Exploitation of Spatial Heterogeneity for Food Security by Smallholder Farmers in a Semi-Arid Area of Zimbabwe

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Abstract

Agriculture by smallholder farmers in Zimbabwe is influenced by biophysical, socio-economic and political factors. Despite the land reform program initiated in the year 2000, the majority of smallholder farmers are still in adverse semi arid areas characterised by risk, uncertainty and spatially heterogeneous arable environments. Farmers in such environments have developed a range of risk-averse practices to increase the probability of a yield every growing season. The objective of this study was to determine smallholder farmers' exploitation of spatial heterogeneity as a food security strategy. The study was conducted in Mutoko Communal Area, a typical semi arid area of Zimbabwe. Purposive sampling was used to select 84 households with conspicuous soil fertility gradients (niches) in arable areas. Structured interviews, field observations, key informants and focus group discussions were tools for collecting data that was analysed using descriptive and non-parametric statistics. Results showed that termitaria environments and homestead surroundings were the most productive niches ($p<0.001$) regardless of the type of crop planted. Niche productivity depended partly on management practices and largely on assessment of yields over years. Regardless of knowledge of matching a specific crops to a productive niche, farmers at times chose to grow a different crop to that appropriate. Farmers selectively grew small grains at a smaller extent though these are recommended for the semi arid areas. They did not show any niche selection when growing maize because of comparative advantages and the crop benefited directly from input amendments whilst small grains benefited from residual use. Yields of most crops declined due to a combination of low soil fertility and moisture stress with open sandy patches being most affected. The legume base was so narrow that only groundnut was grown in substantial portions. The study showed that severe soil fertility and moisture stress in niches like open sandy patches threatened food security. Recommendations included extension of technological packages such as agronomic advice, crop rotation and introduction and management of different legume crops in niches.

Keywords: Niches, Spatial heterogeneity, Smallholder farmers, soil fertility gradients, semi arid area

Introduction

In agriculture, biophysical factors have as much influence on smallholder farmers as socio-economic and political ones. Agriculture by indigenous farmers in Zimbabwe and South Africa was characterised by a history of land dispossession and a legacy of marginalisation of black farmers (Taylor, 1993). Smallholder farmers were relegated to areas characterized by sporadic rainfall and inherently low soil fertility with marginal to poor agricultural potential (Mehretu, 1994). Their traditional practices that included low resource inputs were considered inferior (Carter and Murwira, 1995). Despite implementation of the controversial land reform program in Zimbabwe from the year 2000, the majority of smallholder farming communities have not benefited and are still in the hostile farming environment. The smallholder farmers' survival strategy has involved developing risk-averse practices that take advantage of spatial heterogeneity in soil fertility and increase the probability of a yield every growing season whilst actively managing their environment (Mombeshora *et al*, 1995).

Most of smallholder farmers' practices centre on risk minimisation. According to Van Oosterhout (1993), farmers in semi arid areas consider consistent, reliable and stable yields more important in their cropping systems than high yields. Mushita (1993) also found out that in most communal areas of Zimbabwe mixed cropping or intercropping represented one of the most important practices within traditional farming systems. It involved a combination of crops with different food values, maturity periods and capacity to withstand calamities. Intercropping and crop diversification are better able to cope with weather variability during the growing season and minimise total crop failure as different crop varieties are planted in micro-environments or niches perceived to be favourable. Nyamapfeni (1987) observed that in Zimbabwe crops like okra (*Abelmoschus esculantus*), pumpkins (*Cucurbita* spp and *Lagenaria* spp), "Tsunga" (*Brassica juncea*) and sweet sorghum (*Sorghum bicolor*) were grown almost exclusively on termite mounds as a way of exploiting spatial heterogeneity in arable areas.

