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Determinants of maize yield variability on smallholder farms in Western Kenya

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Abstract

Variability in maize productivity among the neighboring smallholder producers is a common phenomenon in developing countries, a factor attributed to biophysical, agronomic and socio-economic constraints. Field surveys were conducted in Shikomoli and Mukuyu villages in Western Kenya to evaluate the socio-economic factors influencing maize yield variability on smallholder farms. Classification and Regression Trees (CART) were then used to show maize yield variability and the associated causal factors at different levels. In Mukuyu, maize yield ranged from 0.04 - 7.13 tonnes/ha with an average value of 3.0 tonnes/ha. In Shikomoli, maize yield ranged from 0.01 – 5.14 tonnes/ha with an average value of 2.2 tonnes/ha. The CART analysis showed a combination of factors that resulted in high maize yield. In Mukuyu these factors were; higher amounts of inorganic fertilizer application (>226.5 kg/ha; $p<0.001$), higher man-hrs hired labor (>338 man-hrs; $p<0.001$), higher education levels of farm operators (>11 years in school; $p<0.001$), higher seed rate (>25 kg/ha), higher frequency of weeding (>2 times in a season; $p=0.031$), higher quantity of manure application (>640.8) and lower age of farm operator (≤27 years; $p=0.001$). In Shikomoli, highest maize yield was obtained because of higher application of farmyard manure (>1033 kg/ha; $p<0.001$), higher quantity of inorganic fertilizer application (>358.8 kg/ha), shorter distance to market (≤13 km; $p<0.002$), higher education level of operator (>12 years in school; $p<0.002$) and larger land sizes (>4.5 acres; $p=0.0015$). The findings indicate the significance of CART analysis in showing a combination of factors resulting in high maize yields which can help guide soil and crop management measures to enhance yields. The findings also highlight the need to address the socio-economic and agronomic constraints to reduce maize yield variability among the smallholder farmers.

Keywords: maize productivity; yield variability; socio-economic factors; smallholder farmers.

1.0 Introduction

Despite being one of the most important staple crop in Sub Saharan Africa, maize productivity remains low and widely variable among the producers (Sileshi et al., 2010). In Kenya, the actual yield of maize achieved by farmers is 1.8t ha^{-1}compared to potential yield 6t ha^{-1} (Tittonell et al., 2008). Some studies have linked the high yield variability to the impoverished soil quality, poor agronomic practices and adverse changes in climatic conditions (Kaliba et al., 2000; Tittonell et al., 2006). High maize productivity variations has been related to agronomic and socio-economic factors which vary strongly within the sites and between the growing seasons (Djurfeldt et al., 2011). Maize yield variations on smallholder farming systems are greatly determined by the differences in farmer's ethnic origin, availability of family labor, land ownership, low input use, and access to market and credit facilities (Banerjee et al., 2014). This is in agreement with (Oluoch-kosura, (2010) who highlighted marketing and institutional factors such as land tenure insecurity, weak research and extension capacity and poor access to financial services as some of the major factors influencing crop productivity in developing countries.

Narrowing the high yield variability and productivity gaps of maize in developing countries therefore requires strategies that adjust the existing socio-economic and agronomic constraints. Realization of this goal relies on careful assessment of the farmers' socio-economic background, their existing agronomic management and how these factors interact to influence maize productivity. Access to market and capital by the smallholder maize producers should be considered when evaluating the maize yield variability as it directly affects farmers' ability to acquire the farm inputs (Salami et al., 2010). Educational background of the farmers may influence the manner in which the limited resources are allocated to farm management activities. Soil management factors become more important as they can interact with the socio-economic factors to influence the crop yield (Xu et al., 2009).

It is against this background that maize yield variability analysis is gaining research focus with the aim to narrowing the productivity gaps in developing countries. In Kenya, a few studies have been conducted to unravel the relative importance of soil parameters and agronomic practices on maize yield variability (Djurfeldt et al., 2011; Tittonell et al., 2008). Paucity of information however exists on the interactive effect of socio-economic and agronomic factors on maize productivity gaps among the smallholder maize producers. This study was therefore conducted to 1) determine the impact of socio-economic and agronomic factors on maize yield variability and to 2) identify the variables contributing to maize yield variability among smallholder maize producers in Western Kenya. Understanding the effect of these factors on maize productivity is imperative for development of effective crop and nutrient management strategies so as to reduce yield variability and enhance national food security. This is based on the general assumption that regions where the yield variabilitys are large holds promise for productivity gains and increase in food security if the identified causes are ultimately alleviated.

