Influence of Short-duration Legume Fallow on N Availability and Performance of Tomato in a Tropical Rainforest Zone of Nigeria

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Summary

The incorporation of plant biomass (litter/prunned residues) into the soil constitutes an important pathway for nutrient cycling in ecosystems. The feasibility of meeting N needs of tomato (*Lycopersicon esculentum* Mill) with short-duration pigeon pea fallow was studied in the field in Akure, a humid zone of Nigeria. The trials were set up on site where late season pigeon pea – maize intercrop was previously assessed between August and December in years 1999 and 2000. Fallows were allowed to grow during the five months of dry season and were cleared before planting tomato in the following rainy season. Treatments consisted of 3 x 2 factorial combinations of tomato macroplots established following the previous years layout on fallows of pigeon pea alone, pigeon pea interplanted with maize and non-fallow land at two levels of inorganic N fertilizer (0 and 150 kg N ha^{-1}) with three replications per treatment. In both seasons, preseason topsoil inorganic N correlated with tomato fruit yield ($r^2 = 0.45$; $P < 0.001$). Accumulation of N in the aboveground biomass related weakly to initial soil N contents ($r^2 = 0.32$; $P<0.001$) while fruit yields of tomato significantly correlated with N concentration in aboveground biomass ($r^2 = 0.97$; $P < 0.01$). The status of soil nitrogen, plant N uptake and yields of biomass and fruits of tomato under pigeon pea biomass incorporation following legume fallow were similar to those obtained under mineral fertilizer application. Therefore, N requirement of tomato can be partly substituted by short-duration legume fallow.

Key words

tomato, legume fallow, N, availability, growth, yield

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Introduction

Vegetables are high-value crops and the intensive production systems involve high application rates of fertilizers to maximise yields. The bane of continuous cropping systems of the tropics is soil fertility depletion. Green manuring/leguminous fallows can improve soil fertility and vegetable quality in addition to reducing excessive use of mineral fertilizers (Thonnissen *et al*., 2000). Although, leguminous fallows are possible means of maintaining soil fertility, high population density and scarcity of land preclude extended fallow periods. Short duration leguminous fallows are mainly planted with herbaceous legumes and N_2-fixing fast growing trees. These influence nutrient availability and supply through N_2 fixation (Giller and Wilson, 1991), increased N from labile organic matter (Barious *et al*., 1998) and by recycling N from deeper soil layers (Ikerra *et al*., 1999). Nitrogen from organic sources is nevertheless tied to complex microbial cycling of C and N and this affects the availability of legume N. Thonnissen *et al*. (2000) reported increased tomato yield following legume green manure comparable to mineral fertilizers. Legume green manuring and short-duration legume fallows had focused more on staple crops while their potentials in nutrient cycling in tropical horticulture has received scanty research attention (Thonnissen *et al*., 2000). Pigeon pea /maize intercropping is a common component of the farming systems of the tropics. Pigeon pea planted with maize competes less during maize growth but continues to grow into the dry season after maize harvest. Although, pigeon pea offers little soil N benefits to companion maize crop (Sakala *et al*., 2000), it nevertheless produces edible and marketable yield benefits. In the following planting (rainy) season, the pigeon pea biomass is cut and incorporated during land preparation. Plant biomass (litter/prunned residues) releases nutrients when decomposed and produces a feedback effect on nutrient dynamics in the crop production systems of the tropics. The rate of litter decomposition is affected by the interaction between the decomposing community, physicochemical environment and litter quality. Litter quality is a set of chemical/structural characteristics which govern the activities of decomposing organisms and the ease with which organic matter decays/mineralises (Giller and Wilson, 1991; Ikerra *et al*., 1999). The feasibility of meeting N needs of tomato (*Lycopersicon esculentum* Mill.) with short-duration legume (of about four to five months) fallow and the integration of this legume fallow systems into vegetable production systems of the humid tropics was studied in a humid zone of Nigeria.

