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# Ecological and Socio-economic Factors Affecting Agricultural Intensification in the West African Savannas: Evidence from Northern Nigeria

**I Okike**[1], **M A Jabbar**[2], **V M Manyong**[3] and **J W Smith**[4]

[1]International Livestock Research Institute (ILRI), Ibadan, Nigeria. c/o Lambourn & Co., Carolyn House, 26 Dingwall Road, Croydon CR93EE England. **i.okike@cgiar.org**.

[2] ILRI, PO Box 5689, Addis Ababa, Ethiopia. **M.Jabbar@cgiar.org** (*Corresponding author*)

[3]International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. c/o Lambourn & Co., Carolyn House, 26 Dingwall Road, Croydon CR93EE England. **V.Manyong@cgiar.org**

[4]Canadian International Development Agency, 200 Pomonade du Portage, Hull K14 OG4, Quebac, Canada. **J.Smith@cgiar.org**

## Abstract

Agricultural intensification in West Africa is at an early stage and the process is taking place through various pathways. Population pressure and market access are generally considered as major factors driving intensification and crop-livestock interaction. In this paper both ecology and economic factors and their interactions are hypothesised as driving forces in intensification and crop-livestock interaction. Analyses of a survey involving farming households in Nigeria confirm the hypothesis and show that the degree of intensification is higher in the Sudan savanna than the Northern Guinea savanna. Intensification is occurring mostly through higher land and labor use intensity, higher livestock stocking rates and application of more manure per hectare. It is concluded that policies to enhance market access will facilitate the process and that different technological options need to be pursued in the two agroecological zones to facilitate intensification.

**Key words:** agricultural intensification, crop-livestock interaction, northern Guinea savanna, Sudan savanna.

## Introduction

Agricultural intensification and technical change have followed different paths in different parts of the globe. Tiffen et al. (1994) define agricultural intensification as increased average inputs of labor or capital on a smallholding, either cultivated land alone, or on cultivated and grazing land, for the purpose of increasing the value of output per hectare. Overall, the intensification process can be said, in practice, to result from a) an increase in the gross output in fixed proportions due to inputs expanding proportionately, without technological changes, b) a shift towards more valuable outputs or c) technical progress that raises land productivity (Carswell, 1997). According to the theory of induced innovation, the nature of technical change in a given society will be induced by the endowment of resources, particularly land and labor, reflected in their relative prices, and their relation to product prices (Hayami and Ruttan, 1985).

In a significant part of sub-Saharan Africa (SSA), particularly in West Africa, agriculture is at the early stages of intensification. Several hypotheses have been postulated in which population pressure and market access have been considered as key drivers of the process of agricultural intensification and crop-livestock interaction in SSA (Boserup, 1965; McIntire et al., 1992; Smith et al., 1993; Jabbar, 1996; Okoruwa et al., 1996; Manyong et al., 1996; Smith et al., 1997). However, the possible pathways of intensification in the region, especially in different agro-ecological zones, are still not very clear. Consequently, development and dissemination of technologies and resource management options are also being pursued haphazardly, without giving adequate attention to the specificities of different ecological conditions, with sub-optimal results creating potential problems for sustainability of the evolving production systems.

In this context, we argue in this paper that in addition to socio-economic factors such as population pressure and market access, ecological differences in different parts of sub-Saharan Africa are also significant determinants of the form and pace of agricultural intensification, and overall economic development. So a better understanding of the pathways and driving forces for intensification will help to design research, policy and institutional mechanism to facilitate beneficial outcomes from the process as technology and management options then can be targeted more accurately. Better understanding about the possible pathways of development in SSA, with an ecological dimension, is important because in this continent human population is growing more rapidly than in any other region of the world. Its population of 0.5 billion in 1990 is projected to reach 1.3 billion by 2025. Urbanization is also occurring and incomes are increasing, expanding the demand for food. Africa is also often cited as the only developing region where agricultural output and yield growth is lagging seriously behind population growth. In SSA, for example, population doubles every 25 years while agricultural productivity has, in fact, declined from 1.9 per cent to 1.5 per cent during the past 15 years (World Bank, 1997). In addition to urbanization, livestock population is also expanding and these pressures on a fixed land base are likely to promote severe competition for resources and drive agriculture progressively towards intensification. And these features are not uniform across different agro-ecological zones, so the potential and form off intensification is also likely to be different.

One of the earliest hypotheses about the evolution of production systems was that population pressure would induce agricultural intensification and that this would be reflected in smaller holdings and increased land use intensities, e.g. shorter fallow periods to regenerate fertility, and more frequent annual cropping (Boserup, 1965, 1981). de Wilde (1967) postulated that apart from population pressure, market access, presence of cash crops such as cotton, or dominance of cereals in the cropping pattern might induce intensification in crop production and crop-livestock interaction, particularly adoption of animal traction, in specific situations. Ruthenberg (1980) considered population pressure as the main driver for intensification and classified seven types of production systems, which would move from less to more intensive cultivation methods. However, no integral role for livestock was defined in these systems, not-with-standing their presence, implying that intensification in crop production might proceed without significant interaction and integration with livestock.

Other authors (Pingali et al., 1987; McIntire et al., 1992; Winrock, 1992; Smith et al., 1993) considered population pressure and market access to be the principal driving forces for both intensification in crop production and fostering crop-livestock interaction and integration. Some of these authors have characterized the role of livestock in intensification as an evolutionary process. They postulate that population growth increases the area of cropland through forest clearing, encroachment into traditionally used pastureland and shortened fallow periods thus making external inputs necessary to maintain soil fertility. Where livestock are available, farmers paddock animals on cropland or otherwise collect and use manure and graze crop residues. As population pressure increases further, more intensive technologies including heavier applications of manure and fertilizer are required to increase production. A shift from paddocking to collection, processing and incorporation of manure takes place. Herders increasingly use crop residues, become settled and engage in crop production. Then the grazing of natural pasture falls, crop residues are harvested and preserved for feeding, and manure is more intensively used. Farmers may also grow legumes and forages to improve soil fertility, crop yield and livestock productivity. Finally, human labor may be replaced by traction and mechanization, if labor costs increase in real terms due to increase in employment opportunities outside the farm.

In West Africa, the Northern and Southern Guinea savannas (sub-humid zone) and the Sudan savanna (higher rainfall part of the semi-arid zone) are said to have the highest potential for crop-livestock farming (Winrock, 1992). Yet the linear evolutionary process of crop-livestock interaction and integration postulated by Pingali et al. and McIntire et al. (*op cit*.) may not equally hold everywhere. Crop-livestock interaction and integration are evolving in varying degrees across ecological gradients of the region and the process may be slightly more advanced in the drier regions because of the greater possibility of settled or semi-settled crop-cattle production in a more disease-free environment. In fact, high disease challenge to livestock from the NGS southwards appears to be a major reason why the rate and extent of crop-livestock interactions and integration have not, as might be expected, advanced rapidly. Also, many local situations in terms of driving forces, production potential and other ecological or socioeconomic conditions may lead to alternative or sub-pathways for intensification (Jabbar, 1996). Okoruwa et al. (1996) have shown that relative profitability and competition for resources between crop and livestock would play a significant role in determining the pace of evolution of mixed farming in specific situations. Within an agroecological zone, higher degree of crop-livestock interaction and intensification may be observed as one moves from low population, low market access situations to high population, high market access situations. However, the process may not follow a linear path. In some situations, improved market access may induce intensification before population pressure becomes a significant factor while in another situation, population pressure may induce intensification to a certain degree even before market access become a significant driver.

