Agronomic technologies in maize and their adoption and diffusion in semi-arid central Rift Valley Ethiopia: agronomic and economic analyses

Agronomiske teknikker i mais og deres bruk og spredning i central Rift Valley i Etiopia: en agronomisk og økonomisk analyse

Philosophiae Doctor (PhD) Thesis

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Abstract

This thesis evaluates the agronomic and economic responses to agricultural technologies in maize, identifies the agronomic technologies reaching farmers, and assesses their adoption and diffusion. The thesis consists of an introductory chapter and four papers.

Rainfall variability, poor soil quality, high cost of input technologies, an inefficient extension system, and low economic capacity are among the agro-ecological, institutional and socioeconomic constraints to increasing the productivity of maize in the central Rift Valley. Field experiments were conducted in the central Rift Valley of Ethiopia during the 2011/12 and 2012/13 cropping seasons to evaluate the agronomic and economic responses of tillage systems, fertilizer application systems and various packages of conservation agriculture, seed priming and fertilizer microdosing technologies in maize. A participatory research with the concept of 'learning by doing' and 'collaborative' and 'consultative' approaches for co-learning and co-innovation were used to enhance the participation of important stakeholders. To supplement the quantitative data, a case study was carried out to identify the agronomic technologies transferred to farmers, and to assess their adoption and diffusion. An adoption and diffusion theory was used as conceptual framework to study the adoption and diffusion. The data were collected through a series of key informant interviews, focus group discussions, and field observations.

Paper I evaluates the agronomic and economic responses of tillage and water conservation systems in maize. Conventional tillage and conservation agriculture were used as main plots whereas mulching, no mulching and planting basins were used as subplots. Results showed that agronomic and economic benefits of conservation agriculture were lower than those of conventional tillage under short-term practice. Conventional tillage had 13% to 20% higher grain yield (GY) than minimum tillage and 40% to 55% higher than zero tillage. Mulched treatments had 23% to 33% and 14% to 19% higher grain yield than no mulching and basins respectively. Conventional tillage had 28% and 89% higher labor productivity, and 6% and 60% higher gross margin (GM) than minimum tillage and zero tillage respectively. Mulching tended to improve volumetric soil moisture content and suppress weed density. However, due to the widespread practice of free grazing, this practice is not feasible on open fields. Yet, it can be practiced in the vicinity of homes where farmers traditionally fence smaller plots for growing early maturing maize varieties.

Paper II evaluates agronomic and economic benefits of fertilizers applied as microdosing and banding in maize. The treatments were: control without fertilizer, microdosing with the rate at 27 kg DAP ha^{-1} + 27 kg urea ha^{-1}, 53 kg DAP ha^{-1} + 53 kg urea ha^{-1}, and 80 kg DAP ha^{-1} + 80 kg urea ha^{-1}; and banding of fertilizer with 100 kg DAP ha^{-1} + 100 kg urea ha^{-1}. Small quantities of fertilizers applied as microdosing increased these benefits. Application of 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} gave similar maize yields as the recommended rate of 100 kg DAP ha^{-1} + 100 kg urea ha^{-1} applied as banding. The 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} increased the GY by 19%, 45% and 46% at Hawassa, Ziway and Melkassa respectively over farmer's practice. Its value cost ratio

varied from 7 to 11 whereas it varied from 2 to 3 in banding across sites. This shows that the lower fertilizer dose applied as microdosing is far less risky than the banding method. Similarly, its fertilizer use efficiency (kg grain kg^{-1} fertilizer) varied between 23 and 34 compared to the banding treatment that had a fertilizer use efficiency varying between 7 and 8 across sites. Both value cost ratio and fertilizer use efficiency decreased with increasing fertilizer doses applied as microdosing. The lowest dose of fertilizer applied as microdosing gave the highest gross margin, fertilizer use efficiency and the least risk to fertilizer application. This shows that the application of this particular dose in maize may be an option for the poorer farmers who can only afford to buy small quantities of fertilizers. A fertilizer dose lower than this particular dose may also be an option. It needs further investigation.

Paper III examines different options of increasing maize yield by sequentially introducing minimum tillage and seed - priming, DAP fertilizer microdosing, surface mulching and urea fertilizer microdosing to the farmers' practice. There were five treatments or steps consisting of conventional tillage (farmers' practice as a control); minimum tillage + seed - priming, unfertilized (step 1); step 1 + microdosing 53 kg DAP ha^{-1} (step 2); step 2 + 4 ton ha^{-1} maize stover as mulch (step 3) and step 3 + 53 kg urea ha^{-1} (step 4). Results showed that except at the lowest level, agronomic and economic benefits increased with increasing levels up the ladder. The second level increased GY by 19% to 22%, and GM by 12% to 19%; the third level increased GY by 25% to 35%, and GM 24% to 39%; the final level increased GY by 47% to 61%, and GM by 39% to 55%. The value cost ratio was above four even at the highest levels of inputs indicating that this level of intensification can be achieved at low risk. Likewise, the fertilizer use efficiency was quite high even at the highest level of inputs showing the efficacy of microdosing. This gives farmers different technology options for increasing the productivity of maize. This study also showed that with no mulching, minimum tillage in combination with seed - priming and fertilizer microdosing can be used to increase the productivity of maize. This could be an option for farmers lacking sufficient traction power even with free grazing.

Paper IV identifies the agronomic technologies transferred to farmers, and assesses their adoption and diffusion. Transferred technologies are mostly related to improved seeds, fertilizer application methods, and *in situ* rainwater-harvesting systems, which are also farmers' priorities of interventions. Technologies reach farmers through the national extension system, social networks or a combination of these. Use of improved maize and haricot bean varieties, the banding method of fertilizer application, row sowing, intercropping and traditional *in situ* rainwater-harvesting methods are among the technologies spreading recently. Most of the technologies transferred to farmers through the national extension system lack adequate information. Use of new hybrid maize and bean varieties has increased through the social networks although they have not been part of the national extension system. Technology adoption and diffusion is constrained by seasonal rainfall variability with recurrent dry spells and droughts, poor soil quality with poor fertility and water retention capacity, high prices for improved seed and fertilizer, and inappropriate fertilizer

technologies. Subsidies, an efficient seed and fertilizer supply system, an adequate extension system, and provision of reliable seasonal agrometeorological information are lacking.

In conclusion, the technologies developed in this study are potentially low cost, low risk and agro-ecologically adaptable. They mostly appear to comply with farmers' interests and priorities and have positive prospects. They may be used separately or in combination to intensify the production of maize and improve farmers' income, food security and livelihood in the central Rift Valley in Ethiopia. It is still recommended that further studies based on long-term data and wider areas be done before integrating the technologies into the national extension system or social networks.

Sammendrag

Denne PHD avhandling omhandler hvordan nye teknikker i maisproduksjon bedrer agronomisk- og økonomisk utbytte i sentral Rift Valley i Etiopia. Videre presenteres bruk og spredning av de nye teknikkene blant bønder i dette området. Den første artikkelen fokuserer på agronomisk- og økonomisk utbytte av ulike jordarbeidings- og vannhøstingsmetoder. Resultatene viste at redusert jordarbeiding og bruk av halmdekke gav lavere avling enn pløying flere ganger med en ard (plog som ikke vender jorden). Likevel kan redusert jordarbeiding og bruk av halmdekke være interessant særlig i områder hvor beiting av halmen kan reduseres. Den andre artikkelen viser hvordan mikrogjødsling av mineral gjødsel (tilføring av små mengder gjødsel i plantehullet) kan øke agronomisk og økonomisk utbytte. Mikrogjødslingsmengde 27 kg di-ammonium fosfat /ha + 27 kg urea/ha gav samme avling som 100 kg di-ammonium fosfat/ha + 100 kg urea/ha tilført som radgjødsling. Denne mikrogjødslingsmengden gav høyest dekningsbidrag, høyest utnyttelsesgrad av gjødsel og minst risiko. Artikkel 3 fokuser på hvordan øke avling og økonomisk utbytte ved trinnvis å ta i bruk nye jordbruksteknikker som redusert jordarbeiding, frøbehandling, mikrogjødseling og halmdekke. Agronomisk- og økonomisk utbytte økte dess flere av disse teknikkene som ble tatt i bruk. Artikkel 4 viser teknikker som har blitt innført gjennom ulike kanaler og vurderer deres bruk og spredning blant bøndene. Bøndene har tilgang til nye teknikker gjennom det nasjonale veiledningssystemet, sosiale nettverk og gjennom en kombinasjon av disse. Teknikker som har blitt tatt i bruk i de senere årene inkluderer nye mais- og bønnesorter, radsåing, radgjødsling, samplanting og vannhøstingsmetoder. Bøndene får ofte for lite informasjon om de nye teknikkene som blir introdusert gjennom det nasjonale veiledningssystemet. Hybrid-mais og nye bønnesorter har blitt innført gjennom sosiale nettverk og det nasjonale veiledningssystemet har her ikke vært involvert. Bruk og spredning av nye teknikker er påvirket av variable nedbør, mangel på værvarsling, lav jordfertilitet, jorda's dårlige vannlagringsevne, høye priser for såfrø og gjødsel, dårlig tilgang til innsatsfaktorer og lite tilpassede gjødslingsteknikker. Disse faktorene må adresseres for å bedre produksjonen og sikre bøndene høyere inntekter.

List of papers

This thesis is based on four papers referred by their roman numerals:

Paper I:

Sime, G., Aune, J. B. & Mohammed, H. (2015). Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia. *Soil & Tillage Research* 148: 20-30.

Paper II:

Sime, G. & Aune, J. B. (2014). Maize Response to Fertilizer Dosing at Three Sites in the Central Rift Valley of Ethiopia. *Agronomy* 4: 436-451

Paper III:

Sime, G. & Aune, J. B. (2015). Sequential effects of minimum tillage, seed priming, fertilizer microdosing and mulching in maize, semiarid central rift valley of Ethiopia. *Experimental Agriculture FirstView*: 1-15, DOI: http://dx.doi.org/10.1017/S0014479715000125.

Paper IV:

Getachew Sime and Jens B. Aune (2015). Exploring agricultural technologies, and their adoption and diffusion in the central Rift Valley, Ethiopia. Submitted to *Journal of Development Studies*

Part I Extended summary

1.0 Introduction

Food security remains a major concern in sub-Saharan African (SSA) countries (FAO, 2011). According to the World Bank (World Bank, 1997), agriculture is the main economic activity in SSA supporting over 67% of the population, out of which 60% depends on rain-fed agricultural practices; generating 30% to 40% of the countries' gross domestic product (GDP). Vanlauwe *et al.* (2011) report that the need for intensification of agriculture in SSA has recently grown because of the recognition that farm productivity could be a major entry point to break the vicious cycle underlying rural poverty. To achieve increased agricultural productivity, investment in agricultural research and extension is a key factor (Vanlauwe *et al.*, 2011). This is because the growth generated by agriculture in SSA is several times more effective in reducing poverty than GDP growth in other sectors (Schaffnit-Chatterjee, 2014). However, Binswanger-Mkhize *et al.* (2011) report that further acceleration of agricultural growth is challenged by poor investment in climate and agricultural research and services, and poor infrastructure.

With about 51.3 million hectare (ha) of arable land, Ethiopia has an enormous potential for agricultural development and is one of the largest grain producing countries in Africa (Taffesse *et al.*, 2011). According to the International Fertilizer Development Center (IFDC) over 90% of cultivated land in Ethiopia is under food crops, mostly grains (IFDC, 2012). Agriculture is dominated by subsistence rain-fed farming with average landholdings of less than one hectare. About 12.7 million smallholders produce 95% of the agricultural GDP (WorldBank, 2010). Though Ethiopia has tremendous potential for agricultural development; not all of its land is suitable for cultivation (Taffesse *et al.*, 2011). Area expansion has been the conventional means of increasing agricultural output (Byerlee *et al.*, 2007; Diao *et al.*, 2007) but this has become difficult in most places in recent times. This is because all available cultivable land including marginal and pasturelands have been converted to permanent farmlands. As available arable land is becoming increasingly scarce, increases in production will be largely driven by increasing land productivity rather than expansion of land area. This makes fertilizer application and the use of improved seeds a key element of any agricultural strategic plan. These two factors are emphasized in the five year Growth and Transformation Plan (GTP) of Ethiopia that extends from 2010/11 to 2014/15 (IFDC, 2012) to increase the agricultural productivity.

As part of achieving the UN Millennium Development Goals (MDGs) of halving the number of poor and hungry in the world by 2015, Ethiopia has adopted the GTP, which aims at doubling the production of grains by 2015 (FAO, 2014). Building on achievements from the previous Plan for Accelerated and Sustained Development to End Poverty (PASDEP), and following the Agricultural Development-Led Industrialization strategy, the GTP has prioritized intensification of the productivity of smallholder farmers. Strategies to ensure rapid agricultural growth include strengthening extension services, adopting new technologies and practices that conserve soil and natural resources (FAO, 2014).

Ethiopia has pursued an agricultural production intensification approach to boost crop productivity through the application of modern agricultural inputs: primarily improved varieties, fertilizers and improved agronomic practices. Accordingly, substantial amounts of resources were devoted to the development and dissemination of improved maize varieties and fertilizer application (Alemu *et al.*, 2008). However, yield increase, especially in food crops, has been difficult in many regions. The use of fertilizer and improved seeds are limited despite government efforts to encourage the adoption of modern agricultural practices (FAO, 2014). The predominantly low-input agriculture and fragmented landholding system contribute to low productivity in grain production, with Ethiopian farmers among the lowest users of fertilizer and improved seeds in SSA (FAO, 2014). Farmers are extremely vulnerable to external shocks such as droughts and dry spells (FAO, 2014). These climatic shocks are disastrous, particularly in the semi-arid regions of Ethiopia.

