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Full Length Research Paper

Enhancing the contribution of the legumes to the N-fertility of soils of the semi-arid zone of Nigeria

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This paper attempts to focus attention on the N-fertility status of soils of the semi-arid zone of Nigeria. This is because, the region harbours a significant proportion of the national population figure, 75% of which is engaged in crop farming and animal keeping. These economic activities depend heavily on the soil resources available in the region. The first section, therefore, is a concise review of the general fertility status of the soils found in the region. This is followed by a section covering the position of legumes in the farming systems practiced by the semi-arid farmer. The role of the legumes as potential contributors to the N-economy of soils of the semi-arid zone is then highlighted. The need to develop appropriate technologies towards enhancing the contribution of legumes to the N-economy of the semi-arid soils is also advocated. The paper concludes with a call on microbial physiologists, geneticists and ecologists in concert with soil and plant scientists to rise to the challenge.

Key words. Legumes, Rhizobium, seed inoculants, N-economy.

INTRODUCTION

In this paper, the semi-arid zone of Nigeria would be considered as that zone of the country that lies between latitude 10 to 14°N and longitude 3 to 14°E. The area so define is characterized by an annual rainfall of between 750 to 1500 mm, 90 to 95% distributed between May and October of each year. The vegetation cover is of the scrub type usually dominated by short grasses interspersed by dwarf acacias and other low canopy trees (Adeleke and Cheog, 1978). This zone is said to habour about one third of the country's total population, 75% of which earn their living by crop farming and animal keeping. These economic activities depend heavily on the available soil resources. Over the years, there has been increased pressure on those soils allocated to crop cultivation and animal grazing in the zone owing to increase in the population of both humans and animals.

Most if not all the soils found in this region are poor in terms of their total-N contents and are therefore, relatively unproductive. This problem is compounded by the gross inadequacy in the supply of nitrogenous mineral fertilizers to the predominantly subsistence farmers operating in the zone. In response, farmers in the zone resort to farming practices in which the legumes form an important part. In this region, therefore, the legumes are cultivated either in rotation or mixtures with non-legumes. This is out of the realization that, the legumes have the capacity to maintain or even improve on the N-fertility of agricultural soils. The result is the unmistakable prominence of legumes in the indigenous cropping pattern of the semi-arid farmers.

Despite the apparent potentials of the crop legumes as contributors to soil-N, very little conscious efforts have been made towards enhancing their performance. This paper therefore advocates for the development and application of Rhizobium seed inoculants from the existing populations present in soils found in this region. This advocacy is founded on the understanding that, doing that would provide a simple means of maximizing both their yield as crops and their contribution to soil-N.

This paper, therefore highlight the general fertility of the semi-arid zone. This is then followed by a section covering the position of the legumes in the farming systems practiced by the semi-arid farmer. The role of the legumes as

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Table 1. Nutrient status of soils at five locations within the semi-arid zone.

Parameter	Location				
	Sokoto	Katsina	Kano	Kaduna	Zaria
Organic-C(5)*	0.70	0.50	0.15	0.58	0.57
Total-N (%)+	0.03	0.01	0.01	0.06	0.08
Available P(ppm)	1.00	1.05	0.94	1.62	6.95
Exch. Cations (meq./100 g)*					
Ca	1.63	0.52	0.37	2.47	3.7
Mg	0.69	0.22	0.11	0.48	0.91
K	0.30	0.07	0.08	0.38	0.31
Na	0.20	0.13	0.10	0.33	0.29

*Mean of 4 replicates + mean of 2 replicates. Sources: Saminu (1989), Olufajo et al. (1988) and Machido (2009).

Table 2. Nutrients removal by annual crops grown in the semi-arid zone.

