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Phosphorus and nitrogen uptake of spring cereals in different tillage systems

Alakukku, L.
MTT Agrifood Research Finland, E-House, FI-31600 Jokioinen
Present address: University of Helsinki, Department of Agrotechnology, P.O. Box 28, FI-00014 University of Helsinki, Finland Tel. +358919158682, Fax.+358919158491, E-mail: laura.alakukku@helsinki.fi

Abstract
The conventional Finnish tillage system for spring cereals involves mouldboard ploughing. Currently, farmers have been increasingly interested in conservation tillage systems e.g. stubble cultivation and direct drilling (zero tillage). In this study, the effects of reduced tillage intensity on the yield of spring cereals (barley (*Hordeum vulgare*) and oats (*Avena sativa*)), and the phosphorus (P) and nitrogen (N) uptake of crop were examined on two field experiments on clay soils. The objective of the study was to investigate the yield quantity and nutrient use efficiency of spring cereals when the tillage intensity of clayey soil was reduced. In the present paper, the results of the first 4 to 5 experimental years (transition period) are discussed.

Field experiments were conducted on a clay soil (Vertic Cambisol, in 2000), and a clay loam soil (Eutric Cambisol, in 2001) at Jokioinen in southwestern Finland. In the layer of 0-20 cm, the mean clay (< 0.002 mm) content was 0.62 g g^{-1} and 46 g g^{-1} for clay and clay loam soils, respectively. The experiments were laid out in randomized complete-block design with four replicates. The treatments were: (PA) autumn ploughing to 20-25 cm depth and combined rotary harrowing and combi drilling in spring; (SA) stubble cultivation (10-15 cm) and spring tillage and sowing as in PA, and (NC) zero tillage in autumn and in spring sowing with a direct drill (seed and fertilizer placed in the same row). The grain yield, and the P and N content of grain were determined annually. The P and N yield harvested in grain yield was calculated.

On the clay soil, the mean grain yield of stubble cultivated and direct drilled treatments was 3 and 18% less, respectively, than that of ploughed treatment. The relative reductions in P and N uptake were the same magnitude than the grain yield reductions.

On the clay loam soil, the differences in yields and crop nutrient uptake between treatments were clearly less than on the clay soil. The mean grain yields of ploughed, stubble cultivated and direct drilled treatments were 4490, 4410 and 4330 kg ha^{-1}, respectively. On direct drilled plots the P uptake was 10% and the N uptake 8% less than in ploughed plots. The present results originated, however, from a ‘transition’ period to direct drilling. More experimental years are needed to evaluate the long-term effects of direct drilling on grain yield and nutrient uptake.

Keywords: Ploughing; Stubble cultivation; Direct drilling; Yield; Barley; Oats

1. Introduction
In Finland, the conventional tillage system for spring cereals involves mouldboard ploughing. Recently, farmers have been increasingly interested in conservation tillage systems. The increasing adoption of conservation tillage systems follows the high cost

of fuel and labour with conventional tillage. Likewise, the advances in herbicide technology (and reduced price of glyphosate) and improvements in tillage implements and drilling machines have made it possible to control weeds and manage crop residue without intensive tillage. For environmental point of view it is important that conservation tillage practises are known to be advantageous in respect of erosion control (e.g. Puustinen et al., 2005).

In Scandinavia, the mouldboard ploughing is usually replaced by chisel or disc implements. Both have been found to be potential conservation tillage methods for spring cereals on clay, silty clay and clay loam soils in humid climate (Rydberg, 1987; Børresen, 1993; Comia et al., 1994; Pitkänen, 1994; Aura, 1999; Heinonen et al., 2002). At present, the farmers are, however, more and more interested in zero tillage. In 2005, the zero and reduced tillage areas were about 110 000 and 270 000 ha, respectively (8.4 and 20.7% of cultivated area of spring cereals and oilseed crops in Finland).

