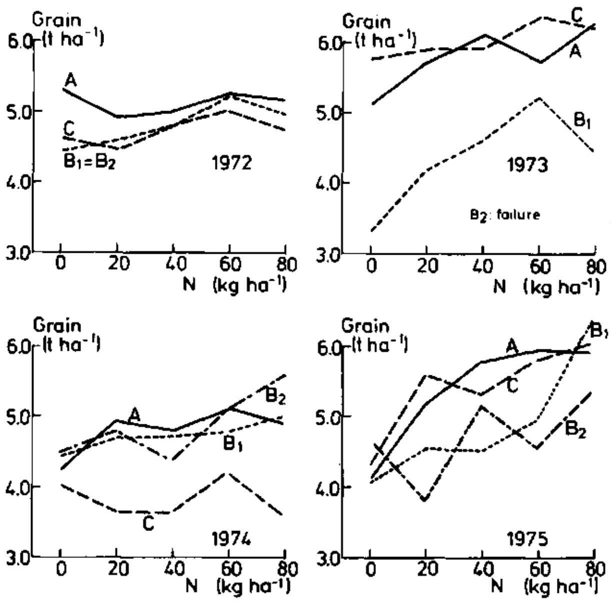


Fig. 27. Grain yield of spring barley in separate years.

by birds. Hence, in Repetition III, where the yield determinations of annual nitrogen levels were carried out, the crop had to be reseeded, causing a much lower yield. In System A, due to a coarse seedbed and prolonged drought after sowing, yield was also lower than normal and about equalled yields in Systems B1 and B2.

In *1975*, as in 1973, typical nitrogen response curves were obtained, indicating Systems A and C to yield about the same and, except for the highest nitrogen level, clearly higher than Systems B1 and B2.

On average, relative nitrogen response of Systems A and C was about the same (Fig. 28), with an optimum at about 60 kg ha^{-1}. In Systems B1 and B2 nitrogen response was clearly stronger and no optimum was obtained within the range of nitrogen levels studied.

The four-year average yield level 1972–1975 was about the same for Systems A and C, and for all nitrogen levels it was about 5 % higher than the average yield of all systems (Fig. 29). Systems B1 and B2 also yielded about the same, but here yield level was about 5 % lower than the average, although at high nitrogen levels differ-

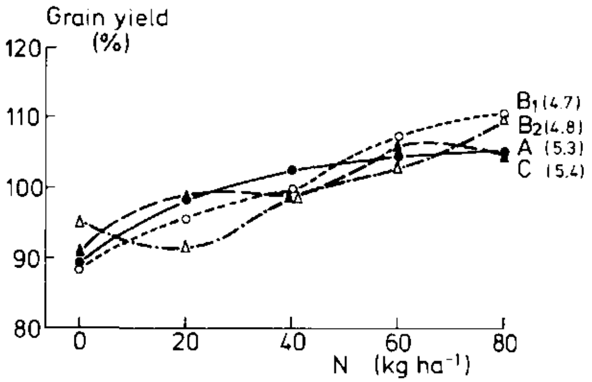


Fig. 28. Grain yield of spring barley, relative to the four-year average 1972–1975 per tillage system (in parenthesis; t ha^{-1}).

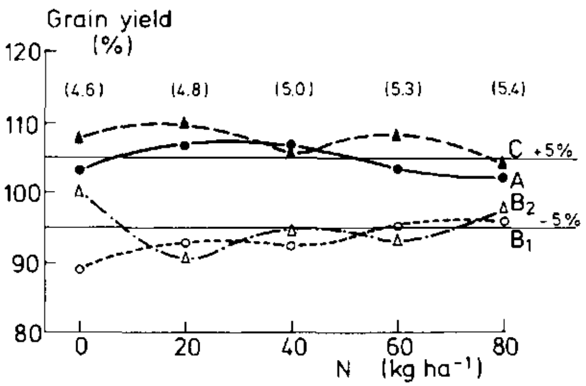


Fig. 29. Grain yield of spring barley, relative to the four-year average 1972–1975 per nitrogen level (in parenthesis; t ha^{-1}).

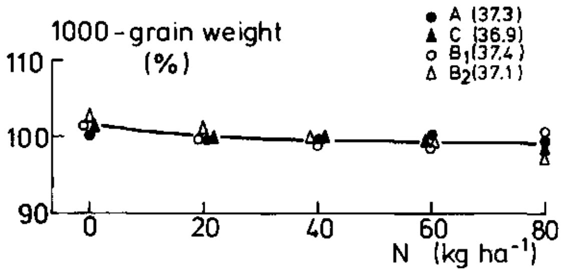


Fig. 30. 1000-grain weight of spring barley, relative to the four-year average 1972–1975 per tillage system (in parenthesis; g).

ences were smaller. Increasing nitrogen fertilization did not have detrimental effects on 1000-grain weight of spring barley unlike that of winter wheat (Fig. 30).

6.6 Discussion

At the start of the experiment the three tillage systems were only newly conceived. Therefore, in the course of time they had to be further developed and adapted to the demands of soil and crop. Consequently, it is not surprising that with the more sophisticated but far more complex System A ideal conditions have not been reached. In this system the heavier tractor, often needed for combining seedbed preparation and planting, resulted in heavier traffic under critical soil conditions. Therefore, results with respect to soil structure and seedbed quality were below expectations. In fact, with the more progressive System C about the same soil structure was obtained as in System A. Thus average yields as determined at perennial nitrogen levels were only slightly different for Systems A and C (Table 48).

Within the range of perennial nitrogen levels System B1 was capable of producing

Table 48. 1972–1975 average crop yield, relative to crop yield in System C (%), average of three perennial nitrogen levels.

Years averaged	Crops	A rel.	B1 rel.	C	
				rel.	t ha^{-1}
1972–1975	Potatoes (tubers > 35 mm)	97	91	100	54.8
1972, 1974, 1975	Winter wheat (grain)	95	97	100	6.3
1973–1975	Sugar beet (roots)	96	83	100	62.9
	(sugar)	94	79	100	10.6
1972–1975	Spring barley (grain)	106	83	100	4.9
Average[1]		98	87.5	100	

1. For sugar beet: sugar yield.

Table 49. 1974–1975 average grain yield of winter wheat and spring barley in Systems B1 and B2, average of three perennial nitrogen levels.

Crop	B1		B2	
	t ha^{-1}	rel.	t ha^{-1}	rel.
Winter wheat	6.6	100	6.6	100
Spring barley	3.9	100	4.3	111

87.5 % of the yield obtained in System C. This yield was insufficient to suggest any practical future for the system under Dutch conditions. On the other hand these results showed that crops are far more tolerant to a compact soil than it was thought hitherto. System B1 also proved to be less safe due to failures caused by unsuccessful weed control and soil slaking of the finely crumbled soil left at the surface after potato harvest.

Comparison of Systems B1 and B2 was only possible for winter wheat and spring barley. Moreover, because in 1972 treatments for cereals were similar for both systems and in 1973 winter wheat failed in System B1 and spring barley in System B2, the comparison had to be restricted to 1974 and 1975 (Table 49). Within the range of perennial nitrogen levels winter wheat yields were similar for both systems. However, spring barley yielded 11 % more in System B2 than in System B1.

Within the range of perennial nitrogen levels studied System A yielded with winter wheat on average 5 % less than System C, but with spring barley the reverse was true. Compared with those of Systems A and C, yields of Systems B1 and B2 were clearly lower for spring barley but not for winter wheat (Table 48). Another feature was that, on the average, for spring barley there was no optimum in the nitrogen response curve, whereas for winter wheat there was a clear optimum (Fig. 31).

