Tomato Crop Response to Short-Duration Legume Green Manures in Tropical Vegetable Systems

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ABSTRACT

The potential of legume green manure (GM) as an alternative to mineral N fertilizer in tropical horticulture has received scant attention. The feasibility of meeting N needs of tomato (*Lycopersicon esculentum* Mill.) with GM was studied in six field experiments at three locations in major vegetable growing areas of Taiwan and the Philippines between 1993 and 1995. Legume biomass, N_2 fixation and N accumulation, and tomato yield and N uptake were quantified within a 6-mo experiment cropping pattern. Yields of GM-amended tomato crops were compared with those amended with fertilizer N (0–150 kg N ha^{-1}). The residual effect of the fertilizing method of a second crop (maize; *Zea mays* L.) was estimated at AVRDC by measures of biomass and N uptake 30 d after sowing. Legume N recovery in tomato crops was traced with ^{15}N at Mariano Marcos State University (MMSU). Soybean [*Glycine max* (L.) Merr.] harvested at 60 to 74 d accumulated a minimum of 2.8 Mg ha^{-1} biomass and 100 kg ha^{-1} N in all locations and seasons. A maximum of 6 Mg biomass ha^{-1} and 140 kg N ha^{-1} was reached in the wet season (WS) at AVRDC. Indigofera (*Indigofera tinctoria* L.) and mungbean [*Vigna radiata* (L.) Wilcz.] biomass yields were more variable and always inferior than soybean yields. Tomato yields across locations ranged from 3 to 70 Mg fruit ha^{-1}. Tomato yields responded to GM N in the WS in Taiwan and in the northern Philippines, comparing favorably with fertilizer at 38 to 120 kg N ha^{-1}. No response to GM N was found in the dry season (DS) at AVRDC or at Bukidnon Resources Company, Inc. (BRCI). The ^{15}N experiments showed that only a small fraction of legume N (9–15%) was recovered by the tomato crop at MMSU. Maize biomass and N uptake, following the tomato crop, was increased with soybean GM compared with the control in the AVRDC WS and DS. Tomato yield response to GM N is high on infertile soils and tomato N requirement can be substituted fully or partially by GM, depending on soil N mineralization.

Vegetable production systems in the tropics and elsewhere are mostly intensive, because vegetables are high-value cash crops. High fertilizer rates are commonly applied to maximize yields. There is an urgent need for the implementation of alternative methods to reduce excessive use of mineral fertilizers and to improve soil fertility and vegetable quality.

The age-old practices of green manuring, application of compost, crop rotation, and inter- and relay-cropping, which were used in various soil fertility programs for developing countries until the early 1960s, have declined with the increased use of mineral fertilizer (Singh, 1975). A major benefit of legume green manures (GM) is the contribution of N to the soil via N_2 fixation. Because the role of N from organic sources such as GM is tied to complex microbial cycling of C and N, the availability and effects of legume N are more difficult to predict than those of chemical fertilizer N (Groffman et al., 1987). Most recent research on GM has focused on staple crops, especially on rice (*Oryza* spp.) (Ladha et al., 1989). Few published results exist for tropical vegetable production systems, although organic manuring is still a common practice in some vegetable farms in India and Nepal (Babha Tripathi, Nadia, India, personal communication). Stivers and Shennan (1991) and Abdul-Baki and Teasdale (1993) reported tomato yield following legume GM and mulch comparable to those obtained with synthetic fertilizers in the USA, but Lennartsson (1990) showed that vegetable yields following GM did not outfield those grown after fallow in the UK. Investigations are needed to evaluate the potential role of legume GM in tropical horticulture and to estimate the risks to production before promoting it as a widespread practice for farmers.

The objective of this study was to assess the feasibility of meeting N needs of tomato with legume GM at one location in southern Taiwan and two locations in the Philippines through integration of the legumes into established vegetable cropping patterns of these areas. This cropping strategy was tested for its location specificity by quantifying legume biomass, N_2 fixation, N accumulation, and tomato yield and N uptake. Tomato N nutrition was monitored by NO_3–sap samplings in the southern Philippines. To quantify the contribution of various N sources to tomato plants, legumes were labeled with ^{15}N in an additional experiment in the northern Philippines and ^{15}N was traced in tomato plants.

MATERIALS AND METHODS

Field Trials

Six field experiments in major vegetable growing areas of Taiwan and the Philippines were conducted between 1993 and 1995: four experiments on the experiment farm of the Asian Vegetable Research and Development Center (AVRDC) in southern Taiwan and one each in the north and south of the Philippines. At AVRDC, two experiments were conducted during the wet season of 1993, with average air temperatures of 27.6°C and a total rainfall (6-mo experiment period) of 1348 mm. Two experiments were conducted in the dry season of 1993–1994, with average air temperatures of 21.6°C and a total rainfall (6 mo) of 52.9 mm. The cropping history of the

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Published in Agron. J. 92:245–253 (2000).

Abbreviations: AVRDC, Asian Vegetable Research and Development Center; BRCI, Bukidnon Resources Company, Inc.; DS, dry season; GM, [legume] green manure; IRRI, International Rice Research Institute; MMSU, Mariano Marcos State University; WS, wet season.

field used for the 20 yr prior to our experiments was a rotation of vegetables grown in the DS and flooded rice grown in the WS. The soil is of the Take series (loamy, mixed, hyperthermic Fluvaquentic Entochrepts), with pH (H_2O) of 8.2, total Kjeldahl N of 0.7 g kg^{-1} (Bremner, 1965), and total C 6.4 g kg^{-1} (Walkley–Black method). Prior to the first run of our experiments, the field area was cropped with maize for about 1 mo, to obtain a homogeneous soil mineral N distribution. Maize stubble was removed before the trial started.

In the Philippines, the first experiment was conducted on the experiment farm of the Mariano Marcos State University (MMSU) in Batac, Ilocos Norte (IRRI rainfed lowland consortium site). The rainfed lowlands of the province Ilocos Norte are characterized by intensive cropping systems, although soil fertility and rainfall distribution appear unfavorable (Tripathi, 1995). Rice is grown during the wet season and upland crops (legumes, maize, and vegetables) are grown in the dry season. Average air temperature during the DS experiment period of 6 mo was 27.3°C (max. 33°C, min. 20°C). After strong rainfall events in October (175 mm), no more rainfall occurred within the 6-mo experiment period. The soil is a Fluvaquentic Ustropept (fine-silty, mixed isohyperthermic), with pH (H_2O) of 8.1, total Kjeldahl N of 0.7 g kg^{-1} (Bremner, 1965), and total C of 5.9 g kg^{-1} (Walkley–Black method). To obtain a homogeneous soil mineral N distribution, this soil has been previously cropped to one rice crop without N fertilizer application. Rice straw was removed from the field before the trail started.

