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NITROGEN AND PHOSPHORUS DYNAMICS IN A LEGUME BASED INTEGRATED NUTRIENT MANAGEMENT SYSTEM.

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ABSTRACT

This study was carried out on a tropical alfisol for two consecutive years to investigate the effect of a legume based integrated nutrient management system on the soil status of nitrogen and phosphorus. The treatments consisted of two rates of poultry manure (0 and 5 t ha^{-1}), three rates of N fertilizer (0, 50 and 100 kg N ha^{-1} applied as urea), three rates of P fertilizer (0, 30 and 60 kg P ha^{-1} applied as single superphosphate) and two soybean treatments (with or without legume residue) arranged as a factorial experiment using Randomized Complete Block Design (RCBD) with three replicates. Soil samples were collected, processed and analyzed before planting and after harvests each year for N and P and other soil properties. Results show that the impact of legume on Soil P was the least as it accounted for mere 4.0% and 0.8% increase in Soil P in 2004 and 2005 respectively. Manure x P fertilizer interactions produced the most significant effect on Soil P as it accounted for 47.2% increase in Soil P at 5 t ha^{-1} M and 60 kg P ha^{-1} level of combination over control. Of all the interactions studied on Soil N, only the LxMxN and MxN interactions were significant. In 2005, MxN interaction increased Soil N by 110.5% while LxMxN interaction increased Soil N in 2004 by 166%. Manure, fertilizer N and fertilizer P were found to be controlling factors in Soil N and soil P. Soybean on its own had little or no effect on Soil N and P.

INTRODUCTION

Since the beginning of the 20th century, considerable efforts have been made to introduce and promote legume technology in West Africa. Such technology include the use of grain legumes, forage legumes, and green manures in promoting soil fertility. Schulz *et al.* (2001), however noted that with the exception of grain legumes which in 1999 were grown on more than 12 million ha, the adoption of legume technology has been disappointingly low in West Africa.

The grain legumes adapted to West Africa include cowpea (Vigna *unguiculata* (L.) Walp), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*). At present, Cowpea and Groundnut are the most widely grown grain legume crops in West Africa accounting for 50% and 38% respectively of the 12 million ha cultivated throughout West Africa in 1999. The cultivation of Soybean however, remains very low accounting for mere 12% of the hectarage (FAO, 1999).

The proportion of nitrogen that is fixed and the Nitrogen Harvest Index (NHI) are important indicators for N contribution of legume crops. The residual N effects of high grain yielding pulse crops, according to Giller and Cadisch (1995), are generally not very pronounced. The cultivation of high yielding grain legumes may therefore, result in negative N balances as more N may be removed from the system than is added through N fixation. Findings by Ogoke (1999), for example, showed that the net N contribution of Soybean grown in three locations in Nigerian moist savanna varied between -5 and -25 kg N ha^{-1} and that the residual effect of soybean on subsequent maize was similar to that of a preceding rice crop.
The principal forms of mineral N in soil are NH_4 and NO_3 ions. Under aerobic conditions, NH_4^+ is rapidly nitrified to NO_3^- even in acid soils of the tropics, which may contain small numbers of autotrophic nitrifying bacteria (Wild, 1972a; Van Veen *et al.,* 1987). Nitrate –N is highly mobile in soils and it is easily lost by leaching. It becomes necessary therefore, for the tropical farmer to have within his reach, farming techniques that can help offset the great loss of N from bush burning, leaching and denitrification. Such techniques involve the use of legumes in all aspects of crop production (Ahmad, 1985). Legumes, according to him, are normally self-supporting in their N-requirement and in addition, incorporate in their vegetation large quantities of atmospheric N through the rhizobia, which are associated.

Important progress has been made with regard to the transformation and fate of N in the soil through the use of labeled N (Hood, 2002; Vanlauwe *et al.,* 2001). Because a successfully nodulated legume crop makes little or no demand on native Soil N for its N nutrition throughout the life of the crop, it is quite likely that the nitrifiable N content of any soil on which a legume is being grown actually increases. This would partially explain why there is always a residual effect of N following a legume when there is usually no such response if N fertilizers are used.

