JARQ 44 (1), 25 - 31 (2010) http://www.jircas.affrc.go.jp

Evaluation of an Agropastoral System Introduced into Soybean Fields in Paraguay: Positive Effects on Soybean and Wheat Production

Katsuhisa SHIMODA[1,3]*, Toshiyuki HORITA[2], Ken HOSHIBA[2] and Jorge BORDON[2]

[1] Animal Production and Grassland Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305-8686, Japan)

[2] Paraguay Agricultural Technology Center, Japan International Cooperation Agency (CETAPAR-JICA) (Yguazu, Alto Parana, Paraguay)

Abstract

Effects of an agropastoral system on the production of soybean and wheat were investigated by comparing, from 2003 to 2007, agropastoral plots that had been converted from 7-year pasture (guinea grass: *Panicum maximum*; 1996 to 2003) to crop cultivation, with control plots that had been continuously cropped over 10 years with soybean at the Japan International Cooperation Agency's Paraguay Agricultural Technology Center (CETAPAR-JICA). Soybean productivity in this area increased from 1979 until 1993, when yield peaked at 3.39 t/ha and then declined. In this study, soybean yields ranged from 1.48 to 3.56 t/ha in agropastoral plots and from 0.63 to 2.47 t/ha in control plots. In each year, the yield in the agropastoral plots was 1.1 to 2.4 times more than in the control plots. Wheat yields were also higher in agropastoral plots (1.59 to 3.17 t/ha) than in control plots (1.18 to 2.31 t/ha). In each year, yield in the agropastoral plots was 1.2 to 1.8 times more than in the control plots. Thus, soybean and wheat yields were sustained by introducing an agropastoral system. We also examined the chemical and physical properties of the soil under initial conditions in both plot types. The concentrations of phosphate, potassium and magnesium in surface soil in agropastoral plots were significantly lower than in control plots. The content of organic matter at soil depths of 0 to 60 cm in the agropastoral plots was significantly higher than in the control plots, and the physical properties of the agropastoral plot soil (gaseous phase, bulk density, and soil aggregates) were improved. We conclude that the agropastoral system positively affected all these properties.

Discipline: Crop production / Grassland
Additional key words: guinea grass, pasture, rotation

Introduction

The tropical savannas of South America are among the most important potential areas in the world for expansion of agricultural production. Tropical savanna covers approximately 250 million ha[15] in South America, with large areas opened up over the last 40 years. For example, the Brazilian savanna has 12–14 million ha of grain crops[6] and over 50 million ha of newly introduced pasture areas[9]. There will be increasing pressure to bring more land into agricultural production as the world population and food demands continue to grow[15]. However, croplands under continuous cropping might degrade due to soil loss, soil compaction, loss of organic matter, and increases in pests, diseases and weeds. Pastures also tend to degrade from a lack of maintenance fertilization and poor grazing management[8]. To solve these problems, Kerridge[6] suggested integrated agropastoral systems with no-tillage as a sustainable production method. Most studies on agropastoral systems have focused on the renovation of degraded pastures by cultivating grain crops on them[4,7,9-12,16].

This study was supported by funds from the JIRCAS research project "Comprehensive Studies on the Development of Sustainable Soybean Production Technology in South America".

Present address:
[3] Nasu Research Station, National Institute of Livestock and Grassland Science (Nasushiobara, Tochigi 329-2793, Japan)
*Corresponding author: e-mail shimoda@affrc.go.jp

Received 28 July 2008 ; accepted 22 January 2009.

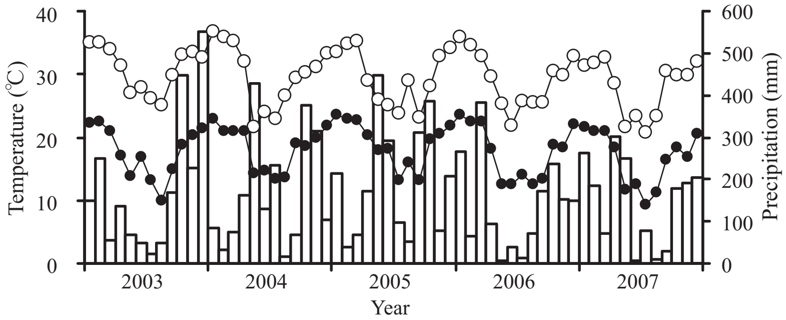

Fig. 1. Monthly temperature and precipitation in CETAPAR-JICA

Precipitation, —○— Max. temperature, —●— Min. temperature.