The second experiment in the Philippines was conducted in collaboration with the tomato processing company Bukidnon Resources Company, Inc. (BRCI), at their experiment farm in San Juan, Bukidnon, Mindanao. An extensive subsistence farming is practiced in this area. Soils in Bukidnon are rich in organic matter and of volcanic origin. Average air temperatures during the 6 mo were 24.1°C (max. 28.3°C, min. 19.8°C). Total rainfall during the experiment period was 1471 mm, with an average daily rainfall of 25 mm. The soil is a clayey, kaolinitic, hyperthermic Ultisol, with pH (H_2O) of 5.7 (after liming with 5 Mg ha^{-1} $CaCO_3$), total Kjeldahl N of 2.1 g kg^{-1} (Bremner, 1965), and total C of 19.5 g kg^{-1} (Walkley–Black method).

Experiment Design

Asian Vegetable Research and Development Center Experiments

Experiments were run simultaneously on two fields, each with different bed systems; raised or low beds. The raised beds were 45 cm high and 2 m wide, with 2-m furrows between the beds. The furrows were sown with rice (*O. sativa* L.) and permanently flooded. The low beds were 20 cm high and 2 m wide, with 50-cm-wide irrigation furrows between beds. Both experiments (raised and low beds) were adjacent, such that the soil type, the cropping history, and meteorological conditions were the same. The experiment design for each experiment was a randomized complete block. Treatment plots measured 2 by 6 m, with four replicates. The eight treatments were (Table 1) two legume species, two green manure management (mulch and incorporation), and four controls having weed-free fallow (instead of legumes) and receiving 0, 30, 60, or 120 kg N ha^{-1} applied to the tomato crop. In the DS treatment, plots were split into three equal-sized subplots prior to planting the vegetable crop to study N release in planted (tomato; cabbage, *Braissica oleracea* var. *capitata* L.) vs. unplanted plots (Thönnissen Michel, 1996).

Mariano Marcus State University Experiment

Experimental design was a randomized complete block with split plots and four replicates. Main treatment plots were 6 by 6 m; subtreatment plots were 2 by 6 m. The eight main treatments were similar to those at AVRDC (Table 1). In contrast to AVRDC experiments, N rates (0, 38, 75, or 150 kg N ha^{-1} applied to the tomato crop) in fertilizer N treatments were adjusted to local recommendations. Tomato planting time was varied in two of the subtreatments, early and late transplanting: transplanting tomato plants immediately after vs. 2 wk after GM application. The third subplot was kept unplanted for inorganic N measurements (Thönnissen Michel, 1996).

Bukidnon Resources Company, Inc., Experiment

Experimental design was a randomized complete block with split plots and three replicates. Main treatment plots were 4.8 by 4.6 m; subtreatment plots grown to tomato were 4.8 by 3 m and subtreatments kept unplanted were 4.8 by 1.5 m. The eight treatments were comparable to those at AVRDC and MMSU, with the difference that mungbean, which is locally grown, replaced indigofera at BRCI (Table 1).

Green Manure and Tomato Crop

Legumes and tomato crops were grown in a 6-mo experimental cropping pattern (Table 2). Legumes were inoculated with a *Rhizobium* strain mixture, specific for each legume. Bacterial strains were provided by the Soil Science Department of the Chung Hsing University in Taichung, Taiwan for AVRDC trials, the Soil Microbiology Unit at IRRI for the MMSU trial, and the Department of Agriculture for the BRCI trial. Legumes were hand-sown at 80 seeds m^{-2} for soybean and 1.32 g m^{-2} for indigofera at AVRDC and MMSU. Soybean and mungbean were hand-sown at 55 seeds m^{-2} at BRCI. Phosphorus at 35 kg P ha^{-1} as superphosphate and K at 83 kg K ha^{-1} as KCl were broadcast in all beds before legume sowing at all three locations. At BRCI, soil was limed at a rate of 5 Mg ha^{-1} $CaCO_3$. From 60 to 74 d after sowing, legumes were cut at ground level, chopped into 5- to 10-cm pieces, and either incorporated by rototilling to the 15-cm depth or left as mulch on the soil surface, as required for each treatment (Table 2). At BRCI, legumes for the incorporation treatment were left on the soil surface for 1 wk before incorporation.

Tomato (AVRDC accession no 5915-93-1-0-3, a short-duration, determinate bushy type at AVRDC, Northern Food Corporation (NFC-line) at MMSU and BRCI variety 1403, selection 1584 at BRCI) seedlings (34 d old at AVRDC, 24 d old at MMSU, and 14 d old at BRCI) were transplanted in two rows per bed (40 cm plant to plant and 100 to 150 cm between rows). Nitrogen fertilizer was applied and split in basal at tomato transplanting and two side dressings, 2 wk and 4 to 5 wk after transplanting. At AVRDC, 30 kg N ha^{-1} was applied to Ck120, Ck60, and Ck30 as basal N application, 30 kg N ha^{-1} to Ck120, Ck60 for the first side dressing, and 60 kg N ha^{-1} to Ck120 for the second side dressing. At MMSU, N basal fertilizer application were 48, 24, and 12 kg N ha^{-1} for Ck120 (normal), Ck60 (one-half), and Ck30 (one-quarter), respectively. Nitrogen at 60, 30, and 15.5 kg ha^{-1} was applied to Ck120, Ck60, and Ck30, respectively, for the first side dressing and at 42, 21, and 10.5 kg N ha^{-1} to Ck120, Ck60, and Ck30, respectively, for the second side dressing. At BRCI, 2000 kg ha^{-1} of poultry manure (*Gallus* sp.) containing 2% N, 1.3% P, and 2.1% K w/w was applied immediately before transplanting tomato plants in all treatments (Table 2). For N fertilizer treatments, 30 kg N ha^{-1} was applied to Ck30 and

Table 1. Treatments in field experiments at the Asian Vegetable Research and Development Center (AVRDC) (Taiwan: 1993–1994) and at Mariano Marcos State University (MMSU) and Bukidnon Resources Co., Inc. (BRCI) (Philippines: 1994–1995).

Treatment	1st Crop (legumes)	2nd Crop (vegetables): Green manure management, fertilization	2nd Crop (vegetables): Crop	3rd Crop†
1	Soybean (Si)	Incorporation	Tomato	Maize
2	Soybean (Sm)	Mulch	Tomato	Maize
3	Indigofera (Ii)	Incorporation	Tomato	Maize
4	Indigofera (Im)	Mulch	Tomato	Maize
3‡	Mungbean (Mi)	Incorporation	Tomato	Maize
4‡	Mungbean (Mm)	Mulch	Tomato	Maize
5	Fallow (Ck 0) control	0 kg N ha^{-1}	Tomato	Maize
6	Fallow (Ck 30)	30 (38§) kg N ha^{-1}	Tomato	Maize
7	Fallow (Ck 60)	60 (75§) kg N ha^{-1}	Tomato	Maize
8	Fallow (Ck 120)	120 (150§) kg N ha^{-1}	Tomato	Maize

† A third crop was planted only at AVRDC.
‡ At BRCI mungbean was used instead of indigofera.
§ At MMSU N fertilizer rates were adapted to local recommendations, with normal rates of 150 kg N ha^{-1}.