Phosphorus deficiency is widespread in the soils of the tropics. In general, low available P in soils is a problem throughout tropical Africa and many of the soils in the humid zone of West Africa are naturally low in P. The problem is more severe on acid soils as the applied P is converted to unavailable forms as a result of fixation by Fe and Al hydroxides (Warren, 1992).

Like nitrogen, phosphorus occurs in soils in organic and inorganic forms. The organic fraction is found in humid and other organic materials. The inorganic fraction occurs in numerous combinations with Fe, Al, Ca and other elements resulting in the formation of compounds that are only slightly soluble in water. The organic soil P is important especially in the tropics because as noted by Udo (1985), it may readily undergo mineralization to release available P for the plant. In contrast, the inorganic P forms may be fixed and made unavailable to plants. Early research works on soils from Kenya (Friend and Birch, 1960) and Southern Nigeria (Adepetu and Corey, 1976) revealed a strong and direct relationship between total soil organic P and plant available P.

Not much is known yet about the immobilization and mineralization of P in soils in relation to the C:N:P ratios. However, it has been suggested that if the C:P ratio is 200:1 or less, mineralization of P will occur and that if the ratio is 300:1 or more, immobilization of P will occur (Tisdale and Nelson, 1975; Lyasse *et al.,* 2002). This paper reports a research conducted on a tropical alfisol in 2004 and 2005 to investigate the effect of the inclusion of soybean in a rotation on the dynamics of N and P in the soil.

MATERIALS and METHODS

Surface soil samples (0-20cm) were taken from the experimental site at the University of Agriculture in Abeokuta, South Western Nigeria. The site had not received fertilizer for five years prior to the experiment. The project

site was located on the upper slope of a highly weathered sedentary soil (Iwo series). The soil is sandy loam in texture and classified as Kandic Paleustalf (Aiboni, 2001). The soil samples were air-dried, sieved through a 2mm sieve and analyzed for selected physical and chemical properties.

Particle size distribution was determined by the hydrometer method (Udo and Ogunwale, 1986) using sodium hexameta-phosphate as the dispersing agent. Soil pH was determined potentiometrically in distilled water at soil to water ratio 1:1. Exchangeable bases (K, Na, Ca and Mg) were extracted with neutral normal $NH_4OA_{c.}$ Potassium and Na in the extract were determined by flame photometry while Ca and Mg were read by atomic absorption spectrophotometer. Exchangeable acidity was determined by titration of normal KCl extract against 0.05 sodium hydroxide to a pink end point using phenolphthalein as indicator (Mclean, 1967). Effective cation exchange capacity (ECEC) was obtained by summation of exchangeable bases and exchangeable acidity. Available P was determined by using the Bray 1 method. Total N was determined by regular Macro-Kjeldahl method while the organic matter was determined using the wet oxidation method.

The poultry manure (PM) used for experiment was from the government poultry farm at Alabata village, Odeda Local Government, Ogun State, Nigeria. The PM was dried and analysed by standard procedures for the following characteristics: total P 24.80 g kg^{-1}; total N 20.00g kg^{-1}; NH_4-N 1.40%; organic C 26.5%; C:N 18.9; Na 0.42%; K 0.72%; Ca 0.21%; Mg 0.16%; Zn 50.00 mg kg^{-1}; Cu 90.00 mg kg^{-1}; Mn 30.00mg $kg^{-1.}$

The field experiment was conducted in 2004 and 2005 as a factorial experiment arranged as Randomized Complete Block Design (RCBD) with three replicates. The treatments consisted of three nitrogen rates (0, 50 and 100 kg N ha^{-1}) applied as urea (46%N); three rates of phosphorus (0, 30 and 60 kg P ha^{-1}) applied as single superphosphate (18% P_20_5) and two rates of poultry manure (0, 5 t ha^{-1}). Soybean (*Glycine max*, variety TGX 1448-2E) was introduced earlier in the season to precede maize cultivation. It was sown by drilling and spaced 30cm apart. At 12 weeks after planting, the pods were harvested while the stovers (residues) were incorporated into the soil. The amount of residue incorporated was estimated at 5 t ha^{-1}.