Given the above, it is hypothesized that biophysical peculiarities of ecological zones (ecology), population density and market access are the most important drivers of agricultural intensification and crop-livestock interaction. Intensification may depend more on the interaction among the three drivers rather than any driver playing a dominant role. These hypotheses were tested with data from the Northern Guinea savanna and Sudan savanna agro-ecological zones in Northern Nigeria.

## Analytical methods and data

### Study area

The study was conducted in northern Nigeria covering two agroecological zones - the Northern Guinea savanna (NGS) and Sudan savanna (SS).[1] These zones lie between

[1] Jahnke (1982) and McIntire *et al* (1992) consider the area as falling under semi-arid zone with 90-180 days' growing period while the FAO (1990) has divided it into a dry semi-arid (75-119 days' growing

latitudes 8° and 13.5° north of the equator. Mean annual rainfall ranges from 500mm in its northern fringes to 1600mm along its southern boundary. Rainfall is unimodal and allows 75-180 days growing period across the gradient—north to south. There are distinct and striking differences in farming practices between the two zones. For example, the NGS or moist semi-arid zone is a maize belt in which sorghum becomes important only towards its drier northern margins while in the SS or the dry semi-arid, sorghum and millet are the major cereals grown in combination. In this latter case, millet assumes higher importance as one moves towards its northern fringes. In effect, the study area could also be defined in terms of a maize belt to its south and a sorghum/millet belt to its north corresponding roughly to the NGS and SS, respectively (Fig. 1).

[INSERT FIGURE 1 ABOUT HERE]

Cattle, sheep, and goats are the predominant livestock species reared, in both zones. The majority of farmers cultivate crops and own livestock in varying degrees of combination. The NGS has higher cropping potential and is used traditionally by herders from SS as a dry season grazing area while the SS has higher number of livestock per person with lower cropping potential.

Crop-based farmers are traditional landowners with two to four work bulls and a number of small ruminants. They depend on manure (from own stock and from purchases) a great deal to maintain soil fertility. Their relatively large farms offer them a reasonable abundance of crop residues, so the tendency for this group is to acquire more livestock to utilize the residue and save them the cost of purchasing manure – even if they could do this from the proceeds of selling the crop residues. Among this group, also, there are some who keep only a limited number of small ruminants lacking in the skill for large ruminant rearing. This latter group is involved in crop residue and manure exchange contracts with pastoralists - maintaining soil fertility mostly through crop-livestock interaction rather than integration. An emerging trend is that the manure market has extended beyond farmer-to-farmer, as frequently described, to abattoirs. At the time of this study, manure collected at abattoirs that used to constitute a disposal nightmare, was already selling for the equivalent of US$8.2/tonne and indications are that the price will continue to rise given the tendency for contemporary government policies to withdraw subsidy on chemical fertilizers. Obviously, where an abattoir is sited and the number of animals slaughtered will depend on population and market access, so not many farmers have access to this source of manure. Another source, outside farmer-to-farmer exchanges, is major livestock markets. There are a growing number of entrepreneurs who originally sold forage to livestock traders and served as intermediaries for livestock purchases. As additional business, this group now gathers manure from the market for sale. Again, access to manure from this source is logically limited to nearby farmers who are able to afford transport facilities or absorb associated transportation costs.

On the other hand, livestock-based farmers are mostly former transhumant pastoralists who acquire small farm plots, as they begin to settle, to produce cereals for home consumption and for making some milk products that they sell. These small farms produce too little residue for their large herds to survive on but they benefit from relative surplus of manure deposited around the homestead – usually part of the farm - by their livestock after extensive grazing on rangelands. They also exchange manure for crop residue with crop farmers through paddocking on the crop farmers' plots. As

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period) and moist semi-arid (120-179 days). In this study the FAO classification is adopted therefore NGS and SS correspond to the dry and moist semi-arid zones.

encroachment on rangelands by crop farming occurs with increased population, this group has to depend more and more on production, exchange and purchase of crop residue as feed resource. Sale of livestock allows them to meet family expenses. Once settled, they tend to acquire more land and produce as much of their cereal and crop residue requirement as possible.

Crop-livestock integration for crop-based farmers in the savanna regions of West Africa, therefore, involve acquiring more animals and leasing or selling off less fertile parts of their farmlands. On the other hand, livestock-based farmers sell some animals and acquire these plots knowing they have the resource – manure – to restore and sustain their fertility. Thus, for these farm types, crop-livestock integration means land-for-livestock and livestock-for-land exchanges to arrive at fairly stable, single-household-owned, mixed crop-livestock systems.

<u>Sampling and data collection</u>

In order to focus strategic and diagnostic research for generating technologies targeted at specific recommendation domains, the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, has delineated and characterized selected villages within a benchmark site in the NGS zone of Nigeria. This was done essentially on the basis of resource use intensity for agricultural production and the underlying influences of human population density and access to market (see Manyong et al., 1996). As a rule, areas with less than 150 persons per square kilometer were regarded as low population locations while the market access was defined in terms of travel time to the nearest wholesale market on a year-round basis (FDL&PCS, 1992; Brunner et al., 1995). The International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Kano station in Nigeria, followed and conducted a similar characterization exercise for the SS (see Ogungbile et al., 1999). There is considerable interaction between population and market access, e.g. high population density could attract markets and roads to a location just as a good road across a small village could attract immigrants and increase population density. For this reason, villages within the benchmark sites in each of the two zones were classified broadly into four domains representing population and market interactions as follows: low population and low market access (LPLM); low population and high market access (LPHM); high population and low market access (HPLM); and high population and high market access (HPHM), giving eight socio-ecological domains in the two agroecological zones (Okike, 2000).

From each of the benchmark sites in the two zones, four villages representing the four domains were selected purposively for this study. From the selected villages, 559 households were selected randomly from comprehensive lists of households available from village/district heads. Data were collected during February-March 1998 using a detailed and structured questionnaire.

## Empirical model

Based on the definitions, hypotheses and literature review on agricultural intensification and crop-livestock interaction the following indicators of intensification were used as dependent variables in the empirical models:

(a) Land use intensity (cycles of continuous cropping a plot before putting into short fallow),

(b) Labor intensity (person days/hectare) for crop and livestock production,

(c) Manure (kg) applied per hectare,

(d) Chemical fertilizers (kg) applied per hectare,

(e) Animal traction (animal days) used per hectare,

(f) Tropical livestock units (TLU) per hectare

(g) Share (%) of livestock in farm cash income.

Although combination of ecology, population pressure and market access were hypothesized as principal driving forces for intensification, there are other determinants e.g. farm size, herd size, household size, number of years of experience in mixed farming, that could influence the specific indicators of intensification. In order to isolate and separate the effects of the main driving forces (the socio-ecological domains) from those of the other factors, the Analysis of Covariance (AnCov) technique was considered a suitable technique. AnCov is a combination of classical linear regression and analysis of variance (ANOVA) and can be used to examine the effect on a dependent variable of a set of factors, each with different levels, and a set of covariates (continuous variables). Thus, the general form of the model may be written as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \ldots\ldots + \beta_k X_{ik} + \phi_2 Z_2 + \phi_3 Z_3 + \ldots + \phi_n Z_n + \varepsilon_i \qquad (1)$$

where $Y_i$ is any of the indicators of intensification listed above, $X$s are factors *1* to *k* with *i* categories such that i is equal to or greater than 2, $Z$s are covariates, numbering 2 to *n*, $\beta$ and $\phi$ are parameters to be estimated, and $\varepsilon_i$ is the error term. A full factorial model will include all possible main-effect and interaction terms but it usually suffices to include only the relevant interaction terms along with all main-effect terms. For example, if *Y* is the observed measure of agricultural intensification e.g. labor use per hectare, that depends on market access (low and high) as a factor and farm size as a covariate, then AnCov measures if labor use is significantly different between the two market access domains when the effect of farm size is controlled for. The advantage of AnCov over simple regression is that the former does not only show the direction of the difference between factors but actual magnitudes of the differences as well (Norusis, 1993).

