GREEN-MANURE TURNIP FOR SOYBEAN BASED NO-TILLAGE FARMING SYSTEMS IN EASTERN PARAGUAY

Aki Kubota[1]*; Kent Hoshiba[2]; Jorge Bordon[2]

[1]*DAPO 7777, Metro Manila - Philippines.*
[2]*CETAPAR-JICA, Ruta 7, km 45, Distrito Yguazú, Depto. Alto Paraná, Paraguay.*
**Corresponding author <akikubota@yahoo.com>*

ABSTRACT: A no-tillage soybean-wheat cropping system has been practiced for many years on the “Terra Rossa” soils of eastern Paraguay. Soil compactness and soil erosion have recently been identified as potential problems. This study examines the effect of replacing unprofitable wheat by green-manure turnip (*Raphanus sativus* L. *var. oleiferus* Metzg.) on soil properties and soybean production. Gaseous phase, porosity, bulk density, water saturation, cone index, pH, exchangeable-cations, available-phosphorus (P) and aggregate size distribution of the soil were measured. Contrary to initial expectations, turnip did not reduce soil compactness. Instead, turnip stabilized the aggregate structure of the surface soil. Positive effects of turnip on subsequent soybean growth and yield were detected in a rather dry year but not in an exceptionally wet year. In a second part of this study, nutrient return from turnip and wheat residues were compared. Turnip produced 10.7 t ha^{-1} of shoot dry matter, and absorbed 294, 27, 302, 175, and 33 kg ha^{-1} of N, P, K, Ca, and Mg, respectively. Wheat absorbed 98, 11, 67, 11, and 7 kg ha^{-1} of N, P, K, Ca, and Mg, respectively. About 75% of the N absorbed by wheat was removed from the field at harvest whereas most nutrients in the turnip residue were returned to the soil before planting of soybeans with positive effects on soil fertility. Additional benefits of green-manure turnip would include a reduced chance for erosion through improvements in aggregate structure and through a more complete soil cover.
Key words: soil compactness, aggregate structure, crop residue, nutrient return

ADUBAÇÃO VERDE COM NABO PARA SOJA EM SISTEMA DE PLANTIO DIRETO NO LESTE PARAGUAIO

RESUMO: Um sistema de plantio direto de rotação soja-trigo foi praticado por muitos anos em uma “Terra Roxa” no leste do Paraguai. A compactação do solo e a erosão foram reconhecidas recentemente como problemas potenciais. Este estudo examina o efeito da substituição do trigo antieconômico pela adubação verde com nabo (*Raphanus sativus* L. *var. oleiferus* Metzg.) sobre as propriedades do solo e a produção de soja. A fase gasosa, porosidade, densidade do solo, saturação em água, índice de cone, pH, cátions trocáveis, fóforo disponível (P) e distribuição de agregados foram medidos. Ao contrário das expectativas iniciais, o nabo não reduziu a compactação do solo. Ao contrário, ele estabilizou a estrutura dos agregados na superfície do solo. Efeitos positivos do nabo no crescimento e produtividade da soja plantada em seguida, foram detectados em um ano muito seco, mas não em um ano excepcionalmente úmido. Em uma segunda parte desse estudo foram comparados os retornos de nutrientes do nabo e do trigo. O nabo produziu 10.7 t ha^{-1} de matéria seca da parte aérea e absorveu 294, 27, 302, 175, e 33 kg ha^{-1} de N, P, K, Ca, e Mg, respectivamente, enquanto o trigo 98, 11, 67, 11, e 7 kg ha^{-1} de N, P,K,Ca, e Mg, respectivamente. Aproximadamente 75% do N absorvido pelo trigo foi removido do solo por ocasião da colheita, enquanto que a maioria dos nutrientes do resíduo do nabo retornaram ao solo antes do plantio da soja, com efeitos positivos em relação à fertilidade do solo. Benefícios adicionais da adubação verde com nabo, incluem a probabilidade reduzida de erosão através da melhoria da estrutura dos agregados e uma melhor cobertura do solo.
Palavras-chave: compactação do solo, estrutura de agregados, resíduo de cultura, retorno de nutriente

INTRODUCTION

No-tillage farming is widely practiced on the fertile “Terra Rossa” soils of the Yguazú district, eastern Paraguay. Soybeans [*Glycine max*. (L.) Merr.] are the dominant summer crop and yields are among the highest of major soybean producing countries. Wheat [*Triticum aestivum* L.] is the most common winter crop but yields are low due to unfavorable climatic conditions. Benefits of no-tillage systems that leave crop residues on the soil surface are the stabilization of soil moisture and temperature (Benegas, 1998), an improvement of aggregate stability and an increase in soil organic matter (Hajabbasi & Hemmat, 2000), higher water infiltration rates (Gill, 1998), and a reduction in soil erosion (Sidiras et al., 1982, Dabney et al. 2004). However, negative effects of long-term no-tillage farming have recently attracted attention. Nutrients accumulate in the surface soil (Seki et al., 2001; Pierce et al., 1994), bulk density and soil penetration resistance may increase due to a lack of tillage (Pierce et al., 1994; Vazquez et al., 1989) and weed competition may rise (Kemper & Derpsch, 1981). Seki et al. (2001) observed a reduction of soybean yields in dry years due to soil compaction that prevented root penetration to deeper layers containing residual soil moisture.