CRO (Part)	Nutrients removed (kg/ha)						
	Yield (t/ha)	N	P	K	Ca	Mg	References
Sorghum (S/G)	16	200	40	40	34	22	(1)
Maize (S/G)	14	200	34	130	3.1	24	(1)
Millet (S + G)	10	260	30	100	60	16	(3)
Rice (S + G)	16	141	37	90	28	14	(3)
Cassava (WP)	30	120	9	187	102	40	(1 and 3)
Sweet Potato (WP)	62	147	10	40	60	31	(3)
Groundnut (G)	10	720	70	420	150	90	(4)
Cowpea (G)	10	388	34	66	13	44	(1 and 3)
Soybean (G)	10	661	51	211	31	30	(3)

S = Stover, G = grains. Sources: 1 = Jones and Wild (1975), 2 = Gordon (1981), 3 = Sanehez (1976) and 4 = Yayockano (1981).

potential contributors to the N-economy of the semi-arid zone is then presented. This is followed by a section that emphasizes on the need for an appropriate biotechnology towards enhancing the contribution of the legumes to the N-economy of the semi-arid soils. The paper concludes by a call on microbiologists, biochemists and plant and soil scientists to rise to the challenge.

FERTILITY STATUS OF SOILS OF THE SEMI-ARID ZONE

Soils found in the semi-arid zone of Nigeria are mostly aridosols and entisols with the latter occurring on aeolian deposits (Ojanuga, 1987). Over most of the zone, the soils are predominantly sandy, a property responsible for the many problems of moisture control of soil. Management and therefore, agricultural production in the region was also studied (Ann, 1968; Jones and Wiled, 1975).

Another feature common to soils found in this region of the country, is their low content of organic carbon, total N and P (Raya and Haruna, 1985; Kargbo and Adana, 1985; Raya, 1987, Fada and Raya, 1988; Olufajo et.al., 1981). As a consequence, these soils are, inherently of low fertility, most especially, with regards to availability of N and P (Table 1). The low fertility of these soils remains one of the major constraints to production of both food and cash crops in the zone (Agboola, 1981; Raya, 1987).

Given this low level of soil fertility vis-a-viz, the rate of nutrient removal by annual crops (Table 2), it appears that subsistence agriculture within this zone of the country is already operating against a steep fertility gradient. This already bad situation is further aggravated by the gross inadequacy in the supply of mineral fertilizers to the predominantly small scale farmers operating in the zone, particularly N-fertilizers.

To forestall a further decline in the current low levels of crop production in the region, there is the need to intensify cultivation of legumes which thrive in these soils of low fertility status. Already, the legumes feature prominently in the multiple cropping system operating in the zone (Dart and Krantze, 1977; Norman, 1976). What need to be done is to improve the N_2-fixing capacity of the legumes with the view to enhance their role in the improvement of N-fertility of soils found in this zone. This is an important factor in our bid to increase the productivity of soils;

Table 3. Yields (Kg/ha) of crop mixtures in Zaria.

Crop	Crop mixture	
	Millet/Sorghum	Millet/sorghum/cowpea
Millet	370	400
Sorghum	768	741
Cowpea	-	167
Total yield (Kg/ha)	1138	1308

Table 4. Cropping systems at two locations in the semi-arid zone.

Variable	Location surveyed	
	Zaria area	Sokoto area
Latitude (N)	11^0, 11"	13^0, 01"
Longitude (E)	7^0 23"	5^0, 15"
Length of growing season (days)	174	143
Total rain fall (mm)	1040	760
Total hacterage surveyed	360.5	350.7
Percentage in fallow	19.0	3.4
Percentage in sole crop	13.4	6.3
Percentage in crop mixture	67.6	90.3
Two crop mixtures	50.5	23.4
Three crop mixtures	28.4	51.0
Four crop mixtures	14.5	23.9
Five or more crop mixtures	6.6	1.7

Source: Norman (1976).

particularly soils of the semi-arid zone.

