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Evolution of crop yields in different tillage and cropping systems over two decades in southern Brazil

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ABSTRACT

In the last three decades, the no-tillage system (NT) has provided environmental and economic advantages for farming in southern Brazil, especially when associated with crop rotation. The objective of this study was to evaluate the effects of different tillage and cropping systems on the grain yields of soybean, maize and wheat, in a 23-year experiment established on an Oxisol in the southern region of Brazil. The experiment was carried out in randomized block experimental design with four replications. The treatments consisted of three tillage systems [NT, NT with chiseling every three years (NTC), and conventional tillage (CT)] and two cropping systems [an annual crop sequence with wheat in the winter and soybean in the summer, designated as crop succession (CS), and a 4-year crop rotation with the following species in winter–summer, respectively: white lupine–maize; black oat–soybean; wheat–soybean; and wheat–soybean (CR)]. Soybean yields were correlated to the water requirement satisfaction index (WRSI) estimated for the soybean reproductive period. With few exceptions, the NT showed higher soybean yields in relation to CT from the 7th year of the experiment onwards, especially under crop rotation and in growing seasons with lower water availability expressed by lower WRSI values. The percentage of NT soybean yield advantage over CT increased consistently over the time, and this increase was greater in CR than in CS, reaching on average 23%. The yields of wheat and maize were not influenced by the tillage systems, but the wheat yields were increased by crop rotation. In the most of the growing seasons, the soil chiseling, at every three years, did not increase significantly the yields of soybean, maize and wheat. Crop rotation and NT, allowed high and stable crop yields, especially under water-stress conditions. Results indicate the need of minimizing soil disturbance and diversifying cropping system for sustainable grain production in southern Brazil.

1. Introduction

The sustainable production of food, fiber and bioenergy depends on tillage and cropping systems that provide high yields and, at the same time, preserve soil, water and biodiversity. The importance of continuous use of soil-conservation tillage methods, such as the no-tillage (NT), is widely recognized for the sustainability of farming systems, particularly in tropical and subtropical regions. Currently, the NT is used on more than 100 million hectares worldwide, and in Brazil, the area under NT already exceeds 25.5 million hectares (FEBRAPDP, 2011). The use of NT by farmers is mainly based on reducing fuel and agricultural machinery costs, reduction in the need of manpower, and reduction of soil erosion (Lal, 2007). Depending on environmental conditions, however, the NT can provide other benefits, as compared to conventional tillage (CT) system, such as: better conservation of water in the soil (Alvarez and Steinbach, 2009; Putte et al., 2010; Jin et al., 2011); increase in the organic carbon contents (Bhattacharyya et al., 2009; Babujia et al., 2010); increase the microbial biomass in topsoil (Babujia et al., 2010); decrease the maximum daily soil temperature in tropical regions (Derpsch et al., 1986); and increase soil biodiversity (Adl et al., 2005). In addition, the NT reduces the time required between rainfall and the sowing procedure, thus allowing for the sowing of crops at the proper time.

Conversely, the lack of soil tillage may increase topsoil compaction into levels in which the growth of roots is limited, especially on clayey soils and/or in soils with low organic matter content (Secco et al., 2009). In southern Brazil, many farmers are performing the chiseling of soils, at regular intervals, to minimize soil compaction. However, the increase in soil bulk density and penetration resistance in the topsoil under the NT, even after periods of over a decade, have not reduced growth of roots and yield of most crops (Cavalieri et al., 2009; Lima et al., 2010).

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Changes in the physical, chemical, and biological soil properties, resulting from cropping and tillage systems carried out for long-term periods, may affect crop yields over time. In the literature, most studies correlating crop yields with tillage and cropping systems, are fairly recent, conducted in a period of less than two decades (Secco et al., 2009; Alvarez and Steinbach, 2009; Cavalieri et al., 2009; Lima et al., 2010; Putte et al., 2010; Jin et al., 2011). In some cases, the yield results are divergent, as consequence of effects of tillage and cropping systems and depend on several factors such as: soil properties, climate, crop species, cultivars, and crop management. Therefore, it is very important to carry out long-term field experiments by using the main cropping systems that are suitable for each region.

With the hypothesis that reduction of soil disturbance associated to crop rotation, increases the yield of crops over time, especially under water-stress conditions; the objective of this study was to evaluate the grain yields of soybeans, maize and wheat carried out in three tillage systems associated with two cropping systems, over a 23-years period under the southern Brazil climate conditions.

2. Materials and methods

2.1. Field area and experimental design

The field experiment was initiated in the summer of the 1988/1989 crop season, at the Embrapa Soybean experimental station, located in municipality of Londrina (latitude 23°11′S; longitude 51°11′W; and 620 m altitude), State of Paraná, southern Brazil. The climate in the area, according to Köppen climate classification, is humid subtropical (Cfa), with annual mean temperature of 21 °C, and mean maximum temperature of 28.5 °C, in February; and mean minimum temperatures of 13.3 °C, in July. The mean annual precipitation is 1651 mm, with mean of 217 mm, in January (the wettest month); and 60 mm, in August (the driest month). The experiment was installed on an Oxisol (Eutroferric Red Latosol, in the Brazilian classification; or Rhodic Eutrudox, in the USA classification) with 710 g clay kg^{-1} soil, 82 g silt kg^{-1} soil, and 208 g sand kg^{-1} soil. The mean slope of the experimental area is 0.03 m m^{-1}. Some chemical and physical properties of soil, evaluated at the 21th year after installing the experiment, and performed according to the methodologies described in Babujia et al. (2010), are shown in Table 1.

