Nitrogen Flow in Agropastoral Systems, Brazil

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Abstract

Agropastoral systems that combine soybean and grasses in a crop rotation have been proposed for sustaining grassland productivity in the low-fertility soils of the Brazilian savanna. We studied the nitrogen flow under an agro-pastoral system developed in 1993 in a Purple Red Latosol in Campo Grande, MS. Four cropping systems were included: continuous soybean cropping, soybean cropping after 4 years of grass cultivation, continuous grass cultivation, grass cultivation after 4 years of soybean cropping. The rate of N fixation in soybean was determined by the N difference method and 15N natural abundance method. A non-nodulating isoline, T201, was used as a control in both methods. The rate of N2 fixation ranged from 23 to 51% of the total plant N. The amount of N taken out as grains was larger than the amount of fixed N in soybean. The amount of N entering the system through rainwater was 6 kgN/ha/yr. Nitrate accumulating in soil from the surface to a depth of 100 cm under soybeans indicated the potential leaching of nitrate. The estimated amount of nitrate leaching from the soybean fields was large compared with that from the grasslands. A large negative N balance of 134-211 kgN/ha/yr was estimated in the soybean fields, whereas the N balance in the grasslands was a slightly negative.

Additional key words: leaching, nitrogen fixation, soybean, grassland, nitrogen balance

Introduction

Most of the area of central Brazil is covered by a tropical savanna vegetation referred to as "Cerrado". The soil of the area is characterized by a low pH (4.8-5.2), a high degree of Al saturation, and a low level of extractable P[12]. The area is mainly used as grasslands planted to *Brachiaria* for beef cattle grazing. As a root mass of the grass species is large and deep[9,16], organic matter accumulates in the soil profile of the grassland over years[6].

Because N and P fertilizers are usually not applied in a grassland after reclamation, the productivity of the grassland gradually decreases. Maintaining soil fertility is an important issue to sustain productivity in any agricultural systems. Agropastoral systems that combine soybean and grasses in a crop rotation have been proposed for sustaining grassland productivity in low-fertility soils. One of the major advantages of these systems is that lime and P fertilizer are used for the crops and that subsequent grasses benefit from the residual P. Since N is added to the system through N_2 fixation by soybean, the grasses grow relatively well. On the other hand, the organic matter content of the soil decreases steadily under cropping[22] and soybean cultivation[20]. Therefore, the content of organic N in soil also decreases. It can be considered that soybean plants absorb a large amount of N mineralized from soil N and that this crop fixes a considerable amount of atmospheric N_2.

To evaluate the role of soybean in agropastoral systems, a quantitative study was carried out to determine the contribution of N_2 fixation by soybean and the N flow in the system.

Materials and Methods

Experimental site

A long-term field experiment was carried out at the National Beef Cattle Research Center, National Corporation of Agricultural Research (EMBRAPA-CNPGC), Campo Grande, MS, Brazil, located at 20° 27'S and 54° 37' W. The climate is subtropical with a mean annual rainfall of 1,544 mm. The rainy season starts in September-October and ends in April-May. The mean maximum and minimum temperatures were 28.8℃ and 18.3℃, respectively. The soil in this area is classified as Purple Red Latosol (Oxisol).

The experimental layout is shown in Table 1. In 1993, at the beginning of the experiment, 80 kg P_2O_5/ha and 2.5 t/ha of calcium dolomite were applied as fertilizer. For our study, four systems were selected, as follows:

1) Continuous grassland. Grass (*Brachiaria decumbens cv. Basilisk*) was sown in November 1993. 2) Continuous soybean cropping. 3) Rotational soybean cropping. Grass (*Panicum maximum cv. Tanzania*) was cultivated for 4 years, followed by soybeans for 2 years; and, 4) Rotational grassland. Soybeans were cultivated for 4 years, followed by grass (*Panicum maximum cv. Tanzania*) for 2 years. Several beef cattle were sometimes grazed in the grasslands. In the continuous grassland plot, NPK fertilizer (14 kg N/ha, 70 kg P_2O_5/ha and 70 kg K_2O/ha) was applied in 1993 just before sowing. In the soybean cropping plot, PK fertilizer (80 kg P_2O_5/ha and 80 kg K_2O/ha) was applied when the soybean plants were sown in November. Soybeans were harvested in April of the next year.

