Spatial Variability: Perceptions, Practices and Implication on Sustainability of Soil Fertility Management by Smallholder Farmers in a Semi-Arid Area of Zimbabwe.

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Abstract

The study investigated smallholder household characteristics and their soil fertility resource allocation to different arable niches and discussed their implications for sustainable management in a typical semi-arid communal area of Zimbabwe. Results showed that socio-economic circumstances of smallholder farmers were so diverse that application of nutrient inputs largely depended on availability of resources and their perception of niche fertility. Relatively rich households concentrated organic amendments in homestead surroundings and open areas of sandy patches but showed little selection of niches when applying inorganic inputs. Most of the poor households applied leaf litter and chicken manure in open sandy patches and could not afford high quantities of cattle manure and basal inorganic fertilizers. The medium wealth category mainly applied composts in homestead surroundings and open sandy patches. Resource allocation for sustainable soil fertility management was conspicuously a major challenge especially were there was no comprehensive and systematic application in similar niches. Deliberate or inadvertent resource allocation to niches contributed to pronounced soil fertility gradients within smallholder farming systems where niches like termitaria environments and open sandy patches hinted at nutrient mining. Homestead surroundings had potential to sustain agricultural production. It is recommended that development agents and researchers focus on programmes that improve the resource base of smallholder farmers such as livestock, implement ownership and effective support services as modest external inputs are essential. These strengthen the capacity of smallholder farmers to manage their arable environments sustainably.

Keywords: Farmer perception; Niches; Smallholder farmers; Socio-economic; Soil fertility resources. Soil fertility management

Introduction

Traditional methods of agriculture practised by smallholder farmers in most parts of the tropics and sub-tropics are blamed for low crop yields and often condemned as wasteful and destructive of the natural resources (Webster and Wilson, 1980). On the contrary, some studies reveal that smallholder farming systems appear to be dynamic and keep evolving with gradual adoption, to some extent, of 'new' technologies that improve agricultural productivity and are benign to the environment (Tomlow and others, 1995; Kumwenda and others, 1995).

The biophysical factors, among others, impose challenging scenarios to the smallholder farmer especially where infield soil variability occurs in arable lands accompanied with declining soil fertility. Farmers' fields in the communal areas are not always homogeneous though most researchers have ignored in-field soil variability. Brinn and Black (1993), pointed out that land micro-variability is widespread in semi arid regions of Africa and has a major effect on crop yields in areas of marginal rain and low soil fertility. Soil variability is associated with topography and soil type (topo-sequence of soil types and degradation intensities), physical discontinuities (rocky outcrops, swamps, valley bottoms, hillsides), distance from the homestead and/or from livestock facilities. This variability is normally perceived through crop performance in terms of growth, plant density, weed infestation, pests and diseases and may drive farmers' decisions in terms of resource allocation (Pablo, 2003). Though soil variability has been seen as a problem affecting soil surveys and their interpretation and causes within field crop growth variation which can reduce farmers' yields and complicates the interpretation of agronomic experiments (Brouwer and others, 1993), it is at this level where soil fertility gradients become relevant at showing the consequences of short and long-term management effects of smallholder farmers and helps to explain crop growth variability.

Despite soil variability, the availability of different mixes of opportunities to different farming families to ameliorate agricultural production becomes influenced to a large extent by asset holdings, *inter alia,* income earning potentials, social networks, labour availability, technology input availability and own farming skills (Chibudu and others, 2001). These conditions lead to different approaches to agricultural practices that encompass different soil fertility management strategies within and across farms and consequently have different impacts on soil fertility.

Amidst the highlighted complex factors influencing the smallholder farmers, soil fertility decline was shown to be one major factor with dominant and unfavourable effects in tropical and sub-tropical smallholder agriculture systems contributing to threatened livelihoods (Grant 1981; Scoones and Toulmin, 1999; Kumwenda and others, 1995). Both farmers and researchers are seeking solutions to alleviate undesired effects of declining soil fertility through use of improved technologies and better management of resources. A range of input resources for soil fertility management was indicated to be accessible and in use by smallholder farmers (Carter and others, 1993 1995; Scoones, 1996; Scoones 2001). However, there is a paucity of information on soil fertility management in common niches found in smallholder farming systems in relation to prevailing socio-economic circumstances of farmers. The information contributes insights in the quest for practical options for smallholder farmers not only to improve soil fertility and productivity but to ensure sustainable management. Therefore, the objective of this study was to characterize households and determine their soil fertility resource management and implications for sustainable management in spatially variable arable environments.