The somewhat higher yield of potatoes in System C compared with that in System A indicates that definitive formation of the ridges directly at planting (System A) was disadvantageous. It caused delay in emergence and early development which could not be made up afterwards. In System B1 both the nitrogen response as such and the gross yield level were about the same as in System A, probably because in System B1 the potatoes were grown in ridges of satisfactory shape and quality. However, in System B1 yield quality was clearly inferior resulting in a saleable yield of only 91 % compared with System C.

For sugar beet ploughing to 25-cm depth in both Systems A and C levelled out any differences in soil structure produced in previous years. However, in System A seedbed quality and, hence, plant number and plant distribution were usually worse than in System C. This explains the 5 % lower yield in System A. In System B1, due to leaving out the main tillage treatment, soil bulk density was too high for satisfactory root development of sugar beet. Also, sugar content left much to be desired. Hence, on average, sugar yield in System B1 was 21 % lower than in Systems A and C.

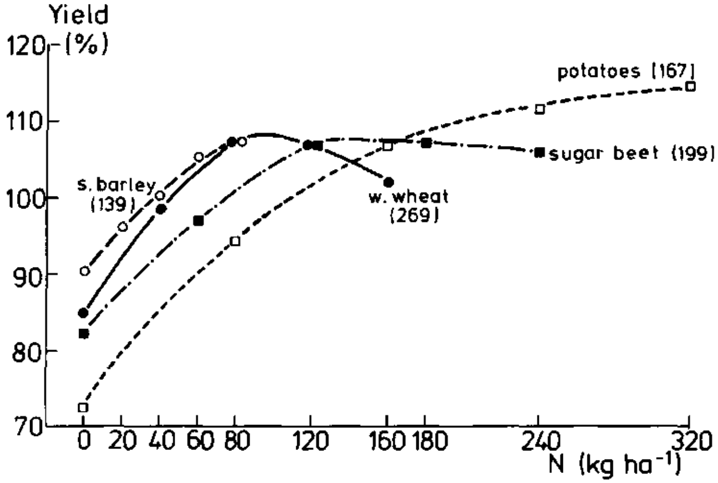


Fig. 31. Yield of spring barley and winter wheat (grain), sugar beet (sugar), and potatoes (tubers > 35 mm), relative to the four-year average 1972–1975 for all tillage systems. In parenthesis: average length of the growing period (days).

To compare crop response to perennial and annual nitrogen levels it is assumed that there are no cumulative effects of the perennial nitrogen levels. The average amount of nitrogen applied at the three perennial nitrogen levels may then be calculated as the arithmetic mean of the amounts of freshly applied fertilizer nitrogen, which varied from year to year (Table 50).

The average amounts of nitrogen applied in the perennial nitrogen levels usually do not correspond exactly to the amounts applied in the annual nitrogen levels. However, the average values N^-, N and N^+ of two appropriate annual nitrogen levels may be regarded as a reasonable approximation.

Table 51 shows that crop response to nitrogen, averaged for all tillage systems, and relative to the mean yield 1972–1975 of each crop, was almost identical for perennial and annual nitrogen levels. With winter wheat, potatoes and sugar beet nitrogen response was only small, whereas with spring barley the effect of nitrogen appears to be fairly strong.

Table 50. 1972–1975 average nitrogen fertilization (fresh application; kg ha^{-1}).

	Perennial nitrogen levels			Annual nitrogen levels[1]		
	P^-	P	P^+	N^-	N	N^+
Spring barley	22.5	40.0	57.5	20	40	60
Winter wheat	65.0	85.0	105.0	40/80	80	80/120
Potatoes	190.0	240.0	290.0	160/240	240	240/320
Sugar beet	120.0	157.5	195.0	120	120/180	180/240

1. $N^- \approx P^-$; $N \approx P$; $N^+ \approx P^+$.

Table 51. Mean yield response 1972–1975 to three perennial nitrogen levels and to three corresponding annual nitrogen levels,[1] averaged for all tillage systems, expressed as percentage of the mean yield of each crop.

	Perennial nitrogen levels					Annual nitrogen levels				
	P^-	P	P^+	mean		N^-	N	N^+	mean	
				$t\ ha^{-1}$	rel.				$t\ ha^{-1}$	rel.
Spring barley (grain)	94.7	99.7	105.5	4.66	100	95.7	99.6	104.7	5.07	100
Winter wheat (grain)	99.6	99.7	100.7	6.08	100	97.3	101.4	101.3	6.19	100
Potatoes (tubers > 35 mm)	98.7	99.8	101.3	52.70	100	98.1	100.4	101.7	53.50	100
Sugar beet (sugar)	99.1	101.2	99.8	9.68	100	100.3	100.2	99.6	9.51	100

1. $N^- \approx P^-$; $N \approx P$; $N^+ \approx P^+$.

From the close agreement between crop response to perennial and annual nitrogen levels it may be concluded that the assumption made is justified, in other words: in the first four-year period, 1972–1975, there were no cumulative effects of perennial nitrogen levels on crop yield. This result is in accordance with the only small differences in nitrogen availability in the soil profile (Chapter 5).

The small effect of nitrogen on crop yield observed with winter wheat, potatoes and sugar beet, may be explained from the small range of nitrogen levels applied. Differences between nitrogen levels P^- and P, and P and P^+ were only of the order of 20 % of the amounts applied at nitrogen level P. Moreover, nitrogen level P represents the amount applied in practice, which means that with winter wheat, potatoes and sugar beet the range of nitrogen levels P^-, P, P^+ is largely in the flat part of the nitrogen response curve. With spring barley, however, the differences in nitrogen level were much greater: −44 % (P^-) and +44 % (P^+) of the amounts applied at nitrogen level P.

6.7 Conclusions

1. Averaged over the four main crops tested: potatoes, winter wheat, sugar beet and spring barley, loose-soil husbandry (System A) and rational tillage (System C) yielded about the same when nitrogen was applied at a rate as usual in practice. However, with this nitrogen fertiliz_tion, no-tillage with root crops (System B1) produced only 87.5 % of the yield obtained in System C.

2. The very complex machinery and heavy tractor needed in System A for nitrogen application, seedbed preparation and planting potatoes in one pass, did not come up to expectations with respect to quality of seedbed and potato ridges and of soil structure below the ridges. Therefore, within the range of perennial nitrogen levels no extra crop yield was gained in System A compared with System C. System B1 seems to be less suitable for potato growing because although, gross yield was about

the same, the average saleable yield of tubers was only 91 % of the yield obtained in System C.

3. Of the four crops tested winter wheat which has a rather long growing period, was least affected by the differences between the three tillage systems. When slaking did not hamper emergence and early growth, System B1 (no-tillage) yielded nearly the same as System A, in which the soil was ploughed to 20-cm depth. Leaving out seedbed preparation in System A produced a too coarse and irregular surface, whereas fixed-tine cultivation to a depth of 15–20 cm (System C) produced an acceptable seedbed. Hence, yield in System C was 5 % higher than in System A. Therefore, fixed-tine cultivation seems an attractive tillage method; moreover, it controls groundkeepers by exposing them to frost action.

4. Due to a lower quality of the seedbed, sugar beet yields were slightly lower in System A than in System C. Therefore, System A (seedbed preparation combined with drilling in one pass) is not to be recommended. In System B1 because of the compact soil, root yield and sugar yield within the range of perennial nitrogen levels were only 83 % and 79 %, respectively, of those in System C. Consequently, System B1 is not favourable for sugar beet.

5. On average, spring barley following sugar beet yielded in System A 6 % more than in System C, probably because in late, wet springs it is difficult to obtain a good seedbed on soil treated with a fixed-tine cultivator in autumn. Within the range of perennial nitrogen levels Systems B1 and B2 yielded only 83 % and 88 %, respectively, compared with System C.

