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Winter wheat yields in a long-term tillage experiment under Pannonian climate conditions

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ABSTRACT

Long-term field experiments are important for assessing the yield response of crops to different tillage systems and pre-crops. An experiment was established in 1996 in Raasdorf (Austria) on a chernozem with four tillage treatments (mouldboard ploughing (MP), no-till (NT), deep conservation tillage and shallow conservation tillage) and two crop rotations. Winter wheat yields were generally at similar levels with all four tillage systems in most years between 1998 and 2012. Yields increased with higher amounts of rainfall during the vegetation period (from October until June) with the smallest increase among tillage treatments in NT. This indicates that MP can be superior to NT regarding yield at higher amounts of rainfall. Pre-crops considerably influenced winter wheat with higher yields after maize, soybean and winter wheat than after sugar beet. In one year with high rainfall, a tillage × pre-crop interaction showed that yields were lower after maize in NT than in other tillage systems whereas yields after sugar beet tended to be higher with NT in years with low rainfall.

Keywords: *Triticum aestivum* L.; soil tillage; pre-crop; drought

Tillage systems are generally categorized in conventional tillage using a mouldboard plough (MP), conservation tillage (CT) using chisel plow, disk plow, harrow disk or cultivators, and no-till systems (NT) using direct drilling in untilled soil. There is increasing worldwide interest in soil conservation systems due to their economic and environmental benefits. Economic benefits of no-till systems may arise from lower drought susceptibility due to higher plant-available soil water content, resulting in more stable yields and savings of labor and fuel. Ecological benefits include an increase of soil organic carbon, biotic activity, soil porosity, agroecological diversity, less soil erosion and lower carbon emissions (due to less fuel consumption) (Derpsch et al. 2010). No-till establishment of wheat (using a direct drilling machine with disc coulters) on a silty loam chernozem could reduce fuel consumption and work time by more than 85% compared to conventional tillage (i.e. using a heavy cultivator for stubble cultivation and a mouldboard plough) and subsequent seeding (using a power harrow and a seeding machine) (Moitzi et al. 2013).

Soil tillage influences soil chemical characteristics and nutrient distribution (e.g. of phosphorus and potassium) in the soil (Neugschwandtner et al. 2014) and soil physical characteristics like bulk density, pore volume and pore size distribution, infiltration, soil water supply, aggregate stability and penetration resistance (Liebhard 1994, Liebhard et al. 1994, 1995). Residues on the soil surface play an important role in soil water conservation in NT (Lampurlanés and Cantero-Martínez 2006). A disadvantage of no-till is higher weed infestation compared with plowing (Gruber et al. 2012).

Crop yields in NT were observed to be within five percent of those obtained by MP in experiments from several European countries (Soane et al. 2012) with soil, crop and weather factors

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exerting important influences. Yield with NT tends to exceed that of MP as rainfall decreases from northern to southwestern Europe. For winter wheat (*Triticum aestivum* L.) (WW) yields, contrasting results have been reported for yields of tillage systems with additional factors such as crop rotation, fertilization (López-Bellido et al. 1996, Rieger et al. 2008) and climatic conditions influencing the relation. WW yields under temperate conditions in Austria (Liebhard 1995) and south-western Germany (Gruber et al. 2012) were lower in NT than in MP mainly due to impaired crop emergence. Under cool and humid conditions in Switzerland, no yield differences of WW between tillage systems were reported by Anken et al. (2004), whereas Rieger et al. (2008) observed slightly lower WW yields with NT than with CT and MP, mainly due to a lower ear density and a lower thousand-kernel weight (Rieger et al. 2008). In Mediterranean dryland conditions of Spain and Italy, variability of tillage effects due to climatic conditions was observed with higher WW yields with NT when drought stress occurred and higher yields with MP when water availability was adequate (López-Bellido et al. 1996, De Vita et al. 2007, Amato et al. 2013).

The aim of the present study was to assess the influence of four soil tillage systems, sometimes after different pre-crops, on winter wheat yields in a long-term field experiment under Pannonian climate conditions on a chernozem in eastern Austria.

