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Assessing Farm-level Limitations and Potentials for Organic Agriculture by Agro-ecological Zones and Development Domains in Northern Nigeria of West Africa

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ABSTRACT Farm-level use of organic fertilizer could be influenced by development domains that comprise human population density and markets access. Analysis of 320 farm households from 16 geo-referenced villages provided the basis for assessing farm-level limitations and potentials for organic agriculture by agro-ecological zones and development domains in northern Nigeria of West Africa. The analysis was based on four identified development domains. The development domains were clusters of population and market access which are: low population density, low market access (LPLM); low population density, high market access (LPHM); high population density, low market access (HPLM); and high population density, high market access (HPHM). It was found that cereal-legume based cropping systems accounted for 74 percent of the total share of organic fertilizer used on the farm. The actual and potential use of organic fertilizer revealed that the current levels of organic fertilizer use as share of the minimum requirements for take-off for organic agriculture in Nigeria was low (37 percent) despite its potentials. Based cost effectiveness of livestock ownership, the development domains of HPLM and HPHM in the northern Guinea savanna revealed best potential for take-off of organic agriculture in Nigeria.

INTRODUCTION

Organic agriculture is a production system that sustains the health of soils, ecosystems, biodiversity and people. It relies on ecological processes and nutrient cycles adapted to local conditions, rather than the use of external inputs. Organic agriculture combines traditional knowledge, innovation and modern science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (IFOAM 2004; AdeOluwa 2010). Indeed, the underlining basic criterion for a production system to be termed organic derives primarily from the soil use/amendments that constitute the health of the soil. A healthy soil is one that is culturally managed and amended with organic fertilizer. Animal manure compost is the most common source of soil amendment in organic agriculture in Nigeria and indeed Africa (Omiti et al. 1999). Therefore, the assessment of the use of animal manure is capable of revealing the limitations and potential of organic agriculture in Nigeria.

Table 1 provides soil fertility parameters of soils in the three major agro-ecological zones (AEZs) of West Africa (Windmeijer and Andriesse 1993). The difference in the agro-ecology and development domains drives the demand for manure use and agricultural production practices. Further, manure use is critical in meeting the soil fertility requirements especially for carbon and nitrogen which are limiting in the Guinea savanna and Sudan savanna areas. Additionally, Hood (2002) found high and significant carbon: nitrogen ratio (C:N) for animal manure compost as soil amendment.

Table 1: Soil fertility parameters (0-20cm) of upland soils on acid parent materials indifferent agro-ecological zones (AEZs) in West Africa

AEZ	*pH-H_2O*	*Organic C (g kg-1)*	*Total N (g kg-1)*	*Total P (mg kg-1)*
Equatorial forest	5.3	24.5	1.60	628
Guinea Savanna	5.7	11.7	1.39	392
Sudan Savanna	6.8	3.3	0.49	287

Source: Windmeijer and Andriesse 1993.

Further, there is growing body of knowledge on the seriousness of soil fertility decline in Africa. An equally interesting set of information at the farm-level shows the widely different

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coping strategies of farm families. Farmers tend to list soil fertility decline as top priority, and FAO acknowledges the importance of the problem in "World Agriculture: Towards 2010" (Alexandratos 1995; Smaling et al. 2002).

Besides, Nigeria occupies a significant position in West Africa; and therefore is expected to play a great role in leading the frontiers in organic agriculture development. However, with only 0.007 percent of the total land in the region (Willer and Kilcher 2009), the low status of organic agriculture activities in West Africa calls for needs assessment of its limitations and potentials as undertaken by this study. Similarly, the sourcing of appropriate inputs for organic agriculture coupled with the fact that producers are not able to produce beyond resources at their disposal; even if they are willing (AdeOluwa 2010) underscores the importance of this study in developing organic agriculture in Nigeria.

Nations in Africa that are remarkable in organic agriculture include Kenya and Uganda (Willer and Kilcher 2009). Studies in the semi-arid and semi-humid zones east of Nairobi, Kenya revealed that 86 percent and 91 percent respectively used animal manure (Omiti et al. 1999). However, manure use is only a necessary but not a sufficient condition for organic agriculture. The application rate of manure is as important as it use. Palm et al. (1997) reported that an average of less than 700 kg $ha^{-1}$of manure, ranging from 450 to 1600 kg ha^{-1}, is available for semi-arid West Africa. This is much less than the 3 to 20 t ha^{-1} recommended for replenishing nutrients removed by the yearly crop harvest (Bationo and Mokwunye 1991; Fernandez-Rivera et al. 1995).