2.0 Materials and methods

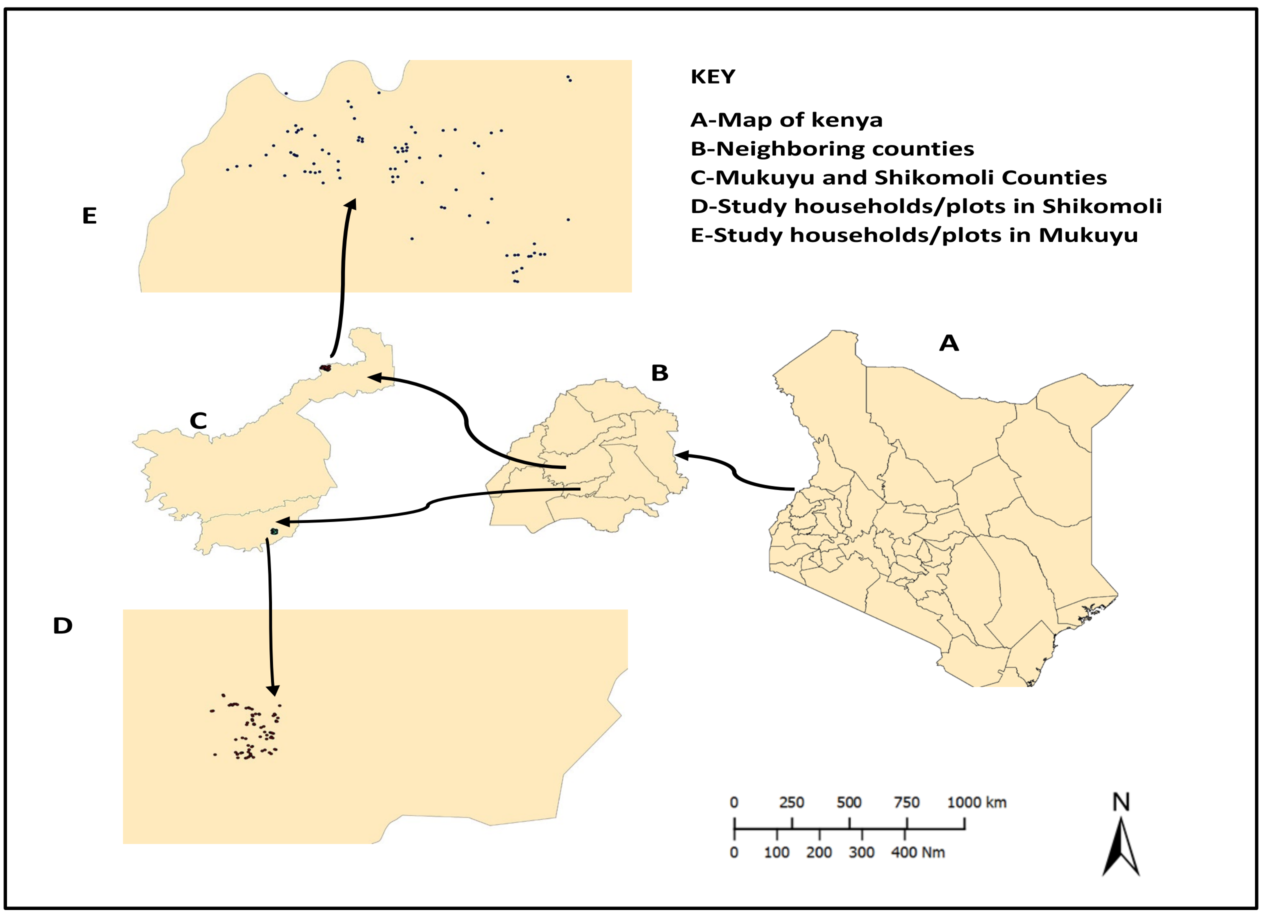

Figure 1: The study sites; Mukuyu and Shikomoli

2.1 Site description

This study was carried out during the rainy seasons of 2016-2017 in Shikomoli and Mukuyu villages located in Vihiga and Kakamega Counties in Kenya. Shikomoli is located along latitude N 00 03. 782' to N 00 03. 09' and longitude E 034 46.795' to E 034 47.232' at an altitude of 1621-1785 m above sea level while Mukuyu is located along latitude N 00 43.956' to N 00 44.153' and longitude E 034 56.369' to E 034 55.961', at altitude 1534-1780 m above sea level. The two sites are broad representative of demographic and agro-ecological characteristics of maize growing belt of Western Kenya. The site selection criterion was based on localized factors which would cover much of the variability in maize yield. Among these factors are the differences in maize growing season, farm sizes, farmer resource endowment, land use types, soil types and topography.

Most households in Shikomoli grow maize on small landholdings averaging to about 1.5 acres and obtain average yields of 0.5-3.7 t ha^{-1} (Odendo et al., 2001)). Mukuyu is however characterized by larger landholdings averaging to 5 acres per household with an average maize yield of 2.5-6 t ha^{-1} (Mable Mercy Mulanya, 2016). Maize production is carried out in two seasons per year (March to September and October to February) in Shikomoli and one season in Mukuyu (March to October) (Mable Mercy Mulanya, 2016). Marginal farmers are more predominant in Shikomoli compared to Mukuyu with a percentage greater than 60% (Karugia, 2003). Use of tractor for land preparation is popular in Mukuyu due to the gentle topography and larger land sizes. Landholding fragmentations and rugged topography however prompts the use of oxen and hand tillage in Shikomoli (Karugia, 2003).

2.2 Household interview

The interviews were conducted by enumerators, using ODK tablet. Besides, a 4 x 4 m grid was established at the center of farmers' plots and away from physical obstructions to collect selected maize yield parameters used for computing maize productivity gaps. A hand-held garmin eTrex GPS receiver (Garmin Ltd., Schaffhausen, Switzerland) was used to measure the area of each of the identified farm. Yields were transformed into t ha^{-1}.