MATERIAL AND METHODS

Experimental site. The long-term experiment is carried out at the experimental farm of the BOKU University in Raasdorf (48°14'N, 16°33'E; 153 m a.s.l.). The field is located east of Vienna, Austria, on the edge of the Marchfeld plain, which is an important crop production region in the north-western part of the Pannonian Basin. The silty loam soil is classified as a chernozem of alluvial origin and is rich in calcareous sediments (pH_{CaCl_2}: 7.6, soil organic carbon: 2.3%). The mean annual temperature is 10.6°C, the mean annual rainfall is 538 mm (1980–2009). Long-term rainfall pattern shows most rainfall from May to September with monthly values above 55 mm with the highest amount in June (72 mm). Long-term average temperature and rainfall during the vegetation period of WW (from October until June) were 7.7°C and 362 mm (1980–2009).

Experimental design. The experiment was established in August 1996 in a split-plot design with four replications and involves two factors: tillage system is assigned to the main plots (24 × 40 m) and crop rotation to the subplots (12 × 40 m). Crop-specific fertilization is performed according to good agricultural practice. The tillage treatments include: (1) mouldboard ploughing after harvest to a soil depth of 25–30 cm. The crumbled and loosened soil is turned over and thereby residues are fully incorporated into the soil. (2) No-till: Direct drilling in untilled soil with a disc drill without previous removal of residues. A non-selective herbicide is sprayed before sowing for weed control. (3) Deep conservation tillage (CTd) to a soil depth of 20–25 cm using a wing share cultivator. (4) Shallow conservation tillage (CTs) to a soil depth of 8–10 cm using a wing share cultivator. Two flexible crop rotations are performed on sub-plots with sugar beet (*Beta vulgaris* L.) or maize (*Zea mays* L.) as central crops. Both rotations frequently included winter wheat.

Experimental conditions and treatments. Sowing, plant protection, fertilization and harvest were performed with regular farm machinery. Wheat was sown in mid-October (between 12^{th} and 24^{th}) with 320 germinable seeds/m^2. The following winter wheat cultivars were used: Capo (1998), Josef (2000–2009) and Astardo (2010–2012). Weed control was generally performed with herbicides in mid-April on all plots and on NT plots additionally with non-selective herbicides for weed control before sowing. The nitrogen fertilizer calcium ammonium nitrate (CAN, 27% N) was applied at a total of 120–130 kg N/ha. Combine harvest was performed in July (between 5^{th} and 26^{th}).

Statistical analysis. Statistical analyses were applied using SAS version 9.2 (SAS Institute, Cary, USA). Analysis of variance (PROC GLM) was calculated and means were separated by the least significant differences (*LSD*) when the *F*-test indicated factorial effects at $P < 0.05$. Wheat yields after different pre-crops were analyzed separately for factors soil tillage and year. When winter wheat was grown in both rotations in the same year, the effects of different pre-crops on WW yields were additionally assessed. The effect of rainfall on grain yield with different tillage

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across all experimental years was quantified by linear regression analysis.

RESULTS AND DISCUSSION

Winter wheat yields after different crops. WW was grown twice after oilseed rape (*Brassica napus* L.) and after cereals and once after sunflower (*Helianthus annuus* L.) and soybean (*Glycine max* (L.) Merr.) with no tillage effects on WW yields. WW was grown six times after maize and four times after sugar beet with large yield variations between the years ranging from 3.62–5.94 t/ha after maize and from 1.30–5.03 t/ha after sugar beet (means over tillage treatments) (Table 1). There was a significant tillage × year interaction for WW grown after maize and sugar beet. WW yields after maize were significantly lower with NT compared to MP, CTd and CTs in 2004 and 2006 and compared to MP in 2010. These years showed average (2006) to high rainfall (2004, 2010). No significant differences between tillage systems occurred in 1998, 2008 and 2009 (when WW yields were always slightly higher in NT than in MP). In these years rainfall was low (1998) or above average (2008, 2009) (Figure 1a). WW yields after sugar beet were higher in NT than in MP and CTd in the dry year of 1998. In 2002, CTs yielded significantly less than MP and CTd (with NT showing an intermediate value). WW yields in the dry season of 2011 were higher with CTs than with NT; NT yielded slightly less than MP (ns – not significant) (Figure 1b).

