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Evaluation of an Agropastoral System Introduced into Soybean Fields in Paraguay: Effects on Soybean and Animal Production under Intensive Grazing Systems

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

[1] Crop, Livestock and Environment 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

The effects of an agropastoral system on the production of soybean and wheat were investigated by comparing (from 2007 to 2009) agropastoral plots that had been reconverted from 4-year pasture (Guinea grass: *Panicum maximum*; 2003 to 2007) to crop cultivation, with control plots that had been continuously cropped over 13 years with soybean and wheat at CETAPAR-JICA. In 2003, Guinea grass pastures were converted from 10-year continuous cultivated soybean and wheat fields, and then grazed intensively from 2004 to 2007, while the control plots continued to be cultivated with soybean and wheat. Animal production in converted pastures was very high and the weight gain per hectare was 1,113 to 1,500 kg/ha over 3 years after introducing an intensive grazing system with supplemental feeding in dry season. The average daily gain was maintained at 0.554 to 0.621 kg/head/day despite a high stocking rate (4.5-6.0 UA/ha). However, after the reconversion in 2007, the soybean yields from 2008 to 2009 were 3.71 and 1.24 ton/ha, which were 1.02 and 1.43 times higher than those in the control plots, respectively. In 2008, the wheat yield was 2.72 ton/ha, the same as that in the control plots. Thus, we concluded that the agropastoral effects on the soybean and wheat yield were small after reconversion to intensive grazing. The reason for the small effect is likely to be the low supply of Guinea grass litter under high grazing pressure, which did not result in any accumulation of the organic matter in the soil.

Discipline: Crop production / Grassland

Additional key words: Guinea grass, intensive grazing, pasture, rotation

Introduction

The tropical savannas of South America have been developed for cropland since the 1970s[7, 9, 18], but continuous cropping might lead to degradation due to soil loss, soil compaction, loss of organic matter, and increased in pests, diseases, and weeds. To overcome these problems, an agropastoral system may require a sustainable production method[7]. Many types of rotation systems and periods of conversion to pasture, however, exist. We clarified the positive effects of agropastoral systems, in which continuously cropped fields of soybean and wheat were converted to Guinea grass complementary pasture for 7 years, on the productivity of soybean and wheat at the Japan International Cooperation Agency's Paraguay Agricultural Technology Center (CETAPAR-JICA)[18]. While soybean farmers may find it difficult to keep their fields as pasture for long periods due to reduced income, the introduction of an agropastoral system could be promoted if livestock productivity is also improved. Therefore, one must demonstrate the positive effects on the productivity of soybean and wheat when the period of conversion into pasture is short and intensive grazing is also carried out with reasonable livestock productivity.

In addition, we clarified the positive effects of an

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*Corresponding author: e-mail shimoda@affrc.go.jp

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agropastoral system, in which a soybean field was converted to complementary pasture for 7 years, leading to a reduction in excess nutrient accumulation at the soil surface, the promotion of organic matter accumulation, and development of soil aggregation[18]. No previous research has examined the positive effects on soil condition after conversion to intensive grazing pasture for several years.

In this report, we clarify the positive effects of an agropastoral system in which a soybean field was converted to an intensive grazing pasture for 3 or 4 years on soybean production, animal production and the chemical properties of the soil.

Materials and methods

1. Study site and experimental design

Details of the study site are described in our previous report[18]. The experimental site was set up in a field at CETAPAR-JICA, where soybean and wheat had been continuously cropped in a no-tillage system since 1993. The mean annual temperature and precipitation from 1972 to 2002 were 21.6°C and 1545 mm, respectively[1] while the mean monthly temperature and precipitation from July 2006 to June 2009 are shown in Fig. 1.

We arranged 15 plots at the study site; each of which was 0.68 ha (124 m × 55 m). Twelve plots were randomly converted to Guinea grass (*Panicum maximum* cv. Monbasa) pasture in November 2003 (Fig. 2). These pastures were managed as intensive grazing pastures under high grazing pressure (referred to as agropastoral plots). Four or five heifers [Brahman, Brangus (Brahman × Aberdeen Angus), and Pampa (Hereford crossbred in Paraguay)] were grazed year-round in each pasture (Table 1). The stocking rate was from 4.5 to 6.0 UA/ha for 3 years. We divided each pasture plot into nine compartments using an electric fence and conducted rotation grazing at intervals of 3 or 4 days. In the winter season, we fed the cattle on a supplement of corn (0.25% of the heifer weight), nonstandard soybean (0.75%), and Guinea grass hay (0.55%) for 4 months.

