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Grain yield and agronomic traits in soybean according to crop rotation systems

Henrique Pereira dos Santos ([1*]); Renato Serena Fontaneli ([1]); João Pires ([1]); Evandro Ademir Lampert ([1]); Ana Maria Vargas ([1]); Amauri Colet Verdi ([2])

([1]) Embrapa Trigo, BR 285, km 294, 99001-970 Passo Fundo (RS), Brasil.
([2]) Universidade de Passo Fundo (UPF/FAMV), BR 285, 99052-900 Passo Fundo (RS), Brasil.
(*) Corresponding author: henrique.santos@embrapa.br

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Abstract

The effects of crop rotation systems (CRS) on soybean yield and agronomic characteristics were evaluated from 1996/1997 to 2010/2011 at Embrapa Trigo, Passo Fundo (RS), Brazil. Four soil management systems (SMS) were compared, namely: 1) no tillage, 2) minimum tillage, 3) conventional tillage using a disk plow and a disk harrow, and 4) conventional using a moldboard and a disk harrow - and three CRS: system I (wheat/soybean), system II (wheat/soybean and common vetch/corn or sorghum) and system III (wheat/soybean, white oats/soybean and common vetch/corn or sorghum). This is a split-plot, randomized, complete block design with three replications. SMS were assigned in the main plot and CRS systems in the split-plots. This work addressed only data on crop rotation systems. There were no significant differences between the CRS for number of grains per plant, 1,000 grain weight and first pod height in soybean. The crop rotation for a summer, with corn or sorghum, propitiates a higher soybean yield compared with the other systems and monoculture soybean. The combination of conservation systems (no tillage and minimum tillage) and CR resulted in a higher soybean yield. The lowest grain yield and grain weight per plant were obtained in monoculture soybean.

Key words: number legumes, number grain, grain mass per plant.

Rendimento de grãos e características agronômicas de soja em função de sistemas de rotação de culturas

Resumo

O objetivo deste trabalho foi avaliar o efeito dos sistemas de rotação de culturas (SRC) sobre o rendimento de grãos e as características agronômicas de soja no período de 1996/1997 a 2010/2011 em Latossolo Vermelho distrófico típico, na Embrapa Trigo, em Passo Fundo, RS. Foram comparados quatro tipos de manejo de solo (TMS): 1) sistema plantio direto (SPD); 2) cultivo mínimo (CM); 3) preparo convencional de solo com arado de discos (PCD); e 4) preparo convencional de solo com arado de aivecas (PCA) e três SRC: sistema I (monocultura de trigo/monocultura de soja); sistema II (trigo/soja e ervilhaca/milho ou sorgo); e III (trigo/soja, aveia branca/soja e ervilhaca/milho ou sorgo). O delineamento experimental foi em blocos completos ao acaso, com parcelas subdivididas e três repetições. A parcela foi constituída pelos TMS, e as subparcelas, pelos SRC. No presente trabalho serão abordados somente os dados sobre sistemas de rotação de culturas. A análise conjunta dos dados obtidos não indicou diferença entre os SRC em relação ao número de grãos por planta, à massa de mil grãos e à altura de inserção das primeiras vagens de soja. A rotação de culturas por um verão utilizando milho ou sorgo propicia maior rendimento de grãos de soja em comparação com os demais sistemas estudados e com a soja em monocultura. A combinação de sistemas conservacionistas (SPD e CM) e SRC favoreceu o maior rendimento de grãos de soja. Os menores rendimentos de grãos e massa de grãos ocorreram em monocultura de soja.

Palavras-chave: número de vagens, número de grãos, massa de grãos por planta.

1. INTRODUCTION

Crops of corn, soybeans, wheat and winter and summer annual pastures dominate the northern Rio Grande do Sul State, Atlantic Forest biome. On average, 4 million hectares of soybeans have been grown in this region, producing around 2,100 kg ha^{-1}.

Crop rotation, as current practice in agricultural production, has been recognized, from a technical point of view, as essential to the stable development of agriculture (Thomas and Costa, 2010). Therefore it becomes important the use of different cultures with abundant and vigorous root systems, providing advantages to the farmer, highlighting the increase in grain yield of soybean.

However, yet little is known about the combination of soil management systems and crop rotation in southern Brazil. Ruedell (1995) and Ciotta et al. (2002) analyzed crop rotation systems, but without the joint analysis of years in soybean yield. In the work of Ruedell (1995), in the comparison within each soil management: no tillage (3,196 and 2,821 kg ha^{-1}) or conventional tillage with disk harrow, twice (2,911 and 2,795 kg ha^{-1}), soybean grown after crop rotation was higher for grain yield in relation to monoculture soybean, respectively. Ghaffarzadeh (1997) and Yusuf et al. (1999) compared crop rotation systems in the set of years, and found no significant difference for soybean yield.

