

Improving Soil Structure and Nitrogen Use Efficiency by GPS-controlled Precision Tillage Technology in Organic Farming

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Key words: soil structure, GPS-controlled traffic systems, nitrogen use efficiency.

Abstract

A field experiment was conducted to determine the effects of tillage technique (GPS-controlled traffic system and traditional tillage) and level of fertilization (farmers' practice or phosphate equilibrium) on yield, soil structure and nitrogen use efficiency. Manure inputs could be seriously reduced without yields being diminished during the first three years of the intensive crop rotation. Results suggest that an improved soil structure under GPS-controlled precision tillage enhances nitrogen use efficiency.

Introduction

Organic agriculture should play a leading role and set an example for sustainable soil management. This implies greater nutrient use efficiency and fewer inputs. GPS-controlled precision tillage using the same traffic lanes every year offers the opportunity to improve soil structure (Vermeulen & Klooster, 1992). Our hypothesis is that the improved soil structure of the beds will provide better aeration and rooting for the crop and access to necessary nutrients. This would mean that nitrogen use efficiency would improve in GPS-controlled precision tillage systems. In this study we evaluate the effects of a GPS-controlled precision tillage system using permanent traffic lanes in combination with low manure input on soil structure, nitrogen use efficiency and crop yield in an intensive crop rotation.

Materials and methods

During a period of four years on site field experiments were conducted at an organic vegetable farm in Langeweg (N. Br), the Netherlands (4° 38' East, 51° 39' North). The soil of the experimental field was characterized as clay loam (2.6% organic matter, 23% clay, pH-KCL 7.4). In 2003 the experiment was set up with two tillage treatments (GPS-precision and Traditional) and two fertilization treatments (Farmer's practice (FP) and Phosphate Equilibrium (PE), defined as P₂O₅ removed at harvest = P₂O₅ input with manure) in a split-plot arrangement (Tab. 1). The experimental design was a randomised complete block with four replications and 6,3 m x 25 m plot size. In each experimental year one crop was studied, following the intensive vegetable rotation of the farm: spinach (2003), carrot (2004), potato (2005) and grass seed (2006). During each growing season, soil structure was determined visually. Soil structure was rated as a percentage of crumbly and angular structures at a relevant depth, using a modified method according to Shepherd (2000) as described in Koopmans & Brands (1993). Nitrogen use efficiency was calculated in 2004 (spinach) and in 2006 (potato) as the N-application rate with fertilization divided by the total N amount taken up by

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the leaves and tubers, excluding roots. The data were analyzed by analysis of variance (ANOVA) using tillage treatment as main plots and fertilization levels as subplots. Significant effects were separated by the least significant difference (LSD) at $P = 0,05$.

Tab. 1: Tillage and fertilization treatments of the field experiment in Langeweg

Tillage system	Fertilizer application	N	P ₂ O ₅	K ₂ O
		Kg ha ⁻¹ year ⁻¹		
Traditional	Farmer's practice (FP)	128	53	150
Traditional	Phosphate equilibrium (PE)	62	26	72
GPS precision	Farmer's practice (FP)	128	53	150
GPS precision	Phosphate equilibrium (PE)	62	26	72

Results

In the first year, significant ($P < 0.05$) higher yields were obtained in spinach using GPS-precision techniques (Fig.1).

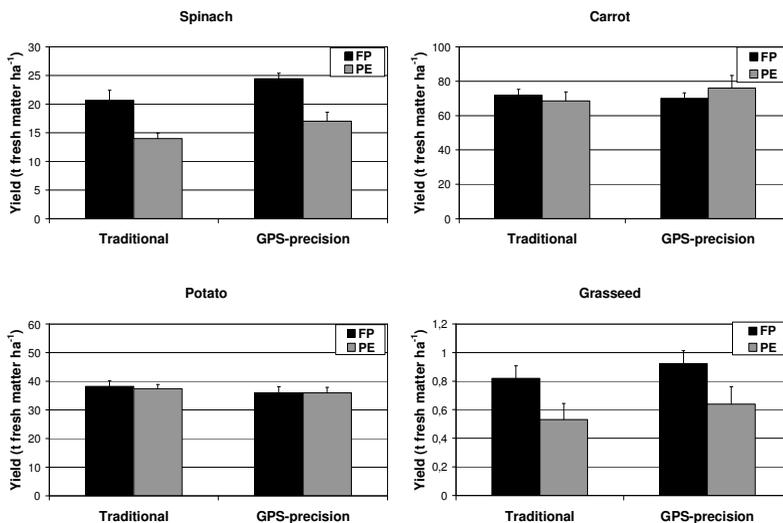


Figure 1: Yields of spinach (2004), carrot (2005), potato (2006) and grass seed (2007) in management practices Traditional (FP and PE) and GPS-precision (FP and PE). Errorbars indicate standard error of the mean (SE).