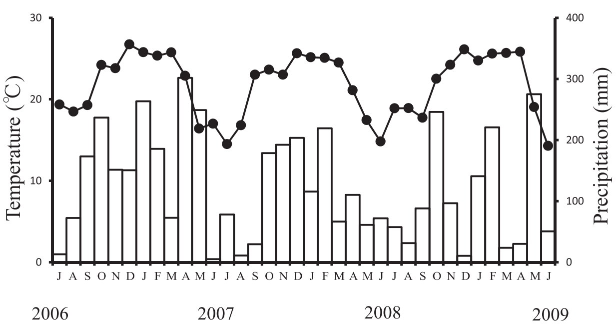

Fig. 1. Monthly temperature and precipitation at CETAPAR-JICA
□: Precipitation, –●–: Temperature.

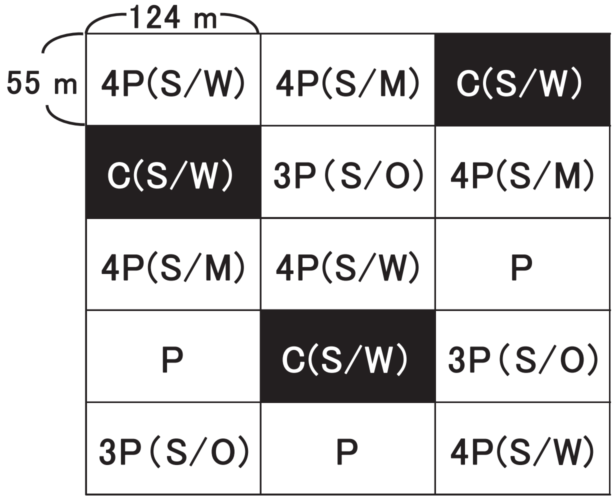

Fig. 2. Arrangement of experimental plots
Black block: Control plot,
P: Continuous pasture (Guinea grass),
3P: 3-year agropastoral plot,
4P: 4-year agropastoral plot,
S/W:Soybean (summer) and wheat (winter),
S/M:Soybean (summer) and millet (winter),
S/O:Soybean (summer) and oats (winter).

Three plots of these pastures were reconverted to soybean fields in October as no-tillage system after using herbicide (Roundup, Monsanto Ltd.) to kill off the Guinea grass in September 2006 (referred to as 3-year agropastoral plots). Six plots were also reconverted to soybean fields in October 2007 (referred to as 4-year agropastoral plots) as no-tillage systems. In the winter season, we cultivated wheat, millet, and oats in 2007 and 2008 (Figs. 2 and 3). The non-converted treatment was replicated in three plots (referred to as control plots), where soybean and wheat had been continuously cultivated in a no-tillage system since 1993.

2. Cultivation design and measurement

In each plot, we fertilized and cultivated each crop using no-tillage methods. Tables 2 and 3 list the annual fertilization and cropping system for soybean and wheat in each plot respectively. Soybean and wheat yields were measured for the whole area in each plot by truck scale. After harvesting, the remaining haulms and straws were abandoned and incorporated into the soil as organic matter. The yields of oats and millet were not measured.

Table 1. Intensive grazing profile

	2004-05	2005-06	2006-07
Grazing period (days)	387	338	393
Weight at start of a test (kg)	186	188	223
Weight at end of a test (kg)	401	398	448
Average weight gain per animal (kg/head)	214	210	225
Average daily gain (kg/head/day)	0.554	0.621	0.572
Cumulative heads per hectare (heads/ha)	6.6	7.2	5.0
Number of animals per hectare (UA/ha)	4.8	6.0	4.5
Weight gain per hectare (kg/ha)	1,395	1,500	1,113

Each value is the mean of all heifers of three strains in all pastures.
Brahman, Brangus (Brahman × Aberdeen Angus), and Pampa (Hereford crossbred in Paraguay).
UA=400 kg matured cattle.