Studies in Zimbabwe's semi-arid communal areas confirmed the presence of spatial heterogeneity in smallholder arable environments and highlighted major crops grown by farmers (Chibudu, 2001; Carter and Murwira, 1995; Carter *et al* 1993; Govaerts, 1989; Ashworth, 1990). There is however a paucity of documented information regarding farmers' preferences, perception of cropping patterns and yields from specific niches in adverse arable farming environments. The objective of this study was to determine smallholder farmers' exploitation of spatial heterogeneity as a food security strategy. This encompassed their perceptions of niche productivity and associated preferences, cropping patterns within niches and yield variation over years. The information serves to inform policy makers with respect to agronomic advice, sustainable land use and constraints to production in risk- prone and spatially heterogeneous farming environments.

Materials and Methods

Study area description

The study was conducted in Mutoko small-scale communal areas in Mashonaland East province in the North Eastern area of Zimbabwe. Much of the communal area is in Agro-ecological Region 4 (<500 mm annual rainfall) with a portion of the communal area in the southwest in Agro-ecological Region 3 (600- 650 mm annual rainfall) (Brinn, 1986). 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 dry land cropping of maize. Other crops grown are bulrush 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. The characteristics of the communal area are typical of most smallholder farming areas in the tropics and subtropics.

Data collection and analysis

Purposive random sampling was used to select 84 households that had conspicuous soil fertility gradients or niches in arable fields in three adjacent villages of Charewa ward in Mutoko communal area. The niches were identified together with farmers during preliminary surveys and the most prevalent were homestead surroundings, termitaria environments, under *Parinari curatellifolia* and open areas of sandy patches. Structured interviews, field observations, key informants, focus group discussions together with a formal questionnaire survey were tools for data collection. Questions sought to expose niche utilisation and some included ranking of niches with respect to yield production per given crop, ranking of crops in specified niches with respect to farmer preference, long term yield changes in niches and accompanying reasons. Additional data was collected through monitoring cropping patterns in niches for two growing seasons. Major reasons for changes or no changes in crop yield were compared using the strength index scale with a range of 0 to 100.

The data were synthesized and where appropriate analysed using descriptive statistics. Ranked data for matched measurements were analysed using Wilcoxon's signed rank test.

Results

Farmers indicated that they used a mix of niches to cultivate crops including maize, bulrush millet, groundnuts, sorghum, sunflower and finger millet.

The crop yields in different niches, as assessed by farmers over years, were considered indicators of relative niche productivity. This exposed farmers' skills at matching various crops in order to increase chances of a better yield (Table 1).

Table 1. Wilcoxon signed rank test of productivity of niches with different crops.

Crop within Niche	Comparison of niches	Z- value	More productive niches
Maize	Tm vs Hs	-2.556	Tm*
	Hs vs uP	-6.495	Hs***
	uP vs Os	-0.417	NS
Bulrush millet	Hs vs Tm	-2.517	Hs*
	Tm vs Os	-2.730	Tm**
	UP vs Os	-0.690	NS
Groundnuts	Os vs Hs	-1.169	NS
	uP vs Hs	-4.042	Hs***
	Os vs uP	-3.082	Os**
Sunflower	Tm vs Hs	-0.978	Ns
	uP vs Os	-0.381	Ns
	uP vs Tm	-5.065	Tm***
Finger millet	Tm vs Hs	-2.086	Hs*
	uP vs Hs	-4.273	Hs***
	Os vs Tm	-1.744	Ns
Sorghum	Tm vs Hs	-4.518	Tm***
	uP vs Hs	-4.271	Hs***
	uP vs Os	-0.996	NS

***= p<0.001 **= p<0.01 *=p<0.05 NS = Not significant at p>0.05

Tm = termitaria environment Hs = homestead surrounding
Os = Open sandy patches u*P* = under *P*. *curatellifolia*

The productivity of termitaria environments was considered highest for sorghum, and maize followed by homestead surroundings. However, farmers perceived that homestead surroundings had better productivity than termitaria environments when they cultivate millets. Cultivation and production of groundnuts in open sandy patches was not significantly different from that done in areas surrounding homesteads. Niche productivity under *P*. *curatellifolia* and open sandy patches were not significantly different under various crops such as maize, millets, sunflower and sorghum.