There is a need to identify socioeconomically and agro-ecologically adaptive technologies that can intensify the productivity of maize in the central Rift Valley. Farmers are smallholders, subsistence-oriented and operate under highly variable rainfall and poor soil fertility (Kassie *et al.*, 2013). Nearly all the cultivable land including rangelands and marginal areas have been converted to permanent farmlands, which makes agricultural expansion impossible. In addition, farmers' decisions to invest in fertilizer and improved maize varieties depend on the seasonal rainfall and on their economic capacity. Most risks originate from the recurrent droughts and dry spells, high input prices, and inappropriate technologies. Farmers use various risk diversion strategies such as adjusting the cropping calendar, practicing intercropping and traditional rainwater- harvesting and conservation to cope with the unfavorable rainfall conditions. It was also reported that under unfavorable rainfall conditions, farmers desist from investing in fertilizers and improved seeds in the central Rift Valley (Kassie *et al.*, 2013). This study reports the agronomic and economic potential of tested agricultural technologies as well as the characteristics, challenges and opportunities, and adoption and diffusion pattern of institutionally transferred technologies in the central Rift Valley. This study is based on three quantitative studies (Papers I to III) supplemented by a qualitative study (Paper IV). The quantitative studies tested conventional and conservation agriculture systems, fertilizer application methods and various packages of minimum tillage, seed priming, mulching, and fertilizer microdosing technologies for their agronomic and economic responses in maize. The qualitative study was a case study that assessed institutionally transferred technologies.

The succeeding sections describe the context in which this study was undertaken, the rationale for the study, research objectives and research questions, before the theoretical framework and methodological approach are presented. The last part of the report presents a synthesis of individual papers that resulted from the study.

2.0 Contextual status of knowledge

The next section describes the knowledge base related to conventional and conservation agriculture systems, soil fertility, fertilizer application methods, possible scenarios for combining conservation agriculture, seed priming, mulching, and fertilizer technologies for increasing maize productivity in the central Rift Valley in Ethiopia. The knowledge gap in each of these technologies is also described.

2.1 Tillage system

The first paper in this study evaluates the agronomic and economic responses of conventional and conservation agriculture and attempts to address the two most important agro-ecological variables influencing crop production in the central Rift Valley, namely the variable rainfall and low soil quality in terms of fertility, water retention capacity and moisture stress.

Like elsewhere in Ethiopia, traditional tillage systems predominate the agricultural activities in the central Rift Valley. In Ethiopia, depending on the type of crop to be cultivated, two to five strips are used for seedbed preparation (Aune *et al.*, 2001). Tillage is normally done with a traditional plow (ard) drawn by a pair of oxen. However, oxen traction power is expensive for most farmers, particularly those farmers with no or an insufficient number of oxen (Aune *et al.*, 2001). Tillage operations are needed for seedbed preparation, weed control, management of crop residues as well as improving soil aeration, mixing fertilizer into the soil, alleviating compaction and optimizing soil temperature and moisture regimes (Unger, 1984). Conventional tillage may cause soil degradation. It alters soil structure and increases the porosity of the upper layer (Rusinamhodzi *et al.*, 2011; Temesgen *et al.*, 2008). It increases the initial water infiltration into the soil, but total infiltration is often decreased by subsoil compaction (Deressa and Hassan, 2009; Temesgen *et al.*, 2008). It is reported that repeated conventional tillage practice reduces the impact of the low and irregular rainfall on crop yields by causing soil crusting that leads to serious infiltration problems of available rainwater (Biazin and Stroosnijder, 2012; Biazin *et al.*, 2011). The soil in the central Rift Valley has poor water holding capacity (Biazin and Stroosnijder, 2012). High temperatures, high evapotranspiration, unpredictable rainfall, and shorter and unreliable growing seasons further aggravate the agricultural conditions (Kassie *et al.*, 2013).

To avert the challenges of conventional tillage, there is a need to shift to conservation practices. One such practice is conservation agriculture, which could reverse soil degradation, enhance crop productivity, and improve food security (Hobbs *et al.*, 2008). It involves minimum tillage, crop rotation and permanent soil cover to enhance soil fertility (Rusinamhodzi *et al.*, 2011). Conservation agriculture reduces erosion and contributes to water conservation (Unger *et al.*, 1991; Lal, 1982). Minimum tillage is one of the few soil and water conservation practices introduced in selected areas of Ethiopia with the aim of tackling soil erosion, improving soil fertility and enhancing sustainable crop production (Tulema *et al.*, 2008).

Manipulating tillage and mulch management to improve water infiltration and reduce water loss from the soil surface in crop fields has the potential to substantially improve crop yields and soil conditions in the semi-arid tropics (Temesgen *et al.*, 2008; Araya *et al.*, 2012; Adekalu *et al.*, 2007). The mulch component of conservation agriculture controls soil erosion by reducing raindrop impact on the soil surface, decreasing the water runoff rate and increasing infiltration of rainwater (Lal, 1982; Castro *et al.*, 2006). Under semi-arid conditions, mulches also play an important role in the conservation of soil water through reduced evaporation (Scopel *et al.*, 2004). Alternative to the mulching, planting basins can be an efficient method of moisture conservation if they can be maintained after weeding operations (Mupangwa *et al.*, 2007).

Conservation agriculture was widely adopted by farmers in South America mainly because it significantly reduced soil erosion, decreased labor costs and generally led to higher income and a better standard of living for the farmers (Lahmar, 2010). It is mostly adopted by large-scale mechanized farmers with the concomitant widespread use of glyphosate for weed control (Derpsch *et al.*, 2010). Practicing conservation agriculture in Africa, particularly in the semi-arid regions, has different challenges. In the semi-arid regions in Africa, success of conservation agriculture depends on the ability of farmers to retain crop residues and to ensure adequate weed control (Giller *et al.*, 2009). However, crop residue retention is difficult in this area as the farming systems are predominantly mixed crop–livestock systems and crop residues are freely grazed by livestock (Zingore *et al.*, 2007). Low fertilizer use, shortage of labor, no use of herbicides, competition for crop residues, poor soils, variable rainfall and the absence of crop rotation are constraints for practicing conservation agriculture in Southern Africa (Giller *et al.*, 2009). On top of that, conservation agriculture practices are input-intensive depending on the farmers' ability to use fertilizer in adequate quantities and correct proportions (Rusinamhodzi *et al.*, 2011). The other challenge with conservation agriculture is that agronomic and economic benefits are mostly realized over the long term. A study of conservation agriculture conducted over five years in Southern Africa showed an improvement in maize yields over time (Rusinamhodzi *et al.*, 2011). Though most findings confirm the long-term benefits of conservation agriculture in attaining sustainable agricultural intensification (Govaerts *et al.*, 2005; Rusinamhodzi *et al.*, 2011; Rockström *et al.*, 2009), there is less consensus on its short-term impacts (Giller *et al.*, 2009). The choice of tillage practice and its successful application depends on climatic factors, soil types, crop species and socio-economic factors (Unger et al., 1991; Lal, 1982; Hulugalle et al., 1986). These could be some of the reasons for the contrasting reports on the benefits of conservation agriculture (Rusinamhodzi *et al.*, 2011). Knowledge of specific crop responses to tillage and surface crop residues as affected by soils, climate and fertilization is necessary in the selection of appropriate tillage and crop residue management strategies for improved crop production in conservation agriculture (Aina *et al.*, 1991).

For multiple reasons, the practice of conservation agriculture may be an interesting option in Ethiopia. Tillage is expensive, which is a challenge for farmers lacking sufficient draft power.

Traditionally the land is tilled by the ard, which causes minimum disturbance to the soil. The ard can also be used for making permanent seedbeds in furrows and ridges with lower human and oxen traction power needs in subsequent years in conservation agriculture (Nyssen *et al.*, 2010). Kapusta *et al.* (1996) report that production of maize under conservation agriculture was more positive on well-drained soil than on poorly drained soil, particularly under wet soil conditions. In this regard, the soils in the central Rift Valley are well-drained (Itanna, 2005) and have poor water holding capacity (Biazin and Stroosnijder, 2012) and this makes conservation agriculture an interesting option in the central Rift Valley of Ethiopia. Rainfall is erratic with high variability both within and between seasons, and droughts are common in the central Rift Valley (Kassie *et al.*, 2013). Therefore, these existing socioeconomic and agro-ecological conditions in the dry lands of the central Rift Valley might make the practice of conservation agriculture an alternative option to the widely practiced conventional tillage.

2.2. Fertilizer application method and fertilizer rate

The second paper in this study evaluates fertilizer application methods, fertilizer rates, as well as their agronomic and economic responses in maize in the central Rift Valley in Ethiopia.

It is reported that soil erosion and land degradation contribute significantly to the problem of food insecurity that plagues Africa (Sanchez, 2002; Lobell *et al.*, 2008; Clair and Lynch, 2010; Kiage, 2013). Addressing soil fertility decline can be considered key to overcome hunger in Africa (Sanchez, 2002). Nitrogen is often the most limiting nutrient for maize production in the tropics (Osmond and Riha, 1996). As a result, to reverse the trend of declining per capita food production, more intensive land use with fertilizer application has become necessary. Agriculture in Ethiopia is no exception: more soil nutrients are exported compared to natural and anthropogenic inputs. In Ethiopia, nutrient export is twice as high as the average value for SSA, which indicates the severity of nutrient depletion (Haileslassie *et al.*, 2005). Depletion of soil fertility is one of the fundamental biophysical causes for declining per capita food production on smallholder farms (Haileslassie *et al.*, 2005).

Nutrient depletion in Ethiopia has several causes. Phosphorus and nitrogen are the primary nutrient deficiencies. Application of organic fertilizers like crop residue and manure is limited because of competitive uses such as for animal feed and household energy (Tadesse, 2001; Haileslassie *et al.*, 2005). In addition, problems in the fertilizer sector have restricted the wider use of inorganic fertilizers (Tadesse, 2001; Haileslassie *et al.*, 2005). Fertilizer subsidies have been eliminated since 1997 (fertilizer subsidies were 15% in 1993, 20% in 1994, 30% in 1995, 20% in 1996, 0% in 1997) and consequently the cost of fertilizer has increased (Haileslassie *et al.*, 2005). Currently, Di-Ammonium Phosphate (DAP) and urea are the only inorganic fertilizers applied by smallholders (Haileslassie *et al.*, 2005). There is no domestic fertilizer production. According to National Fertilizer Industry Agency (NFIA) and Central Statistical Agency (CSA) of Ethiopia, urea and DAP are the only fertilizers imported into the country since 1971 (NFIA, 2001; CSA, 2013). Urea is chemically composed of 46% nitrogen, while DAP contains 18% nitrogen and 46% phosphorus

(NFIA, 2001; FAO, 2000). Potassium application through inorganic fertilizer is not reported in Ethiopia (NFIA, 2001). Fertilizer trials conducted on major cereal crops also indicated that cereal crops were not responsive to potassium (FAO, 1991).

Croppenstedt *et al.* (2003) think there are two reasons why Ethiopian farmers do not purchase fertilizer. Affordability is a major constraint due to lack of credit on supply-side, suggesting that farmers' financial resources are inadequate to secure fertilizer. On the demand side, formal education, household size and value: cost ratio influence the adoption and intensity of the application of fertilizers. Farmers' price sensitivity suggests that a urea subsidy could be useful in addressing the nutrient imbalance in Ethiopian agriculture (Croppenstedt *et al.*, 2003). A panel survey suggests that although fertilizer markets are not entirely missing in rural Ethiopia, the unfavorable rainfall events, high cost, price risk and inadequate information on fertilizer application present a hurdle to farmer participation (Zerfu and Larson, 2010). Households with greater assets would overcome the hurdles showing the link between poverty and low agricultural productivity (Zerfu and Larson, 2010; Croppenstedt *et al.*, 2003). It is suggested that reducing the cost of fertilizers and increasing yields can advance the intensity of fertilizer application (Zerfu and Larson, 2010).

A key tenet to achieving the agricultural growth targets in the GTP is the adoption of improved technologies together with management practices, which augment yields and therefore increase smallholder farmers' incomes. It is estimated that Ethiopia must double its fertilizer consumption to 1.2 million metric tons to meet the GTP targets (IFDC, 2012). In Ethiopia, the blanket and unbalanced application of DAP and urea fertilizers provides a limited set of products to smallholders who face heterogeneous agro-ecological settings and cultivate a variety of crops. There is a need for a more varied set of fertilizer types, application rates and application methods.

Establishing domestic blending facilities may offer farmers attractive prices (IFDC, 2012). The fertilizer industries currently under construction could somehow lower fertilizer prices and increase access to farmers. The average fertilizer application rate in Ethiopia is reported to be 21 kg ha^{-1}, which is much lower than the national recommended rates of 60–100 kg ha^{-1} (Debelle *et al.*, 2001). However, lowering fertilizer rates using efficient fertilizer application methods can be another option for increasing farmers' use of fertilizers. This study attempts to develop an efficient fertilizer application method that significantly reduces fertilizer rates, reduces risks and increases yields. Such a method presumes to attract the poorest farmers' interest in fertilizer application. Efficient soil fertility management that aims at maximizing the agronomic efficiency of applied nutrients is vital for intensifying agriculture (Vanlauwe *et al.*, 2011). Importantly, the use of proper fertilizer management, the use of improved grain varieties and the adaptation of input application rates following soil fertility gradients are important (Vanlauwe *et al.*, 2011).

In Ethiopia, most of the studies on fertilizers relate to land degradation, soil erosion, prices, policies, lack of subsidies, financial constraints, use of organic fertilizer and distribution. Research related to fertilizer application methods and rates are nonexistent or limited. Fertilizer broadcasting used to be the common application method in Ethiopian agriculture. Since the 2010/11 cropping season, the government has been attempting to replace it with row fertilizer application, which is equivalent to the banding of fertilizer. The banding application method has a long history in Ethiopian agriculture research, but it has not become part of the extension system before 2011. In the banding method, the maximum efficiency of phosphorus fertilizer was obtained when the fertilizer was applied in a band 5 cm from the seed at the time of sowing. Higher efficiency has been obtained with the band application as compared to the broadcasting method (Debelle *et al.*, 2001). Row sowing has made banding of fertilizer a more feasible and practical method. Since the 2010/11 cropping seasons, the complementing banding and row sowing methods have been launched through the national extension system. Both the broadcasting and banding methods recommend high fertilizer rates of 100 kg DAP + 100 kg urea ha^{-1} (Debelle *et al.*, 2001). This study adopted an alternative fertilizer application technology, which is referred to as microdosing. It was developed by the researchers of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its partners. It is a precision farming technique, where a small amount of fertilizer is placed adjacent to the seed at planting (Twomlow *et al.*, 2010; Bagayoko *et al.*, 2011).