Table 1: Variables used in the survey and classification and regression tree analysis

Variables	Description
Education level of operator	Formal education received by the farm operator; categorized as – Illiterate (0-3 years of study); primary (4-8 years); secondary (9-12 years) and tertiary (above 12 years).
Household size	Number of members in a family who share food from a single source.
Land size	Size of the cultivable land in acres (whether inherited, leased or purchased) owned by the farmer.
Total labor	Total family and hired labor used for all operations related to maize cultivation (man hour ha^{-1}); categorized as 1-Family, 2-Hired, 3-Family+Hired.
Distance to market	Physical distance (km) from the household to farm output market.
Age of operator	Length of time in years the person responsible for the daily farm activities has lived.
Gender of farm operator	The state of the farm operator being male=1; or female=2.
Decision making	The person in charge of farm operation and management decision making. categorized as 1-Plot operator, 2-Household head; 3-Spouse; 4-Adult male; 5-Adult female child; 6-Children <18 years; 7-Others.
Family involvement in farm activities	Proportion of family members taking part in actual farm operations such as cultivation, planting, weeding etc.
Credit facility	Whether the farmer has access to formal institutional credit; Yes=1; Otherwise=0.
Family man-hours in farm operations	Amount of hours taken by family members to conduct amount of work that can be done by one person within a season.
Hired man-hours in farm operations	Amount of hours taken by hired persons to conduct amount of work that can be done by one person within a season.
Total cost per Ha of land operation	Total amount of money (KShs) paid to a person employed to carry out farm activities per hectare of land.
Cost of transport from household to the market	Total amount of money (KShs) used by the farmer/farm operator from the household to the market to acquire farm inputs.

2.3 Statistical analyses

Statistical analyses (summary statistics and step-wise linear regression analysis) were performed by STATA 14 (Stata Software, San Jose, CA). The statistical tests were considered significant at 0.05 probability level.