Farmers' preference for maize in homestead surroundings was significantly higher than for any other crop (Table 2).

Table 2: Wilcoxon signed rank test of farmer preference of crops in homestead surroundings.

Crop compared	Z- value	Crop given first priority
Maize vs Bulrush millet	-7.303	Maize***
Maize vs Groundnuts	-7.195	Maize***
Maize vs Sunflower	-6.422	Maize***
Maize vs Finger millet	-6.642	Maize***
Maize vs Sorghum	-6.148	Maize***
Bulrush millet vs Groundnuts	-1.902	NS
Bulrush millet vs Sunflower	-3.046	Bulrush millet**
Bulrush millet vs Finger millet	-3.280	Bulrush millet**
Bulrush millet vs Sorghum	-3.697	Bulrush millet***
Groundnuts vs Sunflower	-1.407	NS
Groundnuts vs Finger millet	-1.072	NS
Groundnuts vs Sorghum	-1.959	NS
Sunflower vs Finger millet	-0.229	NS
Sunflower vs Sorghum	-0.613	NS
Sorghum vs Finger millet	-0.836	NS

***= p<0.001   NS = Not significant at p>0.05.

Bulrush millet was the second preferred. However, there was no significant difference in preference between bulrush millet and groundnuts in homestead surroundings. This implied possible decision to mix the two crops in this niche. The rest of the crops were least preferred in homestead surroundings. In this niche, greater than 50 % of the farmers noticed some yield changes of maize, bulrush millet, groundnuts and sunflower that either increased or decreased over the years (Table 3). The major reason given by farmers for an increase in either maize or sunflower yields was mainly due to increased use of inorganic fertilizers. Bulrush millet yield increased over the years due to crop rotation. Groundnut yields declined over the years in homestead surroundings due to increased incidence of pests and diseases (Table 3). Finger millet and sorghum yields declined mainly due to erratic rainfall. Generally, moisture stress was highlighted as the major critical factor contributing to yield decline of most crops. The second critical factor, as shown by the strength index, for yield decline was infertile soil that, in some cases, was obviated by use of inorganic fertilizers. The minority (< 20 %) of smallholder farmers who did not notice a change in crop yields indicated invariable crop management strategies over the years. Some of these farmers used fertilizers (organic and inorganic), practised crop rotation and perceived their soil as fertile in the homestead surroundings.

In termitaria environments, preference for maize, sorghum and bulrush millet were most significant (Table 4). Farmers significantly ($p<0.01$) preferred maize to sorghum. However, bulrush millet and sunflower had equal preference while finger millet was the least preferred.

Farmers who noticed yield changes over years for all crops in termitaria environments were slightly more (52%) than those who did not notice any change (Table 5). The strength indices of reasons for yield decline were stronger for all crops except maize than those given for increase in crop yields. Increase in maize yields was mainly due to the use of inorganic fertilizers. The critical reason that influenced yield decline for most crops was again pointed out as inadequate moisture. Farmers who observed no yield change over years attributed that to relatively high soil fertility in this niche.

Table 3. Yield changes of various crops over the years (>5yrs) in homestead surroundings and reasons.

Crop	% Farmers noting yield changes (n=84)	Major reason for yield increase	Strength index of reason	Major reason for yield decline	Strength index of reason	% Farmers noting no yield changes (n=84)	Major reason for no yield changes	Strength index of reason
Maize	86.9	-Use of fertilizers	27.7	-Erratic rainfall	15.5	11.9	-Fertile soil	3.6
				-Inadequate use of fertilizer	14.5		-Use of fertilizer	2.4
Bulrush millet	66.7	-Crop rotation	18.1	-Erratic rainfall	18.1	19.0	-Use of organic amendment	5.5
				-Depleted soil	13.9			
							-Crop rotation	5.5
G/nuts	67.9	-Use of organic amendment	14.9	-Pests and diseases	16.2	20.2	-Use of organic amendment	6.8
S/flower	50.0	-Use of fertilizer	19.6	-Depleted soil	11.8	10.7	-Crop rotation	5.8
		-Better variety	13.7					
Finger millet	46.4	-Organic amendment	11.3	-Erratic rainfall	20.8	16.7	-Fertile soil	13.2
				-Depleted soil	11.3			
Sorghum	45.2	-Organic amendment	15.7	-Erratic rainfall	19.6	15.5	-Fertile soil	15.7
				-Depleted soil	11.8			