Bearing in mind that some of the indicators of intensification were used as dependent variables in some equations and independent variables in others, a problem of endogeneity could be expected. So the test of simultaneity was done exhaustively using Hausman procedures and where confirmed, the predicted rather than observed values of affected variables were used in the respective models (Hausman, 1978).

In the empirical model, ecology, market access and population pressure were used initially as separate factors and their interactions were included. However, testing with different specification options indicated that the best fit was obtained when the interaction of ecology (NGS, SS), population density (low, high), and market access (low, high) was used to define various socio-ecological domains of main-effect factors. Thus the eight socio-ecological domains (as previously described) were arranged in a hierarchical order, though these domains could differ with respect to some other characteristics such as presence of lowland valleys and major crop types, which could influence the nature and extent of intensification, but those could not be fully captured in the present analysis.

The other factor included in the model is farm type (with crop farming, livestock farming and mixed farming as categories, the underlying assumption is that mixed farms were likely to be more intensively cultivated given the ‘advantage’ of crop-livestock integration). In each equation a number of relevant covariates, to be described later, were used. Some covariates that exhibited endogeneity/high collinearity were automatically excluded from the model e.g. manure/ha with TLU/ha as dependent variable.

It is important to note that since farming systems evolve over time, in general, from low input systems (e.g. LPLM) to intensive systems (e.g. HPHM), the use of socioeconomic domain as the first stratifying variable for the entire data set may also be considered as equivalent to conducting a time-series (panel) survey. The time period is equivalent to the actual time that it would have taken for a low input system to evolve into an intensive one. Therefore, from this single cross-sectional survey, it is possible also to infer possible changes in the farm application of the relevant covariates over time.

## Results and discussion

Household characteristics and farming systems in the savanna zones of Nigeria

In the savanna zones of Nigeria, the head of the farming household is about 44 years old and the average household has 11 persons who provide 63.2 per cent of farm labour needed to cultivate an average of 5.8 ha of land annually (Table 1). The trend is towards mixed (crop-livestock) farming as households previously dependent on crop farming incorporate livestock and *vice versa*. As a result of the above, the number of years of experience in mixed farming is often far below the active farming age of the farmers in the region. Farmers in the NGS have about 15 years experience in mixed farming compared to 22 years in the SS. Since the average age of farmers in both zone vary by only about two years, this result suggests that crop-livestock integration has been in place longer in the SS than in the NGS, though not necessarily practiced at a higher level of intensity. The longer tradition of mixed farming stands to reason in terms of the well known and dated tradition of keeping livestock as well as the higher concentration of livestock, especially large ruminants, in the drier SS compared to the wetter NGS, where disease challenge is a major constraint to livestock production.

[INSERT TABLE 1 ABOUT HERE]

Farm holdings of households are usually in 4 to 8 separate locations and about 1.6 km from the homestead. Fallow periods are shortening and it is common to cultivate farms continuously for up to an average of 17 cycles before being put to a short fallow. If soil fertility and structure are maintained, continuous cropping has the advantage of eliminating the cost of land clearing which could be substantial when long fallow periods lead to a sufficient level of regeneration of bush to demand stumping. Crop labor input varies from an average of 73 person days/ha/yr in the NGS to 81 person days/ha/yr in the SS. Rates of livestock manure application (479 kg/ha) are similar in both zones while the higher rate of application of chemical fertilizers per ha may partly account for the higher rate of labour use per ha in the SS compared to the NGS. Okike et al. (2004) show that, given the lower agricultural potential of the SS, this higher level of application of chemical fertilizers is economically inefficient.

Average households in the SS own 7.0 tropical livestock units (TLU) of livestock compared to 5.4 TLU in the NGS and this is expected in terms of tradition and the suitability of the environment. However, the use of animals for draught power is higher in the NGS than in the SS. This is mainly because the soils in the NGS are heavier and more difficult to till and, therefore, requires more urgently the deployment of alternative sources of draught power to complement human effort. Herdsmen are paid about the same wages to take care of anything between one and 40 cattle or more, and since herds are smaller in the NGS than the SS, the number of person days/TLU is comparatively higher even when herding is done with household labor.

In the complementary exchange of manure and crop residues between livestock and crops, farmers sometimes have to supplement crop residues from their own farms to survive the long dry season characterized by feed scarcity. This is a bigger problem in the SS than in the NGS as farmers in the two zones, on the average, spend N894 and N462 annually to purchase cowpea and groundnut fodder as well as guinea corn and millet stover for their animals.

The survey shows that farmers in the savanna zones of Nigeria get an average annual revenue of N24,834 per ha. This does not vary across the savanna zones but is different in terms of the proportion of the income from crop or livestock. Farmers in the NGS get more income from crops while livestock income accounts for a higher proportion of total farm income in the SS.

Result from the AnCov models

The results of the best-fit AnCov models are presented in Table 1. Results with respect to each of the seven selected indicators of intensification are discussed below. Tests of endogeneity showed significant relationships (at 10% level of significance) between the dependent and some independent variables in some equations. In these cases, predicted rather than observed values of the independent variables were used in final estimates. In general the explanatory power of the equations are reasonably high in some and not in others. One possible reason is that some unknown important covariates were not included in the models. The covariates control for within domain variations. For example, a village classified as high or low population density will have differences among the sample farms in terms of land per capita, which in turn could have impact on an intensification indicator. Use of land/capita as a covariate captured any difference between a high and a low population density domain. However, there was no farm-specific market access data to use as a covariate, so the difference between market access domains could not be assessed as precisely as the effects of population density. Consequently, the overall explanatory power of the model was lower than it could possibly be.

However, it may be noted that agricultural intensification is at early stages in West Africa and as will be explained below, the process is taking place through various pathways, with population and market interchanging the timing and importance of their roles in the two agroecological zones. As a result, the number of factors and covariates that explain each indicator of intensification and the level to which they do so vary both spatially and temporally. In other words, where intensification is more advanced, its indicators would be expected to be better explained by the specified factors and covariates and more so when the hypothesized pathway for the location approximately fits the actual pathway.

*Land use intensity* (Table 2, col.1)

Theoretically, land use intensity would be expected to be one of the first indicators of intensification driven by population pressure and further enhanced by better market access. Ruthenberg (1980) index uses years of continuous cultivation before putting a plot to fallow as a key variable for classifying systems into various stages of intensification. Following that, the number of cycles[2] of continuous cropping before

[2] In the study area, it is usual to obtain only one harvest per year. However, through the help of irrigation, some farmers are able to plant more than once on the same plot. To capture this effect, the cycles of

fallow was used as the indicator of land use intensity. The specified factors and covariates explain 48 per cent of the variation in the land use intensity and both socio-ecological domain and farm type appear to be important factors. The results of this survey indicate an average of 17 cycles of continuous cropping before a plot is put into short fallow. In the NGS and the SS, farm plots were being cultivated annually for up to 9 and 23 cycles, respectively, before being allowed to lie fallow for 1 or 2 years. Compared to the NGS LPLM domain, continuous cultivation is significantly shorter only in the NGS HPLM

domain but longer in all the domains in SS, the highest being in SS LPLM and SS LPHM. In the SS HPHM in particular, farmers not only use land more continuously, they practice double or even triple cropping on some plots in a given year aided by the availability of private or public irrigation facilities. Hence land use intensity is highest in this domain than any other domain in the study area.