The notion behind the development of the microdosing technology was to maximize the return on fertilizer investment and not to maximize yields (ICRISAT, 2009). Sasakawa Africa Association with its agricultural program Sasakawa Global 2000 took the technology to the farmers and implemented over 1,000 demonstrations on farmers' fields in 2010 and 2011 in collaboration with the national agricultural extension service in Mali. The findings indicated that the microdosing technology increases yields and economic profitability (Camara *et al.*, 2013). Such a method of fertilizer application entails a minimal economic risk and can contribute to higher yields and improve food security and farmers' income (Camara *et al.*, 2013). For traditional agriculture with low yields and no fertilizer input, microdosing could be used as an entry point towards a more productive and fertilizer input-based agriculture (Aune and Bationo, 2008; Camara *et al.*, 2013). There is a debate whether microdosing of fertilizers can be a sustainable technology because nutrient uptake by the crop and nutrient removal from the soil might be higher than nutrient applications through microdosing (Twomlow *et al.*, 2010; Camara *et al.*, 2013). To ensure agronomic sustainability and mitigate nutrient depletion, the use of organic manure or compost together with inorganic fertilizer in microdosing is presently promoted in the SSA (Camara *et al.*, 2013). The Ethiopian government promotes and encourages the use of manure and compost as organic fertilizer to increase agricultural productivity. Other technologies that are compatible with microdosing are seed priming (Aune and Ousman, 2011; Camara *et al.*, 2013), ridging for water conservation (Camara *et al.*, 2013), organic fertilizers (Camara *et al.*, 2013), and surface mulching (Aune and Bationo, 2008).

The microdosing technology is low cost, low risk, more feasible to the farmers and gives immediate agronomic and economic benefits (Aune *et al.*, 2007; Aune *et al.*, 2012). The economic profitability of a new technology is more decisive for its adoption than its long-term productivity.

It is only when farmers can generate positive returns from the alternative practice that they adopt it (Camara *et al.*, 2013). Microdosing of fertilizer has shown in on-station research as well as in large-scale on-farm studies, that it might be a valuable option to increase crop productivity with a relatively limited input of resources (Camara *et al.*, 2013). Farmers need robust technologies, which are not too demanding on skills, knowledge and resources, but which improve productivity and/or yield stability. The fertilizer microdosing technology enhances fertilizer use efficiency and improves yields while minimizing input cost. Besides saving on fertilizer, it increases nutrient uptake and yield of cereal crops particularly when the soil surface becomes dry (Tabo *et al.,* 2006). It was reported to increase yield from 44% to 120% compared to the recommended dosage and farmers' practice in Niger. The income of farmers using fertilizer microdosing increased by 52% to 134% (Tabo *et al.*, 2006).

In addition, microdosing can be applied after sowing without much penalty on yield (Camara *et al.*, 2013; Hayashi *et al.*, 2008). Delayed fertilizer application can lessen the financial burden of the local farmers during the sowing period and give them another option to increase productivity and economic returns. Farmers can then have greater flexibility in managing their labor and cash resources. The economic returns from the delayed fertilizer application option were high enough to make this option attractive to small farmers (Hayashi *et al.*, 2008). This quantity of fertilizer, nevertheless, come at too high a price for most subsistence farmers (Zerfu and Larson, 2010). One of the purposes of this study is to develop a low-rate fertilizer application method that enables farmers to apply both fertilizer types in proper combination.

The third agricultural technology adopted and evaluated in this research is seed priming. Seed priming entails soaking seed in water for a specific period of time and then drying it for a while under shade before sowing. There are standard times of priming for different species (Harris, 2006). It advances germination by inducing a wide range of biochemical changes in the seed. It is associated with faster seed germination, higher seedling vigor, improved stand uniformity, earlier heading, maturation and harvesting, and higher yields (Harris, 2006). In marginally arid and semi-arid rain-fed areas like the central Rift Valley, low-vigor seedlings and patchy plant stands resulting from failure of the crop to emerge quickly and uniformly are common challenges to farmers. When farmers face patchy seedling establishment, they may re-sow although this entails increased labor and financial costs. Evidently, this considerably affects the livelihood of farmers. In these semi-arid and rain-fed areas, seed priming is, therefore, an important option available to farmers. It increased pearl millet yields in the low-rainfall areas in Mali (Aune *et al.*, 2012). The combination of seed priming with microdosing improved agronomic and economic returns in millet in low-rainfall regions in Mali (Aune *et al.*, 2012). Such a combination also decreases the risk of investing in fertilizer, keeping the value cost ratio above the minimum requirement (Aune *et al.*, 2012).

In the semi-arid regions like the central Rift Valley, the availability of soil water determines the agronomic and economic responses of fertilizer. Applying a lot of fertilizer without an assured water supply is economically risky, because the response to fertilizer depends on the availability of water at critical stages of plant development. For instance, it has been reported that the application of 2 g of fertilizer at sowing may burn the seeds of millets if the soil humidity is not sufficient (Aune *et al.*, 2007).

The fourth issue assessed in this study is the existing technology development and extension systems, the characteristics of available technologies, adoption and diffusion patterns and the challenges and opportunities for their adoption and diffusion. In recent years, Ethiopia has developed strategies to strengthen the extension system and to encourage the adoption of new technologies and practices that conserve soil and natural resources and increase agricultural productivity (FAO, 2014). An agricultural production intensification approach has been pursued to boost crop productivity through the application of modern agricultural inputs, primarily improved varieties, fertilizers and improved agronomic practices (Alemu *et al.*, 2008). Although the government has ambitious plans to develop and extend new agricultural technologies, there are a number of factors limiting agricultural technology adoption and diffusion in Ethiopia. High cost of inputs, insufficient credit services and high financing costs are critical constraints to the adoption of the available seed-fertilizer technology packages (Spielman *et al.*, 2011). Farmers' insufficient knowledge and inadequate extension systems, insufficient supply of seeds, and limited choice of new varieties (Kassie *et al.*, 2013) and market and institutional failures (Alemu *et al.*, 2008) are other important factors limiting the adoption and diffusion of agricultural technologies.

2.3 Maize production in Ethiopia

Maize plays a central role in food security, especially in the rural areas of Ethiopia. Per capita consumption of maize in rural areas is estimated at about 45 kg year^{-1}; triple the 16 kg year^{-1} consumption in urban areas. More than 80% is consumed at the household level, with commercial marketing largely limited to large-scale producers. Although there are large-scale commercial farms engaging in maize production, smallholders and subsistence farmers still represent 95% of production (FAO, 2014).

Among the cereals produced by farmers, maize has the largest smallholder coverage with 8 million holders compared to 5.8 million for *teff* (*Eragrostis tef* (Zucc.) Trotter) and 4.2 million for wheat. Maize accounted for 36% of all grain production in the 2011/12 cropping season. It is critical to smallholder livelihoods in Ethiopia, in particular in the semi-arid farming communities where over 95% of the smallholders cultivate maize. Maize is the staple crop with the greatest production. Its production was 4.99 million tons, 6.07 million tons and 6.50 million tons in 2010/11, 2011/12 and 2012/13 respectively, compared to *teff* at 3.48 million tons, 3.49 million tons and 3.77 million tons respectively. It is the lowest cost source of cereal calories, providing 1.5 times and twice the calories per dollar compared to wheat and *teff* respectively (CSA, 2013). Therefore, increasing the productivity and production of maize could promote Ethiopia's food production to reduce the national food deficit.

2.3.1 Maize production in the semi-arid dry lands in Ethiopia

Maize is cultivated in all the major agro-ecological zones in Ethiopia up to an altitude of 2400 meter above sea level (m.a.s.l.). The maize-growing areas in Ethiopia are broadly classified into four agro-ecological zones: high altitude moist (1800–2400 m.a.s.l.), mid-altitude moist (1000–1800 m.a.s.l.), low altitude moist (below 1000 m.a.s.l) and moisture stressed (500–1800 m.a.s.l.) (Mulatu *et al.*, 1992).

The semi-arid region in the central Rift Valley of Ethiopia primarily supports a one-crop per year farming system. Land degradation, deforestation and soil nutrient erosion are among the major physical factors limiting maize production (Meshesha *et al.*, 2012; Garedew *et al.*, 2009). Soil moisture stress resulting from intra-seasonal rainfall variability, such as low and uneven distribution in the amount, recurrent dry spells, or droughts influence crop production. The key to increased maize production is to maximize infiltration and the amount of water available. Farmers minimize surface evaporation and runoff by establishing traditional ridges and furrows (Biazin and Stroosnijder, 2012). Socioeconomic factors that influence the productivity of maize include high prices, inaccessibility, inadequate supply system, and instability in prices of improved maize seeds and fertilizers (Kassie *et al.*, 2013). A poor agriculture extension system and inappropriate technologies, insufficient training and inadequate knowledge of extension workers are the remaining limitations (Beshir and Wegary, 2014).

2.3.2 Maize varieties

In the central Rift Valley, the two most widely cultivated varieties of maize are mid-maturing and early maturing. Hybrid maize varieties are higher yielding under favorable conditions, but their seeds cannot be recycled due to gene segregations. Farmers will always need to get first-generation seeds. Market availability is a constraint to the hybrid seeds. Only public institutions or certified agencies supply the seeds. Moreover, hybrid maize seeds are more expensive than the open pollinating seeds due to high production costs (Beshir and Wegary, 2014).

In contrast to the hybrids, the open pollinating maize varieties have variable maturity dates. They are available to farmers as extra-early and early maturing varieties. The extra-early maturing varieties can escape peak season and terminal drought stresses. The early maturing varieties are also more stress tolerant, which decreases the risk of cultivating maize. The national extension system promotes open pollinating maize varieties for the drought-prone areas in the central Rift Valley (Beshir and Wegary, 2014). Their seeds are cheaper, more accessible and, under unfavorable seasonal rainfall, are preferable to the hybrid maize seeds. Such seeds can be recycled and have a lower seed production cost (Beshir and Wegary, 2014). The open pollinating maize gives lower yields and responds less to fertilizer than the hybrid maize. Farmers cultivate the open pollinating maize with no or small quantities of fertilizer (Beshir and Wegary, 2014; Abakemal *et al.*, 2013). For these reasons, this study selected one of the most popular and wide- spread, early maturing and open pollinating varieties of maize (*Zea mays* var. Melkassa-II), as its test crop.

3.0 Rationale for the study

In SSA, the major biophysical reasons for food shortages include insufficient and highly erratic rainfall (Falkenmark and Rockström, 2008) and the poor water-holding capacity of the soil and infiltration problems (Stroosnijder, 2009). The distribution of rain rather than the total amount of rainfall in Ethiopia, in the semi-arid areas in particular, is of major importance to crop production because dry spells in the rainy season strongly depress crop yield (Segele and Lamb, 2005). High runoff and evapotranspiration losses in semi-arid areas in Ethiopia further exacerbate the low crop productivity (Yosef and Asmamaw, 2015). Therefore, improved rainwater management for agriculture has many potential benefits to reduce vulnerability and to improve productivity in dryland in Ethiopia (Stroosnijder, 2009; Biazin and Stroosnijder, 2012; Rockström *et al.*, 2009). The rainfall pattern in terms of amount and frequency in the growing season is also essential for the planning and management of agricultural practices in semi-arid areas in Ethiopia (Yosef and Asmamaw, 2015). In the central Rift Valley, there is a high inter- and intra-seasonal rainfall variability and severe soil moisture stress (Kassie *et al.*, 2013; Biazin and Sterk, 2013). The recurrent dry spells or droughts often result in crop failure or yield reduction and is a common challenge to crop production (Kassie *et al.*, 2013). Appropriate seasonal rainfall forecasts are lacking, constraining the management of crops. Farmers reduce rainfall shocks through making traditional ridges of different kinds (Biazin and Stroosnijder, 2012) and adjusting the cropping calendar and choice of crops to be grown (Kassie *et al.*, 2013).

Apart from the high rainfall variability, the low fertility and water-holding capacity of soils in the Rift Valley increased farmers' reluctance to invest in the high-price inputs (Kassie *et al.*, 2013). The soil is responsive to DAP and urea fertilizers and is well-drained with low water-retention capacity (Biazin *et al.*, 2011). Fertilizer and improved maize seeds are expensive and farmers do not have the money to purchase them (Beshir and Wegary, 2014). An efficient fertilizer application method is lacking. The national extension system promotes the banding method of fertilizer application which involves application of fertilizer at a relatively high rate. The extension system also promotes the use of improved extra-early and early maturing maize varieties (Beshir and Wegary, 2014). The improved seed-fertilizer package being promoted institutionally is, however, expensive to the farmers as both improved seeds and fertilizers are expensive. There is a need for developing an efficient fertilizer application method that is low cost, low risk and productive. Technologies reach farmers through the national extension, social networks or a combination of these. The national extension system uses the top–down approach for transferring technologies. Consequently, technologies reach farmers with inadequate information (Beshir and Wegary, 2014). In addition to these unfavorable growing conditions, limited access to cash increased farmers' aversion to risk and made adoption of new technologies difficult (Kassie *et al.*, 2013; Beshir and Wegary, 2014). This study considers these production constraints as the rationale for investigating the productivity, profitability, riskiness and adaptability of new agricultural technologies to existing agro-ecological and poor socioeconomic settings in the central Rift Valley.

4.0 Objectives and research questions

The overall objective of this PhD research was to evaluate the agronomic and economic responses of agricultural technologies in maize and the adoption and diffusion of agricultural technologies in the semi-arid central Rift Valley in Ethiopia. The specific objectives included the following:

1. To evaluate the agronomic and economic responses of tillage and *in situ* rainwater conservation systems in maize (Paper I).