Introducing green manure crops during winter could represent a biological solution to these problems. All cover crops evaluated in the study of Kemper & Derpsch (1981) produced a substantially higher root mass than wheat with positive effects on reducing soil compactness. Green-manure turnip (*Raphanus sativus* L. *var. oleiferus* Metzg.), locally called "nabo", has recently been introduced to Paraguay as a green manure crop. However, the effect of turnip on reducing soil compaction and improving soil physical properties by biopore formation is not well documented. The objective of this study was to compare the effects of wheat and green-manure turnip on soil properties and on soybean productivity (Experiment I). An additional objective was to estimate benefits of turnip residue on soil nutrient balances (Experiment II).

MATERIAL AND METHODS

Experiment I: Effect of green-manure turnip on soil properties and soybean production

A field experiment was conducted in the Yguazú district of eastern Paraguay. The field consists of a clayey soil called "Terra Rossa", classified as Rhodic Kandiudox. Location and soil texture are shown in Table 1. Prior to this experiment the field was cropped with soybean-wheat under the no-tillage system typically practiced in the region. The experimental design consisted of complete randomized blocks with three replicates, comparing winter crops: wheat (*Triticum aestivum* L.) to green-manure turnip (*Raphanus sativus* L. *var. oleiferus* Metzg.). Soybeans (*Glycine max.* [L.] Merr.) were planted in all plots after winter crops. The area of the experimental units was 25 m^2 (5 by 5 m). The experiment was conducted over a 3-year period from May, 1998 to April, 2001. The first year served as a transition period, data having been only collected for years two and three.

No-tillage farming was practiced in all plots. Fertilizer application and sowing rates followed local farmer's practices with the exception that all the work was performed manually. A compound fertilizer was broadcasted on the soil surface every year before planting winter crops at a rate of 36 kg N and 92 kg ha^{-1} of P. No fertilizer was applied before planting soybeans. The distance between rows was 20 cm for wheat and turnip and 35 cm for soybeans. Seeds were sown manually to satisfy 110 kg, 20 kg and 55 kg ha^{-1} for wheat, turnip and soybean, respectively. Timing of planting, harvesting and cutting down turnip were decided according to the weather and growth stages of the plants. Growing periods of each crop are presented in Table 2. Varieties used were IAN9 for winter wheat, and Aurora for soybean. Aurora is a nodulating soybean variety that has recently been introduced into eastern Paraguay. The growing period is usually 130 to 140 days. However, a soybean variety suitable for late sowing (FT2001, nodulating) was used in the 1999-2000 growing season because dry conditions delayed sowing.

Table 1 - Location and soil properties of the site.

Depth	Location	U.S.Taxonomy class[1]	Soil particle size distribution (g kg^{-1})			Texture	Soil color
			Sand	Silt	Clay		
			2.0-0.05	0.05-0.002	< 0.002 mm		
cm							
0-5	25°27'22.8"S 055°02'42.3"W	Rhodic Kandiudox	454	207	339	Clay Loam	2.5YR 3/3
5-15			436	224	340	Clay Loam	2.5YR 3/3
15-30			334	191	475	Clay	10R 3/3

[1]U.S. soil classification, Gorostiaga et al., 1995.

Table 2 - Growing period of crops in Experiment I.

Growing season	Winter crops		Summer crop	
1999-2000	Wheat	May 10 -- Sep. 27, 1999	Soybean	Jan. 4 -- May 11, 2000
	Turnip	May 10 -- Aug. 23, 1999		
2000-2001	Wheat	June 1 -- Oct. 13, 2000	Soybean	Nov. 8, 2000 -- March 28, 2001
	Turnip	June 1 -- Sep. 22, 2000		

In the final year of the study, soil samples for physical analysis were taken after winter crops (October 2000) and after soybean (May 2001) using a core sampling cylinder with 5 cm height and 100 cm^3 volume. Samples were taken along soil profiles in 5 cm increments to a depth of 30 cm. Two core samples were taken for each depth in each plot and mean values were used. Three soil phases were measured by a soil three-phase meter (Daiki Rika Kogyo Co., Ltd., Japan) which is a type of gas pycnometer based on Boyle's Law (Danielson & Sutherland, 1986). Gaseous phase, total porosity and water saturation percentage were then calculated. Bulk density was estimated from oven-dry mass of the solid phase in core samples. The cone index was measured 4 times in every 5 cm depth with a push-cone soil hardness meter (penetrometer) with a 12° 40' degree circular cone and a 1.8 cm-diameter base.

Soil samples for the analysis of aggregate structure and chemical properties were taken from three points per depth (5 cm increments to a depth of 30 cm), and then mixed in plastic bags. Wet aggregate distribution was determined by the wet sieving method (Sato, 1972) using a Yorder type aggregate analyzer (Yorder, 1936) that shakes 30 times per minute. The weight percentage of each size fraction (> 2.0, 2.0-1.0, 1.0-0.5, 0.5-0.25, 0.25-0.1, and < 0.1 mm) was determined. This procedure was repeated twice and mean values were used in data analysis. Soil samples for chemical analysis were air-dried, crushed, and sieved to < 2 mm. Soil pH was measured in a 1:2 air-dried soil/distilled water suspension. The available soil phosphorus (P) was measured by the Mehlich-3 method (Mehlich, 1984). Exchangeable calcium (Ca), magnesium (Mg) and potassium (K) in soil samples were determined by atomic absorption spectroscopy after extraction with a Mehlich-3 extractant (Mehlich, 1984).