Two maize seeds (*Zea mays*, variety DMR-ESR-Y) were planted per hole and later thinned to one per stand two weeks after emergence. The planting distance was 25cm by 75cm. Each plot size was 3m x 5m and the plant population was 53,333 maize plants per ha. All plots received basal application of 30 kg K ha^{-1} as muriate of potash. Plots receiving poultry manure had the manure worked into the soil two weeks before planting. Weeding was done manually with native hoe at three weeks after planting (3WAP) and seven weeks after planting (7WAP). Twenty leaves were taken from each plot at tarselling for tissue analysis. The plant samples were dried to constant weight and analyzed for N and P. Plot by plot surface soil samples (0-20cm) were taken twice and the samples were analyzed for N, P, organic carbon, pH and exchangeable bases using methods previously described. Maize was harvested at maturity, dried, shelled and weighed.

The data collected were subjected to analysis of variance using the Statistical Analysis System (SAS, 1999). Means were separated by Duncan Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

The soil used for the study is of moderate acidity (pH 5.8), low cation exchange capacity (CEC 3.06 Cmol kg^{-1}) and low available phosphorus. The values for total N (0.9 g kg^{-1}) and soil organic matter (15.7 g kg^{-1}) also fall within the critical low range in soils of Western Nigeria (Adepetu, 1986). With low N low P, low organic matter and low CEC, it is

obvious that the soil is inherently low in fertility (Table 1) and therefore, expected to exhibit response to soil amendments.
The soil is loamy sand with Fe concretions, well drained and classified (Aiboni, 2010) as Kandic Paleustalf. The low available P status of the soil is probably due to high P fixation capacity of the soil.

Table 1: **Some physical and chemical properties of the soils used for the experiment.**

Parameters	**Values**
pH (H_2O)	5.80
Av.P (mg kg^{-1})	9.50
Na (cmol kg^{-1})	0.83
K (cmol kg^{-1})	0.12
Ca (cmol kg^{-1})	1.10
Mg (cmol kg^{-1})	0.89
H	0.12
ECEC (cmol kg^{-1})	3.06
% Base saturation	96.08
N (g kg^{-1})	0.9
O.M (g kg^{-1})	15.7
SILT (%)	20.10
CLAY (%)	11.00
SAND (%)	68.90

The effect of treatments on soil P status (Tables 2 and 3) shows that soil P was significantly and positively affected by all the treatments in the two years of study. The effect was however most pronounced with P-fertilizer input in both years where soil P increases due to P fertilizer at 60 kg P ha^{-1} was 41.8% in 2004 and 29.8% in 2005. Soil P increase due to manure application was also increasingly high in both years. The effect of legume on soil P was the least in both years. It accounted for 4.0% increase in Soil P in 2004 while in 2005, it accounted for mere 0.8% increase. Only the LxM and MxN interactions were significant for Soil P in 2004. Values for soil P in response to LxM interactions are presented in Table 4.

Table 2: Effect of treatment rates on some plant and soil characteristics in the field (2004).

