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African Journal of Agricultural Research

Review

Agricultural intensification in Ethiopia: Review of recent research

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This review of research presents recent agricultural studies conducted in Ethiopia. After a brief contextualization of the discourse regarding agricultural research globally, material specific to Ethiopia is discussed in themes, synthesizing the types of findings, summarizing the trends and highlighting knowledge gaps. A review of this nature makes diverse research results available and accessible, facilitates knowledge translation and enables researchers to identify areas for future research.

Key words: Ethiopia, agriculture, intensification, diversification.

INTRODUCTION

Researchers, organizations and governmental bodies inside and outside Ethiopia recognize the crucial role of smallholder agriculture and have engaged in the agricultural sector for decades. However, significant debate exists as to what form of change ought to be advocated. Additionally, researchers often specialize in specific areas of agricultural research and may be unaware of the developments outside of their area of interest. This study aims to address this by reviewing recent agricultural research in Ethiopia, synthesizing the types of findings, summarizing the trends in research and highlighting areas of knowledge gaps. A brief global context will begin this work so as to contextualize the debates about the desired direction of agricultural development generally.

This review presents an overview of recently conducted research, specific to Ethiopian agriculture. Some of the material comes from 'grey' literature (such as non-governmental reports), with some studies that are small and methodologically problematic while many studies are robust, peer reviewed and appear in important academic journals. The reason that all forms of research have been included is because the aim of this review is not to analyze the validity of the studies themselves, but to present the types of findings, trends and gaps in the research conducted within recent years. Although this review presents findings from a large number of research projects, there are some that will have been missed and areas that could have been further expanded with sector-specific developments, such as irrigation technologies or innovations in crop breeding.

The first section provides a global context for the understanding and role of agriculture, and its debated direction moving forward. The review of research of Ethiopian agriculture that follows includes over one hundred published studies and is presented thematically, such as the subjects of livelihood, inputs and tenure. The discussion at the end points out areas for future research.

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GLOBAL CONTEXT

Individuals, organizations and governments interested in agriculture in Africa assert that change is required. Although, as described below, they differ as to what the change ought to entail. The world has sufficient agricultural production per capita to meet collective needs (FAO, 2002) and suggestions have been made about how production can be made more efficient and equitable (Godfrey et al., 2010). At present, chronic food insecurity persists making it clear that availability and access are as important as yield. Increasing production is vital (Wegner and Zwart, 2011), but that does not necessarily result in improved access for all. Even with highly proactive policies, the current level of availability may not increase in some countries with changes in population, food demand, global markets and climate (Vervoort et al., 2013).

According to Norman Borlaug and Jimmy Carter, African agricultural production is significantly lower than its global counterparts; average yields in Africa are one-third of Asia's, and less than one-third of its cropland uses seed developed by modern plant breeding techniques, compared to eighty-two percent in Asia (Paarlberg, 2008:vii).

Food production per capita has declined in sub-Saharan Africa since the 1980s (Carr, 2011), indicating that the *Modus operandi* will not result in improvements in human development.[1] New complexities, such as environmental change, may result in increasing scarcity (Wegner and Zwart, 2011) and create other unforeseen vulnerabilities in the existing food system (Ericksen, 2008). This is particularly the case for Ethiopia which is both expecting adverse changes as a result of climate change and is home to an economy that is agriculturally dependant (Admassu et al., 2013). The negative impact of this change will not be restricted to the agricultural sector either, and may negatively impact Ethiopian human and economic development generally (Block et al., 2008).

Global population increases in the coming decades expected to reach 9.1 billion by 2050 will largely occur in nations with relatively lower financial capacity which will face difficulty ensuring the nutritional needs of their expanding populations (FAO, 2009). This will also occur in the context of increasing global urbanization which stood at 49% in 2009 and may reach 70% by 2050 (FAO, 2009). Unlike other regions of the world, a significant proportion of the population in sub-Saharan Africa are rural and involved in smallholder agriculture.

In the countries of Eastern Africa, for example, not only are the majority involved in agriculture but the backbone of the national economies are also agriculturally-based (Salami et al., 2010). Additionally, 80% of people that suffer from malnutrition and chronic hunger are located in the rural areas, people who are largely disconnected from markets (Human Rights Council, 2010), which is mostly due to insufficient infrastructure (Aerni, 2011). As a result of these trends, particularly in the nations experiencing significant increases in population growth, agricultural policy and practice reform are advocated. The nature of these suggested reforms and the processes that ought to be initiated in order to improve and intensify smallholder agriculture are subject to on-going debate. One side of the discussion suggests that Africa can 'leapfrog' into intensification by adopting new biotechnology and synthetic inputs, amongst other, more traditional agricultural reform. The other side suggests that successful, sustainable and appropriate agricultural reform can only be done in the form of organic agro ecological practices, amongst other, more traditional agricultural reform. Although proponents of each side of the debate distance themselves from each other, many policy and practice reforms are shared by parties from all sides of the debate, as shown in (Table 1). Indeed, far more commonalities exist, as demonstrated in the (Table 1), than differences. An example of an agreed upon area of intensification is crop diversification and use of integrated pest management techniques, which can improve smallholder yields (Pretty et al., 2011).

REVIEW OF RECENT RESEARCH

As demonstrated, agricultural intensification has been defined in significantly different ways. For the purposes of this research review, intensification refers to action that makes agricultural systems more productive, which might be a result of the use of improved seed varieties, improved resource management, irrigation, farming practice(s), diversification and so forth. Intensification in a general sense does not imply sustainability or a lack thereof nor does it imply improved human or environmental resilience. That being said, many smallholder farmers are reluctant as discussed in the research to adopt new practices that are unsustainable environmentally, economically or as a result of inconsistent access and availability.

The concept of sustainability has been applied to diverse spheres from ecology to politics and has many different definitions. It is beyond the scope of this paper to explore this myriad of meanings. However, in the context of agricultural intensification, certain directions and shifts are more suited to sustained intensification than others. Increasing irrigation with a higher use rate than replenishment rate may result in higher immediate yield but is unsustainable in the long term. Resiliency on the other hand, is the ability to overcome challenges or viewed in another way, a reduction of vulnerability such that change is manageable. Ensuring land tenure

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[1] Human development here refers to the indicators of the Human Development Index, which include inequality, life expectancy, education and income. This approach to understanding development is in contrast to common analyses of gross domestic product per capita and was first developed by Mahbub ul Haq and Amartya Sen in 1990.

Table 1. Approaches of Intensification.

The Monpellier Panel (2013)	Shared	Alteiri (1993, 1995, 2000)
(i) Biotechnology	(i) Integrated Pest Management	(i) Organic Methods
(ii) Synthetic Inputs	(ii) Crop Rotation	(ii) Self Sufficiency
(iii) Herbicides	(iii) Intercropping	(iii) Sovereignty
(iv) Pesticides	(iv) Water Conservation	(iv) Traditional Practices
(v) Market Connectivity	(v) Diversification*	(v) Preserving and supporting genetic diversity within a crop
(vi) Improved Value Chains	(vi) Access to Information	
(vii) Infrastructure	(vii) Biodiversity*	
(viii) Access to Credit	(viii) Develop Social Capital	
(ix) Genetically engineered improved varieties	(ix) Low/no Plowing	
	(x) Sustainable Livelihoods	
	(xi) Precision Irrigation	
	(xii) Retain and Build Soils	
	(xii) Develop Human Capital	

*Although the same terminology are used, they are defined differently.

facilities for increased investment such as planting trees and building terrace systems, which improves resiliency to shocks such as drought or flooding as soils are retained and built and water can be utilized more efficiently. Although not a focus of this work, both sustainability and resilience will be referred to in the exploration of current research.

The research presented in this review includes all forms of research, the vast majority of which have been published within the last five years. Although a large number of studies have been included some will have been missed. Research was collected using academic databases, general search engines and keyword tracking from 2012 to 2014 (academic and general).

The objective of this overview is present in all forms of on-going research in order to identify trends and knowledge gaps. This section provides a thematic overview of recent research done in Ethiopia related to agricultural intensification. The themes were determined after having reviewed the research. The content was clustered into themes although many areas do intersect and overlap in some instances there are areas of overlap; some sections refer to others while some specific points are repeated so as to present a review that represents the interconnectedness of the research. The section that follows presents a brief summary, knowledge gaps and explores the future direction of agricultural intensification. Unless otherwise mentioned, the studies included in this section are specific to Ethiopia.

Seed and crop diversification

Ethiopia is home to a diverse array of agro-ecologies which results in an agricultural context that is significantly influenced by location (Chamberlin and Schmidt, 2012). This is further complicated with differing degrees of geographical connectivity to markets, city centers, telecommunications, roads and electricity. These infrastructural factors, although not a focus of much of the literature play an important role in supporting food security (Gebrehiwot and Veen, 2014). As a result of these diverse contexts, crop production varies widely throughout the agro-ecological zones .Although, five cereals (teff, wheat, maize, sorghum and barley) account for three-fourths of total cultivated area and almost a third of agricultural gross domestic product (Taffesse et al., 2012).

Over the last decade significant improvements have occurred in the agricultural market system (Minten et al., 2014), production has risen (Taffesse et al., 2012) and chronic food insecurity has significantly fallen (GHI, 2013).The adoption of seed developed as a result of modern breeding practices seed varieties in Ethiopia such as wheat and maize have the potential to increase food security and protect against disease (Geta et al., 2013; Joshi et al., 2011; Shiferaw et al., 2014). However, in 2007 and 2008 season, improved seed was applied on only 5% of cereal acreage (Taffesse et al., 2012). In 1970s, more than forty improved varieties have been utilized in Ethiopia although adoption during that period varied greatly being influenced by individual, community and institutional factors (Jaleta et al., 2013). Low uptake of improved seed has been attributed to supply being less than demand resulting in inconsistent availability (Spielman et al., 2012) which may continue to be the main constraint for widespread adoption of improved varieties (Tefera, 2013). With regards to the means of achieving this, efforts to stabilize market conditions through investments in infrastructure and market institutions may be more effective in signaling farmers to the long-term availability of inputs than subsidies (Larson and Gurara, 2013).

As almost all of smallholder agriculture in Ethiopia is rain-fed, crop choice and irrigation are important factors that may help address variable and deficient rainfall. As the expansion of irrigation takes investment and time, new crop types are being tested, such as mungbean, which may be suitable to arid and semi-arid regions of the country (Ambachew et al., 2014). Research on drought-tolerance of bean varieties in Ethiopia, as another example, indicates how important research and breeding can be in adapting to changing environments as well as improving yield (Asfaw and Blair, 2014). Others crops, such as disease-resistant potato have been tested and introduced (Tefera, 2013). However, more research needs to be conducted on potato varieties that are suitable to soil, rainfall and other environmental factors (Fufa, 2013).

Biotechnology

Juma and Gordon (2014) suggest that genetically modified crops should be considered as one component of system-wide agricultural improvement in Africa. Although the introduction of such crops poses potential opportunities there are also many challenges in implementation (Falck-Zepeda et al., 2013) as well as concerns about environmental impacts (Altieri, 2005). The Ethiopian Biosafety Proclamation of 2009 which banned genetically modified crops is viewed by some as unwise as it stifles innovation being driven by external pressure and having sought little national input (Demissie and Muchie, 2014; Paarlberg, 2008). The government approved the ban as a means to protect biodiversity and health. Alternatively, some argue that a well-designed regulatory framework to evaluate genetically modified crops may have facilitated research, innovation, protected health and safety allowed for Ethiopia to take advantage of appropriate and safe developments in food and non-food agricultural crops (Horna et al., 2013; Wedding and Tuttle, 2013).

Livelihood diversification

It has been suggested that biofuels markets may negatively impact land used for food production whereby farmers switch to cash crops and move away from nutrient producing crops (Wendimu, 2013). One example from a food insecure region indicates otherwise; when smallholders plant, on average, 15% of their land is for contract-based biofuel markets. The result is improved household food security and may also result in a spill over effect of increasing food crop productivity (Negash and Swinnen, 2013).

Diversification efforts are also underway to reduce vulnerability in pastoral areas. For some this includes advocating a shift away from pastoral livelihoods to ones which are supported with sedentary agriculture and non-farm related economic activity (Headey et al., 2014). Much of the research, however, looks at ways of improving production and income within the existing livelihood practice. Diversification of livestock for example supports improved dietary intake and reduces vulnerability to loss, although that may not address all forms of micronutrient deficiencies (Megersa et al., 2013).

Livestock accounts for 11% of national gross domestic product and acts as an important household level asset (Negassa et al., 2012). Yet, this important asset also requires agricultural resources and some regions are not able to supply sufficient feed suggesting that integrated extension services need to take into account livestock demands (Abera et al., 2014) as well as changing environmental conditions.

Some shifts in livestock are already underway in response to a changing climate (Yosef et al., 2013). Agricultural extension services in Ethiopia have not focused upon livestock and respective veterinary services; however, the potential for targeted programming of this nature is significant (Atsbeha, 2013). This is particularly the case for regions where specific livestock such as poultry or camel, play an important economic and nutritional role in households. Research with agro-pastoralists suggests that in addition to livestock and land, food security is linked with the educational level of both spouses and security (Asenso-Okyere et al., 2013). Other work has found that educational background was not an important factor for the level of conservation effort undertaken by those engaged in livestock production (Atanga et al., 2013). Another important factor in parts of Ethiopia is market access, as many pastoralists sell livestock that are destined for export markets (Debsu, 2013).

Irrigation

Expanding access to and availability of irrigation is not a simple process. Low seasonal river flows result in a limited area that can be irrigated by surface water throughout the year including in areas of relative water plenty such as the Lake Tana basin. As a result, expanded irrigation requires infrastructural supports (Wale et al., 2013). Investment in irrigation can contribute to poverty reduction particularly when rural markets and human capital are also developed (Hanjra et al., 2009). An additional benefit of having such infrastructure is that time spent previously obtaining water allows more time for other activities. Research in Ethiopia indicates that 1% reduction of time spent obtaining water can result in a per capita increase of food consumption by a fifth of a percent (Aklilu, 2013).

It is unrealistic for resource constrained and capacity limited community-based groups to be expected to develop institutional frameworks, achieve economic efficiency, and enact social equity within a model of environmental sustainability (Gutu et al., 2014). Many community-based organizations that are established are unable to sustain themselves and their work which is commonly due to a lack of participation and training (Simane, 2013).

However, principle-driven and policy-enforced water sharing often do not take into account complex socio-cultural factors affecting water use and water sharing. Supporting the development of sustainable and equitable water sharing systems requires consideration of a diverse array of socio-cultural, historical, environmental, political and institutional factors (Gutu et al., 2014). Although complex, meeting the irrigation needs of smallholders with sustainable use levels requires that such an investment be made which may be most effective when traditional systems are supported with research, extension services and local government.

All of the small-scale irrigation practices used in the Lake Tana basin were found to have resulted in significantly higher (27%) household income, when compared to those not using an irrigation system (Ayele et al., 2013). Research on the staple teff grain showed a three-fold yield increase when irrigated fields were compared with rain-fed ones, and the crop yield significantly dropped when it experienced seasonal water stress (Yihun et al., 2013). A study conducted in an agro-pastoral area of the Somali Region found that high levels of poverty are related to a lack of access to irrigation, as well as distance from a market, land size, off-farm activities, educational status, livestock holding and livestock diversification (Muktar et al., 2014).

Cultivation practices

A set of principles are being tested and scaled-up by the Agricultural Transformation Agency in Ethiopia, which include techniques to reduce competition between plants, increasing organic matter in soil and soil aeration which contribute to increased productivity and profitability (Abraham et al, 2014). These practices were first developed for rice intensification and are now being applied to a broad range of crops, which is on-going within Ethiopia. A study conducted in northern Ethiopia found that planting techniques including spacing and transplanting greatly affected rice yield and can shorten growing periods (Birhane, 2013). Other techniques such as row planting for teff, resulted in moderate positive impacts (Vandercasteelen et al., 2013). Intercropping is commonly practiced in parts of Ethiopia. One study of legumes found that basic intercropping reduced weeds by almost a third and that intercropping and weeding significantly increased plant height, yield and monetary benefit (Workayehu, 2014).

Fertilizers and pesticides

In the 2007and 2008 season, about 40% of cereal acreage used chemical fertilizers and pesticides were applied to 20% of cereal acreage (Taffesse et al., 2012). The Government of Ethiopia is actively promoting the use of these types of agricultural inputs yet unstable and insufficient supply is not matching demand (Spielman et al., 2012). One estimate is that Ethiopia must double its current consumption of 1.2 million metric tons of fertilizer products in order to meet the government objectives (IFDC, 2012). Many of the challenges, as with seed and crop diversification, require market stabilization and expansion, infrastructure development and the supply chain, from procurement to extension services, must be strengthened (IFDC, 2012).

Some research suggests that agricultural output might be increased by almost 60% with the appropriate input mixes in production (Tirkaso, 2013); although not as high as that theoretical figure, field studies show higher yields are significant (Abera and Abebe, 2014). Despite a rise of fertilizer use in Ethiopia, overall usage remains low, despite its profitability in use with primary cereal crops, such as wheat (Rashid et al., 2013). In many parts of Ethiopia land holdings are declining in size; in land constrained villages inputs are used more often to raise yield and income (Headey et al., 2013). However, farm size remains strongly correlated with farm income and linked with rural poverty (Headey et al., 2013).

Some innovative practices reduce the need for pesticide application and are particularly important for rural smallholders that do not have access or capacity to purchase such inputs. An example of innovative locally-developed practice is that of termite control through integrated pest management and crop choice. These improved practices may also support improved water productivity as well as rehabilitate damaged rangelands (Legesse et al., 2013; Peden et al., 2013; Taye et al., 2013). In addition to controlling pests as an alternative to pesticides, integrated management systems have the potential to significantly raise production as many farmers cite this as one of the primary reasons for loss (Mulualem and Melak, 2013).

Environmental interventions

Modeled scenarios that utilized integrated land-use redesign and conservation practices showed the greatest potential for soil loss reduction include terracing, grassed waterways and stabilization structures (Tesfahunegn et al., 2012). Vegetation cover and exclosure practices have been found to be the most effective means to prevent runoff, better utilize available water resources and prevent nutrient loss (Descheemaeker et al., 2006; Girmay et al., 2009). Exclosures can also support land rehabilitation which includes vegetation restoration as well as nutrient restoration (Mekuria et al., 2007, 2011; Yayneshet et al., 2009), although it can negatively impact horticulture and needs to be analyzed before expansion in communally used areas (Mekuria et al., 2011). Promotion of sustainable resource management practices has not resulted in widespread adoption of them by smallholders, despite struggles with soil erosion, nutrient depletion and land degradation. Educational level, contact with extension workers and slope of land positively affected farmers adoption of soil conservation technologies (Fentie et al., 2013).

One important factor found to promote uptake of new techniques and technologies was connectivity to informal networks and the size of those networks (Krishnan and Patnam, 2012). These existing networks need to be integrated with extension services in order to increase adoption (Wossen et al., 2013). Other studies suggest the role of social networks is similarly important in adoption of irrigation practices (Dessalegn, 2013).

The importance of sustainable resource management practices cannot be understated. A 25 year follow-up of a pilot terracing project showed sustained improved crop productivity as well as soil and water conservation (Adgo et al., 2013). In another follow-up study of households that maintained sustainable land and watershed management investments, a 24% higher value of production continued almost two decades after having started compared to those that did not (Schmidt et al., 2014). Such investments, however, need to be supported with other input changes to result in profitability that outweighs comparable off-farm income (Schmidt et al., 2014). This research indicates that packaged smallholder approaches will be the most effective. Two factors that have the greatest potential to inhibit adoption of new, more appropriate, practices are a lack of information and a lack of finance (Gebrehiwot and Veen, 2013).

Teklewold et al. (2013) analyze decision making of sustainable agricultural practices, its impact on income (for maize specifically), chemical input use and labour. They find that the adoption of sustainable agricultural practices increases income and the greatest increases occur when such practices are adopted in combination, rather than in isolation. Teklewold et al. (2013) also find conservation tillage increased pesticide use and demand of labour.

Sustainable land management practices must not focus solely upon yield and soil. Some areas of Ethiopia are experiencing increasingly extreme weather, particularly flooding, which include loss of yield as well as livestock, households and result in disease outbreaks (Haile et al., 2013). Planning at national, regional and district levels, as well as by individual households, must be informed by changing climate and how that may affect their respective areas of work in order to engage in planning that anticipates such changes. In this regard, sustainability planning must be considered in light of resiliency enhancing and vulnerability reducing interventions.

Soil quality and soil quality degradation significantly impact smallholder production. Smallholder knowledge and assessment of soil quality were found to be highly accurate showing that local knowledge-based assessments can be effective and low-cost, and need to be integrated into research and extension services (Tesfahunegn et al., 2011). Similar studies indicate local ecological knowledge can be used to better understand water, plant types and deforestation (Pagella et al., 2013).

In addressing the serious challenge of soil erosion, food for work and cash for work programs have been utilized as a means to implement improved land and water use. However, participants in community efforts of this nature are often not convinced of the effectiveness of processes undertaken (Gebre and Weldemariam, 2013). The government has done an effective job at raising awareness about the importance of tree planting so effective that many associate climate change only with deforestation (Cochrane and Costolanski, 2012). These successful campaigns need to be expanded and diversified so that other land and water management changes are supported the way that tree planting and reforestation are.

The expansion of smallholder agriculture and wood harvesting has resulted in high rates of deforestation in parts of Ethiopia which occurred alongside population growth and the nationalization of land, which affected forest responsibility and control. Unofficial traditional systems have had limited impact in keeping this process in check (Stellmacher, 2013). Initiatives that counter deforestation need to take into account rural household needs, such as that of wood for fuel (Bekele et al., 2013). Meeting the needs of smallholders through alternatives will be crucial in substituting the unsustainable use of forest products.

Gender

Although a framework has been proposed, limited data exist to-date on the gendered allocation of labor and resources (Arora and Rada, 2013). One study on gender differentials suggests there is a productivity gender gap in Ethiopian agriculture (Aguilar et al., 2014), while another indicates that despite participating in a wide variety of farming activities, women have little to no decision making ability (Mulugeta and Amsalu, 2014). This was suggested to be the result of a wide array of factors, such as illiteracy, socio-cultural assumptions and a lack of experience.

A majority of Ethiopian women are poor and vulnerable and are disproportionately affected by food shortages within the household (Gebreselassie and Haile, 2013). Research outside of Ethiopia suggests that agricultural development can disenfranchise women furthering existing vulnerability and economic insecurity (Carney, 2007) and there are some indications that this may also be the case with some developments in Ethiopia (Hebo, 2014).

One study in Ethiopia found that the adoption of sustainable agricultural practices increased the workload for women and suggests policy makers be aware of the potential gender-specific outcomes (Teklewold et al., 2013). A review of recent land reform suggests that despite improvements in tenure for women, these changes have not brought about change in socio-cultural and traditional norms that would allow for greater decision making power, income control, and political participation (Gebreselassie and Haile, 2013; Tefera, 2013). As such, the gains made in tenure need to be understood within this context and understood as just one of many required interventions to support the rights and empowerment of women. Some progress in policy and practice has been made in areas outside of tenure (Ogato, 2013), however implementation varies across the country (Lavers, 2014) and greater integration of efforts is required so that changes reinforce one another, rather than in piecemeal fashion.

Supportive policy

Infrastructural change can result in improvements both for smallholders and consumers in Ethiopia. An example of this is in the dairy industry, wherein supply has not kept pace with demand, yet supply chains and production technologies and extension services require investment in order to support smallholder engagement with the sector (Altaye et al., 2014; Bereda et al., 2014; Ergano et al., 2013). This is an area where the private sector and private-public partnerships may facilitate investment and market creation (Hoddinott et al., 2014). As with elsewhere, and particularly in capital-strained Ethiopia, the government cannot be relied upon to develop all sectors. It can however, support the direction of private development through. In addition to investment, knowledge and skills required to support the sector, not specifically related to livestock but also entrepreneurship, need to be embedded within education systems (Lemma, 2014).

In addition to the Government of Ethiopia's agricultural extension services and research into inputs, geographical conditions, agroecology, access to markets and population density also affect the opportunities and constrains that smallholders encounter (Chamberlin et al., 2006). In the last two decades significant expansion in road networks, telecommunications, electricity and market institutions have taken place resulting in improved market efficiency and expanded market access (Rashid and Negassa, 2012). An additional supportive proposed initiative in this realm is minimum support prices for staple crops to encourage domestic production and reduce reliance upon imports (Minot and Rashid, 2013). Innovative practice in Ethiopia, ranging from pest management to irrigation and breeding, is on-going and shows great potential (Abebe et al., 2013).

Much of the research done in recent years has been conducted by local researchers and government in collaboration with smallholders. Supporting innovation is an area that agricultural extension can work more on, in order to bring together respective resources and expertise as well as share lessons learned. New opportunities, such as rapidly expanding mobile network coverage and mobile ownership as experienced in Uganda, present potential for integration with extension services and information sharing (Campenhout, 2013). This might include enabling farmers to have greater access to market prices, facilitate increased information sharing amongst informal social networks and increase the accessibility of information sources via such technologies.

Safety net

In 2005 the Government of Ethiopia launched the Productive Safety Net Programme which would support food insecure individuals and households to ensure their needs are met and assets not depleted. Although not directly related to agricultural research per se, the safety net is linked with agriculture in that many of its manifestations support agricultural development through the protection of asset loss, creation of infrastructure and food security. Analyses of the Productive Safety Net Programme in Ethiopia found that the program is effective (IFPRI, 2013a; Katane, 2013), targets beneficiaries (Fisseha, 2014; Kassa, 2013), positively impacts child nutrition in the shot-term (Debela et al., 2014) and positively influenced the adoption of fertilizer, with no known disincentive impacts (Bezu and Holden, 2008).

Despite regional variation of the Productive Safety Net Programme, it is more targeted than the average global safety net program and better than any other reported African programs (Coll-Black et al., 2012). The safety net has improved since its inception (Hoddinott et al., 2013) and can become increasingly effective as capacity at the district level increases and improved data and predictive models forecast drought with greater accuracy (Belayneh et al., 2014; Tadesse et al., 2014).

Other research challenges the effectiveness of the program. One study found disincentives for creating successful systems done by those involved in the Food for Work program and that failure helps secure employment in the program (Segers et al., 2008). Another study found the Programme is effective at protecting household food security and maintain asset levels but was not an effective mechanism to overcome poverty or result in the governmental objective of food self-sufficiency (Maxwell et al., 2013; Rahmato, 2013; Siyoum, 2013). Some suggest that the impact of these programs may be limited in terms of sustained change when compared with enhancing land tenure security through on-going certification systems (Gebremariam et al., 2013), however they appear to be highly effective at targeting those in need and working towards the provision of basic needs (Devereux and Teshome, 2013).

Insurance and credit

In the last decade millions of Ethiopians were affected by drought; 12.6 million in 2003, 2.6 million in 2005, 6.4 million in 2008, 6.2 million in 2009, 4.8 million in 2010 and 1 million in 2012 (IFPRI, 2013b). This emphasizes the importance of social safety nets as well as the potential that smallholder insurance schemes could play in Ethiopian smallholder agriculture and the role they may play in light of on-going climate change. Farmers that were offered insurance but did not take it were correlated with areas that were covered by social safety net programs, thus safety nets may potentially impact uptake of insurance negatively (Oren, 2013). That study also indicates that governmental trust and therefore reliance upon safety nets, may be stronger than that of alternative market-based options, finding that greater governmental credibility results in less insurance uptake (Oren, 2013).

The availability of formal credit in Ethiopia is limited due to banking regulations within the country, which also restrict non-governmental action that would provide such a service as a stand-alone service or part of a package. However, credit and insurance are important supports for smallholder intensification. The provision of credit is key to the work of One Acre Fund, whose work has supported more than 130,000 smallholders in East Africa, resulting in two- to three-fold yield increases and a doubling of farm profits, with a 98% repayment rate (Juma, 2011; One Acre Fund, 2014). The organization is currently running pilot projects in Ethiopia, with plans for expansion. More research is required to support the development of an enabling environment that is supportive of micro-credit services and meets the credit needs of smallholders.

Credit rationing systems, often practiced in informal forms in Ethiopia, are commonly linked with social and political networks (Ali and Deininger, 2012). These play an important role throughout the country and more research is needed to understand the potential, demand and methods of the practice as well as the means available to support and formalize existing informal credit systems. Such research also needs to take into account who takes part in these informal systems and who is excluded from them, which may be a result of gender, ethnic or religious difference. Supporting informal networks that exclude marginalized members of society may further entrench their marginalization.

Tenure

The Ethiopian Constitution prohibits the sale or exchange of land, which is owned by the state, and people (nationals or foreigners) are limited to land use rights (Mekonnen, 2012). The government has initiated a land-use certification system as a means to ensure tenure within its current system. In general, land rights result in increased investment (Deininger et al., 2003). The Ethiopian land certification system allows for analysis of this question. The Government of Ethiopia’s land certification system that affirms the right to use land has protected tenure, reduced disputes, increased land security and therefore investment enhanced women’s control of land and helped to improve yield (Deininger et al., 2007, 2009; Gebre-Egziabher, 2013; Hagos and Holden, 2013a; Hagos and Holden, 2013b; Holden et al., 2011). These outcomes support development of resiliency, as smallholders feel more secure with their land, make investments that enhance soils and improve resource management.

External advocacy and international donors have long suggested Ethiopia privatize land ownership and land sale, although the current system is not foreign to Ethiopia historically (Crewett et al., 2008). The restrictive nature of land use rights may have resulted in inefficient types of land use (Deininger et al., 2011), but the restrictive nature of tenure and rules regarding land use inheritance may have other purposes, such as slowing the rate of urbanization. Population growth rates are high in Ethiopia with its current 93 million person population expected to reach 119 million by 2030 and 145 million by 2050 (Evans, 2012). Its urban population is relatively low, under twenty percent, but the country is urbanizing and is expected to reach one-third urban by 2040 (Evans, 2012). The government recognizes these challenges and is working to address both population growth and urbanization rates. For example, during the last two decades Ethiopian contraceptive use has increased nine-fold and the fertility rate fell from seven to under five (Olson and Piller, 2013). However, relatively lower population growth rates have not been matched by sustainable agricultural output growth, resulting in high import costs to meet demand (Demeke et al., 2013).

There are concerns that the lease of large tracts of land in Ethiopia will negatively impact smallholders (Rahmato, 2011), decrease local accessibility and food security (Cochrane, 2012) and result in human rights violations (Human Rights Watch, 2012; Makki, 2013). However, recent developments indicate that the scale of land leases are not as large as originally assumed (Cotula et al., 2009) and that human rights abuses may not be as extensive as claimed (Cochrane and Thornton, 2014). Some leases have already been ended by government and/or investors and the government has implemented new land size restrictions for agricultural investment (Africa Intelligence, 2013; Hallam, 2013).