Pedersen and Lauer (2003) worked with types of management and crop rotation in soybean, and observed that, when this legume was grown in crop rotation (3,900 to 4,300 kg ha^{-1}), yielded more than monoculture (3,800 kg ha^{-1}) over a period of four years. The same authors showed a higher 1,000 grain weight and plant height in soybean using crop rotation relative to monoculture.

Considering only crop rotation with winter or summer species, Santos and Reis (1991) in Passo Fundo, Rio Grande do Sul State, observed higher grain yields for soybean grown for two or three consecutive years when in rotation with corn (2,604 to 2,650 kg ha^{-1}). The lower yield of this crop was found in monoculture (2,107 kg ha^{-1}). In other works (Santos et al., 1998), when soybean was cultivated under no tillage, grain yields were higher with a (wheat/soybean and common vetch/corn – 2,868 kg ha^{-1}) or two consecutive summers of crop rotation (wheat/soybean, flax/soybean and common vetch/corn – 2,840 kg ha^{-1}).

On the other hand, Santos et al. (2013) analyzed crop-livestock integration systems for five years and detected no difference for grain yield, 1,000 grain weight, plant height and first pod height in soybeans.

Grain yield and other agronomic traits of soybean may be more affected by monoculture, compared with crop rotation systems. This study aimed to investigate the effect of crop rotation on yield and agronomic traits of soybean.

2. MATERIAL AND METHODS

The trial was conducted in Passo Fundo, Rio Grande do Sul State (28º15'S, 52°24'W, 678 m altitude), in April 1986, on soil classified as dystrophic red oxisol (Streck et al., 2008). The results presented in this work are for the period between 1996/1997 and 2010/2011.

This was a split plot randomized block design with three replications. Treatments consisted of plots with four types of soil management, and subplots with three crop rotation systems. The plot was 360 m^2 (4 m width and 90 m length), and subplot was 40 m^2 (4 m width and 10 m length). The four soil management systems were: 1) no tillage, 2) minimum tillage in the winter, and no tillage in the summer; 3) conventional tillage using a disk plow and a disk harrow in the winter and no tillage in the summer, and 4) conventional using a moldboard and a disk harrow in the winter and no tillage in the summer. The crop rotation systems were made up of: system I (wheat/soybean), system II (wheat/soybean and common vetch/corn or sorghum) and system III (wheat/soybean, white oats/soybean and common vetch/corn or sorghum) (Table 1). The present study addressed only data on crop rotation systems.

Soybean cultivars used were BR-16 in 1996 and 1997, BRS 137 in 1998 and 1999, BRS 154 from 2000 to 2003, BRS 153 in 2004, BRS 244 RR in 2005, BRS Charrua RR in 2006, BRS 255 RR from 2007 to 2009, and BRS Tertúlia RR in 2010, sown preferably in November (in single seeding).

The maintenance fertilization was performed as recommended for winter and summer crops and based on the results of soil analysis (Wiethölter, 2011). Soil samples were collected after the harvest of winter crops with the exception of 2004 and 2007, when no analyses were performed (Table 2). The sowing date and weed control followed the indication for winter and summer crops.

The following traits were evaluated: plant height, first pod height, grain yield (corrected to 13% moisture), 1,000-grain weight and soybean yield components (number of pods, number of grains and weight of grains per plant).

Table 1. Soil management systems and crop rotation systems for wheat

Rotation System	Soil management system			
	SPD	PCD	PCA	CM
System I	Wheat/soybean	Wheat/soybean	Wheat/soybean	Wheat/soybean
System II	Wheat/soybean	Wheat/soybean	Wheat/soybean	Wheat/soybean
	Common vetch/sorghum	Common vetch/sorghum	Common vetch/sorghum	Common vetch/sorghum
System III	Wheat/soybean	Wheat/soybean	Wheat/soybean	Wheat/soybean
	Common vetch/sorghum	Common vetch/sorghum	Common vetch/sorghum	Common vetch/sorghum
	White oats/soybean	White oats/soybean	White oats/soybean	White oats/soybean

SPD: no-tillage; PCD: conventional tillage with disk plow and a disk harrow in the winter and no tillage in the summer; PCA: conventional tillage with moldboard plow in the winter, and no tillage in the summer; CM: minimum tillage in the winter and no tillage in the summer.