Materials and Method

Study area description

The study was conducted in Mutoko communal areas in Mashonaland East province in the North Eastern area of Zimbabwe, centred on 17 20'S and 32 20'E. Much of the communal area is in Agro-ecological Region 4 (<500 mm annual rainfall) with a portion of Agro-ecological Region 3 (600- 650 mm annual rainfall) in the southwest. The communal area is suitable for semi-intensive and semi-extensive agriculture based on livestock production (Brinn, 1986). Annual rainfall ranges have a coefficient of variation of about 30 %. Much of the study area is underlain by granitic rocks of the Basement Complex with scattered and localized intrusions of dolerite (Stagman, 1978). The soils are predominantly granite-derived, coarse grained, sands of low inherent fertility that are mainly used for dryland cropping of maize. Other crops grown are pearl millet, finger millet, groundnuts and to a small extent, sunflower and cotton (Ashworth, 1990). The average arable area per household is two hectares. Farmers traditionally rear cattle, goats, sheep and pigs. Mangoes (*Mangifera indica* L.) and market gardening contribute significantly to the local economy. The characteristics of the communal area are typical of most smallholder farming areas in the tropics and subtropics.

Data collection and analysis

Structured interviews, key informants, focus group discussions together with a formal questionnaire survey were tools for data collection in three adjacent villages of Charewa ward in Mutoko communal area. Purposive random sampling was used to select 84 households that had visually conspicuous soil fertility niches in arable fields identified together with farmers during preliminary surveys. The most prevalent niches identified were homestead surroundings, temitaria environments, under *Parinari curatellifolia* and open areas of sandy patches. The questionnaire was first pre-tested with five respondents in each village in order to test the validity of the questions before administration. Overall, questions sought to ascertain household characteristics their perceptions and preferences, acquisition and application of amendments to different niches.

The data were synthesized and where appropriate analysed using descriptive statistics. Percentages, cross-tabulations and correlations were used to investigate variables and their associations. Ranked data for matched measurements were analysed using Wilcoxon's signed rank test.

Principal components analysis was used to generate a wealth index, a composite variable that comprised variables that were accepted by farmers as indicators of wealth in the study area. These variables included number of people in formal employment at homestead, financial assistance, hiring of casual labour, type of house, ownership of livestock and of implements The index was divided into three categories namely, the poor, medium and rich wealth classes. Wealth classes were analysed for the use of organic and inorganic amendments in different niches.

Results

Household characteristics

The study area had 51 % (n=437) of the people below the age of eighteen years while only 13 % were above 55 years. Thirty six percent of the people were between 18 and 55 years. The marital status of household heads were significantly different ($p < 0.001$), with married household heads constituting about three quarters of the total number of households while a third were single. The single household heads were either male or female with dead, divorced or separated spouses. The average household size consisted of 5 people. A wide period of residence, spanning 70 years, was noted with about 55 % of households established before independence in 1980. The post independence era had a higher rate of establishment with 19% of households established in the 5year period before the year 2000.

Two people per household aged 18 or more provided effective labour. Effective labour was largely contributed by the 30-55 age group (38%) followed by the 18-30 age group (33 %). Generally, farmers considered children less than 18 years as not contributing effective labour since some were too young to work and others attended school and were only available on Saturdays and Sundays.

Financial assistance and casual labour

The number of household members in gainful employment ranged from one to three, with an average of one for the majority of families. No family member was gainfully employed in 39 % of the households. From the study, external financial assistance from working family members differed significantly (X^2=7.41 df=2 $p<0.05$). About half the households irregularly received financial assistance while 28% received most of the time. The remainder, though with members in gainful employment, did not receive any financial assistance at all.

Sixty percent of households, including half the households without any member in gainful employment, could hire casual labour and paid for it either in cash or kind. Households that could not hire labour had nothing to offer as payment.

Cattle and Implements Ownership

Cattle were owned by 64 % (n=84) of the households with a mean of 3.6 animals. A wide variation in cattle numbers across households ranged from zero to fourteen. However, a few households kept cattle at relatives staying elsewhere and only collected the animals when draft power was needed. These households did not have somebody to herd the cattle. Other livestock like goats and pigs were owned by a few households while sheep and donkeys did not exist in the study area.