Ck60 and 60 kg N ha^{-1} to Ck120 for the first side dressing, and 30 and 60 kg N ha^{-1} for Ck60 and Ck120, respectively, for the second side dressing. The tomato crop was harvested, depending on season and variety, at 80 to 120 d after transplanting (Table 2). At AVRDC, maize was sown 2 d after final tomato harvest in six rows per bed (30 seeds m^{-2}) and sampled at 30 d (Table 1).

Plant Analysis

Legumes were sampled at 60 to 74 d (Table 2). Plants from 0.5 m^2 at AVRDC and BRCI and from a microplot of 0.64 m^2 at MMSU (see ^{15}N experiment) of each treatment replicate, which was afterwards excluded from further sampling, were carefully dug out to a depth of 15 to 20 cm and the soil was separated from the roots. Shoots, roots, and nodules were dried at 60°C for 72 h and weighed for biomass determination. Plant samples were ground in a Wiley Laboratory Mill Model 4 (Thomas Scientific, Philadelphia) to pass through a 1-mm sieve, subsampled, and ground again in a vibrating sample mill (Heiko T1-100, Heiko Seisakusho Ltd., Tokyo, Japan). Nitrogen content in shoots and roots including nodules were determined by the Kjeldahl distillation method (Bremner, 1965).

At tomato harvest, marketable fruit fresh weight, and fresh and dry weights and N content of tomato fruits and plants were determined. Maize plants (30 d; including roots) were pulled out from the soil and biomass and total N were determined as a relative indicator of the inorganic N available in the soil after tomato harvest.

Plant Petiole Sap Nitrate Analysis

Tomato was sampled weekly for plant petiole sap nitrate content (sap N) at BRCI between 0600 and 1000 h, 2 d after the second weekly irrigation. Sampling took place from 42 d after GM application (9 Aug. 1995) to 91 d after GM application (26 Sept. 1995). The fifth leaf (counted from the top) of five randomly selected plants per treatment was collected, in order to sample the most recently matured leaf (Drews and Fischer, 1989). Petioles were chopped into 1-cm pieces and squeezed with a garlic press. Petiole sap was diluted by 50 times with distilled water, and mixed thoroughly for 1 min. One drop of this solution was poured onto two reaction zones of Reflectoquant nitrate test strips, and sap N was determined by refractometric reading on the RQ-flex instrument (RQflex, Merck, Darmstadt, Germany).

Nitrogen Fixation and Nitrogen-15 Experiment

Biological Nitrogen Fixation

The amount of N acquired through biological N_2 fixation by legumes was estimated using the N difference method (Talbott et al., 1985). Legumes and reference plants were grown in a small experiment conducted in parallel in a field adjacent to the main field experiment. Seeding rates and harvest dates were the same as those for legumes in the main field experiment. A nonnodulating soybean line (provided by the NifTAL Project, Hawaii) was used as a non-N_2–fixing reference plant for soybean and an upland rice variety (IF 600 80-46A) as a reference for indigofera. Plants were grown on 8-m^2 plots, with two replicates.

Enriched Nitrogen-15 Balance in Tomato

Production of Nitrogen-15 Labeled Legume Plant Material

Legumes were enriched with ^{15}N by foliar application (Zebarth et al., 1991) of 1 0.5% urea (30 atom % ^{15}N) solution at

Table 2. Time schedule of field experiments at the Asian Vegetable Research and Development Center (AVRDC), Taiwan, in the wet (WS) and dry (DS) seasons and at Mariano Marcos State University (MMSU) and Bukidnon Resources Co., Inc. (BRCI), Philippines (1993–1995).

Location	Season	Year	Crop: Legumes: Sown	Legumes: Harvested	Legumes: d‡	Tomato: Transplanted	Tomato: Harvested	Fertilizer applications to tomato†: N	P	K
AVRDC	WS	1993	12 Apr.	15 June	68	18 June	17 Aug.–1 Sept.	0/0/0§	35/0/0	50/50/50
	DS	1993–1994	8 Oct.	6 Dec.	60	8 Dec.	1–16 Mar.	0/0/0	35/0/0	50/50/50
MMSU	DS	1994–1995	6 Oct.	13 Dec.	74	15 Dec.	7 Mar.–4 Apr.	0/0/0	30/0/0	14/18/14
BRCI¶	WS	1995	17 Apr.	21 June	66	28 June	9 Sept.–18 Oct.	40/0/0#	40+26/0/0	42/160/160¶

† N fertilizer applications as required for treatments Ck30, Ck60, and Ck120 treatments (Table 1) are not listed.
‡ Days after sowing.
§ Values indicate basal/1st/2nd side dressing.
¶ 11.5 kg Mg ha^{-1} as Kieserit, 1.5 kg Zn ha^{-1} as zinc sulfate, and 1.5 kg B ha^{-1} as borax were applied in the 1st and 2nd side dressing to BRCI tomato crops.
# Applied as poultry manure at a rate of 2000 kg ha^{-1}.

a total rate of 10 kg N ha^{-1}. The ^{15}N fertilizer was split for progressive foliar applications at 21, 28, 35, 42, and 48 d.

Application of Nitrogen-15 Labeled Legume Material as Green Manure

One day before legume harvest, metal frames measuring 0.8 by 0.8 by 0.3 m (length by width by height) (microplots) were pushed into the soil to a depth of 25 cm in soybean and indigorera incorporation and mulch treatments of the main field experiment. Legumes within the metal frames were removed, including roots. On the same day, ^{15}N-labeled legumes were carefully dug out to a depth of 20 cm, the soil was separated from the roots, and the legumes were chopped into 5- to 10-cm pieces and applied (incorporated or as mulch) to microplots of the corresponding treatments in the main field experiment.

Legume Nitrogen-15 Recovery in Vegetables

Two tomato seedlings were transplanted into each microplot. Tomato fruit yield and plant biomass, N and ^{15}N content of tomato fruits and plant were determined to calculate ^{15}N recovery in the tomato plant. Percent N in tomato derived from soybean (S^{15}N) was calculated using

$$S^{15}N = a/b \times 100 \qquad [1]$$

where a is the ^{15}N atom % excess of tomato and b is the ^{15}N atom % excess of soybean. Recovery of soybean ^{15}N by tomato was calculated using

$$\text{Recovery of soybean} - {}^{15}\text{N by tomato} = (S^{15}N \times TN)/AN \qquad [2]$$

where TN is the total N uptake by tomato and AN is the amount of soybean N applied (Harris and Hesterman, 1990).

Statistical Analysis and Presentation of Yield Data

Data were analyzed by analysis of variance (ANOVA) procedure using JMP Version 2 (SAS Inst., 1989) and SAS version 6.03 (SAS Inst., 1991). Yields and N accumulations of legumes, tomato crops, and maize of the raised beds are presented on the basis of planted area, without allowance for space occupied by rice.