Yields of WW after all pre-crops are plotted against rainfall in Figure 2. Yields increased with higher amounts of rainfall during the vegetation period (from October until June) with a steeper increase in MP, CTd and CTs than in NT. Lines

Table 1. Winter wheat (t/ha) yields as affected by tillage system (mouldboard ploughing (MP); no-till (NT); deep (CTd) and shallow conservation tillage (CTs)), years and pre-crops

		Pre-crop						Temperature (°C)	Rainfall (mm)
		maize	sugar beet	oilseed rape	cereals[1]	sunflower	soybean	October–June	
Tillage	MP	4.66^{a}	3.21	4.51	3.04	2.85	4.23		
	NT	4.19^{b}	3.39	4.80	3.45	3.70	3.61	mean (1980–2009)	
	CTd	4.84^{a}	3.24	4.99	3.36	3.07	4.23	7.7	362
	CTs	4.78^{a}	3.26	4.96	3.36	2.94	4.68		
Year	1998	3.65^{d}	3.17^{c}	–	–	–	–	8.6	264
	2000	–	–	3.40^{b}	–	3.14	–	8.7	300
	2002	–	3.72^{b}	–	–	–	4.24	8.8	350
	2004	5.94^{a}	–	6.23^{a}	–	–	–	7.5	455
	2006	3.62^{d}	–	–	–	–	–	6.9	373
	2007	–	–	–	3.87^{a}	–	–	10.6	314
	2008	5.10^{b}	–	–	–	–	–	8.5	478
	2009	5.18^{b}	–	–	–	–	–	8.6	415
	2010	4.21^{c}	–	–	–	–	–	7.8	407
	2011	–	5.03^{a}	–	–	–	–	7.9	274
	2012	–	1.30^{d}	–	2.74^{b}	–	–	8.6	221
ANOVA results	tillage (T)	**							
	year (Y)	***	***	***	***				
	T × Y	***	*						

[1]2007: spring durum (*Triticum durum* L.), 2012: winter wheat. Different letters indicate significant differences for main effects; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

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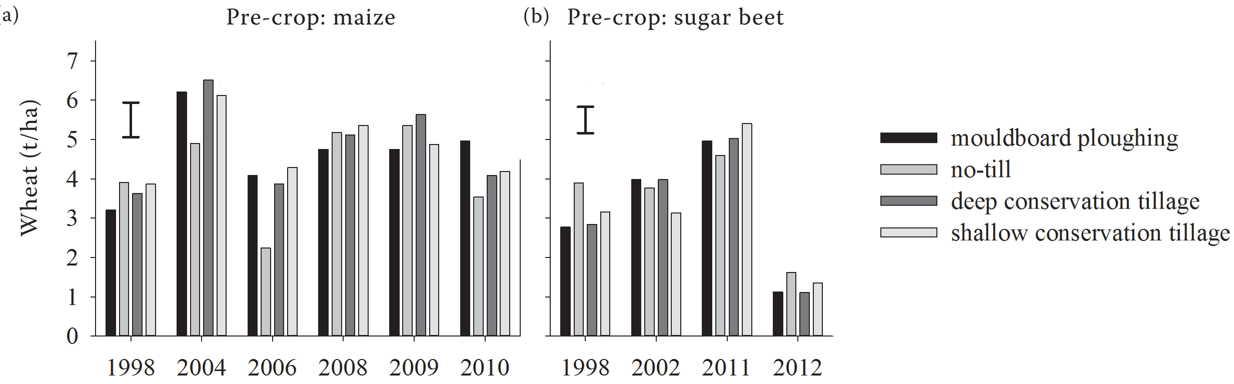

Figure 1. Winter wheat grain yields as affected by tillage system × pre-crop. Error bars are *LSD* (least significant difference, $P < 0.05$)

of MP and NT indicate that at higher amounts of rainfall MP can be superior to NT regarding yield.

WW yields with NT exceeded those with MP in the dry growing seasons of 1998 (after both maize and sugar beet) and 2012 (after both WW and sugar beet) whereas they were lower with NT than with MP in one year with average rainfall (2006) and two years (2004, 2010) with above-average rainfall. In several other growing seasons with varying conditions, no differences between tillage systems were observed. Higher yields at lower amounts of rainfall with NT and at higher amounts of rainfall with MP were reported for wheat under Mediterranean conditions (López-Bellido et al. 1996, De Vita et al. 2007, Amato et al. 2013). Our results obtained under Pannonian conditions in eastern Austria partly confirm the statement by Soane et al. (2012) that there is a reduced reliability of crop yields with NT especially in wet seasons. We can also partly support the observation by Amato et al. (2013) that WW yield can be higher in NT under conditions of drought, as long-term adoption of conservation tillage can improve soil water storage capacity (Bescansa et al. 2006). Morell et al. (2011) observed under NT higher soil water content, higher root length densities and higher grain yields of barley under semi-arid conditions in Spain. However, soil mineral nitrogen levels tend to be higher in MP than in reduced tillage systems (Alvarez and Steinbach 2009). Consequently, we assume that higher WW yields with NT than with MP in dry seasons with a low yield level (1998 and 2012) were a result of improved water availability, whereas in the seasons with higher yield potential (2004) nitrogen availability rather than water availability may have been the key yield limiting factor for WW (after maize) in NT.