In Nordic countries, several conservation tillage studies focused on grain yield have been published (Rydberg, 1987; Børresen, 1993; Comia et al., 1994; Pitkänen, 1994; Ekeberg and Riley, 1997; Aura, 1999; Heinonen et al., 2002; Pietola and Tanni, 2003). There is, however, little information on the effects of conservation tillage on the nutrient uptake and nutrient use efficiency of spring cereals in boreal conditions. In the present study, the effects of stubble cultivation and direct drilling on the grain yield and nutrient yield harvested in grain yield of spring cereals were compared to autumn mouldboard ploughing on two field experiments on clay soils. The objective was to investigate the nitrogen and phosphorus uptake of cereals when the tillage intensity was reduced. This information is needed when assessing the impact of the tillage methods on the nutrient balance of spring cereals, and the risk of nutrient leaching and greenhouse gas emissions from arable fields. In this paper, the results of the first 4-5 experimental years (transition period) are discussed.

2. Materials and methods

Field experiments were conducted on a clay soil (Vertic Cambisol (FAO 1988), in 2000), and a clay loam soil (Eutric Cambisol (FAO 1988), in 2001) at Jokioinen (60°49'N, 23°28'E) in southwestern Finland. The characteristics of the experimental soils are given in Table 1.

The field experiments were laid out in a randomized complete-block design with four replicates. The treatments were: (PA) autumn ploughing to 0.20-0.25 m depth and combined rotary harrowing and drilling (one pass method, combined drill: seed and fertilizer placed at the same time in separate rows in spring, (SA) autumn stubble cultivation to 0.10-0.15 m depth and seedbed preparation and sowing like in PA, and (NC) zero tillage in autumn and drilling with direct drill, seed and fertilizer placed in the same row, in spring. On the clay soil, the plot area was 6×40 m^2 and on the clay loam it was 10×25 m^2.

On both field experiments, the crop was spring barley (*Hordeum vulgare*, variety Inari (in 2000) and Saana (2001, 2002, 2004)) or oats (*Avena sativa*, variety Roope in 2003). The target seed rate was 500 viable seeds per square meter (Table 2). The nitrogen fertilization rate was 90-100 kg N ha^{-1} as NPK-fertilizer. The same combined drill was used in autumn tilled plots (PA, SA) and the no-till plots were sown with a special direct drill. In no-till plots, the N and P fertilizer rates were 9 and 6-9% greater, respectively, than in autumn tilled plots (Table 2). The spacing of seed rows was 140 mm for direct drill and otherwise 125 mm. Except for direct drill, the fertilizer was placed between every second crop row.

Table 1. Average soil organic carbon and easily soluble phosphorus content, pH and particle size distribution. The values are means of 4 measurements.

Depth (cm)	Soil organic carbon ($g\ g^{-1}$)	$pH_{water(1:2.5)}$	P_{AAC} [1] ($mg\ l^{-1}$ soil)	Particle size distribution ($g\ g^{-1}$) Clay < 0.002	Silt 0.002-0.02	Sand > 0.02 mm
	Clay soil field Vertic Cambisol (FAO 1988)					
0-20	0.027	6.19	18	0.617	0.190	0.193
20-40	0.010			0.808	0.113	0.079
	Clay loam field Eutric Cambisol (FAO 1988)					
0-20	0.025	6.24	21	0.461	0.287	0.252
20-40	0.012			0.547	0.271	0.182

[1] The easily soluble P was determined by a method used in the routine advisory soil test in Finland (ammonium acetate, pH 4.65; Vuorinen and Mäkitie, 1955).

In spring, the sowing time was decided based on the drying of the soil. In 2000-2002, the treatments were sown in the same day (Table 2). It was possible to wait the drying of the no-till plots, since the autumn tilled plots were levelled by a harrow 2 to 10 days before drilling to reduce evaporation. In 2003 and 2004, the autumn tilled plots were sown 7 to 21 days earlier than direct drilled plots (Table 2). In those years, the spring was rainy and the no-till plots dried very slowly after showers. Except tillage and drilling, field operations were carried out following the common farming practice in Finland.

An area of 43 to 63 (clay) or 27 to 38 (clay loam) m^2 was harvested from each plot and the dry matter content of grain was determined by drying a subsample of 40 g at 105ºC overnight. The nitrogen content of the dry matter was measured by Kjeldahl method using a Kjeltec Auto 1030 Analyzer (AOAC methods, 1980). For phosphorus determination the dried grains were ashed at 450 °C and dissolved with 100 ml 0.2 M HCl. Phosphorus was determined colorimetrically with modified ammonium-vanadate-molybdate method (Gericke and Kurmies, 1952). The nitrogen and phosphorus content values were adjusted to give the grain harvested nitrogen and phosphorus yields.