   Research questions: What are the short-term agronomic and economic benefits of conservation agriculture relative to conventional tillage? What are the short-term agronomic and economic benefits of mulching and planting basins?

2. To evaluate the agronomic and economic responses of fertilizer microdosing and banding application methods in maize (Paper II).

   Research questions: What are the agronomic responses of fertilizer microdosing relative to fertilizer banding in maize? What is the fertilizer use efficiency, level of risk and the economic profitability of fertilizer applied as microdosing and banding?

3. To evaluate agronomic and economic responses of various packages of minimum tillage and seed priming, microdosing of DAP fertilizer, surface mulching, and microdosing of urea fertilizer (Paper III).

   Research questions: What are the agronomic responses of various packages of minimum tillage and seed priming, fertilizer microdosing, and mulching? What is the fertilizer use efficiency, level of risk of fertilizer microdosing and economic profitability when used with different packages of minimum tillage, seed priming, and mulching?

4. To identify the agronomic technologies transferred to farmers, and assesses their characteristics, adoption and diffusion pattern and the challenges and opportunities for adoption and diffusion (Paper IV).

   Research questions: What type of technologies reach farmers? What system of technology transfer is in place? Do technologies transferred match farmers’ priorities and address their socioeconomic and agro-ecological challenges? What are the constraints and opportunities to adopting technologies?

5.0 Conceptual framework

This study employed participatory research approach (Papers I - III) and adoption and diffusion theory (Paper I) in order to investigate the agronomic and economic responses of technologies in the central Rift Valley in Ethiopia.

5.1 Participatory research approach

There is no a universally agreed approach to agricultural research. Different approaches have their own strengths and weaknesses. This study categorized them broadly into a top-down research approach and a participatory research approach. In the top-down approach, technologies and knowledge are typically developed and validated by research professionals where the task of the extension agencies is to take these technologies to farmers (Rogers and Kincaid, 1981). The assumption in this approach is that when farmers are aware of technologies, they will adopt them and the technologies will spread to other farmers.

In the strategies of the top-down approach, Chambers (1983) argues that the skills, knowledge and other adaptive abilities of farmers are systematically and unjustifiably devalued. This is because agricultural scientists tend to perceive farming systems through the narrow window of their professional discipline. Apart from that, all the key research decisions are made by scientists who experiment on research stations or under controlled, simplified conditions in farmers' fields. However, there are many internal linkages that matter in farming systems, particularly in the complex farming systems, which resource-poor farmers often possess, but that professional disciplines often oversee. Agricultural researchers tend to adopt one or two single criteria to measure performance. For example, in a crops and livestock mixed system the emphasis is often on grain yield while the straw may be considered as leftovers (Chambers, 1993; Ashby and Sperling, 1995). But, in many farming systems like in Ethiopia, the straw is used for multiple purposes like animal fodder, fuel, construction materials, a component of organic fertilizer, etc., and is a vital part of the crop-livestock farming system. Therefore, the top-down approach is insensitive to realities on the farm and the livelihood strategies of poor farmers in developing countries. As a result, it has failed to improve the livelihoods of the rural poor, particularly in Africa. Nevertheless, farmers as managers of complex environments use risk-minimizing strategies considering different criteria like the choice of crop varieties and farm activities, and the diversification of their farms and household endeavors (Chambers and Jiggins, 1987; Chambers, 1993).

A reaction to this approach was the development of a participatory research approach (Chambers, 1993). As opposed to the positivist and reductionist methodology in the top-down approach, the participatory research approach is typically location specific, focusing on diversity, decentralization, and democracy. The participatory research approach makes farmers more active in the innovation and diffusion of agricultural technologies (Chambers, 1993; Lilja and Dixon, 2008; Bruges and Smith, 2008). Several families of *participatory movements* evolved in postmodernism. These approaches have evolved as behaviors and attitudes, methods, and practices of sharing knowledge against the top-down approach of agricultural research methodology. Since the 1990s participatory rural appraisal, participatory learning and action and farmer participatory research have spread and are applied in most countries of the developing world. In re-conceptualizing the research and development process, there has been a growing interest in the use of participatory approaches, in the natural resource management, agriculture and rural livelihood researches at the expense of the top-down approach (Biggs, 2008; Chambers, 1993; Lilja and Dixon, 2008). Epistemologically and ideologically, participatory approaches seek and embody participatory ways to empower local and subordinate people, enabling them to express and enhance their knowledge and take action. Promising performance moves towards an eclectic pluralism in which branding, labels, and ownership give way to sharing, borrowing, creativity and diversity, complemented by mutual and critical reflective learning and responsibility (Biggs, 2008; Hoffmann *et al.*, 2007; Asten *et al.*, 2009).

Participatory approaches urge critical inquiry as a tool for social change, in which power relations are key lines of analysis. They are social movements that become a radical challenge to the traditions of conventional approaches (Chambers, 1993; Biggs, 2008). The participation of all stakeholders, namely farmers, researchers and institutions, is vital in ensuring the application and sustainability of developed technologies (Ashby and Sperling, 1995). The degree of participation in participatory research may vary according to the nature of a research topic, level of researchers' facilitation skills, experience of farmers in on-farm trials and the level of mutual trust between researchers and farmers. One argument for consulting potential beneficiaries, the farmer in this study, in the development and transfer of technology is to obtain feedback necessary to produce a technology that is appropriate and therefore likely to be adopted and diffused. End-user participation with this intention is often referred to as *consultative participation* that increases the working efficiency and effectiveness of the existing technology development and transfer process (Pretty, 1994; Ashby and Sperling, 1995). Moreover, by empowering end-users to enhance the capacity to innovate and to influence research agenda, participatory research can lead to fundamental changes in the nature of the innovation process, bringing in new actors and altering existing power relationships. User participation with this objective is often referred to as *empowering participation* (Ashby and Sperling, 1995; Nancy *et al.*, 2003). In consultative participation, researchers alone make the decisions, but with organized communication with farmers. Researchers know about farmers' opinions, preferences, and priorities through organized one-way communication. Such decisions include setting research topics and designs. Farmers' participation in decision making is limited. In the empowering participation, the decision-making authority is shared between farmers and scientists, and involves an organized communication between them. Researchers and farmers know about one another's opinions, preferences, and priorities through an organized two-way communication. Decisions about farmers' needs are made jointly and participation is balanced to achieve the objectives of both the farmers and the researchers (Biggs, 2008).

The framework used by Neef and Neubert (2011) provides a basis for agricultural researchers engaged in participatory processes with local stakeholders to decide on which issues and in which phases certain participatory elements could be used in a specific research context. In accordance, this study used combinations of the consultative and collaborative participatory approaches. The consultative approach was used for the selection of the technologies and the design of research trials in the field, while the collaborative approach was used for selection of participating farmers, crop varieties to be tested, fields for hosting on-farm trials, trials to be tested on-farm, as well as for collecting feedback and facilitating the adaptation and/or adoption and diffusion of the best-performing technologies. Researchers collaborated with farmers to decide on the plot size for the trials to compare results across farms. This approach helps to get reliable agronomic and economic data across a range of farms, facilitating the analysis of outputs like crop yields and economic return. It is also useful for enhancing farmers' perceptions and knowledge of the technologies and for facilitating farmer-to-farmer experience sharing.

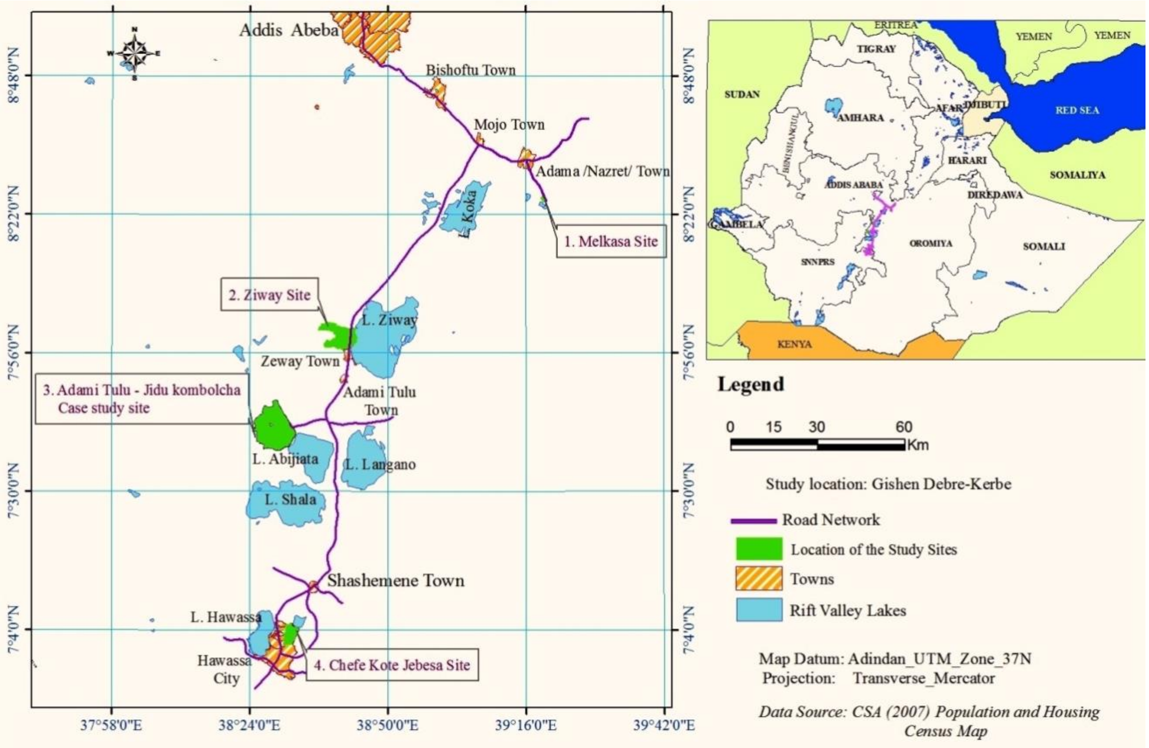
5.2 Adoption and diffusion theory

The processes of adoption and diffusion of technologies transferred to farmers were assessed according to Rogers' innovation adoption and diffusion theory. Rogers (1995) defined an *innovation* as 'an idea, practice or object that is perceived as new by an individual or other unit of adoption'. An innovation does not necessarily mean better or that the new idea is more beneficial to an individual. Adoption theory examines the individual and the choices an individual makes to accept or reject a particular innovation. Adoption theory does not only focus on the whole but also on the pieces that make up the whole (Rogers, 2003). In contrast, diffusion theory describes how an innovation spreads through a population across time. Rogers (2003) argues that diffusion is the process by which an innovation is communicated through certain channels over time among the participants in a social system. Rogers proposes that four main elements influence the spread of a new idea: the innovation itself, communication channels, time, and a social system.

6.0 Materials and methods

6.1 Description of the study sites

The research sites, Ziway, Melkassa and Hawassa, are situated in the semi-arid central Rift Valley in Ethiopia at 7°9′N and 38°43′E, 8°4′N and 39°31′E, and 7^{0}4'N and 38^{0}31'E latitude and longitude, at 1642, 1550 and 1675 m.a.s.l., and at 122, 115 and 260 km south of Addis Ababa respectively (Figure 1 below). Ziway has well-drained clay loam soil (40% sand, 32% silt and 28% clay), with pH = 8.40, 3.21% organic carbon, 0.25% total nitrogen and 18.2 mg available phosphorus kg^{-1} soil. The average total annual rainfall in Ziway over the past 12 years ranges from 518 to 1002 mm (average 815 mm), with an average maximum and minimum air temperature of 28°C and 13°C. Melkassa has well-drained loam soil (37% sand, 40% silt and 23% clay), with pH = 7.42, 1.7% organic carbon, 0.14% total nitrogen and 19.20 mg available phosphorus kg^{-1} soil. The average total annual rainfall for Melkassa over the past 12 years ranges from 549 mm to 1093 mm (average 877 mm), with an average maximum and minimum air temperature of 29°C and 14°C. Hawassa has well-drained loam (46% sand, 28% silt and 26% clay), with pH = 7.1, 2.3% organic carbon, 0.19% total nitrogen and 46.40 mg available phosphorus kg^{-1} soil. The average total annual rainfall for Hawassa over the past 12 years ranges from 776 mm to 1145 mm (average 988 mm), with an average maximum and minimum air temperature of 26.6°C and 13.7°C. The soil in the central Rift Valley is classified as Haplic Solonetz with a texture ranging between loamy sand to sandy loam (Itanna, 2005) based on FAO soil classification systems.



Data Source: CSA (2007) Population and Housing Census Map

Figure 1. Map showing the location of the study sites

6.2 Farm characteristics

Farmers practice a mixed farming system, characterized by a strong integration between crop and livestock production. Cattle provides traction and threshing power, manure to improve soil fertility and to use as domestic fuel. Crop residues are used as fodder, particularly during dry seasons, as well as providing a source of domestic fuel. Monocropping of cereals, mainly maize, and *teff* (*Eragrostis tef* (Zucc.) Trotter), is a common practice in the region. The production of pulses such as haricot bean (*Phaseolus vulgaris* L.) as a sole crop or intercrop has increased in recent time.

Maize is the predominant cereal crop and staple food. Increasing food demand in the region, driven by considerable population growth, has increased pressure on the fragile land system (Alemayehu *et al.*, 2006; Legesse and Ayenew, 2006; Meshesha *et al.*, 2012).

There used to be two overlapping seasons for crop production on the study sites. The first season usually extends from April to September (six months) while the second season, which is the main rainy season, extends from June to October (five months). July and August are the wettest months. Local and mid-maturing maize is the main crop for the first season, while haricot bean, wheat and *teff* are the main crops for the second season. Early maturing maize is cultivated during both seasons. Farmers manage the cropping calendar according to the seasonal rainfall events. When the rain starts late, farmers cultivate early maturing maize varieties during the second season, usually in early June. In recent times, at Ziway and Melkassa, adjusting cropping calendar from the longer to the shorter season has happened (Kassie *et al.*, 2013). As a result, farmers rely on the second season for the cultivation of most of the crops. Extra-early maturing maize is usually cultivated to fill the severe food shortage occurring pre-harvest. The government normally encourages farmers to cultivate early and drought-tolerant varieties of maize in these areas. Fertilizers and improved seeds are supplied to farmers through farmers' cooperative unions and agricultural offices; however, delays in supply are frequent in either of the supplies. Due to financial constraints and inadequate market information, farmers sell their agricultural produce at local markets, usually at lower prices when the market saturates. There is instability in the input and output market prices.