In the small versus large farm debate which underlies the smallholder-investor discussion, it appears that size itself does not result in greater productivity while the practice of efficient farming does (Deininger et al., 2013). In the Ethiopian context, smallholders work most of the agricultural land with low technical efficiency (Geta et al., 2013), thus focusing on smallholder intensification can result in the same levels of productivity as large investment firms, while at the same time protecting rights and livelihoods.

TRENDS AND GAPS

Despite a significant amount of research in agricultural intensification, there are knowledge gaps that require continued research and dissemination. Research on diversification particularly with improved varieties as well as crop types has received a significant amount of research yet uptake remains low and requires more research to ensure that smallholders benefit from the developments in this area.

Irrigation research has indicated the potential and need as well as the complexity, and the large gaps at this stage are in the area of implementing sustainable, relatively low-tech, irrigation systems and water harvesting/storage systems so that irrigation is available throughout the dry season. Important research is available on the potential practices to manage land, soil and water.

However, more research is needed in understanding how to support smallholders to utilize these practices. Much more research is needed in order to understand the gendered nature of agricultural practice in Ethiopia. Innovative practices may not be the result of research directly, but research can support innovation through evaluation, dissemination and collaboration with extension services to expand the use of effective practices. Working with smallholders as well as sharing that research with extension service agents will enable research and researchers to pay an important role in the on-going intensification process. Similarly with systems development, areas in need of systematic change require multi-stakeholder engagement of which researchers may play an important contributing role. Potential efficiencies in this realm are numerous and on-going, and research has the potential to support systematic and policy change that can result in improvement for entire sectors. The relationship between social programs and market services require a greater understanding, as the government cannot annually support millions for the long-term. Research may indicate directions for the program to support beneficiaries to overcome poverty traps and graduate from the program, potentially through engagement with market services. This may include the expanded provision of credit and insurance as well as the development of markets and infrastructure.

In addition to the on-going research, there needs to be greater attention given to the relationships between on-going changes so that research anticipates change in a holistic fashion. In particular, this means better understanding the role of climate change, vulnerability and resiliency in smallholder agriculture. Current seed development, for example, may be suitable for current rainfall but may not be as suitable for different rainfall patterns or take place within agricultural settings that are able to withstand weather of events of greater intensity. As Ethiopia has a history of both drought and flooding, agricultural research should be connected with, and feedback into, research related to climate change, which also needs to be integrated with research about vulnerability and resiliency. This is particularly important as some research indicates outcomes contrary to what might be expected (Bezabih et al., 2014).

CONCLUSION

Improved agricultural productivity for smallholders can reduce poverty and improve household welfare (Abraham et al., 2014; Abro, 2014). A review of 40 projects of intensification in Africa suggest a number of key lessons ought to be integrated, shared and scaled-up in on-going and future work. These include:

(1) Scientific and farmer input for technology and practice development
(2) Creation of new social infrastructure
(3) Improvement of farmer knowledge and capacity
(4) Engagement with the private sector
(5) Improving the participation of women in intensification activities
(6) Ensuring the availability of financing or banking
(7) Ensuring public sector support for agriculture (Pretty, Toulmin and Williams, 2011).

This review of recent agricultural research in Ethiopia has found that a significant amount of research is being done and that international and national bodies as well as individual researchers are investing in this sector.

Research to-date has supported the yield increase experience in Ethiopia since the 1990s and offers new knowledge for continued improvement and expanded practice of newly developed and improved techniques, inputs and management approaches.

In addition to providing an overview of the recent research trends, this work highlights specific areas for future research as well as areas of on-going debate and discussion. The Government of Ethiopia recognizes the importance of smallholders and is investing in smallholder agriculture. It is doing so through research and services with international support acting upon a home-grown development plan that is driven by the objectives of the state. The result has not been perfect. It has however resulted in Ethiopia becoming one of the world's fastest growing economies becoming one of the nations to make the most progress on the Millennium Development Goals and having made significant progress in reducing hunger and protecting against famine. Governmental support for smallholders and smallholder agriculture has been an important factor in these changes. Although progress in some areas has not moved as swiftly as many hoped, it is expected that human and economic development, supported with an agricultural foundation, will continue to progress at higher than global average rates. This is needed as demand outstrips supply and population growth rates continue to be higher than agricultural production growth rates. On-going research strengthens the intensification process. The Government of Ethiopia has been supportive of agricultural research and researchers, which provides additional incentive for continued research as many decision makers are engaging with, and responding to, the findings.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Impact of adoption of scientific interventions in fenugreek on grain yield and farmers income: An assessment by FLD's in Arid Zone of Rajasthan, India

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Fenugreek is one of the major seed spice crop grown in India and mainly cultivated in the state of Rajasthan. The crop occupies about 94000 ha area with annual production of 116000 tonnes (2011-12). Front line demonstrations (FLDs) on fenugreek with three interventions (improved varieties, line sowing and seed treatment) were conducted at Farmers' fields of adopted village Alniawas in district Nagaur of Rajasthan state during winter season of the years 2009 to 2010, 2010 to 2011 and 2011 to 2012. On the basis of three years' overall average, it is inferred that about 23.51 higher grains yield was recorded under FLDs than that of the farmers' traditional check/ practice. The study exhibited mean extension gap of 299 kg ha-1, technology gap of 929 kg ha-1 with mean technology index of 37.16%. An additional investment of Rs. 1400 ha-1 coupled with recommended nutrient, water management, plant protection measures, scientific monitoring and non-monetary factors resulted in additional mean returns of Rs. 8970 ha-1. The overall average Incremental benefit: Cost ratio was calculated as 6.41.

Key words: Economics, fenugreek, front line demonstrations (FLDs), gap analysis, grain yield.

INTRODUCTION

Fenugreek (*Trigonella foenum graecum* L.) commonly known as *Methi,* is an important self pollinated seed spice crop belonging to subfamily *Papilionaceae* of the family *Fabaceae* (Suleiman et al., 2008). It is native of South Eastern Europe and West Asia and has been part of North African Countries, Argentina, France, Morocco and Lebanon. India is the major producer of fenugreek and its production is concentrated mainly in the states of Rajasthan, Madhya Pradesh, Maharashtra, Punjab, Gujarat and Uttar Pradesh. The major districts growing fenugreek in Rajasthan are Sikar, Chittorghar, Jaipur, Pali, Nagaur, and Alwar. In India the area under fenugreek is 94000 ha with production of 116000 tonnes and average national productivity (yield) is 1200 kg/ha during 2011-12 (Anonymous, 2012). The seeds are mainly used as flavoring agent in many vegetable preparations and having high medicinal and neutraceutical value. Fenugreek seed contains protein (9.5%), fat (10%), crude fiber (18.5%), carbohydrate (42.3%) and many other minor nutrients and vitamins.

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It also contains good percentage of gums (20.06%), mucilage (28%), trigonelline (0.13 to 0.30%), and saponin (1.7%) with 370 calories per 100 g calorific value (Budaavari, 1996).

The average productivity of fenugreek in India is remaining less (1200 kg ha^{-1}) in spite of making tremendous efforts by various developmental agencies. The major factors responsible for low productivity are: low level of awareness among the farming community about area specific recommended package of practices, less availability of high yielding and resistant varieties seed, lower adoption of recommended plant production and protection technologies. Traditionally farmers are using the seed available with them and most of the time they take advice from fellow farmers. Simultaneously, the availability of quality seed near the vicinity of farmers is also less. Earlier the fenugreek was grown only for fodder purpose and broadcasting was in practice to maintain the high density. Later on farmers started cultivation of fenugreek for grain but with the old method of sowing i.e. broadcasting. Line sowing with recommended crop geometry enhances the yield as the seed is placed at right place leads to proper germination and plant vigour besides it facilitate easy weeding and hoeing. The competition of crop with respect to light, air, water and nutrient is reduced if sown in line. In the initial growth phase fenugreek crop is infected by bacterial wilt and rhizoctonia root rot cause the loss in the rage of 15 to 30%, some times more. These diseases can be cured with proper seed treatment with Trichoderma or bavistin.

Introduction of high yielding varieties can boost the yield levels in the adopted areas. Farm mechanization and appropriate plant protection measure with the recommended package of practices (nutrition, irrigation and intercultural operations etc.) can also play a crucial role. Besides these, effective management of biotic and abiotic stresses at crucial time with the help of available chemicals and organic means is also very important to increase the productivity and production of the crop, which ultimately enhanced the net returns and benefit cost ratio of the growers.

Therefore, to assess the impact of adoption of improved package of practices in fenugreek, village Alniawas located in Nagaur district in the central arid part of Rajasthan state was selected. The selected areas predominantly have sandy soils and cool and dry winter having temp range of 4 to 30 °C. The farmers of this district were away from the adoption of improved agricultural technologies (Garhwal and Arora, 2013) and were practicing the farming with available local varieties and practices for fenugreek. Keeping these facts in view, three high yielding varieties of fenugreek with the scientific interventions like seed treatment and line sowing (with improved seed cum fertilizer drills) through front line demonstrations were tested on fifteen farmer's fields with the following objectives:

1. To exhibit the performance of high yielding fenugreek varieties with scientific interventions at large scale under common package of practices;
2. To compare the yield levels of local (checks) cultivar cultivated using local practices with improved varieties cultivated following mechanized sowing and seed treatment method; and
3. To calculate and compare the economics incurred in following farmers' practice and in adopting scientific interventions (improved varieties, mechanized sowing and seed treatment).

MATERIALS AND METHODS

The present study was carried out by National Research Centre on Seed Spices (NRCSS), Ajmer under national agricultural innovation project (NAIP) Component-2 on "Value chain in major seed spices for domestic and export promotion" during *rabi* season from 2009 to 2010 to 2011 to 2012 (03 years) at farmers' fields of adopted village Alniawas of Nagaur district of Rajasthan having arid climate. About 15 frontline demonstrations per year in about 3.75 ha area on the fields of different farmers were conducted every year. Each demonstration was of 0.25 ha area. The soils of the Alniawas village is sandy in texture with low nitrogen (70 to 20 kg ha^{-1}), low to medium phosphorus (12 to 15 kg ha^{-1}) and medium to high potash (150 to 250 kg ha^{-1}) having organic carbon from 0.26% to 0.45% with low water holding capacity. Three varieties of fenugreek *viz.,* RMt-305, AFg-1 and Afg-2 (Table 2) were tested through front line demonstrations (FLDs) with seed treatment and line sowing and interventions compared with local variety grown with farmer's practices. The materials and inputs required for the study with respect to front line demonstrations (technologies demonstrated) and farmers' practice are given in Table 1.

In demonstration plots, few critical inputs in the form of quality seed, balanced fertilizers, and agro-chemicals for plant protection measures were provided and non-monetary inputs like timely sowing in lines and timely weeding and irrigation were also performed. Whereas, traditional practices were followed in case of local practice or local checks. The farmers who adopted scientific intervention under FLD's were guided in performing field operations like field preparation, sowing, spraying weeding, harvesting etc. through regular trainings and visits. One On-campus and two Off-campus trainings were also organized for the group of beneficiaries under FLD's.

Seed treatment was done with *Trichoderma viride* (6 g kg^{-1}) and Bavistin (2.5 g kg^{-1}) in a closed container and then shade dried for some time before sowing. Line sowing was performed with the help of multi seed spices seed cum fertilizer drills developed by CIAE, Bhopal (RK Agro Model) and by a local manufacturer of Sanderao town, district Pali, Rajasthan (Sanderao Model). For balanced nutrition, the crop was fed with 25 kg N and 25 kg P_2O_5 ha^{-1} through urea (46% N) and DAP (18 % N and 46% P_2O_5) at the time of sowing. Two sprays of malathion (0.2%) at 15 days interval for the control of aphids (on incidence) and one spray of dinocap (0.1%) for the control of powdery mildew (on initial appearance of symptoms) were given. Growing of locally available seed of fenugreek without seed treatment and fertilization with indiscriminate use of pesticides and fungicides is the farmer's practice prevailing in the area. Sowing was done during third week of October. The demonstrations were conducted to study the gaps between the potential and demonstration yield, extension gap and technology index. Data with

Table 1. Details of existing farmers' practices and scientific interventions for fenugreek cultivation.

S/No.	Farmers' practice	Intervention	Scientific proven technology demonstrated
1.	Locally available seed	Use of improved seed	RMt-305, AFg-1 and AFg-2 as improved varieties 1st from SKNCOA (SKRAU), Jobner (Rajsthan), India and 2nd & 3rd from NRCSS, Ajmer (Rajasthan), India
2.	Broadcasting	Sowing method	Line sowing by 02 tractor operated multi seed spices seed cum fertilizer drills (Sanderao Model- procured from a local manufacturer from Pali district of Rajasthan and R.K Agro Model from Rajkot, Gujarat, India)
3.	No seed treatment	Seed treatment	Seed treatment by Bavistin (2.5 g kg^{-1} seed) and *Trichoderma viride* (6 g kg^{-1} seed)

respect to grain yield from FLD plots and from fields cultivated following local practices adopted by the farmers of the area were collected and evaluated. Potential yield was taken in to consideration on the basis of standard plant population (333330 plants/ha) and average yield per plant (7.5g/ plant) under recommended package of practices with 30 × 10 cm crop geometry (Kakani et al., 2009). Different parameters as suggested by Yadav et al. (2004) was used for gap analysis, and calculating the economics. The details of different parameters and formulae adopted for analysis are as under:

Extension gap = demonstration yield (DY) – Farmers' practice yield (FPY)
Technology gap = Potential yield (PY) – Demonstration yield (DY)

$$\text{Technology index} = \frac{\text{PY- DY}}{\text{PY}} \times 100$$

Additional cost = Demonstration cost – Farmers' practice cost
Effective gain = Additional returns – Additional cost
Additional returns = Demonstration returns – Farmers' practice return
Incremental B: C Ratio = Additional returns / Additional cost

RESULTS AND DISCUSSION

Grain yield

It is revealed from the performance (Table 3) of the interventions given that significant increase in the yield was recorded in all the FLDs in all the years of the study period. Adoption of improved varieties of fenugreek exhibited 17.80 to 24.86% more yield over the local check, however the mean yield of AFg-1 and AFg-2 was at par. The fluctuation in yield can be explained on the basis of variation in prevailing social, economical and microclimatic conditions of that particular site and year as RMt-305 performed better in first year. Mukharjee (2003) and Jaitawat (2006) has also opined that depending on identification and use of farming situation, specific interventions and microclimatic conditions may have grater implications in enhancing system productivity. Line sowing with the help of seed cum fertilizer drill gave 19.30% (Sanderao Model) to 30.74% (RK Agro Model) higher yield over traditional broadcasting practice. Furrow opener of RK Agro seed drill is relatively wider than Sanderao model, hence placement of seed is at proper depth leads to higher germination percentage and plant vigour, which consequently increased the yield of fenugreek per plant as well as per unit area. Broadcasting leads to higher plant population, gives least facility for weeding and hoeing resulted into more competition for light, air, water and nutrients. Therefore, plant vigour become poor and yield per plant and per unit area remains low. Similarly seed treatment with bavistin exhibited 16.23% and *Trichoderma* 28.33% higher yield over local practice i.e. sowing without seed treatment. Scientific interventions with improved varieties and recommended package of practices were the factors responsible to exploit higher yields over traditional checks/ practices. Further, it is very much clear from the study (Table 4) that, in fenugreek grain yield, significant improvement was recorded with the interventions (improved varieties, seed treatment and line sowing) given in demonstrations as compared to farmers' existing practices. Maximum yield (1649 kg ha^{-1}) under FLDs was recorded in the year 2011 to 2012, which was 24.08% higher than the yield (1329 kg ha^{-1}) obtained under farmers' practice. The increase in grain yield under demonstrations was 23.09 to 24.08 per cent higher than farmers' local practices. On the basis of the above study, it is inferred that an overall yield advantage of 23.51% over farmers' practices was recorded with per hectare yield of 1571 kg ha^{-1} under demonstrations carried out with improved varieties and scientific cultivation practices (Table 4). Similar findings have also been reported by Lal et al. (2013) and Singh et al. (2011).

Gap analysis

Evaluation of findings of the study (Table 4) stated that an extension gap of 284 to 320 kg ha^{-1} was found between demonstrated technology and farmers' practice

Table 2. Brief information about fenugreek varieties.

Name of variety	Brief description	Year of release	Recommended area of cultivation	Potential yield (kgha^{-1})	Maturity duration (days)
AFg-1	Indeterminate type, pure line selection, erect type plant, single pods on nods, medium duration maturity, seeds bold and large, 17-20 seeds per pod.	2005	Rajasthan state of India	2500	137
AFg-2	Indeterminate type, pure line selection, long erect type plants, single or double pods on nods, medium duration maturity, seeds small in size, 16-18 seeds per pod.	2005	Rajasthan state of India	2500	138
RMt-305	Mutant of variety RMT-1, First determinate type, dwarf, early maturing, synchronous maturity, bold size seed, pods in bunches.	2007	Rajasthan state of India	2500	120

Source: Kakani et al. (2009) and personal communication with Dr. Dhirendra Singh, Professor (PBG), SKN College of Agriculture (SKRAU), Jobner, Rajasthan, India and Breeder of RMt-305 fenugreek.

Table 3. Yield performance of different varieties of fenugreek and scientific intervention as compared to local practices during 2009 to 2012.

Interventions		**Yield (kgha^{-1})**				**Yield increase over local check or practice (%)**
		2009 to 2010	**2010 to 2011**	**2011 to 2012**	**Mean**	
Improved varieties	RMt-305	1795	1390	1420	1535	17.80
	AFg-1	1600	1650	1620	1623	24.61
	AFg-2	1450	1780	1650	1627	24.87
	Local check	1300	1250	1360	1303	-
Line sowing by seed drill	Sanderao Model	1300	1450	1571	1440	19.30
	RK Agro Model	1412	1590	1733	1578	30.74
	Traditional practice (Broadcasting)	1160	1220	1240	1207	-
Seed treatment	Bavistin (2.5 g kg^{-1})	1400	1460	1694	1518	16.23
	Trichoderma (6g kg^{-1})	1520	1650	1857	1676	28.33
	No seed treatment	1180	1350	1387	1306	-

Table 4. Technological gap analysis of front line demonstrations on fenugreek at farmers' fields.

Year	Number of FLDs	Potential yield (kgha^{-1})	FLD yield (kgha^{-1})	Farmers' practice yield (kgha^{-1})	Yield increase (%)	Extension gap (kgha^{-1})	Technology gap (kgha^{-1})	Technology index (%)
2009 to 2010	15	2500	1497	1213	23.41	284	1003	40.12
2010 to 2011	15	2500	1567	1273	23.09	294	933	37.32
2011 to 2012	15	2500	1649	1329	24.08	320	851	34.04
Overall average	15	2500	1571	1272	23.51	299	929	37.16

Table 5. Economic analysis of technological interventions on fenugreek at farmers' field.

Year	Cost of cash input ($Rs.ha^{-1}$)		Add. Cost in FLD* ($Rs.ha^{-1}$)	Sale price of grain ($Rs.ha^{-1}$)	Total returns ($Rs.ha^{-1}$)		Add. Returns in FLD ($Rs.ha^{-1}$)	Effective gain ($Rs.ha^{-1}$)	INC B:C ratio (IBCR)
	FLD	FP			FLD	FP			
2009-10	3700	2300	1400	30	44910	36390	8520	7120	6.09
2010-11	3700	2300	1400	30	47010	38190	8820	7420	6.30
2011-12	3700	2300	1400	30	49470	39870	9600	8200	6.86
Overall average	3700	2300	1400	30	47130	38160	8970	7570	6.41

FLD: Front line demonstration, FP: Farmers' practice, INC: Incremental; *Cost of seed drill is Rs. 32000.00 and life assumed 10 years. The hiring cost of seed drill is Rs. 300/ha.

and on average basis the extension gap was 299 kg ha^{-1}. The extension gap was highest (320 kg ha^{-1}) during 2011 to 2012 and lowest (284 kg ha^{-1}) during 2009 to 2010. Such gap might be attributed to adoption of improved technology especially high yielding varieties sown with the help of seed cum fertilizer drill with balanced nutrition and appropriate plant protection measures in demonstrations which resulted in higher grain yield than the traditional farmers' practices. The study further exhibited a wide technology gap during different years. It was lowest (851 kg ha^{-1}) during 2011 to 2012 and highest (1003 kg ha^{-1}) during 2009 to 2010. The average technology gap of all the years was 929 kg ha^{-1}. The difference in technology gap in different years is due to better performance of recommended varieties with different interventions and more feasibility of recommended technologies during the course of study.

Similarly, the technology index for all demonstrations in the study was in accordance with technology gap. Higher technology index reflected the inadequate transfer of proven technology to growers and insufficient extension services for transfer of technology. On the basis of three years study, overall 37.16% technical index was recorded, which was reduced from 40.12% (2009 to 2010) to 34.04% (2011 to 2012). Hence, it can be inferred that the awareness and adoption of improved varieties with recommended scientific package of practices have increased during the advancement of study period. These findings are in the conformity of the results of study carried out by Meena and Singh (2011), Meena (2011), Meena and Singh (2013) and Dayanand et al. (2012).

Economic analysis

Variables like seed, fertilizers and pesticides were considered as cash inputs for the demonstrations as well as farmers' practices. Data of economic analysis presented in Table 5 exhibited that, an average additional amount of Rs. 1400/ha was incurred under demonstrations (FLDs) as compared to FP. Economic yield as a function of grain yield and sale price were taken into consideration. Maximum additional returns (Rs. 9600/ha) were obtained in the year 2011 to 2012 due to higher grain yield. The higher additional returns and effective yield obtained under demonstrations could be due to improved variety, scientific proven technology, non-monetary factors, timely operations of crop cultivation and scientific monitoring. The lowest and highest incremental benefit: cost ratio (IBCR) was 6.09 and 6.86 in the year 2009 to 2010 and 2011 to 2012, respectively depends on obtained grain yield. Overall average IBCR was found as 6.41. The results of the study corroborate the findings of front line demonstrations carried out by Lal et al. (2013) on cumin and Singh et al. (2011) on seed spices.

Conclusion

Average yield of the FLDs with improved varieties and scientific technologies was 23.51% higher than the yield under farmers' practice. Front line demonstration program was found to be effective in changing attitude, skill and knowledge by using improved varieties and recommended package of practices of fenugreek cultivation including adoption. It has been verified that yield advantage can be attained by the use of improved varieties, seed treatment, line sowing, application of balanced nutrition with appropriate plant protection measures on farmer' fields. Two varieties of fenugreek (AFg-1 and AFg-2) can be recommended for central arid Rajasthan with technological interventions like line sowing and seed treatment with *Trichoderma viride* (6 g kg^{-1}) or bavistin (2.5 g kg^{-1}).

Conflict of Interests

The authors have not declared any conflict of interests.

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Review

Recent advances towards understanding and managing Kenyan acid soils for improved crop production

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This review focused on the efforts made to understand and manage Kenyan acid soils by use of inorganic, organic materials (OMs) and crop germplasms tolerant to soil aluminium (Al) toxicity and/or low soil available phosphorus (P). Kenyan acid soils which occupy 13% of the total land area were developed through parent materials of acid origin, leaching of base cations and use of acid forming fertilizers. They are high in Al (>2 cmol Al/kg and > 20% Al saturation) and low in soil available P (< 5 mg P/kg soil) due to moderate-high (107-402 mg P/kg) P sorption, hence crops recover only 9.6 to 13.5% of the P fertilizer. Application of lime, P fertilizer and OMs increases soil pH, available P and reduces Al toxicity on Kenyan acid soils. Lime, P fertilizers and OMs have increased maize grain yield by 5-75, 18-93 and 70-100%, respectively on Kenyan acid soils. Similarly, deployment of crop cultivars tolerant to Al toxicity and/or low soil available P increases crop yields. However, lack of knowledge on the importance of lime, credit to purchase farm inputs, crop varieties tolerant to soil acidity constraints and inadequate amounts of OMs limits crop yield on Kenyan acid soils.

Key words: Acid soils, lime, phosphorus, organic materials, tolerance to soil acidity.

INTRODUCTION

Soil acidity is a widespread limitation to crop production in many parts of the world (van Straaten, 2007). The total area covered by acid top soils is estimated to vary from 3.777×10^9 to 3.950×10^9 ha (Eswaran et al., 1997; von Uexkull and Mutert, 1995), which represents 30% of the total land area of the world. Most acid soils are found in South and North America, Asia and Africa. They occupy about 40% of the total arable land area in the world, most of which are found in the tropical and subtropical regions (Haug, 1984). About 43% of tropical land area comprising 68, 38, and 29% of Tropical America, Tropical Asia and Tropical Africa, respectively, are acidic (Panday et al., 1994). Acid soils occupy about 13% (7.5 million ha) of the Kenyan total land area (Figure 1) (Kanyanjua et al., 2002). Strong soil acidity is associated with Al, H, iron (Fe) and manganese (Mn) toxicities to plant roots in the

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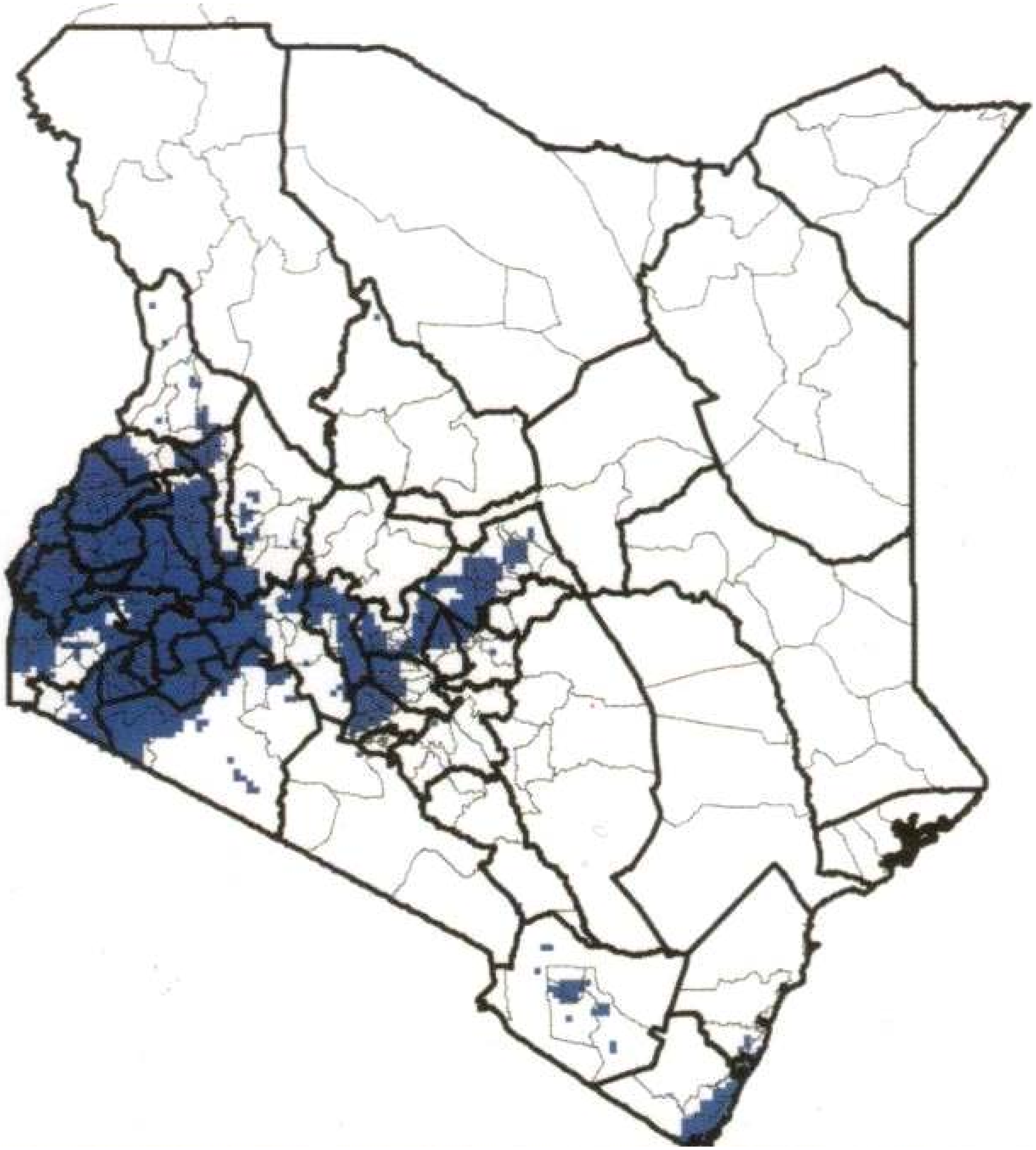

Figure 1. Map of Kenya with shaded areas showing acid soils. Sources: Kanyanjua et al. (2002).

soil solution and corresponding deficiencies of the available P, molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium–(K) (Giller and Wilson, 1991; Jorge and Arrunda, 1997).

Excess H^+ ions in acid soils are toxic to plant roots, negatively affect root membrane permeability thus interfering with ion transport and could lead to loss of the previously absorbed cations and organic constituents (Foy, 1984). However, the main constraint to crop production in highly acid soils is not high H^+ ions *per se*, but the increased concentration of highly toxic Al^{3+} ions at pH < 5.5 (Sale and Mokwunye, 1993). Aluminium toxicity in acid soils inhibits root development which leads to reduced water and mineral uptake resulting in an overall

Table 1. Soil pH, exchangeable Al^{3+} and percent Al saturation.

Region	Location (latitude and longitude)	Sampling site	Soil pH (1: 2.5; soil: water)	Exchangeable Al^{3+} (cmol/kg)	% Al Saturation
Western Kenya	0° 14.466”N and 34° 13.415”E	Sega	4.65	2.07	33
	0° 18.910’N and 34° 13.231’’E	Bumala	4.62	2.01	27
	0° 36.781’’’Nand 35° 18.280’’E	Kuinet	4.55	2.24	34
Highlands east of RV	0° 25.004’’S and 37° 30,062’’E	Kavutiri	4.07	4.29	71
	0° 40.883’’S and 36° 56.097’’E	Kangema	4.69	3.32	45
	0° 28.181’N and 35° 15.752’’E	Kerugoya	4.85	2.71	42

Source: Kisinyo (2011).

poor plant growth and low crop yields (Kochian, 1995; Kanyanjua et al., 2002; Ligeyo and Gudu, 2005). Al toxicity reduced root growth in Al toxicity sensitive maize inbred lines than the tolerant ones grown under similar conditions (Ouma et al., 2013). Kenya acid soils contain high Al (normally > 20% Al saturation), low P (< 5 mg P/kg soil) and N (< 0.2% total N) reduce maize yield by 16, 28 and 30%, respectively (Okalebo et al., 1997; Kisinyo, 2011; Ligeyo, 2007). As a result, maize grain yield are low and has been declining over the years (Ayaga, 2003). This review focuses on the efforts made so far to understand and manage the Kenyan acid soils by use of inorganic, organic materials (OMs) and germplasm tolerant to Al toxicity and/or low soil available P crop cultivars for improved crop production in acid soils of Kenya.