[INSERT TABLE 2 ABOUT HERE]

Land-man ratio, herd size, rates of application of manure and fertilizers, crop labor and years of experience in mixed farming were among the covariates with significant effects on land use intensity. At low livestock density (TLU/ha), land use intensity was low and it increased with higher livestock density, indicating that when crop-livestock interaction and integration increase, land use intensity also increases. Land use intensity is higher in mixed farms and it increased with longer experience in mixed farming. This is further evidence of the positive relationship between crop-livestock interactions and agricultural intensification through application of manure and utilization of crop residues from livestock and crops within the same enterprise, as this sustains yields longer than either of livestock-based or crop-based farms.

[INSERT TABLE 3 ABOUT HERE]

*Labor intensity* (Table 2, col.2)

Population pressure first induces more intensive use of land. Then, it induces higher rates of labor use to increase productivity through better land and crop management, manure and fertilizer application, caring and feeding animals (Boserup, 1965, 1981; Rutherberg, 1980; Jabbar, 1981; McInitre et al., 1992). Improved market access may enhance the process (Jabbar, 1996). As stated earlier, intensification through crop-livestock integration has different implications for the crop-based farmer and the livestock-based farmer in the study area. For the livestock-based farmer intensification is expected to lead to smaller herd sizes and more intensive management involving crop residue gathering and cut-and-carry feeding. Consequently, labor per TLU is expected to increase. The reverse is the case for crop-based farmers whose stock sizes are still small and probably need to increase in order to optimize their land and labor use as well as crop residue utilization. In this case, labor per TLU is expected to decrease as the herd size increases. These apparently different uses of farm labor for livestock and for crop production was first tried separately in the equations but the results were not as distinct as when aggregated into total person days of labor per hectare. Even at low levels of statistical significance, the results obtained from disaggregated enterprise types have been reported because of their important implications for alternative use of farm labor in crop- or livestock-based farms.

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planting per plot per season was aggregated instead of number of years of continuous cropping which assumes only one harvest per season for all farmers.

The specified factors and covariates explained 44 per cent of the variation in labor use intensity. Compared to the LPLM domain in NGS, only the HPLM domains in both the NGS and SS applied labor at significantly higher rates. Compared to mixed farms, crop and livestock farms applied labor at significantly lower rates, which might be expected especially since land use intensity has been found to be higher in mixed farms. The estimated parameter of farm size per caput was significant at 1 per cent level of significance, with a negative sign. This confirms that farms with smaller farm plots had higher labor use intensity. Higher application rates of fertilizers led to higher labor use but the reverse was the case for higher levels of manure application per hectare. This was the case because kraaling animals overnight on given portions of the farm, which is a major way of applying manure, does not require extra labor unlike the application of fertilizers which have to be done using human labor. The results also show that initial increases in herd size required extra labor but this reduced as herd sizes got larger, as should be expected since the relationship between herding labor and herd size is not linear. For example, it is common practice among pastorlists in the study area to use one herdsman per 20-40 cattle. This tradition should be an indication of optimal herd labor and herd size ratios. In practice, since herd sizes cannot increase or decrease in multiples of 20-40, the effect of change in herd size relative to herd labor is more pronounced at lower herd sizes than at much higher herd sizes. For livestock-based farmers, higher herd sizes are more labor-optimising.

*Rate of application of manure per hectare* (Table 2, col.3)

This indicator portrays both input intensification and crop-livestock interaction (McInitre et al., 1992; Jabbar, 1996). The factors and covariates explained 48 per cent of the variation in manure application. The mean application rate for manure was 479 kg/ha and 81 per cent of the farmers applied manure to their fields (Table 3). There was no significant difference in manure application rates among the domains within the NGS. All the high population domains in SS applied significantly higher rates than the base domain (NGS LPLM), with the exception of the SS HPHM. In the SS, a higher proportion of farms use manure and fertilizers as complements than in the NGS (Table 4), so it not so surprising that with access to fertilizers, they applied the comparatively lower levels of manure per hectare. With this exception, a gradient of increasing rates of application of manure exists in the SS as one moves toward higher population and higher market access situations.

Compared to mixed farms, livestock farmers applied significantly higher rates of manure and crop farms applied significantly lower rates, which would be expected. Livestock farms had more manure in relation to the available land, so could apply at higher rates while mixed farms used manure mainly from own sources and through various contracts and exchanges with livestock farmers, hence these differences (Table 5).

[INSERT TABLE 4 ABOUT HERE]

[INSERT TABLE 5 ABOUT HERE]

Several covariates in the model acted as significant modifiers. Farm size per caput decreases rather than increases in the study area because fixed household land holdings are constantly sub-divided to accommodate household members who get mature enough to set up separate households. As this happened, more manure was applied per hectare mainly because livestock ownership is personalized. As such, while farm size decreased, personal livestock owned remained similar (or increased) and provided manure for a smaller area.

Manure application per hectare was endogenous with TLU/ha. Thus the predicted values of TLU/ha were used in this particular case. The result still showed, as expected, that owning more cattle led to higher rates of manure application. Manure application rate also increased with cycles of continuous cropping, further reinforcing the fact that the contributions of livestock to intensification takes place through manure to improve soil fertility when land use intensity is increased. As also expected, manure application rates or intensification increased when capital investments in farm equipment e.g. traction implements, spraying equipment increased. The increase in manure application as capital investment increases does not imply a decline in the efficiency of manure application. Rather, farmers with more capital are enabled to acquire and use manure from other sources than their own farms. This is simply because stocking rates capable ensuring soil fertility maintenance based on manure alone have not been attained even in the drier regions of West Africa where livestock densities are higher.

*Animal traction days used per hectare* (Table 1, col.4)

Use of animal traction portrays both input intensification and crop-livestock interaction and signifies an important stage in the process of intensification (Pingali et al., 1987; McIntire et al., 1992). As much as 58 per cent of the sample used traction indicating that the process of intensification is occurring in the study area. However, based on the proportion of farmers using animal traction and its combination with other external inputs, it could be said that the agroecological zones and farm types were at various stages in the process of intensification. For example, a higher proportion of NGS farms and a higher proportion of livestock farms used traction from either own or purchased sources (Table 3, Table 6). Also a higher proportion of farms in SS combined either manure or fertilizer with traction while a higher proportion of farms in NGS combined all three- manure, fertilizer and traction. A higher proportion of crop-based farms combined all three inputs than mixed or livestock farms (Table 4). Ordinarily, a combination involving more of the above external inputs should indicate higher levels of intensification such that farms in the NGS and crop-based farms would be adjudged to be at more advanced stages of intensification than others. However, it appears that it was the relatively lower concentration of livestock and, therefore, the lower availability of manure that led crop-based farms compared to mixed farmers and livestock-based farmers; and many farms in the NGS compared to the SS to purchase chemical fertilizers in addition to manure.

The factors and covariates in the model explain 23 per cent of the variation the used of animal traction. Compared to the LPLM domain in NGS, all the other domains used significantly lower number of days of animal traction. Since traction is supposed to replace human labor, lower traction use in high population density areas may not be unrealistic. But in better market access domains where the process of agricultural intensification is usually more advanced in response to greater demand for farm products, higher traction use would be normally expected.

The somewhat opposite result in this study may be explained by the observed pattern of migration in the study area where youths migrate to urban, peri-urban areas for better jobs but are forced to work as cheap farm labor or engage in urban/peri urban agriculture in open spaces and roadsides, as a survival strategy, during their initial period of search for other employment (Okike, 2001). Consequently, areas with better market access in peri-urban areas, with the abundance of unemployed able-bodied youths, are able to continue to use human labor for farm operations while low population, low market access domains, being labor constrained due to migration, may be forced to use traction sooner in the evolutionary pathway than the high population, high market access domains.