Generally, with the exception of a mould board plough owned by 74 % of households, ownership of basic farming implements was low. Farmers rarely owned cultivators. Though ox-drawn carts were commonly used for biomass transfer and delivery of bulky commodities in the area, only 17 % of households owned this type of important implement.

Association of socio-economic variables and soil fertility resource use in niches

Households that hire casual labour were significantly associated (X^2=7.664 df= 1 $p<0.01$) with those receiving external financial assistance. Again, hiring of casual labour was associated with the period of residence. Households with a longer period of residence (established before independence) hired less labour and also had significantly (X^2=7.651 df=1 $p<0.01$) more ploughs than those with a shorter residence period. These were mostly the relatively rich and medium class farmers. Significant associations existed between ownership of cattle and ownership of implements such as a plough, improvised cart and an oxcart, as expected.

Cross-tabulations showed that application of fertility amendments in all the niches was not influenced by number of family members in formal employment, reception of financial assistance, period of residence or ability to hire casual labour. Except for ownership of ploughs, no significant association existed between implement ownership and application of organic and inorganic amendments in any niche. Ownership of cattle influenced application of cattle manure in homestead surroundings and open sandy patches. It also influenced application of basal and top N dressing fertilizers in these niches. Farmers, mostly in the rich category with relatively large quantities of manure could afford inorganic fertilizers as well.

Generally for households owning cattle significant correlation existed between cattle numbers and quantities of cattle manure applied in different niches (Table 1). Stronger association occurred between cattle numbers and the quantity of manure applied in open sandy patches followed by homestead surroundings.

A significant association existed between wealth classes of farmers and the use of cattle manure in sandy patches, chicken manure in homestead surroundings, and top dressing under *Parinari curatellifolia* (Table 2).

Observed trends revealed that relatively higher percentages of households in the poor category than the corresponding percentages in other classes applied leaf litter and chicken manure in open sandy patches. Some of these households did not apply the little cattle manure available to niches under *Parinari curatellifolia*. Households in the medium wealth category had relatively the highest percentages applying compost manure in the homestead surroundings and in the open sandy patches (Table 2) as they had relatively more available labour. Except for application of cattle manure in the open sandy patches and chicken manure in the homestead surroundings, application of organic amendments by households across all wealth classes was generally lower than application of inorganic amendments. Basal inorganic fertilizer application by households in the medium and poor wealth classes was lowest in termitaria environments, under P. *curatellifolia*, and in homestead surroundings that were perceived as relatively fertile. In the rich category, the lowest percentages (25%) of households applied basal fertilizer dressing in termitaria environments followed by under P. *curatellifolia* (36%).

Application of organic and inorganic inputs in niches.

Application of amendments in niches depended on availability of the input resource, labour, farmer perception and preferences. Farmers preferred to allocate most organic and inorganic amendments to sandy patches in open field areas followed by homestead surroundings (Table 3). Termitaria environments were perceived to require the least soil fertility inputs.

In practice, monitoring of application of organic amendments revealed application mainly in open sandy patches and homestead surroundings (Table 4). Chicken manure, though in small quantities, was commonly applied in homestead surroundings. A few households (14 %) applied goat manure to open sandy patches. Most farmers apply organic amendments in spring before the start of the rainy season. Farmers who did not apply organic amendments in previous seasons highlighted a combination of lack of livestock and relatively better soil fertility as major reasons (Table 5).

Though cattle manure was deemed the most important organic resource, its unavailability limited its application and also contributed to selective application based on farmer preference. On average, farmers owning cattle had a total of 5000 kg manure per household per year. The study showed that half the households had never applied cattle manure in niches surrounding homesteads and 44 % apply after three or more seasons. Eighty one percent of households had never applied cattle manure in niches under *P. curatellifolia*. Meanwhile, in open sandy patches 37 % of households have never applied cattle manure and 56 % apply at intervals of two or more seasons.

The majority of farmers managed to buy between one and two 50 kg bags of either basal or top dressing fertilizer (Figure 1), with wealthier farmers buying more. Generally, households bought more top dressing fertilizer than basal fertilizer. Use of organic amendments such as cattle manure, composts and chicken manure helped to reduce the requirements for basal fertilizer in homestead environments. Fertilizer prices varied widely depending on the time of purchasing. Two main groups of farmers bought fertilizer at different prices. These were those who bought fertilizers early in the period May to October and those who purchased at the onset of rains in November/December. The majority of households that applied inorganic fertilizers purchased early while those who purchased from the onset of rains procured at higher prices of approximately 50%.