6. Crop response to nitrogen, averaged for the three tillage systems, and relative to the mean yield 1972–1975 of each crop, was almost identical for corresponding perennial and annual nitrogen levels. Consequently, it may be concluded that in the first four-year period, 1972–1975, there were no cumulative effects of perennial nitrogen levels on crop yield.

7. With winter wheat, potatoes and sugar beet, crop response to perennial nitrogen levels was only small, because with these crops perennial nitrogen levels extended only between −20 % and +20 % of the amounts usually applied in practice. With spring barley the effect of nitrogen was fairly strong because here perennial nitrogen levels extended between −44 % and +44 % of the amount usually applied in practice.

8. From nitrogen response curves based on annual nitrogen levels, it may be concluded that on average for winter wheat and spring barley System C needs about the same amount of nitrogen as System A, whereas for sugar beet and potatoes System C needs slightly more nitrogen to obtain maximum yield. In Systems B1 and B2 more nitrogen is needed, especially for spring barley, to obtain maximum yield. It appears that with adequate nitrogen fertilization in all systems the same yield (winter wheat) or about the same yield (spring barley and potatoes) can be obtained. With sugar beet, nitrogen response was about the same as in Systems A and C, but maximum yield was much lower.

7 Control of weeds, diseases and pests and treatment of mulch

W.A.P. Bakermans & C. Vader

7.1 Weed control

In this experiment tillage was mainly applied to influence the structure of the top soil and to prepare a seed bed. Although weed control inherent to soil cultivation is an aspect that should not be under-estimated, the soil was only occasionally tilled for weed control, exclusively. In 1972, for instance, the seed bed of rational tillage (System C) was harrowed additionally for the control of chickweed (*Stellaria media*), catchweed (*Galium aparine*) and chamomile (*Matricaria chamomilla*) before sowing spring barley. Since tillage was not carried out especially for the purpose of weed control, intensive chemical weed control corresponding to modern agricultural practice was applied similarly to all systems. Table 52 shows an outline of the herbicide treatments.

Due to the chemical weed control, the effect of tillage as a weed control measure could not be determined separately, for example the generally less frequent occurrence of annual weeds after ploughing than after cultivation with a fixed-tine cultivator. Even though chemical weed control was more intensive with no-tillage, there were clearly more weeds than on the tilled soil. Especially, perennial weeds were difficult to control adequately and spreading of couch grass (*Elytrigia repens*) could only be prevented by drastic measures (patchwise killing of crop and weeds together by spraying). On the untilled soil there were generally more annual weeds too, partly due to the sometimes somewhat irregular stand of the crops which left more bare patches that were rapidly invaded by weeds. Chemical weed control was needed more on the untilled soil than on the tilled soil. As a result, severe weed infestation sometimes occurred, especially when, due to adverse weather conditions chemical weed control could not be applied in time or failed to work properly.

On the untilled soil the grass sown was sometimes harrowed lightly into the soil, which stimulated the germination of many weeds. In September 1972 Italian ryegrass was sown one day after spraying with paraquat as a second crop to winter wheat, whose straw had been left on the land. The grass germinated well, but shortly afterwards the seedlings died, having come in contact with paraquat still adhering to the straw. In spring the crop had tc be resown.

In the next years perennial ryegrass together with spring barley were sown without problems. Intensive chemical weed control in the barley crop and barley stubble together with the considerable competition of the perennial ryegrass for seed, rendered weed control in the grass crop unnecessary in the second year.

Rape was grown only on the no-tillage system B2. In the first year it was grown after barley, but because the barley volunteer plants were very troublesome, thereafter rape was sown after winter wheat. Due to the enclave effect of the small rape

Table 52. Herbicide treatments kg active ingredient per ha.

Potato	Winter wheat	Sugar beet	Barley	Rape	Grass seed
Tillage treatments A B1 B2 and C				*B2*	
after planting 1 terbutryn/ 0.5 terbutylazin or 0.7 metribuzin	after sowing: 2.8 methabenzthia-zuron end of April: incidentally 4 DNOC beginning of May: 1.6 MCPA+2.1 MCPP end of May: repeated 1.2 MCPA half September: on grass as green manuring crop 2.5 2.4-D+2.4 MCPA	after sowing: 2.6 pyrazon May/June: once or repeatedly 1 fenmedifam application over the crop row on A and C overall application on B1	April/May: 4 DNOC end of May: 1.2 MCPA + 1.6 MCPP incidentally 1.25 broomfenoxim beginning of June: 1.6 MCPA half September: on grass as green manuring crop 1 2.4-D/0.48 dicamba or 1.6 MCPA+2.5 2.4-D	after sowing: 0.25 simazin + 12 TCA October: incidentally 2 dalapon Jan./Febr.: incidentally 1 propyzamide or 1.4 carbeetamide	Grass under cover-crop and in stubble: see barley and winter wheat. half September: to control volunteer barley: 0.88 endothalnatrium + 1 Citowett In 2nd year in dense stanc of grass usually no chemical weed control necessary.
Additional on B1 and B2 weed and crop killing instead of tillage					
October: incidentally 1 paraquat	half October: killing of grass (green manuring) 1 paraquat half December: repeated with 1 paraquat half March: incidentally repeated with 1 paraquat	March: incidentally to control regrowth beet-tops on C and B1 0.4 paraquat + 0.4 diquat	half October: killing of grass (green manuring crop) 1 paraquat half December: repeated with 1 paraquat spring: incidentally repeated with 1 paraquat	half October: 0.8 diquat + 0.2 paraquat incidentally repeated with 1 paraquat	end of September: 1 paraquat end of November: repeated with 1 paraquat half March: incidentally repeated with 1 paraquat.

seed plots surrounded by bare soil, the crop was almost exclusively a feeding place for game. This resulted in a thin stand or even complete failure of the crop so that excessive weeds developed.

In beets chemical weed control had to be supplemented every year with more or less intensive hoeing and weeding. In general chemical weed control was effective in cereals and in potatoes.

Unlike the situation with weeds, volunteer potato plants were practically absent on the untilled soil. In System A there were many, in C few, and in B practically no volunteer potatoes. Since the potatoes left on the untilled soil were mainly on top or in the top layer, a period of light frost was sufficient to kill them.

In accordance with other experience it was established that application of paraquat and diquat only for controlling weed and crop growth in autumn and winter, was less effective than ploughing. For chemical weed control in winter fallow, herbicides with a more persistent effect in the soil could be applied. In experiments at the Centre for Agrobiological Research (CABO) good results were obtained against couch (*Elytrigia repens*), butterbur (*Tussilago farfara*) and thistles (*Cirsium arvense*) with TCA and amitrol/thiocyanate.

7.2 Diseases and pests

In all the tillage systems the same intensive chemical control of diseases and pests was applied. Table 53 gives an outline of these treatments.

Damage due to diseases and pests could be satisfactorily prevented in this way. Apart from a tendency for less mildew in the cereals on untilled soil where growth was slightly less rank, there were hardly any differences in incidence of diseases and pests between the different tillage systems. However due to the enclave effect of the B2 plots surrounded by bare soil during winter, more damage by game and by mice

Table 53. Chemical control of diseases and pests in kg of active ingredient per ha.