Compared to mixed farms, crop and livestock farms applied significantly less traction days. Most livestock farmers have small farm size in relation to available labor, so use hand tools for land preparation. Several covariates in the model modify animal traction at highly significant levels. Traction use increased with land per capita (implying labour shortage to perform tasks adequately), experience in mixed farming and special capital investments. The increase in the use of traction with longer experience in mixed farming is expected because mixed (crop-livestock) farmers usually start by exploiting the complementarities of manure and crop residue exchanges which are readily available. The matter of acquiring a pair of work bulls dedicated to traction is more expensive and takes longer time to attain. In terms of capital investment, one of the important items on which farmers invested was animal traction equipment. It is, therefore, expected that traction use should be comparatively higher among farmers making more capital investments. This suggests that considerable expansion in animal traction use could be achieved through enabling farmers to acquire traction equipment among other capital investments.

[INSERT TABLE 6 ABOUT HERE]

*Rate of application of fertilizer per hectare* (Table 2, col.5)

Manure and fertilizers may be complements or substitutes depending on the stage of intensification and crop-livestock interaction (McInitre et al., 1992: Smith et al., 1993; Jabbar, 1996). It would appear from the results in Table 1 that manure and fertilizers were used as substitutes in the NGS but as complements in the SS. Overall, eighty one percent of sample farms used manure, 72 per cent used fertilizers. A higher proportion of farms in SS applied manure than those in NGS, and more mixed farms applied manure than the other two farm types (Table 4). On the other hand a higher proportion of NGS farms applied fertilizer than those in SS even though application rates were higher in the SS (205kg/ha) than the NGS (175kg/ha).

The model explained only 20 per cent of the variation in the quantity of fertilizer applied per hectare. This low explanatory power may be partly attributed to the definition of the variable. The rate has been calculated assuming that all plots of a farm have been fertilized as data on plot-specific application were not available. By traditional practice in the study area, fertilizers are applied to cereals (maize, sorghum and millet) but not legume crops (mainly groundnuts and cowpea). A cropping pattern of repeated alternating (1:1) rows of cereal:legume are common in the savanna zones (Tarawali et al., 2001). It is, however, the case that an increasing number of farmers in the area are adopting new cowpea varieties and this group – not considered as a special group in this study – usually applied fertilizers to cowpea. Also, a farmer would typically cultivate a number of plots in different locations, which make up the total cultivated farms for that season. We obtained information on the actual quantity of fertilizers applied for the season studied but not crop-specific plot-level application. Where a farmer chose not to apply fertilizers to all plots, measurement errors were introduced into the variable that could have led to a loss in its explanatory power.

Having said that, among the covariates, the explained part indicates that the farm size, the percentage of farm with legume crop, the number of TLU per hectare, labor use intensity and land use intensity were significant modifiers. Fertilizer application rate increased with higher labor intensity. Between manure and chemical fertilizers, either as substitutes or complements for soil fertility maintenance, the demand for additional labor for application is higher with chemical fertilizers than manure. This is so because kraaling of animals on different spots around the farm has evolved as an efficient way of spreading manure throughout the farm while the application of chemical fertilizers has to be done as an independent operation. The implication is that higher levels of crop-livestock interaction leading to higher use of manure by farmers will lower the cost of production by reducing the amount of labor required for soil fertility maintenance, all other things being equal.

The positive relationship between fertilizer and the proportion of land under legume crops is as a result of the use of fertilizers in growing new cowpea varieties, which are increasingly being adopted in the study area. Evidence of the positive impact of these new cowpea varieties on the livelihoods of farmers in the area and the fact that they also see additional benefits of cowpea cultivation in maintaining soil structure along with other benefits (Kristjanson et al., 2001) suggest that the trend will be towards an increase in fertilizer use with increased cowpea cultivation. As crops are grown in combination or relay and hardly as sole crop, it is expected that other crops grown in association with cowpea will benefit indirectly from the fertilizer application leading to increased yields, as was the case with additional benefits from important residual effects that fertilizers targeted at cotton had on cereal production in Mali (Giraudy, 1999).

*Number of tropical livestock units per hectare* (Table 2, col. 6)

Mixed farming is emerging in the region in two ways: i) pastoralists with large herds are becoming agropastoralists and then mixed farmers and in the process decreasing their herd sizes; and ii) crop farmers are adopting a small number of livestock in the beginning, then increasing herd size with experience (Jabbar, 1996). Both population pressure and market access would be expected to expedite this process of convergence. The specified factors and covariates explained 31 per cent of the variation in number of TLUs per hectare. Compared to the LPLM domain in NGS, all the other domains have no significant difference.

As implied in the stratification of the sample by farm types, livestock farmers had significantly higher TLU per hectare than mixed farmers and crop farmers. Animal traction use did not have any significant influence on animal density. As already explained, livestock farmers who have higher density of livestock per unit land have small sized farms where hand tools are sufficient. Among the covariates, land per capita, labor use, experience in mixed farming and capital investments acted as significant moderators. Animal density decreased with farm size, higher proportion of legume crops on farms, livestock labor intensity, land use intensity, and increased with capital investment, crop labor intensity and experience as mixed farmer. The inverse relationship between animal density and farm size is a confirmation of the description of the farm types; where land holdings were larger in size and the number of TLU were low for crop-based farmers, and the reverse for livestock-based farmers that had higher livestock-to-land ratios. The trend is expected to continue to be towards convergence of the above ratios for all farm types based on land-for-livestock and livestock-for-land exchanges.

The common practice among livestock-based farmers is to grow cereals especially sorghum and millet for food and for production of a composite dough, mixed and marketed with sour milk. Among them, growing legume crops is rare while it is very common among crop-based farmers. The result that farms with lower number of animals (a characteristic of crop-based farmers) also had higher proportion of land planted to legume crops (another characteristic of crop-based farmers) is not surprising. This phenomenon leaves crop-based farmers with excess residues of legume crops, which they sell and perceive to be a very important source of revenue and an additional incentive for cultivating legume crops especially cowpea. Livestock is an attractive store of wealth and for crop farmers, much of the income realized from sale of crops and their residues is invested in the purchase of more livestock. That is how incomes from crops and crop residues play a role in reducing the land-to-livestock ratio and contribute to crop-livestock integration.

An increase in crop labor could be seen to lead to some increase in crop and residue yields and, therefore, an increase in the ability of each hectare of farmland to support additional TLUs. In this sense, even though more labor is required, intensification of crop-farming systems will promote crop-livestock integration through producing more crop residue for livestock, which in turn leads to more manure and increased sustenance of the soil.

*Share of livestock in farm cash income* (Table 2, col. 7)

Intensification driven by market forces is expected to lead to an increased cash income from crop and livestock but the share of crop and livestock would be expected to vary depending on the type of farm as well as where they are located. Among several options to define this dependent variable, the best fit was obtained for livestock cash income as a ratio of total farm cash income and the model explained 22 per cent of the variation in this indicator. Crop farmers had a significantly lower ratio of livestock cash income compared to mixed farmers. Among the covariates, herd size and experience as mixed farmer acted as significant modifiers: livestock cash income ratio increased with herd size and experience in mixed farming.

Compared to the LPLM domain in NGS, LPLM in NGS and HPLM domains in SS had significantly lower cash income from livestock while LPHM domain in SS had significantly higher cash income ratios from livestock.