6.3 Data collection

This study relies mainly on quantitative data supplemented by qualitative data. The quantitative method involved carrying out three field experiments, namely tillage and rainwater conservation methods (Paper I), fertilizer application methods of microdosing and banding (Paper II), and sequential application of various packages of minimum tillage, seed priming, fertilizer microdosing, and mulching (Paper III). The field experiments were carried out during the 2011/12 and 2012/13 cropping seasons. In all the experiments, Di-ammonium phosphate (DAP) ($(NH_4)_2HPO_4$) and urea ($CO(NH_2)_2$) were applied at planting and knee height respectively (Papers I - III). All the treatments under the different experiments (Papers I–III) were arranged in a randomized complete block design with four replications.

The first study (Paper I) was carried out to evaluate the agronomic and economic responses of conventional tillage and conservation agriculture under similar conditions of mulching, no mulching and planting basins and their suitability to local settings. It therefore compared conservation and conventional tillage methods. The field experiments for the tillage and rainwater conservation methods were carried out at Ziway and Melkassa. The experimental design was a split plot with four replications. The tillage treatments were the main plots, with mulching, no mulching and planting basins as the subplots. The main plots of the conservation agriculture were minimum tillage and zero tillage. Likewise, the main plot of the conventional tillage had similar subplots. The treatments received one g DAP per planting station (where seeds and fertilizer were placed adjacent to each other) at planting and one g urea per planting station was also applied at knee height, 40 days after planting. This corresponds to 53 kg fertilizer ha^{-1} for each of DAP and urea, which is 47% less than the national recommendation for maize. Biophysical data were collected from the field experiments, including soil physico-chemical analysis, soil volumetric water content for the determination of available soil water for plant growth, weed density, maize yield and yield characteristics. The economic data collected include total revenue, total variable costs, gross margin and labor productivity.

6.3.1 Rainfall data

The long-term climate data and that of the experimental seasons for Melkassa, Ziway and Hawassa sites were gathered from the meteorological centers located closest to Melkassa, Ziway and Hawassa.

6.3.2 Soil sampling and laboratory analysis (Paper I)

Twenty-four composite soil samples (from six random treatments per replication) were randomly collected at the depth of 0 to 20 cm to determine the pre-experiment physico-chemical characteristics of the soil. The soil samples were collected one week before planting and fertilization in 2011. The same number of soil core samples from the same treatments was collected for the determination of total porosity and bulk density. The pH was measured on 1:2.5 soil/water suspensions with a glass electrode pH meter. Organic carbon was measured using wet oxidation methods (Wakley and Black, 1934) and total nitrogen by the Kjeldahl procedure (Bremner and Mulvaney, 1982). Available phosphorus was determined according to the Olsen method (Olsen *et al.*, 1954). Exchangeable calcium and magnesium were determined using an atomic absorption photometer, while sodium and potassium were determined by flame photometry (Black *et al.*, 1965). Cation exchange capacity was determined with the ammonium acetate method (Chapman, 1965). Particle size analysis was performed using the Boycous hydrometric method (Black *et al.*, 1965). Bulk density was determined after drying the core samples in an oven at 105°C. Total porosity (%) was computed from the values of bulk density and particle density (Brady and Weil, 2002).

6.3.3 Percent volumetric soil moisture content (Paper I)

The SM300 Soil Moisture Sensor with the Delta-T HH2 hand-held Moisture Meter (data logger) were used to measure the volumetric soil moisture content (%), with ±2.5% accuracy. The sensor can measure from 0% to 50% volume water in the soil. The sensor/probe (51 mm) was inserted into the surface and subsurface of the soil (0–15 cm, crop root zone). Accordingly, three soil moisture measurements were recorded from the central row of the mulched, no mulched, and basin treatments. The measurements were taken systematically at different intervals the day after it rained: first week after planting, flowering, and physiological maturity. The purpose of measuring volumetric soil moisture content was to estimate the effect of mulching and no mulching, and planting basins and tillage management on soil moisture content, which depicts the plant-available water in the soil.

6.3.4 Weed data and measurement (Paper I)

Weed count data (number m^{-2}) were recorded three and six weeks following planting, just prior to manual weeding. A one meter by one meter quadrat (1 m^2) was placed randomly in three places in each plot, resulting in a total sample area of 3 m^2 $plot^{-1}$. The counting was conducted three (first weeding) and five (second weeding) weeks after planting. Additionally, before flowering and seed setting, remaining weeds were slashed to reduce weed seed banks.

6.3.5 Yield and yield characteristics, and measurements (Papers I - III)

The major agronomic data collected include days to emergence, pocket seed germination (50%), seedling vigor (rated 1–5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous), days to tassel (50%) and to physiological maturity (75%), lodging count, plant height (cm), and grain and stover yield (kg ha^{-1}). Plants fallen, inclined or with broken stalks were considered as lodged. Plant height was measured from the ground level to the base of the tassel for five randomly selected plants per plot. Biomass weight was taken after sun drying for eight days. Threshing was done manually. To avoid border effects, data of all the parameters were taken from the four central rows, thus, the net plot size was 9 m^2. After harvesting cobs, for each treatment, cobs were shelled, weighed and grain moisture content was measured immediately by a multigrain digital moisture meter. Eventually, the grain yield weight was adjusted at 12.5% moisture level. Yield was extrapolated and then reported on a per hectare basis.

6.3.6 Economic data and analysis

Standard enterprise budgeting techniques were used to estimate production costs and profitability (Papers I - III). Total variable cost (TVC) was estimated from the input costs of labor, fertilizer and seed. Input costs for fertilizers and seeds and average labor costs for planting, fertilizer application, weeding, and harvesting were estimated. Price per kg (averaged over 2011 and 2012) of maize seeds, DAP and urea were 1.14 US$ kg^{-1}, and 0.82 US$ kg^{-1} and 0.63 US$ kg^{-1} respectively at the local market at Ziway and Melkassa. Both Ziway and Melkassa are close to fertilizer markets and the price was therefore the same. The market price for output was also similar. At Hawassa, price per kg (averaged over 2011 and 2012) of maize seeds and DAP and urea fertilizer were 1.19 US$ kg^{-1}, and 0.84 US$ kg^{-1} and 0.64 US$ respectively. The market price of the grain per kilogram was estimated at 0.23 US$ at Ziway and Melkassa, and 0.22 US$ at Hawassa. Rental cost was estimated at 10.96 US$ ha^{-1} for one time passage with oxen. Labor cost was estimated at 1.64 US$ $person^{-1}day^{-1}$ across the sites. Gross income (GI) was estimated from grain yield multiplied by grain price. Gross margin (GM) was calculated as the difference between GI and TVC. Monetary values related to cost and income were converted from Ethiopian birr to

US$ at the exchange rate of one US$ to 18.24 Ethiopian birr. For each treatment, the time spent for each activity (seedbed preparation, planting, fertilization, mulching, making planting basins, thinning, weeding, harvesting and threshing) was recorded. Data related to mulching (Papers I and III) and planting basins (Paper I) were collected. Time use for the different activities was observed in all the plots of the experiment for the two years across both sites. In addition, the time spent when farmers worked as a group on the plots was observed. The average for each treatment was calculated. Cost of seeds, fertilizers, harvesting and threshing were considered to be the same for all treatments. Finally, labor productivity (Paper I) of each treatment was estimated as a ratio between maize grain (kg ha^{-1}) and the total amount of labor required (day ha^{-1}). Family labor was used as the major source of labor to increase farmers' participation, knowledge and attitude for adoption and diffusion of the technologies.

The second study (Paper II) was conducted to evaluate fertilizer applied as microdosing and banding for agronomic and economic responses and for suitability to local settings. Field experiments with the following treatments were conducted: control without fertilizer, microdosing treatments at 27 kg DAP ha^{-1} + 27 kg urea ha^{-1}, 53 kg DAP ha^{-1} + 53 kg urea ha^{-1}, and 80 kg DAP ha^{-1} + 80 kg urea ha^{-1}, and banding of fertilizer at 100 kg DAP ha^{-1} + 100 kg urea ha^{-1}, applied at planting and jointing, respectively. The experiments were conducted at Ziway, Melkassa and Hawassa.

The third study (Paper III) examined different levels of maize yield increasing options by sequentially introducing minimum tillage and seed priming, DAP fertilizer microdosing, surface mulching and urea fertilizer microdosing to the farmers' practice. On-farm and on-station experiments were conducted with five treatments, or steps: conventional tillage (farmers' practice as a control), minimum tillage + seed priming, unfertilized (step 1), step 1 + microdosing 53 kg ha^{-1} DAP (step 2), step 2 + 4 ton ha^{-1} maize stover as surface mulch (step 3) and step 3 + 53 kg ha^{-1} urea (step 4). These steps represented increasing levels of agricultural intensification. A ladder approach (Aune and Bationo, 2008) was used for sequencing the different technology packages. The experiments were conducted at Ziway and Melkassa.

In Papers II and III, fertilizer use efficiency (FUE) for determination of fertilizer use efficiency and value cost ratio (VCR) for determination of level of risk of fertilizer application were analyzed as follows:

Fertilizer use efficiency

The FUE of each treatment was computed as the difference in grain yield (kg ha^{-1}) between each treatment and control divided by the amount of fertilizer applied (kg ha^{-1}).

$$\mathrm{FUEt} = \frac{\mathrm{Yt\text{-}Ct}}{\mathrm{Ft}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where *FUEt* is the agronomic fertilizer use efficiency of treatment *t*; *Yt* is the grain yield of treatment *t*; *Ct* the grain yield of the control treatment; and *Ft* is the rate of fertilizer used for treatment *t*.

Value cost ratio

For each treatment (compared to the control), *VCR* was calculated as follows:

$$\mathrm{VCRt} = \frac{(Yt - Yc)xPGt}{CFt} \text{..............................} (2)$$

Where *VCRt* denotes the value cost ratio for treatment *t*, *Yt-Yc* denotes the incremental grain yield resulting from fertilizer use in treatment *t* and control *c*, *PGt* denotes the grain price kg^{-1} in treatment *t*, and *CFt* denotes the cost of fertilizer ha^{-1} in treatment, *t*.

The fourth study (Paper IV) was a case study conducted at Ziway that assessed the agronomic technologies transferred to farmers, their characteristics and the opportunities and challenges for their adoption and diffusion. Primary data were collected from stakeholders through a series of focus group discussions, key informant interviews and field visits. A pre-set semi-structured questionnaire was set and used. A qualitative and quantitative approach in research and development systems complement each other. The quantitative approach focuses on the outputs and impact of research and development of a technology while the qualitative approach examines and questions underpinning validity of institutional arrangements, concepts and methods (Hall *et al.*, 2001; Biggs, 1990). It was in this sense that the qualitative approach was used to reveal contextual variables of the agro-ecological and socioeconomic conditions in the central Rift Valley that could be used to further promote the developments and extension of the best-performing technologies. This study was carried out in time almost parallel to the field experiments.

As all the data collected are qualitative, we used cross-association for ensuring the validity and reliability of the information collected. A comparison analysis was used to assess common themes and subthemes in reaching data saturation. Finally, every theme/subtheme was described.

6.3.7 Statistical analyses

The General Linear Model of the ANOVA of SAS System Version 9.3 of SAS Institute Inc. (SAS, 2011) was used to determine treatment effects on agronomic and economic responses. Means comparisons were conducted using the least significant differences (LSD), established at 5% significance level (P-value < 0.05).

6.4 Reliability and validity

This study involved quantitative and qualitative research. Reliability and validity address issues of the quality of the data and appropriateness of the methods used in carrying out a research project.

Reliability is concerned with the idea of replicability or repeatability of results or observations as supported by a positivist epistemology. It addresses the consistency and stability of the data, and if repeated applications of the methods under similar conditions give consistent results. Whereas validity relates to the extent of causal relationship examined – how the data support conclusions (internal validity), and how the results of the study can be generalized beyond the specific contexts in which the research was carried out (Bryan, 2012).

In this study, the reliability and validity issues of the quantitative researches were addressed through careful selection of experimental sites, random sampling of farmers to host trials, randomization of treatments and replication of trials. Randomization was used to control external sources of variations. Three representative sites in the region were selected and used for conducting the field experiments. Instrumentation used for data gathering such as auger, sensitive digital balance, soil moisture meter and soil laboratory analyses followed standard procedures. Extension workers, farmers and field assistants were adequately trained on how to manage field trials and collect standard data.

For the qualitative research, important local actors, namely different groups of farmers (sex, age, educational level and wealth category), extension workers and agricultural experts were used for collection of data. Pre-set semi-structured questions were used for conducting a series of focus group discussion, key informant interview, and informal discussion during field visit. Discussants were allowed to respond to questions and comments raised by the other discussants. Trust was built and consensus of valuing information was reached. Similar discussions were held in each village for cross-checking and increasing the validity and reliability of the information collected. For the purpose of further cross-checking of the information collected from the discussant farmers, similar issues were raised during the discussion held with extension workers and the interview with the agricultural experts. The field visits were conducted through informal and interactive discussion with farmers to further cross-associate the issues raised during the discussion and interview. The principal researcher, assistants, extension workers and experts understood the language and culture of the farmers.

6.5 Research ethics

A collaborative and consultative approach was used as platform to interact with all stakeholders. The objectives of the on-farm, on-station and qualitative research were explained to all stakeholders and an agreement was reached before launching the studies. After a brief explanation about each experiment, interested farmers were allowed to host a mother or baby trial on their farms. The farmers themselves primarily managed the on-farm trials. Both the on-farm and on-station trials were in close proximity to each other so that farmers had easy access to both trials as well as to the researchers for the purpose of consultation and evaluation of the performances of the on-farm and on-station trials. For the qualitative information collection, the respondents were assured that they would remain anonymous and that the information gathered was to be used for academic purposes only and would remain confidential. Other ethical issues such as obligations and protocols were recognized, such as involving local leadership, respecting norms and cultural practices. The proper channels of data collection as required by various organizations were followed closely working with agricultural offices, extension workers and farmers.