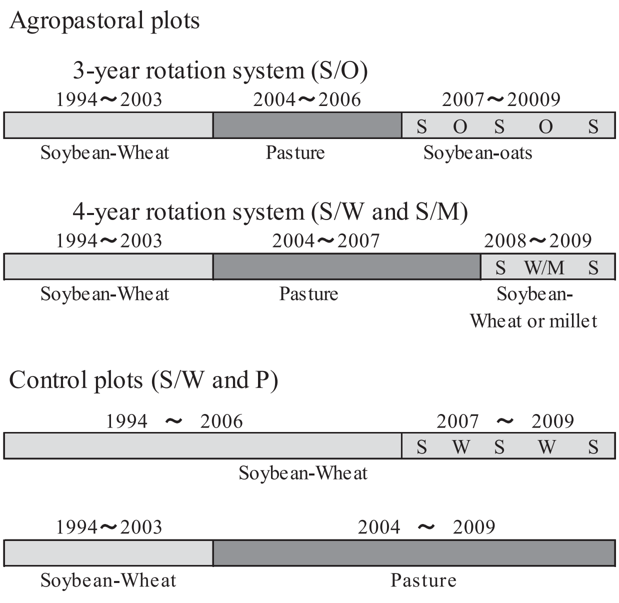

Fig. 3. Cultivation schedule

3. Chemical properties of soils

We collected soil samples in November 2003 as initial data for each plot. 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 and pH, were measured. 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. The pH of soils was measured using a pH meter (Horiba Co. Ltd.). These investigations were repeated in April 2005 and 2006.

We analyzed soybean and wheat production and soil chemical data between agropastoral and control plots using a t-test, and the annual variation of chemical data in both plots using the Tukey-Kramer method.

Results

1. Soybean and wheat yields

For the 3-year agropastoral soybean/oat plots, the soybean yield on the truck scale in 2007 was 2.06 ton/ha, which was significantly lower than the control plots (Table 4), because Guinea grass seeds germinated as weeds grew vigorously after heavy rain in September and inhibited soybean growth. The soybean yield was 3.83 ton/ha in 2008 and 0.78 ton/ha in 2009, respectively. Although the former and latter were 1.05 and 0.90 times respectively relative to the control plots, both data were statistically insignificant. The soybean yields in agropastoral and control plots in 2008 were high due to the relatively good weather conditions, but that in the 2009 harvest was low because a drought in December 2008 damaged soybeans.

For 4-year agropastoral soybean/wheat plots, the soybean yield in 2008 was 3.71 ton/ha, which was very high, namely 1.02 times the control, although statistically insignificant. The yield of 2009 was 1.24 ton/ha, which although low was significantly higher (43%) than that in the control plots.

For the 4-year agropastoral soybean/millet plots, the soybean yield was 3.78 ton/ha in 2008 and 1.04 ton/ha in 2009. The former and latter were 4 and 20% higher than that in the control plots respectively, but both data were statistically insignificant.

Table 2. Fertilizer application (kg/ha) of agropastoral and control plots

Year	Season	Agropastoral (3 years)			Agropastoral (4 years)			Control		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
2003	Wet	−	−	−	−	−	−	4.2	10.0	15.0
2004	Dry	−	−	−	−	−	−	82.0	92.0	−
	Wet	32.0	−	−	32.0	−	−	−	60.0	20.0
2005	Dry	32.0	−	−	32.0	−	−	36.0	92.0	−
	Wet	32.0	−	−	32.0	−	−	−	54.0	27.0
2006	Dry	32.0	−	−	32.0	−	−	78.0	92.0	−
	Wet	7.2	54.0	18.0	45.0	45.0	15.0	7.2	54.0	18.0
2007	Dry	36.0	92.0	−	32.0	−	−	36.0	92.0	−
	Wet	7.2	54.0	18.0	7.2	54.0	18.0	7.2	54.0	18.0
2008	Dry	70.4	28.4	28.4	12.3	32.4	18.4	70.4	28.4	28.4
	Wet	4.8	43.2	43.2	4.8	43.2	43.2	4.8	43.2	43.2

Wheat, millet, and oats were cultivated in the dry season.