Potatoes	According to requirement 10 to 15 times application of 1.2 maneb + 0.24 fentinacetate per growing season. Mixed the 1st 1 or 2 times with 0.25 parathion or thiometon against aphids.
Winter wheat	1.0 chloormequat in stage 5 against lodging Just before flowering 1.7 maneb + 0.24 carbendazim If necessary 0.2 dimethoate (since '75 0.25 primicarb) against aphids
Sugar beets	Occasionally on infected plots 1.5 aldicarb Seed treatment with Carbaryl against fungi and soil insects Occasionally a field treatment with lindane against mangold beetle and spring tails Four applications of 0.25 thiometon or 0,4 oxy-demeton-methyl Against aphids (yellowing disease) since '75 0.25 pirimicarb
Spring barley	Occasionally 0.6 tridemorf against mildew Occasionally in B2 methaldehyde grains against molluscs
Rape seed	A field application of 0.5 parathion against flea beetles 0.70 fosalone against rape beetles and weevils

occurred and there was incidental damage from slugs present in the mulch. It is possible that there were no other differences between the systems because of chemical disease control.

7.3 Treatment of mulch

In designing the experiment the intention was to leave on the plots of all systems the same level of organic matter and as much as possible. Organic matter consisted of plant remains (straw, potato foliage, beet tops and leaves and green manure). Under cover of cereals Italian or perennial ryegrass was grown as a green manuring crop. The cereal straw was left on the field. The combine harvester chopped the straw and distributed it on the land, so that it did not hamper the development of the green manuring grass crop. On the tilled soil generally ploughing under this mulch was easily done, even with a rather irregular distribution of the chopped straw. Occasionally, voluntary grass growth, due to less successful ploughing, had to be sprayed with paraquat. The first two years a plough was used not designed to plough shallower than 25 cm.

To grow potatoes on untilled soil, usually, the rather thick layer of mulch (in March some 4000 kg of dry matter per ha was still present on the soil) was intensively mixed with the soil with a rotavator before planting the potatoes; this treatment provided a good seed bed when the soil was tilled very intensively (see Section 4.2.6). At the same time the grasses and weeds that were present were destroyed completely.

With other crops the mulch left on the untilled soils caused many problems with emergence and early crop growth. After growing grass as a seed crop volunteer grass sometimes appeared due to germination of dropped seeds. In general it was impossible to distribute the chopped straw, left in the grass green manuring crop, equally on the land. Frequently, a too thick layer of chopped straw remained in patches so that sowing of the next crop was hampered. In sowing with the no-tillage seeder (Bakermans, 1970) a too thick layer of straw is not cut, but is pressed slightly into the soil, and the seed is not sown deeply enough or covered with soil. In this way the seed dries out easily or is pecked off by birds. When the seed was successfully brought into the soil and the drill slot was properly closed, the seedlings could hardly grow through the straw layer, partly because of etiolation. It is, however, also possible that the poor germination and later the dying of the seedlings was mainly due to a toxic effect of decomposing straw. Once, some paraquat damage occurred, after a pre-emergence treatment with Gramoxone, due to contact of the seedlings with the product still adhering to the straw.

In the winter of 1972/1973 the winter wheat crop failed. It had been sown in the bare very fine soil left at the surface after potato harvesting on the untilled soil. On the other hand the wheat sown in a light mulch wintered well. The favourable effect of a mulch was clearly shown in this treatment. However spring barley on the untilled soil was a failure in 1973, because it was sown in a layer of mulch that was too thick. Germination was insufficient and early growth was hampered by regrowth of grass and by slugs. The thin stand was infested by weeds.

Since 1973 after root crops the soil on System B1 was tilled superficially with a fixed-tine cultivator after which cereals could be sown with a conventional seeder.

Slaking of the usually bare soil was mainly prevented in this way.

When sowing with the no-tillage seeder in the stubble of the grass seed crop and in rape or grass for green manuring, on System B2 excessive amounts of mulch were removed. In both instances germination was satisfactory. Sugar beet on the untilled soil presented problems since this crop tolerates only a thin layer of mulch at sowing. The straw of the preceding wheat crop had to be removed and the green manuring grass crop had to be killed early by spraying, and the excess mulch removed or burned.

In 1973, when the beets were sown, some 4500 kg of dry matter per ha of the wheat straw left was still present on the land, varying from 2500 kg to 6500 kg per ha from place to place. Since this amount was much too high for the sowing of beets, the mulch was burned before sowing, after which the beets could be sown easily.

This burning was carried out so efficiently that wide areas of completely bare soil remained. In spring this bare soil formed a crust, in which germination of the beets was very poor. During the drought period the resown beets dried out completely in the hard crust. The presence of a light mulch would almost certainly have had a favourable effect.

Based on experience gained from experiments at the CABO, it can be stated that when sowing beets in spring not more than about 2000 kg of dry matter of undecomposed straw remainders can be tolerated on the surface. Cereals can tolerate some 3000 kg to 4000 kg of dry matter per ha, provided it is well-distributed. Siletta and grass seed can tolerate greater amounts. Lignified stubbles of grass seed crops may cause difficulties, when over 3000 kg of dry matter is present on the surface. In general amounts of over 4000 kg of dry matter per ha such as undecomposed straw or lignified grass stubbles will cause difficulties, especially because this dry matter is never evenly distributed.

Hence we finally decided that the wheat straw should be removed from the no-tillage plots and other excessive amounts of mulch were to be burned or also removed before sowing the crops. That Systems B1 and B2 in this way received somewhat less organic matter than the ploughed soil was accepted as inherent to the system.

Non-lignified plant remains, such as beet tops and leaves were not troublesome, except that sometimes, in a mild winter, they became established and then had to be killed by spraying.

7.4 Discussion

Since tillage was not carried out especially for the purpose of weed control, weed growth on the tilled treatments was also controlled chemically, as shown in Table 52. Even though chemical weed control was more intensive with no-tillage, more failures occurred than on the tilled soil. Perennial weeds were especially difficult to control adequately. In all the treatments the same intensive control of diseases and pests was successfully applied, as mentioned in Table 53.

The intention was to leave the same level of and as much organic matter as possible such as plant remains and green manure on the land. This did not meet with any difficulties on the tilled plots. Due to problems in sowing and germination of the crops on the non-tilled soil experienced in the first year, we decided not to leave the wheat straw and excessive amounts of mulch of other crops, but to remove or to burn them before sowing. Beets particularly tolerate only a thin layer of mulch. In System B1 insufficient mulch was present after potatoes, which caused a crop failure of wheat due to soil slaking. Therefore, a seed bed was prepared so that a conventional seeder could be used. Consequently the germination and seedling development of the crops on the mulch free soil was clearly stimulated and soil slaking was decreased.

7.5 Conclusions

1. In potatoes and in winter wheat the chemical weed control was successful in all systems.

2. Due to the somewhat unsuitable crop rotation in System B2 and because the development of rape was seriously hampered by game damage, the effect of the chemical weed control in this crop was usually insufficient.

3. Weed control in spring barley was successful, in Systems A, B1 and C but in System B2 occasionally regrowth of the seed grass, too much mulch or weeds left over from the previous crop (rape), were troublesome.

4. In sugar beet weed control by applications of pyrazon and fenmedifam was insufficient. Weeds were controlled by additional hoeing and weeding for all treatments.

5. In the grass seed crop in System B2, no chemical weed control was necessary in the second year, due to heavy crop competition.

6. Exclusive application of paraquat and diquat in autumn and winter on the no-tillage plots controlled the weeds less successfully than the main tillage operation.

7. Application of paraquat just before sowing in the presence of much straw and stubble sometimes caused damage because of contact between young plants and paraquat adhering to the straw.

8. In the no-tillage plots the stand of the crops was frequently somewhat irregular so that weed growth increased. Apart from the beet crop, the control of annual weeds generally was successful. The control of perennial weeds, e.g. couch grass, was, however, more difficult on zero-tillage

9. Apart from somewhat less damage by mildew and somewhat more damage by animals on the no-tillage plots covered by mulch, e.g. slug and mice damage, consumption by pigeons and pheasants, no obvious differences were found in incidence of diseases and pests in the different tillage treatment.