Manyong et al. (2003) reported that farmers' use of manure in northern Nigeria was 485 kg ha^{-1} while Chianu et al. (2004) found manure application rate in northern Nigeria to be 2000 kg ha^{-1}. Overall, there is knowledge gap in the actual and potential use of manure in Nigeria. Evidence from past studies in Africa and Nigeria suggests the need to assess the limitations and potential of manure with a view to confronting the challenges of increasing population and low productivity in Nigeria in order to meet the soil fertility needs for emerging organic agriculture production and development in Nigeria.

MATERIALS AND METHODS

Study Area, Agro-ecological Zone and Development Domains

This study was carried out in Guinea savanna (NGS) and the Sudan savanna (SS) agro-ecological zones (AEZs) with Kaduna and Kano States chosen as benchmark areas (Manyong et al. 2003). A total of 16 villages, made up of 8 villages from each agro-ecological zone were chosen. Suddu, Richifa, Ungwa Tamuwa, Ungwa Geri, Ungwa Pa, Awai, Gangara, Turawa are in Kaduna state. The ecology in Kaduna state is northern Guinea savanna with 600-1,200mm annual rainfall. On the other hand, Jalli, Madachi, Babban Ruga, Bambarawa, Hugungumai, Duguji, Zugachi, and Waga are in Kano State. The ecology in Kano State is Sudan savanna with 300-600mm annual rainfall. Rainfall is unimodally distributed in both ecologies. The methodology of *length of growing period* (LGP) was adopted in stratifying sample by global agro-ecological zoning (FAO/IIASA 2000). The agro-ecological zone methodology follows an environmental approach that provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production. Crop modeling and environmental matching procedures are used to identify crop-specific limitations of prevailing climate, soil and terrain resources, under assumed levels of inputs and management conditions (Fischer et al. 1998, 2000; FAO/IIASA 2000). The LGP is 150-180 days for the NGS and 90-150 days for the SS. Kaduna State lies between latitudes 90°04′/ to 11°50′/ N and longitude 6°09′/ to 10°41′/ E. Kano State lies between latitudes 10°33′/ to 12°37′/ N and longitude 7°34′/ to 9°25′/ E (Chianu et al. 2004). Figure 1 is the map of the of the study area showing the grids of the selected villages. The coordinates of the geo-referenced 16 villages were verified using a handheld Magellan© 330 geo-positioning system (GPS) instrument during the ground truthing/verification exercise.

The agro-ecological zone (AEZ) mapping (see Fig. 2) is also a tool for analyzing the working hypothesis that soil moisture (by LGP) influences the application of soil fertility inputs such as manure (Jha and Sarin 1984). The concept of the development of AEZ mapping is consistent with the growing trend in strategic