TOWARDS UNDERSTANDING THE KENYAN ACID SOILS

Attempts have been made towards understanding the extent and behaviour of Kenya acid soils. According to Kanyanjua et al. (2002) acid soils occupy about 13% of the Kenyan land area. Most of these soils are found in the highlands east of Rift Valley (RV) and western Kenya regions (Kisinyo, 2011; Obura, 2008). Because of high rainfall, they are found in the medium to high potential agricultural areas where most crops are grown (Jaetzold and Schmidt, 1983). However, due to high rainfall, most base cations in these acid soils have been leached hence the predominant exchangeable cations are H^+, Al^{3+}, Fe and Al^{3+} and Mn^{2+} ions (Kisinyo, 2011; Obura, 2008). Continuous use of acidifying fertilizers and reclamation of peat soils such as Gleysols (e.g. Yala swamp) has also led to soil acidification (Sombroek et al., 1982; Kanyanjua et al., 2002). To a large extent, most Kenyan acid soils were developed from non-calcareous parent materials such as syenites, phonolites, trachytes, olivines, older basic tuffs and nepholites which are acidic in nature (Sombroek et al., 1982).

Acid soils in the highland east of RV and western Kenya are strongly acidic (pH 4.5 to 5.0), have high exchangeable Al^{3+} ions and % Al saturations (Table 1) (Kisinyo, 2014). Exchangeable Al^{3+} ions > 2.0 cmol /kg are considered excess for many crops (Landon, 1984) while Al saturation > 20% cannot be tolerated by most improved maize germplasm in Kenya (Ligeyo, 2007). At soil pH < 5.0, Al minerals hydrolyse to form octahedron hex hydrate (Al^{3+}) and mononuclear hydroxides [$Al(OH)^{2+}$ and $Al(OH)_2^+$] which are responsible for P sorption (Kinraide, 1991; Kochian, 1995). High exchangeable Al^{3+} in the Kenya acid soils has led to P sorption in these soils (Kisinyo et al., 2013; Obura, 2008). The predominant clay minerals in the Kenyan acid soils include kaolinite, gibbsite, goethite, Al and Fe oxides (Obura, 2008; Otinga, 2012). These minerals are common in tropical acid soils and are responsible for high P sorption (Buresh et al., 1997; Obura, 2008; Tisdale et al., 1990; Uehabra and Gillman, 1981). Phosphorus sorption in the Kenya acid soils range from moderate to high (Obura, 2008; Kifuko et al., 2007; Kisinyo et al., 2013; Opala et al., 2010a) as P sorptions of 100 to 400 and > 400 mg P/kg are classified as moderate and high, respectively (Buresh et al., 1997). Kenyan acid soils have different P sorption capacities. The acid soils found in the highlands east of RV have higher P sorption (343 to 402 mg/kg soil) than those found in western Kenya (107 to 294 mg/kg soil) probably due to high exchangeable Al in the former region compared to the latter (Table 2) (Kisinyo et al., 2013).

High P sorption in the Kenya acid soils leads to low recovery of applied P fertilizer. For example, only between 9.6 to 13.5% of P fertilizers applied at the rates of 26 to 52 kg P/ha are recovered (Table 2) (Kisinyo et al., 2014). Similarly, crop P fertilizer recoveries of 10 to 25% have been reported in tropical acid soils due to high P sorption by Al and Fe oxides (Keerthisinghe et al., 2001). Consequently, Kenyan acid soils have low soil available P (< 5 mg P/kg) which is partly responsible for low crop yields (Gudu et al., 2005; Okalebo et al., 1997;

Table 2. Langmuir parameters of Kenyan acid soils in the highlands east and west of Rift Valley.

Region	Location (latitude and longitude)	Sampling site	q (mg/kg)	k (mg/L)
West Kenya	0° 14.466”N and 34° 13.415”E	Sega	258	3.89
	0° 18.910’’N and 34° 13.231’’E	Bumala	107	0.63
	0° 36.781’’’N and 35° 18.280’’E	Kuinet	137	1.02
	0° 34.997”N and 350 18.561”E	Vihiga	294	1.80
	0° 10.614”N and 340 45.225”E	Ikolomani	250	1.67
	0° 03.112”N and 340 23.658”E	Siaya	204	1.22
	0° 47.574”S and 340 51.446”E	Kisii	155	0.86
	0° 17.773”S and 350 16.350”E	Kericho	191	1.18
Highlands east of Rift Valley	0° 25.004’’S and 37° 30,062’’E	Kavutiri	402	7.94
	0° 40.883’’S and 36° 56.097’’E	Kangema	343	6.63
	0° 28.181’N and 35° 15.752’’E	Kerugoya	388	8.73

q = P sorbed per unit soil mass at equilibrium concentration of 0.2 mg/L and k = constant related to the energy of bonding between soil phosphate ions and the surface of soil particles (mg P/L). Sources: Kisinyo (2011) and Obura (2008).

Schulze and Santana, 2003; Kisinyo, 2011).

MANAGEMENT OF ACID SOILS

Crop production in acid soils with Al toxicity and low soil available P may be improved by use of lime and /or fertilizers with liming effects, organic materials (OMs), crop germplasms tolerant to Al toxicity and/ or low soil available P (Baligar et al., 1997; Ouma et al., 2013; Viterello et al., 2005). Use of the above technologies to manage the Kenyan acid soils forms the discussion of this review.

Liming and use of P fertilizers

Lime is widely known as the most effective means of correcting soil acidity (Kanyanjua et al., 2002; The et al., 2006). Application of agricultural lime containing Ca and/or Mg compounds to acid soils increase Ca^{2+} and/or Mg^{2+} ions and reduces Al^{3+}, H^{+}, Mn^{4+}, and Fe^{3+} ions in the soil solution. This leads to increase in soil pH and available P due to reduction in P sorption (Kamprath, 1984; Kanyanjua et al., 2002; Kisinyo, 2011; van Straaten, 2007; Tisdale et al., 1990; The et al., 2006). In addition to neutralization of soil acidity, lime enhances root development, water and nutrient uptakes~~,~~ necessary for healthy plant growth (Raij and Quaggio, 1997; van Straaten, 2007; The et al., 2006). Several studies have shown that lime reduces Al toxicity, increases soil pH, available P, Ca, Mg, uptake of N and P thus improving crop productivity in Kenya acid soils (Kanyanua et al., 2002; Kisinyo, 2011; Opala et al., 2010a, b). Nekesa (2007) reported increased soil pH and available P in western Kenya acid soils by application of agricultural lime containing 21% calcium oxide (CaO). At one of the sites, three rates of lime (96, 192 and 287 kg lime/ha) raised and maintained soil available P above 10 mg P/ kg soil in 57, 118 and 178 days after planting, respectively. In four year experiment, Kisinyo (2011) reported increased soil pH, available P, maize grain yield, P use efficiency and reduction in exchangeable Al^{3+} on highlands of RV Kenya acid soil. In these trials burnt lime with 92.5% calcium carbonate equivalent at the rates of 0, 2, 4 and 6 tons/ha were used. Higher rates of lime (4 and 6 tons/ha) increased and maintained higher soil pH, available P and grain yield than the lower rate (2 tons /ha) (Figures 2 and 4) (Kisinyo, 2011). In a trial on a western Kenya acid soil, higher rates of lime reduced and maintained lower levels exchangeable Al^{3+} than the lower rates (Figure 3) (Kisinyo et al., 2014). The benefits of lime on crop production are enormous with maize grain yield increments of 5 to 75% reported on Kenya acid soils with applications of 0.77 to 6.18 tons lime/ha (Gudu et al., 2005; Kisinyo, 2011). These benefits were attributed to reduction in soil acidity related constraints making conducive environment for healthy plant growth.

Use of P fertilizer increases the soil available P in P deficient tropical acid soils (Kisinyo et al., 2014; The et al., 2006). Application of P fertilizer increased soil available P and maize grain yield, with higher rate (52 kg P/ha) increasing and maintaining higher levels than the lower rate (26 kg P/ha) on Kenya acid soil (Kisinyo et al., 2011) (Figure 4). Similar increases on soil available P and resultant high maize production have been reported in acid soils of western Kenya due P fertilizer application (Opala et al., 2007). The P fertilizer sources with liming effects achieve better results than those without. Use of different P fertilizer sources such as triple superphosphate

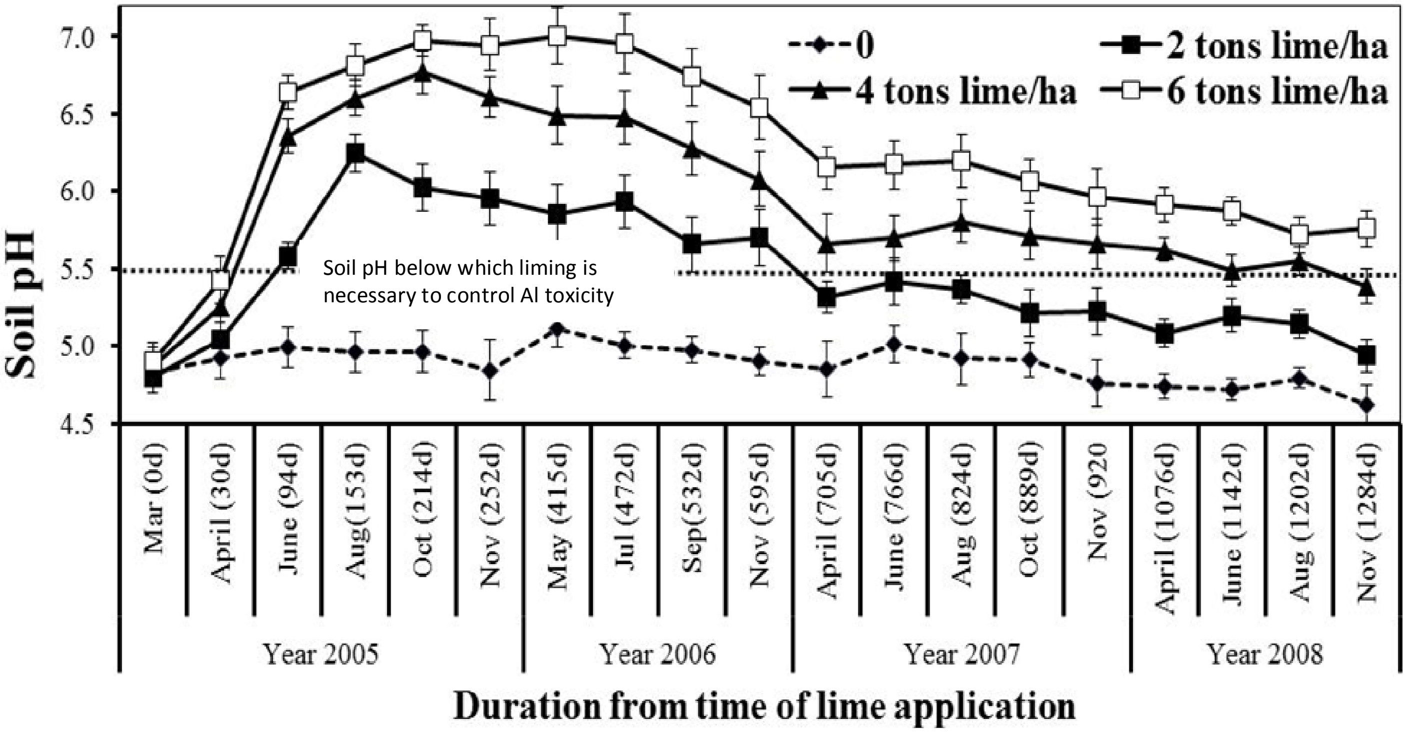

Figure 2. Effect of lime on soil pH during the cropping period at the highlands of RV, Kenya acid soil; d = days from the time of lime application and error bars indicate standard errors of means (SEM). Source: Kisinyo (2011).

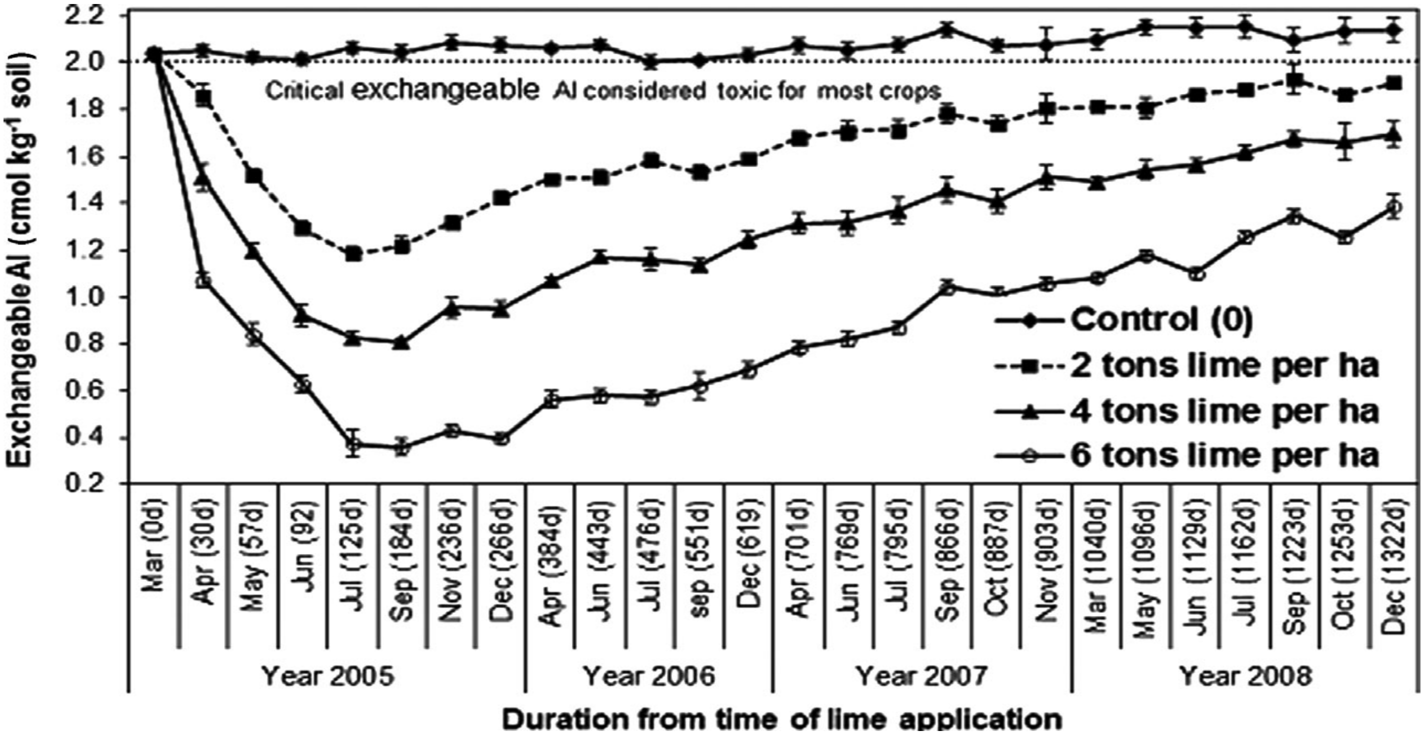

Figure 3. Effect of lime on exchangeable Al^{3+} during the cropping period on a western Kenya acid soil; d = days from the time of lime application and error bars indicate SEM. Source: Kisinyo et al. (2014).

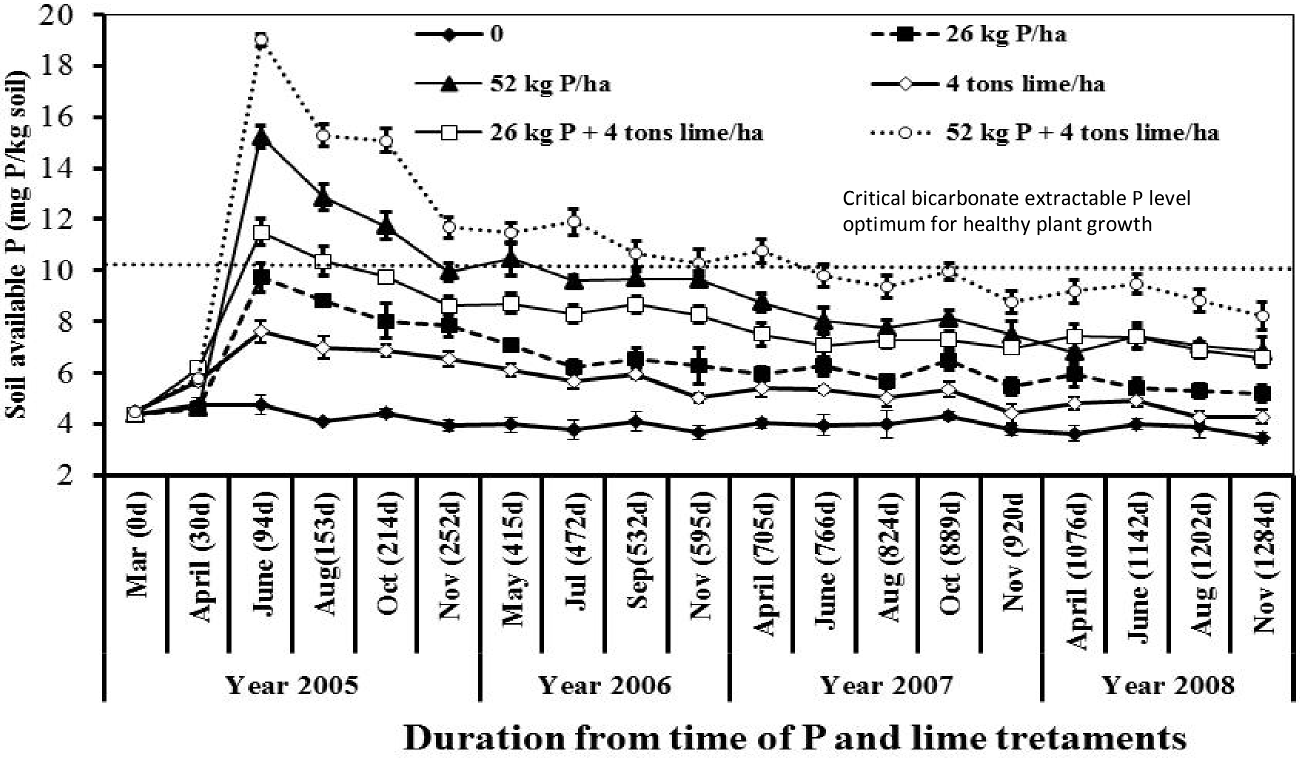

Figure 4. Effect of lime and P fertilizer on soil available P during the cropping period at the highlands of RV, Kenya acid soil; d = days from the time of lime application and error bars indicate SEM. Source: Kisinyo (2011).

(TSP), Busumbu phosphate rock (BPR) and Mijingu phosphate rock (MPR) at the rates of 60 kg P/ha increased soil available P and maize grain yield in western Kenya acid soils (Opala et al., 2010a). Soil available P and grain yield response followed the increasing older of BPR→TSP→MPR. The MPR produced the highest grain yields due to neutralization of soil acidity because of its liming effect in addition to increasing soil available P. The BPR produces the lowest response due to its low reactivity to release P into the soil. Maize grain yield increments of 17.5 to 93% has been reported due to applications of 26 to 60 kg P/ha on Kenya acid soils (Gudu et al., 2005; Opala et al., 2010a, Kisinyo, 2011). The increments were attributed to improvement soil available P necessary for healthy plant growth.

Residual benefits of lime and P fertilizer have been reported in Kenyan acid soils (Kisinyo, 2011; Nekesa, 2007; Opala et al., 2010a). Similar results were reported on an acid soil of Hawaii by Mahilum et al. (1970) where 2 tons $CaCO_3$ ha^{-1} kept exchangeable Al below 1.0 cmol kg^{-1} from the original 3.0 cmol kg^{-1} for 5 years. Due to its slow reactivity, not all the benefits of lime may be realized during the first year of its application (Halvin et al., 2006). Elsewhere in tropical acid soils, residual effect of P fertilizer has been reported to persist for as long as 5 to 10 years or more, depending on the initial P rate applied crop removal and the soil buffering capacity (Tisdale et al., 1990). Combined application of both lime and P fertilizer has increased soil available P, seedlings growth and crop yields more than either of them alone in Kenyan acid soils (Kisinyo, 2011, Kisinyo et al., 2012; Kanyanjua et al., 2002). In low P acids soils with high P sorption, use of both P fertilizer and lime have been suggested for maximum soil available P and efficient utilization of the P fertilizers by plants (Kisinyo et al., 2014; The et al., 2006). Many studies have reported improved soil available P and its utilization due to combined applications of both lime and P fertilizer on Kenyan acid soils (Kanyanjua et al., 2002; Kisinyo, 2011; Kisinyo et al., 2012; Opala et al., 2014). Therefore, it is imperative that combined application of both P fertilizer and lime are important for both short and long term management of P deficient acid soils such as found in Kenya.

Despite the enormous benefits, use of lime and inorganic fertilizers face a number of challenges. Most Agro-Chemical Dealers do not stock lime as a result it is not readily accessible to farmers. Lime application is labour intensive; particularly hand broadcasting and subsequent spreading are expensive for small holder

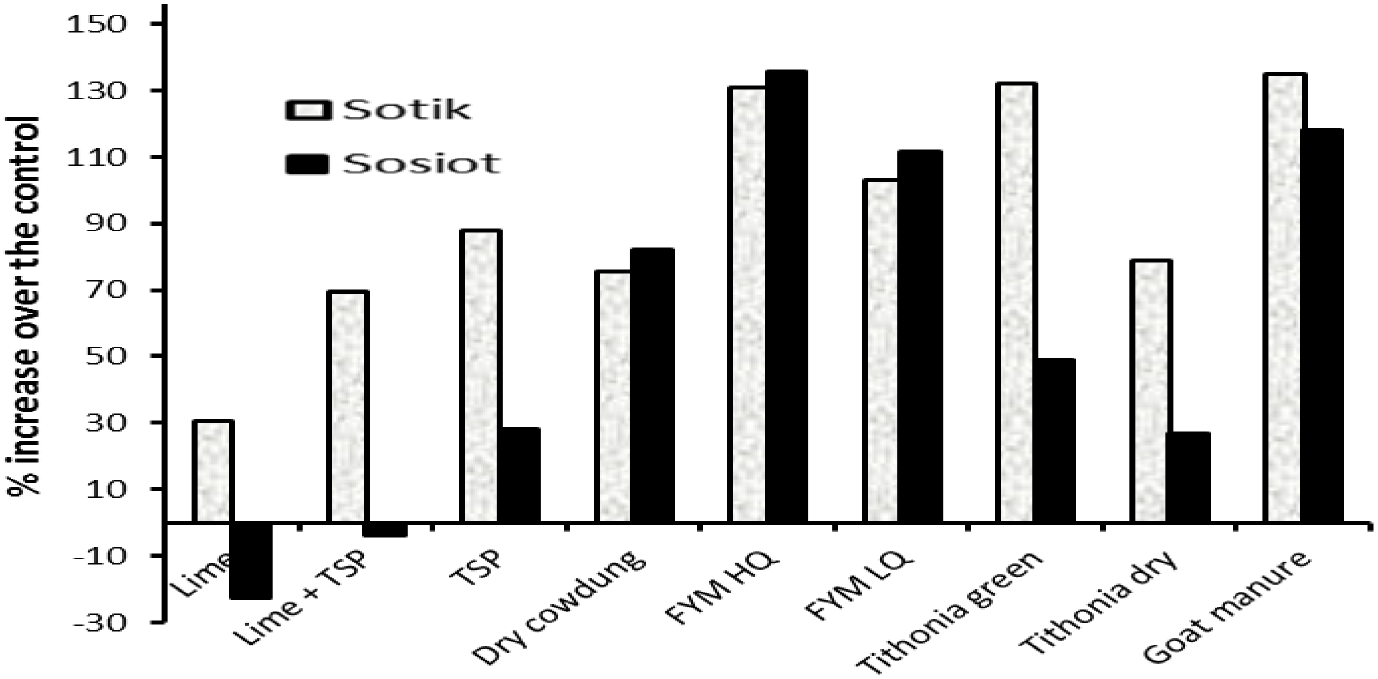

Figure 5. Percent increase in drymatter yield over the control at Sosiot and Sotik. TSP = triple superphosphate, FYM HQ = farmyard manure of high quality (> 1.5% N), FYM LQ = farmyard manure of low quality (< 1.0% N). Source: Opala et al. (2014).

farmers who lack the credit to hire labour. Also low demand for lime by farmers in Kenya as a result of lack of knowledge on its importance hinders its use by farmers. Fortunately, Kenya has large lime deposits and many companies such as Homa Lime, Athi River Mining are producing liming materials. Therefore, use of lime has the potential to improve crop production in Kenya acid soils and hence the need to create awareness among farmers on its importance. This will help create demand for the Agro-Chemical Dealers to stock so that farmers may access it easily. Like many parts of SSA, most small holder farmers in Kenya rarely use the recommended rates of inorganic fertilizers (N and P) due to their high cost and lack of credit (Okalebo et al., 1997, 2006; Sanchez et al., 1997). Due to these challenges, there is need to explore alternative management options discussed below to improve crop production in the Kenyan acid soils.

Use of organic materials (OMs)

Use of OMs has been proposed as an alternative to liming to reduce Al toxicity in acid soils (Lungu, 1993). During OMs decomposition, there is release and synthesis of organic compounds which combines with Al to form solid- organic material phase leading to reduction of Al solubility (Tang et al., 2007; Haynes and Mokolobate, 2001). Organic materials also interact with P in soils in a variety of ways that potentially influences P sorption and release reactions. Direct and indirect mechanisms have been proposed for the increase of soil available P as a result of the addition of OMs by Guppy et al. (2005). OMs are known to reduce soil acidity, Al toxicity and increase soil available P in acid soils. In western Kenya, Opala et al. (2010a) demonstrated that *Tithonia diversifolia* (tithonia) green manure is effective in increasing maize yield due to its ability to reduce exchangeable Al in soils without necessarily increasing the soil pH (Figure 5). This was attributed to the ability of the tithonia to form complex with Al. However in the same study, farmyard manure (FYM) increased the soil pH but it was less effective in decreasing the exchangeable Al^{3+} compared to tithonia. It was thus concluded that the ability of an organic material to reduce Al toxicity was related to its ability to complex the Al through organic acids produced during its decomposition process. The tithonia green manure was therefore more effective because of its ability to release larger quantities of organic acids compared to the well rotten FYM which had lost most of the organic acids. This confirmed earlier findings by Ikerra et al. (2006) who found larger quantities of organic acids in soils treated with tithonia than those that received FYM in Tanzania. In another study in Kericho County in Kenya, Opala et al. (2014) tested the effect of a range of organic materials of diverse composition commonly found on small holder farms on maize dry matter production on two acid soils. These were compared to lime and triple superphosphate (TSP). Results showed that manures of high quality that is > 1.8% N increased maize dry matter yields above the control with no nutrient inputs and were generally superior to lime applied alone or in combination with TSP (Figure 5). This was attributed mainly to the ability of the OMs to ameliorate Al toxicity while providing a range of nutrients that were not provided by lime. This confirmed earlier observations by Opala et al. (2013) that some organic materials such as tithonia could substitute lime as an amendment for soil acidity. It had been previously recognized that organic materials can indeed decrease P sorption in acid soils and hence farming systems that include additions of green or animal manures may be able to increase availability of P by increasing the solubility of soil P (Ohno and Crannel, 1996). There has been intensive research in Kenya by International Centre for Research in Agroforestry, Tropical Soil Biology and Fertility, Kenya Agricultural Research Institute and Moi University in the past two decades focused on increasing available P in acid soils of western Kenya using organic materials such as tithonia, calliandra and farmyard manures with /or without inorganic P sources such as triple superphosphate or phosphate rocks. This was based on the fact that decomposing organic materials produce organic acids that solubilize P from phosphate rocks (PRs) through chelating or complexing action (Kpomblekou and Tabatabai, 1994). Use of OMs to increase the dissolution of PRs has been widely studied in East Africa region (Okalebo et al., 2006; Savini et al., 2006; Kifuko et al., 2007).

There is, however, a wide divergence of opinion as to the effect of OMs on PRs dissolution. Many of the earlier studies reported enhanced dissolution of PR when it is combined with OMs such as FYM (McLenaghen et al., 2004). There is, however, emerging evidence that some high quality organic resources, especially those with a high Ca content, e.g. tithonia, can inhibit dissolution of reactive PRs such as MPR (Smithson, 1999). Other workers have, however, suggested that organic materials enhance dissolution of unreactive PRs but inhibit dissolution of reactive PRs such as Mijingu (Zarah and Bah, 1997). Ikerra et al. (1994) observed that the agronomic effectiveness of MPR increased when it was combined with high quality FYM but not with low quality compost. Interestingly, Tian and Kolawole (1999) found increased uptake of P following incubation of low quality materials such as maize stover with PRs. More recently in Kenya, Gikonyo et al. (2006) attributed the reported declines in crop yields as a result of combination of OMs and insoluble PR to very high toxic levels of available P in the soil. According to these authors, the toxic levels of P a rose from enhanced dissolution of the PRs by the OMs and not the inhibition of PRs dissolution as reported earlier (Smithson, 1999). Though most of the results showed increased yields as a result of combining PR and OMs, it did not explain how some OMs, such as FYM, which are known to increase pH in certain cases, can at the same time increase dissolution of PR which is favoured by acidic conditions. Thus Opala et al. (2010a) hypothesized that the reported increases in crop yields as a result of combining PR and OMs could be due to the P released from mineralization of the OMs and not increased dissolution of the PR. These authors demonstrated that combining OMs (tithonia or FYM) with PR or TSP did not enhance P availability, although the maize yields obtained by the combined application of OMs and the inorganic P sources was higher than that of the inorganic P sources where the available soil P was in most cases higher. The studies however, showed large reductions in exchangeable Al in the soils treated with the OMS, particularly tithonia and concluded that the ability of an OM to reduce Al in acid soils was more effective in increasing maize yield than its ability to increase soil available P. Maize grain yield increments of 70 to 100% have been reported through use of various OMs in Kenya (Opala et al., 2010a).

