Jurnal Teknos-2k Vol. 11, No.2, Juli 2011

Soil Nitrogen Constraint Removal Using Legume Rotation For Sustainable Maize Production In Northern Nigeria

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Abstract

Nitrogen (N) is a major constraint to maize production in the Northern states of Nigeria. This is due to the inherently low content of N in the soils. The problem is further exacerbated by high N requirement of maize, non-availability of inorganic N fertilizer, and the practical limitations of organic fertilizers. Maize is one of the major cereal crops grown in Northern Nigeria. In addition to its direct use as food for human and livestock, maize is also an industrial raw material for starch, pharmaceutical, corn flakes, brewing and flour million industries. Maize rotation with legumes (grain and herbaceous) can improve N nutrition of the maize and reduce the inorganic N fertilizer need of the maize. Grain yield benefits are realized when maize succeeds legume. Greater yields benefits are also obtained with incorporation of the legume residue. N use efficiency (NUE) of maize is improved by rotation with a legume thereby reducing nitrate pollution of ground water. Integration of legumes into the cropping systems of northern Nigeria is recommended for sustainable maize production.

***Keyword**: Nitrogen, Northern states of Nigeria, Maize,legume rotation*

1. Introduction

The northern region of Nigeria lies within three savanna agro-ecologies including southern guinea savanna in the southern part, northern guinea savanna in the central and Sudan savanna in the extreme northern part of the region. Rainfall pattern throughout the region is mono-modal with annual rainfall varying from as high as 1600mm and growing season of over 200 days in the southern part to as low as 500 mm and growing period of less than 100 days in the northern part of the region (Jagtap, 1995). The mono-modal rainfall pattern suited the cultivation of maize throughout the region, but yield potential is highest in the northern guinea savanna compared to the southern guinea savanna (Kassam*et al*, 1975), because of adequate moisture, relatively low disease pressure, high solar radiation and low night temperatures (Carsky and Iwuafor, 1999).

Soils of the northern region of Nigeria are dominated by Alfisols, Oxisols, Ultisols, Vertisols and weakly differentiated coarse-textured Entisols and Inceptisols, which are characterized by low activity clay. The soils are slightly acid to neutral in soil reaction, low levels of soil organic matter (>1.0% organic carbon), low effective cation exchange capacity, low nutrient – and water-holding capacities, a low supply of nitrogen (N) and phosphorus (P) and sometimes of potassium (K), sulphur (S) and zinc (Zn) and high susceptibility to soil compaction and erosion (Kang and Spain, 1986). The soils are therefore inherently low in soil fertility and susceptible to rapid nutrient depletion with intensive farming. With maize production, the soil fertility constraint in terms of N is further heightened by the high N requirement of maize. The soil must supply about 60kg of N in plant available form for each tone of grain produced (Weber et al., 1995).

In the past years, in the northern region, with the traditional system of low cropping intensity practiced at that time, farmers used bush fallow, plant residues, household refuse, animal manure and other nutrient sources to maintain soil fertility for sustainable production. The ever increasing population has resulted in not only continuous but intensive cropping and almost total disappearance of fallow period with consequent decline in crop yield. In order to maintain the soil fertility under intensive and continuous cropping, farmers have had to rely on inorganic fertilizers as these traditional means of maintenance became impracticable. However, research have shown that inorganic fertilizers especially nitrogenous fertilizers cause decline in soil organic matter (Juo et al., 1995), acidification (Jones, 1976) and deterioration of the often physically and chemically fragile savanna soils in the long-term (Pieri, 1992).

In a developing nation like Nigeria, where fertilizer production technology is limited and with the removal of direct subsidy by the government, the product has become very expensive as input resource for cropping. In fact, the price of a bag is beyond the reach of peasant farmers in the northern region. Sometimes when available at a subsidized rate, inaccessibility to local infrastructures such as transport and delivery facilities is hindering the farmers from gaining access to the fertilizer when it is needed. In addition, the use of organic fertilizer (manure) is also limited by the huge quantities required to meet crop needs due to its low nutrient content. In fact the huge quantity required cannot be obtained in majority of the northern region. Another drawback to the use of manure is due to their low quality (high C/N ratio) which will result in immobilization of soil N by the microorganism thereby rendering n unavailable to plants.

Given the above scenariosthe need to look for a relatively less expensive mean of maintaining soil N fertility, and hence more sustainable maize production in both economic and ecological terms become imperative. The use of leguminous crops can play a major role in removing soil N constraints to maize production in the northern region of Nigeria.Generally, leguminous crops have the ability to improve the N status of the soil. In addition, the crop can be grown throughout the region and the N impoverished soils may be greatly improved. Thus, the crop can be grown and rotate with maize. The legume residue left after the seed and other parts of the plant have been harvested are a viable source of other nutrient elements apart from N, for the maize in the soil. The seeds of the grain legumes and the haulm of the herbaceous legumes are an important source of dietary protein and cash income for the farmer and his livestock. The objectives of this paper, therefore, are, to examine maize production in northern Nigeria, N nutrition of maize, N2 fixation by legumes, effects of legumes on soil N status in northern Nigeria, and some of the benefits derivable from legume rotation with maize.