Normally, higher share of livestock in cash income would be expected as one moves toward high market access situations. Okike (2000) show that income from livestock and its products account for 12.2 per cent of gross income in the area, the highest (21.8%) being in the LPLM domains and lowest (4.2%) in the HPHM. They further showed that this decline in HPHM domain happened without a decline in the absolute income of each household from livestock and its products. It means that the widening of the gap in the contributions of crop and livestock to household income is more due to higher returns from higher value crops rather than due to a decline in returns from livestock and its products. The challenge is to match high value crops in the farming systems with high performance of animals that produce milk as a high value animal product.

Boosting income from the livestock component with increased intensification is a desirable goal as it retains farmers' interest in both the crop and livestock components and encourages the implied sustainable use of natural resources. This increase will come more easily from policies that improve the output of livestock products e.g. milk - which is in high demand and must be sold quickly, rather than from policies that seek to encourage sale of live animals, which perform several functions on farm – manure, store of value, security.

## Summary and conclusions

Generally population pressure and market access are considered as principal drivers of agricultural intensification and crop-livestock interaction in sub-Saharan Africa. Intensification is manifested mainly in increased intensity in the use of inputs. In this paper, it is hypothesized that ecology, market access and population pressure and their interactions determine the form and pace of agricultural intensification and crop-livestock interaction. The results based from a survey of 559 stratified sample farms from the Sudan savanna and Northern Guinea savanna zones of Nigeria confirm the hypothesis.

The degree of intensification is generally higher in the SS than in the NGS and this occurs principally through increased intensity in the use of land, manure, and labor followed by increased intensity in the use of commercial inputs and cash income orientation. Although resource use intensity is higher in the drier SS zone compared to the better rainfall endowed NGS, the intensification rate in the SS may be limited by diminishing productivity of inputs under moisture stress conditions. This implies that different technological options and opportunities, such as soil moisture and fertility management, crop variety and management regimes, optimal fertilizer and other input rates, need to be developed and disseminated to promote intensification for optimal economic outcomes in the two agroecological zones.

The results show the following implications for technology dissemination, adoption, and better farm management:

- Mixed (crop-livestock) farming improves the chances of higher land use intensity in terms of longer cycles of continuous cropping before fallow. In the face of shrinking land per capita due to rapid population increases, mixed farming provides a better option than either crop-based or livestock-based farming to increase the number of years of continuous cropping. This has the advantage of sustaining yields over longer periods of time and saving the costs of land clearing required after fallow.
- The intensity of labor use increases with agricultural intensification and in terms of labor for soil fertility maintenance, the use of livestock manure may be labor-saving compared to the use of chemical fertilizers at early stages of intensification. This is especially true for mixed farms where uniform manure application is simply achieved by rotating the kraaling location of the animals around the farm compared to chemical fertilizer application that requires direct human labor.
- As agricultural intensification occurs and livestock-for-land exchanges take place, less ‘excess’ manure will become available from livestock-based farms whose own needs will increase in response to their increasing farm size. This means that traditional exchanges of manure-for-crop residues, which used to occur on other farmers’ plots—to the advantage of crop-based farmers—will decline. Crop farmers are likely to be faced with the choice of acquiring livestock or depending more on chemical fertilizers, live or dead mulching, agro-forestry, etc. for maintaining soil fertility.
- The use of animal traction appears to be a recognized technology among farmers to supplement or substitute human labor. At the moment, it appears too expensive—requiring long years of capital accumulation—to be taken up spontaneously by farmers who realize its potentials. Increasing the probability and intensity of uptake of this technology may need credit support to farmers.
- Livestock stocking rates to support the levels of nutrient cycling and natural resource management that depend entirely on manure application and crop residue utilization by livestock on the same farm are yet to be attained in the study area. This likely to

be limited by the low levels of moisture and its consequent effect on quantity of available biomass to support higher stocking rates. As a result, all farmers including owners of large herds applied chemical fertilizers. In this situation, the use of other methods of soil fertility maintenance than livestock manure, especially chemical fertilizers - that give quick results, are likely to continue into the foreseeable future. However, the indication from this study is that mixed farmers will be less distressed to reach out for other sources than crop-based farmers.

- Decreasing herd sizes among livestock farming households and increasing herd sizes among originally crop farming households in both agroecological zones indicate that greater crop-livestock interaction and integration occur as intensification increases. In fact, it points to the emergence of mixed farming enterprises owned and managed by single farming households rather than the interaction of separate crop and livestock farming households induced mostly by the benefits of manure, crop residue and animal traction.
- Among mixed farmers, the relative contribution of livestock to farm revenue may decline due to the increasing contribution from high value crops if not matched by corresponding increase in high value livestock products such as milk.

It can be concluded from the results of this study that in the savanna zones of Nigeria, agricultural intensification—as an imperative rather than an option—is occurring and evolving proactively and also in response to rapidly increasing population and urbanization and the expansion in market opportunities that accompany them. The processes of agricultural intensification involving changes in the intensity of use of labor, land, capital, managerial skills and knowledge are leading to the convergence of previously separated crop and livestock farming enterprises into single, functionally united crop-livestock farms under the management of single household units. Mixed farming (crop-livestock integration) is emerging as holding the greatest potential for sustainable agricultural intensification in the savanna zones of West Africa exemplified by the case of Nigeria.

Improving market access for products and inputs will facilitate these processes of agricultural intensification. It is equally important that high value livestock production is promoted to balance the contribution of crop and livestock components to the farm unit, in order to retain the interest of farmers in crop-livestock integration and sustainable farming. The emergence of mixed farms will have the added advantage of reducing the bloody conflicts that regularly occur between pastoralists and crop farmers over crop damage and access to feed resources.

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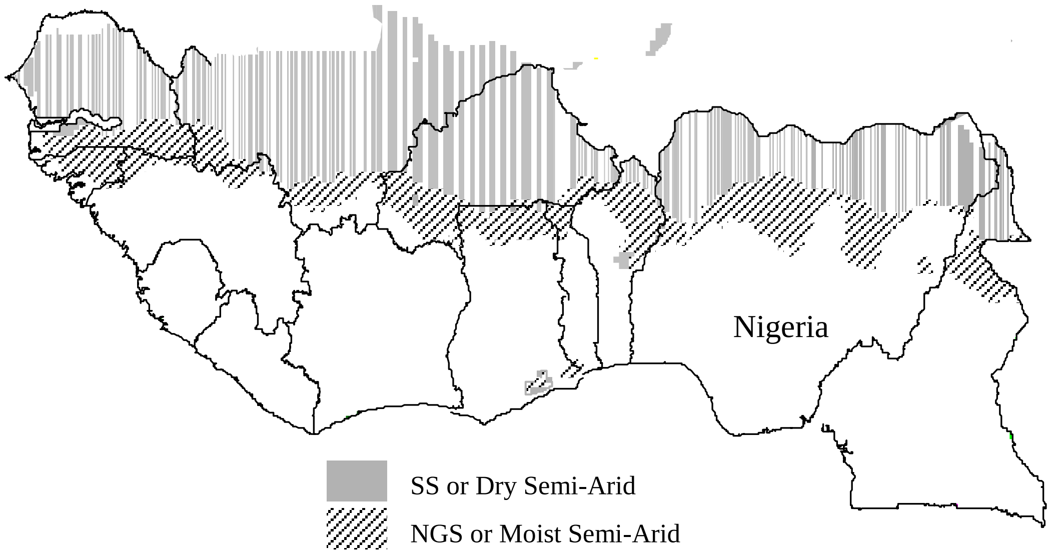