Table 2. Values of pH, Al, Ca + Mg, MOS, P and K in different years

Elements	Year												
	1996	1997	1998	1999	2000	2001	2002	2003	2005	2006	2008	2009	2010
pH (water 1:1)	5.2	4.3	5.1	5.1	4.9	5.2	5.3	5.2	5.1	5.0	5.1	5.2	5.4
Al (mmol$_c$ dm^{-3})	0.5	5.7	6.7	7.8	10.5	7.6	9.8	13.8	15.1	15.2	15.2	3.9	7.4
Ca+Mg(mmol$_c$ dm^{-3})	60	59	60	53	43	50	52	50	46	48	39	59	62
MOS (g k^{-3})	30	28	28	30	29	31	32	29	29	28	30	27	27
P (mg kg^{-3})	4.8	5.5	4.6	5.5	22.2	18.0	24.0	23.4	36.8	28.0	38.0	32.1	31.9
K (mg kg^{-3})	107	161	164	153	167	160	222	158	259	202	219	190	211

We conducted an analysis of variance for grain yield and agronomic traits of soybean (within each year and in the average of the years from 1996/1997 to 2010/2011). The effect of treatments (different crop rotation systems) was considered as fixed, and the effect of year as random. The means were compared by Tukey's test at 5% probability.

Rainfall data, average temperature and relative humidity were taken at the weather station located at Embrapa Trigo, shown in table 3, which lists the monthly averages from 1996/1997 to 2010/2011 as well as the currently normal value (1961-1990) of climatic variables.

3. RESULTS AND DISCUSSION

The amount of water required by the soybean crop to complete the physiological cycle is 650 - 700 mm (Farias et al., 2010). With the data of the fifteen years of study, in two of years (1996/1997 - 619 mm and 2008/2009 - 640 mm), rainfall indices were below the required in the region of Passo Fundo, and also below normal (833 mm), but in most years, rainfall was above these values (Table 3). In the period 1996/1997, with the exception of January 1997, the deviations of rainfall in relation to the normal values were always negative. In 1998/1999, with the exception of April 1999, there were negative deviations of rainfall compared with the normal. In the periods 2004/2005, 2005/2006 and 2008/2009, the rainfall distribution was deficient in most months of soybean development, affecting grain yield, especially in the first two periods.

In the period from 1996/1997 to 2010/2011, differences were observed between the mean grain yield, number of pods per plant, number of grains per plant, grain weight per plant, 1,000-grain weight, plant height and first pod height for the factor year. The results indicate that these characteristics were mainly affected by climatic variations between the years studied (Table 4). Similar results for grain yield and other agronomic traits and the effect of year were obtained by Santos et al. (2013) with crop-livestock integrated production systems. It should be noted that different soybean cultivars were used throughout the study, however, within each period the genetic material was the same in all rotation systems.

There were differences between crop rotation systems for mean grain yield, number of pods per plant, grain yield per plant and plant height in soybean (Table 4). Moreover, the interaction between year and crop rotation systems was significant for grain yield and plant height of soybean. The interaction between soil management and crop rotation systems was significant for 1,000-grain weight and soybean plant height. The interaction between year and soil management and crop rotation systems was not significant for any trait. Grain yield and some agronomic traits of soybean are presented in (Tables 5-11).

Nine out of the fourteen harvests showed differences in soybean grain yield, related to crop rotation systems (Table 5). The soybean grain yield of the 2007/2008 growing season was reduced by a hail event that occurred in April 2008. In crops of 1997/1998, 1999/2000, 2001/2002 and 2010/2011, the soybean planted after wheat, in the system II (wheat/soybean and common vetch/corn or sorghum) presented a higher grain yield than soybeans planted after wheat in systems I (monoculture wheat/soybean) and III (wheat/soybean, white oats/soybean and common vetch/corn or sorghum). This difference in grain yield is partially explained by the number of grains per plant (table 7) in the 1997/1998 growing season, by the number of pods per plant (Table 6) and by the grain weight per plant (Table 8), in the 1999/2000 growing year, and by plant height (Table 9) in the 2001/2002 growing season, which were higher in soybeans. In these cases, the rotation with only one summer with soybean was enough for increased production per hectare with the alternation of some yield components. In all these studied periods, there was excessive rainfall, above the normal (Table 3). Given that observed, the excess of water affected the height of soybean plants in 2011/2012, and thus the yield. According to Thomas and Costa (2010), the larger the grain size, the smaller the number of grains per unit area, although it can be achieved high grain yields from cultivars that have both large (18 g to 100 grains) and small (12 g to 100 grains) grains. However, there is a strong relationship between grain yield and grain number per area (Board and Maricherla, 2008). In this study, this observation was true only in the 1997/1998 growing season.