Strength index of reason = $\frac{\text{Number of farmers giving the same reason}}{\text{Total number of farmers responding}} \times 100$

Table 4. Wilcoxon signed rank test of farmer preference of crops in termitaria environments.

Crop compared	Z- value	Crop given first priority
Maize vs Bulrush millet	-6.553	Maize***
Maize vs Sunflower	-5.698	Maize***
Maize vs Finger millet	-5.724	Maize***
Maize vs Sorghum	-2.904	Maize**
Bulrush millet vs Sunflower	-0.566	NS
Bulrush millet vs Finger millet	-2.723	Bulrush millet**
Bulrush millet vs Sorghum	-3.878	Bulrush millet***
Sunflower vs Finger millet	-2.741	Sunflower**
Sunflower vs Sorghum	-2.934	Sorghum**
Sorghum vs Finger millet	-5.073	Sorghum***

***= $p<0.001$ **= $p<0.01$ NS = Not significant at $p>0.05$.

In niches under *P. curatellifolia*, the farmer preference for maize and bulrush millet was significantly higher than for any other crop. However, groundnuts and bulrush millet were assigned equal priority. On a smaller extent, farmers preferred sunflower to sorghum. More than 45 percent of farmers noted some yield changes over the years in niches under *P. curatellifolia*. Only an increase in maize yields was attributed to inorganic fertilizer use whilst a yield decline for the rest of the crops was observed over the years. Prevalence of pests and diseases were mostly cited for reduced yields of bulrush millet and groundnuts in this niche. Erratic rainfall contributed to the decline of yields of sunflower, finger millet and sorghum, explaining why these crops had least preference. A maximum of 30% of smallholder farmers did not experience any substantial yield differences in crops cultivated under *P. curatellifolia* trees over the years. This was perceived to be due to fertile soil under *P. curatellifolia* trees. The adduced reason of soil fertility was relative to potential of specific crop performance. For example, farmers purported that fertile soil in this niche stabilised yields more for bulrush millet and sunflower than for maize, sorghum or finger millet over the years.

In open sandy patches, maize, bulrush millet and groundnuts had the highest significant preference over the rest of the crops (Table 6).

This suggested equal priority of these crops in this niche. In absence of the three crops mentioned above, smallholder farmers had significantly ($p<0.001$) higher preference for finger millet than for sunflower in the open sandy patches. However, at least 59 % of farmers noted yield changes for all crops over the years. Yields for all crops declined because of infertile soil and inadequate use of soil amendments. Erratic rainfall was considered the second major reason for yield reduction of most crops and prevalence of diseases for groundnuts. A few farmers who noticed no yield decline of bulrush millet, finger millet and sunflower used inorganic fertilizers, crop rotation and better cultivars.

Monitoring of cropping patterns in niches over two growing seasons showed little selection of niches when cultivating maize (Table 7).

In the second season, less farmers planted bulrush millet in all niches except homestead surroundings and sorghum was only grown on termitaria environments. Groundnuts was also reduced in the second season in homestead surroundings and increased in open sandy patches while maize was reduced in homestead and increased in termitaria environments. The total amount of rainfall was 993mm, 51 % more than that received in the previous season.