Table 3. Profile of cropping system common to 3- and 4-year agropastoral plots

	Soybean			Wheat	
	2006/07	2007/08	2008/09	2007	2008
Variety	CD202	CD202	CD202	Itapua45	Itapua70
Seeding date	24-31/Oct.	19/Oct.	8/Oct.	10/May	8/May
Harvesting date	7-8/Mar.	14/Mar.	4/Mar.	19/Sep.	16/Sep.
Seeding rate (kg/ha)	50	50	50	110	110
Row space (cm)	45	45	45	20	20

CD: COODETEC.

Table 4. Soybean production (ton/ha) from 2007 to 2009

Cultivated Year	Harvested Year	Agropastoral			Control
		3 years pasture	4 years pasture		
		Soybean/Oats	Soybean/Wheat	Soybean/Millet	Soybean/Wheat
		n=3 (Mean±SD)	n=3 (Mean±SD)	n=3 (Mean±SD)	n=3 (Mean±SD)
2006-2007	2007	2.06±0.11*	−	−	2.47±0.15
2007-2008	2008	3.83±0.11†	3.71±0.06	3.78±0.07†	3.63±0.11
2008-2009	2009	0.78±0.09	1.24±0.15*	1.04±0.25	0.87±0.06

* : Data differ significantly from the control ($P<0.05$).
† : Data differ from the control ($P<0.10$).

The wheat yield in the control plots was 2.41 ton/ha in 2007 (Table 5). A severe drought in June and August 2007 caused a wheat yield decrease. The wheat yield in 4-year agropastoral soybean/wheat plots in 2008 was 2.72 ton/ha and did not exceed the control plots (2.80 ton/ha).

2. Animal production

The weight gain per hectare was 1,113 to 1,500 kg/ha over 3 years after introducing an intensive grazing system (Table 1). The average daily gain was maintained at 0.554 to 0.621 kg/head/day despite a high stocking rate (4.5-6.0 UA/ha). The mean weight was about 400 kg 1 year after the start of grazing.

3. Chemical properties of soils

The concentration of phosphate in soil samples in 2003 (initial data) did not differ significantly between the agropastoral and control plots (Table 6); however, in the continuous cropping field converted to Guinea grass pasture, it decreased rapidly in the soil surface layer and halved within 1 year. In contrast, phosphate increased rapidly in the control plots, and doubled in the surface layer year after year.

Table 5. Wheat production (ton/ha) in 2007 and 2008

Cultivated Year	Agropastoral (4 years pasture) n=3 (Mean±SD)	Control n=3 (Mean±SD)
2007	−	2.41±0.07
2008	2.72±0.08	2.80±0.14

Concentrations of potassium and organic matter in soil samples in 2003 (initial data) did not differ significantly between the agropastoral and control plots (Tables 7 and 8) and did not change the following year. In 2006, the concentration of potassium in the soil surface layer tended to decrease in the control plots and rose significantly in the agropastoral plots.

Concentrations of magnesium and calcium in soil samples in 2003 (initial data) did not differ significantly between the agropastoral and control plots (Tables 9 and 10), but tended to decrease at each depth in both plot types. In particular, the concentration of magnesium in the agropastoral plots decreased significantly at each depth.

The pH of soil samples in 2003 (initial data) did not differ significantly between the agropastoral and control plots (Table 11). However, it tended to increase gradually in the agropastoral plots and decrease gradually in the control plots. In particular, at the soil surface, the pH in the agropastoral plots was significantly higher than in the control plots.

Table 6. Change in phosphate concentration (mg/kg) in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	13.35±4.94[a]	6.66±2.72[b**]	6.82±2.99[b**]	12.10±2.82[a]	22.73±5.20[a]	42.79±5.61[b]
10−20	1.78±0.91	1.44±0.89[**]	1.99±1.86[**]	2.04±0.60[a]	3.10±0.45[a]	14.33±5.32[b]
20−40	0.85±0.69	0.86±0.57	1.01±1.80	1.05±0.71	0.86±0.45	3.04±3.73
40−60	0.67±0.70	0.66±0.54	0.93±1.80	0.82±0.64	0.63±0.33	2.17±3.58

Pasture considered with all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).
** : Data differ significantly from the control (P<0.01).