Soybean shoots were sampled from two 4 m rows per plot following growth periods of 127 days in 2000 and 140 days in 2001. The soybean samples were dried at 80ºC for 48 h and weighed. Seeds were removed from plants, and total seed weight and 100 seeds weight were recorded. All data was subjected to analysis of variance using PROC GLM of SAS (SAS, 1989). The LSD test was used for comparisons of treatment means within years.

Experiment II: Nutrient uptake and return from wheat and turnip residues

This study was carried out in 1999 in an area adjacent to the one used for experiment I. The experimental design consisted also of complete randomized blocks with three replicates. Wheat and green-manure turnip were sown on May 10, 1999. Sowing and fertilizer application were made by machine with row distances and fertilizer application rates as given for experiment I. For the analysis of total nutrient uptake, plant shoots from two 5-m rows were sampled randomly from three points that were out side of the residue experiment plots. Wheat grains were harvested 136 days after sowing (Sep. 23), while straw was left on the soil surface. Turnip plants were cut 104 days after sowing (Aug. 24), and all plant parts were left on the soil surface. Crop residues were picked up manually from an area of 1 m^2 in each plot on the day after crops were cut down and in monthly intervals thereafter. Wheat residue was sampled three times, (Sep. 24, Oct. 26, Nov. 26) and turnip residue 4 times (Aug. 25, Sep. 24, Oct. 26, Nov. 26).

Residue samples were dried at 80ºC for 48 h and weighed before being ground to pass a 2-mm mesh. For total N analysis, ground samples were digested with H_2SO_4 and analyzed by the Kjeldahl method using an auto destillator (MRK-MATIC Auto Vapor-Still). For P, K, Ca and Mg analysis, samples were digested with HNO_3 and $HClO_4$. P was analyzed by the ammonium metavanadate colorimetric method, and K, Ca and Mg were analyzed by atomic absorption spectroscopy. The inorganic-N content of soil samples (a total of NO_3-N and NH_4-N) was measured by the Conway (1947) microdiffusion method. Soil samples were taken from the surface layer (top 5 cm) at the flowering stage of soybeans (Exp.I) and before soybeans were planted in November (Exp.II).

In addition we investigated the effect of green-manure turnip on growth and N content of corn as a representative of non-N-fixing crops. Following wheat and green-manure turnip that were grown as described for experiment II, corn (c.v. Dekalb747) was sown on Oct.1, 2000. The seeds were sown by machine with a planting space of 80 cm between rows, and 3 to 4 seeds m^{-1}. Fertilizer was not applied. Five corn shoots were sampled on February 2, 2001 from 3 randomly chosen points. Samples were dried, weighed, milled and analyzed for total-N uptake as described in experiment II.

RESULTS AND DISCUSSION

Experiment I: Effect of turnip on soil properties and soybean production

Effect on soil physical properties - Data on gaseous phase ratio, bulk density, water saturation and cone index, as influenced by different winter crops, are presented in Figure 1. The gaseous phase ratio was higher at a depth of 5 to 15 cm following turnip. Turnip roots were observed to about 15 cm depth in the soil, and this difference was due to turnip roots. The ratio of gaseous phase is often used as an indicator of oxygen supply in soils (Hasegawa, 1994). Soybean roots consume a high amount of oxygen because of their association with rhizobium (Ae & Nishi, 1983). A gaseous phase of more than20% at a depth of 7.5 cm and of more than 10% at 10 to 15 cm is considered optimal (Kouda, 1983). The