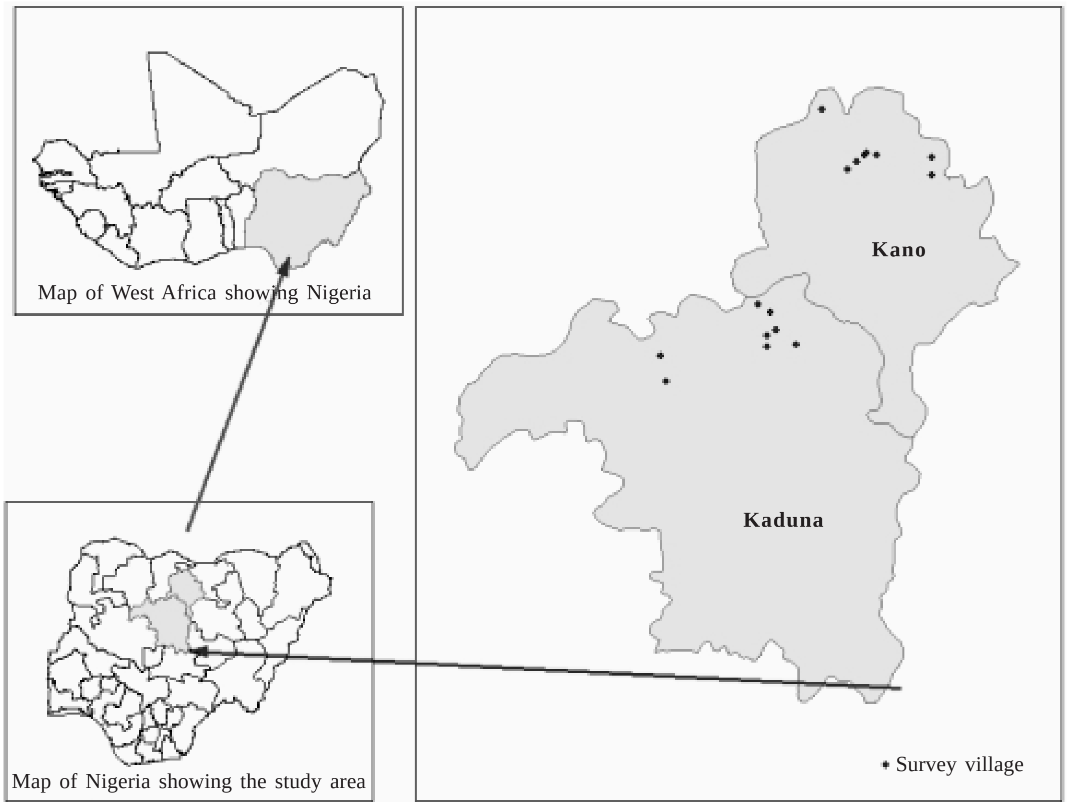

Fig. 1. Map of West Africa showing the study area

research development and tool for identifying the key drivers for change in agriculture and economic development (World Bank 2009). The NGS and the SS were chosen because these two zones support the highest concentration and density of livestock in Nigeria and have potentials for crop-livestock integration and organic agriculture development in West Africa (Winrock International 1992; Thornton et al. 2002; Manyong et al. 2003).

Development Domains

Four development domains of the clusters of similar resource and farming conditions (as clustering sorts things into groups, so that the associations are strong between members of the same cluster, weak between member of different clusters), resulting from a combination of low and high population density areas with low and high market access areas were generated through a geo-spatial mapping operationalized using the ArcGIS© software. Figure 3 shows the georeferenced villages. In deriving the population factors, a rural population density of less than 100 people per square kilometers was estimated and identified as low population density (LP) while a population density of 100–500 people per square kilometer was estimated and identified as high population density (HP). Population above 500 per square kilometers was defined as urban. Similarly, a proximity of 20 km radius (or less) to a town or city was defined as high market access (HM); anything otherwise or higher than 20 km radius to a town or city was defined as low market access (LM). These domains reflect differences in opportunities and correspond to agricultural intensification (Manyong et al. 1996; Lapar and Pandey 1999; Okike 2000; Devendra and Pezo 2002).

Method of Data Collection and Analysis

Data collection included village-level characterization. A sample of 20 farm households was randomly selected from each of the selected 16