2. Maize Production in Northern Nigeria

Maize (*Zea mays L.*) is an important staple cereal crop in the diet and economy of the northern region of Nigeria. The importance of maize in human diet, livestock feeds, and as raw material for some industries has increased tremendously in the later part of the 20th Century. In 1900, it was a relatively minor food crop in Africa but the most dramatic expansion of maize production occurred from 1970 onwards (Manyong*et al*., 2003). For the West and Central Africa (WCA) subregion as a whole (including northern Nigeria), maize grain yield per unit land area increased by 41% from 1970 to 2000 and total production from about 2.74 to 10.49 million metric tons, a 384% increase with Nigeria producing 43% of West Africa subregion production (Ajala*et al*, 2000, Manyong et al., 2003). Yields have increased by 41% from an average of 858kg ha^{-1} in 1970 to about 1210 kgha^{-1} in 2000 (FAO, 2001). Maize output in Nigeria has increased from 1.19million tonnes in 1985 to 6.42 million tonnes in 1994 with the northern region accounting for over 60% of the production (CBN, 1994a, b). In northern Nigeria, maize evolved from a major food crop in 33% of the villages in 1970 to a major food crop in 96% and a major cash crop in 70% of the villages in 1989 (Smith *et al*. 1993).

In the past two decades, maize has spread rapidly into the northern fringes of the Guinea savanna and Sudan savanna displacing the traditional grain crops, sorghum and millet where maize was relatively unimportant a decade earlier. According to FAO (2001), in 1970 land area under maize in WCA was only 43 and 50% of land area under millet and sorghum respectively. In 2000, however, land area under maize had increased to 61 and 73% of that occupied by millet and sorghum respectively (Table 1).

Table1. Total land area (000 ha) under major cereals in West and Central Africa. 1970 and 2000 [Manyong et al, 2003]

Crop	1970	2000	Percentage change 2000 over 1970
Maize	4,674	9,884	+111
Millet	10,851	16,131	+49
Rice	2,234	5,064	+127
Sorghum	9,324	13,626	+46

3. Nitrogen Nutrition of Maize

N seems to have the most pronounced effect on plant growth and development among the essential plant nutrients. N is an important constituent of chlorophyll, protoplasm, protein and nucleic acids. It increases the growth and development of all living tissues and improves the protein content of food grains. When in short supply, plants get stunted, flowering is greatly reduced and grains have protein content.

Maize has high and relatively rapid nutrient requirements especially N. Maize grain generally contains up to 2% N which means 100kg of harvested grain yield contains 2kg N inferring that 2.6kgN per 100kg of grain produced is exported, if above-ground residues are removed with above-ground residues containing about 0.6% N (Cretnet*et al*., 1994). STUDIES by Uyovbisere and Lombin (1991) in the Guinea savanna of northern Nigeria, have shown that a 4 tonnes grain and 7 tonnesstover yield per hectare per annum of maize removed 170kg N per hectare per annum. All these are a pointer to how maize can quickly deplete soil N especially when yields are high and stover is exported. The problem thus faced by the farmers in northern Nigeria, is that the soils cannot supply the quantities of N required by maize and the soil N level declines rapidly once maize cropping is commenced.

4. Legumes Nitrogen Fixation in Northern Nigeria

Legumes are plants that are able to convert atmospheric N to the plant available form by a process called N2 fixation. The process is carried out by bacteria that reside in the nodules of legumes in a symbiotic association with the legumes – the legumes provide the bacteria with carbohydrate and the bacteria give the legume, nitrate. The terrestrial flux of N from biological N fixation has been calculated to range from 139 to 170 x 10^6 $tNyr^{-1}$ (Burns and Hardy, 1975; Paul, 1988).

All the legumes that are well adapted to the northern region of Nigeria can fix substantial amount of N when nodulated effectively. The amount of N_2 fixed by the legumes is usually higher when the legume is a sole crop than when the legume is intercropped. In the southern Guinea savanna of northern Nigeria, the amount of N_2 fixed by different soybean lines have been found to range from 40 to 83 $kgNha^{-1}$ (Sanginga*et al.*, 1997). Among the major shrubs and herbaceous legumes, found in northern Nigeria, *Centrosemapascuourum* and *Mucunapruriens* have been found to be the highest N_2fixers with most of them having the proportion of their N derived from N_2 fixation as high as 80% (Sanginga*et al.*, 1996).