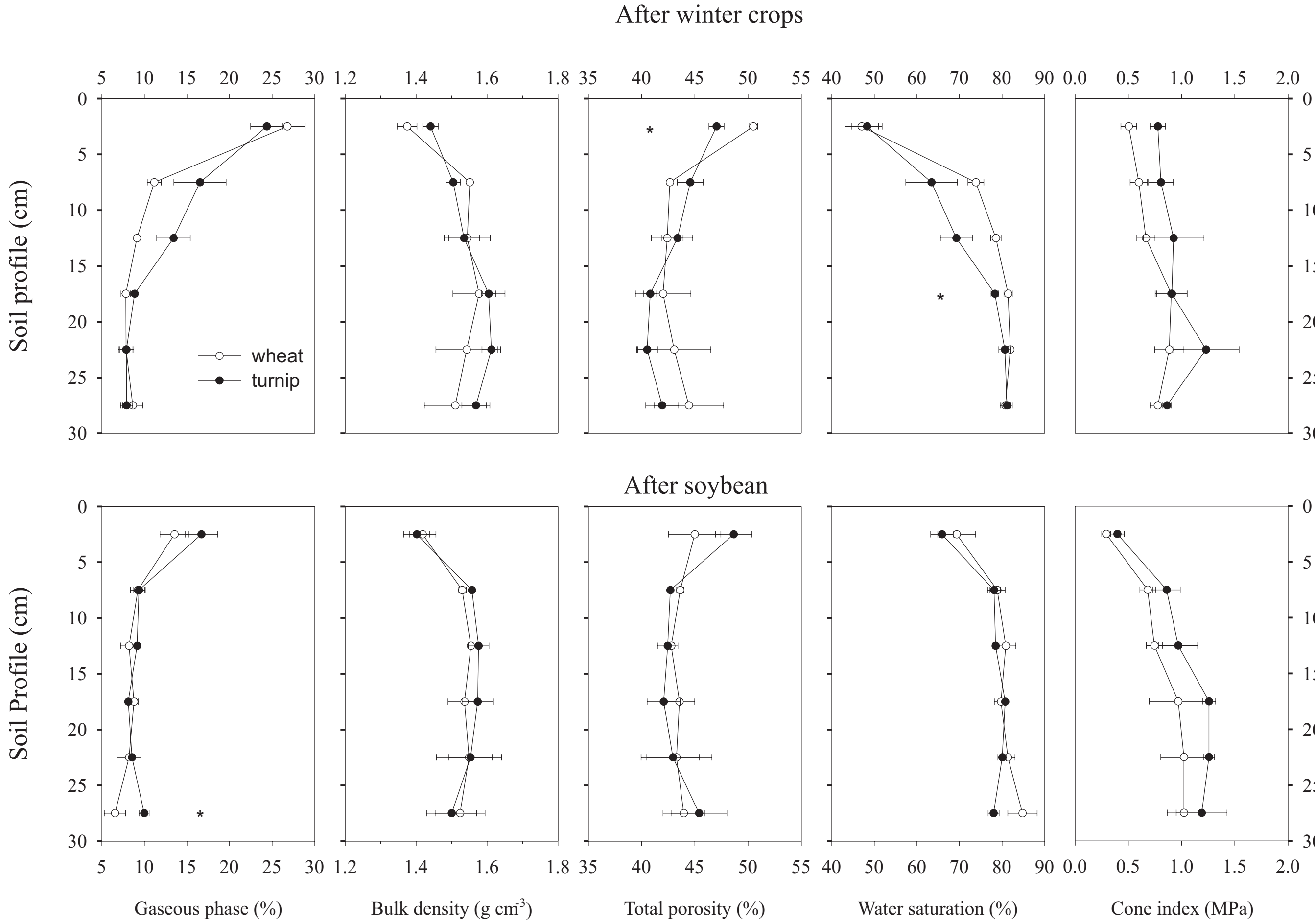

Figure 1- Effects of winter crops on soil physical properties, measured after winter crops (Oct., 2000) and after soybeans (May, 2001) in the 2000-01 growing season. Error bars: SE (n = 3).
*indicates difference at $P = 0.05$ (LSD).

gaseous phase ratio following wheat was below these values, which indicated that continuous soybean-wheat cropping may have a negative effect on symbiotic nitrogen fixation due to an oxygen shortage for optimum rhizobium activity.

Soil bulk density was not clearly influenced by winter crops. Soil bulk density in the top 5 cm was slightly higher after turnip but this inverted at 5 to 10 cm depth. The higher density in the surface soil may have been due to the lateral enlargement of turnip roots. Values of bulk density were inversely related to values of total porosity. It was expected that turnip roots produce biopores in the soil and increase porosity, thereby decreasing bulk density. However, results over the entire soil profile were contrary to this expectation. Soil water saturation was lower after turnip at 5 to 15 cm depths, indicating that soil containing finer wheat root residues could hold more water.

Soil hardness as measured by the cone index was not reduced following turnip. This result was also contrasting to the initial expectation that turnip reduces soil compactness through biopores formed by roots. One possibility is that measuring soil hardness with a pointed cone-shaped penetrometer may not be able to present a reliable average value for soil hardness. Soil adjacent to turnip roots may have hardened due to the radial growth pattern of turnip roots. A positive effect on hardness may only be noticeable where turnip roots have been decomposed over time. Such an effect would not have been detectable with present methods because measurements were taken before roots have been decomposed. However, hardness remained slightly higher even after the subsequent soybean crop. The cone index in turnip plots did not exceed the critical value of 1.27 MPa, which was found to restrict soybean taproot growth (Sato et al., 2001). The maximum cone index measured in turnip plots was 1.26 MPa. From a soil survey of the Yguazú district conducted in 2000, we obtained a maximum cone index of 4.72 MPa in a coarser-textured soil under soybean-wheat based no-tillage farming (data not shown). An undisturbed forest soil also showed a higher value (2.40 MPa) than the cone index of this study.

Aggregate size distributions in the surface layer (0-5 cm) were affected by winter crops (Figure 2). The portion of large aggregates (> 0.5 mm) increased from 54% in wheat plots to 67% in turnip plots. This difference was especially pronounced for aggregates larger than 2 mm. The aggregate stability of the surface soil was probably influenced by the amount of biomass left on the surface. This result indicated that growing turnip as a winter green manure would stabilize soil aggregates with possible benefits for erosion control. Surface residues reduce erosion indirectly by increasing size and stability of soil aggregates (Black, 1973). This positive effect is noteworthy because soybean roots tend to have a negative effect on soil aggregate stability (Fahad et al., 1982). This can lead to greater soil erosion as compared to other crops such as corn (Alberts et al., 1985; Laflen & Moldenhauer, 1979), and high erosion rates have indeed been observed for the large-scaled soybean-wheat farming system of eastern Paraguay, even under no-tillage farming.