7.0 Papers (summaries)

Paper I

This study examined the agronomic and economic responses of tillage and water conservation management in maize. Field experiments were laid out as a split plot design with conventional tillage, minimum tillage and zero tillage as main plots with mulch, no mulch and planting basins as subplots. The minimum tillage and zero tillage with their subplots were considered as conservation agriculture plots. Results showed that conventional tillage had 13% to 20% higher grain yield than minimum tillage and 40% to 55% higher than zero tillage; and minimum tillage had 27% to 37% higher yields than zero tillage. Mulch treatments had 23% to 33% and 14% to 19% higher grain yield than no mulch and basins respectively. The conventional tillage had 28% and 89% higher labor productivity, and 6% and 60% higher gross margin than minimum tillage and zero tillage respectively. The minimum tillage had a 37% higher gross margin than zero tillage. The highest yield response in conventional tillage also resulted in its highest gross margin and labor productivity. This showed that conventional tillage gives a better agronomic and economic response than conservation agriculture practices. However, the practice of conventional tillage is highly constrained by the availability of oxen traction power and the short window period for planting. Mulching tended to be attractive and promising in suppressing weed density and hence reducing labor demand for weeding, besides improving volumetric soil moisture content and maize yield. However, the viability of practicing mulching is highly constrained by the widely practiced open grazing on stubble after harvest. Yet, it can be practiced in plots adjacent to homes that are traditionally fenced for growing extra-early and early maturing maize and vegetables. Long-term studies are needed to identify appropriate alternative tillage and water conservation management systems that can reduce the vulnerability of maize production to the high rainfall variability in the central Rift Valley. As this is a short-term study and conducted over only two sites, we suggest further studies that include different and contrasting agro-ecological and socioeconomic conditions.

Paper II

To increase maize productivity, efficient fertilizer application methods and rates are important to increase farmers' investment in fertilizers, reduce risk of fertilizer application and promote a balanced DAP and urea fertilizer application. This study examines the agronomic response, efficiency and profitability of fertilizer microdosing and banding in maize. Field experiments with the following treatments were conducted: control without fertilizer, microdosing treatments at 27 kg DAP ha^{-1} + 27 kg urea ha^{-1}, 53 kg DAP ha^{-1} + 53 kg urea ha^{-1} and 80 kg DAP ha^{-1} + 80 kg urea ha^{-1}, and a banding of fertilizer at 100 kg DAP ha^{-1} + 100 kg urea ha^{-1}, applied at planting and jointing, respectively. The treatments were arranged in a randomized complete block design with four replications. The experiments were conducted at Ziway, Melkassa and Hawassa. Compared to the control, the fertilizer treatments had higher yields. The application of fertilizers offered increased yield and profitability. The 27 kg DAP ha^{-1} + 27 kg urea ha^{-1}, which is the lowest dose, increased the grain yield by 19%, 45% and 46% at Hawassa, Ziway and Melkassa, respectively. This treatment gave the same yield as the banding treatment. In the different fertilizer doses under the microdosing, the value cost ratio varied from 7 to 11 whereas the value cost ratio in banding varied from 2 to3. This shows that the lowest fertilizer dose under the microdosing is far less risky than the banding method. Similarly, in the lowest fertilizer dose under the microdosing the fertilizer use efficiency (kg grain kg^{-1} fertilizer) varied between 23 and 34 compared to banding treatment that had a fertilizer use efficiency between 7 and 8. This showed that the application that had the lowest microdosing rate is much more efficient in increasing maize yields than the banding method. The improved yield, fertilizer use efficiency, value cost ratio and gross margin in maize with the lowest microdosing rate show that this is a low-cost, low-risk, productive and profitable treatment. Therefore, the application of this particular rate in maize may be an option for the marginal farmers in the central Rift Valley in Ethiopia. Lower rates than the 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} could also be an option.

Paper III

There is a need for new technologies in the Rift Valley to address the problems related to high seasonal rainfall variability, poor soil quality, financial constraints and inappropriate technologies. Using the ladder approach, this study examined different levels of agronomic and economic intensification options in maize by sequentially introducing minimum tillage and seed priming, DAP fertilizer microdosing, surface mulching and urea fertilizer microdosing. Field experiments were conducted with five treatments, steps consisting of conventional tillage (farmers' practice as a control); minimum tillage + seed priming, unfertilized (step 1); step 1 + microdosing 53 kg DAP ha^{-1} (step 2); step 2 + 4 ton ha^{-1} maize stover as surface mulch (step 3) and step 3 + 53 kg urea ha^{-1} (step 4). These steps represented increasing levels of intensification of agronomic practices. Except at the lowest step (step 1), agronomic and economic responses improved with increasing levels of inputs on the ladder. Gross margin increased significantly with increased levels of intensification while the production costs were low and increased only to a limited degree with increasing levels of inputs. Except at the lowest level, the value cost ratio was above four even at the highest levels of inputs, demonstrating that such kinds of intensification can be achieved with low risk. Likewise, the fertilizer use efficiency was quite high even at the highest of levels of inputs showing the efficiency of microdosing. The improvement in maize establishment and yield and the reduction in the days to maturity show that this type of intensification can produce a more robust and productive cropping system. The experiment shows that farmers can choose different levels of agricultural intensification depending on their resource endowment.

Paper IV

The semiarid central Rift Valley in Ethiopia is characterized by high rainfall variability, low fertility and low water-holding capacity of the soils, low economic capacity and inefficient technologies. This case study assesses agricultural technologies introduced to farmers, and their characteristics, adoption and diffusion patterns and challenges and opportunities for adoption and diffusion. The viewpoints of stakeholders, namely farmers, agricultural extension workers and experts were collected from a series of focus group discussions and key informant interviews, supplemented by a series of field observations. Resulted showed that technologies reach farmers through an extension system, social networks or both. Improved early maturing maize varieties and improved practices, such as row sowing, fertilizer banding, intercropping, and traditional rainwater - harvesting are among the technologies adopted and disseminated through the extension system. Row sowing, fertilizer banding and traditional water harvesting methods benefit one another mutually. These technologies are promoted through social networks as well. Technologies can spread even though they are not part of the extension system. This was observed for hybrid maize and haricot bean varieties. These crops were adopted because they have high yields, high market prices and fit within the existing intercropping system. There is high likelihood of dis-adoption for once adopted technologies when such technologies lacked support from the national extension system or social network. It happened to seed priming, harvesting at physiological maturity and cultivation of finger millet, among others. Although most of the adopted technologies are in line with farmers' priorities, improved seeds and fertilizers are expensive and the technologies lack adequate information. When inputs are not affordable, farmers use no or small quantities of fertilizer, or replace improved seeds with local varieties or recycled seeds. Therefore, to help farmers exploit the full potential of adopted technologies, constraints related to inadequacy of the extension system, financial constraints and provision of reliable agrometeorological information need more attention. Promising technologies need to be fully integrated into the extension system, social networks or both for ensuring sustainability. Furthermore, for rational adoption and diffusion, technology development and the extension system need to have a strong institution-researcher-extension worker-farmer linkage.

8.0 Synthesis of papers

This section provides a synthesis of the papers and gives a reflection on the agronomic and economic characteristics of the technologies studied under the different papers and their importance to the existing local agro-ecological and socioeconomic setting in the central Rift Valley. It also gives a reflection on the weaknesses, strengths, relevance of the findings and the implications of the findings. The study makes use of the participatory research approach, and adoption and diffusion theories, which assume that technology development and extension need to consider local settings, in our context the agro-ecological, institutional and socioeconomic conditions in the central Rift Valley in Ethiopia (see Table 1 below).

Conservation agriculture, fertilizer microdosing, and seed priming technologies were developed with an active participation of farmers and other local actors, following a consultative and collaborative approach (Papers I to III). Such an approach of technology development and extension that makes local actors active players can improve the knowledge of stakeholders and enable better utilization of technologies (Papers I - IV). Technologies that have been transferred to farmers through the national extension system are mostly based on the linear approach for technology transfer. These technologies are largely high-input and lack provision of adequate information. To maximize the utility of such technologies, in addition to the information obtained from the extension system, farmers use information available within their social networks. Social networks play substantial roles in the adoption and diffusion of technologies (Paper IV). Technologies fitting farmers' priorities particularly have a better likelihood of adoption through the social networks (Paper IV). This suggests that a technology development and extension system based on a participatory approach is important to help farmers get adequate information for rational adoption of technologies. It is recommended that further studies on the technologies developed in these studies be approached from the participatory research perspective. For upscaling, adoption and diffusion, there is a need for the technologies to be integrated into the extension system, social networks or both (see Table 1 below).

The technologies tested in this study, namely conservation agriculture and rainwater - harvesting management systems (Paper I), fertilizer microdosing (Paper II) and sequential application of packages of technologies (Paper III) were found to have several positive attributes. Except conservation agriculture, the other technologies increased yield and profitability compared to farmer's practice. Most of the technologies appear feasible options in the central Rift Valley to increase the agricultural productivity (Papers I - III). Despite the highly variable rainfall pattern, there is a fast-growing population that has caused a shrinking landholding size per a household. Pastures and fallow lands have turned into permanent cropland. Agricultural extensification had been taking place during the last three decades to increase agricultural productivity. Therefore, the development and extension of appropriate agricultural technologies is important to intensify the agricultural productivity on the smallholdings operating under the existing socioeconomic and agro-ecological settings (Paper IV).

Farmers are more interested in open pollinating and early maturing maize varieties for two reasons: 1) their seeds can be saved or recycled thereby reducing financial costs to buy seeds every cropping season; and 2) they can be grown in both favorable and unfavorable rainfall conditions. They are particularly farmers' choice when there is a late onset of rainfall, and their early maturity makes them escape the end-of-season cutoff rainfall (Paper IV). The poor socioeconomic and agro-ecological setting makes farmers prioritize low-cost, low-risk, and productive technologies. Farmers also prioritize technologies providing immediate agronomic and economic benefits (Paper IV). Technologies that require less technical knowledge are also farmers' preference. Most of the technologies developed in this research have these adoptable attributes (Paper II and III). Technologies such as fertilizer microdosing (Paper II), seed priming (Paper III) and minimum tillage (Papers I and III) are low cost and low risk, which can reduce farmers' financial constraints. Similarly, technologies such as mulching (Paper I and III), basins (Paper I) and seed priming (Paper III) can contribute towards addressing the impact of seasonal rainfall variability and soil moisture stress on maize production. Due to the frequent dry spells and droughts, and unreliable agrometeorological information, there is a high risk of partial crop failure or total harvest loss (Paper IV).

Farmers are reluctant to apply the recommended high fertilizer dose (Paper IV). The attractive agronomic and economic responses with the small quantities of fertilizer in microdosing (Papers II and III) could therefore encourage farmers to apply fertilizer to increase the productivity of maize (Paper IV). Small quantities of fertilizer under the microdosing was able to give the same yield as high fertilizer doses under the microdosing and the banding method. Importantly, such small quantities of fertilizer gave higher economic benefits than higher doses under both methods (Paper II). The use of such an efficient fertilizer application method could also increase the application of urea (Papers II and III), which is mostly lacking in the central Rift Valley (Paper IV). Most farmers apply DAP only (Paper IV). Only a few farmers apply urea fertilizers in maize due to high prices and inadequate information (Paper IV). Urea fertilizers increased agronomic and economic responses in maize (Paper III). In response to the variable rainfall, the national extension system also promotes the traditional *in situ* rainwater - harvesting and management, like ridging and furrowing, to increase the water-holding capacity of the soil and to improve infiltration (Paper IV). In this regard, the practice of mulching and digging basins (Paper I) can help to reinvent or further promote the existing innovation of the traditional *in situ* rainwater - harvesting and conservation methods (Paper IV). On top of that, various packages of minimum tillage, seed priming, mulching and the microdosing method of phosphorus and nitrogen fertilizer application appear to have positive prospects for boosting the productivity of maize (Paper III). The different options of technology packages can increase the productivity of maize at a low cost and at a low risk. This provides farmers different intensification scenarios depending on their resource endowments (Paper III).

The low agronomic and economic responses in conservation agriculture might be because these technologies were tested for only two years. Yet, minimum tillage with mulch was able to give promising benefits (Paper I). The competing use of crop residues for livestock fodder and domestic fuel, low agricultural productivity and the free grazing system are the central constraints to practicing conservation agriculture on open fields (Paper IV). Minimum tillage can be an alternative for farmers lacking sufficient traction power. It also could be an option for such farmers without mulch, in combination with seed priming and fertilizer microdosing (Paper III). Yet, mulching can be practiced in traditionally fenced small plots near the home for growing extra-early and early maturing maize varieties. Such a practice is used to fill severe food shortages during pre-harvest (Paper IV). The high labor demand for the fertilizer application in the microdosing method could be minimized using a two-finger approach. Farmers also recommended this approach as a more feasible option. A plastic cup was used in this study for measuring the rate of fertilizer to apply per planting station (Papers I - III).