In spinach (2004) yields at FP fertilization level were significantly higher ($P < 0.001$) than yields at PE fertilization level. Interestingly there was no significant difference between yields in plots with GPS-precision techniques with PE fertilization level and traditional tillage with FP fertilization level, indicating a higher nutrient availability in GPS-precision plots. In carrots (2005) and potatoes (2006) no significant differences between treatments were observed. Grass seed yield (2007) in the PE fertilization treatment significantly diminished ($P < 0.001$) compared to the FP treatment. No effect of tillage strategy was observed. Results in grass seed confirmed the earlier observation in spinach in which there was no yield difference between GPS-precision tillage at PE fertilization level and traditional tillage at FP fertilization level.

Soil quality

Visual determination of soil structure clearly showed the effect of GPS-precision tillage on soil quality in 2004 and 2007. The percentage of angular elements at 0-15 depth in spinach and at 0-10 cm depth in grass seed was significantly higher ($P = 0.02$) using traditional tillage as compared to GPS precision tillage (Tab.2). In carrots no angular elements were found. The percentage of crumble elements in the ridges was significantly higher using precision tillage. In potato, after traditional harvest of the carrots under suboptimal soil conditions, soil structure was diminished in all treatments and soil clods in all plots were characterized as 100% angular elements.

Tab. 2 Percentage of angular soil elements per soil layer per year. Values are mean, n=4.

	Angular elements (%)			
	0-10 cm depth	0-20 cm depth	0-20 cm depth	0-10 cm depth
	Spinach	Carrot	Potato	Grass seed
	2004	2005	2006	2007
Traditional				
FP	31	0	100	43
PE	38	0	100	45
GPS precision				
FP	6	0	100	19
PE	2	0	100	6
Tillage system	*	NS	NS	*
Fertilization	NS	NS	NS	NS

* Indicate significance at $P \leq 0.05$.

Nitrogen use efficiency

In the first year of the experiment nitrogen use efficiency of spinach was significantly higher ($P < 0.001$) with PE fertilisation (87%) as compared to FP fertilisation (44%). Two years later, in 2006, similar results of nitrogen use efficiency were found in potato. Nitrogen use efficiency was significantly higher ($P = 0.006$) with PE fertilisation (255%) as compared to FP fertilisation (145%). However, there was no difference in

yield of potatoes grown with PE fertilisation and yield of potatoes grown with FP fertilisation.

Discussion

The results of this study support the hypothesis that tillage techniques using GPS-precision can enhance soil structure, resulting in lower manure input needs and higher nitrogen use efficiency. Lowering the amount of fertilizer towards phosphate equilibrium, meant that nitrogen input was seriously reduced. Strikingly, this reduction had no significant effect on yield reduction of spinach, carrot and potato. Visual determination of soil structure showed the negative effects of traditional tillage on subsoil structure which is in agreement with earlier studies on the effects of subsoil compaction (Van den Akker and Schjønning, 2004). Furthermore, in 2005 and 2006 it showed the negative effects of conventional harvest under suboptimal conditions of the soil. If carrots and potatoes had been harvested by using traffic lanes, there would have been less soil compaction and this could have resulted into higher yields and N utilization coefficients of the crops. The higher nitrogen use efficiency at lower fertilisation levels stretches the possibilities for reducing inputs in organic agriculture.

Conclusions

The study shows that manure inputs could be reduced to phosphate equilibrium without lowering yields in three out of four years of an intensive crop rotation on a clay loam soil in the Netherlands. Our results in spinach and potato suggest a higher nitrogen use efficiency due to a better soil structure after GPS-precision tillage. The results also make clear that this promising new technology only can improve soil structure and result in higher yields on the long term, when all tillage is done from the same traffic lanes, including harvest.

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