Effects on soil chemical properties - Figure 3 shows the influence of turnip on soil pH, available phosphorus (P), and exchangeable calcium (Ca), magnesium (Mg) and potassium (K). Soil pH was not strongly affected except in the surface soil where it was higher following turnip. The amount of exchangeable Ca in the soil did not differ notably between treatments, although it is reported that large amounts of Ca are dissolved from turnip residues on the soil surface (Pavan, 1997). Exchangeable Mg was slightly higher following wheat but exchangeable K was higher in the turnip plot throughout the soil profile. Available-P only differed at depths exceeding 15 cm. The difference was small but significant between 25 to 30 cm depths. The effect of improving the P status in subsurface soil could be important since phosphorus accumulation in the soil surface is one of the problems with long-term no-tillage farming. None of these effects were long-lasting and were not detectable in soil samples taken after the soybean crop.

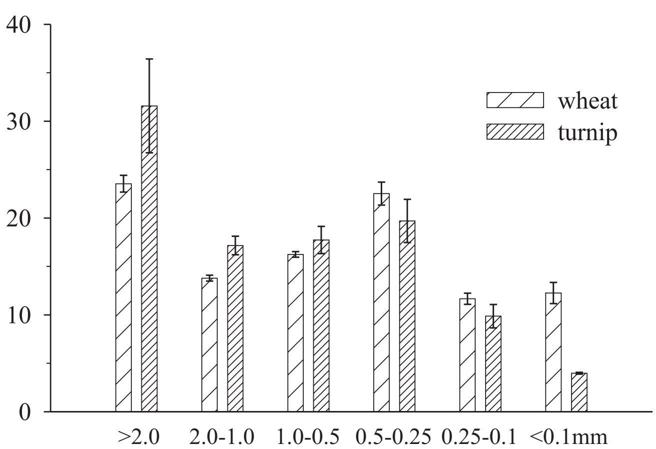

Figure 2 - Aggregate size fraction (mm) of surface soil (0-5 cm) measured at the end of experiment, May, 2001. Error bars: SE (n = 3).

Effects of turnip on following soybean yields - Sowing was delayed in the 1999-2000 growing season (Table 2), because of insufficient rain in October and November (Figure 4). A soybean variety suitable for late sowing, FT2001, was used. Dry weather and a shorter vegetative growth period restrained soybean growth (Table 3). Shoot dry weight and seed yield were consequently lower compared to the 2000-01 growing season. In that dry year, yield and shoot dry weight of soybean was higher after turnip than after wheat. Doran et al. (1984) also showed that effects of surface residues on soybean yields are greater in stressful climatic conditions. In the 2000-01 growing season, the plot received high rainfall and seed yields were exceptionally high due to, we assume, high uptake of N with high mass flow rates, especially during the flowering period when plants take up high amounts of soil-N (Figure 4). Shoot weight was higher in turnip plots but seed yield was lower, and that resulted in a slightly lower harvest index. The 100 seed weight of soybean was higher after turnip compared to wheat. These data indicated that soybean plants following turnip had very vigorous vegetative growth and that some flowers and pods were aborted before maturity. This has also been observed in farmer's fields, and it could be a symptom of excess N (Hoshi et al., 1978). These results suggest that growing turnip as a green manure crop in winter is beneficial for the growth of following soybeans when soybean growth and yield are restrained by insufficient soil moisture or soil N. No positive effect was noted in wet years. However, this impact will not only depend on N fertility but also on physical / chemical soil properties of the field.

Table 3 - Shoot dry weight, seed yield, 100 seed weight and harvest index of soybeans as affected by winter crops.

Winter crop before soybean	Seed yield	Shoot dry wt.	100 seeds wt.	Harvest Index
	------ kg ha^{-1}	------	g	
		1999-2000		
Wheat	2213	6319	14.1	0.35
Turnip	2653	7371	13.8	0.36
	ns	*	ns	ns
		2000-2001		
Wheat	4657	8495	16.8	0.56
Turnip	4390	8724	17.5	0.50
	ns	ns	*	ns

ns - Non significant at 5% (LSD)
*different at 5% (LSD).