There are however some challenges in the use of OMs to manage acid soils and replenish soil fertility. The quantities and qualities of organic materials available to farmers are limiting factors to their use in Kenya. Due to their low nutrient content, large amounts have to be applied thus increasing the labour cost (Jama et al., 1997; Kisinyo et al., 2006). The high costs in some cases cannot be offset by the extra yields obtained by applying some of the organic materials including tithonia (Opala et al., 2007, 2010b), calliandra and maize stover (Nyambati and Opala, 2014; Jama et al., 1997). However, OMs such as FYM of high quality have in most cases been shown to be economically attractive under most smallholder situations (Opala et al., 2007, 2010b, 2013). This highlights the need for high quality OMs as sources of nutrients in acid soils. Nziguheba et al. (2002) concluded that OMs suitable for use as P sources should have a high P content and low cost of production. The P concentration in plant materials such as tithonia is controlled by genetics and environmental factors and can, therefore, not easily be manipulated by the farmer through management. Opportunities for increasing the quality of FYM, however, do exist. Practices such as using pits for manure storage and storing manure under shade (Murwira and Nzuma, 1999; Rufino et al., 2006) can greatly enhance the quality of FYM, therefore, making its use more profitable. Increasing the quantity of high quality FYM to resource-poor farmers in western Kenya may however be limited, particularly in the absence of large numbers of improved livestock breeds (Jama et al., 1997). Therefore, FYM and other OMs that have shown potential for use as nutrient sources while amelioration soil acidity can be applied together with appropriate inorganic P sources such as TSP and MPR in an integrated soil fertility management program on small holder farms.

Use of acid tolerant crops

To deal with soil acidity related problems, plant breeding programs have developed germplasms tolerant to Al toxicity and/ or low soil available P (Parentoni et al., 2006; Donswell et al., 1996). The low soil available tolerant genotypes can obtain adequate P even from sparingly soluble P through enhanced microbial colonization and symbiotic association with P solubilizing microorganisms in the rhizosphere (Oliveira et al., 2006). In addition, some of the genotypes express a protein kinase gene called phosphorous starvation tolerance gene (Pstol1) which enables acquisition of P and other nutrients (Gamuyao et al., 2012) even in P deficient soils. The sensitive crop germplasms do not express this gene and hence are not able to utilize the applied fertilizers and /or fixed P with high efficiency and hence the reason for low grain yields. Incorporation of this gene to P deficiency sensitive cultivars could greatly improve crop yields in acid soils of Kenya and other regions experiencing similar constraint.

On highly acid soils (pH<5.0), aluminum toxicity is a primary limitation for crop production. Liming to mitigate its effect is not sustainable as has been stated and this has led to discovery and use of Al tolerant genotypes. A major physiological mechanism of plant aluminum tolerance involves aluminum activation of membrane transporters that mediate organic acid release from the root apex, the site of aluminum phytotoxicity, with the released organic acids forming stable, nontoxic complexes with Al^{3+} in the rhizosphere (Magalhaes et al., 2007). In sorghum a multidrug and toxic compound extrusion (MATE) gene that transport citric acid was found to confer Al tolerance (Magalhaes et al., 2007) and in maize a similar gene, *ZmMATE1*, (Maron et al., 2013) was also found. The introgression of such genes into Al sensitive cultivars have been shown to improve grain yield performance in acid soils.

Although the approach of using tolerant plant germplasm is not able to reverse soil acidity conditions, it minimizes the problems experienced by farmers, especially those who do not use lime (Clark, 1997). In recent studies, Kenyan maize and sorghum germplasms tolerant to Al toxicity and /or P use efficient have been identified (Ouma et al., 2013; Ligeyo, 2007; Matonyei, 2010; Too, 2011). These elite materials provide a good foundation for breeding for tolerant cultivars to Al toxicity and/or P use efficiency in Kenya at the moment. Currently, there are no commercial maize/sorghum or other crop varieties available to farmers that are adapted to soil acidity in Kenya (Ligeyo, 2007). Therefore, there is need to develop crop varieties adapted to acid soils for enhanced crop productivity in the Kenyan acid soils.

CONCLUSION

Acid soils occupy about 13% of the total land area in Kenya. Most of which has developed partly due to leaching of base cations by high rainfall, use of acid forming fertilizers and parent materials of acids origin. These contain low soil available P (< 5 mg p/kg soil) owing partly to high P sorption by clay minerals such kaolinite, gibbsite, goethite, and Al and Fe oxides. Acid soil in the highlands east of RV have high Al (2.71 to 4.29 cmol Al /kg soil and 27 to 34% Al saturation) compared to western Kenya (2.01 to 2.24 cmol Al /kg soil and 42 to 71% Al saturation). Due to higher Al levels, highlands east of RV tend to have high P sorption (343 to 402 mg P/kg) than western Kenya (107 to 294 mg P/kg). Consequently crops can only recover 9.6 to 13.5% of the applied P fertilizer. In the Kenyan acid soils, improved crop productivity has been achieved through use of lime, manures, fertilizers with liming effects, crop germplasms tolerant to Al toxicity and low soil available P. Lime has increased soil pH, available P and crop yields and reduces Al toxicity in these soils. Combined application of lime and P fertilizer or use of P fertilizers with liming effects is more effective increasing soil available P and crop yields than lime alone or P fertilizer without lime. Use of organic materials reduces Al toxicity through production of organic acids that form complex with Al^{3+} ions leading to high crop yields in the Kenyan acid soils. Similarly utilization of high quality OMs such as tithonia produces economic crop yields since small volumes are required compared to low quality ones. Deployment of crop germplasms tolerant soil Al toxicity and /or low available P has the potential to increase crop productivity in the Kenyan acid soil. Therefore there is need to develop crop varieties tolerant to soil Al toxicity and /or low available P to increase crop productivity in the Kenyan acid soils. However, challenges such as lack of credit to purchase inorganic inputs, knowledge on the importance of lime, improve crop varieties tolerance to soil acidity constraints and inadequate amounts of organic materials limit crop productivity on the Kenyan acid soils.

Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Understanding the small-scale agricultural sector as a precondition for promoting rural development in South Africa

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Economic development in South Africa (SA) has been an issue that has been on top of the government's agenda for many years now. Whilst SA as a nation is well endowed in terms of natural resources, the skewed distribution of these resources has left rural economies at a great disadvantage when compared to the urban ones. Questions have thus been asked about how best to address this imbalance and boost rural economies so that every citizen enjoys an adequate share of the nation's resources. One common suggestion for achieving this goal has been that of promoting smallholder agriculture, especially since this form of farming is dominant in the country's rural areas where at least 70% of the country's poorest households dwell. The basis for such an argument has been that smallholder agriculture can stimulate rural development as it is labour-intensive which in turn translates to high employment opportunities being created. The sector also dominates in the deepest corners of the nation where poverty is rife and their survival means enough food could be produced to sustain these households. A healthy smallholder sector has also been proven to facilitate backward and forward linkages between various industries with income flowing both ways. Nevertheless, the success of the smallholder sector is dependent on the removal of certain barriers that have, in some cases, forced some farmers to seek alternative livelihood strategies other than farming. This paper therefore seeks to discuss the characteristics of smallholder agriculture which are crucial to understand prior to using the sector to develop rural SA. It also brings to light some of the factors that have limited the growth of this sector and concludes by recommending a few solutions that could help eliminate or at least reduce the impact of these barriers.

Keys words: Smallholder farmers, poverty alleviation, economic development, rural income, employment creation.

INTRODUCTION

South Africa is one country that is characterized by high unemployment and poverty rates, particularly in its rural areas. In 2004, Landman *et al.* estimated that at least 40% of South Africans were still living in poverty, a decade into democracy. A second decade of democracy later research findings suggest that the situation has not improved at all. Such high rates exist despite policies that the government has adopted since 1994 which have

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focused on poverty alleviation, improving economic growth, relaxing import controls and reducing the budget deficit. One of the approaches used is the social security system which aims to assist those that are not economically active either due to disability, age or poor health. Since its implementation, the nation's social security system has remained a major source of income for millions of South Africans by helping the poor afford food, clothes and education (CASE, 2000). However, the challenge with this approach is that its impact depends on the amount the "taxman" takes from the employed. As such, it is necessary to explore other poverty alleviation strategies that do not necessarily disadvantage other people.

One such approach, which is the focus of this paper, is the revival of the smallholder agricultural sector which Eicher (1994) suggested could also be used as the best vehicle to get the entire agricultural sector moving, hence should be given adequate attention by policy makers and those in positions of influence. Delgado (1998) added by arguing that the smallholder agricultural sector is "simply too important to employment, human welfare, and political stability in Sub-Saharan Africa to be either ignored or treated as just another small adjusting sector of a market economy ….".

In terms of the structure of the agricultural sector in South Africa, Vojtech (2006) described it as being very dualistic in nature as it consists of both a well-developed commercial sector and a high number of smallholder farms. Sandrey and Vink (2008) argued that the latter is made up of few but very big, successful and profit minded farmers that are relatively well advanced in terms of technology, most of which is imported. The former, on the other hand, has a high number of setups emanating from almost every corner of the country.

This paper starts by defining the small-scale farmers in terms of their size, location, objectives, etc. The paper further reveals and discusses numerous challenges that literature has identified as hindering the success of the smallholder sector in SA and most developing countries. However, for purposes of developing the sector, it goes without saying that these challenges have to be dealt with as part of or prior to the implementation of any development initiative aimed at boosting the sector. As such, the paper concludes by suggesting a number of interventions that could help deal with these challenges.

DEFINING SMALL-SCALE FARMERS IN THE SOUTH AFRICAN CONTEXT

When defining small-scale farming in South Africa, Kirsten and Van Zyl (1998) believed that this concept is usually value-laden and creates wrong impressions hence is often viewed in a negative light. In their view, Kirsten and Van Zyl (1998) equated "small-scale" in South Africa with a backward, non-productive, non-commercial, subsistence agricultural sector that is found in parts of the former homeland areas. It is generally associated with blacks who do not have the ability to become large-scale commercial farmers. Some agricultural economists have accepted this definition of small-scale farmers postulated by Kirsten and Van Zyl (1998) but with a bit of skepticism. As a matter of fact, they postulated that small-scale farmers should also be defined in terms of agricultural activity in whatever form. Thus, this sector is made up of those farmers whose main goal is to produce food for their families on a daily basis. Under such circumstances, only surplus is considered for sale in order to supplement their income and diversify their diet. However, to try to prove the validity of this definition, Ouattara and Graham (1990) and Baydas and Graham (1996) carried out a study in the Northern and Kwa-Zulu Natal Provinces where they compared small-scale business enterprises and small-scale farmers. Their results indicate that farming played a small role in terms of income; although a major proportion of small-scale farming households (and small business households) cultivate the land and produce crops. A similar state of affairs was also noted by Monde (2003) in the Eastern Cape Province.

Another context through which a small-scale farm can be defined is through its size. The general, but not necessarily correct, perception is that small-scale farmers are those who cultivate small pieces of land, usually one hectare in size or less. Whilst from a broad perspective this might be true, such an approach is made invalid if one looks at it from the efficiency and productivity point of view. Bravo-Ureta and Pinheiro (1997) explained the importance of small farms and asserted that these farms are multi-functional, more productive, more efficient and contribute more to economic development than larger farms. This means that there is a proven inverse relationship between farm size and its productivity. In other words, smaller farms are more productive and efficient but tend to lose their productivity as they grow in size.

Berry and Cline (1979) had earlier come to the same conclusion based on the fact that small farms generally use family labour which is personally committed to the success of the farm, unlike large farms that use relatively alienated hired labour which may not be as committed. Furthermore, Carter (1994) noted that the land to labour ratio is higher for large than small-scale farmers, which leads to decreasing output per hectare with respect to farm size. In short, it is clear from Kirsten and Van Zyl's (1998) argument that size is not a good criterion for defining small farms. These authors gave an example that a single hectare of irrigated peri-urban land suitable for vegetable farming or herb gardening has been proven to have a higher profit potential than 500 hectares of low quality land in the Karoo. With this in mind, their conclusion was that the level of net farm income does determine the farm size category and not the land size as believed by some people. Thus far, a number of possible definitions for small scale farming have been highlighted. Even though none of them can be said to be “all-inclusive” and more relevant than the rest, when the term small-scale farm is used in the rest of the study, it should be interpreted against all the above arguments. The bottom line drawn by Kirsten and Van Zyl (1998) is that a small-scale farm is a concept relative to the particular ecological region and soil quality and also relative to the particular farming industry. Tomich, et al. (1995) also emphasized that small-scale farms should not be regarded simply as smaller versions of large farms since systematic differences in output and input intensities result from farm-size effects and have important policy implications.

Nevertheless, agriculture is usually seen as the backbone of most African countries. In fact, in as much as the commercial agricultural sector is important to any given economy, so is the small-scale sector in its own right simply because it reduces poverty and food insecurity at household level. For this reason, the definition of a small-scale farm is also important for the South African government from a policy point of view. Since the Department of Agriculture needs to identify its target group or clientele before intervening through its policies, Kirsten and Van Zyl (1998) suggested that the department should view a small-scale farmer as one whose scale of operation is too small to attract the provision of the services he/she needs to be able to significantly increase his/her productivity.It is these farmers that need government assistance and who should be empowered to form part of a new and vibrant agricultural sector.

SOCIO-ECONOMIC CHARACTERISTICS OF SMALL-SCALE FARMERS

There are a number of socio-economic features or characteristics that define small-scale farmers. Some of these have to do with their demographic characteristics, land holdings, ownership of capital resources and also their level of training and farming skills.

Demographic characteristics

In terms of demography, Feynes and Meyer (2003) described the small-scale farmers as usually the aged (both male and female), able-bodied women and children. Population-wise, Aliber and Hart (2009) put the number of female rural black farmers in South Africa at sixty percent (60%). Literature also suggests that members of the rural farming households that get formal education are rarely found in their homesteads participating fulltime in farming. Instead, they prefer to seek jobs in other sectors than staying at home to farm. Thus, the conclusion that could be drawn from this is that smallholder agriculture in South Africa is not only dominated by women, but by women who also do not have much formal education. The majority of the few men found also do not have much formal education.

In absolute terms though, Aliber and Hart (2009) presented findings of a Labour Force Survey (LFS) done by Stats SA between 2001 and 2007 which show that younger people involved in subsistence farming outnumber older people but their numbers tend to decline with age. These findings were supported by Aliber and Hart (2009) who further argued that in South Africa in general, there are twice as many 15 to 19-years-old involved in agriculture than there are 55 to 59-years-old. For example, in the community of Kenton-on-sea in the Eastern Cape, Monde and Ansle (2008) discovered that 34% of the total population in this community was either below the age of 15 years or over 64 years, hence economically inactive. No household head was younger than 40 years or older than 95 years. In addition to this, Monde and Ainsle (2008) wrote that more than half of the household heads in that community were older than 64 years.

Land holdings

Land holding amongst smallholder farmers in general is usually very small. In several countries such as those in Asia, for example, Pookpakdi (1992) noted that the average size of land holdings has continued to fall over the years. According to Pookpakdi (1992), the average size of farms was seen to decline in several of these Asian countries between 1970 and 1980 from 0.92 down to 0.88 ha in Bangladesh, from 2.28 to 1.82 ha in India, from 0.64 to 0.59 ha in Indonesia and from 3.6 to 2.6 ha in the Philippines. At the same time, the number of smallholdings increased significantly. As for the South African situation, Vink and Van Rooyen (2009) revealed that between 2002 and 2006, the number of people in the country with land for agricultural purposes declined by 21%. In 2002, 1.8 million households had access to arable land but by 2006, only 1.4 million were still in possession of it (Vink and Van Rooyen, 2009). On the other hand, commercial farms were also declining in numbers during the same period not because the sector was losing its viability in the market but because farms were being merged into larger units of ownership and production (Vink and Van Rooyen, 2009). Vink and Van Rooyen (2009) further estimated that at least 97% of these households practice agriculture on their land. However, the land holdings vary between different individuals.

Fraser et al. (2003) analyzed the land holding situation in the Eastern Cape Province and concluded that some small-scale farmers actually do have access to arable land. However, due to their lack of proper resources with which to work the land, most of them tend to resort to cultivating home gardens in an attempt to provide some measure of food supplementation. Fraser et al. (2003)

further highlighted that such farmers remain unable to afford the purchasing of inputs even if they pool their financial resources amongst five households. In short, the reality is that those small-scale farmers in possession of land only have access to small pieces which they also rarely cultivate due to the unavailability of the means with which to work it.

Skills and training

In the opinion of Fanadzo (2012), small-scale farmers currently have limited access to training due to various factors such as their remote location, lack of education and training opportunities. According to Fanadzo (2012), there is training offered in some of the areas where the small-scale farmers are found but the unfortunate thing is that this little training available is focused almost exclusively on scaled-down versions of high-cost, high-risk commercial production practices. This therefore means that the trainings generally are not appropriate to the food insecure households that need training the most. In addition, the Water Research Commission (WRC) (2007) noted that such training is usually offered in institutions such as agricultural colleges which are rarely located in the deepest corners of rural areas where most small-scale farmers are found. As a result, most rural farmers are left without access to any training. Poverty and lack of basic education also play a role in determining the extent of participation in training programmes. The situation for those that can afford to visit training institutions is further exacerbated by the fact that training usually requires trainees to be away from their homes for periods of at least two weeks. According to WRC's (2007) conclusions drawn from studying the general situation in Limpopo, being away from home for such a long period of time made attending training workshops impossible, especially so for women responsible for food insecure households.

THE ROLE OF SMALL-SCALE FARMERS IN THE SOUTH AFRICAN ECONOMY

A lot has been said about the role that small-scale farmers can play in the economies of developing nations such as South Africa. Some proponents of this sector have advocated the starting point in supporting these farmers to be training them on the necessary farming skills so that their farming activities become sustainable. However, before any training of any nature is administered, benefits such as the growth in output and farmer efficiency likely to result from the success of such trainings should be understood. Questions like "what is the use of these small-scale farmers? Suppose they are taught new farming skills, what and how then is the nation going to benefit from investing in such farmers?" should be asked. To get answers to these questions, it is of paramount importance to at least try and highlight a couple of positive roles played by the small-scale farming sector in African nations and South Africa in particular. Amongst other things, smallholder farmers help in poverty alleviation, employment and rural income creation and also through creating backward and forward linkages with other industries.

Poverty alleviation

Rao and Chotigeat (1981) argue that smallholder agriculture can contribute significantly to poverty alleviation by raising agricultural productivity and rural incomes. The point of small-scale farmers having the ability to raise agricultural productivity goes back to the inverse relationship between farm size and productivity debate. Literature from the likes of Bharadwaj (1974), Sobhan (1993), Deininger (1999) and Ellis (1993), just to mention but a few, suggests that the intensive application of labour inputs by smallholder farms compared to bigger, commercial ones makes them more efficient and productive. This is supported by the fact that the labour used in this small-scale sector is usually family labour that is motivated by the need to get more output from their land. Consequently, Netting (1993) and Moore et al. (1998) believe that such labour is more dedicated to farming than hired labour whose performance or level of dedication is determined mostly by the wage rate. The more wages the hired employees are offered, the more effort they tend to put in their activities.

In addition, Rosset (1999) is of the view that larger farms and land owners usually tend to leave much of their land idle, while small farmers tend to use their entire parcel. This on its own shows that small scale farmers have higher land use intensity which in turn implies that if they are allocated more land, such land will be used more productively rather than being left fallow as is often the case with large farms. This has been the basis for targeting smallholder farmers in SA and other developing nations such as Zimbabwe in their respective governments' Land Reform Programmes. These programmes have targeted the smallholder farmers whilst taking away land from the commercial farmers with the hope the former will become efficient in their production thereby resulting in them escaping the circle of poverty with their households.

In support of the notion that smallholder farmers can drive poverty out of rural economies, Feder (1985) explained that this sector actually helps reduce food prices because smallholder farms can be found even in the deepest corners of any nation where poverty levels are well pronounced. The ability of the sector to exist anywhere and produce more for less makes different types of goods not only available to the general public but also at very low and affordable prices. Part of the sector's success despite the farmers having limited pieces of land is a result of the small-scale farmers' adoption of intercropping farming practices which allows farmers to utilize almost every piece of their fields and intensively produce a variety of crops on their small farms. According to Rosset (1999), this intercropping approach helps the domestic consumers have access to a variety of products at cheaper prices without propelling the depletion of soil nutrients unlike in the case of large-scale farms that produce limited varieties of crops due to monoculture.

Another interesting point to note about the role played by this sector in alleviating poverty is the way food is moved from the rural to the urban sectors. According to Mishra and Agrawal (2012) and de Haan (2000), most urban people tend to migrate to the urban areas for the sake of getting better paying jobs. However, such migrants always leave the majority of their family members back in the rural areas to farm. Due to the expensive cost of living in urban areas, most migrants tend to rely on the agricultural produce sent by the relatives they left behind in the rural areas for cheap food. Such is popular in most African countries and South Africa is not an exception. Kurwijila and Henriksen (2010) documented this pattern in Tanzania where the rapid expansion in urban centres stimulated by the rural-urban drift of young people seeking employment in urban areas has posed serious strains on the socio-economic services and food supplies that must be provided to meet the demand of the urban populations. As a result, this urban sector also depends on food supplies produced in the rural areas.

Contribution towards rural income

As stated earlier, the South African agricultural sector consists of both smallholder and commercial famers but with the former dominating in terms of numbers (Oettle et al*.,* 1998; Vojtech, 2006). The majority of the nation's smallholder farmers lack proper resources with which to cultivate their land in spite of their efforts to intensively farm annually (Rosset, 1999). This means that such farmers are able to produce for themselves, hence they do not have to spend much of their income on food. It should be recalled that in defining the small-scale farming, Kirsten and Van Zyl (1998) described these farms as being so small in size to an extent that their main priority is to produce just about enough food to feed their families. Therefore, since rural households produce their own food, there is not much of a need for them to use money to purchase food unlike those in urban centres who purchase everything they eat. Feder (1985) held the view that through the marketing of surplus produce, farmers stand to earn some income which could also help make them better off compared to if they were not farming at all.

Having these smallholder farms in great numbers also has its advantages too as agricultural products can be accessed from unlimited sources. This implies increased competition amongst producers. Even though the final result of such stiff competition does not favour smallholder farmers, Dorosh and Haggblade (2003) explained that the existence of competitors selling similar products usually permits prices of tradable agricultural goods to fall in response to production increases. For the general public that consumes these agricultural products, lower prices translate to less money being spent on food, thus raising their real income. In consequence, Dorosh and Haggblade (2003) concluded that not only do the rural poor benefit most directly from agricultural growth, but also the urban poor too as falling food prices raise their real incomes as well. This is compared to few commercial farmers where there is low competition, hence higher prices normally prevail and the benefits are only for the select few at the expense of the majority consumers. Based on these arguments, one can argue that agriculture does not only enhance real income through lowering food prices but also improves nominal income too.

Employment creation

It has been proven by Van Zyl et al*.* (1996) that small scale farms have the potential to create employment even in the deepest corners of SA and any developing nation when compared to commercial farms. In their explanation, Van Zyl et al*.* (1996) pointed out that the latter usually make more use of machinery in production as compared to the poor, hence labour-intensive smallholder farmers. These small-scale farms have less wealth and access to credit markets that is why they use an input mix that relies much more on labour than capital thereby generating far more employment than their large counterparts. This view is shared by Welsch (1978) who had earlier documented that the small farm sector is more labour intensive and will serve to combine available labour with other production factors. However, it is worth mentioning that in some cases, some of these small-scale farmers do not hire any labour regardless of the demand. Instead, when labour demand is very high as is usually the case during weeding or harvesting, such farmers resort to labour exchange or what is known as "ilima" in Zulu and Xhosa (Tshuma and Monde, 2012). In terms of employment numbers, Vink and Van Rooyen (2009) put agriculture's contribution to employment for a large proportion of the economically active SA labour force between 8 and 9%.

Backward and forward linkages

According to Haggblade et al*.* (1989), growth of small farms allows for the growth of business activities created through forward and backward linkages. In other words, such growth generates economic growth through production and consumption linkages. This same perception raised by Haggblade et al. (1989) was later shared by Van Zyl et al. (1996) who acknowledged the possibility of substantial increases in the demand for production inputs from other sectors emanating from gains in output caused by investments in any given sector of the economy. These authors argued that the resultant outcome of such changes will be backward linkages. Backward linkages also exist if farming households use the income they obtain from selling their produce to purchase more farming inputs (which is investment) or even spend it on other non-agricultural (another form of expenditure) such as television sets, private cars, etc. (Estudillo and Otsuka, 1999). By doing so, they support the manufacturing sector through agricultural income.

Dorosh and Haggblade (1993) suggested that the initial output gains also raise incomes and consequently spur consumer demand for other goods and services (forward linkages). Estudillo and Otsuka (1999) therefore concluded that there are some non-farm sectors that rely on agricultural produce for their survival. Thus, the agricultural sector, smallholder sector included, provide other sectors with raw materials

Distribution of social capital

Small farms are also important in terms of land ownership. Decentralized land ownership produces more equitable economic opportunity for people in rural areas, as well as greater social capital (Haggblade et al., 1989). This can provide a greater sense of personal responsibility and feeling of control over one's life. Berry and Cline (1979) define smallholder farmers as being usually characterized by their heavy reliance on family labour. Using this definition Rosset (1999) thus raises the point that making use of family labour implies that farming skills are therefore passed from one generation to another under family ownership structures. In other words, the farmers' children acquire farming knowledge and skills through practice as they grow. Furthermore, the nation's land reform programme seeks to give land to the poor, including farm tenants and workers, for agricultural purposes and this will play a big role in the equitable distribution of land within the country (Rugege, 2004; Lahiff, 2007).

CONSTRAINTS FACED BY SMALL-SCALE FARMERS

Despite the above-mentioned benefits that emanate from the smallholder farming sector, the majority of smallholder farmers are faced with a number of obstacles that hinder their productivity. Some successful commercial farmers started as smallholders but grew through various forms of support and their ability to circumvent these barriers. Be that as it may, the majority of smallholder farmers are still faced with such constraints as lack of proper education, skills, capital, infrastructure, just to mention but a few.

Lack of adequate education

One of the biggest challenges noted by Murage (2006) that is faced especially in trying to change the attitudes of most smallholder farmers in South Africa is that the majority of them lack basic education. This makes them unable to make use of things like technology, negotiate with stakeholders for better prices, take advantage of telecommunication systems to acquire relevant information, just to mention but a few. As a consequence, Ozowa (1996) and Ahmed et al. (2012) are convinced that such farmers unwillingly become risk-aversive hence prefer to continue using their old and less-productive ancient farming techniques than try the recently developed ones. Ozowa (1996) and Ahmed et al. (2012) therefore viewed such attitudes driven by lack of basic education as contributing towards the low level of adoption of agricultural production technology. In fact, evidence from Onuoha (2006) suggests that only those farmers with at least some education background tend to be more active in adopting new ideas that their illiterate and risk-aversive counterparts. As the world changes together with its technologies, climate and farming approaches, most illiterate farmers have proven to opt for their tried and tested, though outdated, methods instead of adapting (Taher, 2006; Karanja and Ndubi, 2008).

Lack of finance

According to Thapa (2010), the majority of smallholder farmers cultivate small plots found at the back of their yards. Apart from this behaviour being caused by lack of physical resources such as tractors and farm implements, the small size of their plots is due to lack of proper arable fields. In community such as Zanyokwe, Monde et al. (2005) stated that residents have made progress towards getting title deeds for their land but other farmers such as those in Kenton-on-sea also in the Eastern Cape still cultivate municipal land as they lack land of their own (Monde and Ainsle, 2008). Without land as collateral, smallholder farmers in South Africa are finding it very difficult to access financial capital. Those that are employed in other sectors also struggle to finance their farms due to their low earning capacities (Tshikudu, 2005).

Failure to have access to financial capital often leads to less production as farmers cannot afford to purchase inputs for production purposes. Furthermore, without enough capital, it is almost impossible for any smallholder farmer to take advantage of favourable market conditions such as increased demand. Mbilinyi (1997) provided evidence that financial constraints also manifest themselves in the form of very high interest rates on borrowed loans as financial institutions try to offset the risk that loans will not be repaid. Thus, those that have enough collateral to qualify for loans often find themselves struggling to repay their loans due to the high interest rates charged. In addition to these high rates, most financial institutions do not give farmers enough grace period to raise the money whilst using part of their earnings to keep their farm businesses running (Uganda Export Promotion Board (UEPB), 2004).

This, coupled with very high transaction costs has made smallholder farmers to struggle in their attempts to use their farms as their major source of livelihood. Delgado (1999) blamed these high transaction costs on farmers transporting their produce individually thereby losing their bargaining power. Moyo (2010) further advanced that smallholder farmers usually buy inputs like seeds and fertilizers in small quantities, hence do not enjoy economies of scale in their purchases. Jayne et al. (2007) and Moyo (2010) defined some of the transaction costs incurred by smallholder farmers as search costs and emanate as farmers collect and analyze market information.

Technological constraints

On the technological side, Morton et al. (1999) noted that smallholder farmers also suffer from an inadequate provision of technical information, limited use of modern production and value-adding technologies, and business management services. The UEPB (2004) and Parfitt and Barthel (2010) are of the opinion that at times technology is available to smallholder farmers but due to their limited skills and knowledge of improved agricultural technologies, the rate of their technology adoption is very slow, resulting in high post-harvest losses, poor quality products and generally low production levels.

Lacking this technology means farmers cannot gain in specific areas such as productivity of farming systems; small farm management techniques and production technology; the choice of breeds, crossbred and types of animals; effective control of diseases in rural areas; improved feed and fodder, etc. The inevitable result of this technological constraint is low farm production and productivity and the farmers' consequent loss of their animals and crops to various diseases.

Lack of information

Evidence from Ozowa (1996) seems to show that one of the major constraints faced by smallholder farmers is lack of very vital information. The vital information referred to includes information on product planning such as what crop and variety to grow at a given season with marketability of such a crop as an important deciding factor. As suggested by Parrish et al. (2005), smallholder farmers also require information on current prices, forecast of market trends (to assist farmers in planning their market products) and sales timing (which assists farmers in ensuring that they do not cause a market glut). Using the results from his studies, Ozowa (1996) further came to a conclusion that information on improved marketing practices such as improved harvesting methods and on group marketing which enables small scale farmers to have organized sales of marketable surplus and bulk transport of produce is crucial if smallholder farmers are to perform well in any economy. Having all this kind of information is very difficult because of information asymmetry but in some cases, for example, information on loan facilities might be in existence but due to low levels of literacy farmers are mostly unaware it exists (Ozowa, 1996).

Sibale (2010) and Key and Runsten (1999) attributed this lack of vital information to the scattered and unorganized nature of smallholder agriculture and lack of communication tools in most developing countries. These factors are known to leave most farmers ignorant of potential markets and having to rely on extension workers, where they exist, otherwise it is by word of mouth, which in most cases the information is distorted or inaccurate (Sibale, 2010). According to UEPB (2004), media such as radio, newspapers and commentaries for market information also do contribute in information dissemination but these channels come with a number of shortfalls. UEPB (2004) further pointed out that information from these sources is often inaccurate, not targeted, not update and usually has no information about exports. At the end of the day, farmers who access this information do not benefit at all. Consequently, with agriculture being such a risky industry due to its heavy reliance on the volatile weather, small farmers risk losing their produce and money especially if they mistime their harvesting periods or fail to forecast on the likelihood of natural disasters such as drought occurring (Stringfellow et al., 1997).