Measurement of N_2 fixation by soybean

The amount of N_2 fixation by a nodulating soybean (*Glycine max* cv. *Conquista*) plant was measured by using a non-nodulating isoline, T201, as control. Nodulating soybean seeds were inoculated with proper *Bradyrhizobium* and cultivated in the continuous soybean and rotational soybean plots.

Table.1. Cropping hisotry of grass(G) and soybean(S) in the experiental plots

Plot	Symbol	1993/1994	1994/1995	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000
Continuous grassland	CG	G	G	G	G	G	G	G
Continuous soybean	CS	S	S	S	S	S	S	S
Rotational soybean	RS	G	G	G	G	S	S	S
Rotational grassland	RG	S	S	S	S	G	G	G

Cultivation experiment was carried out for 2 years from November 1998 to March 2000. In November 1998, a nodulating soybean was sown and harvested in March 1999. T201 was sown in November 1998 and harvested in February 1999. In the second year, a nodulating soybean as sown in November 1999 and harvested in March 2000. T201 was grown on vermiculite in a greenhouse, transplanted in December 1999 and harvested in March 2000. Harvested plants were separated into stover and grain, and oven-dried at 60 ℃ for more than 48h. The oven-dried samples were ground to powder and analyzed for total N content by the Kjeldahl method. Ground grain samples were analyzed for ^{15}N natural abundance with a stable isotope ratio mass-spectrometer (Finnigan MAT delta E type) at Shoko Company ltd., Tokyo, Japan .

For the estimation of the N_2 fixation rate, we used two methods, N difference method and ^{15}N natural abundance method. N difference method is based on the difference in N amounts between the nodulating and non-nodulating soybeans. ^{15}N natural abundance method is based on the difference in ^{15}N natural abundance in the grains of the two types of soybeans, as described by Manguiat *et al.*[14].

Measurement of N in rainwater

Rainwater was collected using a plastic container covered with an iron funnel, 26cm in diameter one or two times per month. NO_3^- and NH_4^+ in the samples were analyzed by the hydrazine reduction method[11] and by the indophenol method (JIS K0102), respectively. The annual deposition of inorganic N (NO_3^- N+ NH_4^- N) was calculated by multiplying the monthly mean precipitation[8] by inorganic N concentrations in rainwater.

Measurement of NO_3^- in soil and pH

Soils were collected at a depth of 0-10 cm from the continuous soybean plot and rotational soybean plot from June 1999 to March 2000. Soils were further collected for NO_3^- determination from the 0-10, 10-20, 20-40, 40-60, 60-80 and 80-100 cm depths in June 1999 for the continuous grassland and continuous soybean cropping plots and in November 1999 for the rotational grassland and rotational soybean cropping plots. A 20g aliquot of soil was extracted with 100 ml of 10% (w/v) KCl, and the filtrate was analyzed for NO_3^-. The remaining soil samples were screened through a 2 mm stainless steel sieve and were air-dried. The pH(H_2O) values were determined using a soil-water weight ratio of 1 : 2.5.

Estimation of N leaching

The rate of the downward movement of NO_3^- was estimated by the solution retardation factor (SRF), expressed by:

$$SRF = 1 + kad \times S/W \quad (1)$$

where *kad* is a distribution coefficient related to absorption, S is the soil bulk density, and W is the water content per unit volume. *SRF* is expressed by kad, which is related to the rate of NO_3^- adsorption by the soil in terms of levels of soluble NO_3^- [23].

The *kad* coefficient was calculated from the NO_3^- relationship between the liquid phase and solid phase.

$$kad = SP/LP \quad (2)$$

where SP is the NO_3^- concentration in the solid phase (mg/kg), LP is the NO_3^- concentration in the liquid phase (mg/L).

Measurement of kad was performed for soils of 0-10, 40-60 and 80-100cm depths in the continuous soybean cropping plot. A 5g aliquot of soil was placed in a 100 mL plastic bottle and 50 mL of KNO3 solution (20 or 50mgN/L) was poured. The bottle was shaken for 1 hr. The NO_3^- content in the filtrate was analyzed. The NO_3^- content in soil was calculated from the difference between the total NO_3^- content and NO_3^- content in the solution.