Table 5. **Yield changes of various crops over the years (>5yrs) in termitaria environments and reasons.**

Crop	% Farmers noting yield changes (n=84)	Major reason for yield increase	Strength index of reason	Major reason for yield decline	Strength index of reason	% Farmers noting no yield changes (n=84)	Major reason for no yield changes	Strength index of reason
Maize	52.4	-Use of fertilizer	21.4	-Erratic rainfall	15.5	47.6	-Fertile soil	42.9
Bulrush millet	48.8	-Fertile soil -Crop rotation	10.8 8.3	-Erratic rainfall	23.0	39.3	-Fertile soil	41.9
S/flower	39.3	-Better variety	12.5	-Erratic rainfall	12.5	27.4	-Fertile soil	31.1
Finger millet	35.7	-Fertile soil	8.7	-Erratic rainfall	23.9	19.0	-Fertile soil	30.4
Sorghum	38.1	-Crop rotation -Use of fertilizer	10.7 10.7	-Erratic rainfall	16.1	28.6	-Fertile soil	35.7

Table 6.Wilcoxon signed rank test of farmer preference of crops in open sandy patches.

Crop compared	Z- value	Crop given first priority
Maize vs Bulrush millet	-0.803	NS
Maize vs Groundnuts	-0.755	NS
Maize vs Sunflower	-4.642	Maize***
Maize vs Finger millet	-3.351	Maize***
Maize vs Sorghum	-5.318	Maize***
Bulrush millet vs Groundnuts	-0.489	NS
Bulrush millet vs Sunflower	-3.712	Bulrush millet***
Bulrush millet vs Finger millet	-2.993	Bulrush millet**
Bulrush millet vs Sorghum	-5.643	Bulrush millet***
Groundnuts vs Sunflower	-4.767	Groundnuts***
Groundnuts vs Finger millet	-3.585	Groundnuts***
Groundnuts vs Sorghum	-4.904	Groundnuts***
Sunflower vs Finger millet	-1.431	NS
Sunflower vs Sorghum	-1.838	NS
Sorghum vs Finger millet	-3.472	Finger millet***

***= p<0.001 **= p<0.01 NS = Not significant at p>0.05

Table 7. Percentage of farmers allocating field crops to different niches over two growing seasons (n=84).

_Crop	Homestead surroundings		Termitaria environments		Under *P. curatellifolia*		Open sandy patches	
	Seas I	Seas II	Seas I	Seas II	Seas I	Seas II	Seas I	Seas II
Maize	89	78	78	89	89	100	100	100
Bulrush millet	22	22	67	11	56	33	100	55
Groundnuts	22	11	0	0	33	33	33	66
Finger millet	11	11	22	0	33	0	33	66
Sorghum	0	0	0	44	0	0	44	0
Sunflower	11	0	0	11	0	0	0	11

Seas I = Season I Seas II = Season II

Discussion

The study showed that smallholder farmers considered soil fertility gradients or niches very important as they provided an option to cultivate a range of crops. Generally, the termitaria environments and homestead surroundings were pointed out to be the most productive niches regardless of the type of crop planted and had highest contribution to food security. Meanwhile, termitaria environments were productive mainly because of the type of soil (sandy clay loam) but received relatively low amendments. Niche productivity depended to some extent on the management practices of the smallholder farmers. For example, factors such as protection and proximity of homestead surroundings influenced application of substantial amounts of inorganic and organic amendments into the niches. The conspicuous soil fertility gradients defy blanket recommendations for soil fertility improvements for spatially heterogeneous arable areas.

Smallholder farmers assessed the productivity of a niche based on yield of a planted crop. Maize and sorghum yielded most in termitaria environments while bulrush millet and finger millet had highest yields in homestead surroundings. This probably could be due to farmers' ability, through experience, to match a niche's potential productivity with general growth requirements of various crops as indicated by Purseglove (1975), Rehn and Espig (1991). High yield of finger millet and bulrush millet in homestead surroundings was attributed to more of residual use of nutrients by these crops than direct applications. Better management strategies particularly where protection from bird damage was provided also influenced yields.