However, few studies have investigated the recovery of crop productivity by introducing an agropastoral system.

In Paraguay, soybean-producing areas have expanded since the 1970s. However, even under no-tillage and extensive farming conditions, decreased productivity after continuous soybean cropping has become a serious problem. Therefore, we set up long-term experimental fields to examine the effects of an agropastoral system (conversion to crop production after 7 years of pasture) on sustainable soybean production at the Japan International Cooperation Agency's Paraguay Agricultural Technology Center (CETAPAR-JICA) from 2003 until 2007. In this study, we evaluated the positive effects of the agropastoral system on soybean and wheat production, compared with a continuous double-cropping system.

Materials and methods

1. Study site

CETAPAR-JICA is located in Colonia Yguazu (a Japanese settlement, 35°27'S, 55°04'W) in Alto Parana Prefecture, the main soybean cultivation area of Paraguay[13]. Soil in this area is fertile and is known as "Terras Roxas" in Brazil[3]. Mean annual temperature and precipitation from 1972 to 2002 were 21.6°C and 1,545 mm, respectively[2]. Mean monthly maximum and minimum temperature and precipitation from 2003 to 2007 are shown in Fig. 1.

2. Experimental design

Part of a field at CETAPAR-JICA, where soybean and wheat had been continuously cropped in a no-tillage system since 1993, was converted to guinea grass (*Panicum maximum* cv. Tanzania) pasture in 1996. Established as a permanent pasture, it was maintained without fertilizer, cutting, or renovation for 7 years after establishment, and was used as a complementary pasture. In October 2003, the pasture was converted into an agropastoral site (Fig. 2), where three cropping treatments were implemented: soybean–wheat, soybean–millet, and soybean–radish. The area of each plot was 0.33 ha, and each treatment was replicated in three plots (referred to as agropastoral plots). In another part of the field adjacent to the agropastoral site, where soybean and wheat had been continuously cultivated in a no-tillage system since 1993, the non-converted treatment was replicated in three plots (referred to as control plots). Each plot was 0.68 ha.

3. Cultivation design and measurement

In each plot, we fertilized and cultivated each crop by no-tillage methods. Table 1 lists the annual fertilization in both types of plots, and Table 2 describes the cropping system of soybean and wheat. We set up five sampling

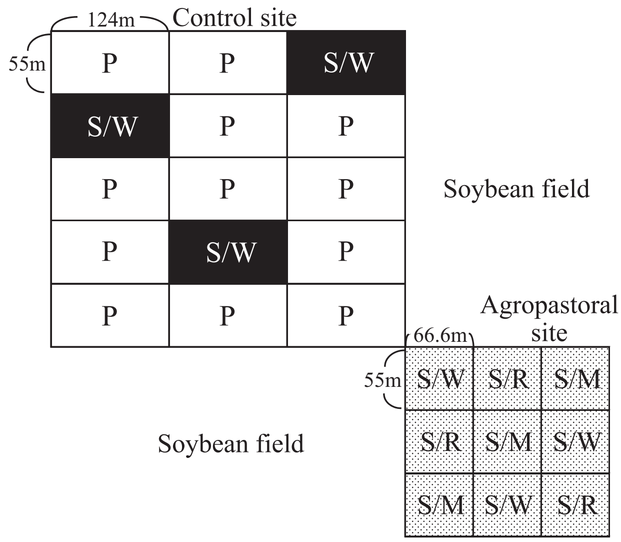

Fig. 2. Arrangement of experimental plots

Only the yield of soybean on a truck scale was measured for the whole area of the agropastoral plots. Other data were measured in the soybean and wheat plots (S/W).