Materials and methods

Site and treatments

This experiment was designed to assess the growth and yield performance of tomato following short-duration legume fallow on the performance of tomato in a humid rainforest zone of Nigeria. The study was conducted at the Teaching and Research Farm of the Federal University of Technology, Akure (7º 5 N; 5º 10 E), a humid zone of Nigeria. The sandy loam soil at the site of the experiment is an Alfisol classified as clayey skeletal, kaolinitic isohyperthermic oxic paleustalf (USDA). The trials were set up on site where late season pigeon pea – maize intercrop was previously assessed between August and December in years 1999 and 2000. Maize (AK96, DMR and LSRW) was planted on 40 cm high ridges two weeks after maize germination. Pigeon pea seeds were sown as sole crop at 0.6 x 0.9 m and at 0.6 x 1.2 m in alternative rows involving maize as an intercrop. This gave densities of zero, 9259 and 18519 pigeon pea plants ha^{-1} on 5 x 4 m plots. Maize was harvested in November of 1999 and 2000. After maize harvest each year, pigeon pea was allowed to grow during the five months of dry season (from December of one year to April of another). At the onset of the rains, pigeon pea plants were cleared, its non-woody biomass and litter in addition to maize stover were spread on soil surface and covered with soil during ridging (land preparation) in April 2000 and 2001 respectively. Three weeks old seedlings of a variety of tomato (*Ibadan local)* raised in the nursery, were transplanted on 23rd April 2000 and 11th April 2001 respectively on ridges at a spacing of 60 x 90 cm. Treatments consisted of 3 x 2 factorial combinations of tomato macroplots established following the previous years layout on fallows of pigeon pea alone, pigeon pea interplanted with maize and non-fallow land at two levels of inorganic (mineral) N fertilizer (0 and 150 kg N ha^{-1}) with three replications per treatment. The inorganic N consisted of application of urea in narrow bands and was split applied two and six weeks after transplanting (WAT) tomato. The plots were weeded twice manually by hand.

Growth and yield characters of tomato

Data were collected on tomato growth and yield parameters from the central 2 x 2 m^2 position of each plot. Pigeon pea biomass incorporation preceeded soil sampling by about a week (allowance for beginning of decomposition). Top soil was packed together (concentrated) in the ridges during land preparation and soil samples 0 – 20 cm taken solely from the ridges in each plot were bulked for ten locations per plot while sub- samples were taken to the laboratory for the determination of pre-planting status of soil N. Field moist soil samples, 20 g each, were extracted with 100 ml of 2M Potassium chloride using Whatman No. 5 filter paper. NH_4-N was determined from the extract by a salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993) while NO_3-N was determined by cadmium reduction method (Dorich and Nelson, 1984). The sum of NH_4-N and NO_3-N refers to total inorganic N. Soil bulk densities calculated from core samples (100 cm^3) col-

Table 1. Some meteorological variables of the site of experiment (1999-2001)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec
Rainfall (mm)	0	1.4	33.2	53.5	97.9	205.1	268.7	253.6	211.9	179.4	17.8	5.1
Relative humidity (%)	47	41	48	55	63	67	73	81	72	63	52	48
Temperature (°C)	32.3	32.9	33.8	33.2	32.4	31.7	30.5	29.7	28.5	29.8	30.2	30.4
Sunshine hours	189.3	217.4	225.7	194.6	189.3	161.9	108.7	89.5	96.3	147.2	209.1	158.6
Solar radiation (MJ/m^2)	43.5	45.8	48.6	50.3	48.5	39.3	37.8	41.4	43.6	45.7	47.5	44.8

lected from each soil depth was used to convert NH_4-N and NO_3-N data from mg N kg^{-1} to kg N ha^{-1}. 1m deep pits were dug between rows of Pigeon pea to observe the trend of root distribution in the soil and large surface roots from the Pigeon pea plants were excavated to observe the extent of their spread beyond tomato roots. Soil samples were collected using core samplers (steel corers – 10 cm diameter and 10 cm depth) from three randomly selected sampling points from each treatment replicates within the field and at soil depths of 0-20, 20-35, 35-50 and 50-65 cm. The depth-wise samples were used for the determination of soil moisture contents and bulk density. The field moist soil samples were oven-dried for 24 hours and at 105 °C. Root weight/plant was determined after oven-dried for 24 hours at 80 °C. Measurements of leaf area using leaf area meter (LiCor 67 R, Mayashi Co., Japan) were made at two week intervals beginning at three weeks after transplanting (WAT) using leaf area meter (Mayashi Denko Co. Japan). Percentage fruit set was calculated as the total number of fruits on a plant to the total number of flowers on inflorescences and harvest index was rated as the ratio of fruit weight to the total plant biomass.

Data collected on plant biomass, fruit yield and soil chemical properties were subjected to a two-way analysis of variance while the means were compared using least significance difference (LSD) test. Statistical significance refers to $P < 0.05$.