3.0 Results

3.1 Characteristics of the households

The average household size was 5 persons per household in Mukuyu and 6 persons per household in Shikomoli. The proportion of males and females above 16 years was similar in Mukuyu (32.5% men; 31.9% females) and Shikomoli (31.2% males; 29.0% females) (Table 2). Children were proportionally higher compared to adults in both the two sites with Shikomoli having higher proportion (39.8%) compared to Mukuyu (35.6%). Maize yield correlated strongly with persons above 16 years regardless of sex and site. Age of farm operator was proportionally higher in age class 55-69 years in both Mukuyu (47.11%) and Shikomoli (43.5%). Yield correlation with age was significant only for the age class 25-39. Illiteracy level of farm operator was markedly higher in Shikomoli (46.6%) compared to Mukuyu (10.67%).Only 1.77% of the farm operators had tertiary level of education in Shikomoli compared to 28.6% in Mukuyu. Yield correlated significantly with the operator’s tertiary level of education in both the two sites. Gender of operator indicated discrepancy in Shikomoli with 78% being females. Most of the farmers were located at a distance above 5 km from the nearest market center with Mukuyu exhibiting higher proportion (79.98%) compared to Shikomoli (53.3%).

Table 2: Household characteristics of the study sites

	Class	Mukuyu		Shikomoli	
		Frequency (%)	Maize yield (t/ha)	Frequency	Maize yield (t/ha)
Household size	Males above 16 yrs	32.50	3.23*	31.20	2.73*
	Females above 16 yrs	31.90	3.45*	29.00	2.43*
	Children (<16 yrs)	35.60	1.98	39.80	1.50
Age of farm operator	25-39	13.92	5.20*	7.68	2.76*
	40-54	33.01	3.51	33.25	2.15
	55-69	47.11	2.99	43.50	2.39
	70-84	5.96	2.96	17.57	1.86
Education level of operator	Illiterate (0-3)	10.67	3.18	46.60	2.04
	Primary (4-8)	34.28	2.84	29.21	2.63
	Secondary (9-12)	26.46	3.45	22.41	2.12
	Tertiary (above 12)	28.59	4.26*	1.77	3.19*
Gender of operator	Male	43.82	3.44	21.07	2.24
	Female	56.18	4.48	78.93	2.21
Distance to market	0-5 km	20.04	3.27	47.70	2.28*
	above 5 km	79.98	3.72	53.30	1.03

* Correlation significant at 5% probability

3.2 Variability of maize productivity in Mukuyu and Shikomoli

Maize productivity varied remarkably among the farmers with Shikomoli indicating higher variability compared to Mukuyu (Fig. 2). Productivity of maize ranged between 0.04 t ha^{-1} and 7.13 t ha^{-1} in Mukuyu and 0.01 t ha^{-1} and 5.14 t ha^{-1} in Shikomoli.