In all the niches, compound D (8 %N; 14 %P_2O_5; 7%K_2O) and ammonium nitrate were used as basal and N top-dressing fertilizers respectively. Most households concentrated application of inorganic fertilizers in open sandy patches and homestead surroundings (Table 4). Basal fertilizer application was based on availability and farmer perception of the niche fertility. For example, farmers indicated that open sandy patches receive more basal dressing than any other niche because the soil fertility was so low that nothing could be harvested without fertility inputs. Termitaria environments were perceived to be of high fertility and received less basal fertilizer dressing.

In applying N top-dressing fertilizer, households did not show niche selection or prioritisation in all niches except for open sandy patches where most households (86 %) applied. Maize was the only crop grown where application of either organic or inorganic amendment was done. Failure to apply fertilizers in different niches in the previous season, particularly by farmers in the poor category, was attributed to either lack of money or a perception that the soils were relatively fertile (Table 5).

Discussion

There were generally few adults that provided effective labour. In contrast to what farmers indicated, monitoring showed that more than half of the households had children below 18 years that contributed significantly to family labour requirements. These children normally help during weekends or school holidays. The ability to hire casual labour for cash in most households, despite irregular or sometimes non-existent financial aid from working members, indicated a different source of revenue. In Mutoko communal area, market gardening and sale of mango (*Mangifera indica* L.) are significant business ventures that sustain families and finance other farming activities (Brinn, 1986).

Cattle and implements ownership are the basic requisites for any farming venture. The study shows that such ownership may define the differences between sustainable farming enterprise and abject poverty. Moreover, application of nutrient input depended on the farmers' perception of soil fertility in different niches. Relatively rich farmers who owned cattle had a few other farming implements and applied substantial amounts of organic and inorganic fertilizers in homestead surroundings, open sandy patches and sometimes under *P. curatellifolia*. The majority of farmers especially those with smaller land holdings applied manure mainly in the open sandy patches. An average of 5000 kg of total available manure per household per year is clearly inadequate for improving soil fertility. According to Nyathi (1997), 10-20 t/ha of cattle manure are required to sustain crop production on sandy soils. Practically, such quantities and quality cannot be produced in smallholder farming sectors due to low livestock numbers. Whilst farmers perceived residual effects of different organic amendments and could, from experience, estimate when to apply, the question stands whether the soils would not be depleted by that time since the quality of organic amendments from such settings is generally low. As indicated by Giller and others, 1997, the quality of manure is more likely to be variable due to differences in the chemical composition of the manure, rates and frequency of application on each field. The soil fertility stalks such as organic carbon, nitrogen, phosphorus in open sandy patches may be very low and continue to decline probably leading to negative nutrient balances though farmers attempt to prime it to production.

Inadequacy or lack of cattle caused farmers to hire draught power. This constraint contributes in most cases to inopportune timing of farming activities such as late ploughing or planting of crops. Consequently, some of the farmers without cattle and mostly the poor were limited to cultivation of specific niches such as homestead surroundings that offer advantages in terms of protection, proximity and organic material inadvertently strewn around. Chicken manure was a common resource mainly applied to homestead surroundings by most households.

Smallholder farmers in the study area were aware of the positive effects of leaf litter on crops as reported in other studies (McGregor, 1994; Wilson, 1989; Hulugalle and Ndi, 1993). Most farmers perceive soil fertility and hence crop yield to be relatively higher under *P. curatellifolia* than in open sandy patches. This was revealed by application of small quantities of inorganic fertilizers under scattered trees that occur in cropland. This practice provides an important cue towards sustaining soil fertility through integration of organic and inorganic resources. However, very few farmers including those with no alternative resources collected leaf litter from woodlands. Those who collected generally applied in open sandy patches. The limit to quantities of litter used by households was most likely set by amounts available in woodlands, labour constraints, access to means of transport and availability of alternatives. In such a scenario agriforestry practices may provide opportunities for reducing some of the limitations.

Most farmers took advantage of the relatively higher fertility of termitaria environments by not applying any organic inputs. This practice reduces organic matter stalks and leads to serious nutrient mining if continued over time. The ultimate scenario might resemble cases where termitaria soils had no comparative advantage in fertility over the adjacent flat areas (Griffioen and O'Connor, 1990; Hulugalle and Ndi, 1993), a far cry from sustainable management. Continued application of organic inputs and improvement of water availability by conservation structures on termitaria environments may maintain soil fertility.