LEGUMES IN THE MULTIPLE CROPPING SYSTEMS OF SEMI-ARID ZONE

Cultivation of leguminous crops in mixture with cereals, cotton and tuber crops is an age old practice. This practice is wide spread amongst small scale farmers operating in the zone (Gomez and Zandstra, 1977). This cropping pattern is attractive to the small scale farmers in this zone for many reasons. First, there are those special attributes of the legumes that make them most suitable for use in intensive and continuous cultivation practices (Gomez and Zandstra, 1977). Second, yields from the legume components of the crop mixture are often considered as bonus since the yield of the main crops (usually cereals) is either unaffected or increased (Agboola and Fayemi, 1972; Eaglesham et al., 1981) (Table 3). Third, the legumes provided the shortfall in the dietary requirement for protein in the rural areas (Borget, 1992). Fourth, the residues of leguminous crops (the haulms) provide excellent source of animal feed (IITA, 1985).

The importance attached to mixed cropping by farmers in this zone has been clearly demonstrated by Norman (1976) in a survey of two locations in the Zone. At both locations, only small proportions of farm land is devoted to solid crops, about 13% in Zaria area and 6% in Sokoto. Crop mixtures occupy 68 and 90% of farm land in Zaria and Sokoto areas, respectively (Table 4). Often, most of the major crop enterprises contain either groundnuts or cowpea or both as components of the mixture. Therefore, what need to be done is to enhance those attributes of the local cultivars such as drought resistance, early maturity, resistance to pests and yield. This would upgrade their position in the farming system as well as facilitate maximum utilization of soils found in the zone. Additional research efforts should also be directed towards identifying crop combinations, sequence and rotation that would take maximum advantage of the N_2-fixing potential of the legumes under continuous cropping system.

LEGUMES AS POTENTIAL CONTRIBUTORS TO N-ECONOMY OF SOILS

By their nature, legumes have the capacity to fix a large quantity of atmospheric N_2 gas while in symbiotic association with soil bacteria of the genus Rhizobium (Alcantara, 1978; Nutman, 1991; Peoples et al., 1995; Anuar et al., 1995, Nutman, 1991; Gordon, 1982). The relative capacity of the three major crop legumes grown in the zone in this regards is shown in Table 5.

Other legumes such as phaseolus are reported to fix between 35 and 50 kgN/ha/yr (Brady, 1990). Pasture legumes such as lupin, field pea and subterranean clover were reported to fix 200 to 322, 80 to 144 and 100 to 300 kg N/ha/yr, respectively (Unkovich et al., 1995). Indeed, this seminal association has been shown to fix sufficient N to satisfy the demands of the crop plants for optimum growth and grain yield and still make substantial addition of N to soils on which they are grown. Peoples et al. (1995) has shown that, soybean contributed more than 15 kgN/ha/yr to the soil. Reports of Jones (1973) and Giri and De (1980), gave the contribution of groundnut crop to soil N at 26 to 60 kgN/ha/yr. The pasture legumes such as lupin and field Pea add 75 and 20 kgN/ha/yr to the soil (Unkovich, 1995). The common practice of cultivating legumes either in mixture or rotation with non-leguminous crops by farmers in the semi-arid zone is a proof of the benefit accrued from the practice in form of increased yield of the non-legumes.

TOWARDS ENHANCING LEGUMES' CONTRIBUTION TO SOIL-N

The contribution of both crop and wild legumes to the N-economy of soils on which they grow lies in their capacity to fix atmospheric N_2 gas. This attribute is confirmed on the legumes by soil bacteria of the genus Rhizobium with which they associate symbiotically (Vincent, 1970). As such, their contribution to soil-N can best be enhanced by enhancing the capacity of the bacterial symbioant to establish an efficient symbiosis with their host legume.

Table 5. N_2-fixing capacity of 3 legumes grown in the semi-arid zone of Nigeria.

Crop legume	N_2-fixed (kgN/ha/yr)	Reference
Groundnut	72-297	Gibson (1982) and Anuar et al. (1995)
Cowpea	73-240	Nutman (1991)
Soybean	54-369	Evans and Barber (1977) and Peoples et al. (1995)

The fact that legumes grow noclulate and fix-nitrogen (N) in quantity required for appreciable yield without human intervention, led to the wrong assumption that, nothing needs to be done. Consequently, this area of agricultural biotechnology suffered a near complete neglect. Hence little or no research effort has been invested towards achieving this noble goal. In deed, so much has been and is still being expected of the legumes, but, very little has been understood of their particular and peculiar needs for optimum performance.