M: millet, P:guinea grass, R:radish, S:soybean, W: wheat,
Left: plant in wet season / Right: plant in dry season,
Black block: Control plot (0.68ha),
Gray block: Agropastoral plot (0.33ha).

Table 1. Fertilizer application of agropastoral and control plots

		Agropastoral			Control		
		Fertilizer (kg / ha)			Fertilizer (kg / ha)		
Year	Season	N	P_2O_5	K_2O	N	P_2O_5	K_2O
2003	Wet		9.67	4.83	4.2	10	15
2004	Dry	128	92		82	92	
	Wet		60	30		60	20
2005	Dry	36	92		36	92	
	Wet		54	27		54	27
2006	Dry	78	92		78	92	
	Wet	7.2	54	18	7.2	54	18

Table 2. Profile of cropping system

	Soybean					Wheat		
	2003/04	2004/05		2005/06	2006/07	2004	2005	2006
	A & C	A	C	A & C	A & C	A & C	A & C	A & C
Variety	Aurora	Aurora	CD202	CD202	CD202	Itapua45	Itapua45	Itapua45
Seeding date	2-5/Dec.	4/Oct.	13/Nov.	12/Oct.	24-31/Oct.	31/May	11/May	31/May
Harvesting date	14-22/Apr.	22/Feb.	28/Mar.	28/Feb.	7-8/Mar.	27-30/Sep.	27/Sep.	9/Oct.
Seeding rate (kg / ha)	55	55	55	55	50	110	110	110
Row space (cm)	37	37	37	37	45	17	17	17

A: Agropastoral plots, C: Control plots.
Aurora: CETAPAR-JICA made, CD: COODETEC.

quadrats in each agropastoral plot of the soybean and wheat treatment and in each control plot. Each quadrat for soybean was 1.0 m × 1.48 m from 2004 to 2006 and 1.0 m × 1.8 m in 2007, and each quadrat for wheat was 1.0 m × 1.7 m throughout the experiments. At the end of the growing season, we measured total seed mass of each crop for seed diameters over 3 mm. In addition, soybean and wheat yields were measured in each control plot and for the whole area of the agropastoral plots at a truck scale. After harvesting, the remaining crops were abandoned and incorporated into the soil as organic matter.

Soybean productivity in the Colonia Yguazu area, to which CETAPAR-JICA belongs, was calculated from data of the Yguazu Japanese Agricultural Cooperative Association, which recorded members' land areas and production from 1979 to 2007.

4. Chemical and physical properties of soils

We collected soil samples in November 2003 as initial data in the agropastoral plots (three soybean and wheat plots) and in control plots. To investigate the chemical properties of the soil, samples from depths of 0–10, 10–20, 20–40, and 40–60 cm were collected independently from nine points per plot, and the concentrations of phosphate, potassium, calcium, and magnesium, as well as the percentage organic matter, were measured. Moreover, soil was sampled from 0–5, 5–10, 10–20, 20–40, and 40–60 cm depths (two points per plot) for measurement of physical properties, three phases of soil, bulk density, and soil aggregates. For concentrations of phosphate, potassium, calcium, and magnesium, we could only analyze samples from 20 cm below the soil surface in the agropastoral plots (three soybean and wheat plots). Soil was sampled using a soil sampler (100 ml, Daiki Rika Kogyo Co., Ltd.). The concentrations of phosphate, potassium, calcium, and magnesium were analyzed using the Mehlich-III method, and the percentage organic matter was analyzed using the Walkley-Black method. Three phases of soils and soil aggregates were measured using a three-phase meter and an aggregate analyzer (Daiki Rika Kogyo Co., Ltd.), respectively.

Results

Soybean yield in Colonia Yguazu increased after 1979, peaked at 3.39 t/ha in 1993, and then started to fall (Fig. 3). During the study period, the soybean crop failed between 2004 and 2006 (Fig. 3) because of droughts in three consecutive growing seasons (Fig. 1). There were droughts in January and February 2004 during the first cultivation season, in December 2004 and February 2005 in the second season, and in November 2005 and February 2006 in the third season. In 2007, the last season of this experiment, there were no droughts, and the soybean yield recovered to about 3.0 t/ha.