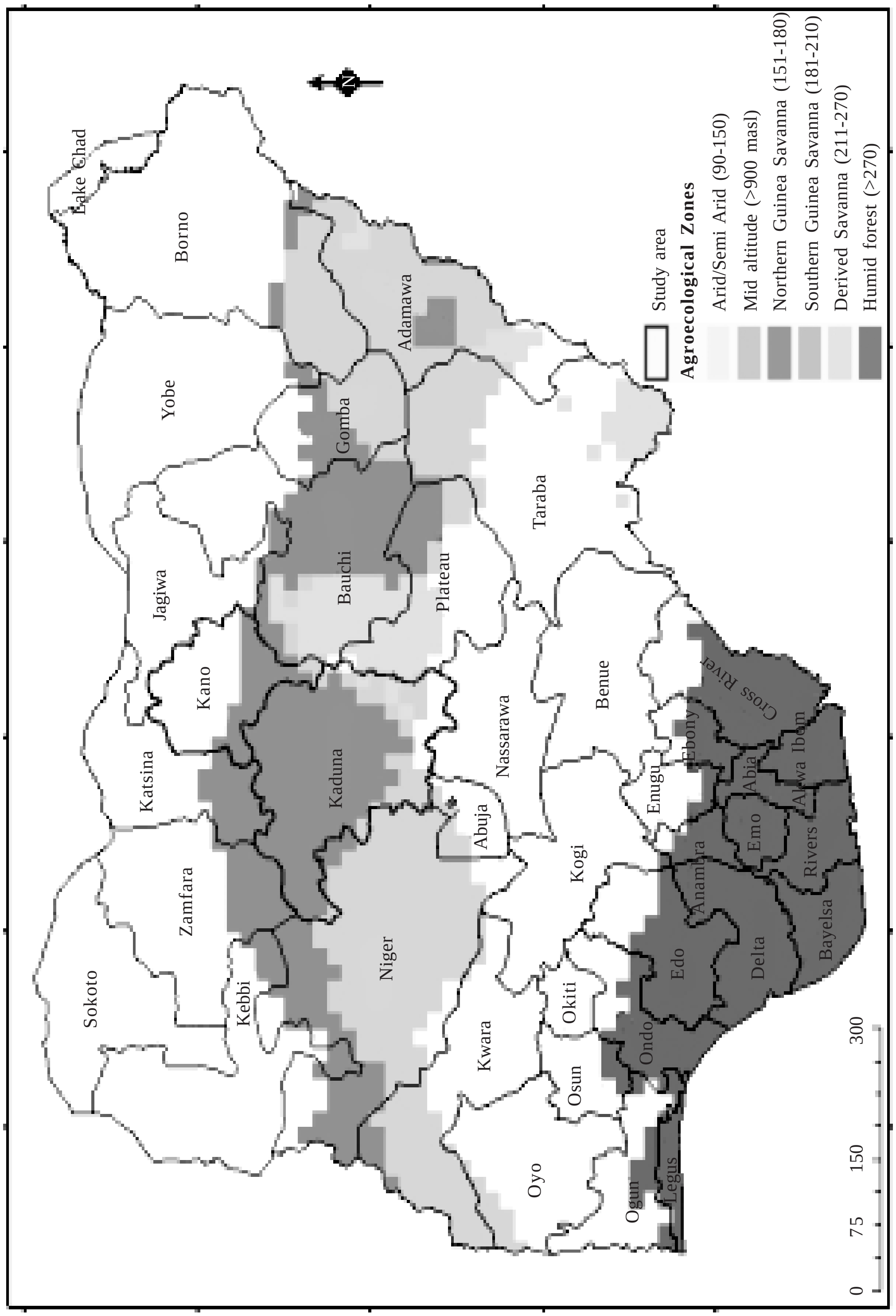

Fig. 2. Agro-ecological map of Nigeria showing the study area

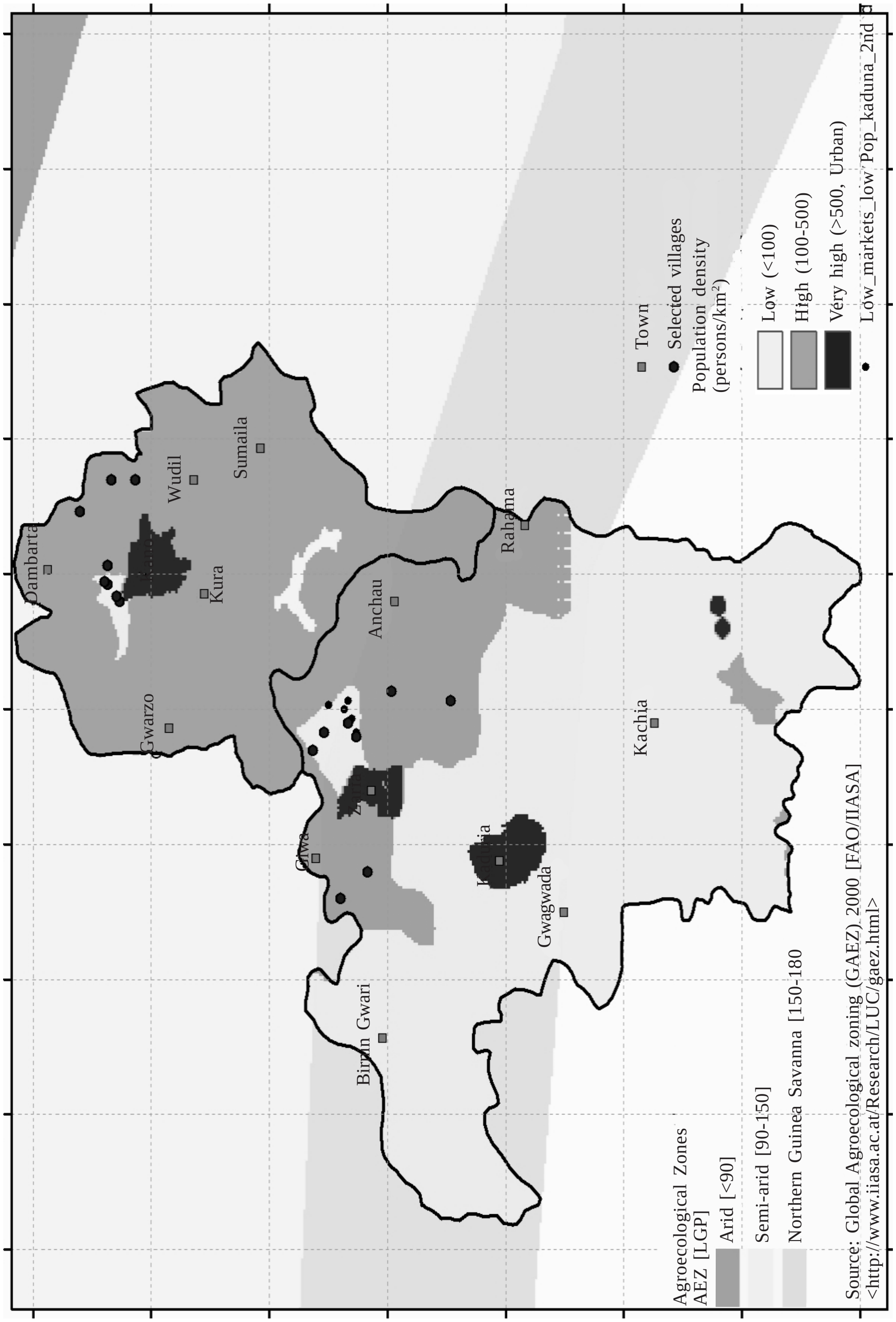

Fig. 3. Geographic Information System (GIS) referenced villages

villages by using the random number table that resulted in 320 farm households for the study area. From each of the randomly selected villages, a list of households was generated and structured questionnaires were administered on the household heads. Information on manure compost used was collected as quantity of animal manure compost (organic fertilizer) in kg dry matter per farm per crop. The tropical livestock unit (TLU) which is the standard conversion factor for live weight of 250 kg cattle was used to estimate the livestock population following Jahnke (1982). Data analysis involved the use of descriptive statistics, computational analysis and logical deductions.

RESULTS AND DISCUSSION

Location of Farmers by Development Domains

The geographical location with respect to agro-ecological zone of survey villages is shown in Table 2. Four of the villages (Madachi, Bambarawa, Zugachi and Waga) which have dispersed settlement pattern were from the SS. This pattern of village settlement has implications for the access to local information on inputs and outputs markets. Only seven (7) of the survey villages were relatively distant from tarred road, hence the relative access of the villages. Similarly, only three - Suddu, Ungwan Tamuwa and Ungwan Geri – of the villages, incidentally all from the NGS, have poor (seasonal/ rough) road access to the village. Further, there is a close link between the road access to the villages and the distance to tarred road. Almost all the villages which have good access road had their roads tarred and are very close to the village. The road access to the villages has implication for the transport of agricultural inputs and outputs to and from the village. The average distance to the nearest market to the villages without local market was 5.7 km (computed). However, most of the villages operated on central market basis.