10. Green manuring crops and the mulch on the non-tilled soil frequently could not be dealt with satisfactorily.

11. Leaving plant remains, clearly protected the soil from slaking and thereby gave better germination of the crops, provided not too much material was left.

12. In the presence of too much or irregularly distributed undecomposed material, germination and seedling development were sometimes seriously reduced with no-tillage

13. Roughly, it can be stated that with sugar beet sowing will be difficult and emergence will be unsatisfactory when over 2000 kg of dry matter per ha of undecomposed straw remains are present in spring. Cereals, grass and siletta tolerate

considerably more mulch. In general, however, even with a good distribution more than 4000 kg of dry matter per ha of undecomposed plant residues are unadvisable when sowing the crops.

8 Remarks on no-tillage cropping with and without root crops

W.A.P. Bakermans & C. Vader

8.1 Introduction

The growing of root crops, especially potatoes usually is associated with a rather intensive tillage. In a rotation with root crops 'pure' zero-tillage, in which no tillage whatsoever is applied at all, is therefore impossible. Therefore, a crop rotation with solely non-root crops was also included. The only tillage taking place in this system is that of the V-shaped rotating sowing coulters between which the seed is brought into the soil. For the best possible comparison of no-tillage between the rotation with non-root crops and that with root crops, the winter wheat and spring barley from the rotation with root crops (B1) were always grown in plots adjacent to those from the rotation with non-root crops (B2).

Initially System B2 consisted of: spring barley – rape – winter wheat – grass seed. Because the control of the troublesome barley volunteer plants failed, in 1973 this was changed to: spring barley – grass seed – winter wheat – rape. Volunteer plants of winter wheat in the rape crop could be controlled by application of 12 kg TCA per ha. Moreover, on the untilled soil it was easier to sow the spring barley and the grass seed together. In winter wheat some light harrowing after sowing the grass was sometimes necessary, which may have stimulated the germination of weeds.

Although this rotation was not optimum from either the viewpoint of practical farm management or timeliness because rape after winter wheat frequently could not be sown in time, it could be used to study the various aspects of 'pure' zero-tillage. The yield of spring barley and winter wheat from both rotations can be directly compared. Attention should be paid, however, to the fact that possible yield differences may be the effect of rotation and soil-tillage together.

8.2 Cereals

When starting the experiment in autumn 1971 the cereals in Systems B1 and B2 had the same cropping history (both followed spring barley). Germination, development and yield were therefore equal as well.

In the winter of 1972/1973 the winter wheat crop sown after potatoes on the B1 plots failed, due to slaking of the soil, whereas the winter wheat sown after rape on the B2 plots in a light mulch, wintered well and had a rather good stand in spring. The spring barley, however, failed on the B2 plots in 1973, due to sowing in a too thick layer of mulch, competition from regrowth of grass seed and damage by slugs.

In the following years a satisfactory germination on the B1 plots was obtained by tilling the soil after potatoes to a depth of ≤ 6 cm with a fixed-tine cultivator, after which the seed could be sown with a conventional seeder. The B2 plots were not tilled at all and sowing was done with a no-tillage seeder. Winter wheat was sown in the seed grass stubble after removing or burning excessive stubble and straw residues. With the same machine spring barley was sown in a light mulch after rape. Here too, germination was good in most cases. Early development of the winter wheat was good, but growth of the spring barley was not satisfactory. Especially in System B2, after rape, the soil was infested by weeds, which, due to adverse weather conditions, could not be chemically controlled in time.

Since crop growth and yields on the B1 and B2 plots were the same in 1971/1972 and since in 1972/1973 the winter wheat on the B1 plots and the spring barley on the B2 plots failed, comparison of the cereal yields of the B1 and B2 plots is valid only for the years 1973/1974 and 1974/1975. The data are shown in the Figs. 32 through 33.

Fig. 32 shows that the winter wheat on the B2 plots required somewhat more N than that on the B1 plots. Fig. 32 (right) indicates that with the higher N applications the yields of the B1 and B2 plots were almost the same. Probably there remained more N in the soil after the potatoes than after the grass, even though the grass seed stubble was fertilized with 50 kg N per ha to stimulate rapid decomposition.

Fig. 33 shows that the yield of the spring barley of the B2 plots on average was higher than on the B1 plots and also the impression was gained that the crop on the B2 plots required somewhat more N than that on the B1 plots. This nitrogen effect is not obvious from the data found in Fig. 33 (right). Roughly, it can be said that the performance as well as the N reaction on the B1 and B2 plots were the same, and the optimum N application was not attained.

In general, development of the spring barley on the B2 plots was somewhat less than that on the B1 plots and both crops were somewhat lighter and ripened somewhat later than those on the A and C plots which grew slightly better from the beginning onwards. Corresponding with this result, the yield of spring barley on the untilled plots was clearly lower than that on the cultivated plots. Only with the highest N application the yields were almost the same (Section 6.5.4). The lower yield may have been partly due to the weeds, especially present on the B2 plots. However, the later ripening of the spring barley indicates retardation in root

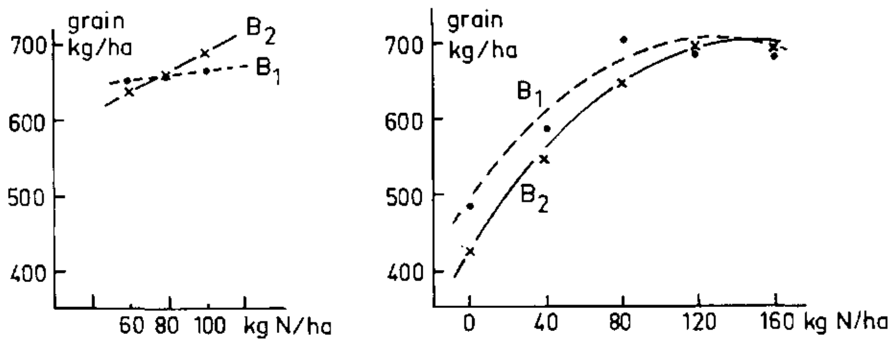


Fig. 32. Grain yield of winter wheat averaged over 1973/1974 and 1974/1975. · = B1; × = B2. Perennial N levels, applied each year on the same plots (left). Annual N levels applied each year on different plots (right).

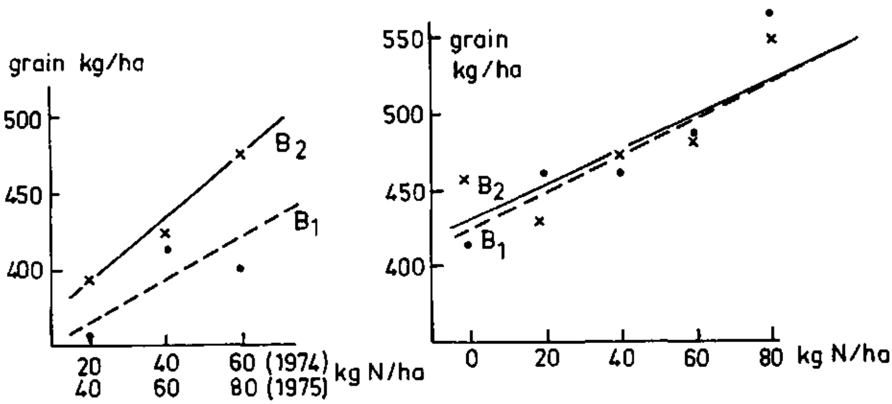


Fig. 33. Grain yield of spring barley averaged over 1974 and 1975. • = B1; × = B2. Perennial N levels applied each year on the same plots (left). Annual N levels applied each year on different plots (right).

development which frequently occurs with no-tillage and is fatal to a crop with a short growing period, such as spring barley. Corresponding with this assumption the winter wheat on no-tillage yielded on average almost the same as on the tilled soil.