Treatments	OM (g kg^{-1})	Ph	Soil P (mg kg^{-1})	Soil N (g kg^{-1})	Plant P (%)	Plant N (%)	CEC (cmol kg^{-1})
Legume							
Without	15.33^{b}	6.48^{a}	4.94^{b}	1.43^{b}	0.46^{b}	0.56^{b}	2.21^{a}
With	16.59^{a}	6.49^{a}	5.14^{a}	1.51^{a}	0.47^{a}	0.58^{a}	2.21^{a}
Manure							
0	12.82^{b}	6.46^{a}	4.51^{b}	1.12^{b}	0.44^{b}	0.53^{b}	2.15^{b}
5	19.11^{a}	6.51^{a}	5.57^{a}	1.82^{a}	0.49^{a}	0.61^{a}	2.27^{a}
Nitrogen							
0	14.11^{c}	6.45^{b}	4.63^{c}	1.14^{c}	0.44^{c}	0.52^{c}	2.18^{c}
50	16.45^{b}	6.55^{a}	5.08^{b}	1.49^{b}	0.47^{b}	0.57^{b}	2.22^{b}
100	17.33^{a}	6.45^{b}	5.41^{a}	1.77^{a}	0.48^{a}	0.62^{a}	2.23^{a}
Phosphorus							
0	15.20^{b}	6.47^{a}	4.13^{c}	1.37^{c}	0.44^{c}	0.55^{c}	2.20^{b}
30	16.27^{a}	6.51^{a}	5.13^{b}	1.45^{b}	0.47^{b}	0.57^{b}	2.21^{b}
60	16.44^{a}	6.49^{a}	5.86^{a}	1.58^{a}	0.49^{a}	0.59^{a}	2.22^{a}
LxM	NS	NS	0.018	NS	NS	NS	NS
LxN	NS	0.036	NS	NS	NS	0.0002	NS
LxP	NS	NS	NS	NS	0.048	NS	NS
MxN	0.003	NS	0.002	NS	NS	0.0035	NS
MxP	NS	0.0012	NS	NS	NS	NS	NS
NxP	NS	0.0008	NS	NS	NS	NS	NS
LxMxN	NS	0.007	NS	0.043	NS	NS	NS
LxMxP	NS	NS	NS	NS	NS	NS	NS
LxNxP	NS	NS	NS	NS	NS	NS	NS
MxNxP	NS	0.0028	NS	NS	NS	NS	0.037

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$. L=legume; M=manure; N=nitrogen; P=phosphorus.

Table 3: Effect of treatment rates on some plant and soil characteristics in the field (2005).

Treatments	OM (g kg^{-1})	pH	Soil P (mg kg^{-1})	Plant P (%)	Soil N (g kg^{-1})	Plant N (%)	CEC (cmol kg^{-1})
Legume							
Without	15.54^{b}	6.61^{a}	4.83^{a}	0.46^{a}	1.15^{b}	0.52^{b}	2.37^{b}
With	17.62^{a}	6.63^{a}	4.87^{a}	0.46^{a}	1.36^{a}	0.56^{a}	2.43^{a}
Manure							
0	13.74^{b}	6.69^{a}	4.51^{b}	0.44^{b}	1.03^{b}	0.51^{b}	2.27^{b}
5	19.42^{a}	6.55^{b}	5.19^{a}	0.48^{a}	1.47^{a}	0.57^{a}	2.52^{a}
Nitrogen							
0	14.82^{c}	6.68^{a}	4.61^{c}	0.44^{b}	1.07^{c}	0.50^{c}	2.34^{c}
50	16.74^{b}	6.58^{b}	4.88^{b}	0.46^{a}	1.25^{b}	0.54^{b}	2.38^{b}
100	18.18^{a}	6.59^{b}	5.06^{a}	0.47^{a}	1.43^{a}	0.57^{a}	2.47^{a}
Phosphorus							
0	15.89^{c}	6.65^{a}	4.19^{c}	0.42^{c}	1.18^{b}	0.52^{c}	2.36^{b}
30	16.62^{b}	6.61^{a}	4.92^{b}	0.46^{b}	1.26^{a}	0.54^{b}	2.40^{a}
60	17.23^{a}	6.60^{a}	5.44^{a}	0.49^{a}	1.31^{a}	0.56^{a}	2.43^{a}
LxM	0.003	NS	NS	NS	NS	NS	0.0083
LxN	NS	0.029	0.0054	0.019	NS	NS	0.0058
LxP	NS	NS	0.0205	NS	NS	NS	NS
MxN	NS	NS	NS	<0.0001	0.0005	0.0007	NS
MxP	NS	NS	0.0017	NS	NS	NS	NS
NxP	NS	NS	0.0078	NS	NS	NS	NS
LxMxN	NS	NS	0.0019	NS	NS	NS	NS
LxMxP	NS	NS	NS	NS	NS	NS	NS
LxNxP	NS	NS	NS	NS	NS	NS	NS
MxNxP	NS	NS	NS	NS	NS	NS	NS

Figures having the same letter(s) as superscripts within a column are not significantly different at P < 0.05. L=legume; M=manure; N=nitrogen; P=phosphorus

Of all the interactions studied in 2005, the MxP interaction was most significant for soil P although the LxN, LxP, and LxMxN interactions were also found to be significant. In 2005, the MxP interaction accounted for soil P increase of 47.2% at the 5 t ha^{-1} M and 60 kg P ha^{-1} level of combination over the control (Table 5).