Table 2. Sowing date, and annual nitrogen (N) and phosphorus (P) fertilizer and seed rate during the experimental period. In 2003, the crop was spring oats and in other years barley.

	Sowing date (Day/Month)						Fertilization				Seed rate	
	Clay soil			Clay loam			N ($kg\ ha^{-1}$)		P ($kg\ ha^{-1}$)		($kg\ ha^{-1}$)	
Year	PA	SA	NC	PA	SA	NC	PA, SA	NC	PA, SA	NC	PA, SA	NC
2000	Same day for all			-	-	-	93	101	19	20	254	276
2001		10/5			9/5		104	113	21	23	250	271
2002		2/5			26/4		93	101	14	15	292	316
2003	28/5	28/5	4/6	22/5	13/5	4/6	114	124	17	19	189	205
2004	3/5	3/5	17/5	10/5	10/5	12/5	93	101	14	15	274	297

PA, autumn ploughing, seedbed preparation and sowing in spring
SA, autumn stubble cultivation, seedbed preparation and sowing in spring
NC, no tillage in autumn, direct drilling in spring

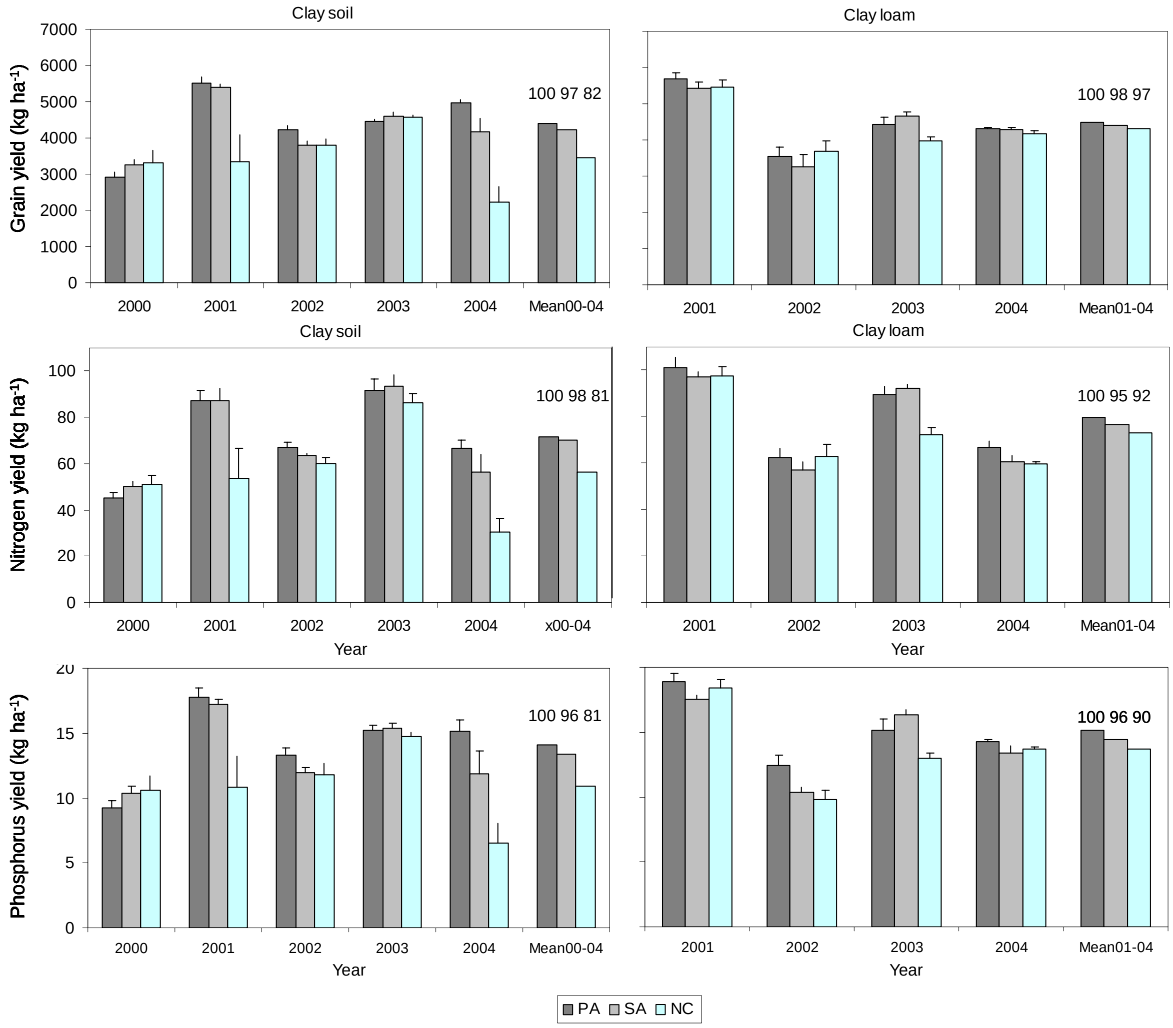

Fig. 1. Grain (at 14 g 100g-1), and in grain harvested nitrogen and phosphorus (dry matter) yields during the first 4-5 years after changing the autumn tillage from ploughing (PA) to stubble cultivation (SA) or no-till (NC) in field experiments on clay and clay loam soils. Mean yields relative autumn ploughing are also shown. Except year 2003, when oats was grown, the crop was barley. On the clay soil in 2001, there was a failure in drilling since the NC plots were sown too deep. The vertical line immediately above the bar indicates on standard error of mean.

3. Results and discussion

Figure 1 shows the yield results of the first 4-5 experimental years. On both fields the average grain, nitrogen and phosphorus yields were greater in autumn tilled plots than in zero-tilled plots. On clay loam field, the mean differences between treatments were, however, less than on the clay soil field. On the clay soil field, as an average of five years, the grain, nitrogen and phosphorus yields were 18-19% less in zero tilled treatment than in ploughed treatment (Fig. 1). In 2001 and 2004, the relative differences between treatments were greater than in other years. In 2001, the direct drilling depth was clearly too deep and sparse sprouting of zero tilled treatment NC was probably one reason for the low yield compared to the other treatments. In 2004, the growing season was extremely rainy. The precipitation sum for May–August was 349 mm compared to the average of years 1970-2000 252 mm. In the spring, the no-till soil stayed