Results and discussion

Soil physical properties and N status

There were variations in soil moisture contents within 40 – 60 cm depth (Fig. 1a) at the beginning of the rains (before planting in April) and at 10 – 40 cm depth (Fig. 1b) at crop maturity (12 WAT). Tomato seedling establishment in rainy season tomato at the site of the experiment coincided with the onset of the rains following the prolonged drought of the dry season (Table 1). However, tomato grown on plots on which Pigeon pea was previously sown have considerable higher soil moisture contents at all sampling dates than sole tomato plots (non-leguminous fallow plots). The leguminous fallow plots had considerably lower bulk densities values (Fig. 2a) particularly after the rains were established about the peak vegetative growth of tomato (Fig. 2b). This could have followed from pigeon pea root activities on fallow plots, litter fall and microbial activities. The lower soil strength could have enhanced rainfall infiltration, soil water storage and root development of tomato. Rapid root proliferation early in a plant cycle ensured root proliferation in cooler and more moist soil environment (Itabari *et al.*, 1993) and might have contributed to enhanced survival, vegetative growth and canopy development in tomato. Biomass incorporation preceded sampling by few weeks, pre-season sampling therefore in-

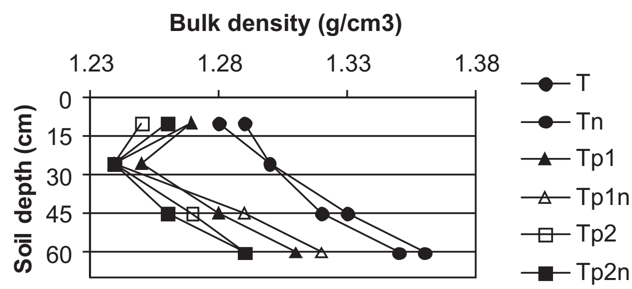

Figure 1a. Effect of pigeon pea biomass incorporation on soil bulk density (four weeks after transplanting tomato). (T is tomato grown on non-fallow land; Tn is tomato grown on non-fallow land plus 150 kg N ha; Tp1 is tomato grown on fallow plots of pigeon pea at 9259.23 plants ha^{-1} plus biomass incorporation; Tp1n is tomato grown on fallow plots of pigeon pea at 9259.23 plants ha^{-1} plus biomass incorporation and 150 kg N ha^{-1}; Tp2 is tomato grown on fallow plots of pigeon pea at 18518.52 plants ha^{-1} plus biomass incorporation; Tp2n is tomato grown on fallow plots of pigeon pea at 18518.52 plants ha^{-1} plus biomass incorporation and 150 kg N ha^{-1}).

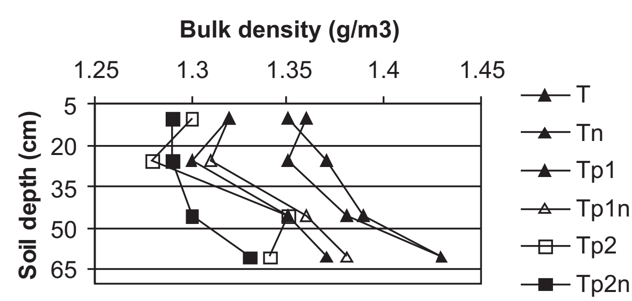

Figure 1b. Effect of pigeon pea biomass incorporation on soil bulk density (12 weeks after transplanting tomato). Legend same as in Fig. 1a.

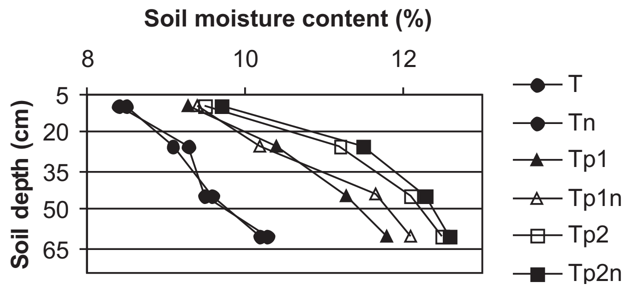

Figure 2a. Effect of pigeon pea biomass incorporation on soil moisture content (four weeks after transplanting tomato). Legend same as in Fig. 1a.