**Figure 1: Northern Guinea and Sudan Savanna agroecological zones of West Africa**

Table 1: Description of household and farm characteristics in the northern Guinea savanna (NGS) and Sudan savanna (SS) agroecological zones of Nigeria.

| **Variables** | **NGS** *n* **= 253** | **SS** *n* **= 306** | **Average** | **t-test (sig.)** |
|---|---|---|---|---|
| Age of head of household (years) | 42.4 | 44.9 | 43.8 | 0.005 |
| Household size (no. of persons) | 9.9 | 11.5 | 10.7 | 0.006 |
| Experience of head of household as mixed farmer (years) | 14.5 | 22.4 | 18.9 | 0.000 |
| Farm size (ha) | 5.2 | 6.3 | 5.8 | 0.128 |
| Average distance to farms from homestead (km) | 1.6 | 1.6 | 1.6 | 0.847 |
| Land use intensity (no. of cycles of continuous cropping) | 9.4 | 22.9 | 17.1 | 0.000 |
| Crop labour (person days/ha) | 73.0 | 81.4 | 77.6 | 0.249 |
| Proportion of household labour in total farm labour (%) | 59.3 | 66.4 | 63.2 | 0.009 |
| Qty of manure (kg/ha) | 494.3 | 467.0 | 479.4 | 0.802 |
| Qty of chemical fertilisers (kg/ha) | 175.6 | 206.4 | 192.5 | 0.786 |
| Livestock owned (TLU) | 5.4 | 7.0 | 6.3 | 0.181 |
| Distance from homestead to watering point (km) | 0.5 | 0.8 | 0.7 | 0.366 |
| Animal traction per season (days) | 11.5 | 6.1 | 8.5 | 0.016 |
| Livestock labour (person days/TLU) | 14.5 | 8.1 | 11.0 | 0.037 |
| Livestock density (TLU/ha/household) | 2.9 | 2.4 | 2.6 | 0.419 |
| Expenditure on crop residues (Naira/yr) | 461.9 | 893.8 | 698.3 | 0.012 |
| Other capital investment (Naira) | 12691.3 | 14665.2 | 13771.8 | 0.610 |
| Farm revenue (Naira/ha) | 29270.4 | 21169.2 | 24834.4 | 0.281 |

*The exchange rate at the time of the fieldwork was Naira 85 to US$ 1.

Source: Field survey

Table 2: Factors influencing selected indicators of agricultural intensification and crop-livestock interaction

| | Table 6, col.1 | Table 6, col.2 | Table 6, col.3 | Table 6, col.4 |
|---|---|---|---|---|
| | Indicators of intensification and C-L interaction | | | |
| Factors and Covariates | Land use intensity (no of cropping cycles before fallow) | Labor intensity (person days/ha) | Manure per hectare (kg/ha) | Animal traction (days/ha) |
| | Coefficient (s.e.) | Coefficient (s.e.) | Coefficient (s.e.) | Coefficient (s.e.) |
| **Intercept** | 3.890 (2.163**) | 112.37(14.15***) | 11.659 (192.8) | 268.27 (34.709***) |
| FACTORS | | | | |
| *Socio-ecological Domains* | | | | |
| NGS LPLM | 0.000 | 0.000 | 0.000 | 0.000 |
| NGS HPLM | -4.891(1.855***) | 25.825 (14.294*) | -368.7 (239.816) | -6.373 (1.192***) |
| NGS LPHM | 0.805 (1.924) | 0.924 (14.767) | 102.9 (171.8) | -5.829 (1.255***) |
| NGS HPHM | 0.564 (1.944) | 12.357 (14.902) | 236.8 (177.1) | -4.098 (1.275***) |
| SS LPLM | 7.260 (1.808***) | 17.393 (13.907) | 293.3 (170.6*) | -4.634 (1.226***) |
| SS LPHM | 4.325 (2.067**) | -0.831 (14.374) | 457.2 (181.1***) | -5.275 (1.237***) |
| SS HPLM | 8.765 (1.879***) | 26.328 (14.332*) | 356.9 (174.9**) | -7.447 (1.180***) |
| SS HPHM | 20.101 (1.965***) | 23.394 (17.322) | 250.6 (203.9) | -7.968 (1.210***) |
| *Farm types* | | | | |
| Mixed farmer | 0.000 | 0.000 | 0.000 | 0.000 |
| Livestock farmer | -0.587 (1.613) | -32.923 (13.453**) | 120.38 (128.7) | -1.922 (1.028*) |
| Crop farmer | -0.150 (1.192) | -22.439 (9.141***) | -2300 (407***) | -1.380 (0.673**) |
| COVARIATES | | | | |
| Farm size/caput (ha) | 2.425 | -71.343 | -257.2 | -403.522 |

| | | | | |
|---|---|---|---|---|
| | (1.202**) | (8.666***) | (112.6**) | (53.331***) |
| Farm size/caput$^2$ (ha) | -0.272 (0.119**) | 5.671 (0.879***) | 23.67 (10.77**) | 34.133 (4.513***) |
| Manure (kg/ha) | 0.0006 (0.000***) | -0.011 (0.002***) | - | - |
| Chemical fertilizers (kg/ha) | 0.001 (000***) | 0.009 (0.003***) | -0.007 (0.031) | - |
| Livestock (TLU/ha) | 0.533 (0.223***) | 13.920 (1.526***) | 104.26 (49.33**) | -91.712 (12.196***) |
| Livestock (TLU/ha)$^2$ | -0.006 (0.004*) | -0.124 (0.025***) | 26.42 (1.85***) | 1.269 (0.169***) |
| Crop Labor (person days/ha) | 0.016 (0.006***) | - | -3.199 (0.945***) | -5.623 (0.746***) |
| Livestock Labor (person days/ha) | 0.018 (0.013) | - | - | -2.368 (0.313***) |
| Animal traction dummy (User =1) | 1.113 (1.059) | -9.958 (8.097) | 110.354 (96.538) | - |
| Experience as mixed farmer (yrs) | 0.303 (0.037***) | 0.121 (0.296) | -14.447 (6.143**) | 2.564 (0.337***) |
| Land use intensity (no of cropping cycles.) | - | 0.458 (0.298) | 11.270 (4.881**) | - |
| Other capital investments (Naira/ha) | - | - | 0.007 (0.003**) | 0.157 (0.021***) |
| $R^2$ | 0.48 | 0.44 | 0.48 | 0.23 |

Table 2 (contd.)

| | Table 2, col. 5 | Table 2, col. 6 | Table 2, col. 7 |
|---|---|---|---|
| | Indicators | | |
| Factors and Covariates | Chemical fertilizers per hectare (kg/ha) | Tropical Livestock Unit per hectare | Cash income from livestock/gross income |
| | Coefficient (s.e.) | Coefficient (s.e.) | Coefficient (s.e.) |
| **Intercept** | 484.685 (207.9**) | 2.323 (1.152**) | 0.209 (0.062***) |
| FACTORS | | | |
| *Socio-ecological Domains* | | | |
| NGS LPLM | 0.000 | 0.000 | 0.000 |
| NGS HPLM | -502.3 (229.8**) | -0.470 (1.150) | -0.113 (0.061*) |
| NGS LPHM | -2941.6 (481.5***) | 1.850 (1.211) | 0.010 (0.065) |
| NGS HPHM | 470.2 (235.6**) | -1.056 (1.210) | -0.078 (0.064) |
| SS LPLM | 1062.9 (275.2***) | -0.741 (1.145) | 0.165 (0.060***) |
| SS LPHM | 1285.5 (296.5***) | -1.160 (1.160) | 0.132 (0.062**) |
| SS HPLM | -131.7 (224.8) | -0.628 (1.154) | -0.159 (0.062***) |
| SS HPHM | -1211.8 (301.5***) | -0.212 (1.203) | 0.053 (0.064) |
| *Farm types* | | | |
| Mixed farmer | 0.000 | 0.000 | 0.000 |
| Livestock farmer | -8690 (1238***) | 7.201 (0.873***) | 0.097 (0.052*) |
| Crop farmer | -1611 (252***) | -2.155 (0.653***) | -0.015 (0.036) |
| COVARIATES | | | |
| Farm size/capita (ha) | 41.882 (8.787***) | -1.484 (0.723**) | -0.084 (0.039**) |
| Farm size/capita$^2$ (ha) | - | 0.104 (0.072) | 0.006 (0.004*) |
| Manure (kg/ha) | -0.024 (0.047) | - | - |
| Chemical fertilizers (kg/ha) | - | 0.0000 (0.000) | 0.00002 (0.000) |