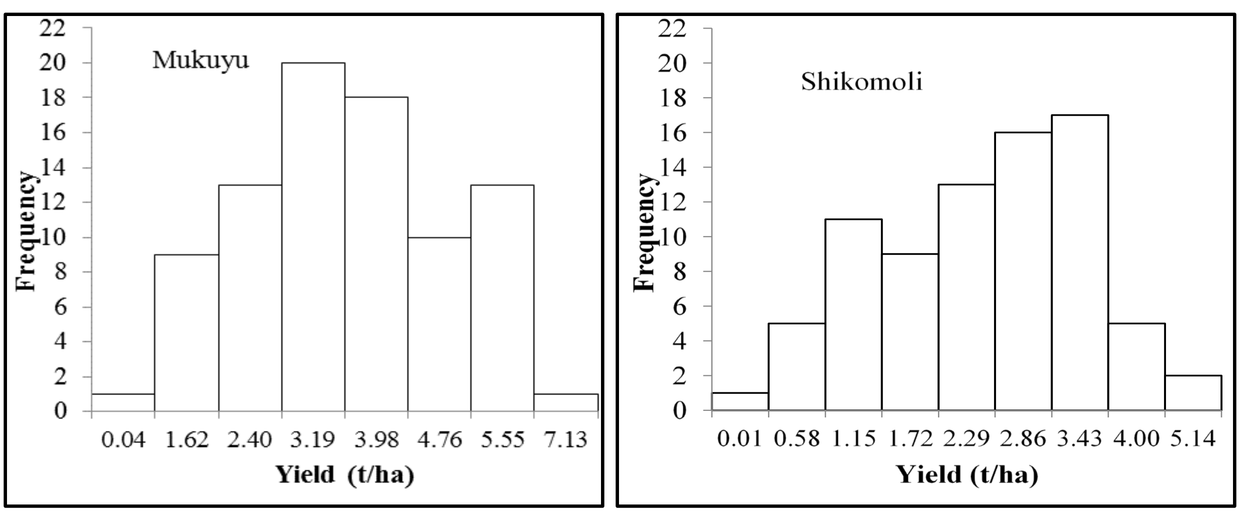

Figure 2: Variability of maize yield in Mukuyu and Shikomoli

3.3 Factors influencing maize yield variability in Mukuyu and Shikomoli

Figures 3 and 4 show regression tree models showing causes of maize yield. In Mukuyu, highest maize yield was obtained because of higher amounts of inorganic fertilizer application (>226.5 kg/ha against ≤226.5 kg/ha; p<0.001), higher quantity of hired labor (>338 man-hrs against ≤338 man-hrs; p<0.001), higher education levels of farm operator (>11 years in school against ≤11 years; p<0.001), higher seed rate (>25 kg/ha against ≤25 kg/ha), higher frequency of weeding (>2 against ≤2; p= 0.031), higher quantity of manure application (>640.8 against ≤640.8) and lower age of farm operator (≤27 against >27 years; p=0.001). Total labor hired to conduct farm activities had multiple threshold values that reappear as splitting criteria in Mukuyu.

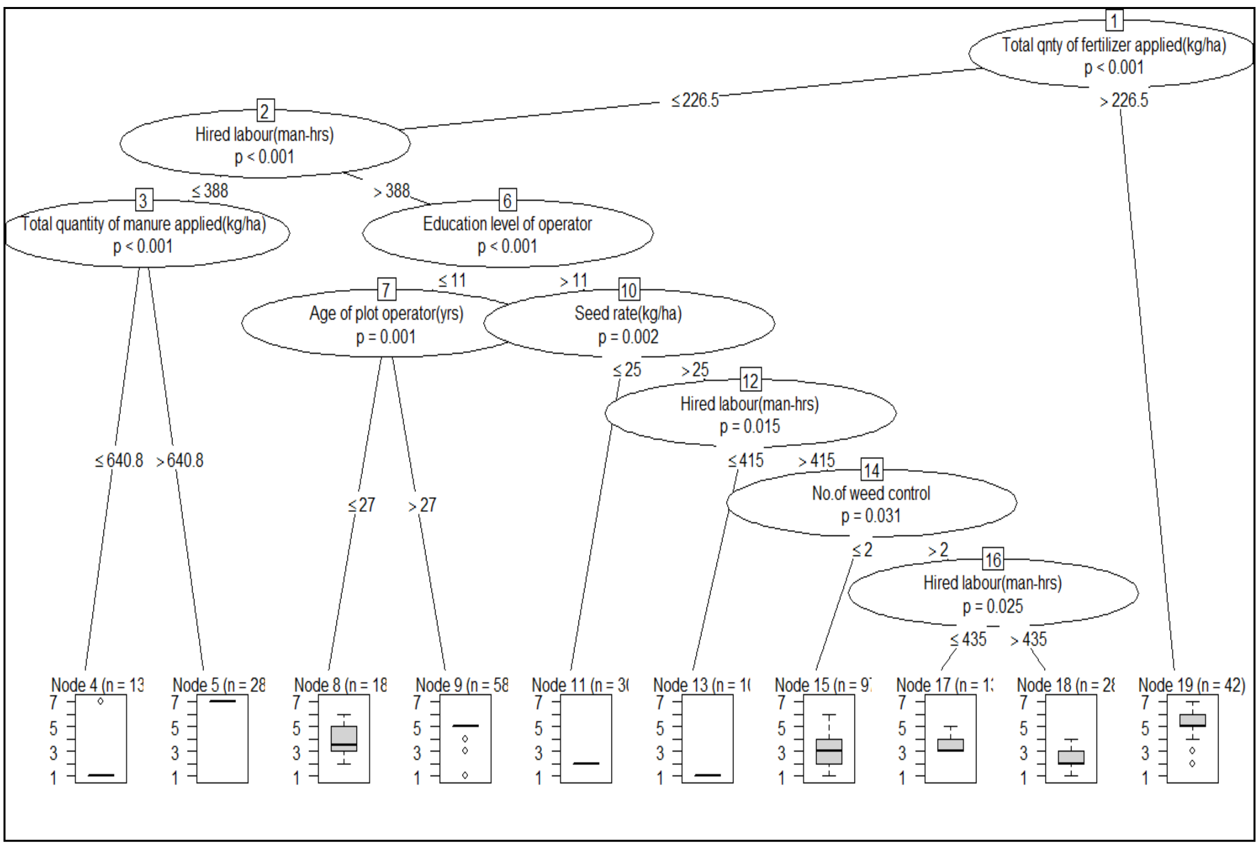

Figure 3: Classification and regression tree models describing maize productivity as a function of socio-economic factors in Mukuyu