In developed and some developing countries, tremendous progress has since been made in this area of agricultural biotechnology (Bathyani, 1977; Gomez and Zanstra, 1977; Graham and Halliday, 1977; Sahni, 1977). Presently, several exortic strains of Rhizobium are being produced and marketed to legume farmers in form of seed inoculants. In contrast, most if not all the investigations conducted at the Institute for Agricultural Research (IAR) Zaria was wholly devoted to assessing the yield potential of the available commercial inoculants strains under the semi-arid condition (Olufajo et al., 1989; Olufajo and Adu, 1991). The result of inoculation trials using these imported inoculants strains often fail to show significant increase in the yield of the inoculated crop (Kosslak and Bohlool, 1985; Thies et al., 1991). Such outcomes have unavoidable given the fact that.

1. The inoculants strains are usually derived from different ecological background and may therefore not be able to withstand the growth conditions provided by the semi-arid soils.
2. The viability of the inoculants strains at the point of receipt may not be at the level required for effective nodulation of the inoculated plants.
3. There is disparity between the cultivars and varieties of the legumes for which the inoculants have been developed and those grown in the semi-arid zone.

Against this background, present and future researchers in this field need to look inwards for candidate strains, strains that are indigenous to and therefore adapted to the conditions found in soils of the semi-arid zone. In addition, such selected strains would be tailored for specific cultivars and varieties of legumes grown in the zone. This is an important pre-requisite if the benefits of legume seed inoculation are to be realized.

THE NEED FOR SEED INOCULANTS

Soils of the semi-arid zone are characterized by extreme temperature and moisture fluctuations in addition to low pH and nutrient contents. These factors have been shown to have profound influence on the occurrence, abundance, species composition distribution and activities of native Rhizobia in soils (Holding and Lowe, 1971; Chartel and Parkef, 1973; Bushby and Marshali; 1977; Pena-cabrieles and Alexander; 1984; Chao and Alexander, 1982; Woomer et al., 1988). Biological factors such as predators and amensals have also been shown to be important in this regard (Tamirez and Alexander, 1980). It is conservable, therefore, that, many of the semi-arid soils could be only sparsely populated or even completely devoid of native Rhizobia. There is also the possibility that many are populated but, by inefficient strains of native Rhizobia, under such circumstances, the use of inoculants strains is deemed necessary to ensure that, the legume crops are well nodulated and by efficient N_2-fixing strains of the appropriate Rhizobia.

Establishing the need for seed inoculants in these soils, therefore, requires that extensive survey be conducted. Such surveys should be directed at determining the occurrence, abundance, distribution, species composition and effectiveness of the native Rhizobia in these soils. Information gathered from such studies would provide the basis for.

1. Deciding the need or other wise for seed inoculants and seed inoculation.
2. Resolving the even more complex issue of manipulating the existing population of Rhizobia for greater benefits.
3. Selection and testing of candidate strains for development of inoculants.

This aspect of present and future researches would crave the indulgence of our available expertise in the areas of microbial ecology, physiology and genetics.

DEVELOPING SEED INOCULANTS

Evidences of the presence of efficient strains of native Rhizobia in soils of the semi-arid zone are inferred from.

1. The fact that, the major crop legumes are often well nodulated under the current cultural practice of farmers in the zone.

2. Good grain yield obtained from un-inoculated and

unfertilized crops.
3. Increased yield of non-legumes grown in mixture or rotation with legumes.

These evidences are now supported by the reports of Olufajo et al. (1988, 1989) which indicated the presence of native Rhizobia compatible to soybean in soils at four locations within the zone. In these soils, counts of indigenous Rhizobia were in the order of 23 to 923 cells/g of the soil.

Given this scenario, the semi-arid soils can safely be presumed to harbour strains of Rhizobia that can and do establish efficient symbiosis with the major crop legumes grown in the zone. All that need to be done is to search for and select candidate strains from which seed inoculants can be developed from among the native populations.