Table 4: Soil P status (mg kg^{-1}) as affected by legume and manure application in the field.

	2004		2005		Mean of two years	
Manure (t ha^{-1})	Without Legume	With Legume	Without Legume	With Legume	Without Legume	With Legume
0	4.47^{c}	4.54^{c}	4.48^{b}	4.54^{b}	4.47^{c}	5.54^{c}
5	5.40^{b}	5.75^{a}	5.18^{a}	5.20^{a}	5.29^{b}	5.47^{a}

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$.

Table 5: Soil P status (mg kg^{-1}) as affected by manure and phosphorus fertilizer application in the field.

	2004		2005		Mean of two years	
P fertilizer (Kg ha^{-1})	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**
0	3.65^{e}	4.61^{d}	3.94^{e}	4.44^{d}	3.79^{e}	4.53^{d}
30	4.54^{d}	5.72^{b}	4.51^{d}	5.34^{b}	4.52^{d}	5.53^{b}
60	5.33^{c}	6.38^{a}	5.07^{c}	5.80^{a}	5.20^{c}	6.09^{a}

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$.

Phosphorus deficiency has been widely regarded as the major biophysical constraint to crop production on many farmlands in the humid and sub-humid zones of West Africa where low activity clays predominate (Mokuwunye *et al.*, 1996). The application of P fertilizer is therefore, essential in order to overcome the depletion of soil reserves because unlike N, P cannot be added by biological N fixation. Although P fertilizer was the major factor responsible for the soil P increases in this study, the effect was greatly enhanced with the addition of manure. The soil P status as affected by LxP interaction is presented in Table 6.

Table 6: Soil P status (mg kg^{-1}) as affected by legume and phosphorus fertilizer application in the field.

	2004		2005		Mean of two years	
P fertilizer (Kg ha^{-1})	Without Legume	With Legume	Without Legume	With Legume	Without Legume	With Legume
0	4.00^{d}	4.26^{d}	4.10^{c}	4.28^{c}	4.05^{d}	4.27^{c}
30	4.97^{c}	5.28^{b}	4.94^{b}	4.91^{b}	4.95^{b}	5.10^{b}
60	5.84^{a}	5.88^{a}	5.46^{a}	5.42^{a}	5.65^{a}	5.65^{a}

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$.

Soil P increased by 39.5% with or without legume at 60 kg p ha^{-1} as reflected in the figures obtained for the mean of the two years of the experiment. This is a clear indication that the increase in soil P was as a result of the P fertilizer component of the interaction with legume contributing nothing to the increase.

The effect of treatments on soil N status as presented in Tables 2 and 3 for 2004 and 2005 respectively shows that soil N was significantly and positively affected by all the treatments in the two years of field study. The effect of manure on soil N was however, most pronounced followed by the effect of N fertilizer. Percentage increase in soil N due to manure application at 5 t ha^{-1} was 62.5% in 2004. This however, dropped to 42.7% in 2005. The pattern was similar with N fertilizer application which accounted for 55.3% increase in 2004 and 33.6% in 2005. A different trend was however, observed for legume. In 2004, legume accounted for 5.5% increase in soil N. This increased to 18.3% in 2005 indicating that legume could be an important factor in soil N maintenance. Of all the interactions studied, only the LxMxN interaction was significant for soil N in 2004 while only the MxN interaction was significant for soil N in 2005. In 2005, the increase in soil N due to the MxN interaction was as high as 110.5% at the 5 t ha^{-1} M and 100 kg ha^{-1} N level of interaction over control (Table 7).

Table 7: Soil N status (g kg^{-1}) as affected by manure and nitrogen fertilizer application in the field.