Pre-crop effects on winter wheat yields. WW was grown in five out of the eleven years in both

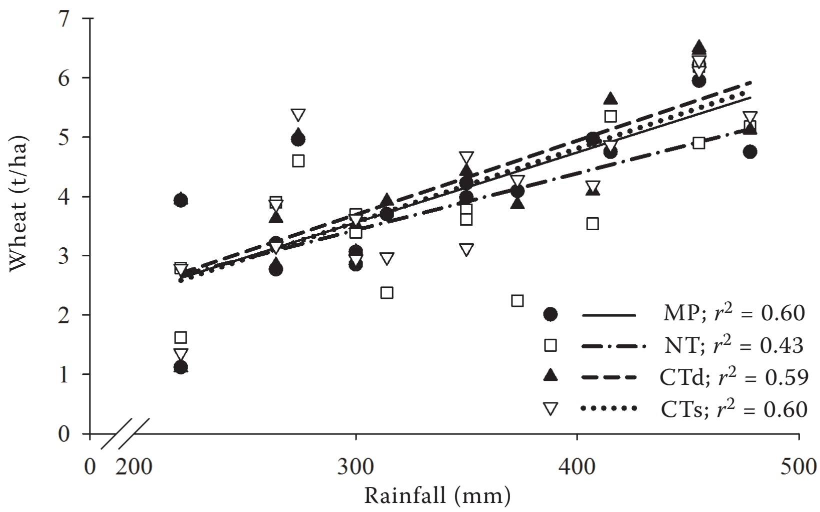

Figure 2. Regressions of winter wheat (WW) grain yields on rainfall (October–June) (WW yields in all years and after all pre-crops). MP – mouldboard ploughing; NT – no-till; CTd and CTs – deep and shallow conservation tillage

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rotations, thus, the effects of different pre-crops on yields within the individual years can be assessed (Table 1, results of analysis of variance are given in brackets). In 1998, WW yield was significantly (P < 0.01) higher following maize than following sugar beet. In that year, a main effect (P < 0.01) of soil tillage was observed as follows: NT (3.90 t/ha), CTs (3.52 t/ha) ≥ CTd (3.24 t/ha) ≥ MP (2.99 t/ha). In 2000, WW yields were slightly higher after oilseed rape than after sunflower (pre-crop: ns; tillage system: ns). Significantly (P < 0.01) higher WW yields were realized in 2002 after soybean compared to sugar beet (tillage system: ns). We found a significant (P < 0.01) tillage × pre-crop interaction on WW yields in 2004; WW yields after maize were lower in NT than in other tillage systems (Figure 1b) whereas no differences between tillage systems were observed after oilseed rape. In 2012, WW yields were higher (P < 0.001) after WW than after sugar beet. Yields in 2012 were ranked for tillage systems as follows: NT (2.30 t/ha) ≥ CTs (2.07 t/ha) ≥ CTd (1.95 t/ha) ≥ MP (1.75 t/ha) (P < 0.01).

Arvidsson et al. (2014) reported that the effects of pre-crops are much more pronounced with NT than with shallow tillage. The tillage × pre-crop interaction on WW yields in 2004, with the lowest WW yield in NT after maize but no differences between tillage systems after oilseed rape, highlights that tillage interacts with crop rotation. Higher WW yields after oilseed rape than after maize in NT are also in accordance with observations by Rieger et al. (2008) who reported higher soil mineral nitrogen after oilseed rape. This crop was shown to have a similar pre-crop value as pea, with both crops outcompeting WW as pre-crop (Christen 2001).

Higher WW yields after soybean compared to sugar beet in 2002 can be explained by soil-N sparing of the legume and the transfer of biologically fixed N via crop residues to the subsequent crop (Chalk 1998, Kaul 2004). Additionally, higher annual average crop water consumption of sugar beet (compared to WW and maize as reported by Shen et al. 2013) may impair the performance of a subsequent WW crop in Pannonian conditions compared to other pre-crops such as maize (in 1998), soybean (in 2002) and WW (in 2012). Under dry conditions in 2012, WW yields after WW were more than two times higher than after sugar beet, whereas Pringas and Koch (2004) reported 10% higher yields of WW after sugar beet than after WW across several environments.

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