In Shikomoli, highest maize yield was obtained because of higher application of manure (>1033 kg/ha against ≤1033 kg/ha; p<0.001), higher quantity of inorganic fertilizer application (>358.8 kg/ha against ≤358.8 kg/ha), shorter distance to market (≤13 km against >13 km; p<0.002), higher education level of operator (>12 years in school against ≤12 years; p<0.002) and larger land size (>4.5 kg/ha against ≤4.5 acres; p=0.0015) (Fig.4). Distance to market, total quantity of manure applied over the season and quantity of inorganic fertilizer applied reappeared as splitting criteria in Shikomoli.

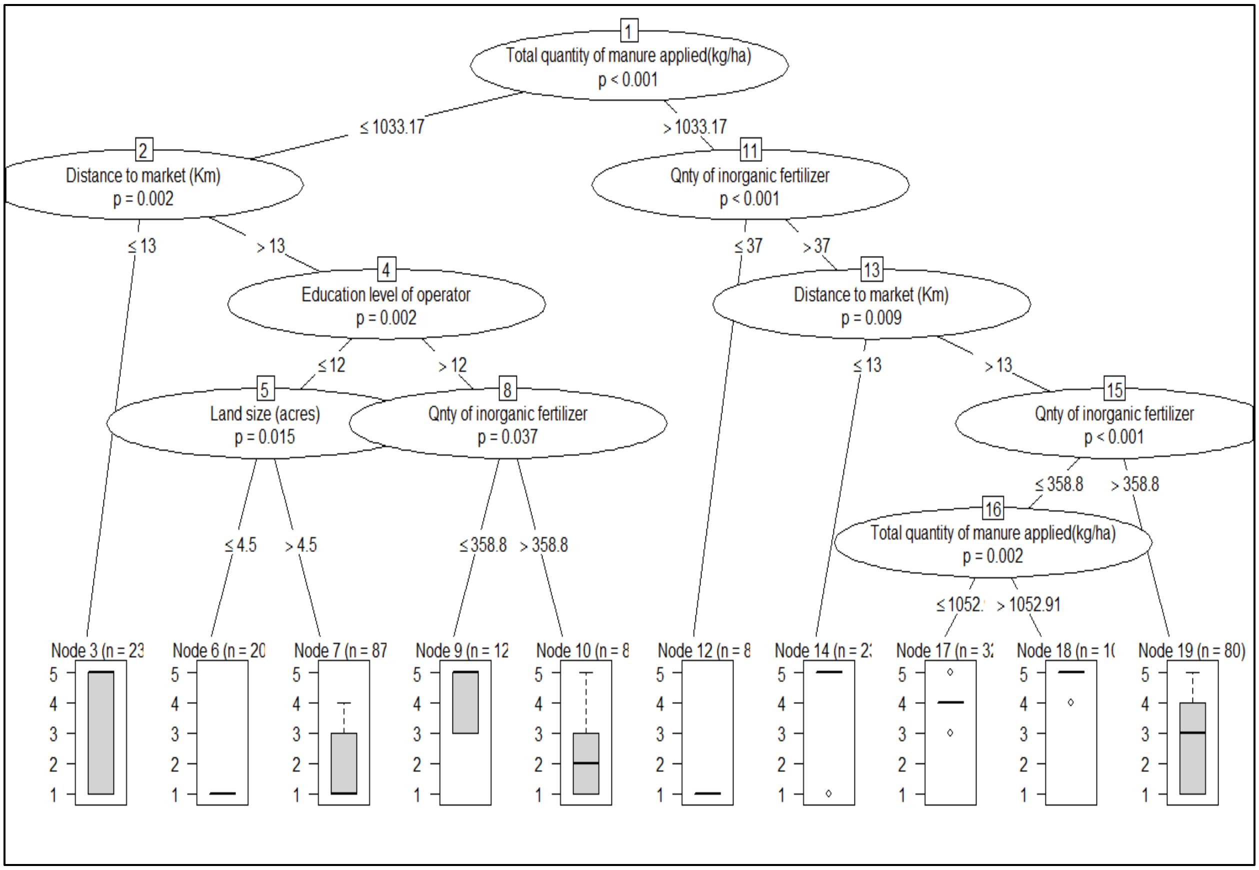

Figure 4: Classification and regression tree models describing maize productivity as a function of socio-economic factors in Shikomoli

Each splitting variable is associated to a threshold value in its own units that separate the larger group of data in two subgroups. The n value corresponds to the number of observation contained in that group.