Results and Discussion

N_2 fixation by soybean

The primary input of N to an agricultural system is through the application of N fertilizer and through biological N_2 fixation. A secondary source is N deposition with rain, specially in areas close to factories emitting N pollutants or agricultural land with a high utilization of N fertilizers. In the present agropastoral experiment, only a small amount of N fertilizer was used. Therefore, N_2 fixation is likely to be the primary route of N input.

Table2. yield of nodulating soybeans

Plot	Harvest year	Dry weight (kg/ha) Stover	Dry weight (kg/ha) Grain	Hundred-grain weight (g)	N uptake (kgN/ha) Stover	N uptake (kgN/ha) Grain
CS	1999	10740	5100	19.9	353	315
CS	2000	8040	4200	17.6	278	257
RS	1999	9980	3740	17.6	277	235
RS	2000	6030	2930	17.0	204	186

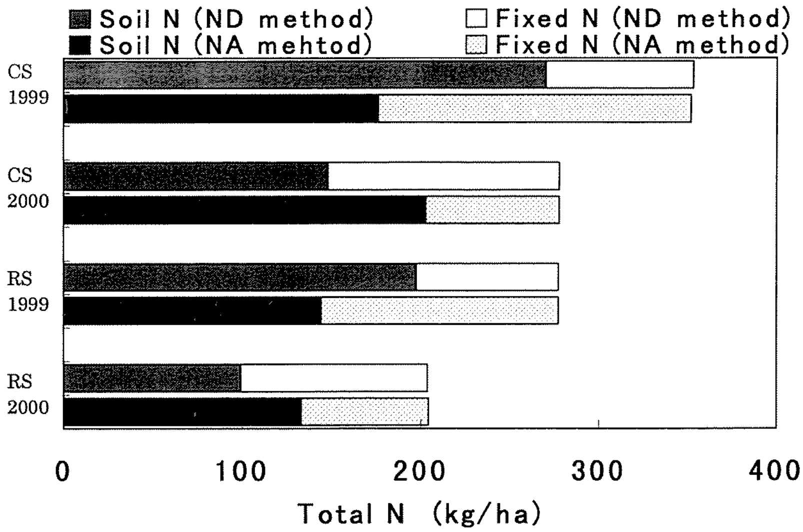

Fig.1. N yield and contribution of fixed N and soil-derived N to total Nof soybean harvested in 1999 and 2000.
CS: continuos soybean plot, RS: rotational soybean plot, ND method : N difference method, NA method: ^{15}Nnatural abundance method.

Table 2 shows the yield of nodulating soybeans. Yield was higher in 1999 than in 2000, and in the continuous soybean plot compared with the rotational soybean plot. The hundreds grain weight increased with increasing grain yields.

Fig. 1 shows the contribution of fixed N and soil-derived N. The amount of soil-derived N determined by the N difference method, which is equivalent to the N uptake by T201, was smaller in 2000 than in 1999, presumely due to the shorter growth period. Since the first seeding in November failed, another seeding of T201 was carried out in December in a greenhouse. Yearly variations of the amount of soil-derived N were smaller when the ^{15}N natural abundance method was used than when the N difference method was used, indicating that the ^{15}N natural abundance method was more appropriate than the balance method for the estimation of N_2 fixation in this system.

The contribution of N_2 fixation ranged from 23 to 50% in the continuous soybean plot and 28 to 51% in the rotational soybean plot. Although these values were smaller than 70-80% reported in other trials in Brazil [3], they were close to or slightly smaller than the mean 50% value recorded in Japan [25]. The estimated amount of fixed N was 116 kgN/ha in the continuous soybean plot and 97 kgN/ha in the rotational soybean plot from the means of N2 fixation.

Fig. 2 shows the amount of NO_3^- N accumulated in the 0-10cm soil of soybean fields. Just before the soybeans were sown, NO_3^- N accumulated at the rate of 20-35 mg/kg. It is known that the rate of N_2 fixation decreases in the presence of mineral N[17]. In this study, the rate of N_2 fixation was less than 50% since the amount of soil-derived N was large.