RESULTS

Legumes

Soybean grown for 60 to 74 d accumulated a minimum of 2.8 Mg total biomass ha^{-1} and 106 kg N ha^{-1} in all locations and seasons in Taiwan and the Philippines (Table 3). A maximum of 5.9 Mg biomass ha^{-1} and 140 kg N ha^{-1} was achieved in the wet season at AVRDC. Indigofera yields were more variable and always inferior to those of soybean. Mungbean biomass and N accumulation at BRCI were comparable to average indigofera yields of 0.9 Mg biomass ha^{-1} and 25 kg N ha^{-1}. Soybean biomass in the wet season at AVRDC was nearly double that produced in the dry season, while indigofera biomass production was less affected by the season. At AVRDC, indigofera produced greater biomass yields on raised beds, while soybean biomass production was not influenced by the bed system. More than 90% of the legume N in 60- to 74-d soybean and indigofera was found in the shoot.

Soybean grown at MMSU derived 84.4% of the N accumulated in its plant biomass from biological N_2 fixation, compared with indigofera at 71.8%.

Tomato Yield, Nitrogen Uptake

Tomato yield in response to GM management and N fertilizer rates differed depending on season and location (Table 4). Greatest tomato yields of 60 to 70 Mg ha^{-1} were achieved with 150 kg N ha^{-1} at MMSU and 120 kg N ha^{-1} at AVRDC in the DS. High tomato yields (40 Mg ha^{-1}) were obtained in the control in the DS at AVRDC and at BRCI although no N was applied. The addition of 38 and 30 kg N ha^{-1} doubled tomato yields compared with the control at MMSU and in the WS at AVRDC, respectively, while 30 kg N ha^{-1} increased yields only by 13% in the DS at AVRDC, and had no effect at BRCI. A strong seasonal effect occurred at AVRDC, as DS yields were 10 times greater than those of the WS. Tomato yields responded lineraly to fertilizer N applications of 38 to 150 kg N ha^{-1} at MMSU (r^2 = 0.81**), and 30 to 120 kg N ha^{-1} in the DS at AVRDC (low beds: r^2 = 0.69**; raised beds: r^2 = 0.54*). Simple regression coefficients between tomato yields and applied fertilizer N were significant neither in the WS at AVRDC nor at BRCI. With the exception of MMSU (r^2 = 0.66**) tomato yields did not correlate with GM N amendments.

Table 3. Dry matter yield and N accumulation of soybean, indigofera, and mungbean grown for 60 to 74 d. Values within parentheses indicate standard deviation (n = 4) in Taiwan (AVRDC) and the Philippines (MMSU, BRCI).

				Dry matter yield			N accumulation		
Crop	Location†	Bed system‡	Season§	Shoot	Root	Total	Shoot	Root	Total
				Mg ha^{-1}			kg ha^{-1}		
Soybean	AVRDC	R	DS	2.9 (0.3)	0.4 (0.07)	3.3 (0.3)	116.4 (15)	8.5 (2)	124.8 (15)
	AVRDC	R	WS	5.2 (0.3)	0.8 (0.16)	5.9 (0.4)	127.1 (8)	11.0 (2)	138.1 (8)
	AVRDC	L	DS	2.5 (0.2)	0.3 (0.3)	2.8 (0.2)	107.0 (9)	5.4 (0.8)	112.3 (10)
	AVRDC	L	WS	5.5 (0.3)	0.3 (0.1)	5.8 (0.4)	134.7 (16)	6.0 (2)	140.7 (16)
	MMSU	–	DS	4.1 (1.01)	0.1 (0.01)	4.2 (1.1)	139.4 (47)	1.6 (0.3)	140.1 (47)
	BRCI	–	WS			3.4 (0.7)			106.0 (20)
Indigofera	AVRDC	R	DS	0.9 (0.2)	0.1 (0.03)	1.0 (0.2)	38.3 (8)	1.7 (0.5)	40.0 (8)
	AVRDC	R	WS	1.7 (0.2)	0.3 (0.07)	2.0 (0.3)	40.1 (4)	3.4 (0.8)	43.5 (5)
	AVRDC	L	DS	0.6 (0.09)	0.07 (0.02)	0.7 (0.1)	24.8 (5)	1.3 (0.3)	26.1 (6)
	AVRDC	L	WS	0.4 (0.17)	0.14 (0.05)	0.5 (0.2)	9.3 (4)	1.7 (0.6)	11.1 (4)
	MMSU	–	DS	0.2 (0.03)	0.02 (0.02)	0.22 (0.05)	4.8 (1)	0.3 (0.3)	5.0 (1)
Mungbean	BRCI	–	WS			1.1 (0.4)			26.0 (8)

† AVRDC, Asian Vegetable Research and Development Center; MMSU, Mariano Marcos State University; BRCI, Bukidnon Resources Corporation, Inc.
‡ 1ixR, raised beds; L, low beds.
§ DS, dry season; WS, wet season.

Table 4. Tomato fruit yields at the Asian Vegetable Research and Development Center (AVRDC), Taiwan, in the wet (WS) and dry (DS) seasons and at Mariano Marcos State University (MMSU) and Bukidnon Resources Co., Inc. (BRCI), Philippines (1993–1995).

	Fruit yield					
	AVRDC (WS)		AVRDC (DS)			
Treatment	Raised beds	Low beds	Raised beds	Low beds	MMSU (DS)	BRCI (WS)
	Mg ha^{-1}					
Soybean incorporated	4.7	2.4	42.6	39.8	25.2	46.5
Soybean mulch	6.3	4.3	33.4	29.0	24.4	46.5
Indigofera incorporated	5.1	2.6	37.4	37.8	12.3	
Indigofera mulch	4.7	1.2	31.5	28.8	10.5	
Mungbean incorporated						44.2
Mungbean mulch						49.2
Ck 0	2.5	2.9	40.7	46.0	12.6	47.5
Ck 30/38†	5.8	3.7	46.2	47.0	39.7	43.0
Ck 60/75†	5.9	3.7	56.2	59.0	47.6	47.7
Ck 120/150†	4.5	4.5	67.3	73.3	70.6	50.1
LSD (0.05)	2.4	1.7	12.7	10.7	10.9	NS

† N fertilizer application adapted to local practice at MMSU.

Tomato crops grown under adverse and suboptimal conditions in the hot tropical WS were able to use N released from GM (soybean mulch and indigofera incorporation) to produce yields comparable to those reached with 120 kg N ha^{-1} applied as fertilizer. The effect of GM management (incorporation vs. mulch) on tomato yields differed with season and locations: tomato yields were greater with incorporated GM in the DS at AVRDC and in the WS at AVRDC with mulched GM; no differences of GM management on tomato yields were found at MMSU and BRCI.