4.0 Discussions

4.1 Causes of maize yield variability in Mukuyu and Shikomoli

Maize yield variability among the farmers was largely dependent on age and education level of farm operator, farmyard manure use, inorganic fertilizer application, hired labor, seed rate, land size and frequency of weed control. Farmers' access to formal education was found to be significantly associated with higher maize yield, illustrating the importance of education in increasing farmers' production efficiency. Farmers with secondary level of education exhibited higher maize yields compared to the farmers with only primary level of education. Farmers' use of conventional and non-conventional inputs on agricultural productivity is greatly dependent on technology adoption status (Farid et al., 2016). As such, the educational background of the farmer is important for generation and dissemination of new input technologies such as the new maize varieties and the use of chemical fertilizers. Education accelerates agricultural productivity by exposing the farmers to the dynamic production systems. (Alene and Manyong, (2006) argued that farmers with good education background have increased ability to choose the optimal levels of inputs and outputs.

Significant increase in maize productivity due to hired labor was an indication of inequality among the maize farmers in Shikomoli. The use of hired labor enhanced timely land preparation, weeding and application of fertilizers. According to the farmers interviewed, allocation of hired labor to farm activities is constrained by the low return from maize production making farmers hesitant to hire the casuals. Mulenya et al. (2015) observed that most of the youths in Western Kenya have adventured into motorbike enterprise, creating farm labor shortage in the rural set-up thus making the available labor expensive. Bandyopadhyay et al. (2012) argued that for hired labor to be productive, it must be allocated to activities which are high-income generating. Family labor influenced the maize yield variabilitys in Mukuyu and Shikomoli implying that farmers with a larger stock of workers may allow more specialization and the division of labor into distinct tasks so as to enhance maize productivity. For instance, some respondents reported that they work together with the hired workers while they supervise their tasks.

Land size exhibited significant relationship with maize yield variability in Shikomoli. This corroborates with studies that demonstrated that the increasing maize production in Africa at the rates of 2.8% per annum is as a result of increasing area cultivated rather than increased yields. The study established that most of the lands in Shikomoli are fragmented into smaller units so as to accommodate all the household siblings. This in return has made the land to be too scarce to make any meaningful contribution to agricultural production. As a result, most of the youths have opted to join motorcycle business operations and other informal business, thus hindering maize production. (Oluoch-kosura, (2010) asserted that low per capita land holdings in Vihiga can only offer a modest opportunity to secure livelihoods, even with agricultural intensification. Oino, P and Mugure, (2013)similarly showed that land tenure problems are more common in continuously fragmented lands, resulting in low adoption of soil conservation techniques, thus leading to reduced maize productivity. Our discussions with some of the respondents in this study revealed that credit facilities and capital are more available for the households with larger farms, so that even though all farms may wish to adopt these facilities, these larger farms are more advantaged. Households with larger landholdings are more likely to be wealthier, with increased ability to purchase the farm inputs.

Income level of the farmer had significant impact on maize yield variability in Mukuyu. Farmer's income level determines the risk taking ability, capital investment in farming practice, and knowledge sharing for technological intervention to maximize the profit (Adhikari et al., 2009). Links between poverty and low maize yields were similarly unraveled by (Tittonell et al., 2016) Studies have shown that less endowed households are more likely to face multiple production constraints and lack the social and economic capital to intensify crop management. The high income farmers can however remove stress in a multi-stress environment and exhibit higher productivity gains. Investment in maize cultivation also has a close association with income of the farmer with the well-endowed families exhibiting the ability to afford the needed equipment for proper crop management (Sulo et al., 2012). High income farmers have the ability to purchase the desired hybrid seeds, organic manures, fertilizers, and pesticides resulting into higher productivity of the crop. The low income farmers may however have lower capacity and higher risk perception about a new crop variety and is expected to be resistant to the adoption decision of improved maize technology package. (Wafula et al., 2016)reported that sub-optimal adoption of sustainable fertilizer management technologies among maize producers in Kenya greatly lies with the farmers' low income levels.