8.3 Other non-root crops

Since rape and grass seed were only grown on the B2 plots a comparison of these crops on B1 and B2 plots is not possible.

The rape crop caused continuous trouble, also due to the somewhat unfortunate crop rotation and especially due to the 'enclave effect' of the plots.

Sowing did not cause any trouble, but in 1972 and 1973 the control of volunteer barley plants was insufficient. After wheat in 1973, considerable trouble was caused by the regrowth of Italian ryegrass sown under the wheat. The stand of rape was damaged by pigeons and pheasants to such an extent, especially in the plots situated furthest from the farmstead, that there was a considerable infestation of weeds, which still had a serious adverse effect on the succeeding summer barley. At harvesting there always was a great loss of seed due to birds. The rape was almost exclusively a feeding place for game.

In so far as the rape wintered without too much damage, it developed during summer into a heavy crop, with high yield expectations. Despite all difficulties, the impression was gained that the crop grows rather well in untilled soil. When cropping on a larger scale bird damage might have been limited and instead of the harvested 1000 to 1500 kg seed per ha, the yields would probably have been much higher.

Unlike growing of rape, that of grass seed hardly caused any trouble, especially not when spring barley and perennial ryegrass were sown together. Intensive chemical weed control in the barley crop and stubble together with the considerable competition of the perennial ryegrass sown for seed, rendered weed control in the grass crop unnecessary in the second year. The grass seed crop usually left a clean almost weed-free stubble.

The grass seed yields, however, were not particularly high, averaging to some 1500 kg of seed in gross yield and some 8000 kg of field dry hay per ha. Possibly, the seed yield was also somewhat lower due to the enclave-effect of the grass seed plots. In view of the thick stand of the standing crop and the successful weed control, the impression was gained that grass for seed is a particularly suitable crop for a no-tillage system.

8.4 Root crops

As mentioned before, potatoes and beets were exclusively grown on the B1 plots. Potatoes followed spring barley with a green manuring grass crop in which the chopped straw was left. As explained in Section 7.3, this caused no problems with mulching and chemical weed control.

As explained in Section 6.2.3, development generally was somewhat slower and the yield of saleable potatoes somewhat lower than on the tilled soil. There were more green and misformed tubers on zero-tillage. The impression was gained that a system of continued no-tillage is not very suitable for potato growing.

Sections 7.1 and 7.3 explain that mulching and chemical weed control in sugar beet caused many problems. The development of the sugar beet was generally somewhat slower (Sections 6.4.2 and 6.4.3), harvest losses being larger and the sugar yields lower than on the cultivated soil. Chemical weed control only, was not successful either. A continuous system of no-tillage does not seem very suitable for growing sugar beet.

8.5 Discussion

Since the growing of root crops is associated with rather intensive soil tillage, on no-tillage a rotation of non-root crops was included, in which rape replaced sugar beet, and a grass seed crop replaced potatoes. Therefore, only the yields of winter wheat and spring barley from both rotations can be compared directly.

In the winter of 1972/1973 the winter wheat sown in bare soil after potatoes on the B1 plots (root crop rotation) failed, due to slaking of the soil, whereas the winter wheat sown in a light mulch after rape on the B2 plots (non-root crop rotation) wintered well. On the other hand, the spring barley failed in 1973 on the B2 plots, due to sowing in a too thick layer of mulch and damage by regrowth of grass seed and by damage of slugs.

In the following years a satisfactory germination of the cereals was obtained on the B1 plots after the root crops by making a seed bed by superficial soil tillage and sowing with the conventional seeder and on the B2 plots after grass seed or rape stubble, by burning or removing excessive amounts of mulch.

Germination, development and yields of the cereals in the root crop rotation were almost the same as those in the non-root crop rotation. Only the nitrogen requirement of the crops in the latter rotation was somewhat greater. Also due to the somewhat unfortunate non-root crop rotation and also to the enclave effect of the rape plots, the control of weeds and volunteer plants in the rape and in the following barley crop was unsatisfactory. Moreover the rape was considerably damaged by game. Grass seed seemed very suitable for a zero-tillage system. The grass seed stubble always left a very clean soil.

No-tillage with potatoes did not pose serious problems, but the yield of saleable tubers was usually lower. There were also more malformed and green potatoes on the untilled soil. In growing sugar beet on untilled soil, germination, development, and yield as well as the control of weeds in the crop were unsatisfactory.

8.6 Conclusions

1. Good results can be obtained with no-tillage in rotations with non-root crops only.

2. In rotations with non-root crops, winter wheat and perennial ryegrass for seed production seem especially suitable crops for no-tillage and with a suitable crop rotation and N-fertilization perhaps rape and spring barley also.

3. The impression was gained that the cereals in the non-root crop rotation showed a greater nitrogen requirement than those in the root crop rotation.

4. Technically, the growing of root crops, especially that of sugar beet seems less suitable in a system of continued no-tillage.

5. To prevent slaking of the untilled soil it is advisable to prepare a seed bed after root crops before sowing in the bare soil

6. A mulch layer will prevent slaking of the soil in a no-tillage system. However, to prevent technical problems with sowing in the mulch and later with germination of the crops, generally not more than about 4000 kg of dry matter of plant remains should be present on the surface.

9 General discussion

W.A.P. Bakermans, F.R. Boone, L.M. Lumkes & C. van Ouwerkerk

Results obtained with three different tillage systems during the period 1972–1975 depend very much on the crop rotations which were deliberately chosen as:
A, B1, C: potatoes – winter wheat + undersown grass – sugar beet – spring barley + undersown grass.
B2: seed grass – winter wheat – oil seed rape – spring barley + undersown grass.

We tried to get the most from each tillage system by adapting it to the conditions created by the harvest of the previous crop and to the conditions to be created for the next crop.

In *System A* (loose-soil husbandry) this was comparatively easy as it was clear that to obtain a loose soil ploughing had to be the main tillage treatment (to a depth of 25 cm for root crops, and 20 cm for cereals). However, the second condition, keeping the ploughed layer loose, was far more difficult to meet, because it required special arrangements for combining several treatments into one pass. The solutions found proved to be less satisfactory than hoped for or even to be principally wrong. For instance, combining ploughing and drilling of winter wheat in a one pass operation, caused an irregular depth of sowing and often a too coarse seedbed. Nitrogen fertilization, seedbed preparation, planting and ridging of potatoes could only be performed with a heavy tractor (80 kW) and a powered harrow, which had to work too deeply (in too wet soil) to obtain the desired quality of potato ridge. Moreover: compaction in the wheel tracks was severe. Combining seedbed preparation and drilling of sugar beet and spring barley did not always turn out well, as the loosened soil should be left to dry for several hours after seedbed preparation.

In *System C* (rational tillage) it was thought to be rational to plough for root crops and to use the fixed-tine cultivator as the main tillage treatment for cereals. Ploughing of soil, not ploughed the year before, did not pose any problem. Fixed-tine cultivation after potatoes, produced usually an acceptable seedbed for winter wheat. However, after sugar beet, as the soil is not inverted, much trash remains at the surface, posing problems with regrowth of sugar beet and weeds and seedbed preparation for spring barley. Although initially potatoes were planted without any seedbed preparation, in the last two years it was thought recommendable to make a seedbed in this system as well.