Further, the results of the availability of local market by development domains revealed that 80 percent of the villages in the HP area had local markets while only 20 percent of the villages in the LP area have local markets. The results support the hypothesis that population and market access are positive correlates. That is, population creates and confirms market potential for agricultural inputs and outputs.

Farm-level Characteristics by Development Domains

Results in Table 3 reveal that market access was important in explaining the difference in land intensification in the HP area in both AEZs. Given HP, there was higher land use intensification in the LM area than the HM area the in the NGS. This scenario was reversed in the SS. The cultivation of large hectares of land, especially in the SS, may be due to good access to farm inputs. The development domains were important in explaining the difference in land area cropped. For

Table 2: Village-level characteristics by development domains

Village name	*Development domains*	*AEZ*	*Settlement pattern*	*Distance to tarred road (km)*	*Road access*	*Presence of local market*
Jalli	LPLM	SS	Linear along road	0	Good	Yes
Madachi	LPLM	SS	Dispersed across fields	2	Fair	No
Suddu	LPLM	NGS	Compound/nucleated	3	Poor	No
Richifa	LPLM	NGS	Linear along road	0	Good	No
Babban Ruga	LPHM	SS	Compound/nucleated	0.2	Good	No
Bambarawa	LPHM	SS	Dispersed across fields	3	Fair	No
Ungwan Tamuwa	LPHM	NGS	Dispersed across fields	2	Poor	No
Ungwan Geri	LPHM	NGS	Dispersed across fields	3	Poor	No
Hugungumai	HPLM	SS	Linear along road	0	Good	No
Duguji	HPLM	SS	Compound/nucleated	3	Fair	No
Ungwan Pa	HPLM	NGS	Dispersed across fields	1	Good	No
Awai	HPLM	NGS	Linear along road	0	Good	Yes
Zugachi	HPHM	SS	Dispersed across fields	0.3	Good	Yes
Waga	HPHM	SS	Dispersed across fields	0.25	Good	No
Gangara	HPHM	NGS	Compound/nucleated	0.25	Good	Yes
Turawa	HPHM	NGS	Compound/nucleated	0.3	Good	Yes