Infrastructural constraints

Physical infrastructure in Machethe's (2004) view consists of communication links, electricity, storage facilities, transportation facilities and roads. Jari (2009) is of the view that all these different forms of physical infrastructure are vital for the success of the smallholder farming sector just as much as they are to all the other sectors in any economy. If these are not available or are in a bad state, then they force the transaction costs faced by the farmers to rise. Adams and Fitchett (1992) further maintained that the state of infrastructure in terms of roads in SA leading to the rural areas has negatively impacted on the progress of these smallholder farms. Furthermore, most of these roads are in very poor conditions that impossible to use especially during the rainy season as they become very slippery when wet (Montshwe, 2006). With farmers not able to afford their own transport, they rely on hired transport which is very expensive due to the condition of the roads. Most transporters charge exorbitant prices so as to cover the maintenance costs of their trucks. This further eats into the small coffers of these farmers especially if they have a deadline such as taking their perishable produce to the market on time. Under such situations where farmers have neither the power nor time to negotiate, they are forced to part with much of their hard-earned cash.

In terms of storage facilities, agricultural products are very perishable, hence need proper handling between the time they are harvested and delivered to the market. Due to the perishable nature of agricultural produce, it is imperative that it is sold whilst still fresh in order to fetch higher returns. This further necessitates the availability of proper storage facilities to keep the quality of the produce, and ultimately the price, very high. However, Tshuma (2009) realized through his study in Zanyokwe that some farmers continue to lack the required storage and marketing facilities. Consequently, they rely on the “farm gate sales” strategy whereby crops are harvested only when an interested buyer has come to the farm to buy and collect them. Even though this has been the most adopted strategy by most smallholder farmer, Machingura (2005) disagrees since the same farmers could receive much higher prices by selling their goods in urban centres. Unfortunately, smallholders rarely have access to such better urban markets as the lack adequate knowledge about their existence and also face high transaction costs in their attempts to find out more about these markets and transport their produce.

CONCLUSION

To summarize their importance, small-scale farms enhance rural income distribution through providing profitable gains for farmers. They also reduce product prices for consumers as well as increase food transfers to those who are unable to engage in the productive economy. Through forward and backward linkages, small farms allow for development of the rural economy.

These and other contributions are responsible for Making the nation’s first democratic government to embark on a land reform drive but, unfortunately, studies have since revealed that despite all these efforts, close to a quarter of farms transferred through the land reform programme have failed to produce anything since the transfer to new owners. The factors contributing to such a poor performance by smallholder farmers come in the form of technological, institutional constraints and infrastructural constraints and the farmers’ lack of adequate education, finance and market information, just to mention but a few. The extent of these constraints varies from place to place and from farmer to farmer. Nonetheless, most smallholders are failing to overcome the constraints in a way that would propel them into the commercial farming sector. As a result, such farmers will never be anything more than peasant farmers unless interventions are made to eradicate most, if not all, the limiting factors they face.

The majority of issues impeding the progress of smallholder farmers have something to do with the limited resources at the disposal of these farmers. In as much as the South African government can wish to assist, the fact remains that the number of these smallholders is too overwhelming to give them enough attention each. Perhaps the famers should come together, share their individual resources and work collectively to achieve their common goals. The government and other relevant stakeholders can assist with such things as proper institutions and other necessary support structures and services.

To overcome the problem of high transaction costs, collective action could also play a vital role. On the issue of losses caused by lack of proper markets and storage facilities, assistance should be focussed on getting the farmers formal contracts with established markets such as food processors, super markets, fruit and vegetable shops just to mention but a few. Such formal arrangements will guarantee farmers a steady market with competitive rates. However, it should be noted that the success of such formal relationships is highly dependent on the farmers themselves being able to deliver adequate produce of high quality as and when expected by the buyers.

It should be recalled that the majority of smallholder farmers are found in the deepest corners of SA where their accessibility is a challenge. As a solution, proper infrastructure in the form of proper roads is likely to make it easier for farmers to bring in inputs and take out their finished products to suitable markets on time. In addition, easy accessibility can enhance the farmers’ chances of getting assistance from various stakeholders as their progress can be easily monitored. Other forms of necessary infrastructure include providing adequate water bodies since any form of agriculture, be it livestock rearing or crop production, depends on water. Where necessary, electricity should be made available especially since agro-processing has already been proposed for adoption by agricultural cooperatives. This is because some agro-processing activities make use of electricity such as packaging and refrigeration of produce.

In conclusion, getting the smallholder agriculture sector to produce at satisfactory levels will require collective action from all role-players. Furthermore, it has been noted that some of the current beneficiaries of the land reform programme have actually been using their newly-acquired land for non-agricultural purposes, hence the consequent decline in overall production from the sector.

As such, stricter beneficiary selection and monitoring measures are needed to make sure that all those that get agricultural land use it specifically for agricultural purposes. This means the government, through its relevant local structures, should make sure the beneficiaries are all actively involved in agriculture after getting land whilst, on the other hand, other role-players such as funders and trainers work closely with the farmers on the ground to help them enhance their productivity. Support for all smallholder farmers should also be arranged in such a way that it continues until the farmers are fully established and actively involved in every aspect of their business, from procuring inputs to cultivating and tending their crops to harvesting and marketing them in the case of crop producers. This means that they should be nurtured to survive stiff competition from the already well-established commercial farmers and also to overcome the challenges discussed above. If this is done, then there is a higher possibility of them playing a significant role in promoting rural development, alleviating poverty and food insecurity at both the household and national levels.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Full Length Research Paper

Susceptibility of sorghum varieties to the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)

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Sitophilus zeamais* Motsch. is one of the most important pests of sorghum in storage causing severe economic damage to the grain. Twenty-one sorghum varieties obtained from Haramaya University Sorghum Improvement Research Program were investigated for their relative resistance to *S. zeamais* attack. The Dobie index of susceptibility was used to group the varieties into different reaction categories. Among the twenty one sorghum varieties evaluated, only one variety, 'WB-77', was regarded as resistant to the weevil. All the remaining varieties were categorized as moderately resistant. Weevils reared on the resistant variety produced a few number of F_1 progeny (20.00), had a high median developmental time (42.00 days) and a low percentage of seed damage (2.67) and seed weight loss (0.30). Percentage seed damage and weight loss are significantly and positively correlated with the mean number of F_1 progeny emergence and are inversely associated with median developmental time. Consequently, those varieties with high number of F_1 progeny scored high percentage of seed damage and weight loss. These results indicated that high lysine content was found to be the predominant factor in sorghum resistance to *S. zeamais.

Key words: Sorghum varieties, resistance, insect infestation, *Sitophilus zeamais*, susceptibility index.

INTRODUCTION

Sorghum, *Sorghum bicolor* L. Moench is an important crop ranking fifth in world cereal production with an annual production of 55.7 million tonnes (FAOSTAT, 2012). It is the main source of calories and protein in some regions of Africa and Asia (Waniska and Rooney, 2000). Sorghum accounts for an average 10% of daily caloric intake of households living in the eastern and northwest areas of Ethiopia (USDA, 2012). Ethiopia is the second largest producer of sorghum in eastern and southern Africa next to Sudan (Demeke and Marcantonio, 2013). In Ethiopia, one third of the cereal diet comes from sorghum, and it plays an important role in achieving food security at the household level (Dendy, 1995). In Ethiopia, both the production and productivity of sorghum have increased since the introduction and selections of high yielding sorghum varieties and landraces by the Ethiopian Institute of Agricultural Research and Haramaya University (EARO, 2000; Adugna, 2007). However, these varieties are reported to be highly susceptible to stored grain insect pests Mendesil et al.,

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(2007). As a result, farmers are hardly the beneficiaries of the high yield potential of these varieties.

The stored sorghum is attacked and damaged by a number of pests that lead to qualitative and quantitative deterioration. Among insect pests of sorghum in storage, the weevils are the most important pests, among them *Sitophilus zeamais* is the major one in Ethiopia (Bekele et al., 1997; Eticha and Tadesse, 1999; Abebe et al., 2009; Tefera et al., 2011; Temesgen and Waktole, 2013). Infestation by this weevil begins in the field (Caswell, 1962; Demissie et al., 2008), but significant damage happens during storage. Reports from other African countries also confirmed the field-to-store infestation of *S. zeamais* (Hill and Waller, 1990). Worldwide seed losses in the range of 15 to 77% have been reported for insecticide untreated sorghum due to the maize weevil (IDRC, 1976; Caswell, 1978; Kidane and Habteyes, 1989; Seifelnasr, 1992; Nyambo, 1993; Eticha and Tadesse, 1999; Ramputh et al., 1999). Losses are particularly pronounced in the tropical developing countries where environmental factors are conducive for the reproduction and development of weevils, and where storage facilities are inadequate (Shazali and Smith, 1985; Gwinner et al., 1996; Bekele et al., 1997). In a country, where production is much lower than the national demand and is characterized by the above stated level of post-harvest loss, a great effort is needed to reduce this loss.

In Ethiopia, Synthetic chemical insecticides are used by few farmers for the management of storage insect pests. The majority of farmers do not apply chemical insecticides against stored sorghum insect pests due to unavailability and high cost (Mendesil et al., 2007). Synthetic insecticides cause environmental pollution, adverse effect on non-target organisms, resistance development, and food contamination with toxic residues (Niber, 1994; Asawalam et al., 2006; Dhuyo and Ahmed, 2007; Kumar et al., 2007).

Thus, the search for easily available, eco-friendly, and cost effective insect pest management options are of paramount importance. One of the benign alternative management options is the use of resistant sorghum varieties against insect pests of sorghum including *S. zeamais*. In countries where storage facilities are inadequate, use of grains resistance to storage pests might be employed either alone or along with other management methods. The use of resistant varieties is economically feasible, technically easy and environmentally friendly alternative to minimize losses to storage insect pests. This study seeks to evaluate released and farmers' local sorghum varieties in Ethiopia for their resistance to *S. zeamais* based on a susceptibility index.

MATERIALS AND METHODS

The sorghum varieties used in this study were: Abshier; AL-70; Awash-1050; Chelenko; ETS-2750; Fendisha-5; Gubiye; IS-9302; Muyra-1; Red Sheferie-2; Red Sheferie-6; Yellow Wogere-6; White Wogere-8; Red Sheferie-1; Red Sheferie-5; Yellow Wogere-1; Yellow Wogere-2; Teshale; White Fendisha; WB-77; Wogere-3.

Culture of *S. zeamais*

S. zeamais was reared on sorghum to obtain similar aged weevils for the experiments. About 15 kg seed of the sorghum variety Muyra-1 was obtained from Haramaya University Sorghum Improvement Research Program. The seeds were cleaned to remove seeds with viable damage symptoms. The cleaned seeds were disinfested by keeping them in a deep freezer at -20 ± 2°C for two weeks to eliminate any potential field infestation. The seeds were then transferred to plastic bags and kept at rearing room conditions for two weeks (Abebe et al., 2009). Then, unsexed *S. zeamais* were collected from the infested sorghum grains and reared on the clean and disinfested sorghum seeds (Muyra-1) in 5 jars, each jar with 2 L capacity. To each jar containing 500 g of seeds, 100 adult weevils were introduced. Subsequently, the jars were covered with muslin cloth and fixed with rubber band to prevent escape of weevils and to allow aeration. The infested seeds were kept at room temperature (20 to 22°C). Eight days after oviposition, all parent weevils were removed from each jar and the seeds were kept at the same experimental conditions. The insect cultures used for the experiment were multiplied in jars of sorghum seeds for two generations to obtain uniform population for the experiment.

Sorghum varieties

The study was carried out in the Plant Protection Laboratory of Haramaya University, Ethiopia. For this experiment, a total of twenty one released and farmers' local sorghum varieties were used. The varieties are currently under production in different parts of Ethiopia. The varieties were collected from Haramaya University Sorghum Improvement Research Program, Ethiopia. Freshly harvested seeds of each variety were cleaned and disinfested by keeping them in a deep freezer at -20±2°C for two weeks before the commencement of the experiment to kill any mites and insect pests that might be present. The seeds were then kept for two weeks at the experimental conditions for acclimatization (Abebe et al., 2009). The moisture content of the seeds was adjusted to 12 to 13%.

Experimental design and procedure

One hundred (100) gram of seeds from each of the sorghum varieties were placed in a 250 ml glass jar covered with white muslin cloth and fixed with rubber band to allow aeration and to prevent escape of the weevils. No choice test method in which predetermined weevils were introduced to each jar was used for the study.

Thirty newly emerged unsexed adult weevils were introduced to each jar to infest 100 g seeds of each variety and were kept for ten days for oviposition. Seeds of each variety without *S. zeamais* were maintained under similar conditions and served as a control. The treatments were arranged in a Completely Randomized Design (CRD) with three replications. The treatments were placed in a laboratory at 25±2°C, 40 to 60% RH and 12:12 (light: dark) photoperiod. Mortality of *S. zeamais* was assessed eight days after introduction of weevils. All insects were removed and dead and alive insects were counted.

The treatments were kept under the same experimental conditions to assess the emergence of F_1 progeny. Seeds were inspected daily and the emerging progenies were removed and

Table 1. Adult mortality, progeny emergence and median developmental time (MDT) of *S. zeamais* on different sorghum varieties.

Variety	Adult mortality (%)	F_1 progeny emerged	MDT (days)
Abshier	3.14 ± 0.6^{a}	100.67 ± 6.92^{def}	37.10 ± 0.12^{cdef}
AL-70	2.98 ± 0.3^{a}	137.00 ± 5.51^{ab}	34.00 ± 0.92^{fgh}
Awash-1050	3.25 ± 0.4^{a}	$91.67 \pm 4.04d^{efg}$	38.10 ± 1.30^{bcde}
Chelenko	3.03 ± 0.1^{a}	125.00 ± 5.51^{bcd}	34.53 ± 1.17^{fgh}
ETS- 2752	3.41 ± 0.2^{a}	99.33 ± 4.62^{def}	37.43 ± 1.46^{bcde}
Fendisha- 5	3.22 ± 0.3^{a}	155.00 ± 4.51^{a}	31.40 ± 1.44^{h}
Gubiye	3.37 ± 0.4^{a}	60.33 ± 3.21^{hi}	39.87 ± 1.60^{abc}
IS-9302	3.19 ± 0.5^{a}	122.33 ± 5.57^{bcd}	35.10 ± 1.83^{defg}
Muyra-1	3.27 ± 0.2^{a}	138.00 ± 7.77^{ab}	33.33 ± 1.26^{gh}
Red Sheferie-2	3.26 ± 0.4^{a}	69.33 ± 3.61^{gh}	39.40 ± 1.22^{abcd}
Red Sheferie-6	3.33 ± 0.2^{a}	66.00 ± 3.0^{ghi}	39.53 ± 1.60^{abc}
Yellow Wogere-6	3.71 ± 0.3^{a}	80.67 ± 7.21^{fgh}	38.10 ± 1.39^{bcde}
White Wogere-8	3.36 ± 0.4^{a}	68.33 ± 4.00^{ghi}	39.53 ± 1.60^{abc}
Red Sheferie-1	4.12 ± 1.2^{a}	118.00 ± 7.51^{bcd}	35.13 ± 0.80^{defg}
Red Sheferie-5	3.56 ± 0.5^{a}	111.00 ± 5.29^{cde}	36.83 ± 0.86^{cdef}
Yellow Wogere-1	3.71 ± 0.2^{a}	102.00 ± 5.29^{def}	36.93 ± 1.69^{cdef}
Yellow Wogere-2	4.02 ± 0.5^{a}	117.00 ± 4.58^{bcde}	34.67 ± 1.94^{efg}
Teshale	3.51 ± 0.3^{a}	42.67 ± 2.31^{ij}	40.93 ± 1.55^{ab}
White Fendisha	3.46 ± 0.4^{a}	128.00 ± 5.29^{bc}	34.00 ± 0.92^{fgh}
WB-77	3.43 ± 0.3^{a}	20.00 ± 1.53^{j}	42.00 ± 1.42^{a}
Wogere-3	3.37 ± 0.2^{a}	77.00 ± 4.36^{fgh}	38.50 ± 0.62^{bcde}

Means followed by the same letter within the column are not significantly different at $p < 0.01$. Original (back-transformed) values are presented here; however, log and angular-transformed values were used for the analysis.

counted per jar on each assessment day. Observations were continued for two months (56 days) until all F_1 progenies were expected to have emerged.

Sixty-four days after introduction of the weevils, 100 seeds were randomly taken from each jar to assess the number of seed damage (seeds with hole) and grain weight loss. Seed damage was expressed as a proportion of the total number of seeds sampled. Grain weight loss was determined using the count and weight method of Gwinner et al. (1996) expressed as:

$$\text{Weight loss }(\%) = \frac{(\text{Wu*Nd}) - (\text{Wd*Nu})}{\text{Wu*}(\text{Nd} + \text{Nu})}\text{*}100;$$

Where Wu = Weight of undamaged seed, Nu = Number of undamaged seed, Wd = Weight of damaged seed, and Nd = Number of damaged seed.

The median development period was calculated as the time (days) from the middle of the oviposition period to the emergence of 50% of the F_1 adults (Dobie, 1977).

The index of susceptibility was calculated as given by the formula of Dobie (1974): Index of susceptibility = 100 x [$\log_e$ (total number of F_1 progeny emerged) / (median development time)]. The susceptibility range of 0 to 11 was used to classify the sorghum varieties; where; 0 to 3 = resistant, 4 to 7 = moderately resistant, 8 to 10 = susceptible and ≥ 11 = highly susceptible (Dobie, 1974).

Data analysis

Data were subjected to analysis of variance (ANOVA) using the statistical software PROC GLM; SAS Institute (2008) (version 9.2). Data on percent adult mortality, percent seed damage, and weight loss were subjected to angular-transformation, while numbers of F1 progenies were log transformed in order to stabilize the variance. Statistical analysis was performed using one-way analysis of variance. Differences among means were compared by Tukey's HSD test. Pearson correlation coefficients were obtained using the same statistical software.

RESULTS

Adult mortality, progeny emergence and developmental time

There were insignificant differences among the sorghum varieties in percentage adult mortality (Table 1). However, highest weevil mortality was recorded in the varieties Red Sheferie-1 and Yellow Wogere-2 whereas, least percent of mortality was noticed in AL-70 and Chelenko. Significant differences ($P<0.01$) were observed between the varieties in the number of F_1 progeny emergence (Table 1). Maximum numbers of F_1 progenies emerged from Fendisha-5 (155) followed by Muyra-1 (138) and AL-70 (137) while significantly the least number of F_1 progenies was counted from WB-77 (20). The median developmental time varied significantly ($P <0.01$) among the sorghum varieties (Table 1).

Table 2. Extent of seed damage and weight loss by *S. zeamais* on different sorghum varieties.

Variety	Seed damage (%)	Weight loss (%)
Abshier	13.00 + 3.67^{bc}	3.13 + 0.59^{d}
AL-70	21.00 + 3.46^{ab}	7.10 + 0.54^{b}
Awash-1050	11.00 + 2.36^{c}	2.80 + 0.41^{de}
Chelenko	15.66 + 4.56^{bc}	5.67 + 0.74^{bc}
ETS-2752	12.67 + 1.20^{bc}	2.98 + 1.20^{de}
Fendisha-5	29.33 + 4.23^{a}	12.40 + 0.84^{a}
Gubiye	4.00 + 1.00^{e}	1.01 + 0.74^{f}
IS-9302	15.00 + 4.35^{bc}	5.50 + 1.10^{bc}
Muyra-1	23.00 + 4.61^{ab}	8.77 + 1.27^{b}
Red Sheferie-2	9.00 + 2.81^{dc}	2.26 + 0.30^{e}
Red Sheferie -6	5.00 + 1.10^{d}	1.98 + 0.43^{ef}
Yellow Wogere- 6	10.67 + 1.15^{c}	2.35 + 0.56^{e}
Yellow Wogere-8	6.00 + 2.00^{d}	2.14 + 0.28^{e}
Red Sheferie- 1	14.00 + 3.31^{bc}	3.90 + 0.16^{c}
Red Sheferie- 5	13.00 + 4.20^{bc}	3.50 + 0.93^{cd}
Yellow Wogere-1	13.00 + 3.46^{bc}	3.05 + 0.16^{d}
Yellow Wogere-2	14.67 ± 3.78^{bc}	4.10 ± 0.60^{c}
Teshale	3.67 + 0.50^{e}	0.85 + 0.10^{f}
White Fendisha	19.00 + 3.43^{ab}	6.22 + 0.50^{b}
WB-77	2.67 ± 0.67^{ef}	0.30 ± 0.26^{g}
Wogere-3	10.66 + 2.43^{c}	2.49+0.59^{e}

Means followed by the same letter within the column are not significantly different at p<0.01. Original (back-transformed) values are presented here; however, angular-transformed values were used for the analysis.

Development from egg to adult ranged from 31.40 days for Fendisha-5 to 42.00 days for WB-77. Generally, as the median developmental period increases, the F_1 progeny emergence decreases. A shorter median developmental time gives rise to more generations a year, and the greater is the susceptibility of the variety.

Seed damage and weight loss

Significant variations (P<0.01) were recorded in the percentages of seeds damaged and weight loss between the sorghum varieties (Table 2). The results revealed that the highest seed damage and weight loss were observed in Fendisha-5, Muyra-1 and AL-70. The least percent of seed damage and seed weight loss were recorded inWB-77, Teshale and Gubiye varieties. Percentage seed damage and weight loss were directly related to the mean number of F_1 progeny emergence. Consequently, those varieties with high number of F_1 progeny scored high percentage of seed damage and weight loss.

Index of susceptibility

The index of susceptibility ranged from 3 for variety WB-77 to 7 for Fendihsa-5 (Figure 1). Out of the twenty-one sorghum varieties evaluated for their resistance to *S. zeamais*, only one variety WB-77, was rated as resistant, while all the remaining varieties were categorized as moderately resistant to weevil attack.

Simple correlation coefficient of the variables

The simple linear association between variables like number of F_1 progeny, median developmental time, susceptibility index (SI), weight loss, and seed damage are summarized in Table 3. SI was positively correlated with important genetic resistant factors such as progeny emergence, percent of seed damage and percent of weight loss. However, median development time was inversely correlated with the susceptibility index, and was negatively and significantly associated with F_1 progeny emergence (r = -0.93, P< 0.01) (Table 3). As can be expected, with the increasing number of F_1 progenies, there was an increasing and highly significant percentage of seed damage (r = 0.94, P< 0.01) and seed weight loss (r = 0.92, P< 0.01) from the varieties.

DISCUSSION

The difference in sorghum varieties were mainly due to

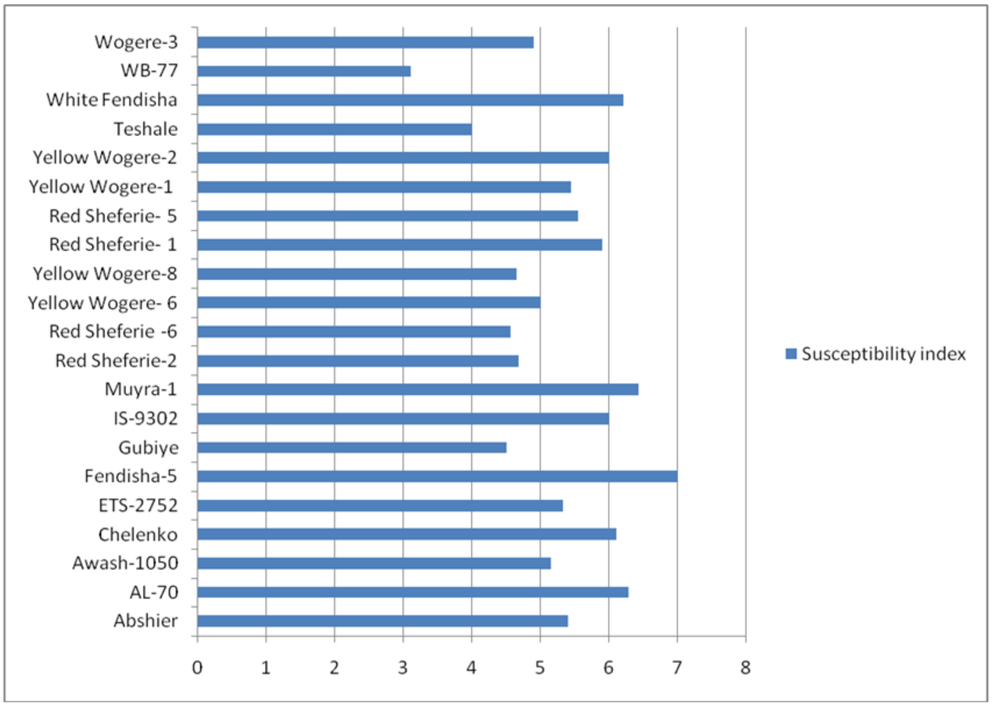

Figure 1. Susceptibility index of sorghum varieties to *S. Zeamais* infestation (0-11 scale), where; 0-3= resistant, 4-7= moderately resistant, 8-10= susceptible and $\geq$ 11= highly susceptible

the variation in seed damage level, the percent of grain weight loss, F_1 progeny emergence, median developmental time and susceptibility index. These variations in the differential susceptibility of the sorghum varieties show the innate capacity of a particular variety to resist *S. zeamais* attack. Resistant varieties exhibited minimum grain damage and weight loss, reduced multiplication of F_1 progeny, longer median developmental period and lower score of susceptibility index. A number of factors contribute to the differences in genetic resistance of sorghum varieties to stored grain insect attack through their influence on fecundity and development (Shazali, 1987; Adentuji, 1998). This indicates that presumably antibiosis and/or antixenosis (non-preference) mechanisms of resistance play a role in varietal resistance. Similarly, several authors reported that antibiosis and non-preference act together as mechanisms of resistance to *S. zeamais* in sorghum and maize grains (Santos and Foster, 1983; Torres et al., 1996; Chuck-Hernández et al., 2013; Temesgen and Waketole, 2013).

Resistance in stored sorghum to insect attack has been attributed to the presence of toxic alkaloids or amino acids, insect feeding deterrents, pericap surface texture, enzyme inhibitors, grain hardness, grain temperature and moisture content. These factors acting alone or in combination are responsible for the varying levels of resistance to certain species of storage insect pests (Baker, 1976; Wongo and Pedersen, 1990; Ramputh et al., 1999; Chandrashekar and Satyanarayana, 2006). Bamaiyi et al. (2007) also reported grain hardness as the main resistance parameter for *S. oryzae* in stored sorghum.

The resistant sorghum variety, WB-77, has high lysine content (ICRISAT, 1985). Higher levels of lysine and tryptophan decreased the rate of reproduction of *S. zeamais* (LeCato and Arbogast, 1974; Abebe et al., 2009). Further, Arnason et al. (2004) also reported that protein content was negatively correlated with the susceptibility of maize cultivars to *S. zeamais*. All the tasted sorghum varieties were not significantly different from each other with regard to weevil's mortality. Abebe et al. (2009) reported a similar result among thirteen maize varieties evaluated against *S. zeamais.* Similarly, Dobie (1974) found low mortality of adult maize weevils on different varieties of maize, and concluded that there was no evidence for variation among the varieties in their effect upon the mortality of *S. zeamais*. Abraham (1991) also stated that mortality of maize weevil was not a good parameter to quantify the susceptibility and/or resistance of varieties, because adult weevils were found to survive without food for more than ten days in a laboratory test.

Progeny emergence was highly correlated with the susceptibility of varieties to weevil infestation. Consequently, varieties which are susceptible to maize weevils produce more number of progeny as compared to the resistant varieties. A large difference in the number of F_1 progenies between the resistant and susceptible varieties

Table 3. Correlation coefficient of *S. zeamais* infestation on sorghum varieties.

Variable	F_1P	MDT	SI	SD	WL
F_1P	1				
MDT	-0.93**	1			
SI	0.95**	-0.92**	1		
SD	0.94**	-0.91**	0.83**	1	
WL	0.92**	-0.91**	0.81**	0.86**	1

F_1P: No. of F_1 progeny, MDP: median developmental period, SI: index of susceptibility, SD: seed damage, WL: weight loss, *: Correlation is significant at 0.05 level; **: Correlation is significant at 0.01 level.

is an important variable for the management of *S. zeamais* in stored sorghum. According to Davey (1965), the difference in the number of emerging progenies of *S. oryzae* is an adequate measure for comparing damage among sorghum varieties. *S. zeamais* required less developmental time on the susceptible variety, Fendisha-5 (31.40 days) while, longer developmental time was elapsed on the resistant variety, WB-77 (42.00 days). This indicates that one effect of increased resistance is prolongation of the developmental period. The susceptible sorghum variety, Fendisha-5, had approximately eleven day shorter developmental period for the number of F_1 emergence than the resistant variety, WB-77. Similarly, *S. zeamais* emerged from varieties having a high index of susceptibility exhibited reduced periods for the completion of developments. According to Horber (1988), the susceptibility index is based on the assumption that the higher F_1 progeny and the shorter the duration of the development, the more susceptible the varieties would be. According to Abraham (1991), the extent of damage during storage depends on the number of emerging adults during each generation and the duration of each developmental time. Thus, varieties allowing rapid and high levels of adult emergence will be more seriously damaged. Several sorghum varieties, especially local landraces have been characterized as sources of resistance to *Sitophilus* species (Anonymous, 1986; Tibebu and Tessema, 1986; Ramputh et al., 1999; Teshome et al., 1999; Chitio et al., 2004; Chandrashekar and Satyanarayana, 2006; Bamaiyi et al., 2007; Chuck-Hernández et al., 2013).

The information obtained from the present study will assist to devise the management strategies against this legendary pest of sorghum as well as other cereals. Based on the present investigation, the most resistant sorghum variety among the varieties tested is WB-77. The resistant variety WB-77 is a variety with reduced number of F_1 progenies, seed damage, weight loss, indices of susceptibility; and extended median developmental time. These indicate that the overall loss incurred to this variety during storage will be minimal. This variety deserves special consideration and can be stored for longer periods of time under traditional storage system of small scale farmers with inadequate storage facilities. Resistant varieties can reduce the cost of weevil's management and can also be utilized as an environmental friendly way to reduce damage by *S. zeamais.* In the past, a reasonable number of sorghum varieties have been evaluated for their resistance to maize weevil, but still more explorations are needed to achieve long-term and sustainable pest management strategies and to diversify the basis of resistance to this pest. Thus, the authors suggest the inclusion of this resistant sorghum variety in the integrated sorghum production system.