4. 1. Legumes and Soil Nitrogen in Northern Nigeria

One of the significant benefits of legumes rotation is the increase in soil N status after the growth of the legumes. Legumes derive most of their N from the atmosphere, thus absorbing fewer nitrates from the soil which has been termed “nitrate sparring” effect of the legumes. The N status of the soil is also built-up by the mineralization of the legume residues including litter, haulm, nodules, and roots left after harvest (Muyinda*et al*., 1998) and through the increased breakdown of root nodule following harvest (Brophy and Heichel, 1989).

Studies in various parts of northern Nigeria have shown increased soil N content after the legumes compared to other non-leguminous crops. The top soil mineral N in

Samaru soil in the northern Guinea savanna was higher after former groundnut and cowpea plots than in previous sorghum plot (Nnadi*et al.*, 1981). Oikeh (1996) reported soil total N at the 0 – 30cm soil depth at the beginning of the subsequent growing season to be 75, 52, and 44 kgha-1 following previous soybean, stylo, and maize, respectively at a site in northern Guinea savanna. The soil total N in the 0-10cm soil depth of previous soybean plots was significantly greater than in previous maize plots at ten sites in both northern and southern Guinea savanna of northern Nigeria (Carsky*et al.*, 1997). Soybean, cowpea, Centrosemapascuorum and fallow at Samaru, increased the soil total N (0 – 15cm soil depth) by 20, 18, 19 and 11% respectively at the end of the season. At the beginning of the following season, incorporation of the residue of previous soybean, cowpea, and Centrosemapascuorum significantly, with no change in plots where fallow residues were incorporated (Adeboye, 2004). Odunze*et al.*, (2004) at four sites in the northern Guinea savanna, reported that previous grain legumes, soybean, cowpea, and groundnut improve the soil nitrogen in the range of between 65 and 85% while nitrogen under previous maize resulted in only 6% increase.

4. 2. Legume Rotation and Maize Grain Yield in Northern Nigeria

Many studies in different parts of northern Nigeria have shown significant maize grain yield benefit when maize is rotated with legumes. At Samaru, maize grain yields after groundnut were significantly higher than after cotton and sorghum (Jones, 1974). Nnadi et al., (1981) reported in both northern Guinea and Sudan savanna of northern Nigeria, grain yield of maize following grain legumes significantly higher than that of maize following sorghum. The average yield of maize in previous legumes and sorghum plots were 2904 and 1945 kgha-1 respectively. At four sites in the northern Guinea savanna, grain yields of maize when grown after soybean and stylo was 24 and 20% respectively, significantly higher than when grown after maize (Oikeh*et al.*, 1998). On-farm trials conducted at Kaduna in the Guinea savanna showed that maize yields after *Mucuna* were 20 to 60% higher than after cowpea confirming the superiority of Mucuna rotation over cowpea rotation on maize grain yield (Oyewole et al., 2000). Carsky et al., (1999) have reported similar results in the same zone.

In central Kaduna State of northern Nigeria, Carsky et al., (in Press) (See Carsky and Iwuafor, 1999) reported previous crop of annual legumes resulted in over 100% higher grain yield compared with previous maize (Table 2).

At three sites in the southern Guinea savanna and a site in northern Guinea savanna of northern Nigeria, maize grain yield following soybean was 65% significantly higher than maize following maize (Singh et al., 2001). Carsky*et al.*, (2001) reported maize grain yield after early cowpea without N application to maize was maintained at significantly higher levels than 30 kgNha-1 inorganic N fertilizer. Maize grain yields following soybean, cowpea, and *Centrosemapascuorum*were significantly higher than maize after fallow with those following soybean and *Centrosemapascuorum*over 100% higher, at Samaru (Adeboye, 2004).

The net N contribution of the legumes to the soil can allow the reduction of inorganic N fertilizer application to the following maize crop. This is the approximate quantity of N fertilizer saved by using the legumes in rotation which has been termed the N fertilizer replacement value (NFRV) of the legume. The NFRV of a legume has been defined as the amount of N fertilizer required by a non-legume when grown after a non-legume to obtain grain yield equivalent to that obtained when the non-legume follow legume in rotation (Hesterman, 1988). The estimation to the NFRV of a legume apart from the net N contribution to the soil by the legume is also affected by legume residues management, type of control – crop or fallow, number of legume crops planted in one season and whether the legume was relay intercropped.