Tomato N was doubled with soybean GM compared with the control in raised beds in the wet season at AVRDC and at MMSU, comparing favorably with that with 120 kg N ha^{-1} at AVRDC and to that with 38 kg N ha^{-1} at MMSU (Table 5). In the DS at AVRDC and BRCI, tomato N was not increased by green manuring compared with the control. Tomato N was correlated with fertilizer N applied at MMSU (r^2 = 0.90**), in the DS (low beds: r^2 = 0.71**; raised beds: r^2 = 0.55**) and in the WS (low beds: r^2 = 0.56**) at AVRDC. Tomato N accumulation in controls differed greatly between experiments, with 20 kg N ha^{-1} in the WS at AVRDC and at MMSU, compared with 70 to 90 kg N ha^{-1} in the DS at AVRDC and at BRCI (Table 5).

The yields due to early transplanting of tomato plants increased by 10 Mg ha^{-1} for tomato fruit and 10 kg ha^{-1} for N, compared with the late transplanting at MMSU (data not shown).

At BRCI, tomato yields and N uptake did not respond to any of the treatments (Tables 4 and 5). However greatest concentration of nitrate in tomato petiole sap (1000–1472 mL NO_3–N L^{-1} plant sap) was found in 30, 60, and 120 kg N ha^{-1} fertilizer treatments in early stages (7 wk after transplanting), while an average of 600 mL NO_3–N L^{-1} plant sap was measured in control and GM treatments (data not shown). Thereafter, nitrate sap contents decreased gradually in all treatments and reached an average of 200 mL NO_3–N L^{-1} at 9 wk after transplanting. From 10 wk after transplanting until final tomato harvest, nitrate sap dropped further in all treatments ranging between 9 and 100 mL NO_3–N L^{-1} plant sap.

Residual Effect on Maize

All four GM treatments in raised beds and soybean GM in low beds increased maize biomass and N compared with control in the WS at AVRCD (Table 6). In the DS, maize biomass and N were markedly enhanced by soybean GM in raised beds and by soybean mulch in low beds. The residual effect of soybean GM applied

Table 5. Nitrogen accumulation (kg ha^{-1}) by tomato (plant and fruit) at the Asian Vegetable Research and Development Center (AVRDC), Taiwan, in the wet (WS) and dry (DS) seasons and at Mariano Marcos State University (MMSU) and Bukidnon Resources Co., Inc. (BRCI), Philippines (1993–1995).

	N accumulation					
	AVRDC (WS)		AVRDC (DS)			
Treatment	Raised beds	Low beds	Raised beds	Low beds	MMSU (DS)	BRCI (WS)
	kg ha^{-1}					
Soybean incorporated	43	17	99	78	41	62
Soybean mulch	56	25	74	59	34	65
Indigofera incorporated	48	20	86	80	20	
Indigofera mulch	33	9	74	57	18	
Mungbean incorporated						55
Mungbean mulch						67
Ck 0	24	20	91	88	22	67
Ck 30/38†	35	21	101	91	53	77
Ck 60/75†	49	21	129	113	75	74
Ck 120/150†	51	27	160	164	124	71
LSC (0.05)	n.d.	n.d.	33.3	22.6	16.1	NS

† N fertilizer application adapted to local practice at MMSU.

Table 6. Residual effect of tomato N fertilization and green manuring on dry matter yield and N content of maize at 33 d after sowing in raised (R) and low (L) beds at the Asian Vegetable Research and Development Center (1993–1994). Values are means of four replicates.

	Dry matter yield				N			
	WS†		DS†		WS		DS	
Treatment	R	L	R	L	R	L	R	L
	Mg ha^{-1}				kg ha^{-1}			
Green manure								
Soybean incorporation	2.46	1.73	1.8	1.1	58.6	42.2	32.4	22.4
Soybean mulch	2.43	1.73	1.3	1.3	56.6	36.9	24.9	22.9
Indigofera incorporation	2.03	1.20	1.6	0.9	40.6	23.1	29.6	14.6
Indigofera mulch	2.13	1.31	1.1	0.9	47.5	26.7	19.8	15.6
$(NH_4)_2SO_4$, kg ha^{-1}								
0	1.24	1.05	1.3	0.9	26.1	19.5	23.3	18.3
30	1.35	1.04	1.2	1.0	28.4	20.3	19.9	15.8
60	1.59	1.00	1.6	1.0	40.0	19.5	26.8	17.7
120	1.86	1.20	2.5	1.4	49.1	25.7	50.8	23.9
LSD (0.05)	0.35	0.39	0.4	0.3	12.7	5.6	7.7	3.4

† WS, wet seasons; DS, dry season.

to tomato on the following maize was similar to that of 120 kg N ha^{-1}. In both seasons, greater maize biomass was found on raised beds than on low beds.

Plant Nitrogen-15 Balance

Thirty percent of the ^{15}N applied for legume ^{15}N enrichment at MMSU was recovered in soybean and 0.8% in indigofera. Most of the ^{15}N applied was recovered in the shoot.

Recovery of GM ^{15}N in tomato at MMSU was comparable among soybean and indigofera (Table 7), indicating that 8.5 to 15% of legume N was taken up by the tomato crop. Slightly higher GM ^{15}N was recovered in early-transplanted tomato. Of the ^{15}N taken up by tomato, 59 to 70% accumulated in the fruits.

DISCUSSION

Legumes

Many legume species respond strongly to different photoperiod and temperature regimes. Soybean accumulated only half as much biomass in the DS than in the WS at AVRDC, while N accumulation in the DS was only 10 to 20% less than in the WS. Soybean biomass and N yields at MMSU and BRCI compared favorably with yields obtained in Taiwan (Thönnissen Michel, 1996) and in Texas (Munoz et al., 1983) where soybean was grown at high seeding densities for hay production. Indigofera yields at MMSU were about one half of the lowest yields obtained at AVRDC, and of the reported yields by Thönnissen Michel (1996) and Batilan et al. (1989). Indigofera has small seeds and seedlings emerge slowly making it more vulnerable to variable soil conditions such as soil crusting and compaction. Heterogeneous seed quality of the indigenous indigofera seed used at MMSU and a strong rainfall at 1 wk after sowing followed by soil crusting may have been responsible for the poor performance of indigofera, which is the main green manure crop used in this area of the Philippines (Garrity and Flinn, 1988). These factors make it difficult to propagate indigofera as a short term (60–74 d) GM. Mungbean yields were inferior to those reported by Meelu and Morris (1988), who obtained mungbean yields comparable to our soybean yields. They stressed the importance of the effect of the environment on N accumulation by GM species which implies that for optimal N accumulation the GM species must be adapted to the physical environment they will experience during growth.

Tomato Yield

Strong seasonal differences between tomato yields at AVRDC can primarily be explained by different night temperatures in the WS and DS. Sugiyama et al. (1966) reported that high night temperatures (<20°C) inhibit pollination of the tomato crop and consequently reduce fruit set. Tropical storms which temporarily flood the field, and bacterial, fungal and viral diseases are further

Table 7. ^{15}N recovery in tomato fruit and biomass at Mariano Marcos State University, Philippines (1994–1995).