N input from the atmosphere

Table 3 shows the concentrations of NH_4^-N and NO_3^-N in rainwater. The mean NO_3^-N was 0.21 mg/L, and the mean NH_4^-N was 0.21 mg/L. The primary sources of NH_3 are factories, intensive agriculture, and poultry production, but since there are no such sources in the Cerrado area, the NH_4^+

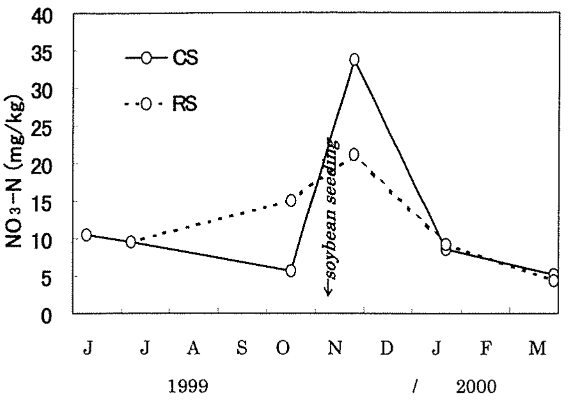

Fig.2. Nirrrete accumulation in surface soil (0-10cm) in soybean fields.
CS: continuous soybean plot
RS: rotational soybean plot

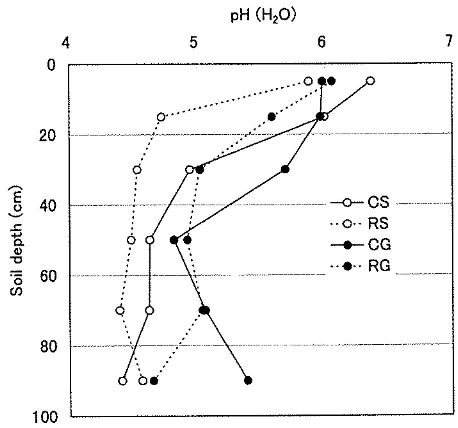

Fig.3. Soil pH in soil profile.
CS: continuous soybean plot, RS: rotational soybean plot
CG: continuous grassland plot, RS: rotational grassland plot

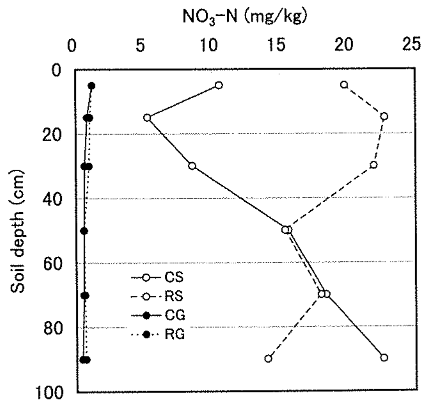

Fig.4. Concentration of NO_3-N (mg/kg) in the soil profile.
CS: continuous soybean plot, RS: rotational soybean plot
CG: continuous grassland plot, RS: rotational grassland plot

Table3. Concentration of NH_4-N and NO_3-N in the rainwater collected in Campo Grande from October 1998 to Decenber 1999

	Mean	Max.	Min.
pH	6.5	7.0	6.1
NH_4-N (mg/L)	0.21	0.77	0.01
NO_3-N (mg/L)	0.21	0.57	0.05
Inorganic N (mg/L)	0.43	1.33	0.06

concentrations in rainwater are low. The annual amount of N deposition from rainfall was approximately 6 kgN/ha. Although this value was much smaller than the 43 kgN/ha of value recorded in urban areas in Brazil[13)], it was almost the same as that obtained in a savanna in Venezuela[7)].

N output by leaching

Fig. 3 shows the value of the soil pH in relation to the soil depth. The surface 0-10cm soil pH increased to around 6 in all the plots as a result of liming, but the subsoil pH remained low, indicating that the effect of lime application would be limited at the soil surface.

Fig. 4 shows the concentration of NO_3^-N at a soil depth up to 100 cm. The amount of NO_3^-N at the 40-100cm soil depth was calculated to be 4, 5, 136 and 114 kg/ha for the continuous grassland plot, rotational grassland plot, continuous soybean plot and rotational soybean plot, respectively. NO_3^- did not accumulate to a depth of 1 m in the grasslands. Because grass roots are dense and grow in all the soil profiles (unpublished), and N fertilizer was not applied in these grassland plots, the results may indicate that grasses absorbed most of the N mineralized from organic soil sources. As a result, NO_3^- did not accumulate in the soil profile.