In 2000/2001, the grain yield of soybean grown after wheat, in the systems II and III (both rotation systems

Table 3. Rainfall data, average temperature and relative humidity of the climatological normal from 1961 to 1990 and of the years between 1996/1997 and 2010/2011, in Passo Fundo, Rio Grande do Sul State

Year	Month						
	November	December	January	February	March	April	Total
				Rainfall (mm)			
1961 to 1990	141	162	143	148	121	118	833
1996/97	107	123	156	130	33	70	619
1997/98	340	236	231	358	230	342	1.736
1998/99	69	122	125	114	65	188	682
1999/00	119	131	144	106	267	76	843
2000/01	164	160	212	196	110	118	960
2001/02	117	194	96	77	357	136	977
2002/03	205	329	176	265	128	114	1.217
2003/04	168	391	97	123	27	142	948
2004/05	122	67	104	26	88	292	699
2005/06	146	82	132	111	165	55	691
2006/07	312	106	261	127	199	254	1.259
2007/08	186	218	83	150	130	297	1.065
2008/09	237	73	94	155	76	5	640
2009/10	349	142	126	104	68	216	1.005
2010/11	60	194	150	219	220	109	952
			Average Temperature (ºC)				Mean
1991 to 1990	19.6	21.4	22.1	22.0	20.5	17.6	20.5
1996/97	20.7	22.3	23.1	22.1	20.1	17.6	21.0
1997/98	20.3	22.6	22.6	21.1	19.6	17.1	20.6
1998/99	20.1	21.1	22.2	21.4	22.2	17.0	20.7
1999/00	18.5	21.9	22.4	21.5	19.8	18.4	20.4
2000/01	19.8	21.5	22.0	22.7	22.0	19.9	21.3
2001/02	20.9	21.1	21.7	20.9	22.6	19.6	21.1
2002/03	20.1	21.5	22.5	22.3	20.5	17.7	20.8
2003/04	19.4	20.2	21.7	20.5	20.6	17.7	20.0
2004/05	19.4	21.5	23.4	23.0	22.2	17.8	21.2
2005/06	20.6	21.3	23.1	21.6	20.9	17.3	20.8
2006/07	19.9	23.5	22.3	21.8	22.2	19.4	21.5
2007/08	18.9	22.3	21.7	21.3	20.6	17.2	20.3
2008/09	20.3	21.7	20.8	22.2	21.4	19.4	21.0
2009/10	22.4	22.4	22.3	23.0	21.1	17.7	21.5
2010/11	19.5	21.5	23.0	21.9	20.4	18.4	20.8
			Relative Humidity (%)				Mean
1991 to 1990	67	67	71	74	75	74	71
1996/97	68	70	71	80	66	64	70
1997/98	76	69	77	83	81	80	78
1998/99	62	67	72	78	73	79	72
1999/00	63	65	71	73	77	73	70
2000/01	66	71	81	83	78	78	76
2001/02	67	69	71	71	79	77	72
2002/03	71	74	72	78	79	72	74
2003/04	65	72	73	69	67	70	69
2004/05	67	64	65	62	63	80	67
2005/06	64	63	73	74	75	70	70
2006/07	66	65	77	75	77	76	73
2007/08	63	66	71	72	75	73	70
2008/09	67	64	73	75	75	66	70
2009/10	79	74	81	78	74	75	77
2010/11	65	70	78	84	75	74	74

Table 4. Summary of F-test for seven agronomic traits of soybean sown from 1996 to 2010. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Agronomic trait	Management	Rotation	Year x Management	Year x Rotation	Management x Rotation	Year x Management x Rotation
Grain yield (kg ha^{-1})	**	**	**	**	ns	ns
Number of pods per plant	ns	*	ns	ns	ns	ns
Number of grains per plant	ns	ns	*	ns	ns	ns
Weight of grains per plant (g)	ns	**	**	ns	ns	ns
1,000-grain weight (g)	**	ns	*	ns	*	ns
Plant height (cm)	**	**	**	**	*	ns
First pod height (cm)	ns	ns	ns	ns	ns	ns

*: significance level of 5%; **: nível de significância de 1%; ns: non-significant.