Table 1. The major challenges farmers face and the possible alleviation strategies

Challenge	Possible alleviation strategies
1. Agro-ecological factor	
- Rainfall variability Recurrent drought and dry spells	- Use of seed priming, mulching, intercropping, traditional *in situ* rainwater - harvesting and conservation strategies
- Poor soil quality Low fertility Low water holding capacity	- Chemical and organic fertilizer application - Practice of mulching and traditional *in situ* rainwater - harvesting and conservation strategies
2. Socioeconomic factor	
- Financial constraints to buy inputs and - Subsistence production and food insecurity	-Development and extension of low-cost, low-risk, productive and profitable fertilizer application technology, e.g. fertilizer microdosing - Adequate supply system for improved seeds of maize and haricot beans that are recyclable - Application of organic fertilizers, e.g. compost and manure from locally available resources
3. Institutional factor	
- Inappropriate technology development and extension system, the top-down approach	- A shift to a participatory research approach for technology development and extension system - Establishment of efficient extension system, continuous training on new technologies to extension agents and farmers - Continuous assessments of transferred technologies, identifying challenges and opportunities for existing and new technologies - Promotion of intercropping of maize with pulse to diversify livelihoods and vulnerabilities
- Inadequate input delivery system	- Establishment of an efficient input delivery system, e.g. the use of farmer unions or cooperatives in close vicinity to farmers
- Inefficient fertilizer application method and high fertilizer rate recommendation	- Development and extension of socioeconomically and agro- ecologically adaptive technologies, e.g. microdosing, organic fertilizer, minimum tillage, seed priming, mulching and their various packages
- Inefficient application of DAP and urea	- Promotion of the benefits of a balanced application of DAP and urea fertilizers
- Instability of fertilizer, improved seed and grain market prices	- Arrangements of subsidies for fertilizers, improved seeds and grain markets, and ensuring the stability of market prices
- Absence of subsidies	- Improvement in farmers’ access to credit facilities and markets
- Poor infrastructure	- Improvement in rural road networks, better markets for agricultural produce, and access to inputs and other information
- Inefficient meteorological information	- Provision of reliable seasonal agrometeorological information

8.1 Tillage and water conservation methods and agronomic and economic responses

This subsection (Paper I) discusses the effects of conventional tillage and conservation agriculture on the volumetric soil moisture content, weed density, and agronomic and economic responses. It also discusses the effects of mulching and planting basins on the volumetric soil moisture content, weed density and agronomic responses.

Although the agronomic responses are lower, conservation agriculture plots tended to retain more soil water particularly towards the end of the growing season. Thierfelder and Wall (2009) also reported higher soil moisture levels throughout the season in conservation agriculture than in conventional tillage. In addition, the same authors suggest that conservation agriculture has a high potential for increasing rainwater productivity and, therefore, is able to reduce the risk of crop failure, particularly during the later growth stage of maize in Zambia. The effect of tillage methods on weed density, however, was low. Only during the second season at Melkassa was an effect on weeds observed. Here the weed density increased in the order of conventional tillage, minimum tillage and zero tillage.

Contrary to these positive tributes, conventional tillage gave higher yield and economic return than conservation agriculture. Conventional tillage increased the average grain yield by 13% to 20% and 44% to 55% over minimum tillage and zero tillage respectively across sites. Similarly, minimum tillage improved the average grain yield by 27% to 30% over zero tillage across sites. Field observations indicated the occurrence of severe temporary waterlogging and yellow-leaved and subtly grown maize stands in minimum tillage and zero tillage plots. Moreover, there was a slight increase in weed infestation in the same plots. Therefore, the higher waterlogging, slightly increased weed infestation and the short duration of the experimentation might be the most likely reasons for the yield depression in conservation agriculture. Giller *et al.* (2009) reports that yield losses or no yield benefits are likely to occur in conservation agriculture. Soil nutrient immobilization, increased weed competition and waterlogging can negatively affect crop production in conservation agriculture (Giller *et al.*, 2009) when practiced over the short-term. It was reported that conservation agriculture depressed maize yield compared to conventional tillage due to waterlogging when there is high rainfall (Rusinamhodzi *et al.*, 2011). In contrast to conservation agriculture, no waterlogging occurred under the conventional tillage, which may be one reason for farmers to practice repeated plowing in Ethiopia. Temesgen *et al.* (2008) reports improved infiltration as a reason for plowing more frequently in Ethiopia. The discussant farmers (Paper IV) stated similar reasons for practicing repeated tillage for most crops. Farmers also practice repeated tillage to control weeds.

The conventional tillage increased labor productivity by 28% and 90% over the minimum tillage and zero tillage respectively while the minimum tillage increased labor productivity by 48% over the zero tillage. In the conventional tillage, oxen energy is used for seedbed preparation, weeding, thinning and threshing, reducing shortage of labor during peak labor requirements (Paper IV). The conventional tillage was more profitable, increasing gross margin by 17% and 60% over the minimum tillage and zero tillage respectively, while the minimum tillage increased gross margin by 37% over zero tillage. A previous study also reported zero tillage having a lower gross margin than the conventional tillage in *teff* production in Ethiopia (Tulema *et al.*, 2008). Although the cost of seedbed preparation was much lower in minimum tillage and zero tillage, their higher cost of weeding constituted a major increase in production cost. As a result, farmers spent more days in minimum tillage and zero tillage weeding than in conventional tillage practice. It is reported that the lower cost of seedbed preparation is an immediate benefit of conservation agriculture (Fowler and Rockstrom, 2001). This current study also found similar results in the rental cost for the seedbed preparation which was 75% less in minimum tillage than conventional tillage. Owing to the reduction in tillage cost and the promising economic responses, minimum tillage may be an interesting option for farmers with a shortage of oxen traction power (Paper IV).

Weed density largely tended to decline when mulching was used across the sites. The suppression of weed incidence by mulching corresponds with the results reported on *teff* production in Ethiopia (Tulema *et al.,* 2008). Effective weed suppression by mulching in maize production has been documented (Uwah and Iwo, 2011; Essien *et al.*, 2009). The suppression of weed density by mulching can reduce the need for herbicides and save on labor costs for weeding. Herbicides are not only expensive but also environmentally hostile. Farmers need special training on herbicide application. The hiring of sprayers also adds to the cost for farmers (Paper IV). The practice of mulching was also able to retain more soil moisture at physiological maturity, one of the critical stages in maize growth that demands a considerable amount of soil moisture. It might have improved infiltration and minimized water evaporation from the surface of the soil, as was reported in an earlier study (Rockström *et al.,* 2009). The higher potential of mulching in conserving water at planting, flowering and physiological maturity, the critical stage in maize growth, might have a remarkable importance in making maize production more resilient to the recurrent rainfall variability in the central Rift Valley. Maize is critically affected by such rainfall events (Paper IV). On top of that, basins tended to capture more water at flowering and physiological maturity. The practice of mulching and making basins could be used as a supplement to the widely practiced traditional ridge and furrow system for *in situ* rainwater - harvesting in the central Rift Valley (Paper IV).

Mulching improved most of the agronomic properties (this was also addressed in Paper III). The relatively higher soil moisture content in mulched plots could be one of the most likely reasons for the improved agronomic characteristics, namely seedling vigor, uniformity, plant height, lodging, and plant population at harvest (this is in line with the results in paper III). As a result, the average grain yield increased by 23% to 33% and 14% to 19% in mulching over no mulching and the use of basins respectively. A previous study reports that mulching increased the biomass and grain yield of maize by 54% and 56%, respectively, compared to no mulching in the moisture-stressed areas in Ethiopia (Tenaw et al., 2002). Mulching increases maize yields through conserving soil moisture and enhancing water infiltration (Adeniyan et al., 2008). Therefore, mulching may increase the productivity of maize (this is in line with the results in Paper III).

One of the challenges with the practice of conventional tillage is the high oxen rental cost (US$ 11 ha^{-1} for one time strip, which is a pressing challenge for farmers lacking sufficient traction power. The discussant farmers (Paper IV) stressed the same issue. Such farmers are often unable to meet the brief window period for planting maize. They have to work for two to three days for the oxen owners in return for traction power for one day on their own farm. Another option for such farmers is to practice sharecropping or rent out farmlands to others when they are unable to get the traction power. The promising agronomic and economic responses from conservation agriculture, particularly minimum tillage and mulch (this was partly addressed in Paper III and similar results were obtained) might therefore be an option for farmers lacking sufficient traction power. However, the practice of mulching on open fields is constrained by the low crop biomass, alternative use of mulch as livestock fodder, free grazing, and ignorance of the importance of conservation agriculture and mulching (this was also addressed in Paper IV and similar results were obtained). Previous studies indicate that critical constraints in adoption appear to be competing use of crop residues (Giller *et al.*, 2009), and the farmers' ignorance of the benefits conservation agriculture can have in Ethiopia (Kassie *et al.*, 2009). The widespread free grazing after crop harvest remains a major challenge to practicing mulching on open fields even under high yields. Conservation agriculture could fill a particular niche here. It might still be practiced on traditionally fenced small fields adjacent to homes. Farmers make such fences for growing vegetables and extra-early and early maturing maize to fill a severe pre-harvest food shortage and to generate income from selling green cobs. Further studies regarding how to incorporate mulching into the farming system is needed.

8.2 Fertilizer application methods and rates, and agronomic and economic responses

This subsection (Paper II) discusses the effects of the fertilizer application methods of microdosing and banding on the agronomic and economic responses in maize. It specifically discusses the yield response and the fertilizer use efficiency, profitability of fertilizer application and the value cost ratio of fertilizer application (this was also partly treated in Papers III and IV and similar results were obtained). These responses were compared to farmers' practices. The microdosing method was also used for the fertilizer application in studies conducted under Papers I and III. The banding method of fertilizer application was also studied in Paper IV.

In Ethiopia the national fertilizer recommendation is 100 kg DAP ha^{-1} at planting and 100 kg urea ha^{-1} at maize knee height or a split. However, farmers seldom follow this recommendation due to high fertilizer cost, shortage of fertilizer supply, inefficient fertilizer application technology and insufficient training in fertilizer application. The DAP is used as a phosphorus and nitrogen fertilizer while urea is used as a nitrogen fertilizer. The failure to apply the recommended rate and the failure to use DAP and urea in proper combinations (also investigated in the study under Paper IV where similar results were obtained) made the effect of fertilizers marginal. The existing fertilizer recommendation is from the early 1990s and is largely out-of-date and not tailored to agro-ecology, soil type and climate. Such low technical efficiency led to non-optimal fertilization and marginal effects on crop production in Ethiopia (Spielman *et al.*, 2010). Proper fertilizer management, use of improved varieties, and adaptation of input application rates, according to soil fertility gradients, are important. Thus, adjusting for site-specific soil conditions are a requirement for maximizing agronomic efficiency (Vanlauwe *et al.*, 2011; Vanlauwe and Giller, 2006).

This study compared the agronomic and economic response of different rates of microdosing of fertilizer to the recommended rate when fertilizer is applied according to the banding method. The treatments were: control without fertilizer, microdosing treatments with 27 kg ha^{-1} DAP + 27 kg urea ha^{-1}, 53 kg ha^{-1} DAP + 53 kg urea ha^{-1}, and 80 kg DAP ha^{-1} + 80 kg urea ha^{-1}; and banding treatment with 100 kg DAP ha^{-1} + 100 kg urea ha^{-1}. DAP was applied at planting while urea was applied at knee height. This shows that the lowest fertilizer rate under the microdosing method is 73% less than the fertilizer rate under the banding method. Irrespective of the spatial variability in the rainfall pattern and soil quality in the three study sites, all the fertilizer rates were able to increase maize yields compared to the control. This indicates that there is a need to apply DAP and urea fertilizers to the soil in all the sites. The lowest microdosing rate gave similar yields to the banding rate. This rate increased maize yields by 19%, 45% and 46% at Hawassa, Ziway and Melkassa respectively, over the control. Previous studies have shown that microdosing is an efficient way to apply fertilizers in SSA countries (Aune *et al.*, 2007; Aune and Ousman, 2011; Hayashi *et al.*, 2008). The relative yield response to fertilizer at Hawassa was lower, which might be due to its relatively better soil quality, rainfall events and longer growth season.

There is a limit as to how much fertilizer can be applied under microdosing. In this regard, the 80 kg ha^{-1} DAP + 80 kg urea ha^{-1} depressed pocket seed germination and lowered plant stand population at harvest. This effect might be attributed to the burning effects of high doses of fertilizer, also regarded as a salt effect. A previous study reported that higher doses of fertilizer in microdosing application may have a burning effect on seed germination and other growth stages (Aune *et al.*, 2007). Unlike higher doses of fertilizer under microdosing, the higher doses of fertilizers in the banding method was found to have a lesser burning effect. This might be attributed to the lower concentration of fertilizer adjacent to the seeds in the banding application method. The distance between fertilizers and seeds is shorter in the banding method as the fertilizer is spread along the line of sowing maize. Despite the burning effect, higher fertilizer rates have higher cash outlay and are more risky. This increases farmers' reluctance to apply fertilizers. This high fertilizer rate can be one of the reasons why farmers in Ethiopia generally apply lower rates of fertilizer (Abegaz and van Keulen, 2009). Spielman *et al.* (2011) report that the average amount of fertilizer used by farmers in Ethiopia is 21 kg N ha^{-1}, which is much lower than the nationally recommended rate (Debelle *et al.*, 2001).

Fertilizer microdosing gave higher fertilizer use efficiency (kg grain kg^{-1} fertilizer), value cost ratio and gross margin (US$) relative to the recommended rate. The fertilizer use efficiency value varied from 5 to 23 at Hawassa, 11 to 34 at Ziway and 10 to 31 at Melkassa for the different doses of fertilizer under microdosing. For the banding rate, the fertilizer use efficiency values were 7, 9 and 8 at Hawassa, Ziway and Melkassa, respectively. These values were mostly lower than the different fertilizer doses under the microdosing method. Other studies in Ethiopia indicated a nutrient use efficiency (kg grain yield per kg nutrient) of maize ranging between 9 and 17 (Heisey and Mwangi, 1996). The fertilizer use efficiency decreased with increasing fertilizer doses. Thus, the lowest rate gave the maximum fertilizer use efficiency across sites. On top of that, the lower fertilizer rates with the microdosing improved the value cost ratio, decreasing the level of risk of fertilizer application. To minimize the risk of fertilizer application, a value cost ratio above two and preferably above four is needed under condition of risk as in the Sahelian region (Koning *et al.*, 1998). The value cost ratio ranged from 1 to 7 at Hawassa, 3 to 11 at Ziway and 3 to 10 at Melkassa under the fertilizer microdosing method. Studies conducted in Sudan and Mali in pearl millet and sorghum reported that the value cost ratio of fertilizer microdosing is generally very favorable (Aune *et al.*, 2007; Aune and Ousman, 2011). In Ethiopia, studies conducted between the 1980s and 2000s reported a value cost ratio ranging from 2.5 to 9 for fertilizer in maize (Meertens, 2006). Besides, the case studies conducted by Sasakawa Global 2000 fertilizer promotion programs reported a value cost ratio of 9 in maize in the mid-1990s in Ethiopia (Howard *et al.*, 2003). The value cost ratio obtained from the banding at 100 kg DAP ha^{-1} + 100 kg urea ha^{-1} and microdosing at 80 kg DAP ha^{-1} + 80 kg urea ha^{-1} was around the threshold. The economic return to the recommended fertilizer application rate has been generally positive in recent years in Ethiopia, with a value cost ratio around the threshold of two (Dorosh and Rashid, 2013). The recommended banding rate appears less attractive to farmers due to high risks and high cash outlays.