	2004		2005		Mean of two years	
N fertilizer (Kg ha^{-1})	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**	**Without Manure (0 t ha^{-1})**	**With Manure (5 t ha^{-1})**
0	0.78^{e}	1.50^{c}	0.76^{e}	1.37^{bc}	0.77^{e}	1.43^{c}
50	1.11^{d}	1.86^{b}	1.06^{d}	1.45^{b}	1.08^{d}	1.66^{b}
100	1.46^{c}	2.08^{a}	1.27^{c}	1.60^{a}	1.37^{c}	1.84^{a}

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$.

In 2004, the increase in Soil N due to the LxMxN interaction was 166% at the 5 t ha^{-1} M and 100 kg N ha^{-1} level of interaction with legume over control (Table 8).

Table 8: Soil N status (g kg^{-1}) as affected by legume, manure and nitrogen fertilizer application.

Legume treatment	*Manure* (t ha^{-1})	*N* (kg ha^{-1})	2004	2005	Mean of 2 years
Without Legume	0	0	0.78^{f}	0.70^{h}	0.74^{f}
		50	1.10^{e}	0.96^{fg}	1.03^{e}
		100	1.41^{d}	1.12^{ef}	1.26^{cd}
	5	0	1.40^{d}	1.23^{de}	1.32^{c}
		50	1.80^{bc}	1.34^{cd}	1.57^{b}
		100	2.08^{a}	1.54^{ab}	1.82^{a}
With Legume	0	0	0.77^{f}	0.83^{gh}	0.80^{f}
		50	1.12^{e}	1.15^{e}	1.14^{de}
		100	1.52^{d}	1.42^{bc}	1.47^{b}
	5	0	1.60^{cd}	1.51^{abc}	1.55^{b}
		50	1.93^{ab}	1.56^{ab}	1.75^{a}
		100	2.08^{a}	1.65^{a}	1.87^{a}

Figures having the same letter(s) as superscripts within a column are not significantly different at $P < 0.05$.

Although the values for CEC in all the experimental plots remained low in 2005, the values were generally higher than what obtained in 2004. Also, although changes in soil pH values were generally small and insignificant, the values obtained in 2005 were observed to be generally higher than what obtained in 2004. These observations are indicators to positive effects of soil amendments and confirm the widely held view concerning the relationship between soil pH and CEC.

Of all the additional benefits derivable from integrated application of nutrient sources, it is the impact on the status of soil P and soil N that is most appealing and tends to give credence to the principle behind integrated nutrient management. Soil N and Soil P were not only maintained, they were improved upon and significant increases in their status were recorded following the additions of soil amendments.

The potential for net N inputs by biological N fixation (BNF) with grain legumes has been observed to be limited. For example, N fixation by peanut (*Arachis hypogea*) ranged from 68 to 206 kg N ha^{-1} but most of it is removed at harvest (Giller and Wilson, 1991). Also, soybean (*Glycine max*) that was used in this experiment has a high BNF capacity but it concentrates N on the pods, adding little to the soil. Therefore, the contribution of BNF by commonly grown grain legumes with high N harvest index does not seem relevant to N replenishment in soils. In this study, soybean on its own had very little or no impact on soil P and Soil N but its combined use with manure, N fertilizer and P fertilizer impacted on soil P and soil N although only slightly. The attraction of legume based integrated cropping system therefore, appears to be in the food and economic value of the legume (soybean in this case) as well as in the maintenance of soil N in particular. Giller (2002), is of the opinion that a major contribution of grain legumes to soil fertility can be through the provision of cash to buy

needed fertilizer rather than simply by direct contributions to the soil. Although considerate research attention has focused on growing legumes for soil fertility improvement in recent times, the actual contributions of grain legumes to cropping systems are surprisingly small.

CONCLUSION

Results of the experiment have shown that soil N and soil P benefited from legume based integrated nutrient management cropping system. Soil N and Soil P were not only maintained throughout the two-year duration of the experiment, they were improved upon. The results also showed that soybean on its own made little or no impact on Soil P and Soil N probably because of its high N harvest index. Most of the increases in Soil N and Soil P observed throughout the experiment were attributed to the manure, N fertilizer and P fertilizer components of the interactions. It appears therefore, that apart from the great food and economic benefits of soybean and other grain legumes, their effects on the maintenance of soil fertility is insignificant as most of the N would have been harvested with the grains.

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