Table 5. Effect of crop rotation systems on soybean grain yield, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	Grain yield (kg ha^{-1})				
1996/97	2,738 A	2,912 A	2,669 A	2,724 A	2,761 c
1997/98	2,636 B	2,932 A	2,789 AB	2,692 B	2,762 c
1998/99	2,152 A	2,269 A	2,208 A	2,187 A	2,204 e
1999/00	2,703 C	3,167 A	3,098 A	2,870 B	2,960 b
2000/01	3,036 B	3,420 A	3,422 A	3,416 A	3,324 a
2001/02	2,427 B	2,720 A	2,699 A	2,465 B	2,578 d
2002/03	2,864 AB	2,689 B	2,830 B	2,940 A	2,831 bc
2003/04	1,760 AB	1,875 A	1,723 B	1,814 AB	1,793 f
2004/05	721 A	916 A	725 A	811 A	794 g
2005/06	1,833 A	1,909 A	1,672 A	1,827 A	1,811 f
2006/07	2,892 B	2,986 AB	3,099 A	2,852 B	2,957 b
2008/09	2,898 A	2,984 A	2,870 A	2,966 A	2,930 b
2009/10	2,927 AB	2,915 AB	2,996 A	2,628 B	2,866 bc
2010/11	3,155 B	3,368 A	3,402 A	3,191 B	3,279 a
Mean	2,482 C	2,648 A	2,586 B	2,528 BC	2,561

Coefficient of variation: 8%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

with a summer without soybean); after white oats, in the system III (soybean for two consecutive years and a summer without soybean), was higher than in soybean grown after wheat, in the system I (monoculture wheat/soybean). In this case, the system I is a winter monoculture and a summer monoculture. This greater difference observed in soybean grain yield per hectare (Table 5) can be explained in part by the grain weight (Table 8) and by the of 1,000-grain weight (Table 10), which were greater in crop rotation systems compared with monoculture soybean. In this case, there was a beneficial effect of crop rotation on soybean grain yield compared with soybean grown for all the years in the same area. During this period, soybeans expressed its greatest genetic potential, relative to the other crops studied.

The grain yield of soybean grown after wheat, in the system III, in 2002/2003, was higher than that of soybean planted after wheat in the system II and after white oats in the system III. In 2003/2004, the soybean grown after wheat, in the system II stood out for grain yield in relation to soybean grown after white oats, in the system III. In 2006/2007 and 2009/2010 growing seasons, the soybean grown after white oats showed a higher grain yield than the soybean planted after wheat, in the system III. In all these periods studied, there was excessive rainfall, above the normal (Table 3). This surplus in 2003/2004 (Table 3) affected the genetic potential of soybean in all crop rotation systems.

In the joint analysis from 1996/1997 to 2010/2011, we found a difference between the rotation systems for grain yield, number of pods per plant, grain weight per plant and plant height of soybean (Tables 5,6,8,9). The soybean grown after wheat, in the system II, showed a higher grain yield compared with the soybean grown after wheat in systems I and III, and after white oats, in the system III. The soybean grown after white oats and after wheat in the

Table 6. Effect of crop rotation systems on the number of pods per soybean plant, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	Number of pods per soybean plant				
1996/97	38 A	39 A	40 A	40 A	39 c
1997/98	30 B	34 A	32 AB	32 AB	32 de
1998/99	27 A	30 A	31 A	30 A	29 ef
1999/00	21 B	24 A	22 AB	21 B	22 g
2000/01	29 B	31 AB	34 A	33 AB	31 def
2001/02	28 A	31 A	31 A	29 A	30 def
2002/03	53 A	48 A	51 A	49 A	51 a
2003/04	26 A	27 A	29 A	28 A	28 f
2004/05	19 A	19 A	20 A	22 A	20 g
2005/06	31 A	33 A	27 A	30 A	31 def
2006/07	46 A	45 A	53 A	44 A	47 ab
2008/09	31 A	35 A	34 A	35 A	34 d
2009/10	40 A	37 A	41 A	40 A	40 c
2010/11	39 A	42 A	47 A	44 A	43 bc
Mean	33 B	34 AB	35 A	34 AB	34

Coefficient of variation: 19%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

Table 7. Effect of crop rotation systems on the number of grains per soybean plant, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Ano	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	Number of grains per soybean plant				
1996/97	69 A	76 A	72 A	79 A	74 c
1997/98	49 B	55 A	52 AB	49 B	51 fg
1998/99	52 A	58 A	59 A	57 A	57 ef
1999/00	42 B	49 A	45 AB	43 AB	45 g
2000/01	59 B	67 AB	72 A	70 A	67 cd
2001/02	55 A	59 A	62 A	58 A	59 def
2002/03	104 A	93 A	99 A	96 A	98 a
2003/04	54 A	56 A	53 A	60 A	56 ef
2004/05	33 A	32 A	33 A	40 A	35 h
2005/06	58 A	59 A	55 A	59 A	58 ef
2006/07	91 A	92 A	84 A	85 A	88 b
2008/09	58 A	63 A	67 A	69 A	64 de
2009/10	59 A	58 A	67 A	52 A	59 def
2010/11	67 A	72 A	81 A	74 A	73 c
Mean	61 A	64 A	64 A	64 A	64