In *System B1* (no-tillage) in principle all tillage was left out and crops were sown in a compact soil, as was the case when sowing sugar beet in the winter wheat stubble (+ mulch of killed off grass). However, harvesting sugar beet resulted in some soil tillage and after this harvest the soil had to be levelled with the fixed-tine cultivator. Of course, during winter the loose soil settled again, so drilling spring barley was done in a more or less compact soil. Potatoes could only be grown in this system by making enough loose soil in the spring barley stubble (+ undersown killed off grass) by means of rotovating to about 5 cm depth, and, later on, by inter-row rotovating another 3 cm. Because a lot of energy is needed to achieve a nicely crumbled soil, the forward speed at this operation was sometimes not more than 1 km h^{-1}. At potato harvest, which was not more troublesome than in both other systems, the ridges were lifted at about 2 cm below the ridge. The result was a sieved layer of about 10 cm loose, very fine crumbled soil which lay on a very compact subsoil. Drilling winter wheat in this 'seedbed' was very dangerous because of the liability of serious slaking. Therefore, it was thought wise to regain contact with the subsoil by means of shallow working with the fixed-tine cultivator.

In conclusion, no-tillage as practised here was 'pure' no-tillage with sugar beet and with spring barley, but with potatoes and winter wheat it was shallow tillage. In *System B2* 'pure' no-tillage was practised, because only non-root crops were grown.

During the first four-year period soil conditions at the main tillage operation, seedbed preparation and sowing were quite often far from ideal. Moreover, during the first two years the available tillage implements were not fully adapted to loose soil husbandry. Hence, it is not surprising that differences in *soil structure* between System A and System C were only small, even smaller than differences in soil structure between different years.

It is striking that the mean level of soil structure decreased steadily during the 4 years in Systems A and C. This was especially so after the extremely wet autumn of 1974 when soil conditions at harvest and subsequent main tillage operations were very bad. Therefore, it can be concluded that compacting actions dominated loosening actions during the first crop rotation, even in the loose-soil husbandry system.

Although the soil in System B1 was already quite compact in the first year, soil density still increased somewhat during subsequent years. Air content at a soil water pressure of −100 cm was clearly lower than on tilled soil but still higher than could be expected from soil density, because gravimetric water content at this pressure was also lower. From the measurements made, no final conclusion about soil aeration can be drawn, but the impression was gained that pore continuity was better on untilled soil than on tilled soil. As cone resistances are always very high in System B it can be expected that root growth is seriously hampered unless there are enough large continuous pores left.

Incorporating *fertilizers and plant debris* was accomplished best in the loose-soil husbandry system as here the soil is ploughed each year. Also in the rational tillage system the grass green manure and grain stubble were ploughed in without problems. After root crops the soil was fixed-tine cultivated and, therefore, the organic material was kept mainly in the top of the arable layer. Consequently, regrowth of beet tops in mild winters can be troublesome. Quite often there was slightly more grass weed in this system, but this could be destroyed easily by chemicals. The scanty occurrence of volunteer potatoes may be regarded as an important advantage of fixed-tine cultivating.

Unlike in Systems A and C, where no real problems were encountered, in System B the management of mulch and plant debris appeared to be a difficult problem. It has been observed that a too high amount or a too irregularly distributed mulch can impede emergence seriously. Sometimes the mulch interfered with the discs of the sowing-machine, so that the seed was placed in the wrong position and not covered properly with soil. Probably also toxic effects of decomposing organic material have occurred. Sometimes even a thin mulch layer clearly prevented soil slaking and safeguarded emergence and early crop growth. However, in dips pool formation and serious soil slaking occurred, particularly when there was little mulch. As a consequence, emergence and early crop growth sometimes was irregular and lagged behind.

Soil tillage increases the decomposition rate of organic matter and therefore, increases the availability to arable crops of the nutrients contained therein. Considering the small differences in soil structure and the nearly equal yields in Systems A and C, it is not surprising the differences in tillage systems applied have caused only minor differences in *nitrogen availability* between Systems A and C.

System B often needed a higher nitrogen fertilization for maximum yields. This result agrees with the fact that soil nitrogen availability in early spring was lower in System B than in Systems A and C. It is not clear to what extent this is caused by nitrogen fixation in fresh humus or denitrification by temporarily and more or less localized anaerobiosis. However, after four years the three tillage systems had broadly the same nitrogen availability, from which we may conclude that the fixation of nitrogen in fresh humus was only temporary.

Omitting soil tillage and in particular the turning action of the plough causes distinct accumulation of organic matter and nutrients in the top soil because all fertilizers, green manure crops and stubbles are left at or near the soil surface. However, this did not have negative consequences for the availability of nutrients other than nitrogen.

Also in Systems A and C normal chemical *weed control*, was applied. Therefore, the effect of tillage as a weed control measure could not be explicitly demonstrated. Still, on tilled soil less weeds were found than on untilled soil, where in particular Elytrigia repens was difficult to control. In general in System A somewhat fewer weeds, in particular Elytrigia repens, were observed than in System C, which points to the advantage of ploughing instead of fixed-tine cultivation. The possibility of applying new herbicides probably will diminish these differences.

The effect of tillage on the appearance of volunteer potatoes was striking. When the soil was ploughed every year (System A), there were many volunteer potato plants and they appeared even in the third crop after potatoes. When the soil was fixed-tine cultivated after potatoes and sugar beet (System C), there were clearly fewer volunteer potato plants in the winter wheat drilled after potatoes, and nearly none in subsequent years. In System B1 there were practically no volunteer potato plants.

In System B1 the presence of mulch on the surface of the untilled soil did not contribute positively to weed control On the contrary, the impression was gained that the mulch encouraged rather than suppressed the germination and emergence of weed seeds.

With cereals and seed grass, weed control was very successful on tilled as well as on untilled soil due to extra applications of herbicides. Also with potatoes there were no big problems, although it must be kept in mind that building up ridges is an effective weed control measure. On the sugar-beet plots mechanical weed control was necessary in all three tillage systems.

Apart from exceptional cases, the weed population in System B never reached the threshold value above which it can be expected to depress the yield by at least 3 %.

In accordance with the small differences in soil structure, differences in *crop yield* between Systems A and C were only small. On average crop yields in System C were slightly higher than in System A.

The clearly inferior structure of the untilled soil scarcely had negative consequences for the yield of winter wheat. Emergence and early growth of spring barley, however, was less favourable than on tilled soil. In spring the root system of winter wheat has already passed the compacted arable layer, whereas spring barley then only starts growing. Slower development of the root system in compacted soil can have adverse effects, especially in a dry spring. To obtain maximum yields spring barley on untilled soil needed higher amounts of nitrogen than on tilled soil. From the results of 1974 and 1975 the impression is gained that at optimal nitrogen dressings yields were probably much the same for all systems.

Once again it appeared that the fine sugar-beet seed is very demanding with respect to seedbed quality. Even loose-soil husbandry did not always satisfy these demands. In System B1 after emergence the growth of sugar beet was hampered by the very compact soil. Net yields of roots and sugar were clearly lower on untilled soil than on tilled soil. This was only partly due to fracturing of root tips in System B1.

The gross yield of potatoes was only slightly lower than on tilled soil. However, on average the percentage of deformed and green tubers was higher and, therefore, saleable yield was clearly lower.

Considering all data we can state that on this type of soil and in this climate there is no real perspective for abandoning tillage in a crop rotation with root crops. For a rotation with only non-root crops prospects are better.