In contrast, large amounts of NO_3^- accumulated in the soil from the soil surface to a depth of 1 m in both the continuous soybean cropping and rotational soybean cropping plots. Similar results were obtained from leguminous trees[24)]. The soybeans were planted in rows spaced 40 cm apart, and it is known that soybean roots grow primarily in the upper soil layers because of the low pH in the subsoil[10)]. Therefore, in this case, NO_3^- among the rows had infiltrated downwards, and a larger amount of NO_3^- leaching may have occurred in the soybean fields.

Fig. 5 shows the distribution of NO_3^- in the solid phase and liquid phase. In the figure, *kad* could be obtained from the slope calculated from this solid liquid relationship. The relation between *kad* and the

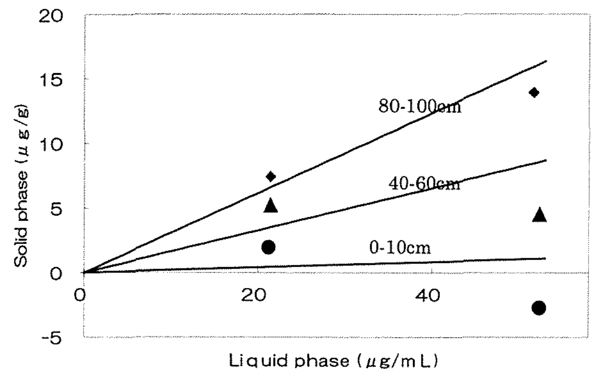

Fig.5. Solid phase-liquid phase distribution of NO_3^- in contiuous soybean field soil.
(Marks are measured value of ● : 0-10cm, ▲ : 40-60cm, ◆ : 80-100cm)

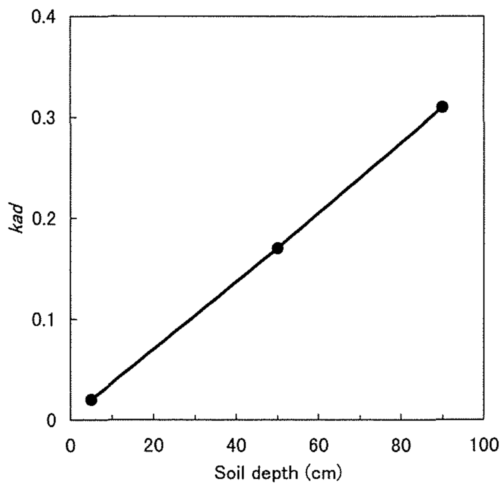

Fig.6. Relationship between soil depth and *kad* in contiuous soybean feild plot.

soil depth is shown in Fig. 6. The value of *kad* increased from almost 0 in the surface soil to approximately 0.3 at a soil depth of 80-100 cm, presumably due to the lower pH in the deeper soil, as pointed out by Takeuchi[23].

N leaching was estimated from the downward water movement, infiltration, and NO_3^- concentrations in the soil water. Rainfall minus evapo-transpiration equals infiltration. The mean annual rainfall with a period of 22 years from 1970 to 1991 was 1,540 mm in Campo Grande[8], and the evapo-transpiration of soybeans was 840mm[18]. During the fallow period, there had been only 330 mm of rainfall. Assuming the absence of infiltration when soybeans were not cultivated, the annual infiltration was 370 mm. Based on a subsoil water content of 21% and annual infiltration, the annual water transport was estimated to be approximately 1,550 mm.

Based on the *SRF*, the annual NO_3^- transport amounted to 600 mm. Using *kad*, the NO_3^- concentration in the soil water was calculated to range from 31-36 mg/L. There were no large differences in the soil water NO_3^- concentrations among the soil depths. Using the soil water NO_3^- concentrations at a 80-100 cm depth, the level of annual NO_3^- leaching in the plot with continuous soybean cropping was estimated to be 76 kg/ha, and in the rotational soybean plot, 48 kg/ha.

On the other hand, annual evapo-transpiration of 1,161 mm[19] was used for the continuous grassland plot, and the NO_3^- concentration in the soil water was calculated to be 0.8 mg/L from the NO_3^- content of the 80-100cm soil layers and kad. As a result, the amount of N leaching was estimated to be only 1 kg/ha, a value smaller than the N deposition through the rain. The lower amount of leaching N than the amount of rain N was also demonstrated in grasslands in Japan[1].