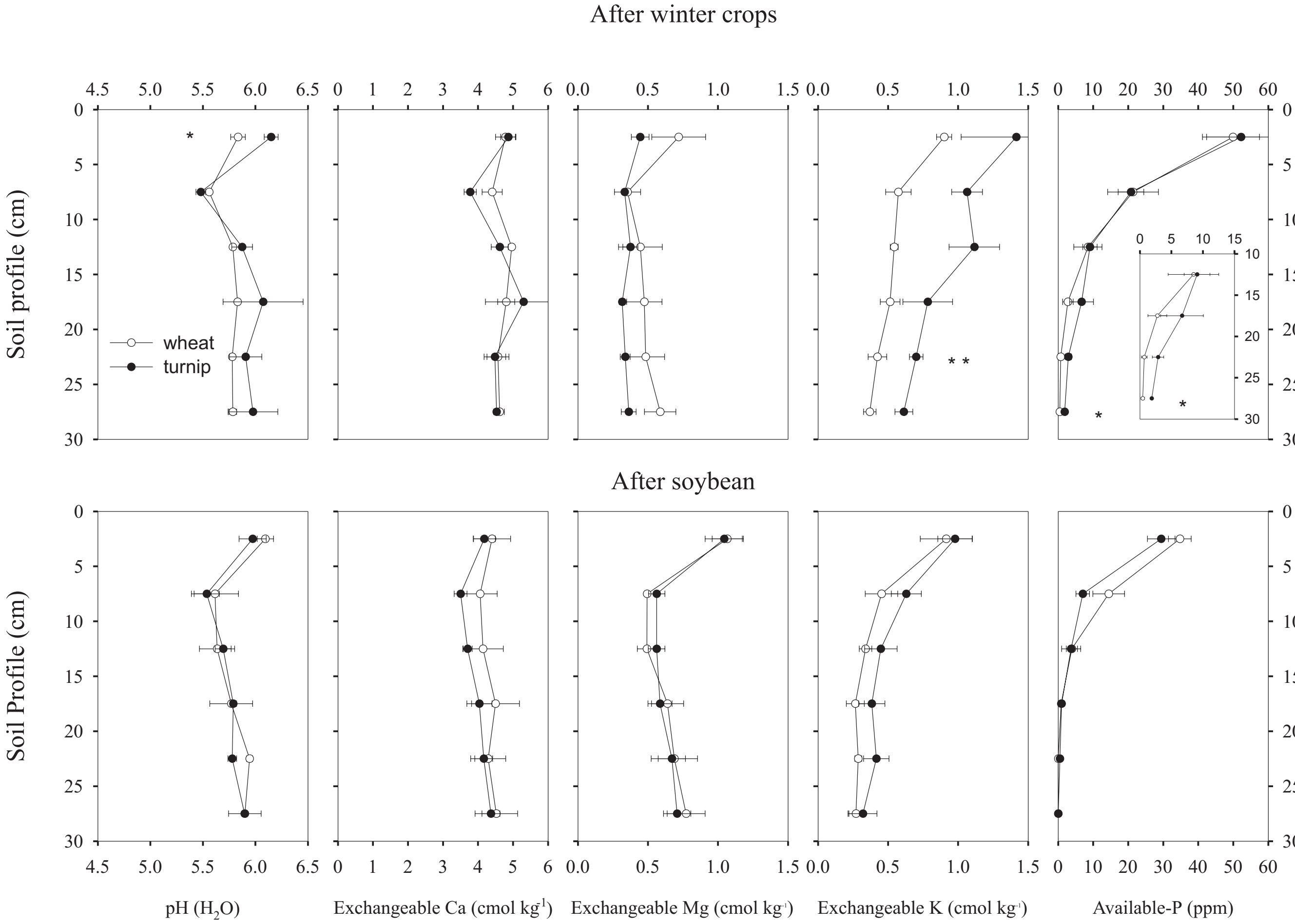

Figure 3 - Effects of winter crops on soil chemical properties, measured after winter crops (Oct., 2000) and after soybean (May 2001) in the 2000-01 growing season. Error bars: SE (n = 3).
**, *indicates difference at 1% and 5% respectively (LSD).

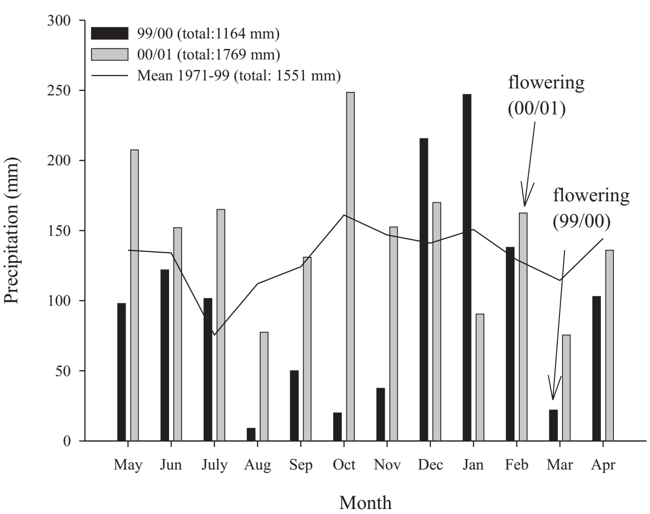

Figure 4 - Monthly precipitation of growing season in Yguazu, eastern Paraguay. The arrow indicates flowering month of soybean plant.

Experiment II: Nutrient uptake and return from wheat and turnip residues

Difference in nutrient uptake - The shoot dry weight of turnip and wheat were 11 t ha^{-1} and 4 t ha^{-1}, respectively (Table 4). For turnip, this dry matter yield was higher than reported in studies conducted in Brazil (Sidras et al., 1985; Kemper & Derpsch, 1981). The high dry matter production of turnip is advantageous for minimizing soil erosion. Residue mulch on the soil surface can effectively protect the soil against wind erosion (Bielders et al., 2000) and runoff after rainfall (Wilson et al., 2004).