10 General conclusions

W.A.P. Bakermans, F.R. Boone, L.M. Lumkes & C. van Ouwerkerk

1. Loose-soil husbandry as practised here (System A) did not give the intended better seedbed quality or a better soil structure and, consequently, did not perform better with respect to crop growth and yield than the rational tillage (System C). Therefore, System A, which is more complex and requires more sophisticated and expensive machinery, seems less attractive than System C.

2. No-tillage with root crops (System B1) produced for these crops a too dense soil. Within the range of perennial nitrogen levels, on average, saleable yield of potatoes was 9 % lower, and sugar yield 21 % lower than in System C. For winter wheat no-tillage gave good results, although when this crop is grown after potatoes it may be a risky system. With spring barley yields were not fully satisfactory at lower nitrogen levels, but at the highest nitrogen fertilization level tested the yield depression was only small. This tendency was also observed with potatoes.

3. No-tillage without root crops (System B2) gave about the same soil bulk density and for winter wheat and spring barley about the same yields as System B1. Perennial rye grass gave good results, whereas winter rape suffered from game damage.

4. Within the range of perennial nitrogen levels, for sugar beet, potatoes and winter wheat extending only from −20 % to +20 % and for spring barley from −44 % to +44 % of the amounts usually applied in practice, cumulative nitrogen effects on crop growth and yield were not found.

5. Full-scale nitrogen response curves including no nitrogen indicate that to obtain maximum yields, System C needs only slightly more and Systems B1 and B2 clearly more nitrogen than System A.

6. Pore space in the tilled soil was quite variable between years, caused by different soil conditions at the time of harvesting and of the main tillage operation, seed bed preparation and sowing. With no-tillage soil bulk density increased in the second year but after three years the soil was not further compacted. Cone resistance of non-tilled soil was much higher, whereas pore continuity probably was better than on tilled soil

7. In the beginning of the experiment nitrogen availability in early spring was lower on untilled soil, but after four years differences in nitrogen availability between tillage systems had disappeared.

8. Although in System A somewhat fewer and in Systems B1 and B2 clearly more annual weeds appeared than in System C, chemical weed control was in general successful in all systems, except for sugar beet. The control of perennial weeds, in particular of Elytrigia repens, however, was more difficult in Systems B1 and B2.

9. Generally, no differences were found in incidence of diseases and pests in the different tillage systems.

10. The management of green manure crops and mulch frequently caused difficulties in the no-tillage system. Too much or too irregularly distributed, undecomposed organic materials sometimes hampered germination and early crop growth.

Summary

To study the loosening and compacting effects of soil tillage and their influence on crop growth, three soil tillage systems were compared during 1972–1975 on a marine loam soil (22% clay) at Westmaas Experimental Husbandry Farm.

The three tillage systems were characterized as follows:

- Loose-soil husbandry (System A). The aim was to produce and maintain a looser soil than normally found in agriculture. The main tillage treatment for all crops was ploughing and care was taken to preserve the loosening effect by minimizing the number of passes for fertilization, seedbed preparation and drilling.
- No-tillage (System B) which resulted in a very compact soil. Soil tillage was only applied for planting and ridging potatoes and harvesting root crops (System B1) or was totally omitted in an alternative four-year rotation with non-root crops only: seed grass – winter wheat – oil seed rape – spring barley + undersown grass (System B2).
- Rational tillage (System C) in which the efficiency of soil tillage was increased by restricting tillage to ploughing for root crops and to fixed-tine cultivation for cereals.

The main crop rotation (Systems A, B1 and C) was potatoes – winter wheat + undersown grass – sugar beet – spring barley + undersown grass. The grass as green manure, and tops and leaves of sugar beet and chopped straw, were incorporated in the soil (Systems A and C) or, after treatment with herbicides, left on the surface as a mulch (Systems B1 and B2).

To study the extent to which crop response is affected by tillage-induced changes in nitrogen availability in each of the four main crops five equidistant 'annual' nitrogen levels were established, ranging from 0 to 200% of the amounts applied in practice. There were also three 'perennial' nitrogen levels, consisting of amounts equal to 80, 100 and 120 % of the amounts applied in practice to these crops. In all tillage systems the same amounts of phosphate and potassium were applied each autumn before the main tillage operation.

In all three systems weeds, diseases and pests were controlled by normal chemical means, except in the no-tillage system where one or more extra herbicide treatments were necessary.

In all systems soil structure varied significantly between the four years of experimentation because of differences in soil conditions at harvest and at the time subsequent parts of the tillage system were applied. Differences in soil structure between Systems A and C were only small. Soil tillage (Systems A and C) created a

mean pore space of about 45% (v/v), corresponding to an air content at pF 2.0 of about 10% (v/v). No-tillage (system B) resulted in a pore space of about 40% (v/v) and an air content at pF 2.0 of about 6% (v/v). Penetration resistance on tilled soil never exceeded 2.5 MPa, whereas on non-tilled soil it was always higher than 2.5 MPa.

Because differences in soil structure between Systems A and C were small, differences in the amounts of mineral nitrogen were also small. At the beginning of the experiment less mineral nitrogen was present in System B1, but after four years the amount of mineral nitrogen in this system was about equal to that in Systems A and C. Ploughing gave a more homogeneous distribution of the mineral nitrogen throughout the soil profile than fixed-tine cultivating. No-tillage caused mineral nitrogen to accumulate in the topsoil.

In agreement with the small differences in soil structure and the amount of mineral nitrogen, average crop yield of the four main crops within the range of perennial nitrogen levels were only slightly different for Systems A and C. However, with this nitrogen fertilization no-tillage with root crops (System B1) produced only 87.5% of the yield obtained in System C. System B1 seemed less suitable for potato growing. Although gross yield was about the same, saleable yield of tubers was only 91% of the yield obtained in System C. Winter wheat was least affected by the differences between the three systems. Fixed-tine cultivation seemed attractive for winter wheat because it produced an acceptable seedbed and controlled ground keepers of potatoes by exposing them to frost action. Because of the lower quality of the seedbed, yield of sugar beet was slightly less in System A than in System C. Because of the compact soil in System B1, yields of roots and sugar within the range of perennial nitrogen levels were only 83% and 79%, respectively, of those in system C. Spring barley yielded 6% more in system A than in System C. Within the perennial nitrogen levels Systems B1 and B2 yielded only 83% and 88% respectively, of System C.

Full-scale nitrogen curves (0N included) based on annual nitrogen levels suggest that under System C winter wheat and spring barley need about the same amount of nitrogen as under System A, whereas sugar beet and potatoes under System C need only slightly more nitrogen to obtain maximum yield. In Systems B1 and B2, more nitrogen was needed, especially for spring barley to obtain maximum yield. Although System B was more risky than Systems A and C it appears that, provided the nitrogen fertilization is adequate, in all systems the same yield (winter wheat) or about the same yield (spring barley and potatoes) can be obtained. Besides cereals, grass for seed and probably oil seed rape seemed well suited for no-tillage systems. Sugar beet responsed to nitrogen in System B1 similar to Systems A and C, but maximum yield was much lower.

Although more annual weeds grew in Systems B1 and B2, and less in System A than in System C, chemical control was generally successful in all systems except for sugar beet. Despite the more intensive chemical control on no-tillage, more failures occurred than on the tilled soil. Perennial weeds like couch grass (*Elytrigia repens*) were especially difficult to control.

Because the same intensive control of diseases and pests was applied, few if any differences were found in the incidence of diseases and pests between tillage systems.

The management of crops for green manure and plant residues left on the field did not pose any problems on the tilled plots. In the no-tillage system too much, or irregularly distributed, undecomposed organic material sometimes prevented proper drilling and thus hampered germination and early growth. When the amount of mulch was insufficient, severe slaking occurred, sometimes causing crop failure.

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