Coefficient of variation: 19%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

system III remained in an intermediate position for grain yield. The soybean grown after wheat, in the system I (monoculture wheat/soybean) exhibited the lowest grain yield. The explanation of this difference may be partially related to the grain weight per plant (Table 8), which was higher in the system II than in monoculture soybean. Importantly, in the present study, soybean grown after white oats and after wheat, in the system III, was planted for two consecutive years (wheat/soybean, white oats/soybean and common vetch/corn or sorghum). This demonstrates that, in part, the effect of crop rotation was of utmost importance to maintain the grain yield of soybean. The cultivar used in each growing season was different; however, it should not have affected the grain yield in these crop rotation

Table 8. Effect of crop rotation systems on the grain weight per soybean plant, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	Grain weight per soybean plant (g)				
1996/97	11.1 A	11.2 A	10.6 A	11.2 A	10.8 de
1997/98	8.0 B	9.9 A	9.0 AB	8.7 AB	8.9 fg
1998/99	7.4 A	8.4 A	8.3 A	8.1 A	8.0 gh
1999/00	7.7 B	9.1 A	8.4 AB	8.1 B	8.3 fgh
2000/01	10.4 B	12.2 A	13.4 A	13.1 A	12.1 bc
2001/02	9.1 A	10.0 A	10.3 A	9.4 A	9.7 ef
2002/03	18.7 A	16.4 A	17.9 A	17.8 A	17.7 a
2003/04	7.7 A	8.1 A	7.7 A	8.7 A	8.1 gh
2004/05	6.8 A	6.3 A	6.5 A	8.1 A	7.0 h
2005/06	9.3 A	9.4 A	8.6 A	9.2 A	9.1 fg
2006/07	12.3 A	12.8 A	11.6 A	10.7 A	11.8 bcd
2008/09	11.1 A	12.6 A	12.2 A	12.7 A	12.2 bcd
2009/10	11.2 A	11.1 A	12.1 A	10.4 A	11.2 cd
2010/11	11.9 A	12.9 A	14.1 A	13.4 A	13.1 b
Mean	10.1 B	10.7 A	10.8 A	10.6 AB	10.6

Coefficient of variation: 19%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

Table 9. Effect of crop rotation systems on soybean plant height, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	Soybean plant height (cm)				
1996/97	91 AB	95 A	86 B	92 A	91 ef
1997/98	94 AB	93 B	93 B	96 A	95 cd
1998/99	103 AB	106 A	103 AB	102 B	103 a
1999/00	80 B	88 A	88 A	88 AB	85 g
2000/01	73 B	81 A	83 A	82 A	80 h
2001/02	88 C	97 A	85 D	92 B	91 ef
2002/03	85 AB	81 AB	79 B	86 A	83 gh
2003/04	87 A	91 A	85 A	92 A	89 f
2004/05	57 A	56 A	58 A	59 A	58 i
2005/06	60 AB	65 A	55 B	59 AB	60 i
2006/07	95 A	99 A	99 A	100 A	100 b
2008/09	97 A	98 A	94 A	99 A	97 bc
2009/10	93 A	91 A	99 A	92 A	92 de
2010/11	96 A	98 A	98 A	98 A	98 bc
Mean	86 B	88 B	85 B	88 A	87

Coefficient of variation: 5%%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

systems. Franchini et al. (2011) also registered that soybean responded positively to crop rotation, particularly when grown in the summer subsequent to summer corn crop. In the same study, considering the average grain yield of soybean in rotation with corn in relation to that verified after wheat, the cumulative gain in grain yield of this oil crop amounted to 17%.

In the joint analysis from 1987/1988 to 1996/1997, previously conducted by Santos et al. (2001), with this same experiment, there were also differences in grain yield between crop rotation systems in soybean. First, all crop rotation systems for soybean were higher than soybean grown in monoculture. In this way, soybean grown after wheat (2,794 kg ha^{-1}), in the system II, showed the highest