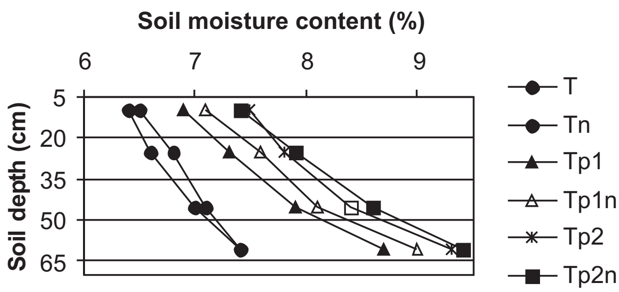

Figure 2b. Effect of pigeon pea biomass incorporation on soil moisture content (12 weeks after transplanting tomato). Legend same as in Fig. 1a.

Table 2. Pre-planting topsoil (0 – 20 cm) inorganic N status (kg ha^{-1})

Pigeon pea density (No of plants ha^{-1})	NO_3-	NH_4-+ NO_3-	soil mineral N
0	15.3	29.1	44.4
9259	19.2	35.4	54.6
18519	21.6	32.3	53.9
LSD (0.05)	4.3	4.7	5.1

LSD (Fisher's least significance difference test; When the difference between two means is greater than the LSD value, such means are said to be significantly different)

cluded little N accumulated from recently added materials as topsoil was very dry at that time. Addition of prunings of P. pea biomass (excluding litter fall which was not quantified) resulted in increased accumulation of inorganic soil N (Table 2) and higher biomass additions under increased pigeon pea densities further elevated the status of soil N. Soil physical and chemical properties could have benefited from leguminous fallow presumably from the activities of the root system, nutrient release from litter fall and N fixation by the legume.

Tomato fruit yield and soil N utilisation

The incorporation of plant biomass and inorganic fertilizer N significantly improved fruit yield of tomato. The incorporated biomass influenced pre-season topsoil inorganic N and produced significant increases in tomato fruit yield. However, the increases were less than fruit yield obtained under inorganic fertilizer N treatment (Table 3). Pigeon pea biomass incorporation following five month fallow period at the highest density of 18518.52 plants ha^{-1} produced 7.03 t ha^{-1} tomato fruit yield which constituted about 43% increase over the control (zero-N plots without Pigeon pea) and 3% less than the 7.26 t ha^{-1} produced under fertilizer N treatment. High rate of mineralisation of organic matter in the humid tropics enhances the susceptibility of released nutrients to rainfall runoff and leaching losses. The reduced efficacy of legume biomass incorporation and hence declined crop yield to losses of nutrient beyond root zone by leaching in under the hgigh tropical rainfall events. Although, pigeon pea biomass yields were variable and biomass incorporation inconsistently relate to soil N status and tomato fruit yields, this practice however offers some modest yield benefits. Initial N levels in soil are relatively high particularly in fallow plots, high N uptake suggested adequate levels of N in the soil to meet the nitrogen demands of tomato. There were some improvements in N uptake and use efficiencies in tomato planted on Pigeon pea fallow plots (Table 4). These experimental groups also had higher nitrate (NO_3^-) and N concentrations in shoots and fruit tissues. Westerman and Edlund (1985) attributed increased solubility and availability of nutrients especially P to increased nitrification and uptake of NH_4^- and NO_3^-. The high fruit yields obtained in tomato planted on legume fallow land is attributable to improved N availability in the soil and accumulation in plant tissues and efficient utilization of extracted nutrients for biomass and fruit production. Nitrogen availability to subsequent tomato crop from N fixation during Pigeon pea fallow and N mineralised from incorporated biomass should explain the variability in aboveground N of tomato crop in the different treatments. During fallow period, fallow plants extensive root systems absorb substantial quantities of nutrients from lower soil horizons, the accumulated nutrients in biomass is returned to the soil through litter fall, root decomposition /root exudate thus enriching the soil. The survival and growth of Pigeon pea in the dry season period and hence the success of dry season fallow depends on the status of soil water reserve. This soil parameter is affected by the amount of rainfall (Table 1) during the late season period (4142.2mm) and the moisture holding capacity of the soil. Following pruning of regrowth of P. pea, the crop persisted after cut-back producing further re-growth and biomass yield. These regrowths exerted competition (below and above ground) with implications for tomato growth and yield. Visual observations of root distribution supported below ground competition between Pigeon pea and tomato. Pigeon pea roots were found in the top 30 cm of soil in addition to its extension beyond zone/depth of

Table 3. Effects of legume fallow and pigeon pea non-woody biomass incorporation on the biomass and fruit yield of tomato