Table 7. Change in potassium concentration (mg/kg) in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	0.69±0.29	0.61±0.21	0.75±0.11[**]	0.70±0.38	0.36±0.07	0.50±0.10
10−20	0.40±0.19[ab]	0.25±0.11[a]	0.47±0.07[b]	0.38±0.29	0.23±0.07	0.37±0.07
20−40	0.29±0.16	0.17±0.07	0.29±0.06	0.30±0.24	0.19±0.07	0.29±0.05
40−60	0.25±0.15	0.14±0.05	0.23±0.07	0.24±0.17	0.19±0.08	0.23±0.01

Pasture considered of all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).
** : Data differ significantly from the control (P<0.01).

Table 8. Change in organic matter percentage(%) in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	3.25±0.37	3.46±0.28	3.33±0.34	3.15±0.40	3.26±0.12	3.20±0.41
10−20	2.40±0.33	2.45±0.20	2.47±0.29	2.28±0.30	2.56±0.05	2.34±0.24
20−40	1.71±0.16[ab]	1.62±0.17[a]	1.81±0.17[b]	1.65±0.17	1.64±0.11	1.73±0.12
40−60	1.42±0.13[a]	1.25±0.10[b]	1.46±0.14[a]	1.39±0.11	1.19±0.22	1.38±0.06

Pasture considered of all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).

Table 9. Change in magnesium concentration (mg/kg) in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	1.63±0.41[a]	1.25±0.22[b]	1.13±0.12[b]	1.64±0.49	1.20±0.18	1.10±0.21
10−20	1.13±0.33[a]	0.89±0.13[b]	0.75±0.10[b]	1.12±0.27	0.88±0.15	0.77±0.15
20−40	1.18±0.34[a]	0.90±0.11[b]	0.66±0.09[c]	1.22±0.29[a]	0.89±0.13[ab]	0.66±0.13[b]
40−60	1.31±0.30[a]	0.99±0.10[b]	0.73±0.12[c]	1.32±0.19[a]	0.94±0.12[b]	0.72±0.11[b]

Pasture considered of all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).

Table 10. Change in calcium concentration (mg/kg) in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	5.26±1.85	4.26±0.96	4.30±0.54	5.67±1.08	3.98±1.13	3.83±0.74
10−20	4.38±1.38	3.84±0.86	3.97±0.50	4.75±1.20	3.52±1.09	3.28±0.72
20−40	4.49±1.26	4.09±0.74	3.92±0.54	5.10±0.91[a]	3.70±0.82[ab]	2.85±0.46[b]
40−60	4.44±1.17	4.12±0.78	3.86±0.41*	5.10±0.94[a]	3.90±0.75[ab]	3.00±0.56[b]

Pasture considered of all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).
* :Data differ significantly from the control (P<0.05).

Table 11. Change in pH in the soil

Depth(cm)	Pasture (n=12. Mean±SD)			Control (n=3. Mean±SD)		
	2003	2005	2006	2003	2005	2006
0−10	5.89±0.16[a]	6.02±0.18[ab*]	6.11±0.12b**	5.83±0.11	5.71±0.19	5.66±0.08
10−20	5.60±0.14	5.76±0.20*	5.80±0.19	5.59±0.12	5.50±0.11	5.59±0.21
20−40	5.57±0.12	5.72±0.13*	5.74±0.14	5.63±0.06	5.53±0.12	5.57±0.22
40−60	5.59±0.14[a]	5.74±0.11[b]	5.78±0.13[b]	5.64±0.08	5.59±0.13	5.66±0.26

Pasture considered of all pasture plots converted from continuous cropping fields.
Values in the same row with a different letter differ significantly (P<0.05).
* :Data are significantly different from the control (P<0.05). ** : (P<0.01).

Discussion

1. Soybean and wheat yields in 4-year agropastoral soybean/wheat plots

The same treatment plots as control plots were only soybean/wheat treatment plots in 4-year agropastoral plots, which can be compared to control plots because the crops are the same and although the soybean yield was high, it did not differ significantly from that in the control plots in 2008. On the contrary, the soybean yield in 2009 was low but differed significantly from that in control plots. In this area, the soybean yield previously amounted to 3 ton/ha[17, 18], the former was a good harvest but the latter was a bad harvest, which was influenced by the low precipitation. Since it is easy to bring about the effects of an agropastoral system in a drought year[17, 18], the effects were only considered obvious in 2009. Many studies reported that the root of the soybean was distributed within a shallow soil layer with a no-tillage system[5, 6, 14]. In addition, the phosphate accumulates near the soil surface, which restricts the crop root distribution within a shallow soil layer with a no-tillage system[4, 17]. Plants with shallower root systems have a disadvantage in terms of uptake and are sensitive to drought[16].