The difference between both crops in nutrient uptake was greater than for biomass accumulation. Turnip generally absorbed three to five times as much nutrients as wheat. Calcium uptake differed most with turnip absorbing 16 times more than wheat. This would support results of Pavan (1997) who detected a high amount of Ca being dissolved from turnip residues. About 300 kg ha^{-1} of N was absorbed by turnip, whereas wheat only absorbed about 100 kg N. Of these 100 kg N, 76 kg would be removed from the field with harvested grains.

Although root depth of the turnip plant (about 15 cm) is shallower than wheat, cation exchange capacity per root surface area of turnip root is about four times greater than that of wheat root (Kumazawa & Nishizawa, 1976). This high cation exchange capacity is probably one of the reasons why turnip could take up higher quantities of nutrients.

Difference in nutrient return from crop residues - Figure 5 presents monthly changes in dry weight and N, P, K, Ca, and Mg content of crop residues. The first measurement taken just after cutting wheat and turnip (after 0 month) showed slightly different values from those given in Table 4 because different sampling methods had been employed; shoot dry weight and total nutrient uptake were measured by sampling whole plants (Table 4), while changes in dry weight and nutrient content of residues were measured by sampling residues from the soil surface. Turnip residues left on the soil surface had higher total dry weight in the beginning but decomposed more quickly and became similar in dry weight to wheat residues by the last month before planting soybeans.

A large portion of nutrients in turnip residues was dissolved within 3 months. The amount of N, K, and Ca returned to the soil was 185, 290 and 120 kg ha^{-1}, respectively. Nutrient return from wheat straw was small in comparison. This was probably due to different decomposition rates of residues and due to a different content of water-soluble inorganic and organic compounds in residues. The "pumping up" function of turnip plants is valuable in minimizing nutrient leaching to deeper soil layers during winter. Especially N, which is consumed in large amounts by soybeans and also leaches easily as nitrate-N after rainfall, can be kept in the surface soil by a green manure crop like turnip. The N in crop residue is first assimilated into microbial biomass before being

Table 4 - Shoot dry weight and nutrient uptake at maturity of wheat and turnip.

Crop		Shoot dry wt.		Nutrient uptake N		P		K		Ca		Mg	
		t ha^{-1}		kg ha^{-1}									
Wheat	Head	3.6		76.4		9.1		10,0		0.9		4.0	
	Stem + leaf	4.1		21.2		1.7		57,0		10.0		2.6	
	Total above ground	7.7	(0.4)	97.6	(7.7)	10.8	(0.4)	67.0	(8.1)	11.0	(1,0)	6.6	(0.5)
Turnip	Total above ground	10.7	(0.8)	294.2	(34.2)	26.9	(1.8)	301.6	(27.3)	175.0	(21,1)	33.2	(4.6)

Values in parenthesis refer to standard errors (n = 3).

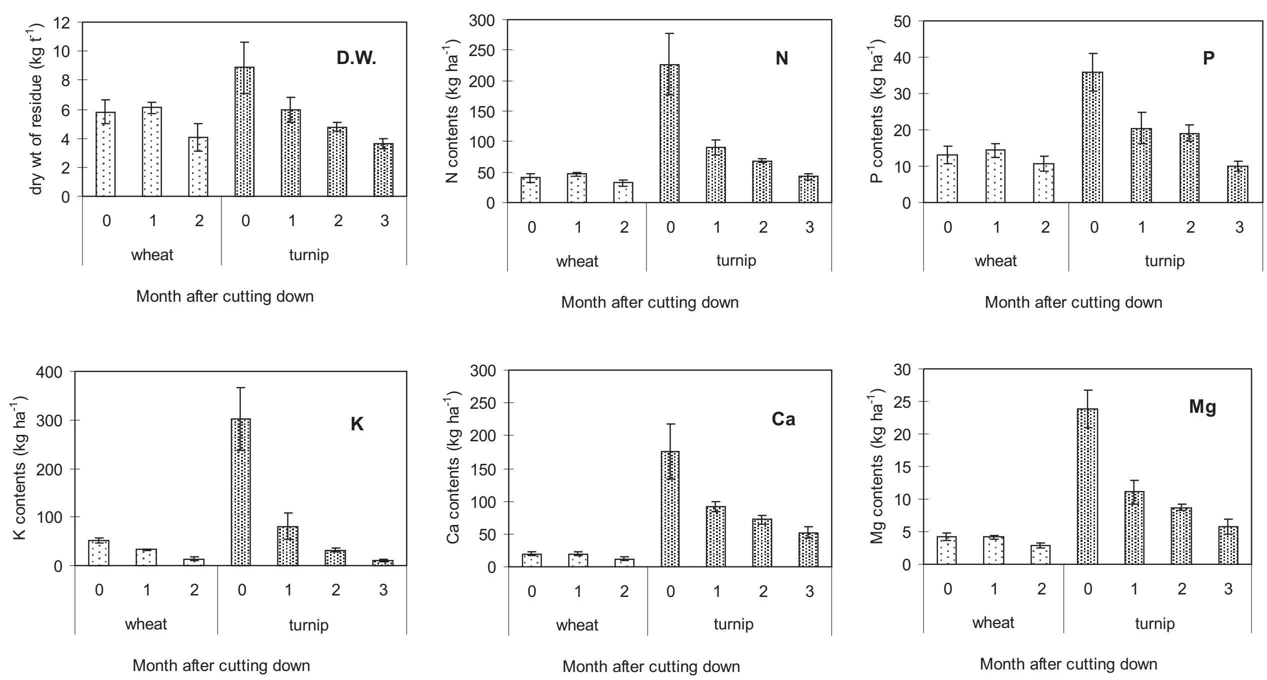

Figure 5 - Changes of dry weight, N, P, K, Ca and Mg contents in crop residues.
Error bars : SE (n = 3).

slowly released as inorganic N (Amato & Ladd, 1980). This cycle is advantageous to applying chemical fertilizer. A slow release of organic N from crop residues is less likely to inhibit N_2 fixation (Eaglesham et al., 1982), and would also reduce the danger of ground water contamination with NO_3-N.