Distance from the household to the market had significant influence on maize yield in Shikomoli. (Romney et al., 2003) concluded that farmers having land near road can easily transport the produce to the nearest market place and therefore are able to save a significant extent of expenditure for farm input acquisition. Farmers with good access to markets can access farm inputs and new innovations much easily. This is particularly true when new technologies are widely available in the market.

Differences in the maize seed rate at planting also showed a significant effect on maize yield. The seed rate influenced the population and distribution of plants which may have affected the proportion of light distribution and biomass accumulation (Kinama et al., 2007). This consequently had profound effect on maize grain yield. Lake and Wade, (2009) observed that maize plant density and arrangement of individual plants within a square meter determine nutrient use efficiency and grain yield of maize.

Application of inorganic fertilizer and manure exhibited significant impact on maize yield, both individually and in combination. The increase in maize yield generally increased with the increase in total quantity of organic manure applied. This agrees with the finding by (Mugwira et al., 1997) who observed that the effectiveness of cattle manure in increasing crop growth and yield increases with the rate and quantity of application due to the increase in quantity of nutrients supplied. The reduction in maize grain yield in sub-Saharan-Africa is due to the low soil fertility that contributes to deficiency of important plant nutrients.

4.2 Interactive effect of socio-economic and agronomic factors on maize yield variability

There was a significant interactive effect between the age and education levels of farm operator on maize yield in Mukuyu (Fig 3). This interaction implies that Agricultural production requires not only labor input, but also technological development. An aging agricultural production needs technology to compensate for physical deficiency. This may incline them to invest in the use of machinery instead of labor input. This suggests that agricultural producers of different ages and education levels make different choices regarding input elements. The greater physical strength exhibited by the youths is required during the process of maize production. For adult producers, the increase in this physical strength culminates in middle age thus necessitating a greater investment of labor for the same production activities. However, the experience of older farmers leads to more efficient combinations of input, which makes a unit of labor more effective. Mingliang et al., (2015) noted that agricultural knowledge and skills in agriculture, such as production, operation, and management, increase with age of farm operator.

There was significant interactive effect of family labour and hired labour on maize yield variability. This relationship asserts that family labour could be more productive and requires lower monitoring costs due to the incentive compatibility because these workers are a residual claimant on farm profits. Similarly, education level of operator interacted significantly with the quantity of fertilizer application to influence maize yield in Mukuyu. Farmers need to accumulate knowledge and skills so as to maximize the efficient use of agricultural input, such as fertilizers, as well as labor input. There was also a significant interaction between the quantity of organic manure and inorganic fertilizer on maize yield. Smaller maize yield variability was observed where a combination of quantity of fertilizer and shorter distance to market was exhibited. However, in some instances the yield variability was large despite apparently good market access. This could be due to institutional and political factors constraining crop production.

Conclusion

The findings indicate the significance of CART analysis in showing a combination of factors resulting in high maize yields which can help guide soil and crop management measures to enhance yields. Maize variability was influenced by interacting socio-economic and agronomic factors resulting in significant maize yield variability in the two study sites. Higher educational levels coupled with reduced degree of land fragmentation are essential to improving maize productivity in Vihiga. The educated farmers were more likely to accept innovations and use it to enhance maize productivity. The observed variability in the use of hired labor in farm activities was partly due to the inequality in income levels of the farmers. Combination of manure and fertilizer resulted in higher maize productivity both in Mukuyu and Shikomoli demonstrating their synergistic effect on maize yield. Farmers with larger land sizes exercised more efficient input management as their cultivation is technology driven. Moreover, farmers with larger holding are generally resource-rich and could invest more in maize cultivation. The secondary effects of fertilizer input, land, and fertilizer interaction, as well as the interaction of land and seeds also showed a significant impact on maize yield, which indicates that a reasonable mix of factor input can lower the maize yield variability. Training should be conducted to farm operators to improve their technological level and to equip them with modern agricultural production skills to make up for the problems caused by aging.

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