	Biomass yield (t ha^{-1})		Fruit yield (t ha^{-1})	
	Zero N	60 kg N ha^{-1}	Zero N	60 kg N ha^{-1}
Sole tomato (non-fallow land)	3.98	4.41	4.92	7.26
9259 Pigeon pea (ha^{-1})	4.67	5.32	6.55	8.73
18519 Pigeon pea (ha^{-1})	5.19	6.23	7.03	9.31
LSD (0.05) (Density; plants ha^{-1})	0.054			
LSD (0.05) (N rate)	0.049	0.073	0.11	

LSD (Fisher's least significance difference test; When the difference between two means is greater than the LSD value, such means are said to be significantly different)

Table 4. Effects of Pigeon pea fallow and biomass application on N concentration and the efficiency of N utilization for biomass and fruit production in tomato

Applied N (kg ha^{-1})	Pigeon pea density (plants ha^{-1})	N conc. (%)		N yield (g m^{-2})		NHI	Kg biomass yield/kg N absorbed	Kg fruit yield/kg N absorbed	Harvested N	Apparent recovery above ground biomass
		Shoot	Fruit	Shoot	Fruit					
0	0	0.02	0.01	1.12	0.18	0.082	15.3	1.47	12.1	—
0	9259	0.05	0.04	2.57	0.22	0.083	11.8	1.25	25.7	5
0	18519	0.07	0.05	3.91	0.55	0.120	9.0	1.13	39.1	9
60	0	0.04	0.03	1.06	0.07	0.054	18.8	1.51	10.6	—
60	9259	0.08	0.05	2.61	0.19	0.070	13.0	1.38	26.1	4
60	18519	0.11	0.08	4.24	0.42	0.090	10.5	1.23	42.4	9
LSD (0.05) P. pea density		0.05	0.04	1.08	0.16	0.031	3.4	0.37	11.3	
LSD (0.05) N rate		0.07	0.06	1.11	0.19	0.064	4.7	0.23	1.9	

LSD (Fisher's least significance difference test; When the differcence between two means is greater than the LSD value, such means are said to be significantly different)

Table 5. Correlations of soil N, biomass and fruit yield of tomato

Y=	x	+ a	r^2
Pre planting soil N and fruit yield of tomato			
Zero N	2.881	16.42	0.43
60 kg N ha^{-1}	2.883	12.21	0.503
Pre planting soil N and biomass N concentration			
Zero N	48.78	28.2	0.39
60 kg N ha^{-1}	26.67	5.17	0.26
Biomass N concentration and fruit yield			
Zero N	17.72	4.02	0.99
60 kg N ha^{-1}	13.42	5.17	0.95

tomato rooting where huge surface roots were excavated. There appears to be shading effects of crown edge of Pigeon pea although very little. The combination of the two forms of competition seemed to have additive effects on tomato yield. Below ground competition is severe between short stature shrub and annuals (Szott *et al*., 1991; Nissen *et al*., 1999), above ground competition is apparent. High year to year variability was smoothed out by plot-wise sum of biomass and fruit yield for the two seasons of study. There were variable relationships of soil inorganic N and fruit yield of tomato (Table 5). Although, pre-season status of soil N is a simple measure of N supply to plants (Ikerra *et al*., 2001), we nevertheless obtained a weak relation of pre-season soil N and tomato fruit yield ($r^2 = 0.45$; $P < 0.001$). Barrious *et al.* (1998) found similar correlations of yield with pre-season inorganic soil N. Erratic pigeon pea biomass yield at the end of fallow period and the variable relations of soil N with fruit yield of tomato may limit the use of fallow biomass and status of preseason soil inorganic N as yield predictor in tropical vegetable production systems. Longer fallows should cause greater yield increases and longer residual effects (Ikerra *et al*., 2001). Tomato (vegetable) cropping systems involving pigeon pea should be considered against other cultural practices, for example, use of short-duration legume green manures (Thonnissen *et al.,* 2000).

The application of inorganic fertilizer N and incorporation of pigeon pea biomass following legume fallow considerably enhanced the growth and yield parameters of tomato. There were however non-significant interactions between pigeon pea biomass incorporation and inorganic fertilizer N application on the growth and yield of tomato.

Conclusion

Pigeon pea fallow and biomass incorporation increased tomato yield performance modestly in this study, P. pea fallowing enhances soil restoration and nutrient recycling processes. Multi-locational trials are therefore recommended to identify the features of leguminous short-duration fallows on soil N status and crop yield. Nevertheless, the study has applications in continuous cropping/intercropping systems involving leguminous plants where longer duration fallows are not necessary. The integration of dry season legume fallow in the continuous cropping systems of the tropic involving vegetable crops is therefore advocated.

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