Conflict of interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Market participation of smallholder maize farmers in the upper west region of Ghana

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This study investigated farmer characteristics, private assets, public assets and transaction cost variables influencing the probability and intensity of participating in the market by smallholder maize farmers in the Upper West Region of Ghana. The Household Commercialisation Index was used to estimate the level of market participation and the Double Hurdle Model was used to estimate the factors influencing both market participation and intensity of participation. The results indicated that about twenty-four percent of maize is sold in the region within a production year which implies low commercialisation index. Specific farmer characteristics, private assets, public assets and transaction cost variables significantly influenced the probability and intensity of market participation behaviour in the region. The study concludes that maize is produced as a staple for household consumption. The study recommends that government through the Ministry of Food and Agriculture should institute productivity enhancing measures to increase the productivity of maize as well as establish rural finance schemes to address the credit needs of smallholders.

Key words: Household commercialisation index, double hurdle model, market participation, maize, smallholder farmers, upper west region, Ghana.

INTRODUCTION

Ghana has a largely agrarian economy. Area under cultivation in 2010 stood at 7,846,551 ha representing 57.6% of the total agriculture land area. Agriculture is however dominated by smallholder farmers who are predominantly rural dwellers, with about 90% of farm holdings less than 2 ha in size.

The implication of this dominance of smallholders is that no meaningful policy to enhance the development of the agricultural sector can overlook these farmers. As a result, many authors (such as Siziba et al., 2011; Chamberlin et al., 2007), policy documents (such as GPRS II, FASDEP II, CAADP) and institutions (such as MoFA, 2007 and the World Bank, 2007) have emphasised the reorientation of policies towards access to markets by smallholder farmers as a means of improving their livelihoods and development. In line with this, the Government of Ghana recognised that strategies to improve agricultural performance should include investments that improve and enhance market access. Siziba et al. (2011) noted that a leap that African agriculture needs to make to reduce poverty and hunger is to transform from the low productivity semi-subsistence

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farming to high level commercial production. Therefore, any pathway that can lift large numbers of the rural poor out of poverty will require some form of transformation of smallholder agriculture into a more commercialized production system (Olwande and Mathenge, 2012).

Northern Ghana, which includes the Northern, Upper West and Upper East regions, is poorly endowed with natural resources and the income per capita of its population falls well below the national average. The Upper West region is among the poorest and least developed regions in Ghana having the least average annual per capita income of GH¢130 as against the national average of GH¢400 (GSS, 2008). The Ghana Poverty Reduction Strategies I & II, indicate that nine out of ten people in the region are poor and almost 90% of its population depends on farming in rural areas.

In the Upper West Region, maize is one of the major crops grown and is of high commercial value. Maize accounts for 50-60% of the total cereal production in Ghana and represents the second largest crop commodity in the country after cocoa. Maize is grown by over three-quarters of farmers nationally with two-thirds being grown in the Upper East and Upper West Regions. The implication is that increased production of maize in the Upper West Region presents opportunities to promote smallholder income growth and hence reductions in poverty levels and also enhance achievement of food security.

Despite this growing emphasis on market participation, agricultural commercialisation is low (IFAD-IFPRI, 2011). They indicated that the national average of marketed surplus ratio which defines the level of commercialisation is 33%, which is observed as low. While there are significant differences of market commercialisation across regions, the Upper West Region has one of the least average marketed surplus ratio of 18% only better than the Upper East Region which has 15%.

Maize which has potentials for increasing incomes is still widely produced as staple crop. Why is maize not making transition from staple to commercial crop in view of the potentials it presents? And why is the level of commercialization of smallholder farmers in the Upper West Region so low? The study specifically addresses the following questions. What is the level of market participation by smallholder maize farmers? What factors influence the intensity of market participation by smallholder maize farmers? Based on these questions, the study addresses these objectives:

1. To estimate and analyse the level of market participation by smallholder maize farmers.
2. To estimate and discuss the magnitude and effects of factors which determine the probability and intensity of smallholder maize farmers' participation in the market.

Literature review

The concept of market participation has been defined and interpreted in various ways. Based on the work of Barrett (2008), two basic interpretations can be inferred: households can participate in the market either as sellers or buyers. Therefore market participation has a demand side; households participating as buyers, and a supply side; households participating as sellers. Both the decision to enter the market as a seller or a buyer is motivated by the theory of optimisation where the household seeks to maximise utility subject to the cash budget and available non-tradable resources. In empirical studies, the supply side of market participation is emphasised as studies tend to focus on that side of the equation. Based on the supply side, market participation is often conceived in terms of sales as a fraction of total output and can be generally referred to as commercialisation of agriculture (Makhura et al., 2001; Omiti et al., 2009).

Empirical evidence of smallholder farmers' participation in the market has been extensively considered for variety of agricultural products in agrarian economies especially Africa. Literature has focused primarily on understanding the role of transactions costs and market failure in smallholder decision making. With respect to the transaction cost variables affecting market participation, Goetz (1992) observed that in small or less developed markets it is costly to identify trading opportunities while poor market access due to lack of transport, distance, and/or barriers such as ethnicity or language increase a household's cost of observing market prices to make transaction decisions, thus reducing the household's leisure time in sun-Saharan Africa. In general, many evidences found strong positive associations between market participation and low levels of transactions costs especially transport costs and information costs (Alene et al., 2008; Ouma et al., 2010).

Empirical evidence of household characteristics/private asset variables and market participation has generally been found to exhibit positive relationship with market participation. For example, Siziba et al. (2011) observed that off-farm income, ownership of radio and number of livestock owned were highly significant private asset variables positively associated with high volume of cereal grain sales among smallholder farmers in sub-Saharan Africa. Socioeconomic characteristics such as age, education, farm size, ownership of some assets and output were observed to have positive effect on market participation of various agricultural commodities (Olwande and Mathenge, 2012; Omiti et al., 2009; Randela et al., 2008).

Public assets variables have also been found to have positive relationship with market participation especially with respect to access to credit and insurance (Cadot et al., 2006; Stephens and Barrett, 2009) and input use and access to extension services (Alene et al., 2008). For example, Olwande and Mathenge (2012) and Omiti et al. (2009) observed price to positively affect market participation. Siziba et al. (2011) observed that extension training and participation in research have positive effect on market participation.

MATERIALS AND METHODS

Study area and data collection

The Upper West region has eleven political/administrative districts. The study focused on four purposively selected agricultural districts: Jirapa-Lambussie, Nadowli, Wa West and Sissala East because of their highest share in the production of maize in the 2011 production season.

The data for the study was completely primary data gathered through a household survey by the use of a semi-structured questionnaire aided by a face to face interview of smallholder maize farmers in the 2011 production season. The semi-structured questionnaire was designed to collect a range of data on amounts of maize production and the proportion sold, household characteristics such as age, gender, marital status, farm experience of the household head, household size, etc.; private assets variables such as farm size, off-farm income, ownership of a mobile phone, etc.; public assets variables such as access to credit, extension contact, etc.; transaction cost variables such as access to market information, point of sale of output, etc. A multi-stage sampling procedure was adopted to draw a sample size of 200 maize farmers. The multi-stage procedure was a three-stage, clustered, purposive and random sampling approach. The three stages involved the selection of districts, the selection of enumeration areas earmarked by MoFA and associated communities and the selection of maize farmers.

Analytical framework

This study is theoretically underpinned by the Barrett's stylized household's non-separable market participation behaviour model which is premised on utility maximisation. The basic assumption of the Barrett's model is that a farm household faces a decision to maximise utility either as a net buyer, net seller or autarkic represented in the reduced form as a function of the exogenous variables (A, G, W, P, Z) capturing private asset stock, public asset stock, household-specific characteristics, commodity price and transaction costs respectively. Boughton et al. (2007) shows that each of the choice variables (being a net buyer, net seller and autarchic) can be represented in reduced form as a function of the exogenous variables. This implies that participating in the market as a seller can be a stand-alone model reflecting a fundamental relationship between market participation of households as sellers and some variables which serve as covariates as:

$$Market\ participation\ (as\ sellers) = f\begin{pmatrix} private\ asset\ stock\ (A), public\ asset\ stock\ (G), \\ household\ characterisitics\ (W), \\ commodity\ price\ (P)\ and\ transaction\ cost\ (Z) \end{pmatrix} \tag{1}$$

Following from equation 1 and other studies (Omiti et al., 2009; Randela et al., 2008; Boughton et al., 2007), the specific theoretical relationship is represented as:

$$Market\ participation\ (as\ sellers) = f\begin{pmatrix} AGE, GEN, EDUC, MARST, HHSIZE, FEXP, MFBO, FRMSIZE, HHINC, \\ OFINC, OUTPUT, TEL, ACCRE, EXTCON, PRICE, MKTINFO, POS \end{pmatrix} \tag{2}$$

In empirical studies however, econometric models applied to market participation in general typically adopt a two-step analytical approach. The reason for the application of two step analytical approach is that market participation is seen to embody two decision processes: the unobservable decision to participate and the observed degree or extent of participation.

The Cragg's double hurdle model (DHM) and the Heckman sample selection model are the widely used models in the two step approach. The Heckman model is designed for incidental truncation, where the zeros are unobserved values. However, in this study, a zero value in the data would reflect farmers' optimal choice rather than a missing value. It would be erroneous to equate these missing observations to zero. Therefore, the DHM is used in this study. It estimates a probit model in the first stage and a truncated regression model in the second stage.

The truncated Barrett's stylized non-separable household market participation behaviour model as summarised in equation 1 does not explicitly capture the two step approach of market participation as indicated in empirical studies. This study adds to the Barrett's theoretical model by creating the empirical dimensions of the unobservable decision to participate and the observed degree or extent of participation as follows.

$$\begin{aligned} Market\ Participation\ model\!: PART &= \alpha_0 + \alpha_1 AGE + \alpha_2 GEN + \alpha_3 EDUC + \alpha_4 MARST \\ &+ \alpha_5 HHSIZE + \alpha_6 FEXP + \alpha_7 MFBO \\ &+ \alpha_8 FRMSIZE + \alpha_9 HHINC + \alpha_{10} OFINC \\ &+ \alpha_{11} OUTPUT + \alpha_{12} TEL + \alpha_{13} ACCRE \\ &+ \alpha_{14} EXTCON + \alpha_{15} MKTINFO + \varepsilon \end{aligned} \tag{3}$$

$$\begin{aligned} &Intensity\ of\ Participation\ model\!: HCI \\ &= \beta_0 + \beta_1 AGE + \beta_2 GEN + \beta_3 EDUC + \beta_4 MARST + \beta_5 HHSIZE \\ &+ \beta_6 FEXP + \beta_7 MFBO + \beta_8 FRMSIZE + \beta_9 HHINC + \beta_{10} OFINC \\ &+ \beta_{11} OUTPUT + \beta_{12} TEL + \beta_{13} ACCRE + \beta_{14} EXTCON + \beta_{15} PRICE \\ &+ \beta_{16} MKTINFO + \beta_{17} POS \\ &+ \mu \end{aligned} \tag{4}$$

The description, measurement and expected signs of variables are displayed in Table 1. The estimation of the market participation models represented in equations 3 and 4 can be achieved by first estimating the level of participation. This achieves the first objective of the study. The Household Commercialisation Index (HCI) proposed by Govereh et al. (1999) and Strasberg et al. (1999) is used but modified to estimate the level of Maize Commercialisation Index (MCI) only and specified as:

$$HCI_{im} = \left[\frac{Gross\ value\ of\ maize\ sale_{ij}}{Gross\ value\ of\ all\ maize\ production_{ij}}\right] * 100 \tag{5}$$

where HCI_{im} is the i^{th} household commercialisation index for maize; the numerator is the total amount of maize sold by the i^{th} household in the j^{th} year (j = 2011 farming season) and the denominator is the total value of output of maize by the i^{th} household in the j^{th} year.

EMPIRICAL RESULTS AND DISCUSSION

Socio-economic characteristics of surveyed households

The age of surveyed household heads range from 21 to 88 years with a mean age of 47 years. This implies that farm households in the region can be described as relatively young and within the economically active population. About 86% of household heads is male while about 14% is female. This is consistent with the gender distribution in Ghana where 65.3% are male-headed and 34.7% are female-headed (GSS, 2012). The majority (84.5%) of household heads is married while 15.5% is

Table 1. Description, measurements and expected signs of variables in the participation and the intensity models.

Variable	Description	Measurement	Expected sign	Model*
PART	Decision to participate in the market or not	Dummy: 1 = farmer participates in market (sold maize); 0 = otherwise		PBT
HCI	Percentage of total output sold	Household Commercialisation Index		TRR
Farmer characteristics				
AGE	Age of the farmer	Number of years	+/-	PBT/TRR
GEN	Gender of the farmer	Dummy: 1 = if male; 0 = otherwise	+	PBT/TRR
EDUC	Education level of the household head	Number of years of schooling	+/-	PBT/TRR
MARST	Marital status of farmer	Dummy: 1 = if married; 0 = otherwise	+	PBT/TRR
HHSIZE	Household size of farmer	Number of people in the household	+/-	PBT/TRR
FEXP	Farmer experience in maize farming	Number of years in farming	+	PBT/TRR
MFBO	Membership of farmer to an FBO	Dummy: 1 = if member; 0 = otherwise	+	PBT/TRR
Private assets variables				
FRMSIZE	Total amount of land cultivated to maize in the 2011 production season	Hectares	+	PBT/TRR
HHINC	Total annual household income	Ghana Cedi (GH¢)	+	PBT/TRR
OFINC	Proportion of off-farm income in total annual household income	Ratio	+/-	PBT/TRR
OUTPUT	Total output of maize produced in the 2011 production season	Number of 50 kg bags	+	PBT/TRR
TEL	Farmer ownership of a mobile phone	Dummy: 1 = if yes; 0 = otherwise	+	PBT/TRR
Public Assets/Social capital variables				
ACCRE	Access to credit by farmer	Dummy: 1 = if farmer applied and received credit; 0 = otherwise	+	PBT/TRR
EXTCON	Farmer contact with extension officers	Dummy: 1 = if yes; 0 = otherwise	+	PBT/TRR
PRICE	Average price at which each 50 kg bag of maize is sold	Ghana Cedi (GH¢) per 50 kg bag	+	TRR
Transaction cost variables				
MKTINFO	Farmer access to market information	Dummy: 1 = if yes; 0 = Otherwise	+	PBT/TRR
POS	Point of sale of output	Dummy: 1 = market centre; 0 = farm-gate	-	TRR

*Model in which variable is applied: PBT is Probit model (Participation/hurdle 1), TRR is Truncated Regression model (intensity of participation/hurdle 2).

unmarried. Mean household size in the region is about 10 people and ranges from 2 to 32. The majority of households (69.5%) have no formal education. This is followed by heads with primary level of education (13.5%). The least are heads with university education (0.5%). The mean years of education shows that on average the highest level of education attained by a household head is primary education (approximately primary 3). Households have on the average 13 years of farming experience in maize farming. The minimum and maximum farming experience are 1 and 68 years respectively. The average annual household income is GH¢1,123.80 and ranges between 25 and GH¢6,900. Household income basically flows from sales of maize output, other on-farm activities, and non-farm activities. About 16% of household heads engaged in non-farm income activities in the region in the 2011 farming season. Mean annual non-farm income is GH¢204.67.

The mean farm size cultivated to maize is 1.10 ha with a minimum of 0.40 and maximum of 2 ha. The mea output of maize is 11.02 bags with a minimum of 1 bag and a maximum of 89 bags. Households with access to credit represented only 22.5% of the sample. This means that access to credit is one of the major constraints faced by households. The majority (92%) of households were n not members of any farmer organisation while 8% belonged to FBOs. Those who are members meet on average 2 times a month. Farmers who had access to market information represented the majority (63%). Market information basically constituted market prices

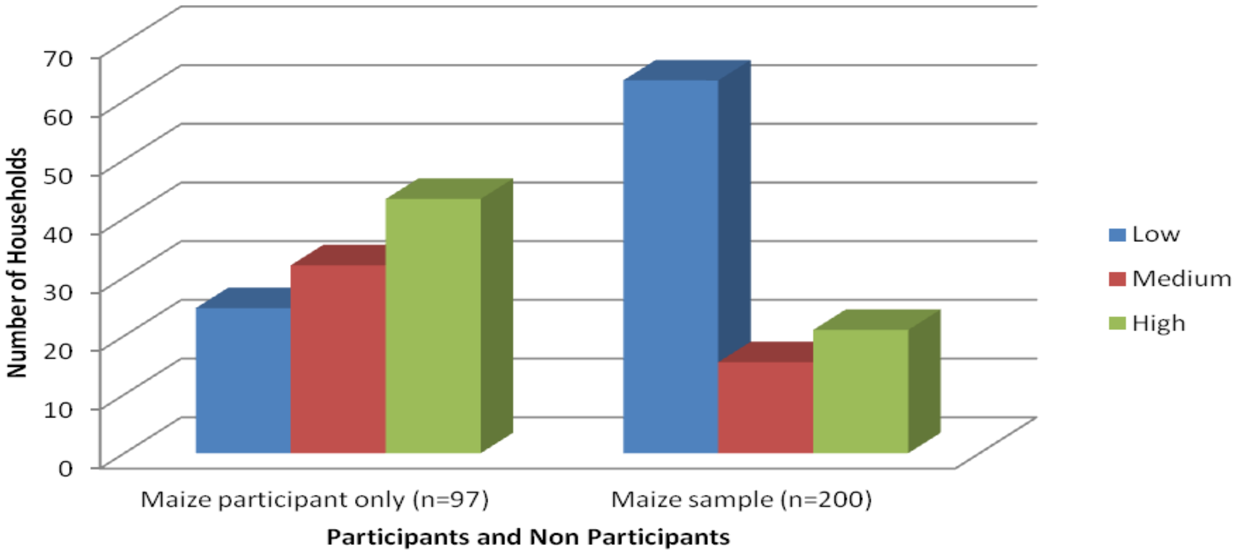

Figure 1. Characterisation of degree of participation by households. Source: Drawn from Household Survey Data (2012).

and where sharp market is. Access to information was from friends/relatives (16%), market women (28%) and radio (56%). Households receiving agriculture extension services constituted 41% of surveyed households while those without contact constituted 59%. This implies that extension contact in the region is very low.

About 48.5% of households participated in the maize market while 51.5% did not. This implies that about 49% of farmers in the region sold maize output from the 2011 farming season while about 52% did not. 55.7, 38.1 and 6.2% of maize sales were done at farm-gate, market centre and both farm-gate and market centre respectively. The average price received by maize farmers is GH¢68.55 per 50 kg bag distributing into GH¢67.03 per 50 kg bag at farm-gate and GH¢71.40 per 50 kg bag at the market centre.

Level of market participation by smallholder maize households

The level of market participation or commercialisation of smallholder maize households from the data gathered indicates that the average marketed surplus ratio is 23.77%. This implies that on average 24% of the output of maize is sold by sampled farmers in the Upper West region within a production season. The result shows a low commercialisation index and hence maize can be regarded as a staple crop cultivated for the purpose of household consumption. The estimate of the level of participation was used to characterise farmers according to low, medium and high commercial farmers. According to Abera (2009), households who sell at most 25% and below of their output are low commercial farmers, those who sell between 26 and 50% are medium commercial farmers and above 50% are high commercial farmers. Following this categorisation, 63.5% are low commercial farmers, 15.5% are medium commercial farmers and 21% are identified as high commercial farmers. Figure 1 gives a pictorial view of the categorisation of households.

The figure shows that there are more high commercial farmers than medium and low commercial farmers for only farmers who sold maize. However, considering the whole sample of maize farmers (both those who sold and those who did not sell), there are more low commercial farmers than high and medium commercial farmers.

Determinants of market participation and intensity of participation of smallholder maize households

The user written command, *'craggit'* by Burke (2009) in Stata was used for the estimation of the magnitude and effects of factors that determine the probability and intensity of smallholder maize farmers' participation in the market. This command estimates the first and second hurdles of the DHM simultaneously. Diagnostic test for multicollinearity which is a common problem in any regression analysis was conducted based on variance inflation factor (VIF) to identify any potential misspecification problems that may exist in the estimated models. The test indicated that the largest VIFs in the probability model is 2.09 and that of the intensity model is 3.11. These values are well below the maximum value of 10 that is used as a rule of thumb to indicate the presence of multicollinearity. This implies that multicollinearity is not a problem in the estimated models. Heteroscedasticity is identified as a common problem with typical cross-section data. The established procedure for the correction of heteroscedasticity is to

Table 2. Estimates of determinants of market participation and intensity of participation.

Variable	Double hurdle estimates			
	Hurdle/Tier 1: Probability of participating in the market (Probit Regression)		**Hurdle/Tier 2: Intensity of participating in the market (Truncated Normal Regression)**	
	Coefficient	**Robust standard error**	**Coefficient**	**Robust standard error**
CONSTANT	1.4578**	0.7373	29.0423***	10.4511
AGE	-0.0408***	0.0100	-0.5130***	0.0991
GEN	-0.1662	0.3860	-10.4799**	4.6090
EDUC	-0.0751**	0.0357	0.2644	0.2719
MARST	-0.3491	0.3800	-3.0830	3.5305
HHSIZE	-0.1580***	0.0337	0.6033***	0.2052
FEXP	0.0010	0.0103	0.0991	0.0996
MFBO	1.2002***	0.4260	0.1742	3.7230
FRMSIZE	0.7742***	0.2835	0.6515	2.3759
HHINC	0.0005**	0.0002	0.0028***	0.0006
OFINC	3.4399***	1.0801	-10.6958**	4.4348
OUTPUT	0.0780**	0.0350	0.1824***	0.0692
TEL	0.0349	0.2819	-1.8071	2.6761
ACCRE	0.9644**	0.3765	8.2491***	3.1061
EXTCON	-0.0090	0.2844	-2.8364	2.4777
PRICE			0.4491***	0.0705
MKTINFO	0.5263*	0.2683	11.1541***	3.8656
POS			-9.1329***	2.5478

No. of observations = 200; Wald $\chi^2(15)$ = 88.83; Prob > χ^2 = 0.0000; Log pseudo likelihood = -417.9167; ***p < 0.01, **p < 0.05 and *p < 0.10. Source: Regression estimates from Household Survey Data (2012).

estimate the models using robust standard errors. Therefore, all the models are estimated using robust standard errors to correct for heteroscedasticity.

Determinants of market participation of smallholder households

The results of the determinants of the probability of participating in the market are displayed in Table 2. The Wald chi-square value of 88.83 is statistically significant at 1% indicating that the explanatory variables jointly explain the probability of participating in the maize market. The decision to participate in the maize market is significantly determined by age of the household head, number of years in school (educational status) of the household head, household size, membership in farmer based organisation, farm size, annual household income, proportion of off-farm income in total annual household income, output of maize, access to credit and market information.

Age is negatively associated with the probability of selling maize. This implies that older farmers are less likely to participate in the market as compared to younger ones. Older farmers might be more concerned about being food secured and would not want to take the risk of draining their maize banks as against the younger farmers who might want to enhance their quality of live hence would engage in the market to achieve their objectives. Randela et al. (2008) observed that younger farmers are expected to be progressive, more receptive to new ideas and to better understand the benefits of agricultural commercialisation.

Number of years spent in school by the household head is negatively related to the probability of selling maize. That is, a higher level of education is associated with a reduction in the probability of participating in the maize market. This observation contradicts the expectation of Makhura et al. (2001), Enete and Igbokwe (2009) and Randela et al. (2008) who argued that education will endow the household with better production and managerial skills which could lead to increased participation in the market. The possible explanation for this is that farmers with a higher level of education engage in farming on a part time basis while they commit to their full time jobs. Since maize is a staple crop, more of the output is stored for household consumption. Households with larger sizes are less likely to sell their maize output. This confirms the finding of Siziba et al. (2011) that households with large family sizes fail to produce marketable surplus beyond their consumption needs. It also confirms the finding of Makhura et al. (2001) that households decide to sell when they cannot consume all they have produced and hence, the more members the household has, the more likely that most of the produce will be consumed thereby decreasing the possibilities for selling.

Households who belong to farmer based organisations are more likely to sell maize. This is consistent with Olwande and Mathenge (2012) who argued that membership of a farmer to a farmer based organisation or group increases access to information important to production and marketing decisions while Matungul et al. (2001) observed that collective action as measured by belonging to farmers' organisations strengthens farmers' bargaining and lobbying power and facilitates obtaining institutional solutions to some problems and coordination. Farm size is positively related with the probability of selling maize. A larger farm size provides a greater opportunity for surplus production. Annual household income and the proportion of off-farm income in total annual household income are positively correlated with the probability of selling maize. Larger incomes and proportion of off-farm income enhance large scale production and input acquisition leading to larger marketable surpluses.

Output of maize is significantly associated with higher probability of participating in the market which is consistent with expectation since a higher output ensures marketable surplus. This finding underscores the importance of increased output by smallholders to enhance their chances of stepping out of poverty and improving their livelihood through increased income from increased participation in the market. Access to credit has a positive influence on the probability of selling maize. This result indicates that farmers with access to credit are able to produce enough marketable surpluses. One supporting argument is that access to credit gives the farm households the economic power to cultivate on large scale. Access to market information has a positive effect on the probability of selling maize. This confirms the finding of Siziba et al. (2011) who argued that access to information reduces risk perceptions. Another possible explanation for this result could be that farmers with access to market information might be easily persuaded to sell than those without such information.

Determinants of the intensity of market participation of smallholder maize households

The results for the determinants of the intensity of market participation are also displayed in Table 2. The intensity of participation in the maize market is significantly determined by age of the household head, gender of the household head, household size, annual household income, proportion of off-farm income in total annual household income, output of maize, access to credit, average price of maize output sold, access to market information and point of sale of maize output.

Age, conditioned on participating in the market, is negatively associated with the quantity of maize sales. Older farmers tend to sell less maize than the younger ones. For an additional year of a farmer, the quantity of maize sold decreases by 0.51%. One possible explanation is that the older farmers are more concerned with food security and therefore livelihood as compared to younger farmers. Gender has a negative effect indicating that male headed households sell less maize than their female counterparts. Female farmers sell 10.48% more maize than male farmers. This finding is unconditional on the probability of participation in the maize market. This finding strengthens the debate in favour of making productive assets accessible to women since it is argued that they are equally productive and commercial. Household size is positively associated with the quantity of maize sold. While the probability of selling maize is significantly negatively associated with the household size, conditional on selling, the quantity sold is positively associated with the household size. An increase in the household size by 1 person increases sale of maize by 0.60%. This implies that though households with larger sizes are less likely to participate in the maize market as sellers, they sell more maize when they participate.

Conditioned on participation in the maize market, household income is positively correlated with the amount of maize sold. A GH¢1 increase in annual household income increases the quantity of maize sold by 0.003%. While the proportion of off-farm income in total annual household income is positively related to the probability of participating in the maize market, it is negatively related to the quantity of maize sold. This implies that conditioned on participation, households with higher proportion of off-farm income in total annual household income sell 10.70% less maize. This implies that maize market participants do not invest off-farm income in farm technology and other farm improvement activities and tends to trigger off-farm diversification. Output of maize is associated with more sales of maize conditioned on participation. For every extra 50 kg bag of maize produced, 0.18% would be sold. This confirms the finding of Reyes et al. (2012) that farmers who have greater production have more surpluses they could sell. Surplus production serves as incentive for a household to participate in market (Omiti et al., 2009; Barrett, 2008). Access to credit is positively associated with the intensity of participation in the maize market. This means that households with access to credit sell 8.25% more maize than households without access. Access to credit is conditional on the probability of participating in the maize market. This result is expected since access to credit provides the financial strength for households to engage in intensive farming leading to more marketable surplus. Average price of the output of maize is positively associated with the quantity of maize sold implying that households who were faced with higher prices sold 0.45% more maize than those who had relatively lower prices. This finding is consistent with expectation and reflects the selling behaviour (selling at their times and at different prices) of the farmers in the region. This finding confirms the assertion from economic theory that output price is an incentive for farm households to supply more produce for sale. It also confirms the findings by Omiti et al. (2009) and Olwande and Mathenge (2012) that output price is an incentive for sellers to supply more maize in the market. Access to market information has a positive association with the quantity of maize sold conditioned on participation in the maize market. Households who had access to market information sold 11.15% more maize than those who did not have access. This confirms the finding of Siziba et al. (2011) and Omiti et al. (2009). Siziba et al. (2011) explains that this finding underscores the positive impact of public infrastructure and services in promoting market participation while Omiti et al. (2009) gathered that formal information sources enhance the intensity of market participation. The point of sale of output (which sort to capture the effect of transaction cost in marketing behaviour of farm households) negatively influences the quantity of maize sold. Households who sold maize travelling to market centres sold 9.13% less maize as compared to those who sold at farm-gate (in their houses). This finding confirms the findings of Omiti et al. (2009) and Martey et al. (2012). Distance to market is an indicator of travel time and cost. Once it is more costly and time consuming to travel to especially bigger market centres as compared to farm-gate sale, farmers are rational to choose to sell more at farm-gate even though big market centres in bigger and more developed communities offer higher prices. The average price of farm-gate sale of maize was GH¢67.03 per 50 kg bag while the market centre average was GH¢79.51 per 50 kg bag in the 2011 production season. Given that higher prices prevail in market centres and yet more output is sold at the farm-gate, it can be opined that transaction cost has a role to play in explaining why more output of maize is sold at the farm-gate. To explain further the role of transaction cost, 68.3% of maize households indicated that they sold at the farm-gate to avoid paying transportation fare or incurring other costs to get to market centres that offer higher prices. This implies that some households are not able to sell at market centres that offer higher prices as a result of transaction cost associated with reaching such markets.

CONCLUSIONS AND IMPLICATIONS

The analysis carried out showed that about twenty-four percent of maize output is sold by maize farm households in the Upper West region. In terms of characterising farm households, about 64, 16 and 21% of maize farm households are characterised as low, medium and high commercial households. Based on these evidences, a strong case can be made in favour of the fact that maize is a household consumption commodity mainly produced as a staple. It has not gained the status of a cash crop. Evidences with respect to few households having access to credit, production of maize on small land sizes, low engagement to farmer based organisations are all reinforcing issues to low marketed surplus ratio in the region.

The study confirms that farmer characteristics, private and public asset characteristics and transaction cost variables are the determinants of the probability and intensity of market participation of smallholder farm households. Specific variables that affect both the probability and extent of participation are age of the household head, household size, annual household income, proportion of off-farm income in annual household income, output of maize, access to credit and access to market information. Literature on market participation concentrates on the role of transaction cost in the market participation behaviour of farm households. The role of transaction has been underscored by this study. Though distant and more developed markets offer better prices for maize, majority of households still find it convenient to sell at the farm gate to avoid incurring cost to reach such markets.