Inorganic fertilizers were increasingly becoming unaffordable to most communal farmers as evidenced by ever escalating prices in a single growing period and limited quantities purchased. If blanket fertilizer recommendations for maize production of 150 kg/ha compound D and 100 kg/ha ammonium nitrate in Agro-ecological Region IV (Twomlow and others, 1995) were followed, quantities bought by farmers were noticeably insufficient and contributed to selective application in niches especially of basal fertilizer generally not applied under P. *curatellifolia* and termitaria environments. As Campbell and others (1998) pointed out, alternative management strategies for organic residues and mineral fertilizers need to be integrated through timing of amendment placement and changing the combinations of these amendments in different niches basing from farmer perceptions.

Some households within the poor category found farming a formidable challenge and their future in it, from a subjective perspective, is bleak. Such households do not apply any fertility amendments in niches and lack basic farming implements. Probably these households survive on other non-farming activities and constitute the majority of the rural poor. In a study by Campbell and others, (1995), similar households, in an effort to meet food security, were engaged in a range of complimentary and sometimes competing strategies for survival. The strategies included provision of casual local employment, more permanent off-farm wage employment, gathering, reciprocal relations with neighbours and dependence on off-farm family members.

The study showed that the main challenge faced by the majority of farmers who desired to improve the low inherent productivity of some niches like open sandy patches was clearly limited access to the required inputs and appropriate farming implements attributable to unfavourable economic conditions. The fertility management of niches by these farmers appears to have been based on individual perceptions, priorities and risk assessment as observed by Carter and Murwira, (1995) and Chibudu and others, (2001). Part of risk minimization by farmers was making decisions on the type of niche to concentrate the scarce soil fertility inputs only after observing the nature of the season. Exploiting fertile niches and enriching or depleting relatively poor ones in order to respond to variation in soil type, changing soil moisture and nutrients is a general strategy smallholder farmers use to minimise risk. However, these decisions impact on soil fertility by gradual development and assertion of soil fertility gradients. Sustainable niche management becomes an intractable challenge especially where there is no comprehensive and systematic management of soil fertility in similar niches.

Conclusion

The study showed that the socio-economic circumstances of farmers and their farming environments were diverse. There is no uniform management of soil fertility in similar niches due to a mix of different perceptions, opportunities and constraints posed by a broad web of socio-economic and biophysical factors. Quantities of nutrient inputs were usually low and may indicate gross nutrient mining. In addition to pedogenic factors, anthropogenic ones further contribute to differential soil fertility gradients bearing importance on sustainable use.

The study calls for developments agents and researches to deliberately focus on strengthening the capacity of farmers to manage their arable environments sustainably as modest external inputs are essential. Since poverty is mainly the underlying factor in poor management of some of the niches by smallholder farmers, deliberate programmes that aim to improve the resource base of farmers such as livestock and implement ownership, and effective support services to improve access to fertilizers need to be pursued.

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Table 1. Correlation between cattle numbers and quantities of manure applied in niches.

Niche type	Correlation coefficient (tau b, Kendall)	Sig.
Homestead surroundings	0.309	**
Under P. *curatellifolia*	0.289	*
Open sandy patches	0.401	**

**=p< 0.01 *=p< 0.05

Table 2. Percentage households in a wealth class applying different amendments in various niches. (The percentages are not mutually exclusive.)

Amendment and niche applied	WEALTH CLASS Rich (n = 28)	Medium (n = 28)	Poor (n = 28)	Sign.
CMHs	25	25	7	
CMuP	18	11	0	
CMSa	71	54	21	***
LLHs	0	7	7	
LLSa	14	18	21	
CPHs	18	21	18	
CPSa	14	25	18	
CHHs	75	43	68	*
CHSa	18	21	25	
BDHs	61	36	39	
BDTm	25	18	11	
BDuP	36	39	21	
BDSa	71	57	71	
TDHs	82	64	61	
TDTm	79	61	61	
TDuP	85	68	50	*
TDSa	86	70	60	

*** = p < 0.001 * = p<0.05

Key
Amendment
CM= Cattle manure CP = Compost CH = Chicken manure
LL = Leaf litter BD = Basal dressing fertilizer TD = Top dressing fertilizer
Niche
Hs = Homestead surroundings uP = Under P. curatellifolia Sa = open sandy patches
Tm = termitaria environments

Table. 3. Wilcoxon signed rank test of farmer preference of niche in applying organic and inorganic amendments.