Treatment	^{15}N Input (legumes)	^{15}N output (tomato) fruit	plant	total	% recovery total
	kg ha^{-1}				%
Main treatment					
Soybean incorporation	0.910	0.0541	0.0387	0.0817	8.9
Soybean mulch	0.910	0.0584	0.0291	0.0875	9.6
Indigofera incorporation	0.022	0.0013	0.0009	0.0022	10.0
Indogfera mulch	0.022	0.0023	0.0010	0.0033	15.0
LSD (0.05)		0.0143	0.0134	0.0263	
Sub treatments					
Early transplanting	0.466	0.0328	0.0206	0.0479	10.3
Late transplanting	0.466	0.0253	0.0142	0.0394	8.5
LSD (0.05)		NS	NS	NS	

responsible for the variable and low tomato yields in the WS (Hossain, 1992). In the WS at AVRDC, low regression coefficients between N fertilizer applied and tomato yields may have been caused by high N losses via leaching. Leaching losses inhibited the soil N accumulation before tomato transplanting in fallow plots. The more gradual release of GM N during decomposition compared with the timely application of fertilizer N may explain the relatively high tomato yields when amended with GM in the WS at AVRDC. In contrast to the DS, tomato yields in the WS did not respond to N fertilizer rats above 60 kg N ha^{-1}. Limited tomato yield response to high fertilizer rates has also been reported by Garrison et al. (1967) and Stivers and Shennan (1991).

Although tomato yields responded highly to dertilizer N at AVRDC in the DS, they were not closely related to application levels of GM N. Green manures undergo decomposition in order to release N. This process is so closely tied to complex microbial cycling of C and N, that the availability and effects of GM N are more difficult to predict than those of chemical fertilizers (Groffman et al., 1987). In the DS, nitrate accumulation due to soil N mineralized during the 2-mo fallow period in the control may have favored tomato crop development relative to those in legume treatments, where soil nitrate contents were low (Thönnissen Michel, 1996), as our legumes may have acted as nitrate catch crops (George et al., 1994). The depletion of soil nutrients, particularly P, the immobilization of soil N, the alteration of soil structure and exacerbated phytotoxicity from upland crops may have contributed to the short term advantages of fallow compared with legume treatments (Hamid et al., 1984). Since control and fertilizer treatments starting with the same initial NO_3 level as legume treatments were lacking, the N-supplying capacity of GM for tomato production in the DS may have been underestimated at AVRDC and at BRCI.

Liming and the application of poultry manure may have enhanced soil N mineralization at BRCI so that tomato crop N needs were met to such an extent that yields did not respond to GM or fertilizer N. High soil N mineralization in AVRDC in the DS and BRCI soil (Thönnissen Michel, 1996) resulted in tomato yields of 40 Mg ha^{-1} after 2 mo of fallow (control and N fertilizer treatments), while low soil N mineralization at MMSU resulted in control tomato yield of 12.6 Mg ha^{-1}. Similar results were found by Stivers and Shennan (1991), where tomato yields after winter fallow were as high as those amended with legume GM or fertilizer N. Wien and Minotti (1987) reinforced the concept of fallow–GM as important for soil mineralization and N nutrition by reporting that tomato forages efficiently for soil N, obtaining only 30 to 40% from fertilizer sources.

The N-supplying capacity of the GM amendment declined after 8 wk, about the time of early fruit development, in all six field experiments (Thönnissen Michel, 1996), which we assume was detrimental to maximum tomato plant growth and yield. To achieve an optimal tomato plant nutrition using GM, an integrated approach combining organic with mineral N fertilizer could be most promising in the DS. Mineral N fertilizer (30–60 kg N ha^{-1}) could be applied to tomato plants starting 8 wk after GM application.

The congruence of N-release kinetics from GM with the N-uptake dynamics of the subsequent crop is a key consideration for GM management. At MMSU, a greater proportion of N mineralized from decomposing GM appears to coincide with tomato N demand of early-transplanted tomato plants, as higher yields and N uptake were achieved. Results also confirm that the efficiency of GM or fertilizer N use largely depends on crop demand (Appel, 1994), the ability of soils to supply N by mineralization of organic N (Campbell et al., 1981), and the growth and climatic conditions for the subsequent crop.

Nitrogen-15 Recovery in Plant

Low indigofera shoot biomass led to low recoveries of applied ^{15}N. Nitrogen-15 recoveries in both legume species in our study were lower than in studies of Zebarth et al. (1991) and Vasilas et al. (1980), where 30% and 57% were recovered by alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.), and 44 to 67% by soybean, respectively. Higher labeled urea and greater quantities of labeled N fertilizer applied in their studies may have lead to higher ^{15}N recoveries than in the present study. The distribution of ^{15}N enrichment in soybean was comparable to results described by Vasilas et al. (1980), where highest enrichment was found in the seed, with hardly any in the roots.

Higher ^{15}N enrichment (50–71; Table 7) in tomato fruit than in the plant compares with results of Ladd et al. (1981), who found higher enrichment in reproductive plant parts of wheat. The ^{15}N recovery obtained in tomato plants is within the reported range (7–25%) by various crops grown subsequent to the application of ^{15}N labeled legume residues (Vallis, 1983; Yaacob and Blair, 1980; Norman et al., 1990; Müller and Sundman, 1988; Harris and Hesterman, 1990). Recoveries of applied ^{15}N in the subsequent crop plus soil were high (Ladd et al., 1981; Müller and Sundman, 1988), giving evidence that the ability of the soil to retain plant-derived N is strong compared with the ability of the subsequent crops and different loss mechanisms to remove it (Müller and Sundman, 1988). Harris et al. (1994) recovered 19% of the applied lugume N in microbial biomass, 38% of legume N applied in nonbiomass organic fractions; and only small amounts (<5%) of legume N were recovered in the inorganic fraction. Seligman et al. (1986) suggested that some of the added organic ^{15}N was incorporated into stable soil organic N pools to be mineralized at a rate approaching that of the stable soil N fraction.

Residual Effect

Maize was for more efficient in N use than was tomato. The lower the tomato N uptake in the WS at AVRDC, the higher the residual effect on maize grown after tomato. Smaller N uptake by maize in the DS than the WS was due to less legume N applied, greater tomato

N uptake and stronger N immobilization. The residual accumulation was comparable to that of fertilizer N application in both seasons. The strong response of maize to GM can be due to a remineralization of N partly immobilized after GM application. The N-supplying potential of GM for succeeding nonlegume crops estimated from the accumulation of inorganic N in bare fallow soil (Bowen et al., 1988) may differ strongly, depending on the succeeding crop. Tendencies towards a higher N recovery by crops with incorporated rather than mulched GM (Varco et al., 1989) were mostly confirmed with tomato, while differences in maize were not consistent.