Table 10. Effect of crop rotation systems on 1,000 grain-weight of soybean, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
			1,000- grain weight (g)		
1996/97	143 AB	146 A	140 B	144 AB	144 i
1997/98	167 B	175 A	174 AB	172 AB	172 f
1998/99	156 AB	159 A	153 B	157 AB	156 g
1999/00	184 B	195 A	192 A	191 A	191 bc
2000/01	179 B	190 A	190 A	189 A	187 cd
2001/02	173 A	173 A	174 A	172 A	173 f
2002/03	184 A	174 A	184 A	187 A	182 de
2003/04	149 A	149 A	150 A	152 A	150 h
2004/05	221 A	218 A	212 A	223 A	219 a
2005/06	160 A	158 A	155 A	155 A	157 g
2006/07	134 AB	138 A	137 A	127 B	134 j
2008/09	188 A	185 A	179 B	185 A	184 d
2009/10	190 A	196 A	193 A	200 A	195 b
2010/11	177 A	180 A	175 A	177 A	178 ef
Mean	172 A	174 A	172 A	174 A	173

Coefficient of variation: 5%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

grain yield than soybean grown after white oat or black oat (2,671 kg ha^{-1}), after wheat (2,601 kg ha^{-1}), in the system III, and after wheat (2,457 kg ha^{-1}), in the system I. The lowest yield of soybean was achieved when grown in monoculture (system I). Earlier works revealed that when the monoculture of any species was practiced for years in a row, it was shown the release of some compounds during the decomposition of plant residues, which accumulated in the soil until they reach concentrations that inhibited the plant growth (Santos and Reis, 1991).

Still in the previous study, with this same experiment, from 1997/1998 to 2002/2003, the soybean grown after wheat (2,866 kg ha^{-1}), in the system II, was superior to that grown after white oat (2,799 kg ha^{-1}) and after wheat (2,804 kg ha^{-1}), in the system III, and after wheat (2,636 kg ha^{-1}), in the system I (Santos et al., 2006). The lowest values of grain yield, grain weight per soybean plant and 1,000-grain weight was observed in monoculture soybean. The system II stood out for soybean grain yield between crop rotation systems, that is, soybean grown only with a summer rotation (wheat/soybean and common vetch/ corn or sorghum). In the case of the system III, in which soybean was grown after a summer rotation (soybean after white or black oats) and for two consecutive years (soybean after black or white oats and later soybean after wheat) the grain yield remained at an intermediate position. In this study period, the practice of crop rotation was of paramount importance to the profitability of this legume. According to Amado et al. (2010), the types of soil management during the year are the most effective in improving the quality of this natural resource, namely, the no-tillage cultivation of soybean with crop rotation and the use of cover crops are essential to achieve high yields of soybeans.

Santos and Reis (1991) developed a study on crop rotation in the same soil in an experiment close to that of the present study and observed that soybean grown after wheat, in systems III (wheat/soybean, white oats/soybean and common vetch/corn – 2,604 kg ha^{-1}) and IV (wheat/ soybean, rapeseed/soybean, flax/soybean and serradella/ corn – 2,650 kg ha^{-1}) showed higher grain yields compared with monoculture soybean grown, in the system I (wheat/ soybean – 2,107 kg ha^{-1}) and soybean grown after rapeseed, in systems II (wheat/soybean, rapeseed/soybean, barley/soybean and serradella/corn – 1,802 kg ha^{-1}) and IV (1,746 kg ha^{-1}). In this case, the system I is a winter monoculture and a summer monoculture.

Also, in the study of Santos et al. (1997), in Guarapuava, Paraná State, from 1990/1991 to 1993/1994, with crop rotation systems for barley under no-tillage system (system I: barley/soybean; system II: barley/soybean and white oats/ soybean; system III: barley/soybean, common vetch/corn and white oats/soybean; and system IV: barley/soybean, flax/ soybean, white oats/soybean and common vetch/corn), the highest yield was obtained in treatments where soybean was sown as follows: after barley in systems III (3,481 kg ha^{-1}) and II (3,460 kg ha^{-1}); and after white oat, in systems II (3,417 kg ha^{-1}), III (3,407 kg ha^{-1}) and IV (3,405 kg ha^{-1}); and after barley (3,357 kg ha^{-1}), in the system IV. However, the last five were similar to soybean grown after barley (3,336 kg ha^{-1}), in the system I. The lowest soybean yield was observed after flax (3,090 ha^{-1}), in the system IV. In this case, the lowest yield of soybean grains was related to the flax plant residue (Santos and Roman, 2001) and not with the rotation system. In this study, flax did not provide an adequate ground cover. Other experiment performed by Santos et al. (1998), at a place nearby and in the same period of the previous study, with crop rotation systems for wheat (system I: wheat/soybean; system II: wheat/soybean, and white oats/soybean; system III: wheat/soybean, common vetch/corn and white oats/ soybean; and system IV: wheat/ soybean, common vetch/corn, barley/soybean and white oats/soybean), found no differences in the average grain yield of soybean. It should be borne in mind that, in both experiments reported by Santos et al. (1997; 1998), soybean was grown in monoculture or in consecutive years.