NICHES COMPARED	Z-Value	PREFERRED NICHE
Organic amendments		
Under P. c*uratellifolia* vs Homestead surroundings	-2.324	Homestead surroundings
Open sandy patches vs Homestead surroundings	-4.881	Open sandy patches***
Open sandy patches vs Under P. *curatellifolia*	-3.640	Open sandy patches***
Inorganic amendments		
Homestead surroundings vs Termitaria	-5.902	Homestead surrounding ***
Under P. *curatellifolia* vs Homestead surroundings	-5.505	Homestead surroundings***
Open sandy patches vs Homestead surroundings	-5.303	Open sandy patches***
Under P. *curatellifolia* vs Termitaria	-2.262	Under P. *curatellifolia**
Open sandy patches vs Termitaria	-6.878	Open sandy patches***
Open sandy patches vs Under P. *curatellifolia*	-7.118	Open sandy patches***

Z- value is the test statistic approximately normally distributed and is often the ratio of an estimate to its standard error.

***= $p<0.001$ *= $p< 0.05$

Table. 4. Average percentage of households applying inputs in niches. (n=84). (Percentages are not mutually exclusive)

Resource	NICHE TYPE			
	Homestead surroundings	**Termitaria environments**	**Under P. *curatellifolia***	**Open sandy patches**
Cattle manure	19	0	10	49
Goat manure	6	0	2	14
Leaf litter	5	0	0	18
Compost	19	0	0	19
Chicken manure	62	0	0	21
Basal fertilizer	45	18	32	67
Top N dressing fertilizer	69	67	68	86

Basal fertilizer: (8 % N; 14% P_2O_5; 7% K_2O) Top N dressing fertilizer: (34.5% NH_4NO_3)

Table. 5. Average percentage of households citing major reasons for not applying basal and top dressing fertilizers in niches.

BASAL APPLICATION			N-TOP DRESSING	
Niche type	**Major reason**	**% Hhold**	**Major reason**	**% Hhold**
Homestead surroundings		**(n=46)**		**(n=25)**
	-Lack of money	78	-Lack of money	68
	-Residual effect of organics	9	-Soil is fertile	24
	-Soil is fertile	9		
Termitaria environment		**(n=69)**		**(n=28)**
	-Soil is fertile	67	-Soil is fertile	68
	-Lack of money	19	-Lack of money	29
	-Fertilizer burns crop	12		
Under *P. curatellifolia*		**(n=57)**		**(n=27)**
	-Soil is fertile	53	-Soil is fertile	44
	-Lack of money	37	-Lack of money	48
Open sandy patches		**(n=28)**		**(n=12)**
	-Lack of money	86	Lack of money	92
	-Late delivery	7	late delivery	8

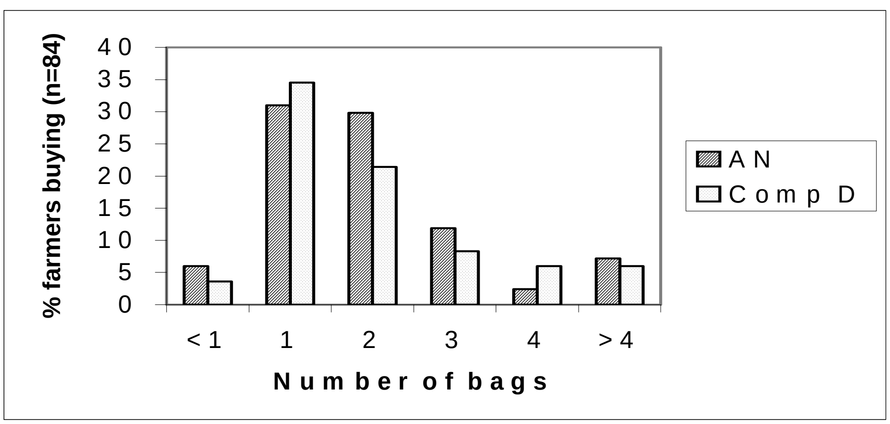

Figure. 1 Average bags of fertilizer bought per households over 3 seasons.