Regardless of the knowledge of matching a productive niche with a specific crop, farmers sometimes decided to grow a different crop to that most appropriate in the niche. This hints at influence by exigent factors, risk and uncertainty to crystallize decisions to grow a crop in a particular niche. Scoones (1996) ascertained that the complex decision to plant a specific crop is arrived at after considering the expense of growing the crop with respect to input requirements for production and processing, disparate gastronomic and storage properties, different market price and sale potential. Maize was the most preferred in all niches because of several advantages over other crops and is both a staple and cash crop. It was considered to be easy to cultivate, was high yielding and its harvesting processing was not labour intensive as observed by Campbell *et al* (1995). Though small grains are recommended for semi-arid areas like Mutoko communal area, farmers selectively grow them at a smaller extent mainly for social, religious and cultural purposes. Over dependency on generally one crop such as the more susceptible maize in the area increased the risk of crop failure. Promotion and price incentives can stimulate production of minor crops.

Presence of pests and diseases affected groundnut yields to such an extent that no observable groundnut yield differences occurred between the more productive homestead surroundings and open sandy patches. These were quite significant constraints that require external intervention. All farmers did not plant groundnuts on termitaria environments due to problems caused by termitaria soil that becomes dry and hard at the time of harvesting and costly in terms of time, labour and yields. Rehn and Espig (1991) confirmed farmers' experience that heavy textured soils or soils with a tendency to form crusts complicated harvesting and were unsuitable for groundnut cultivation.

Farmers had equal preference for maize, bulrush millet and groundnuts in open sandy patches. Availability of seed usually determined the crop to be grown in this niche. Intercropping of maize with groundnuts or maize with bulrush millet was in some cases common in the open sandy patches. In other cases, open sandy patches had the three crops each planted separately and covered small portions of the field. However, the legume base was very narrow with groundnuts dominating. Introduction of a range of legumes readily adapted to such environments is crucial for soil fertility improvement and for complementing the mostly cereal dominated farming systems.

The most critical constraints to crop production by smallholder farmers that even threaten food security in spatially heterogeneous arable environments were soil moisture and fertility. These constraints alternated in severity or had synergistic effects on crops across niches. In termitaria environments moisture stress caused by sporadic and erratically distributed rainfall critically affected crops and yields. In open sandy patches, farmers noted that depleted soil fertility was as critical as moisture stress. This scenario calls for technological interventions that could help improve soil fertility and water availability such as improved fallows, intercropping and conservation tillage.

Farmers' perceptions of yield decline in a particular niche over time were relative to the type of crop and critical factors affecting its growth. For example, in niches under *P. curatellifolia* yields of bulrush millet and groundnuts were perceived to be critically affected by pests and diseases while yield decline of other crops was ascribed to erratic rainfall. Multifarious factors including crop management and soil fertility could be at play to mutually contribute to yield decline.

Cropping patterns monitored over two seasons confirmed that maize, bulrush millet and groundnuts were the major crops grown by farmers. A few farmers however, selectively planted small grains in different niches despite their verbal claims. This could be that the fluidity of farmers' decision-making processes were influenced by, *inter alia*, a reasonable idea of the likely response of certain crops in a particular growing season. The rainfall distribution and the amounts received especially in the second growing season might have contributed to decisions to withhold, reduce or even increase planting of crops in specific niches.

Conclusion

Though smallholder farmers grow different crops, maize was prevalent in all niches showing its high rating despite recommendations for small grains in semi arid areas. On a smaller extent, the agronomic utilisation of niches depended on farmers' ability to match crops, excluding maize, to niches relative to fertility and weather patterns that influence soil moisture. It also relied on farmers' perception of risk and uncertainty. Concentration of crop husbandry practices was reserved for niches that had comparative advantages over others in terms of crop performance. The problem of pests and diseases was prevalent regardless of the type of niche and needed immediate intervention to avert substantial yield decline. Severe soil infertility and moisture stress in niches like open sandy patches required amelioration by reinforcing extension of technological packages such as crop rotation, improved fallows, conservation tillage and introduction and management of different legumes crops.

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