Table 2. Effect of previous annual legumes on yield of maize in central Kaduna State, [Carsky and Iwuafor, 1999]

Previous crop	**Grain yield (kgha^{-1})**
Maize	221
Lablab purpureus	506
Cajanuscajan	434
Crotolariaochroleuca	784
Mucunapruriens (White)	661
Mucunapruriens(black)	990
SE	121.1

The NFRV of some legumes in the northern Nigeria savanna are summarized in Table 3. The NFRV of soybean range from as low as 0kgha^{-1} (Ogoke*et al.*, 2001) to as high as 61kgha^{-1} (Adeboye, 2004) at different sites in the northern and southern Guinea savanna of northern Nigeria. At fields in the northern Guinea savanna, the NFRV of early season cowpea using late season maize was estimated to be 30 kgha^{-1} by Carsky*et al.*, (2001). A lower cowpea NFRV of 13 kgha^{-1} was obtained by Adeboye (2004) at Samaru. Tarawali (1991) estimated NFRV of approximately 45 kgha-1 after 2 to 4 year fodder banks composed of *Stylosanthesguianensis*or *Stylosantheshamata* at four sites in the northern Guinea savanna. The incorporation of *Centrosemapascuorum*residue gave a higher NFRV compared to when the residues are exported (Adeboye, 2004). The NFRV of two years of forage or cover legumes was estimated at 20 to 40 kgha-1 at Samaru (E.N.O Iwuafor, unpublished).

Table 3. Estimates of Nitrogen fertilizer replacement values (kgha^{-1}) of some legumes in northern Nigeria savanna

Legume	**Estimate**	**Source**	**Comments**
Soybeans	20 – 40	Carksy et al., 1997	Two varieties residue exported, maize control
	0 – 17	Ogoke et al., 2001	Four varieties, residue exported, rice control
	20[a], 10[b], 8[c]	Singh et al., 2001	Two varieties, residue incorporated[a], residue face applied[b], residue exported[c], maize control
	61[a], 44[b]	Adeboye, 2004	Residue incorporated[a], residue exported[b], fallow control
Cowpea	30	Carsky et al., 2001	Relay cropping, three varieties residue incorporated and mulched, fallow control.
	13	Adeboye, 2004	Residue incorporated, fallow control.
Stylosantheshamata	45	Tarawali, 1991	Two-to four-year fodder bank
Centrosemapascuorum	39[a], 29[b]	Adeboye, 2004	Residue incorporated[a], residue exported[b], fallow control

4. 3. Legume Rotation and Nitrogen Use Efficiency of Maize

Nitrogen Use Efficiency (NUE) of a crop is the grain yield per unit of soil N (Moll *et al*., 1982). It is determined by N absorption, assimilation and redistribution within the plant. The NUE for major cereals production worldwide has been estimated to be approximately 33% with developing countries including Nigeria having a lower value of 29% (Rain and Johnson, 1999). The reasons for this low efficiency has been attributed to release of N from plant tissues, predominantly as ammonia following anthesis by cereal plants (Francis *et al*., 1993), gaseous N loss due to denitrification (Hilton *et al*., 1994), N loss in surface run-offs (Chichester and Richardson, 1992; Blevins *et al*., 1996) and nitrate leaching, loss and volatilization (Olson and Swallow, 1984; Rain and Johnson, 1995).

Studies have shown that maize following soybean in rotation have high NUE and there is reduced residual N available for leaching when compared with continuous maize (Huang *et al*., 1996). NUE for wheat following legumes is greater than for wheat fallow or continuous wheat (Badaruddin and Meyer, 1994). Adeboye (2004) at Samaru, reported higher NUE of maize rotated with soybean, cowpea and *Centrosemapascuorum*compared to maize rotated with fallow. Maize after the legumes had higher grain N content than maize after fallow.

5. Conclusion

Maize has gained popularity throughout Nigeria as the hunger breaker even in drier part of northern Nigeria where, hitherto, maize was not cultivated. The northern region of Nigeria has been described as the 'maize basket' of Nigeria. An effective indigenous way for the region to continue to live up to this billing as maize basket of Nigeria is to rotate maize with legumes to remove soil N fertility constraint to its production. The rotation will not only ensure high maize production but the sustainability of the production as well.

The use of food legumes including groundnut, cowpea and soybean will not only improve dietary protein intake of the farmers, but the money realized from their sale can be used to purchase the little amount of inorganic N fertilizer needed by the maize. The use of herbaceous legumes including *Centrosemapascuorum, Mucuna*spp, *Lablab purpureus*and pigeon pea (*Cajanuscajan*) will improve the dietary protein consumption of livestock with better livestock production.

The reduction in inorganic N fertilizer application to maize following the legumes will help to prevent environmental degradation in terms of ground-water nitrate pollution and soil acidification. This is because inorganic N fertilizers are subject to substantial leaching losses and their high application can cause soil acidification.

The benefits derivable from legume rotation can be further boosted by incorporation of residues of the legumes including the litter and haulm into the soil after harvest. In the case of herbaceous legumes, farmers can harvest some of the plant and take it to the animals in their pens and drive the animals to the field to feed on the remaining plants left on the field. The animal droppings can then be incorporated into the soil in addition to the litter and haulm still left on the field.

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