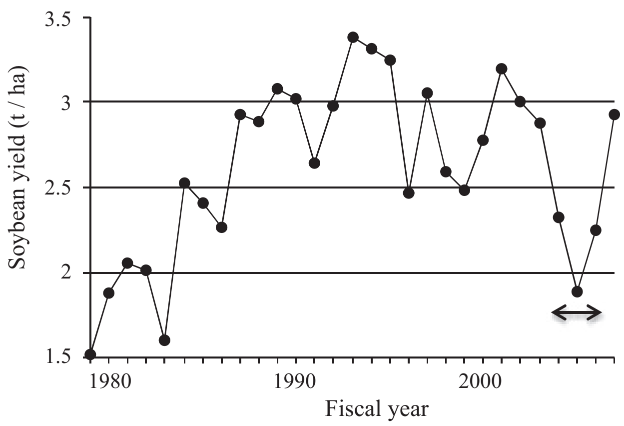

Fig. 3. Change of soybean productivity in the Colonia Yguazu area from 1979 to 2007

Arrow shows drought period during the experimental period.

Soybean yields on the truck scale in agropastoral plots were 1.48 to 3.56 t/ha, and those of control plots were 0.63 to 2.47 t/ha (Table 3). The yield at first harvest in the agropastoral plots was only 1.48 t/ha because guinea grass (as a weed) had germinated from seeds in the soil surface and competed with the crop. In each year, the yield in agropastoral plots was more than in control plots on both a truck scale (1.1 to 2.3 times) and quadrat scale (1.2 to 1.9 times).

There were droughts in August 2004 and from May to July 2006; therefore, the wheat harvest was only good in 2005. Wheat yields of agropastoral plots were 1.59 to 3.17 t/ha and those of control plots were 1.18 to 2.31 t/ha (Table 4). In each year, the yield of agropastoral plots was more than that of control plots on a truck scale (1.2 to 1.8 times) and in quadrat-scale measurements (1.1 to 1.3 times). During the experimental period, the relative yield of soybean and wheat decreased year by year (Fig. 4). The relative yield of soybean decreased from 2.31 t/ha in the first year to 1.11 t/ha in the fourth year, and that of wheat also decreased from 1.75 to 1.20 t/ha.

The concentrations of phosphate, potassium and mag-

Table 3. Soybean production from 2004 to 2007

		Truck scale (t / ha)		Quadrat scale (g / m^2)	
Cultivated Year	Harvested Year	Agropastoral n = 1	control (mean±SD n = 3)	Agropastoral (mean±SD n = 3)	control (mean±SD n = 3)
2003-2004	2004	1.48	0.63±0.21	236±17	137±19**
2004-2005	2005	3.56	1.91±0.16	484±43	253±23**
2005-2006	2006	2.84	1.96±0.10	382±12	225±20***
2006-2007	2007	2.74	2.47±0.15	369±19	304±19*

Agropastral data at truck scale is for the whole area of the agropastoral plots.
Agropastral data at quadrat scale is for soybean and wheat plots (S/W).
*: ($P<0.05$), **: ($P<0.01$), ***: ($P<0.001$).

Table 4. Wheat production from 2004 to 2006

	Truck scale (t / ha)		Quadrat scale (g / m^2)	
Year	Agropastoral n = 1	control (mean±SD n = 3)	Agropastoral (mean±SD n = 3)	control (mean±SD n = 3)
2004	2.07	1.18±0.07	307±19	245±27*
2005	3.17	2.31±0.15	434±24	388±12*
2006	1.59	1.33±0.05	257±29	219±12

Agropastral data at both scale is for soybean and wheat plots (S/W).
*: ($P<0.05$).

nesium in the soil of the agropastoral plots were significantly lower than in the control plots (Table 5). In particular, the concentration of phosphate in agropastoral plots was approximately one-fourth of that in the control plots. The concentration of potassium in agropastoral plots was approximately one-third to one-half, and the concentration of magnesium was approximately two-thirds of that in control plots. However, the concentration of calcium did not differ between the plot types.