Based on the findings of this study, the following policy measures are presented. Productivity enhancing mechanisms such as making fertilizer and other agro-inputs both physically and financially available should be put in place by MoFA through the regional and district offices to increase production of maize in the region. The fertilizer subsidy programme should be strengthened by effectively targeting smallholders. This should be coupled with the delivery of effective and proactive extension service alongside effective monitoring and supervision to ensure that what is delivered to farmers is effectively implemented by them. MoFA and other stakeholders should establish rural agricultural finance scheme aimed at addressing the credit needs of smallholder farmers. The development of the informal credit market should also be considered. The role of credit in enhancing the large scale production cannot be overemphasized. The Statistics, Research and Information Directorate (SRID) of MoFA should create a department solely for providing agricultural market information to make market information delivery effective. Farmers should effectively support efforts to form and maintain effective groups by government and other stakeholders to take advantage of credit facilities offered by microfinance and other credit institutions available. Microfinance institutions are willing to offer credit to groups because of the characteristic of joint liability which minimises their risk. Credit acquired should be invested directly in farm activities instead of diversions. Such effective groups can also better influence market prices for their products through their collective bargaining power.

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Conflict of Interest

The authors have not declared any conflict of interest.

Abbreviations: CAADP, Comprehensive Africa Agriculture Development Programme; **DHM,** Double Hurdle Model; **FBO,** Farmer Based Organisation; **FASDEP II,** Food and Agriculture Sector Development Policy II; **GPRS II**, Ghana Poverty Reduction Strategy II; **GSS,** Ghana Statistical Service; **HCI,** Household Commercialisation Index; **IFAD,** International Fund for Agricultural Development; **IFPRI,** International Food Policy Research Institute; **MoFA,** Ministry of Food and Agriculture.

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Changes in soil chemical properties under different farming systems exploration in semiarid region of Paraíba

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The change of Caatinga natural vegetation in the Brazilian semiarid region, to different systems of agricultural exploitation, that is, the replacement of complex and stable systems by simple and unstable systems has caused changes in soil properties that are dependent on the climate, the type of crops and the management adopted. Based on areas of Caatinga native vegetation, this study aimed to evaluate the changes in the chemical characteristics of soils under different farming systems in Paraiba backwoods. Vertissol samples were collected at 0 to 10, 10 to 20, 20 to 30 and 30 to 40 cm and chemically characterized. Selected systems were native vegetation, sparse vegetation, pasture, annual and permanent crops. Based on the statistical analysis, it was concluded that the replacement of native vegetation by agricultural farming systems in the region of watershed Riacho Val Paraiso, PB, caused changes only in pH, potassium and sodium in the soil attributes. There was a trend of soil chemical properties increasing in the areas of agricultural cultivation and with depth. In all areas of agricultural farming systems, soil fertility is suitable for most crops.

Key words: macronutrients, land use, soil depth.

INTRODUCTION

The caatinga biome, occupying an area of about 850,000 km², about 11% of the national territory, is the main existing ecosystem in the Brazilian Northeast region under semiarid climate. The population in this area corresponds to about 20 million inhabitants. This area has significant socioeconomic and ecological importance.

The complex and stable systems of the natural vegetation of the caatinga has been replaced by simple and unstable crop systems. This has caused changes in soil chemical and physical properties which are dependent on climate, crop type and management type (Santana and Souto, 2011). This change may result in decreased vegetation cover causing soil loss and, consequently, reduced soil fertility.

According to Chaves et al. (2006) the indiscriminate use of natural vegetation, intensive pasture and

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irrational use of agriculture are factors that have contributed to accelerate the process of environmental imbalance. The consequence of this process is related to the reduction of soil fertility and biodiversity (Travassos and Souza, 2011). Barros et al. (2013), for example, noted that carbon and nitrogen stocks in the soil under cultivation of sugar cane decreased compared to the soil under native forest. Likewise, agricultural cultivation in soils of the floodplains of the river Guamá caused a reduction in the concentration of P and K (Lopes et al., 2006).

The characterization of soil in a particular area is fundamental for sustainable models aiming to maximize output and mitigation of natural resource degradation. Among the soils found in the semiarid region are the Vertisols characterized as clayey or loamy soils with high content of expandable clay minerals (2:1) causing the appearance of "slickensides" and splitting the subsurface layers of soil in dry season, and may or may not provide the "Gilgai"-type microrelief (EMBRAPA, 1999). Generally, there are high amounts of exchangeable bases (S) and saturation (V%) and a reaction ranging from moderately acidic (on the surface of some of these soils) to strongly alkaline (at the horizon C) (EMBRAPA, 1999). It was evident in the surveys that the depth profile of the AC ranges from 60 to 130 cm.

In agricultural systems, the soil chemical properties are altered, positively or negatively, depending on the soil management adopted. In this sense, Santos and Ribeiro (2002), when studying the effects of irrigated agriculture on chemical properties of soils of the São Francisco submedium region found that the chemical properties were affected differently, depending on the adopted management. With the objective of evaluating land use, Corrêa et al. (2009) found that in relation to native vegetation, uses of cultures with short cycles, discarded areas, pastures, and fruit cultures were higher in the three analyzed layers of pH, exchangeable Ca and Mg attributes, sum bases, base saturation, and available P. Lopes et al. (2006) also observed that the pasture showed greater sustainability of fertility than the system under rice cultivation.

Generally, in environments under natural vegetation, less variation occurs in chemical and physical soil properties when compared to farm management systems; thus, the natural vegetation is a sure indicator to evaluate different types of land use, allowing the evaluation of the sustainable or unsustainable use of certain agricultural practices (Menino et al., 2012).

Based on areas of Caatinga native vegetation, this study aimed to evaluate the changes in the chemical characteristics of soils under different farming systems in Paraiba backwoods.

MATERIALS AND METHODS

The study area is located in the watershed of Val Paraiso stream, between the cities São João do Rio do Peixe and Sousa, inserted in the Northwest portion of Paraíba State, Brazil (situated in the parallel of latitude 6°37'54" to 6°44'29" South and meridians of longitude 38° 18'21" to 38°24'12" West). According to Koppen classification, the climate is warm tropical climate of severe drought, reaching over 35°C at times of higher temperatures. In the study area the average annual temperature is 27°C and the index average annual rainfall is 967.23 mm; however during the survey, an average temperature of 28.6°C and pluviometric index of 6.2 mm were recorded. The vegetation is basically composed of Caatinga Hiperxerófila and the predominant soil in the Val Paraiso watershed is classified as Vertisol (Fernandes Neto, 2009).

In the watershed, five farming systems exploration were identified: native vegetation, taken as reference (area covered by arboreal natural vegetation); sparse vegetation (area covered by natural vegetation typical of the caatinga in recovery; this area was deforested ten years ago, submitted by three consecutive years for agricultural cultivation, and currently is in the process of forest recovery), pasture (area covered by a sparse vegetation and planted; this area under pasture was deforested for over 40 years and yet is being used as pasture for ruminant animals); annual crops (areas of temporary crops; this area is being used for over 60 years with annual crop under constant activities of burning, disking and plowing) and permanent agriculture (crop with high vegetation cover, mainly composed of permanent crops; this area was deforested for 5 years and is under permanent cultivation agriculture).

For each farming systems, exploration were opened for profiles occurring in the same soil class. In each profile, the soil samples were collected from July to August 2012, at depths of 0 to 10, 10 to 20, 20 to 30 and 30 to 40 cm. These samples, after being air dried and passed through a sieve of 2 mm, were characterized chemically according to the methods recommended by Embrapa (1997). The chemical elements analyzed were: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), hydrogen (H), aluminum (Al) and phosphorus (P). From these data, the sum of exchangeable bases (EB), cation exchange capacity (CEC) and base saturation percentage (BS%) were calculated.

The experimental design was completely randomized in factorial scheme 4 × 5, with four replicates (four profiles) that is four depths (0 to 10; 10 to 20; 20 to 30 and 30 to 40 cm) and five sites (native vegetation, sparse vegetation, pastures, annual agriculture and permanent agriculture).

Data were analyzed using descriptive statistics by calculating the maximum, minimum, mean and coefficient of variation. Analysis of variance (ANOVA) and Tukey test at 5% probability were made for comparison of means of the results, according to Ferreira (2000).

RESULTS AND DISCUSSION

Soil pH was significantly affected ($p < 0.01$) by the different environments studied likewise, there were significant difference ($p < 0.05$) in the amounts of electrical conductivity (EC) and potassium. In relation to depth, there was a significant effect ($p < 0.01$) on the pH results and on the sodium (Na) and potassium (K) amount; there was a significant effect ($p < 0.05$) on the hydrogen (H) amount. However, the interaction of areas of farming systems exploration x depths showed a significant effect ($p < 0.05$) on the H amount (Table 1). The pH is the mechanism used either to identify the soil acidity, or the hydrogen ions concentration in soil solution. Regardless of the depth of soil samples, in accordance with the minimum (6.30) and maximum

Table 1. Summary of variance analysis for the chemical soil properties.

Source of variation	DF	Mean square										
		pH	CE	Ca	Mg	Na	K	H	Al	EB	CEC	P
Local	4	1.5**	0.006*	122.0	28.5	8.3	0.15*	0.16	0.0	115.1	118.1	28.1
Res.(a)	12	0.2	0.002	53.5	22.1	7,6	0.05	0.06	0.0	81.3	79.23	20.3
Depths	3	1.6**	0.001	2.9	2.8	6.7**	0.10**	0.32*	0.0	10.5	5.96	0.9
Dep.x Loc.	12	0.1	0.001	13.3	4.6	1.9	0.01	0.13*	0.0	7.8	5.62	7.3
Res.(b)	36	0,1	0.001	7.1	2.7	1.3	0.008	0.06	0.0	4.9	5.78	9.4

*, ** Significant at 5 and 1% (F test), respectively; Local = areas of farming systems exploration (native vegetation (NV); sparse vegetation (SV); pasture (P); annual crops (AC) and permanent crops (PC)).

(8.86) pH values (Table 2), it was observed by Cardoso et al. (2009) and Lopes and Guilherme (2004), that the soil of the region under study as a whole, presents reaction ranging from moderately acidic to highly alkaline. These pH levels are due mainly to the high levels of exchangeable bases found in the soil of the study area. Among the factors that may have contributed to these high levels, stands out the characteristics of the soil, Vertisol, and regional climate. This soil is young, little weathered, clayey with expandable clay minerals (2:1) and located in semiarid region. Therefore, due to the origin of the soil, low permeability soil, hindering drainage and low rainfall of the region, hindering the leaching of chemical elements, the soil still has naturally high levels of exchangeable bases.

Native vegetation showed minimum and maximum pH values of 6.70 and 8.08; sparse vegetation of 6.30 and 8.15; pasture of 6.70 and 7.80; annual crops of 8.86 and 6.60 and permanent agriculture of 7.60 and 8.17, respectively (Table 2) as can be seen in Figure 1.

According to the results presented in Table 3, the highest average pH values were found in areas under agricultural cultivation. This is probably due to the residual effects of anthropogenic interventions more pronounced along the cycles of crops disagreeing de (Melo et al., 2010). These authors observed no significant differences in the pH of the soil due to different ways of using the watershed Riacho do Tronco in Boa Vista, Paraíba State.

In general, the soil pH increased with depth in all profiles (Table 2) which probably is related to elevation concentrations of calcium carbonates and bicarbonates ions.

The Coefficient of Variation (CV) should be used as a parameter to validate the mean values since, according to Vanni (1998), CV above 35% shows that the average has little meaning and values greater than 65% reflect data very heterogeneous nullifying the trustworthiness of average. According to the CV classification proposed by Warrick and Nielsen (1980), the pH of the soil for all farming systems exploitation at all depths were low (CV <12%), corroborating Cavalcante et al. (2007), Souza et al. (2008) and Neves Neto et al. (2013). This can be attributed to the fact that this variable may be measured on a small scale of values and be a logarithmic function (Neves Neto et al., 2013).

According to Santana et al. (2007), electrical conductivity expresses the salts amount present in the soil solution. Thus the greater the amount of salts presents in the solution, the greater the value of the electrical conductivity. Although there was no difference between the averages of EC in different farming systems and in the depths of the profiles, there was a trend towards higher values in areas under agricultural cultivation (Table 3). According to the classification of Warrick and Nielsen (1980), the coefficients of variation were classified as low (CV < 12%) for all treatments and depths.

Data calcium (Ca) ranged from 10.70 (annual agricultural area) to 29.65 kg cmol$_c$ kg^{-1} (in the permanent agriculture area) and magnesium (Mg) from 4.93 (pasture area) to 17.34 cmol$_c$ kg^{-1} (in the sparse vegetation area) (Table 4) showed that all contents of these elements were classified as high (Lopes and Guilherme, 2004) corroborating Melo et al. (2010) and Chaves et al. (2006). Considering that levels 2 to 3 cmol$_c$ kg^{-1} Ca and around 4 cmol$_c$ kg^{-1} Mg (Raij, 1981) are adequate to crop development, it can be stated that the study areas do not exist deficiencies of these elements.

Although the results of Ca and Mg soil have not shown significant differences in farming systems exploration and different depths, disagreeing with Vasconcelos et al. (2010) and Lima et al. (2011), there was a trend of increasing values in areas of cultivation as well as increase and decrease in the levels of Ca and Mg, respectively, relative to depth.

Data sodium (Na) ranged from 1.54 (in the permanent agriculture area) to 7.62 cmol$_c$ kg^{-1} (in the sparse vegetation area) not presenting significant differences in studied treatments. However, the Na$^+$ increased with depth, presenting significant differences (Table 4).

According to Santos and Ribeiro (2002), the increase of Na with depth may be related to the addition of this element by irrigation water, as may have occurred a displacement of said element of colloids soil by Ca^{2+}, Mg^{2+} and K$^+$, from fertilizer applied, due to its lower

Table 2. Descriptive statistics for pH and electrical conductivity (EC) of soil samples collected at depths of 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm in different areas of farming systems exploration (native vegetation (NV); sparse vegetation (SV); pasture (P); annual crops (AC) and permanent crops (PC))

Depth (cm)	pH				Electrical conductivity (mmhos/cm)			
	Minimum	Maximum	Mean	CV (%)	Minimum	Maximum	Mean	CV (%)
Native vegetation								
0-10	6.70	7.20	6.91	0.03	0.08	0.12	0.10	0.18
10-20	7.06	7.28	7.16	0.01	0.06	0.13	0.01	0.37
20-30	7.40	8.03	7.65	0.04	0.06	0.11	0.08	0.31
30-40	7.83	8.08	7.93	0.01	0.07	0.12	0.09	0.24
Sparse vegetation								
0-10	6.30	7.23	6.75	0.07	0.06	0.10	0.09	0.23
10-20	6.70	7.32	7.04	0.04	0.06	0.12	0.08	0.37
20-30	6.70	7.36	7.11	0.04	0.06	0.09	0.08	0.17
30-40	7.08	8.15	7.55	0.06	0.07	0.14	0.09	0.31
Pasture								
0-10	6.70	7.22	6.93	0.03	0.08	0.10	0.09	0.09
10-20	6.85	7.52	7.26	0.04	0.08	0.13	0.10	0.25
20-30	7.25	7.80	7.61	0.03	0.06	0.14	0.09	0.37
30-40	7.90	7.43	7.75	0.03	0.06	0.13	0.09	0.37
Annual crops								
0-10	6.60	7.82	7.41	0.08	0.09	0.17	0.13	0.26
10-20	6.42	8.86	7.57	0.14	0.07	0.27	0.15	0.58
20-30	6.67	8.63	7.75	0.11	0.07	0.14	0.10	0.32
30-40	7.90	8.50	8.11	0.03	0.11	0.13	0.12	0.08
Permanent crops								
0-10	7.60	8.17	7.91	0.03	0.11	0.21	0.15	0.30
10-20	7.80	7.92	7.87	0.07	0.09	0.15	0.13	0.21
20-30	7.70	8.05	7.86	0.02	0.09	0.20	0.12	0.43
30-40	7.80	8.03	7.91	0.01	0.08	0.12	0.10	0.18

CV= coefficient of variation.

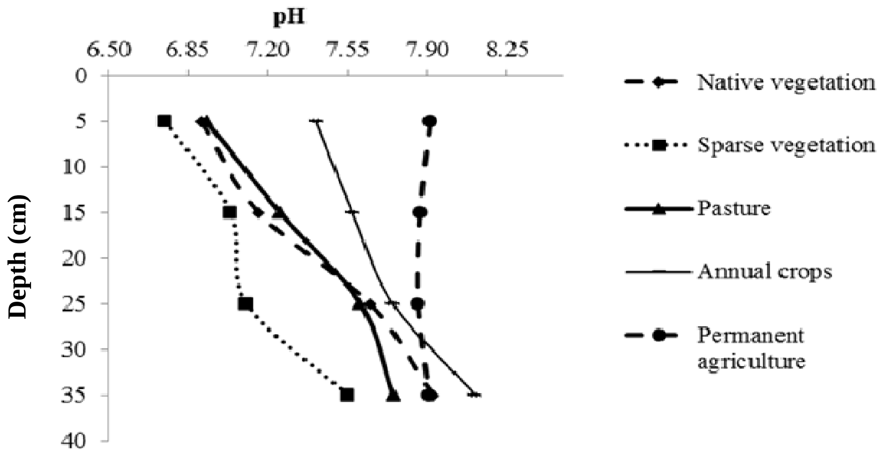

Figure 1. pH values for each area: native vegetation, sparse vegetation, pasture, annual crops and permanent crops at four depths.

Table 3. Mean values of soil pH and electrical conductivity (E.C.) depending on the areas of farming systems exploration and depth.

Attribute	Native vegetation	Sparse vegetation	Pasture	Annual crops	Permanent crops
			Farming systems exploration		
pH	7.41^{ab}	7.11^{b}	7.39^{ab}	7.71^{a}	7.89^{a}
E.C. (mmhos/cm)	0.09^{a}	0.08^{a}	0.09^{a}	0.12^{a}	0.12^{a}
			Depth (cm)		
		0-10	10-20	20-30	30-40
pH		7.18^{c}	7.38^{bc}	7.60^{ab}	7.85^{a}
E.C. (mmhos/cm)		0.11^{a}	0.11^{a}	0.09^{a}	0.10^{a}

Means followed by same letters in the lines do not differ by Tukey test to 5% probability.

Table 4. Mean values of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), the sum of exchangeable bases (EB) and phosphorus (P) depending on the areas of farming systems exploration and depth.

Attribute	Native vegetation	Sparse vegetation	Pasture	Annual crops	Permanent crops
			Farming systems exploration		
Ca ($cmol_c\ kg^{-1}$)	22.58^{a}	17.43^{a}	22.37^{a}	20.47^{a}	24.82^{a}
Mg ($cmol_c\ kg^{-1}$)	9.21^{a}	11.12^{a}	9.56^{a}	12.50^{a}	11.13^{a}
Na ($cmol_c\ kg^{-1}$)	1.13^{a}	2.42^{a}	1.09^{a}	2.63^{a}	2.11^{a}
K ($cmol_c\ kg^{-1}$)	0.41^{b}	0.55^{ab}	0.47^{ab}	0.52^{ab}	0.67^{a}
Al ($cmol_c\ kg^{-1}$)	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
EB ($cmol_c\ kg^{-1}$)	33.49^{a}	31.78^{a}	33.48^{a}	36.11^{a}	38.61^{a}
P ($mg\ dm^{-3}$)	52.10^{a}	52.47^{a}	54.38^{a}	54.16^{a}	55.21^{a}
			Depth (cm)		
		0-10	10-20	20-30	30-40
Ca ($cmol_c\ kg^{-1}$)		21.00^{a}	21.63^{a}	21.58^{a}	21.92^{a}
Mg ($cmol_c\ kg^{-1}$)		11.25^{a}	10.50^{a}	10.62^{a}	10.44^{a}
Na ($cmol_c\ kg^{-1}$)		1.18^{b}	1.66^{ab}	2.15^{b}	2.51^{a}
K ($cmol_c\ kg^{-1}$)		0.61^{a}	0.54^{b}	0.45^{c}	0.49^{bc}
Al ($cmol_c\ kg^{-1}$)		0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
EB ($cmol_c\ kg^{-1}$)		34.04^{a}	34.22^{a}	34.86^{a}	35.64^{a}
P ($mg\ dm^{-3}$)		53.95^{a}	53.69^{a}	53.48^{a}	53.53^{a}

energy retention. Furthermore, for environments that are not irrigated, the increase in sodium in the lower horizons can be related to more restricted drainage in the soil profile, but also because the lowest position in the landscape. The fact sodicity increase in subsurface horizons is worrying, since the plant roots reach those horizons being impaired by the presence of the element sodium. However, the Na content in the samples of the present research is not harmful, once the exchangeable sodium percentage in the complex is below 8%, that samples classified as normal in relation to sodicity.

Data potassium (K) ranged from 0.18 (in the annual crops area) to 0.88 $cmol_c\ kg^{-1}$ (in the permanent agriculture area) that is from the average level (0.16 to 0.30 $cmol_c\ kg^{-1}$) to very high (> 0.60 $cmol_c\ kg^{-1}$). However, in all areas and depths analyzed, the average values ranged from high to very high (Table 4) corroborating Chaves et al. (2007).

The potassium levels were significantly different in both studied areas with lowest values of depths occurrence in areas with native vegetation and layers below 10 cm depth (Table 4), corroborating with Pereira et al. (2009), Leite et al. (2012) and Lira et al. (2012).

The highest values in the area of permanent agriculture and topsoil are probably associated with a continuous supply of plant residues favoring the retention of this nutrient, the absence of tillage, which favors' the accumulation of nutrients in the sampled depth (Barreto et al., 2008) beyond the addition of potassium fertilizers, because it is a cultivated area corroborating according to Matias et al. (2009).

Calcium presented itself as the main contributor to the total exchangeable bases (EB), followed by magnesium, sodium and potassium, reflecting thus the nature of the source material. Aluminum not detected in soil samples (Table 4) with low hydrogen contents the values of the total exchangeable bases of these samples represent practically the values of cation exchange capacity (CEC), which ranged from 30.01 to 39.26 $\mathrm{cmol_c\ kg^{-1}}$ classified as high. Due to equivalence of high values of sum of bases to the cation exchange capacity, percentage saturation of exchangeable bases corresponded to 100% in all systems of farming operation, showing high nutritional potential for plants.

Data phosphorus (P) ranged from 32.30 (in the native vegetation area) to 58.60 mg $\mathrm{dm^{-3}}$ (in the pasture area) shows that all contents of these elements were classified as high (Lopes and Guilherme, 2004). According Falleiro et al. (2003) and Leite et al. (2012) the high levels of P in the soil may be due to the residual effect of previous fertilizations, maintenance of plant residues on the soil surface, which favors the cycling of phosphorus of no soil disturbance, which promotes the formation phosphorus sites (Sa, 2004) and the very origin of the soil.

Although the results of soil P have not shown significant differences in agricultural farming systems and different depths, disagreeing Leite et al. (2012), there was a trend of increasing values in the areas of crop and decrease the levels of P in relation to depth corroborating Leite et al. (2012). The highest levels apparently in the topsoil, is related to the fact that P move by diffusion in the soil, which results in low mobility profile, contributing to its accumulation in this layer (Zalamena, 2008).

According the classification of CV proposed by Warrick and Nielsen (1980), it was observed that the levels of exchangeable bases and P in all environments and at all depths, showed low variability (CV <12%) reflecting homogeneous data with high reliability.

Conclusion

The replacement of native vegetation by agricultural farming systems in the region of watershed Riacho Val Paraiso, PB, caused changes only in pH, potassium and sodium in the soil attributes. The highest concentrations of carbonates and bicarbonates of calcium in the deeper horizons of the soil increased the pH in these horizons. Soil leaching, although low, due to the semiarid climate, causes increased concentration of cations, especially potassium and sodium, in the deeper soil horizons. There was a trend of soil chemical properties increasing in the areas of agricultural cultivation and with depth.

The Vertisol is a young, little weathered and very clayey soil, with low soil permeability because it is located in semiarid region with low rainfall; thus, in all areas of agricultural farming systems, soil fertility is suitable for most crops (high levels of nutrients for plants).

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effects of two drip-irrigation regimes on sap flow, water potential and leaf photosynthetic activity of mature olive trees

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We evaluated the potential of sap flow values estimated from records with the heat dissipation method for irrigation in an olive orchard (*Olea europaea* L, cv. Meski) near Enfidha, Tunisia. Trees were cultivated at 7 × 7 m spacing. Two drip irrigation treatments were imposed using the sap flow and the FAO methods. The two treatments were irrigated by 100% of crop evaptranspiration (ETc). T1: ETc measured by the sap flow method and T2: ETc estimated by the FAO method. Sap flow, leaf and stem water potentials, leaf photosynthetic activity, stomatal conductance and transpiration rate were recorded in representative trees from both treatments, during the full irrigation season from April to August. Results showed that the irrigation dose calculated from T2, based on FAO method compared to the T1, based on sap flow decreased by about 25%. Under T1 irrigation scheduling strategy, the daily transpiration decreased by 20% and consequently the water potentials were decreased significantly. Infect, olive trees under T1 were moderately stressed and subsequently leaf gas exchange parameters were affected by about 15%.

Key words: Sap flow, water potential, leaf photosynthetic activity, olive tree, *Olea europaea* irrigation scheduling.

INTRODUCTION

Olive orchards are main components of agricultural systems in many semiarid regions of Mediterranean climate. In Tunisia, more than 1.68 million hectares are occupied by olive orchards. Most of them are rain fed, with yields limited mainly by water supply. Modern orchards are usually drip-irrigated, with plant densities ranging from 200 trees ha^{-1} to more than 1000 trees ha^{-1}.

Drip irrigation has also been extended to numerous traditional orchards but through the use of poor-quality groundwater from uncertain supply. Commonly, crop evapotranspiration approach (ETc) was used to scheduling irrigation of olive orchards.

The use of irrigation scheduling based on the direct measurements of olive tree water statutes seems to be a suitable alternative to determine the irrigation doses to be applied in the orchard (Nicolás et al., 2005; Tognetti et

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al., 2009). Two interesting measurement effectively related to the water status of the tree were used in olive orchards. Sap flow is considered as the most promising plant-based indicator for the control of irrigation in fruit tree orchards (Ortuno et al., 2005). Sap flow records have been reported as useful to determine actual olive water needs (Fernandez et al., 2001). The heat dissipation method (Granier, 1987) has been used successfully to study transpiration and some physiological aspects of fruit trees (Sellami and Sifaoui, 2008). Compared to other methods, the Granier method is relatively simple, easy to use, and can be used for long-term continuous measurements. To our knowledge, an irrigation controller based on sap flow using the heat dissipation method has not been developed yet, although irrigation protocols based on heat pulse approach have been suggested by Fernandez et al. (2008b).

The main objectives of this study was: To compare the crop evapotranspiration measured by the sap flow and the FAO methods: To evaluate sap flow sensors using heat dissipation method for scheduling irrigation in an intensive olive orchard under arid climate in Tunisia; and - to test this method using some physiological traits of olive trees especially sap flow, leaf water potential, leaf photosynthetic activity and stomatal conductance.

MATERIALS AND METHODS

Site description and environmental measurements

This experiment was conducted from April to August during 2008 at the irrigated olive orchards of Enfidha, Tunisia (36°08'N, 10°22'E, 23 amsl). Our study was performed at commercial olive (*Olea europaea* L. cv. Meski) orchard of about 40 ha. The trees were planted at 1985 with trees density of 204 trees ha^{-1}. The soil was classified as sandy-loam. Soil water content at wilting point and field capacity were 11 and 26% respectively. Air temperature (T, °C), relative humidity (RH, %), global radiation (Rg, Kw m^{-2}) and wind speed (U, m s^{-1}) were registered by a weather station. Soil water content (Hv, %) was measured gravimetrically in watered areas to 0.6 m depth at various distances (0-20, 20-40, 40-60 cm).
During the study period, air temperature ranged from 11 to 33°C, whereas relative humidity varied between 30 and 85%. Wind speed varied between 1 and 4 m.s^{-1}. Maximum humidity and minimum temperature were observed in April, whereas minimum humidity and maximum temperature were recorded in August (Figure 1a). Minimum and maximum solar radiation were 6 and 16 Kw m^{-2} at first April and mid-May, they presented consistently high values during summer (Figure 1b). Potential evapotranspiration showed two periods; during April and June was approximately between 1.6 and 2.9 mm day^{-1}. During the second period (mid June to August), ET_0 ranged between 2.3 and 3.7 mm day^{-1} (Figure 1c).

Irrigation management and experimental design

Water for irrigation was delivered daily using a localized irrigation system with two lines of nozzles, each at 1.0 m from the trunk. Each tree was equipped with four nozzles, 8 L h^{-1} each per side. A randomized complete block design was used with 6 blocks of 6 trees each that received the irrigation treatments denominated T1 and T2.

T1:18 olive trees that received a daily irrigation amount of 100% of crop evapotranspiration measured by sap flow (Figure 2).

$$T1 = Tsf + Es$$

Where Tsf is the tree transpiration measured by sap flow meter and Es is the soil evaporation measured by microlysimeter.
T2: 18 olive trees that received a daily irrigation amount of 100% of crop evapotranspiration (ETc).

$$T2 = Kc * Kr * ET_0$$

ETc was determined according to Allen et al. (1998) with values of 0.6 for the crop coefficient (Kc) and 0.7 canopy size (Kr) to account for tree age and biomass soil coverage. The reference evapotranspiration (ET_0) was estimated by Penman-Monteith equation (Allen et al., 1998) using daily data from a nearby weather station.

Sap flow and soil evaporation measurements

The measurement of sap flow according to Granier (1985, 1987) was based on two cylindrical probes, 2 mm in diameter and 20 mm in length inserted radially in the xylem and spaced vertically by 8 cm. The upper probe was continuously heated, whereas the lower probe was unheated and the resulting temperature difference was measured with copper constantan thermocouples placed in each probe. Under zero flow conditions, the temperature around the heated probe increases to the point where heat dissipation by xylem conduction was in equilibrium with the heat energy supplied, which gives a maximum temperature difference. When sap is flowing, heat dissipation increases by convection and the temperature difference decreases. The major advantages of the method were its easy installation, a simple sap flow calculation and a low cost (Smith and Allen, 1996). Nevertheless, in open stands, natural temperature gradients in the stems of trees give rise to errors. This drawback can be eliminated by the non continuous thermal dissipation method devised by Do and Rocheteau (2002a, b), which is the technique used for our measurements.

Sap flow was recorded at 30 min intervals using heat dissipation instrumentation controlled by a data-logger type (model DL2, Delta-T Devices Cambridge, England). To convert sap flow density to tree transpiration a relationship between sapwood area (S) and trunk diameter was experimentally determined by colouring the sapwood area with safranin. Measurements were taken using three probes at different sides of the trunks of three olive trees with similar cross-sections on each treatment during the fully irrigation season from April to August.