CONCLUSIONS

Tomato yield response to GM N was high on poor soils and N could be substituted fully or in part, depending on soil N mineralization. The effect of GM N on tomato yields was marginal on fertile soils. Crops succeeding tomato (e.g., maize) may benefit from residual GM N. Further research on decomposition and N-release of legume GM, and on specific N-uptake patterns by different crops in contrasting environments, is required to further understand gaps in meeting N needs of tomato crops with GM. This should lead to the development of practicable recommendations for farmers as to optimal application method and opportunity for use of GM in specific cropping patterns.

REFERENCES

Abdul-Baki, A.A., and J.R. Teasdale. 1993. A no-tillage tomato production system using hairy vetech and subterranean clover mulches. Hort. Science 28(2):106–108.

Appel, T. 1994. Relevance of soil N mineralization, total N demand of crops and efficiency of applied N for fertilizer recommendations for cereals. Theory and application. Z. Pflanzenernähr. Bodenkd. 157:407–414.

Batilan, R.T., C.C. Batilan, and D.P. Garrity. 1989. *Indigofera tinctoria* L. as a green manure crop in rainfed rice-based cropping systems. IRRI Saturday seminar, Los Baños. 1 July 1989. IRRI, Los Baños Philippines.

Boddey, R.M., P.M. Chalk, R.L. Victoria, and E. Matsui. 1984. Nitrogen fixation by nodulated soybean under tropical field conditions estimated by the ^{15}N isotope technique. Siol. Biol. Biochem. 16(6):583–588.

Bowen, W.T., J.O. Quintana, J. Pereira, D.R. Bouldin, W.S. Reid, and D.J. Lathwell. 1988. Screening legume green manures as nitrogen sources to succeeding non-legume crops: I. The fallow soil method. Plant Soil 111:75–80.

Bremmer, J.M. 1965. Total nitrogen. p. 1149–1178. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part 2. 1st ed. Agron. Monogr. 9. ASA, Madison, WI.

Campbell, C.A., R.J.K. Myers, and K.L. Weier. 1981. Potentially mineralizable nitrogen, decomposition rates and their relationship to temperature for five Queensland soils. Aust. J. Siol Res. 19:323–332.

Drews, M., and S. Fischer. 1989. Methode zur Kontrolle der N- und K-Versorgung von Gewächshausgurke and Gewächshaustomate über die Pressaftanalyse der Blattstiele. Gartenbau 36:42–44.

Eaglesham, A.R.J., Ayawabaa, V. Rangarao, and D.L. Eskew. 1981. Improving the nitrogen nutrition of maize by intercropping with cowpea. Soil Biol. Biochem. 13:169–171.

Garrison, S.A., G.A. Taylor, and W.O. Drinkwater. 1967. The influence of nitrogen nutrition on flowering, fruit set and yield of processing tomatoes. Am. Soc. Hortic. Sci. 91:534–543.

Garrity, D.P., and J.C. Flinn. 1988. Farm-level management systems for green manure crops in Asian rice environments. p. 111–130. *In* IRRI (ed.) Green manure in rice farming. Proc. Symp. Sustainable Agriculture: Role of Green Manure Crops In Rice Farming Systems. 25–29 May 1987. IRRI, Los Baños, Philippines.

George, T., J.K. Ladha, R.J. Buresh, and D.P. Garrity. 1992. Managing native and legume-fixed nitrogen in lowland rice-based cropping systems. Plant Soil 141:69–91.

George, T., J.K. Ladha, D.P. Garrity, and R.J. Buresh. 1994. Legumes as 'nitrate catch' crops during the dry-to-wet transition in lowland rice cropping systems. Agron. J. 86:257–273.

George, T., P.W. Singleton, and B.B. Bohlool. 1988. Yield, soil nitrogen uptake and nitrogen fixation by soybean from four maturity groups grown at three elevations. Agron. J. 80:563–567.

Groffman, P.M., D.A. Hendrix, and D.A. Crossley. 1987. Nitrogen dynamics in conventional and no-tillage agroecosystems with inorganic or legume nitrogen inputs. Plant Siol 97:315–332.

Hamid, A., G.M. Paulsen, and H.G. Zandstra. 1984. Performance of rice grown after upland crops and fallow in the humid tropics. Trop. Agric. (Trinidad) 61(4):305–310.

Harris, G.H., and O.B. Hesterman. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops. Agron. J. 82:129–134.

Harris, G.H., O.B. Hesterman, E.A. Paul, S.E. Peters, and R.R. Janke. 1994. Fate of legume and fertilizer N^{15} in a long-term cropping systems experiment. Agron. J. 86:910–915.

Hossain, M.A.E. 1992. Risk of off-season vegetable cultivation in Bangladesh. p. 139–146. *In* AVRDC (ed.) Vegetable production and marketing. Proc. Natl. Review and Planning Workshop. AVRDC (Asian Vegetable Res. & Dev. Ctr.), Shanhua, Tainan, Taiwan.

Ladd, J.N., J.M. Oades, and M. Amato. 1981. Microbial biomass formed from ^{14}C, ^{15}N-labeled plant material decomposing in soils in the field. Soil Biol. Biochem. 13:119–126.

Ladha, J.K., S. Miyan, and M. Garcia. 1989. *Sesbania rostrata* as a green manure for lowland rice: Growth, N_2–fixation, *Rhizobium* sp. inoculation and effect of succeeding crop yields and nitrogen balance. Biol. Fertil. Soils 7:191–197.

Lennartsson, E.K.T. 1990. The use of green manures in organic horticultural systems. Paper presented at 8th Int. Conf., Int. Fed. of Organic Agric. Movements, Budapest, Hungary.

Meelu, O.P., and R.A. Morris. 1988. Green manure management in rice-based cropping systems, p. 209–222. *In* IRRI (ed.) Green manure in rice farming. IRII, Los Baños, Philippines.

Müller, M.M., and V. Sundman. 1988. The fate of nitrogen (^{15}N) released from different plant materials during decomposition under field conditions. Plant Siol 105:133–139.

Munoz, A.E., E.C. Holt, and R.W. Weaver. 1983. Yield and quality of soybean hay as influenced by stage growth and plant density. Agron. J. 75:147–149.

Norman, R.J., J.T. Gilmour, and B.R. Wells. 1990. Mineralization of nitrogen from N^{15} labeled crop residues and utilization by rice. Siol Sci. Soc. Am. J. 54:1351–1356.

SAS Institute. 1989. JMP user's guide. Version 2. SAS Inst., Cary, NC.

SAS Institute. 1991. SAS user's guide. SAS Inst., Sparks Press, Raleigh, NC.

Seligman, N.G., S. Feigenbaum, D. Feinerman, and R.W. Benjamin. 1986. Uptake of nitrogen from high C-to-N ratio ^{15}N-labeled organic residues by spring wheat grown under semi-arid conditions. Soil Biol. Biochem. 18(3):303–307.

Singh, A. 1975. Use of organic materials and green manuring as fertilizers in developing countries. FAO Soils Bull. 27:19–30.