The percentage of organic matter at each depth measured in the soil of the agropastoral plots was significantly higher than in control plots (Table 5). Moreover, the soil organic matter decreased at deeper sampling layers. The percentage of organic matter in the soil of the agropastoral plots was 11.1 to 12.1% higher than that of control plots.

In soil samples from deeper than 10 cm, the gaseous phase percentage in the agropastoral plots was significantly higher than in control plots (Table 6), but was lower at the soil surface (0–10 cm depth). The bulk density of samples from the soil surface of agropastoral plots was higher than that of control plots, and the bulk density of soil samples from deeper than 20 cm was lower than in control plots (Table 7). In addition, the percentage of large aggregates in the soil of the agropastoral plots was 3 to 7% higher than in control plots at each depth (Table 7).

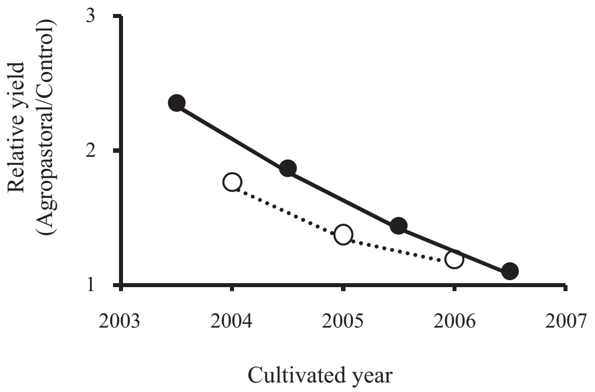

Fig. 4. Relative yields of soybean and wheat on a truck scale.
Soybean, Wheat.

Discussion

Soybean yield in the Colonia Yguazu area, which had been increasing since 1979, peaked at 3.39 t/ha in 1993 and has since declined. Seki[13] also reported that soybean yield in Colonia Yguazu increased to over 3.0 t/ha after the introduction of a no-tillage cultivation system in 1983, but

Table 5. Concentrations of phosphate, potassium, magnesium and calcium, and percentage of organic matter in soil samples

Depth (cm)	Phosphate (mg/L)		Potassium (mol/L)		Calcium (mol/L)		Magnesium (mol/L)		Organic matter (%)	
	Agropastoral (n=27)	Control (n=27)	Agropastoral (n=27)	Control (n=27)	Agropastoral (n=27)	Control (n=27)	Agropastoral (n=27)	Control (n=27)	Agropastoral (n=27)	Control (n=27)
0-10	3.40±3.05***	12.10±6.10	0.33±0.21***	0.70±0.38	5.08±0.52	5.67±2.25	1.00±0.28***	1.64±0.47	3.76±0.55***	3.15±0.50
10-20	0.45±0.39***	2.04±1.12	0.13±0.14***	0.38±0.29	4.90±0.77	4.75±1.39	0.78±0.22***	1.12±0.25	2.75±0.51***	2.28±0.48
20-40	-	1.05±1.16	-	0.30±0.25		5.10±1.07	-	1.22±0.29	1.99±0.59**	1.65±0.22
40-60	-	0.82±1.13	-	0.24±0.21		5.10±1.21	-	1.32±0.26	1.54±0.23**	1.39±0.14

Agropastoral is soybean and wheat teratment (S/W plots in Fig. 1).
: ($P<0.01$), *: ($P<0.001$).

Table 6. Three-phase distribution of the soil samples

Depth (cm)	Gaseous phase (%)		Liquid phase (%)		Solid phase (%)	
	Agropastoral (n=6)	Control (n=6)	Agropastoral (n=6)	Control (n=6)	Agropastoral (n=6)	Control (n=6)
0-5	10.7±2.2	13.5±3.4	34.2±0.4	31.6±4.0	55.0±2.1	54.9±2.4
5-10	7.1±0.8	7.7±2.9	34.6±1.3	34.3±1.4	58.2±0.5	58.1±3.7
10-20	8.7±0.7**	4.7±1.1	33.8±0.8**	37.2±1.2	57.5±1.0	58.1±1.2
20-40	11.6±2.1**	6.1±1.4	33.8±1.5	37.6±2.6	54.6±3.5	56.2±2.6
40-60	15.3±0.4***	7.3±2.1	36.7±0.3	39.9±3.1	48.0±0.7*	52.7±2.4

*: ($P<0.05$), **: ($P<0.01$), ***: ($P<0.001$).