Soybeans, despite being able to fix atmospheric N, still rely on soil-N supply in the range of 110 kg ha^{-1} under no-tillage (Hughes & Herridge, 1989). In dry years soybeans would rely even more on soil-N because nodule activity decreases with decreasing soil moisture (Arihara, 2000). This higher demand for N can be satisfied by “pumping up” of N by turnip, but not by wheat and this was a possible cause for the positive effect of turnip on soybean yields under dry climatic conditions.

That the turnip crop indeed increased soil-N fertility is supported by the data shown in Figure 6. Measurements in Experiment I had been taken at the flowering stage of soybeans whereas measurements in Experiment II were taken in November, before planting soybean. The concentration of inorganic-N, which is sum of nitrate-N and ammonium-N in the soil, was higher following turnip in all cases. At the flowering stage, plants had already taken up a large amount of N, and that soil inorganic-N levels remained higher indicated that the effect of turnip was more than a short-term effect. To estimate the effect of turnip on soil-N fertility without confounding effects caused by the N-fixing capacity of soybeans, one small investigation was conducted with corn planted after wheat and turnip. The corn had twice as much N uptake and produced more biomass after turnip (Table 5). This clearly demonstrated that green manure turnip was capable of restoring soil fertility.

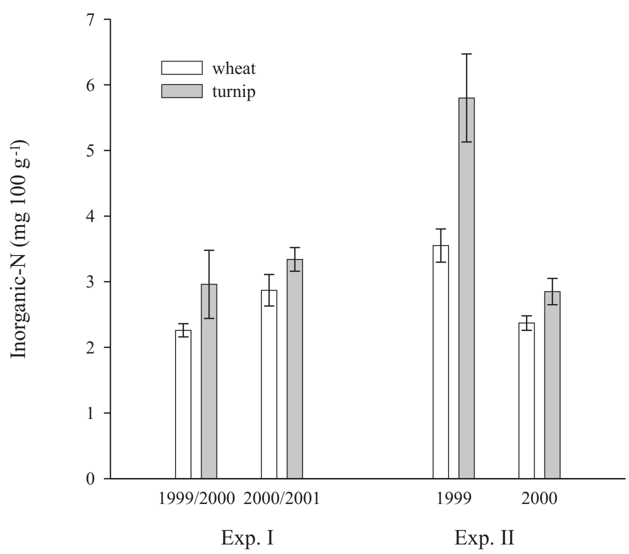

Figure 6 - Soil inorganic-N contents of Exp. I (samples at flowering stage of soybean), and Exp. II (samples in the last month of residue experiment before planting soybean in November). Error bars : SE (n = 3).

Table 5 - Effect of radish on growth and N uptake of following corn.

Crop before corn	Dry wt.		N content		N uptake	
	g plant^{-1}		mg g^{-1}		g plant^{-1}	
Wheat	151.6	(22.0)	6.7	(0.1)	1.0	(0.2)
Turnip	197.5	(25.2)	11.1	(1.0)	2.2	(0.4)

Values in parenthesis refer to standard errors (n = 3).

CONCLUSION

Growing turnip as a green-manure crop in winter instead of wheat improved soil fertility and aggregate structure. The anticipated positive effect on soybean yield and soil compactness could not be confirmed. This could indicate that other winter crops would have to be used if alleviation of soil compactness is the main goal. However, we only conducted experiments in one location and the cone index value at our site was just below the critical value of 1.27 MPa found to restrict soybean taproot growth (Sato et al., 2001). Additional experiments at sites with higher soil compactness are therefore needed to thoroughly evaluate positive effects on soil compactness of turnip and other winter crops.

Turnip produced large amounts of biomass with much higher nutrient content as compared to wheat. A large portion of the nutrients in turnip were rapidly returned to the soil, and this rapid turnover was most likely responsible for the positive effects on soil fertility and aggregate structure. Improved aggregate structure in combination with the better ground cover provided by turnip residues should reduce the risk of soil erosion. Planting turnip as a green-manure crop is expected to be most effective in fields where continuous soybean-wheat cropping reduced soil-N fertility and where the risk of soil erosion is high. It would therefore be important for both soil conservation and crop production, if soybean-wheat growers periodically utilize green-manure turnip in their fields.

ACKNOWLEDGEMENT

To JICA (Japan International Cooperation Agency, Tokyo) for financial support. To Dr. Iwata and Mr. Seki for their technical advice. The assistance provided by Mr. Osamu Sato, Mrs. Aureliana Franco and Mr. Santiago Bogado was greatly appreciated.

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Received May 10, 2004
Accepted February 11, 2005