wet which delayed the sowing (Table 2). Moreover, during the growing period soil wetness hampered crop growth reducing the yield and nutrient uptake. This was in agreement with the results of earlier Finnish studies in which conservation tillage was found to reduce the grain and nitrogen yield of spring cereals in rainy growing seasons (Pitkänen, 1994 (grain); Aura, 1999; Heinonen et al., 2002; Pietola and Tanni, 2003).

On the clay loam soil, zero tillage decreased the average nitrogen and phosphorus yield relatively more than grain yield, because both grain yield per hectare and N and P content of the grain were less in direct drilled plots than in ploughed plots (Fig. 1). On the clay soil field, the tillage intensity did, however, not affect markedly on N and P content. In direct drilled plots, the efficiency of crop fertilizer use (N or P amount harvested in grain yield divided by the N or P amount applied in fertilizer) was clearly less than in autumn tilled plots. During the experimental period, the N and P yield harvested in grain yield was 52-66% and 61-76%, respectively, of the N and P given in fertilizer. In autumn tilled plots the N uptake of crop was 71-79% and P uptake 83-92% of the N and P amount applied in fertilizer, respectively. However, because the fertilizer was not labelled, the results do not show how much the compaction reduced the uptake of N and P given in fertilizer.

The reduction of tillage intensity can act upon the nutrient uptake in different ways. After sowing, the zero tilled soil warmed probably slower than tilled soil. The structure of no tilled soil is often denser than tilled soil, which can slower the root growth. Likewise, the reduction of tillage intensity can also affect the nutrient reactions in the soil by reducing the mobilization of nitrogen from soil organic matter and increasing the denitrification especially in wet soil conditions. The reasons for the reductions in nutrient uptake are, however, not evident from the present data.

The results showed that zero tillage affected the grain yield and nitrogen and phosphorus yield harvested in grain. The present results originated, however, from a ‘transition’ period to zero tillage. More experimental years are needed to evaluate the long-term effects of zero tillage on grain yield and nutrient uptake.

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