However, the wheat yield did not differ from that in control plots. Since the water requirement of wheat is lower than that of soybean[19], the drought damage may be small.

2. Soybean yields in 3-year agropastoral soybean/oat plots and 4-year agropastoral soybean/millet plots

In both plots, only the soybean yields in 3-year agropastoral soybean/oat plots in 2007 and those in 4-year agropastoral soybean/millet plots in 2008 could be used to evaluate the effects of the agropastoral system. The former was significantly lower than that in the control plots because the soybean growth was inhibited by the vigorous growth of the Guinea grass as a weed. The latter did not differ from that in the control plots due to good precipitation.

In other cases, the soybean yield in 3-year agropastoral plots in 2009 did not differ from the control plots. Shimoda et al.[18] reported that the effects of agropastoral system were lost after 4 years in 7-year agropastoral plots, hence these effects might be lost after 2 years of 3 years conversion. The soybean yield in 4-year agcropastoral soybean/millet plots in 2009 exceeded that in control plots but did not differ significantly from the control plots.

Therefore, we concluded that the agropastoral positive effect on the yield of soybean and wheat was small in our three or four year agropastoral conversion experiments.

3. Animal production and the effects of the intensive grazing system

We introduced an intensive grazing system into the converted pastures, which led to a weight gain of 1,113 to 1,500 kg/ha over 3 years (Table 1), about three times that of a conventional agropastoral system[11]. In addition, the average daily gain was 0.554 to 0.621 kg/head/day, and the mean weight of a heifer was about 400 kg 1 year after the start of grazing. Therefore, the animal weight that could be shipped in 1 year could be increased when a calf of about 200 kg was grazed on this system.

Macedo et al.[10] reported that the relative ratio of the soybean yield between all 4-year agropastoral and control plots in the first year was 1.12 (calculated from their table) under a conventional grazing system (weight gain of cattle per hectare one-third that of our intensive grazing system). In addition, Shimoda et al.[18] reported that the relative ratio in 7-year agropastoral and control plots was 2.35 in the first year and 1.86 in the second year under an extensive grazing system (using a complementary pasture). Our relative ratio was 1.02 in the first year and 1.43 in the second year under an intensive grazing system, which suggests that intensive grazing had little effect on soybean production. This may have occurred because the root extension to the deeper soil layers was inhibited[12] and the accumulation of organic matter was reduced by grazing[13].

We thought that the income generated from the grazing animals may support farmers and encouraged the introduction of agropastoral systems. However, since intensive grazing reduces the agropastoral effects, caution is required.

4. Chemical properties of soils

Phosphate in the top soil decreased by half in the first year after converting continuous cropping fields to pasture, but continued to increase in the control plots. Shimoda et al.[18] reported the same phenomenon in 7-year agropastoral system subject to extensive grazing but the positive effects of the agropastoral system on soybean and wheat yields were clear. Therefore, it was thought that the influences of phosphate on the yields of soybean and wheat by reducing the phosphate in the top soil could be small.

In general, soybean does not grow well in acidic soil, and a pH range of 6.0 to 6.5 is best for soybean cultivation[8]. In our system, soil pH in the top soil improved from 5.89 to 6.11 over 3 years in the pasture, whereas soil pH fell and the soil acidified in the control plots. Therefore, the improvement of soil pH may have had the same effect on the increase of the soybean yield in 2008.

Studies have reported that the accumulation of organic matter in soil is promoted by introducing agropastoral systems[11, 15, 18]. In general, organic matter develops the soil aggregate structure and improves its water-retention capacity[20]. However, the accumulation of organic matter was not promoted in our experiment. Ogawa & Mitamura[13] also reported that the accumulation of organic matter was not promoted by grazing. This was because the root growth was inhibited by cutting the aboveground part of the grass[2, 3]. In addition, considerable grass was grazed and 1.54 ton/ha was carried out from the pasture as cattle meat every year under our intensive grazing, as opposed to the small amount under conventional grazing (0.54 ton/ha)[10]. Therefore, the supply of litter was considered small in our experiment, if supplement feeds were taken into consideration. Conversely, Shimoda et al.[18] reported that a 7-year agropastoral system under extensive grazing promoted the accumulation of organic matter in the soil and the effects of the agropastoral system on soybean and wheat yields were clear, hence we considered the effects of the accumulation of organic matter on soybean and wheat yields to be significant.