Stivers, L.J., and C. Shennan. 1991. Meeting the nitrogen needs of processing tomatoes through winter cover cropping. J. Prod. Agric. 4:330–335.

Sugiyama, T., S. Iwahori, and K. Takashi. 1966. Effect of high temperatures on fruit setting of tomato under cover. Acta Hortic. 4:63–69.

Talbott, H.J., W.J. Kenworthy, J.O. Legg, and L.W. Douglas. 1985. Soil-nitrogen accumulation in nodulated and non-nodulated soybeans: A verification of the differences method by ^{15}N technique. Field Crops Res. 11:55–67.

Thönnissen Michel, C. 1996. Nitrogen fertilizer substitution for tomato by legume green manures in tropical vegetable production systems. Thesis ETHZ No. 11626. Swiss Fed. Inst. of Technology, Zürich.

Tripathi, B.P. 1995. Dynamics of soil and nitrogen in selected rice-based cropping systems in northern Luzon, Philippines. Ph.D. diss. Univ. of the Philippines, Los Baños.

Vallis, I. 1983. Uptake by grass and transfer to soil of nitrogen from ^{14}N-labeled legume materials applied to a rhodesgrass pasture. Aust. J. Agric. Res. 34:367–376.
Vasilas, B.L., J.D. Legg, and D.C. Wolf. 1980. Foliar fertilization of soybeans: Absorption and transformation of ^{15}N-labeled urea. Agron. J. 72:271–275.
Varco, J.J., W.W. Frye, M.S. Smith, and C.T. MacKown. 1989. Tillage effects on nitrogen recovery by corn from a nitrogen-15 labeled legume cover crop. Soil Sci. Soc. Am. J. 53:822–827.
Wien, H.C., and P.L. Minotti. 1987. Growth, yield and nutrient uptake of transplanted fresh-market tomatoes as affected by plastic mulch and initial nitrogen rate. J. Am. Soc. Hortic. Sci. 112(5):759–763.
Yaacob, O., and G.J. Blair. 1980. Mineralization of ^{15}N-labeled legume residues in soils with different nitrogen contents and its uptake by Rhodes grass. Plant Soil 57:237–248.
Zebarth, B.J., V. Alder, and R.W. Sheard. 1991. In situ labeling of legume residues with a foliear application of ^{15}N-enriched urea solution. Commun. Soil. Sci. Plant Anal. 22:437–447.

Legume Decomposition and Nitrogen Release When Applied as Green Manures to Tropical Vegetable Production Systems

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ABSTRACT

For legume green manures (GM) to be effective, environmentally sound N sources for horticultural crops in the tropics, their N release must be in synchrony with crop N demand. Decomposition and N release of surface applied (mulch) or incorporated soybean [*Glycine max* (L.) Merr.] and indigofera (*Indigofera tinctoria* L.) GM were studied in six field studies conducted at three locations in Taiwan and the Philippines between 1993 and 1995. Litter bags and inorganic N soil samplings were used in order to understand tomato (*Lycopersicon esculentum* Mill.) crop responses to GM N. Resulting soil N contents were compared with a control (no GM, no fertilizer). The N content of 60 to 74 d soybean GM varied between 110 and 140 kg N ha^{-1} and that of indigofera between 5 and 40 kg N ha^{-1}. Nitrogen-15-labeled soybean GM was traced in the soil and in organic matter fractions (humic acids, calcium humates, humins) in one of the field studies. Soybean and indigofera decomposed rapidly, losing 30 to 70% of their biomass within 5 wk after application, depending on GM placement, season (wet vs. dry), and location. Soil nitrate contents increased corresponding to GM N release at all locations and seasons, with a maximum increase of 80 to 100 kg NO_3–N ha^{-1} with incorporated soybean. The peak N release occurred 2 to 6 wk after GM application in two of the three locations, and 5 to 8 wk in the third location. The apparent decline of GM N release at all locations and seasons 8 wk after application was only partly caused by tomato N uptake. At tomato harvest, 30 to 60% of the GM ^{15}N was found in the soil, and was found mostly in humins. Comparable N release dynamics across seasons and locations suggest a possible N fertilizer substitution by incorporated soybean GM for basal N application and first side dressing to tomato. With respect to season and location, GM N should be supplemented with N fertilizer starting after 8 wk to ensure optimal tomato yields.

For legume green manures (GM) to be considered as effective N sources for horticultural crops, they must supply sufficient N and their N release must be in synchrony with vegetable N demand. Green manure decomposition and subsequent N release depend largely on residue quality and quantity, soil moisture and temperature, and specific soil factors such as texture, mineralogy and acidity, biological activity, and the presence of other nutrients (Myers et al., 1994). In a previous study, 60-d-old soybean [*Glycine max* (L.) Merr.] and indigofera (*Indigofera tinctoria* L.) plants conformed to high-quality litter characteristics (Swift, 1987), releasing N quickly to two of the three soils tested (Thönnissen Michel, 1996). Legume biomass accumulation and chemical composition (e.g., C/N, N, lignin, polyphenol, and tannin) of plants of the same age varied between location and growing season (Thönnissen Michel, 1996), making it difficult to predict their decomposition when grown under different conditions. Residue decomposition can be governed to some extent by GM placement on the soil surface (mulch) or incorporation into the soil (Wilson and Hargrove, 1986). In the southeast of the USA, the greatest N release from decomposing legumes occurred 2 to 5 wk after cover crop killing in spring (Sarrantonio and Scott, 1988). Too rapid GM N release (e.g., within 15 d after incorporation of vetch; Varco et al., 1989), strong N immobilization after GM addition (Mary and Recous, 1994), or early decline of mineral N level over the growing season (Ebelhar et al., 1984) lead to poor synchronization between N release and crop N demand. Studies evaluating the fate of ^{15}N from legume residues decomposing under field conditions led to the conclusions that <30% of legume N was recovered by a subsequent nonlegume crop and large amounts of legume N were retained in soil, mostly in organic forms (Harris et al., 1994; Ladd et al., 1983; Mueller and Sundman, 1988). If, however, lower mineralization rates of mulched GM (nontillage) are responsible for reduced inorganic N accumulation, then such a system could better conserve organic N in the long term (Sarrantonio and Scott, 1988).

The objective of this study was to monitor legume GM decomposition and determine the timing and quantity of GM N release in fields grown to tomato crops (Thönnissen Michel, 1996) at three locations and two seasons (wet season, WS; dry season, DS) in Taiwan and the Philippines. In the tropical WS in Taiwan, nitrate leach-

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Published in Agron. J. 92:253–260 (2000).

Abbreviations: AVRDC, Asian Vegetable Research and Development Center; BRCI, Bukidnon Resources Corporation, Inc.; DS, dry season; IRRI, International Rice Research Institute; GM, [legume] green manure; MMSU, Mariano Marcos State University; SOM, soil organic matter; WS, wet season.