Before the experiment, the area had been cultivated with coffee (*Coffea arabica* L.) for approximately 40 years, and the entire area had received similar management and inputs. A randomized block experimental design with four replications was used. The treatments consisted of three tillage systems [(1) no-tillage: NT, sowing directly performed through the residues of the previous crop, by opening only a narrow furrow in the sowing row; (2) no-tillage with chiseling at every three years in the winter: NTC, by means of a chisel plow equipped with five shanks, without subsequent harrowing, working at a mean depth of 0.25 m; and (3) conventional tillage: CT, performed with disc plowing, at a mean depth of 0.20 m, followed by a harrowing, at a working depth of 0.08 m, preceding the summer crops, and preceding winter crops, a harrowing with a heavy harrow, at a mean depth of 0.15 m, followed by a harrowing with a light harrow, at a working depth of 0.08 m], and two crop systems [(1) wheat (*Triticum aestivum* L.) in the winter and soybean (*Glycine max* (L.) Merr) in the summer; a procedure that was repeated at each year, and designated as crop succession (CS); and (2) a 4-year crop rotation (CR), with the following species in winter–summer: white lupine (*Lupinus albus* L.) – maize (*Zea mays* L.); black oats (*Avena strigosa* Schreb.) – soybean; wheat – soybean; wheat –soybean]. The 6th crop rotation cycle will be ended in the 2012/2013 crop season. Each plot had the measures of 7.5 m in width × 30.0 m in length, thus totaling 225 m^2.

Every three years, an average of 2 Mg ha^{-1} of lime was applied to the soil surface to reach a saturation of bases of 60% and to increase the pH in water to approximately 5.5. At each year, all plots received the same amount of fertilizers, based on soil analysis as well as on the specific recommendations for each crop (Table 2). The fertilizers (N, P_2O_5, and K_2O) were simultaneously applied 0.05 m below and at the side of the seeds, during the sowing procedure. For the wheat and maize, the N was not applied as topdressing fertilization. To the cover crops (black oats and white lupine), fertilizer was not applied.

The plots cultivated with wheat and the winter cover crops (white lupine, or black oats) were sown in the month of April in all agricultural years, since the beginning of the experiment. The wheat cultivars used were: BR 23 (1989–1994), BRS 18 (1995, 1997–2000), Ocepar 16 (1996), BRS 193 (2001 and 2002) and BRS 208 (2003–2010).

The soybean was sown in November of every crop season, and the cultivars used were: Paraná (1988/1989–1993/1994), BR 37 (1994/1995–1996/1997 and 1998/1999), Embrapa 48 (1997/1998 and 1999/2000), BRS 133 (2000/2001 and 2001/2002), BRS 156 (2002/2003 and 2003/2004), BRS 184 (2004/2005, 2008/2009 and 2009/2010) and BRS 232 (2005/2006–2007/2008).

Table 2
Fertilization used for soybean, wheat and maize over 23 growing seasons.

Crop	Fertilization[a]		
	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
Soybean[b,c,d]	0.0	34.0–60.0	22.5–60.0
Wheat	12.8–20.0	45.0–70.0	24.0–40.5
Maize	8.5–30.0	28.0–75.0	34.0–60.0

[a] N, P_2O_5 and K_2O were applied as urea, triple superphosphate and potassium chloride, respectively.
[b] The soybean seeds were inoculated with *Bradyrhizobium elkanii* and *B. japonicum* every growing season.
[c] After the 10th growing season, 20 g ha^{-1} of molybdenum as sodium molybdate and 2 g ha^{-1} of cobalt (cobalt chloride) were applied to the soybean seeds.
[d] The soybeans were not fertilized in 1998/1999 and 2000/2001.

Table 1
Soil chemical and physical properties[a] (0–0.2 m) evaluated at the 21st year of the experiment (April/2010).

Treatment[b]		C (g dm^{-3})	P (mg dm^{-3})	pH $CaCl_2$	K^+ ($cmol_c$ dm^{-3})	Ca^{2+} ($cmol_c$ dm^{-3})	Mg^{2+} ($cmol_c$ dm^{-3})	CEC[c] ($cmol_c$ dm^{-3})	BD[d] (Mg m^{-3})
NT	CR	19.5	23.20	5.22	0.37	3.37	1.50	9.35	1.26
	CS	18.3	18.61	5.07	0.36	3.16	1.36	9.29	1.31
NTC	CR	19.4	26.98	5.20	0.58	3.99	1.61	10.23	1.28
	CS	17.7	24.26	5.10	0.49	3.27	1.60	10.54	1.27
CT	CR	16.3	10.05	4.82	0.32	2.61	1.21	9.79	1.19
	CS	17.4	12.53	5.19	0.43	3.31	1.50	10.72	1.29

[a] Means of four replicates.
[b] NT, no-tillage; NTC, no-tillage with chiseling every three years; CT, conventional tillage; CR, crop rotation (lupine–maize; black oat–soybean; wheat–soybean; wheat–soybean); CS, crop succession (wheat–soybean).
[c] Cations exchange capacity (CEC) = K + Ca + Mg + total acidity at pH 7.0 (H + Al).
[d] Soil bulk density (BD).