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References

1. CETAPAR-JICA (2004) Meteorological data. *Einou tsushin* (Communication paper published from CETPAR-JICA, Paraguay), **46**, 17 [In Japanese].
2. Davidson, J. L. & Milthorpe (1966) Leaf growth in *Dactylice glomerata* following defoliation. *Ann. Bot*., **30**, 174−184.
3. Davidson, J. L. & Milthorpe (1966) The effect of defoliation on the carbon balance in *Dactylice glomerata*. *Ann. Bot*., **30**, 185−198.
4. Holanda, F. S. R. et al. (1998) Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in the soil profile. *Commun. Soil Sci. Plant Anal*., **29**, 2383−2394.
5. Iijima, M. et al. (2007) No-tillage enhanced the dependence on surface irrigation water in wheat and soybean. *Plant Prod. Sci*., **10**, 182−188.
6. Izumi, Y., Yoshida, T. & Iijima, M. (2009) Effects of subsoiling to the non-tilled field of wheat-soybean rotation on the root system development, water uptake, and yield. *Plant Prod. Sci*., **12**, 327−335.
7. Kerridge, P. C. (2001) A historical perspective of agropastoral system research in the savannas of South America. *JIRCAS Working Rep*., **19**, 3−17.
8. Kokubun, M. (2002) Soybean. *In* Encyclopedia of crop science, ed. Crop Science Society of Japan, Asakura Publishing, Tokyo, Japan, 370−377 [In Japanese].
9. Macedo, M. C. M. et al. (2001) Preliminary results of agropastoral systems in the Cerrados of Mato Grosso do Sul - Brazil. *JIRCAS Working Rep*., **19**, 35−42.
10. Macedo, M. C. M. et al. (2004) Results of soybean production, animal liveweight gain and soil fertility changes in agro-pastoral systems. *JIRCAS Working Rep*., **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 Rep*., **36**, 29−33.
12. Ogawa, Y. & Mitamura, T. (1981) Studies on cessation of grazing on permanent pasture ecosystem: 3. Effect of cessation of grazing on the form and function of the root system of orchardgrass pasture. *J. Japan. Grassl. Sci*., **27**, 240−244 [In Japanese with English summary].
13. Ogawa, Y. & Mitamura, T. (1982) Studies on cessation of grazing on permanent pasture ecosystem: 5. Effect of cessation of grazing on some chemical characteristics in the soil. *J. Japan. Grassl. Sci*., **27**, 407−412 [In Japanese with English summary].
14. Oyanagi, A. et al. (1998) Analyses of the vertical distribution of roots in wheat, soybean and rice in tilled and non-tilled multipurpose paddy fields. *Jpn. J. Crop Sci*., **67**, 49−55 [In Japanese with English summary].
15. Salton, J. C. & Lamas, F. M. (2007) Integration of farming-livestock and cultivation of the cotton plant in savannahs. *In* Cotton in the savannah of Brazil, ed. Ferire E. C., Brasilia, Brazil, 379−402 [In Portuguese].
16. Schwinning, S. (1988) Summer and winter drought in a cold desert ecosystem (Colorado Plateau). I. Effects on soil water and plant water uptake. *J. Arid Environ*., **60**, 547−566.
17. 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**, 33−37 [In Japanese with English summary].
18. Shimoda, K. et al. (2010) Evaluation of an agropastoral system introduced into soybean fields in Paraguay: Positive effects on soybean and wheat production. *JARQ*, **44**, 25−31.
19. Stanhill, G. (1986) Water use efficiency. *Adv. Agron*., **39**, 53−85.
20. Uwasawa, M. (2002) Management of organic matter and fertilizers. *In* Encyclopedia of plant nutrition and fertilizers, ed. Editorial committee of encyclopedia of plant nutrition and fertilizers, Asakura Publishing, Tokyo, Japan, 436−439 [In Japanese].