In a typical dystrophic red latosol, Genro Junior et al. (2009) verified no difference for soybean grain yield in crop rotation (corn/oats/corn + dwarf pigeon pea/wheat/ soybean/wheat; pigeon pea/wheat/soybean/wheat/soybean/ oats, and sunn hemp/wheat/soybean/oats/corn/wheat) or monoculture (wheat/soybean).

Likewise, Santos et al. (2013) examined for four years a typical dystrophic red oxisol humic under crop-livestock integrated production systems (annual pastures of winter and of dual purpose cereal), no difference was detected between treatments for soybean grain yield.

Mariani et al. (2012) studied tropical perennial forage grasses simultaneously with soybean in northern Rio Grande do Sul State, in a typical dystrophic red oxisol humic, and found no difference for grain yield between treatments with or without intercropping. In this case, soybean yield ranged from 2,482 to 2,837 kg ha^{-1}.

In the average from 1996/1997 to 2010/2011, soybean grown after white oats in the system III was superior to that grown after wheat, in the system I, for number of pods (Table 6) and grain weight per plant (Table 8), while the soybean grown after wheat, in the system III, stood out in relation to other soybean crops (Table 9). Santos et al. (2013), on crop-livestock integrated systems (with winter annual pastures and dual purpose: white oats, wheat and triticale), verified that soybean grown after common vetch showed a higher number of pods per plant (27.2) and grain weight per plant (117.9 g) than most treatments studied (19.1 to 21.8 and 73.3 to 95.7 g, respectively).

There was no difference between averages from 1996/1997 to 2010/2011 of crop rotation systems for number of grains per plant (Table 7), 1,000-grain weight (Table 9) and first pod height in soybean (Table 11). Santos et al. (2013) investigated crop-livestock integrated systems, and also found no differences between treatments for the 1,000-grain weight and first pod height in soybeans. Nevertheless, in this same study, the authors observed that soybean grown after common vetch had a higher number of grains per soybean plant (75.2), compared with the other treatments (45.4 to 60.7).

Table 11. Effect of crop rotation systems on first pod height in soybean, from 1996/1997 to 2010/2011. Embrapa Trigo. Passo Fundo, Rio Grande do Sul State

Year	Crop rotation system				Mean
	System I: T/S	System II: T/S and E/M	System III: Ab/S, T/S and E/M	System III: T/S, E/M and Ab/S	
	First pod height (cm)				
1996/97	28 A	28 A	28 A	27 A	28 bc
1997/98	24 A	24 A	23 A	23 A	23 ef
1998/99	30 A	27 A	28 A	29 A	29 ab
1999/00	30 A	30 A	31 A	30 A	30 a
2000/01	24 A	25 A	24 A	24 A	24 e
2001/02	26 A	27 A	26 A	27 A	27 cd
2002/03	22 A	23 A	20 A	22 A	22 fg
2003/04	29 A	29 A	28 A	27 A	29 abc
2004/05	19 A	20 A	19 A	19 A	19 h
2005/06	20 A	22 A	20 A	19 A	20 gh
2006/07	24 A	26 A	23 A	23 A	24 e
2008/09	26 A	24 A	25 A	26 A	25 de
2009/10	20 A	21 A	20 A	19 A	20 gh
2010/11	21 B	19 AB	19 A	21 AB	20 gh
Média	25 A	24 A	24 A	24 A	24

Coefficient of variation: 12%; System I: wheat (T)/soybean (S); System II: wheat/soybean and common vetch (E)/corn (M) or sorghum; and System III: wheat/soybean, white oats (Ab)/ soybean and common vetch/corn or sorghum. Means followed by the same letter, lowercase in the column and uppercase in the row, are not significantly different by Tukey's test (p>0.05).

Pereira et al. (2011) conducted studies on a soil classified as euthophic red oxisol, with soil covered with black oats and pearl millet, and observed no differences for 1,000-grain weight or grain yield of soybean between cover crop desiccation periods. Ricce et al. (2011) worked with a soil classified as dystrophic red oxisol in grazing areas with black oats and ryegrass, and detected no differences in the number of pods per plant, number of grains per plant and grain yield in soybean between different desiccation periods before sowing soybean.

4. CONCLUSION

Crop rotation for a summer, using corn or sorghum, results in a higher yield of soybean compared with the other systems studied and monoculture soybean.

The lowest grain yield and grain weight is observed in monoculture (wheat/soybean).

And finally, there was no difference between the crop rotation systems considering the mean values of number of grains per plant, 1000-grain weight and first pod height in soybean, in the study period, from 1996/1997 to 2010/2011.

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