| | | | |
|---|---|---|---|
| % of land with crop legume | 501.11 (215.1***) | -2.271 (1.052**) | -0.086 (0.057) |
| Livestock (TLU/ha) | 968.3 (139.5***) | - | 0.022 (0.006***) |
| Livestock $(TLU/ha)^2$ | - | - | -0.0002 (0.000**) |
| Crop Labor (person days/ha) | 14.180 (2.357***) | 0.013 (0.004***) | -0.0003 (0.000) |
| Livestock Labor (person days/ha) | 30.517 (3.496***) | -0.27 (0.008***) | 0.0008 (0.000*) |
| Experience as mixed farmer (yrs) | -112.970 (16.209***) | 0.109 (0.023***) | 0.003 (0.001***) |
| Land use intensity (no of cropping cycles) | 0.013 (0.004***) | -0.090 (0.035***) | - |
| Other capital investments (Naira) | - | 0.00004 (0.000**) | 0.0000 (0.000) |
| $R^2$ | 0.20 | 0.31 | 0.22 |

Note: NGS = Northern Guinea Savanna, SS = Sudan Savanna, LPLM = low-population-low-market, LPHM = low-population-high-market, HPLM = high-population-low-market, HPHM = high-population-high-market.

For covariates ***, **, * indicate *t* values significant at 1, 5, and 10% levels.  For categories in factors, **, * indicate that the coefficient of that category is significantly different from the base category in the factor, based on Joint Univariate 0.95 and 0.90 Bonferroni interval.

Table 3: Proportion of Farms Using Manure, Fertilizer and Animal Traction by Socio-ecological Domain and Farm Type

| **Socio-ecological Domain and Farm Type** | ***% Farms using*** | | |
|---|---|---|---|
| | ***Manure*** | ***Fertilizer*** | ***Traction*** |
| NGS LPLM | 64 | 67 | 81 |
| NGS LPHM | 86 | 80 | 59 |
| NGS HPLM | 42 | 92 | 34 |
| NGS HPHM | 80 | 91 | 86 |
| **NGS** | **66** | **83** | **63** |
| SS LPLM | 94 | 33 | 81 |
| SS LPHM | 94 | 41 | 82 |
| SS HPLM | 98 | 80 | 31 |
| SS HPHM | 83 | 97 | 21 |
| **SS** | **93** | **62** | **54** |
| Crop farms | 76 | 79 | 53 |
| Livestock farms | 89 | 43 | 77 |
| Mixed farms | 93 | 65 | 61 |
| **All farms** | **81** | **72** | **58** |

Source: Field survey

Table 4: Distribution of Farms According to Combination of Manure, Fertilizer and Traction Use by Socio-ecological Domain and Farm Type

| Socio-ecological domain and farm type | % farms using input type and combination by domain and farm type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No input | M only | F only | T only | M + F | M + T | F + T | M + F + T |
| NGS LPLM | 6 | 5 | 6 | 6 | 11 | 16 | 17 | 33 |
| NGS LPHM | 3 | 12 | 7 | 0 | 39 | 5 | 3 | 31 |
| NGS HPLM | 4 | 1 | 42 | 1 | 31 | 1 | 11 | 8 |
| NGS HPHM | 0 | 0 | 11 | 2 | 18 | 7 | 7 | 55 |
| **NGS** | **4** | **4** | **18** | **2** | **25** | **7** | **10** | **30** |
| SS LPLM | 1 | 18 | 1 | 4 | 12 | 44 | 0 | 20 |
| SS LPHM | 0 | 20 | 0 | 3 | 16 | 37 | 3 | 23 |
| SS HPLM | 1 | 15 | 1 | 0 | 65 | 4 | 0 | 14 |
| SS HPHM | 1 | 0 | 14 | 0 | 65 | 1 | 1 | 17 |
| **SS** | **1** | **13** | **4** | **2** | **40** | **22** | **1** | **18** |
| Crop farms | 3 | 5 | 13 | 2 | 33 | 10 | 6 | 26 |
| Livestock farms | 0 | 15 | 3 | 4 | 23 | 38 | 4 | 14 |
| Mixed farms | 1 | 19 | 5 | 0 | 38 | 16 | 2 | 20 |
| **All farms** | **2** | **9** | **10** | **2** | **33** | **15** | **5** | **23** |

Note: definition of domains as in Table 2
M = Manure, F = Fertilizer, T= Traction

Source: Field survey

Table 5: Distribution of Farms According to Sources of Manure by Socio-ecological Domain and Farm Type

| Socio-ecological domain and farm type | ***% farms by sources of manure by domain and farm type*** | | | |
|---|---|---|---|---|
| | ***None*** | ***Own*** | ***Purchase*** | ***Own + purchase*** |
| NGS LPLM | 36 | 61 | 0 | 3 |
| NGS LPHM | 14 | 83 | 0 | 3 |
| NGS HPLM | 58 | 36 | 3 | 3 |
| NGS HPHM | 20 | 68 | 0 | 12 |
| **NGS** | **34** | **60** | **1** | **5** |
| SS LPLM | 6 | 77 | 1 | 16 |
| SS LPHM | 6 | 66 | 0 | 28 |
| SS HPLM | 2 | 73 | 5 | 20 |
| SS HPHM | 17 | 61 | 3 | 19 |
| **SS** | **7** | **70** | **2** | **21** |
| Crop farms | 25 | 60 | 2 | 13 |
| Livestock farms | 11 | 84 | 1 | 4 |
| Mixed farms | 7 | 69 | 1 | 23 |
| **All farms** | **19** | **65** | **2** | **14** |

Note: definition of domains as in Table 2

Source: Field survey

Table 6: Distribution of Farms According to Sources of Draught Power by Socio-ecological Domain and Farm Type

| Socio-ecological domain and farm type | ***% farms according to source of draught power by production domain and farm type*** | | |
|---|---|---|---|
| | ***None*** | ***Own*** | ***Hired*** |
| NGS LPLM | 19 | 41 | 40 |
| NGS LPHM | 41 | 37 | 22 |
| NGS HPLM | 66 | 18 | 16 |
| NGS HPHM | 14 | 38 | 48 |
| **NGS** | **37** | **32** | **31** |
| SS LPLM | 19 | 37 | 44 |
| SS LPHM | 18 | 52 | 30 |
| SS HPLM | 69 | 21 | 10 |
| SS HPHM | 79 | 4 | 17 |
| **SS** | **46** | **29** | **25** |
| Crop farms | 47 | 25 | 28 |
| Livestock farms | 23 | 42 | 35 |
| Mixed farms | 39 | 38 | 23 |
| **All farms** | **42** | **30** | **28** |

Note: definition of domains as in Table 2

Source: Field survey

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