Table 3: Description of farmers by agro-ecological zone and development domains

Description	*NGS*				*SS*			
	LPLM	*LPHM*	*HPLM*	*HPHM*	*LPLM*	*LPHM*	*HPLM*	*HPHM*
Organic fertilizer used (kg per ha)	1803 (1797)	1816 (1423)	1939 (1451)	1771 (1631)	2100 (1418)	1685 (1010)	2021 (1241)	1690 (930)
Total land cultivated (ha)	6.5 (3.8)	6.78 (3.19)	6.15 (2.69)	5.06 (4.17)	4.76 (2.55)	5.42 (2.92)	5.57 (2.65)	7.21 (3.38)
Proportion of own land cultivated (% of total)	0.96 (0.16)	1.00 (0)	1.00 (0)	1.00 (0)	0.96 (0.12)	0.95 (0.10)	0.98 (0.06)	0.95 (0.11)
Proportion of distant field cultivated (% of total)	0.63 (0.31)	0.69 (0.25)	0.65 (0.29)	0.68 (0.41)	0.48 (0.32)	0.54 (0.35)	0.50 (0.31)	0.44 (0.27)
Draught animal power (% of farmers)	0.60 (0.49)	0.93 (0.27)	0.87 (0.33)	0.93 (0.27)	0.65 (0.48)	0.43 (0.50)	0.77 (0.42)	0.95 (0.22)

Figures in parentheses are standard deviations.

instance, more land area was cultivated in the NGS in the LPLM than the HPHM. This situation was however contrasted in the SS as more land was cultivated in the HPHM than in the LPLM.

The proportion of own land area cultivated by development domains shows that all the farmland cultivated by development domains in the NGS were owned except for the LPLM. This result implies higher level of usufructuary rights in the NGS. Whereas, the SS had varying proportions of rented land area cultivated. Low usufructuary rights or lack of security of access to cultivable land influences farmers' investment in building up soil fertility and applying agricultural inputs (Brook and Julio 2000). By implications therefore, and given the control of land resource, the NGS seems to have more motivation to invest in the land resource and the potential for organic agriculture than the SS.

Distant farms and the use of draught animals were commonly practiced by farmers in the study area. On the average, the SS had more farmland in the homestead (less than 2km radius to homestead). More than 50 percent of the cultivated land by farmers in the SS was homestead while more than 60 percent of the cultivated land by farmers in the NGS was distant farms. The highest proportion of distant farmland by development domains was in the LPHM of NGS (69 percent) and SS (54 percent), respectively. The use of draught animals was also influenced by both high population density and high market access (HPHM) in the study area.

Cropping Systems by Development Domains

Generally, the study area had cereal-legume based systems, with varying (mixed) and highly specialized cropping systems (Table 4). However, maize monoculture and maize-cowpea-sorghum cropping systems were dominant, and had 18 percent and 19 percent share of the total cropped land respectively. The major share of crop type planted had implications for the fertility status (replenishing or depleting) of the soil; particularly with maize and sorghum regarded as soil nutrient depleting and the legumes (soybean, groundnut, and cowpea) were regarded as not depleting soil fertility (Manyong et al. 2001) and hence the need for repeated use of manure as soil fertility amender.

Table 4: Cropping systems (percentage share of cropped area)

Cropping systems	*Agro-ecological zone*		
	NGS	*SS*	*All sample*
Maize + cowpea	8	-	5
Maize + cowpea + sorghum	38	-	19
Millet + cowpea	-	-	8
Millet + sorghum	-	-	5
Maize monocrop	29	9	18
Millet monocrop	-	10	6
Sorghum + cowpea	-	7	5
Sorghum + groundnut	-	14	8
Cowpea + sorghum + groundnut	-	6	-
Millet + cowpea	-	13	-
Millet + groundnut	-	8	-
Millet + groundnut + sorghum	-	8	-
Millet + sorghum	-	8	-
Maize + soybean	5	-	-
Sorghum + soybean	7	-	-
Others (including vegetables)	13	17	26
Total	100	100	100

Livestock Ownership and Tropical Livestock Units by Development Domains

The ownership of livestock conferred the opportunity and potentials for manure use as manure or soil fertility improvement is generated *in-situ*. The *in-situ* generation of manure for soil fertility management is consistent with the practice of organic agriculture.