The search for a candidate strain is an easily surmountable challenge given the many methods currently available. The oldest and still the most commonly employed of these methods involves the use of legumes as trap for their specific Rhizobium. Effective nodules formed on the trap plant are then cultured and the strains of Rhizobium isolated and confirmed. Isolates obtained would then be subjected to rigorous selection procedures. For an isolate to qualify as a candidate strain for development of seed inoculants, it is usually required to possess the following attributes.

1. It must have the capacity to persist in the soil in the complete absence of the host legumes(s). This portends that, the isolate be able to live saprophytically in the soil as well as withstand periods of harsh conditions typifying the soil. Isolates which possess this attribute usually have a greater chance of establishing itself as member of the community in the soil into which it is introduced. It therefore, serves as an assurance that, the inoculum' need not be repeatedly and continuously applied.
2. It must be able to compete for nodule occupancy along side the native strains. Usually, the competitiveness of the isolate is determined by estimating the proportion of nodules formed by the inoculants strain. Prior to availability of DNA-based techniques, several serological methods have been devised and are still in use for this purpose. Of these, the fluorescent antibody method is considered to be the most sensitive and specific and therefore, remains the most commonly used. Others such as the enzyme-linked immunosorbent assay (ELISA) method, is also widely used.
Isolates which exhibit high level of competitiveness are considered promising provided that they also possess the other desirable attributes. This is because; an inoculants strain needs to dominate in nodule formation if the anticipated benefits are to be derived from its application.
3. It must be effective in terms of N_2-fixation while in association with the host legumes(s). Several parameters are used in determining the effectiveness of inoculants strain; but, the most acceptable indices for effectiveness or otherwise of an inoculants strain are.

a. Amount of N_2-fixed usually expressed in terms of kgN ha^{-1} yr^{-1}.
b. Grain yield usually expressed in terms of kg or ton ha^{-1} yr^{-1}.

While the former can be determined exclusively in the laboratory and/or screen house, the latter is determined under field conditions. As such, the participation of microbiologists, soil and plant scientists would be required in determining the effectiveness of the caudate strain.
4. It must be capable of surviving in the chosen inoculants carrier for a long period of time under ideal storage conditions. This is a very important parameter because the viability of the inoculants strain from the point of production to point of application determines the usefulness of the inoculants. As such the material used to serve as the inoculants carrier most is carefully selected. The material selected must be one in which the cells of Rhizobium survive for a considerable period of time under appropriate conditions. In present day practice, materials such as soil, charcoal, peat and oils are used as inoculants careers. In Nigeria, there is abundant supply of these materials to choose from.

Given the availability of virtually all the materials required for the production of legume seed inoculants viz-a-vis the apparent need for seed inoculants, all that is needed is the willingness of these experts in the relevant fields. In addition, the good will of those concerned with agricultural policies in Nigeria in general and the semi-arid zone in particular would be equally important towards the attainment of this agricultural biotechnology.

CONCLUSIONS

Given the potentials of the legumes as contributors to soil-N and therefore increased productivity of the semi-arid soils, efforts should be made so as to maximize their performance. The major step to be taken in this direction is by manipulating the legume-Rhizobium symbiosis. Of importance towards realizing this biotechnological goal should necessarily include.

1. Establishing a database on the occurrence, abundance, distribution and composition of the indigenous populations of Rhizobia in the soils of the semi-arid zone.
2. Identifying promising strains from among the native population that could be used as exortic inoculants strains.
3. Identifying crop combinations, sequences and rotations that would take maximum advantage of the N_2-fixing potentials of the legumes under continuous cropping system as practiced by the semi-arid farmer.

Achieving this biotechnological task requires the full and unreserved participation of experts in the areas of microbiology, biochemistry and soil and plant sciences. Experts in these areas should rise to the challenge as similar efforts have been shown to yield dividends in India

(Sahni, 1977), Columbia (Graham and Haliday, 1977) Brazil (Freire, 1977) and Uruguay (Bathyany, 1977).

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