Table 7. Aggregate and bulk density of the soil samples

	Aggregate≧0.25mm (%)		Bulk density (g/cm^3)	
Depth (cm)	Agropastoral (n=6)	Control (n=6)	Agropastoral (n=6)	Control (n=6)
0-5	92.2±0.6***	85.1±1.5	1.49±0.04**	1.37±0.05
5-10	92.4±0.7*	89.1±1.6	1.56±0.02	1.50±0.07
10-20	92.9±1.1*	89.2±2.1	1.54±0.01	1.54±0.02
20-40	91.9±2.4	89.5±3.7	1.47±0.04	1.48±0.05
40-60	91.4±0.9	89.5±3.0	1.33±0.01*	1.38±0.03

*: ($P<0.05$), **: ($P<0.01$), ***: ($P<0.001$).

the yield increase stopped in the early 1990s. Until now, the downward trend has not stopped and has become a big problem.

The crop failure of soybean corresponded with drought periods. Soybean yields on a truck scale of the agropastoral plots were 1.45 to 2.35 times more than those in control plots. Thus, drought caused much damage to soybean production, which particularly requires adequate precipitation for growth between October and February. However, the drought also highlighted the positive effects of the agropastoral system on soybean production. Seki[14] reported that a large difference in phosphate concentration between the soil surface and deep layers inhibits the deep penetration of soybean roots. Furthermore, Seki[14] and Kawasaki et al.[5] noted that the accumulation of soybean roots in the soil surface layer tended to inhibit growth during droughts. Our results also show that phosphate, potassium and magnesium accumulations in the soil surface were decreased by introducing an agropastoral system. This probably accounted for the increased yield of soybean in the agropastoral plots.

The percentage organic matter at each depth measured in the soil of the agropastoral plots was significantly higher than in control plots. Macedo et al.[10] found that the percentage organic matter in the soil surface layer (0–20 cm depth) increased over 8 years after introduction of an agropastoral system. Miranda et al.[11] also reported that total organic residues in the soil of a continuous cultivation system (collected from a depth of 0 to 40 cm) was lower than that of an agropastoral system. The agropastoral system appears to be effective in accumulating organic matter through litter supply and extension of guinea grass roots.

At the soil surface (0–10 cm depth) in agropastoral plots, the percentage gaseous phase was lower and the soil bulk density was higher. Soil compaction of surface layers inhibits soybean production[1]. However, since soil sampling was carried out immediately after killing the guinea grass with herbicides, soil compaction at the surface disappeared rapidly with the decomposition of the guinea grass roots. Since the percentage gaseous phase of soil in agropastoral plots was higher in the soil layer at 10 to 60 cm, the soil compaction in this no-tillage cultivation was reduced. In addition, the percentage of large aggregates in soil in the agropastoral plots was higher than in control plots at each depth. The higher percentage of large aggregates may promote inflow of air to the soil, promoting nitrogen fixation in soybean[1]. Therefore, it appears that improvements in the physical properties of the soil contributed to recovery of soybean productivity. Hence, we conclude that the introduction of an agropastoral system was effective for recovery of soybean productivity.

However, in the last harvest, the yield of agropastoral plots was only 1.11 times that of control plots on a truck scale. Although the yield fluctuation was large during the experimental period, the positive effects of the agropastoral system on soybean production were obvious (Fig. 4). The positive effects on soil condition after introducing an agropastoral system may disappear after 4 years of cultivation (Shimoda et al. unpublished data), therefore, further studies are needed to evaluate the effects of agropastoral systems on soybean yield and soil chemical and physical properties. The positive effect of the agropastoral system on wheat yield was probably caused by the same factors (improvements in soil chemical and physical properties) as in soybean because the relative yield trend of wheat was similar to that of soybean.