The mean tropical livestock unit (TLU) in the study area was 4.0, (equivalent of 4 cattle, or 2 cattle, 10 sheep and 10 goats). This result is similar to Hoffmann et al. (2001) of 4.4 TLU, but different from Manyong et al. (2003) of 8.0 TLU. When disaggregated into development domains, the HPHM accounted for the highest TLU of 4.1; buttressing the Boserup hypothesis that agricultural intensification is driven by population growth and by higher returns to farming which arise when market infrastructure improves and farm gate prices increase (Boserup 1980); and high potentials for organic agriculture.

There was however an increasing trend from LPHM to HPHM in TLU in the SS across the socio-economic domains, while a decreasing trend was observed for the NGS. The increasing trend along the population characteristics in the SS is consistent with the Boserup hypothesis, and is indicative of the 'autonomous intensification' of agricultural production associated with the growth of human population, through closer interaction between livestock and arable farmers (Boserup 1980; Bourn and Wint 1994), and market access (Manyong et al. 2003) in the high population density area.

Organic Fertilizer Use by Development Domains

The use of organic fertilizer is a well established practice in the agricultural system in the study area. The mean manure use in the study area is 1853.6 kg ha^{-1} (Table 5). This represents 382 percent increase over the 485 kg ha^{-1} as reported by Manyong et al. (2003), but close to the 2000 kg ha^{-1} reported by Chianu et al. (2004). The results thus show higher level of intensification in manure use in the study area. Also, there was higher level of manure use or intensification of 1874.4 kg ha^{-1} in the SS compared to the of 1832.78 kg ha^{-1} in the NGS (Table 5). However, the averages are still insufficient to meet the animal manure of 3–5 t ha^{-1} required to maintain cereal grain yields (Bationo and Mokwunye 1991; Chianu et al. 2004). Increased use of manure is required to meet the challenges of increasing population, low productivity, high land use intensity and expansion of agriculture to marginal lands and organic agriculture practices. On crop-by-crop basis, manure application was very important in the agricultural production systems. Cereal-legume based cropping systems accounted for 74 percent of the total share of manure applied on the farm, with maize-based cropping systems received 37 percent of the total organic fertilizer applied.

The extent of manure use varied widely in development domains (Table 5). The LPLM had higher intensification (2100 kg ha^{-1}) in manure use rate in the SS compared to the 1803 kg ha^{-1} in the NGS. Given the development domains of low population, the difference observed in the intensification levels (reduction) of manure use rate (1685 kg ha^{-1}), when we moved to the LPHM in the SS, could be explained for the difference in the access to the market. Generally, the low market access areas intensified more in manure use rate as hypothesized, than the high market access areas. This result is perhaps due to availability of land and livestock ownership.

Further, the test of significance (t-test) revealed that there was no significant (p>0.05)

Table 5: Current level of organic fertilizer use and share of minimum requirements for take-off of organic agriculture

	Development domains					
	AEZ	*LPLM*	*LPHM*	*HPLM*	*HPHM*	*All*
Current organic fertilizer use (kg/ha)	NGS	1803	1816	1939	1771	1832
	SS	2100	1685	2021	1690	1874
Current TLU	NGS	4.50	4.60	3.80	3.40	4.08
	SS	3.30	3.30	4.40	4.90	3.98
Current organic fertilizer use as % of 3 tons/ha	NGS	60.10	60.53	64.63	59.03	61.08
	SS	70.00	56.17	67.37	56.33	62.47
Current organic fertilizer use as % of 5 tons/ha	NGS	36.06	36.32	38.78	35.42	36.65
	SS	42.00	33.70	40.42	33.80	37.48

difference in the use of manure by development domains. This implies that the current use/application rates of manure by development domains are similar. However, there were significant ($p<0.05$) differences in the use rate of organic fertilizer by AEZ and TLU. Therefore, there is the need to improve the level of manure application rate in order to meet the potentials for organic agriculture.

The actual and potential use of organic fertilizer (Table 5) revealed that the current levels of organic fertilizer use and the share of the minimum requirements for take-off for organic agriculture in Nigeria. The estimate was based on the requirements for meeting the 3-5 tons per ha. Despite the potentials of organic fertilizer requirements for organic agriculture, only 37 percent of the required 5 tons/ha of organic fertilizer is currently used in Nigeria.