To compare sap flow measured to tree transpiration, we used the same mature olive tree cultivar and assessed transpiration simultaneously with sap flow measurement using a balance during one month. To suppress evaporation from the surface of the pot, the pot was covered with plastic film. The transpiration rate was calculated daily from the amount of weight lost, excluding the weight of the irrigation water. Soil evaporation (Es) was measured using twelve cylindrical microlysimeters, 8 cm deep, with 20 cm of internal diameter according to Paco et al. (2006).

Leaf water potential

During the fully irrigation season from April to August 2008, leaf water potential was measured using a portable pressure chamber (Scholander et al., 1965, Turner ,1981). For all measurements, data were collected during sunny days at predawn and midday on the same trees (3 trees from each treatment). Leaf water potentials were established by sampling a total of 3 fully sunlit and 3 covered leaves from each tree. For xylem water potentials 3 leaves from

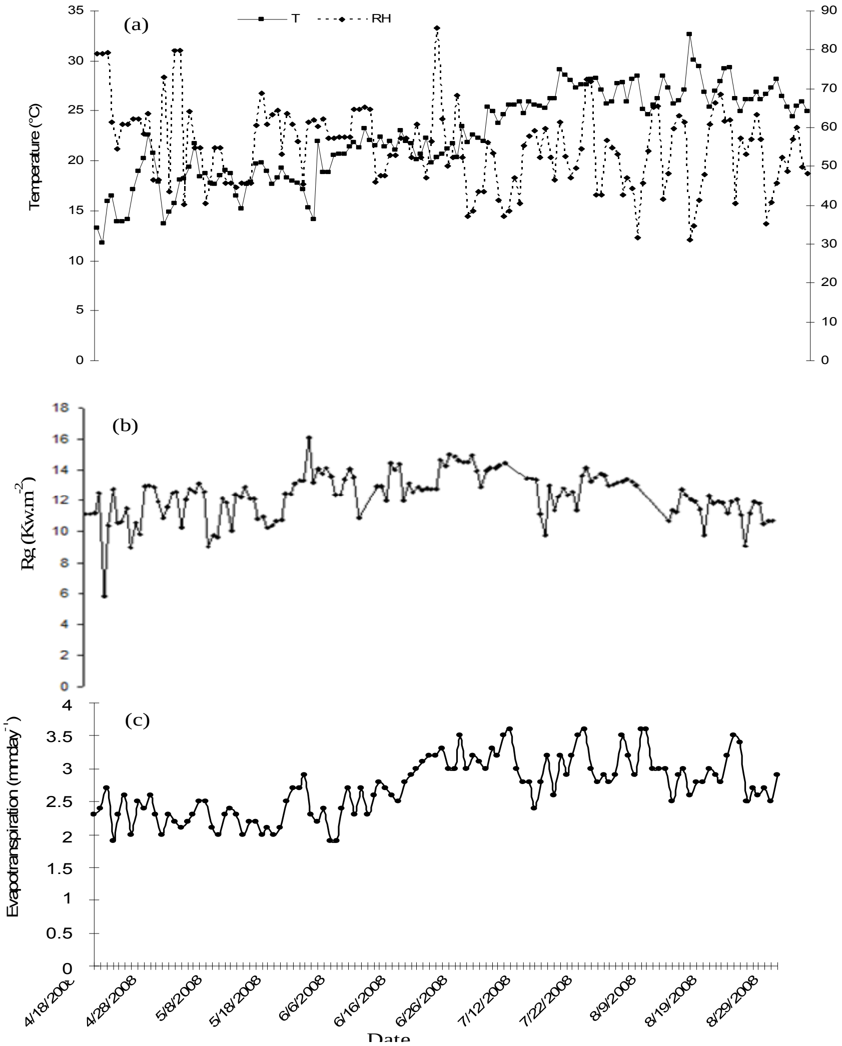

Figure 1. Climatic parameters, temperature and air humidity (a), global radiation (b) and evapotranspiration (c) during the study period.

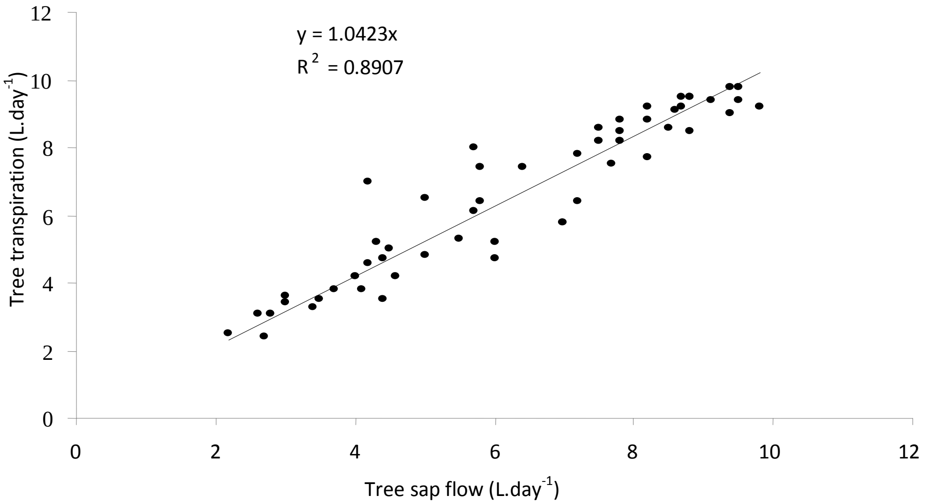

Figure 2. Regression between sap flow and transpiration measured by the weighting method.

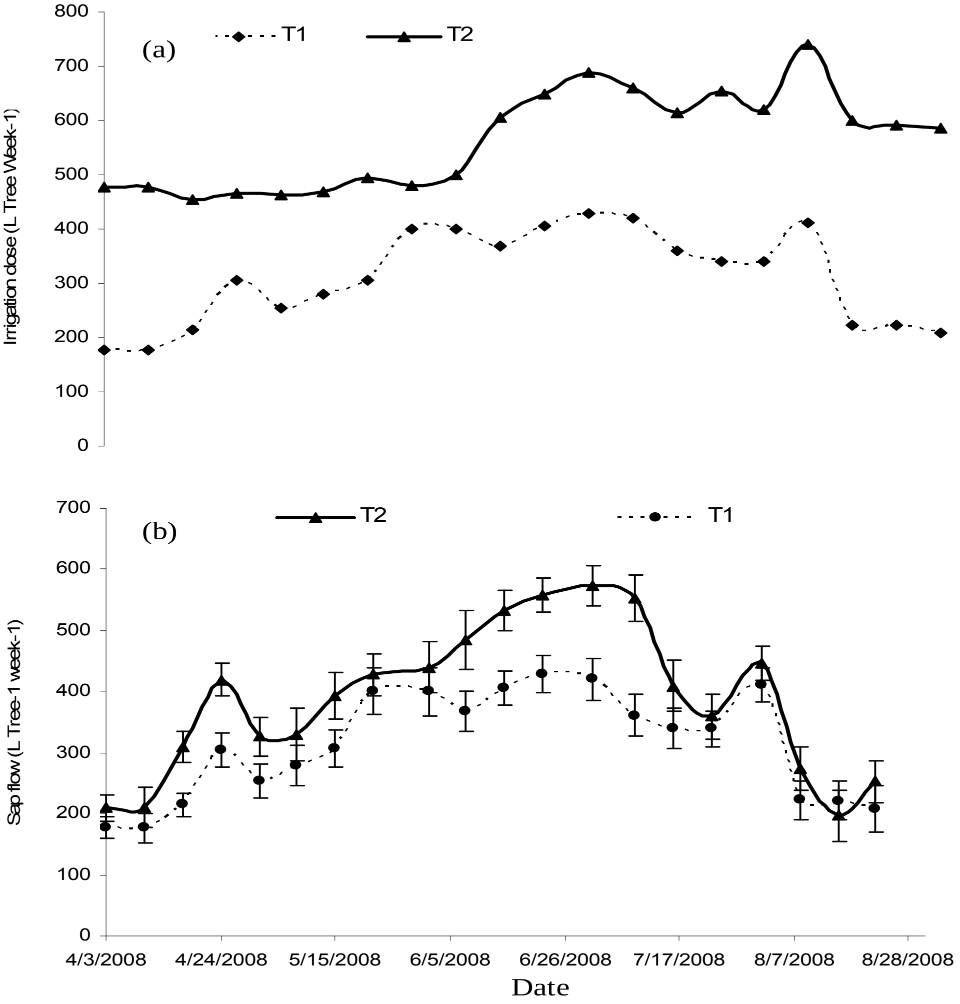

Figure 3. Weekly evolution of irrigation dose (a) and sap flow (b) following the irrigation treatments T1 and T2 during the study period (average ± SE, n = 3). Different letters indicate significantly different values at P≤0.05 according to Duncan test.

each tree were covered with aluminium paper for two hours before measurement to avoid transpiration and establish the equilibrium water potential between leaf and xylem.

Leaf photosynthetic function and water-use efficiency'

Leaf photosynthesis rate, stomatal conductance and transpiration were measured using a portable system IRGA (LI-COR, LI-6400) on 9 sunny leaves per treatment (three leaves per tree). Data were collected monthly from April to August 2008. All measurements were carried out between 9:00 and 11:00 h on cloudless days. Photosynthetic photon flux density was fixed at 1500 µmol m^{-2} s^{-1}. Temperature and humidity rate through the chamber were 25 °C and 60% respectively.

Statistical analysis

All parameters were determined in triplicate for each sample. Analysis of variance (ANOVA) and linear regression analyses were processed by SPSS statistical package (Version 16.00 for Window, SPSS Inc.). Duncan test ($P < 0.05$) was used to determine significant differences between means.

RESULTS

Irrigation doses and soil water content

Irrigation dose in T2 presented similar values during April until the beginning of June approx 490 L $Tree^{-1}$ $Week^{-1}$. This dose increased to reach a maximum value of 700 L $Tree^{-1}$ $Week^{-1}$ at the beginning of August (Figure 3a). Similarly, the irrigation dose obtained from sap flow measurements increased from 180 L $Tree^{-1}$ $Week^{-1}$ in April to reach a maximum level of 400 L $Tree^{-1}$ $Week^{-1}$ in August (Figure 3a). During the full irrigation season from April to August 2008, the total irrigation doses were 7800 (160 mm) and 11300 L $Tree^{-1}$ (230 mm) in T1 and T2 respectively. Soil water content was influenced by the

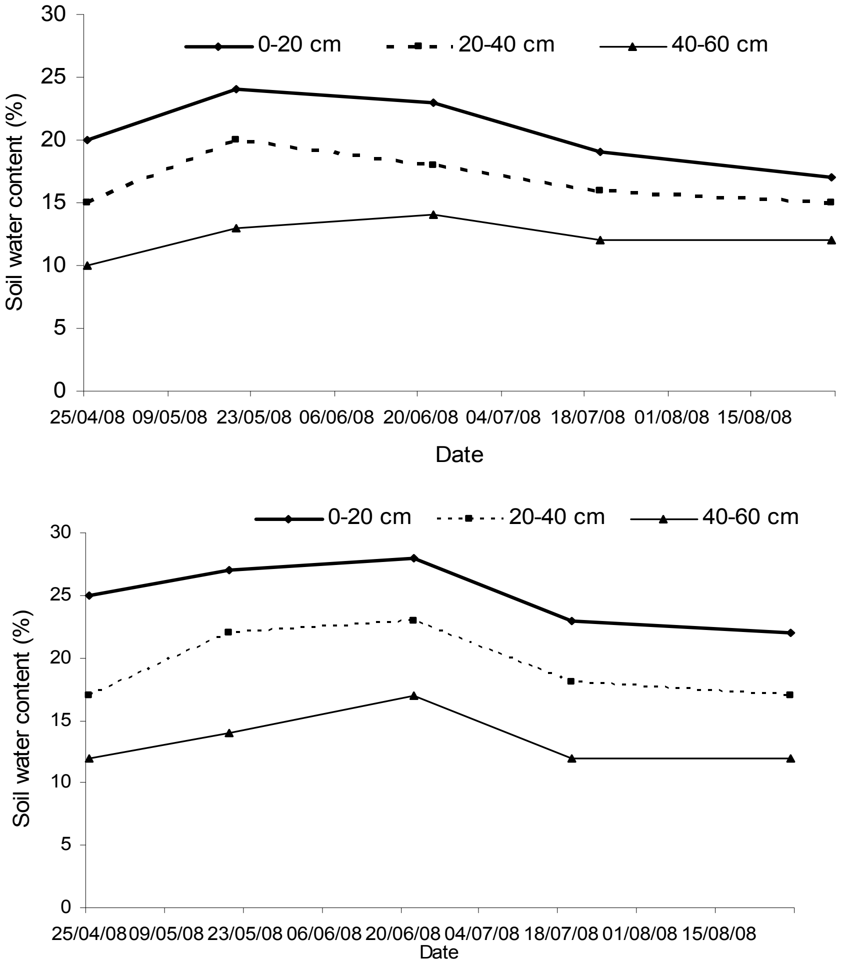

Figure 4. Seasonal patterns of soil water content at different depths following the irrigation treatments T1 and T2 during the study period.

irrigation doses and increased with increasing depth (Figure 4). Under T1, irrigated with the sap flow method, soil water content measured at 20 cm depth increase from 20% (April) to 25% (May), than decreased gradually to reach 18% at the end of the irrigation season (August). Under T2, irrigated with the FAO method, soil water content was very high and ranged between 23 and 28% at 20 cm depth. Large differences of soil water content were observed between treatments at different depths.

Sap flow measurements

Average of the canopy transpiration estimated by sap flow meter was at their minimum during spring (April) and at their maximum during the warmest summer period (July) (Figure 4b). During June and July, transpiration of T2 treatment was 23% higher that of the T1 treatment. During the full irrigation season from April to August, total whole trees sap flow were 6300 and 8400 L Tree^{-1} in T1 and T2 respectively.

Leaf water potential

Predawn leaf water potential (Ψ_{pd}) increased during the full irrigation season from April to August. Infect, under T1 and T2 treatments Ψpd ranged between - 0.3 MPa and - 0.4 MPa and between -0.4 MPa and - 0.6 MPa respectively (Figure 5a). In the two treatments, xylem and leaf water potentials presented a similar seasonal pattern. Higher water potentials values were observed under T2, significant different from those of T1 (Figure 5b and c). Minimums values of Ψ_x and Ψ_{md} were -3.2 MPa and -2.2 MPa in T1 and -2.7 MPa and -2.4 MPa in T2.

Leaf photosynthetic activity

Seasonal patterns of photosynthesis measured during the full irrigation period were similar in both treatments with higher values in T2 (10-16.8 µmol m^{-2} s^{-1}) than in T1(10-14µmol m^{-2} s^{-1}). CO$_2$ assimilation rates were low in April, increased by 60% during May, reached a maximum

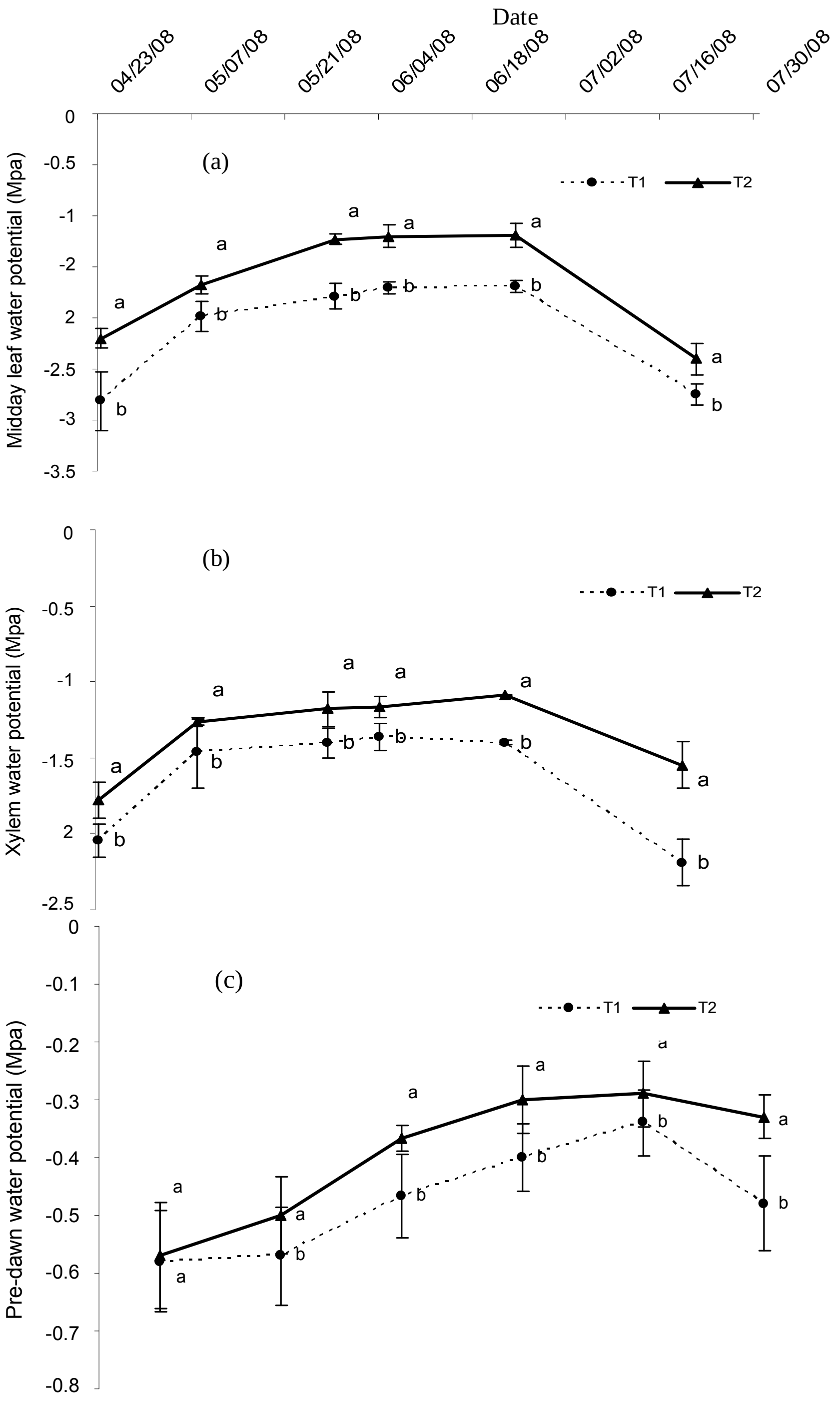

Figure 5. Seasonal patterns of predawn leaf water potential (a), xylem water potential (b), midday leaf water potential (c) following the irrigation treatments T1 and T2 during the study period.(average ± SE, n = 9). Different letters indicate significantly different values at P≤0.05 according to Duncan test.

in June and increased again during August (Figure 6a). During the full growing season, CO_2 assimilation rates were significantly higher under T2 by about 15% to that T1 treatment. Stomatal conductance (gs) followed similar trends to that of CO_2 assimilation rates (Figure 6b). The gs increased from April to June and decreased during August. The maximum gs values were 0.24 and 0.17 µmol m^{-2} s^{-1} in T2 and T1 respectively. Similarly to photosynthesis and stomatal conductance patterns, transpiration rate (E) increased from April to June and

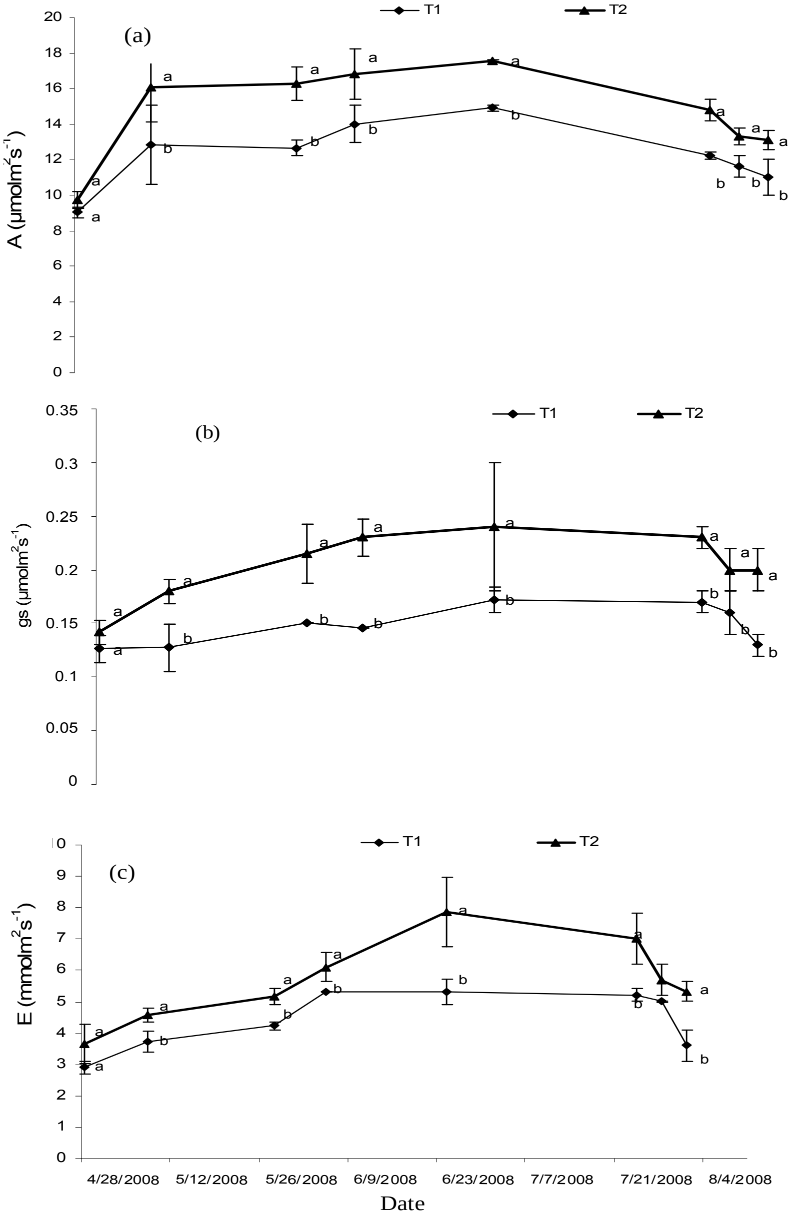

Figure 6. Seasonal patterns of photosynthesis (a), stomatal conductance (b) and transpiration (c) following the irrigation treatments T1 and T2 during the study period. (average ± SE, n = 9). Different letters indicate significantly different values at P≤0.05 according to Duncan test.

decreased during August. The maximum E, values were 5.3 mmol H_2O^{-1} m^{-2} s^{-1} and 7.3 mmol H_2O^{-1} m^{-2} s^{-1} in T1 and T2 respectively (Figure 5c).

Photosynthetic water use efficiency

Photosynthetic water use efficiency (PWUE) expressed as function between photosynthesis rate and transpiration in T1 and T2 have a similar pattern, but there are significant differences between them in some times especially during July. PWUE increased from April, reached a maximum value in May (3.5 µmolCO_2 mmol H_2O^{-1}), and decreased slightly to a minimum values in August (Figure 7).

DISCUSSION

A precise scheduling irrigation can improve the water use

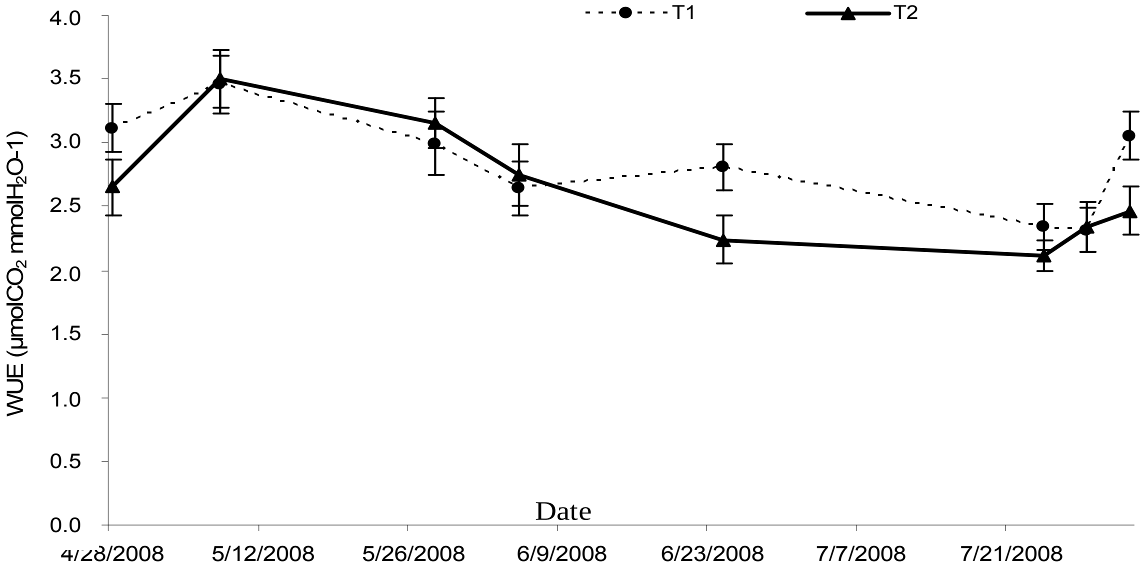

Figure 7. Seasonal patterns of water use efficiency following the irrigation treatments T1 and T2 during the study period (average ± SE, n = 9). Different letters indicate significantly different values at P≤0.05 according to Duncan test.

efficiency and protect the orchards against drought. Plant based indicators for scheduling irrigation, especially sap flow were successfully introduced in fruit trees (Ortuno et al., 2005). Until now several studies have demonstrated that the heat dissipation method developed by Granier (1987) and ameliorated by Do and Raucheteau (2002a, b) can be introduced easily to study water needs in fruit trees (Sellami and Sifaoui, 2003), but it has not been tested for scheduling irrigation. Smith and Allen (1996) advised that the Granier method should be calibrated for individual species.

To evaluate this technique, results from the Granier sap flow method were compared with the transpiration measured by the weighting method. Results show a good relationship between the daily sap flow rate and the daily transpiration rate (Figure 6) with a coefficient of determination (R^2) equal to 0.89.

During the full irrigation season from April to August, the total irrigation doses were 7800 L Tree^{-1} (160 mm) and 11300 L Tree^{-1} (230 mm) in T1 and T2 respectively. Compared to the irrigation dose estimated by the FAO method (T2 = 230 mm) we can by the sap flow technique (T1 = 160 mm) increase the irrigation dose by 70 mm (30%) an agreement with the results published by Fernandez et al. (2008b).

Under T1, irrigation dose decreased and affected significantly the soil water content during the irrigation season, it seems act as a moderate water stress on the physiological characteristics of the tested olive tree cultivar cv Meski. Fernandez et al. (2008b) show that olive trees irrigated using sap flow, xylem water potential decreased significantly in olive trees, indicating that the soil water content was too low to prevent water stress in the olive trees. Our results show that leaf water potentials decreased significantly under T1. Minimum values of ψ_{pd} never exceeded -1.5 and hardly reached -2 MPa, regardless the water treatments (Tognetti et al., 2009) an agreement with our results. During 90 days of experiment, xylem water potential of olive trees irrigated daily near to the field capacity, reached between - 0.9 and - 1.5 MPa (Lopez et al., 2007, 2008). According to our results, under T1, xylem water potential of olive trees cv Meski ranged between –1.5 and –2 MPa. This moderately water stress affects directly and significantly photosynthesis, stomatal conductance and transpiration rate during the full irrigation season. The reduction of the water status has been followed by a stomatal conductance reduction that is due to the closing of the stomata. This state will normally have for consequence a decrease of the photosynthetic assimilation (Ben Ahmed et al., 2007). For the Meski olive tree under T1 treatment, photosynthetic assimilation decreased by 15% compared to irrigated olive trees by T2. Whereas, the irrigation doses decreased by 30% from T2 to T1.

Proietti (2000) and Hagidimitriou and Pontikis (2005) reported that the high leaf CO_2 assimilation rate value of olive trees observed under full irrigation conditions during spring was probably due to favourable air temperature and humidity rate. According to Proietti et al. (2013), the decrease in photosynthesis rate in August is probably due to high temperature and low air humidity registered during this period in our experiment olive orchard. However, Proietti et al. (2012) reported that the lower photosynthetic values in the warmer period of the summer were not caused only by the lower stomatal conductance reduction but rather by non stomatal effects damage to the photosystem induced by high temperature and drought, increase of dark respiration rate.

Photosynthetic water use efficiency of T1 and T2 irrigation treatments estimated in our experiment seems to verify the possibility to introduce the sap flow method to estimate olive water consumption and schedule irrigation on olive tree orchards with accuracy especially during warmer seasons.

The significant differences observed in seasonal variation of water relations and leaf gas exchange proved a moderately stressed trees under T1 (irrigation based on sap flow), due to the lower irrigation dose estimated by the sap flow meter using the heat dissipation method. Infect, Steppe et al. (2010) reported that under laboratory conditions, the heat dissipation method substantially underestimated sap flux density, which indicated that this technique has unique sensitivities to errors in parameter estimates which need to be taken into consideration. The heat dissipation method used in our experiment determined the onset of water stress quite accurately, but it was not as reliable to estimate transpiration because sap flow is determined only in a single point in the radial profile, even though profile correction were done (Altozano et al., 2008). Additionally, for the olive tree, Fernandez et al. (2001) reported that olive sap wood is characterized by heterogeneity on the radial sap flux, than can be considered as a limitation for the heat dissipation method and necessities a large number of sensors to monitor irrigation. Under Tunisian climatic conditions, Masmoudi et al. (2011) reported the possibility to estimates young olive tree transpiration by the heat dissipation method, the maximum transpiration represented only 53% of the ETc as determined by the FAO method. Whereas, the FAO approach based on climatic data overestimated evapotranspiration by more than 15% for some situations (Allen, 2000). For olive and citrus orchards (Testi et al., 2004; Rana et al., 2005) found that crop coefficient vary significantly during the growth season being impossible to assume a constant value. Therefore, some limitations should be expected in the application of the FAO approach to estimate crop evapotranspiration (Paco et al., 2006). Compared to irrigation scheduling methods based on the atmospheric demand, such as the FAO method (Allen et al., 1998), plant-based measurements using the sap flow meter could increase the resolution of the calculated irrigation dose; reduce water use on irrigated olive orchard which is certainly an advantage for precise high-frequency irrigation. In addition, sap flow method can be easily automatized, which is particularly valuable for scheduling irrigation (Jones, 2007).

Conclusions

The sap flow method seems to be a good device able to calculate the real water needs of olive trees and save water by 30%. Under Mediterranean climate in Tunisia, irrigation scheduling of olive orchards based on sap flow technique caused a moderate drought stress affecting soil water content, and consequently leaf water potentials and leaf photosynthetic activity. This problem (underestimation of the irrigation dose by the sap flow meter) seems to be due to the heat dissipation method and the olive wood characteristics.

Conflict of Interest

The authors have not declared any conflict of interest.

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