Acknowledgments

We are grateful to Dr. S. Oshio, Dr. H. Kudo, Dr. K. Suenaga, and Dr. T. Watanabe of JIRCAS and Mr. E. Shiraishi, Mr. H. Aruga, Mr. T. Oki, and Mr. H. Ikeda of CETAPAR-JICA for their support. Dr. K. Toriyama contributed significantly to the clarity of the manuscript. Special thanks are also due to Dr. A. Y. Kojima, Mrs. A. Lin, and Ms. I. M. Naka for assistance with the fieldwork.

References

1. Ae, N. (1997) Issues of fertilization in South America. *JIRCAS Working Report*, **7**, 49-53.
2. CETAPAR-JICA (2004) Meteorological data. *Einou Tsushin* (Communication paper published from CETPAR-JICA, Paraguay), **46**, 17 [In Japanese].
3. Igarashi, T. (1997) Characteristics and problems of soil fertility. *JIRCAS Working Report*, **7**, 15-27.
4. Kanno, T. et al. (2004) Grassland management technology for sustainable agro-pastoral system in the subtropical zone of Brazil. *JIRCAS Working Report*, **36**, 5-13.
5. Kawasaki, H., Iwata, F. & Mesquita, F. M. V. (1985) Concentration of soybean roots in uppermost layers of cerrado soil of Brazil. *JARQ*, **18**(4), 260-267.
6. Kerridge, P. C. (2001) A historical perspective of agropastoral system research in the savannas of South America. *JIRCAS Working Report*, **19**, 3-17.
7. Kluthcouski, J. et al. (2004) The Barreirao system: Recovering and renewing degraded pastures with annual crops. *In* Agropastoral systems for the tropical Latin America, eds. Guimaraes, E.P. et al. CIAT, Cali, Colombia, 205-239.
8. Lopes, A. S., Ayarza, M. & Thomas, R. J. (2004) Managing and conserving acid savanna soils for agricultural development: Lessons from the Brazilian *Cerrados*. *In* Agropastoral systems for the tropical Latin America, eds. Guimaraes, E.P. et al. CIAT, Cali, Colombia, 11-41.
9. Macedo, M. C. M. et al. (2001) Preliminary results of agropastoral systems in the cerrados of Mato Grosso do Sul – Brazil. *JIRCAS Working Report*, **19**, 35-42.
10. Macedo, M. C. M. et al. (2004) Results of soybean production, animal liveweight gain and soil fertility changes in agropastoral systems. *JIRCAS Working Report*, **36**, 15-18.
11. Miranda, C. H. B. et al. (2004) Soil organic residue accumulation in agro-pastoral systems in the cerrados of Brazil. *JIRCAS Working Report*, **36**, 29-33.
12. Sanz, J. I. et al. (2004) Improved rice/pasture systems for native savannas and degraded pasture in acid soils of Latin America. *In* Agropastoral systems for the tropical Latin America, eds. Guimaraes, E.P. et al. CIAT, Cali, Colombia, 240-252.
13. Seki, Y. (1999) No tillage cultivation of soybean in Paraguay. *Nougyou oyobi engei* (*Agr. & Hort.*), **74** (10), 34-38 [In Japanese].
14. Seki, Y., Hoshiba, K. & Bordon, J. (2001) Root distribution of soybean plants in no-tillage fields in Yguazau district of Paraguay. *Nettai nougyou* (*Jpn. J. Trop. Agr.*), **45**(1), 33-37 [In Japanese with English summary].
15. Vera, R. R. (2004) Research on agropastoral systems: Background and strategies. *In* Agropastoral systems for the tropical Latin America, eds. Guimaraes, E. P. et al. CIAT, Cali, Colombia, 3-10.
16. Zimmer, A. H. et al. (2004) Integrated agropastoral production systems. *In* Agropastoral systems for the tropical Latin America, eds. Guimaraes, E. P. et al. CIAT, Cali, Colombia, 253-290.