In this study, the denitrification rate in the subsoil was assumed to be zero. Although denitrification occurred in the subsoil[21], a small part of leached NO_3^- was probably emitted as N_2 or N_2O. In a grassland, the amount of surface run-off water was higher than that by leaching. Therefore, it is likely that a larger amount of N runs off from both grassland and soybean field

N balance

Table 4 shows the estimated N balance for the soybean fields and grasslands. For the soybeans, 10% of the grain N was not accounted due to expected losses during harvest. N fixation provided the largest input of N to the soybeans. In contrast, the grain harvest represented the largest N output from the system. The amount of N leaching from the soybean fields was also substantial. As a result, the N balance in the soybean fields was largely negative compared with the grasslands. Assuming that the soil depth is 40 cm, the annual amount of soil N decrease in the soybean fields corresponds to 27 to 42 mg N /kg soil.

Silva *et al.*[20] described the decrease in organic

Table4. Estimated N barlance for soybean fields and grasslands

	kgN/ha/year			
	Soybean field		Grassland	
	CS	RS	*B. decumbens*	*B. humidicola*
Input				
N_2 fixation	116	97	29[a]	0[c]
Deposition	6	6	6	6
Total	122	103	35	6
Output				
Harvest of soybean and animal liveweight gain	257	189	12[b]	8[c]
Leaching	76	48	1	1
Losses from dung and urine			53[b]	22[c]
Total	333	237	66	31
Balance	-211	-134	-31	-25

[a] Miranda, C. H. B., unpublished, [b] Cadisch *et al.*, 1994, [c] Boddey *et al.*, 1996

matter (OM) in clay soils by the following equation:

$$OM = 0.97 + 1.79 \times \exp(-0.24t) \qquad (4)$$

where t is time (year). With a C/N ratio of 16.6 for the soybean field, the predicted annual decrease in the amount of N ranged from 32 to 83 mg N/kg soil, which roughly corresponds to the amount calculated in this report.

For *Brachiaria decumbens* grasslands, the amount of non-symbiotic N_2 fixation has been estimated to be 29 kgN/ha/year (Miranda et al. unpublished data). This value was small compared with the 45 kgN/ha/yr value reported by Boddey *et al.*[2]. The amount of N taken out for weight gain of beef cattle from this grassland plot was small, and the leaching was almost zero. Nevertheless, the N balance was also negative. In this study, the amount of N_2O emission from a field was not determined. Mean annual N_2O emission from a cultivated field has been estimated to be 1 kgN/ha/yr without N fertilizer application[15].

As NO_3^- leaching occurs in continuously cropped soybean fields, such a system may not be compatible with sustainability. However, the NO_3^- accumulated in the subsoil can be absorbed by grasses that are grown subsequently. Therefore, a system that combines agriculture and animal husbandry may be more sustainable.

On the other hand, both continuously cropped soybean fields and grasslands showed a negative N balance. Therefore, in order to sustain N fertility in soil under these conditions, some application of N fertilizer may be necessary.

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ブラジルの農牧輪換システムにおける窒素のフロー

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摘　要

ブラジルのサバンナの低肥沃土地帯の草地の生産力を持続的に維持するために、ダイズと牧草を組み合わせた農牧輪換システムが提案されている。我々は、マットグロッソドスル州カンポグランデ市の赤紫色ラトソル土で１９９３年から実施している農牧輪換システムにおける窒素のフローを調査した。４種類の作付区を選んだ。：連続ダイズ区、草地４年跡ダイズ区、連続草地区、ダイズ４年跡草地区。ダイズによる窒素固定量は窒素差し引き法と^{15}N自然安定同位体比法から求めた。非根粒着生系統 T201 を両測定法の対照に用いた。収穫時ダイズ地上部窒素の 23 ～ 51% が窒素固定由来であり、収穫物として持ち出された窒素量はダイズによる窒素固定量より多かった。雨水からの窒素の年間負荷量は 6kgN/ha あった。ダイズ畑では硝酸態窒素が表層から 1m の深さに蓄積していたことから窒素の溶脱の可能性が指摘された。ダイズ畑からの窒素溶脱量の推定値は草地に比べて多くなった。ダイズ畑の窒素収支は 134 ～ 211 kgN/ha の大きなマイナスとなった。一方、草地でもマイナスとなったが値は小さかった。

キーワード　；溶脱、窒素固定、ダイズ、草地、窒素収支