Based on the significant relationship between organic fertilizer use and TLU, a computational analysis and trends (Fig. 4) based cost effectiveness of livestock ownership revealed that it is better to operate organic agriculture from the LPLM and LPHM in the SS than the HPLM and HPHM. On the contrary, it is more cost effective to operate organic agriculture from the HPLM and HPHM in the NGS than the LPLM and LPHM. Therefore, the LPLM and LPHM is the cost effective domain to operate organic agriculture in the SS while the domain of HPLM and HPHM is the cost effective domain to operate organic agriculture in the NGS. These results emphasize the need for specific development domains in developing organic agriculture in Nigeria and West Africa.

CONCLUSION

This study fills the knowledge gap in the actual and potential use of animal manure compost as organic fertilizer in Nigeria. Evidence from past studies in Africa and Nigeria suggests the need to assess the limitations and potential of organic fertilizer so as to confront the challenges of declining soil fertility and low productivity in Nigeria, and to meeting the soil fertility needs for emerging organic agriculture production and development in Nigeria.

The analysis was based on four identified development domains. The development domains were clusters of population and market access. The four development domains are: low population density, low market access (LPLM); low population density, high market access (LPHM); high population density, low market access (HPLM); high population density, high market access (HPHM).

The results revealed that on crop-by-crop basis, animal manure compost application was very important in the agricultural production systems in Nigeria. This was evident in the fact that cereal-legume based cropping systems accounted for 74 percent of the total share of manure applied on the farm, with maize-based cropping systems received 37 percent of the total manure applied.

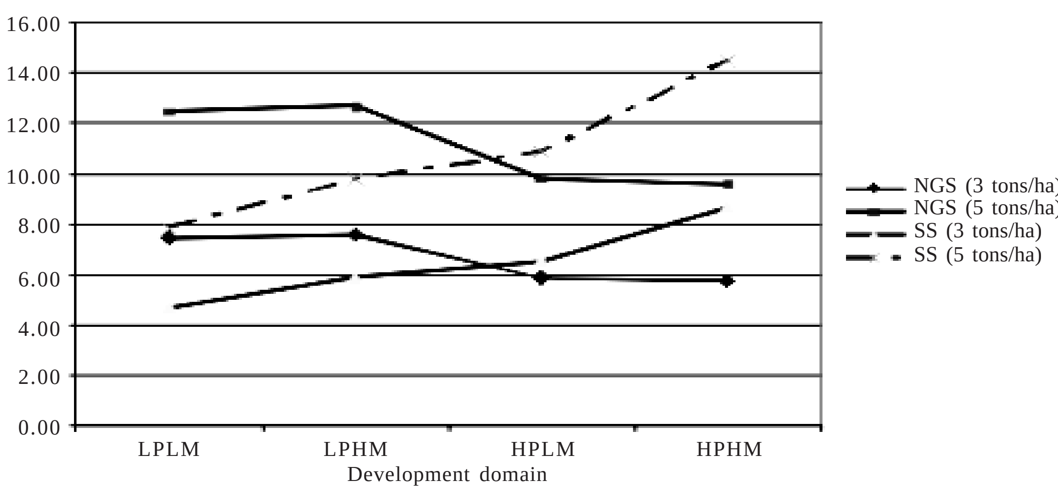

Fig. 4. Estimation of livestock ownership (TLU) for meeting minimum requirements for take-off for organic agriculture by development domains

The actual and potential use of organic fertilizer revealed that the current levels of organic fertilizer use as share of the minimum requirements for take-off for organic agriculture in Nigeria was low. The estimate was based on the requirements for meeting the 3-5 tons per ha. Our result revealed that despite the potentials for meeting the organic fertilizer requirements for organic agriculture development, only 37 percent of the required 5 tons/ha of organic fertilizer is currently used in Nigeria.

RECOMMENDATIONS

Based on the significant relationship between organic fertilizer use and livestock ownership (TLU), a computational/trends analysis based cost effectiveness of livestock ownership revealed that it is better to operate organic agriculture from the LPLM and LPHM in the SS than the HPLM and HPHM. On the contrary, it is more cost effective to operate organic agriculture from the HPLM and HPHM in the NGS than the LPLM and LPHM. Therefore, the LPLM and LPHM is the cost effective domain to operate organic agriculture in the SS while the domain of HPLM and HPHM is the cost effective domain to operate organic agriculture in the NGS. These results underscore the need for practice of organic agriculture in specific development domains in Nigeria and indeed West Africa.

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