The lowest rate of 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} was able to generate a higher gross margin than the 80 kg DAP ha^{-1} + 80 kg urea ha^{-1} and banding dose (except at Hawassa), and control. This shows that the application of small quantities of fertilizer with the microdosing method is more profitable than the application of large quantities under banding methods. The highest increase in gross margin over the control was 13%, 53% and 42%, at Hawassa, Ziway and Melkassa respectively. The higher yield, fertilizer use efficiency, value cost ratio, and gross margin responses of the 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} could attract farmers' investment in fertilizers. Contrary to Ziway and Melkassa, the banding method did not improve gross margin over the control at Hawassa due to lower response to fertilizer. Lower fertilizer use efficiency and value cost ratio were also obtained from higher fertilizer rates under the microdosing method and the banding method at Hawassa. The more favorable soil quality, seasonal rainfall, and longer growing season at Hawassa are the most likely attributes. This indicates that under such favorable growth conditions, farmers can still get reasonable maize yields without applying fertilizers.

Affordable fertilizer rates could increase farmers' interest in fertilizer investment, increase economic viability and ensure sustainability of fertilizer application in crop production. Such rates can also increase the adoption and diffusion of the fertilizer-improved technology package being promoted by the extension system (Paper IV). For the poorest farmers, it would be far less risky to use the 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} applied as microdosing than the banding method. This fertilizer rate was found to be low cost, low risk, productive and profitable across sites. Such rate appears more attractive for resource-poor smallholding farmers (Aune and Ousman, 2011; Aune *et al.*, 2007; Hayashi *et al.*, 2008). The 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} can also promote the application of both DAP and urea in maize, which is mostly lacking in the central Rift Valley (Paper IV). Furthermore, in such a risk-prone environment the microdosing method appears to be of particular interest to farmers who can afford to buy only small quantities of fertilizer. Earlier studies conducted in the central Rift Valley indicated that unpredictable climatic conditions constrain the investment in fertilizers (Kassie *et al.*, 2013; Biazin and Sterk, 2013).

Although the labor demand in microdosing (4.8 man-days ha^{-1}) is twice that of banding (2.3 man-days ha^{-1}) for the application of fertilizers, the microdosing method still appears attractive and viable. The large family size and low opportunity cost in the areas may lessen the labor demand in ways not affecting children's school time. Children are involved in agricultural activities, such as weeding and harvesting after-school hours, usually late in the afternoons and over weekends. Moreover, the wide use of animal traction power in most of the agricultural activities reduce the labor shortage during critical seasonal agricultural operations, such as seedbed preparation, planting, thinning and weeding. Animal traction, like most mechanical technologies, is primarily a substitute for labor. Rather than labor, farmers give more emphasis to yields (Paper IV). Since the use of the microdosing method is a new way of fertilizer application, the upscaling of microdosing would be more efficient if it becomes part of the national agricultural extension system. To implement the technical change, farmers and extension workers must be trained. More research is needed in order to identify the most appropriate rates under different agro-ecological conditions.

8.3 Sequential application of technologies and agronomic and economic responses

This study (Paper III) evaluated how low-cost and low-risk packages of technologies could increase the productivity of maize within farmers' socioeconomic capacity and existing agro-ecological settings. This subsection, therefore, discusses the agronomic and economic responses in maize of various packages of minimum tillage and seed priming, application of DAP fertilizer, surface mulching and application of urea fertilizer. It specifically discusses the responses to maize yield, fertilizer use efficiency, fertilizer profitability and risk of applying DAP and urea under the various packages of the technologies. Following the ladder approach (Aune and Bationo, 2008), a technology was added to each level of the ladder at a time to assess the additional productivity gains. The existing improved maize-fertilizer technology package is a high-input system. Both fertilizers and improved seeds are expensive to most farmers. The technologies minimum tillage, seed priming and mulching have the potential of making maize production more resilient to the variable rainfall in the central Rift Valley. On top of that, the packages could indicate the importance of applying balanced DAP and urea fertilizers as well as the combined effects of DAP and urea with mulching and seed priming to further enhance the productivity of maize.

Although the first step on the ladder, which is a package of minimum tillage and seed priming, did not improve yields, it improved yield characteristics such as days to emergence, seed germination, seedling vigor, and days to tassel and maturity. Previous studies indicated that seed priming promotes seed germination, yield, and yield attributes (Aune and Ousman, 2011; Harris et al., 1999) and can be used as a strategy to mitigate the impacts of climatic variability on maize production (Harris et al., 1999). Seed priming did not increase yield, which might be due to non-fertilization. In the next step, the application of DAP fertilizer improved yield and most of the yield characteristics. It appeared that seed priming and microdosing are compatible in boosting maize yield and its attributes. Previous studies also indicated that a package of fertilizer microdosing and seed priming is an efficient way to improve crop productivity in dryland agriculture in the SSA (Aune and Ousman, 2011; Aune and Bationo, 2008; Aune *et al.*, 2007). Therefore, a productive package of technologies involving seed priming and microdosing could be an opportunity for poor farmers to increase the productivity of maize. The package of minimum tillage, seed priming and microdosing, all potentially low cost and low risk, could be an option, particularly to farmers lacking sufficient traction power. This package exclude mulching and is therefore unaffected by the widely practiced free grazing in the central Rift Valley.

Then in step 3, the addition of mulching to microdosing and seed priming further improved most of the yield characteristics and yields. Mulching was reported to have a high potential for improving maize yields in the central Rift Valley (Paper I). Technologies related to rainwater - harvesting are nonexistent; farmers use the traditional ridge and furrow system for rainwater - harvesting and *in situ* conservation (Paper IV). In the final step, the application of urea fertilizer further improved the yield characteristics and yields, demonstrating the significance of applying urea in maize production. In Ethiopia, due to the high prices of fertilizer and insufficient training, the application of urea in cereal production is low compared to the application of DAP (Dorosh and Rashid, 2013). The number of farmers applying fertilizer to maize is very low. Due to the high price, most farmers use only DAP fertilizer. A balanced DAP and urea fertilizer application is absent (Paper IV). Therefore, the high agronomic response to applying small quantities of urea fertilizer could perhaps motivate farmers to apply urea in maize production. Most of these technologies are low-cost, low risk and increase yields. Overall, the various packages of minimum tillage, seed priming, application of DAP fertilizer, mulching and application of urea fertilizer were able to improve crop establishment, and grain and stover yield. Some of these technology packages could also be used as a mitigation strategy to the increasing rainfall variability in the central Rift Valley (Kassie *et al.*, 2014). Apart from that, the different technology packages could offer farmers different options based on the economic capacity of a farmer, feasibility of a package, and expected seasonal rainfall.

A value cost ratio above four is required in order to have an acceptable level of risk in dry-land areas, such as the Sahel (Koning *et al.*, 1998). In this regard, the results from this study showed that it is economically attractive for the farmers to use any one of the different packages of the technologies. There is normally a distinct drop in the value cost ratio as the level of inputs increases, but in this study, the value cost ratio was maintained above the acceptable level of four even with an increasing level of inputs. Acceptable value cost ratios in the application of such microdose of fertilizers in the central Rift Valley was reported (Sime and Aune, 2014). In this regard, the contribution of microdosing, seed priming and mulching could have been substantive. A similar study conducted in the central Rift Valley indicated that agronomic and economic responses to fertilizer application could be enhanced by applying small quantities of fertilizers through the microdosing method (Paper II). In Ethiopia, despite the considerable use of inputs and efforts to improve the agronomic and economic benefits of fertilizer application, low technical efficiency in the application of fertilizer is a factor affecting agricultural productivity (Spielman *et al.*, 2010). International Food Policy Research Institute (IFPRI) reports that inappropriate fertilizer application may be yielding negative economic returns for many farmers, limiting its use (IFPRI, 2007).

Except at the lowest level of the ladder, gross margin increased with increased levels of inputs in an almost similar way as the yields. Likewise, production costs increased with increasing levels of inputs, but the income generated increased more than the cost. Labor costs tended to increase with increasing levels of inputs.

8.4 Agronomic technologies and their adoption and diffusion

This is a case study (Paper IV) based on qualitative data, supplemented by quantitative studies. This section therefore discusses stakeholders' viewpoints on transferred technologies, technology characteristics in relation to agro-ecological and socioeconomic settings, existing technology development and the extension system and the challenges and opportunities to technology adoption and diffusion in the central Rift Valley.

The viewpoints indicated that institutions promote traditional rainwater harvesting, row sowing, intercropping, fertilizer application, improved seeds, and *in situ* rainwater - harvesting and conservation. These interventions are in line with farmers' interests and priorities. Farmers claim that traditional ridges and furrows, row sowing, row fertilizer application, intercropping and improved varieties of maize and haricot bean give immediate agronomic and economic benefits. These attractive and adoptable attributes enhanced the adoption and diffusion of these technologies. This suggests that similar technologies (Papers I - III) could have a high likelihood of adoption and diffusion.

The national extension system hardly complies with the technology development process (Rogers (2003) that is characterized by the five stages of knowledge acquisition, persuasion, decision, implementation and confirmation. The existing technology adoption-decision process starts commonly with the implementation and proceeds with the confirmation. Moreover, adoption and diffusion procedures commence concurrently in the form of campaigns. In such a system, the distinction between adoption and diffusion is lacking. Earlier studies indicated that although adoption and diffusion are closely interrelated, they are conceptually distinct. The unit of analysis in adoption studies is an individual decision maker whereas that of diffusion is the cumulative adoption path or distribution of adoption over time or space with the community, region, or nation (Rogers, 2003).

Transfer of technologies to farmers occur mainly through the national extension systems, which can be characterized as a rather top-down model for technology transfer. Often not sufficient information is provided to the farmers. . However, Rogers (2003) indicates that adequate information is a key factor to technology adoption-decision and dissemination. The existing trend shows that the extension agents are often given limited training on how to assist farmers in adopting technologies. The inadequate knowledge of the extension workers frequently leads to a large yield gap between the yield on-research stations and the actual yield farmers finally harvest from their fields. Such inefficiencies has fostered farmers' risk-averse behavior, reluctance, and skepticism to a full package technology adoption and diffusion. Earlier studies indicate that communicating adequate information to potential technology adopters is a key factor in promoting adoption behavior (Bandura, 1977; Rogers, 1995; Rogers, 2003; Adesina and Zinnah, 1993). Farmers stated that they prefer a technology development and extension system where they share knowledge and make decisions. The five attributes that Rogers (1995) have identified as important in technology adoption (relative advantage, compatibility, complexity, trialability, and observability) appear also to be relevant in the Rift Valley. Such attributes could easily facilitate technology adoption and diffusion, particularly through social networks.

Agricultural research centers and universities also work on technology development. They usually collaborate with district agriculture offices, extension workers and farmers. Such technology development is based on experimenting on farmer fields and up-scaling best farmers' practices. Considering local conditions, such a technology development attempts to follow the five stages in technology adoption and diffusion developed by Rogers (1995). This approach makes farmers and extension workers active participants in the technology development, and enhances farmers' and extension workers' knowledge of technologies. The challenge with the adoption and diffusion of such technologies is that they are often not integrated into the national extension system due to a poor link to the national extension system. Rather, depending on their adoptable attributes, such technologies are usually more disseminated through social networks.

Farmers also acquire information from social networks, such as peers, neighbors, relatives, and social media. This is a traditional information-sharing system for social learning. Such social learning is the reason for the extensive adoption and diffusion of haricot bean and mid-maturing hybrid maize varieties. The national extension system hardly supports the use of these crops, particularly mid-maturing hybrid maize varieties. This show that farmers take up new technologies even though the conditions are not ideal and the extension service is not delivered to farmers according to Rogers' principles. Farmers also integrate formal and informal information to acquire adequate information on available technologies. This is the reason for the widespread adoption and diffusion of the row sowing, banding fertilizer application, early- maturing maize varieties and the traditional *in situ* rainwater - harvesting practices. Because of inadequate information, a large number of farmers were originally very skeptical towards the introduction of row-sowing and row-fertilizer-application. Broadcasting had been the popular method for fertilizer-application and sowing maize. In terms of the labor requirement, broadcasting is a cheaper method of seed-sowing and fertilizer-application, but is less efficient than the row method.

Farmers use markets, late afternoons, holidays as well funeral and wedding ceremonies for the traditional information-sharing. Most of these social gatherings give plenty of opportunity for information-sharing on new or existing technologies. People at such gatherings may come from quite different places and have different exposures, backgrounds and knowledge. This is in agreement with earlier reports that farmers have the tradition to listen to one another (Rogers, 2003; Rogers, 1995). Most of these farmers' behavior also fit the social-learning perspectives reported in previous studies (Rogers, 1995; Rogers, 2003; Bandura, 1977). When social gatherings are held in the cropping season, there is a tradition that farmers observe the performances of new technologies on other farmers' fields. Adoption of an innovation is a social process in which learning of new practices occurs both in formal and informal settings through sharing information, observation, imitation, or as a normative action (Rogers, 1995).

Farmers have various constraints to technology adoption and diffusion and are barely able to exploit the full potential of adopted technologies. There is inadequate agrometeorological information, volatile market prices of fertilizers and a shortage of improved seeds, and unstable market prices of grains. Among other factors, affordability of inputs is one of the key constraints to technology adoption and diffusion. Subsidies for fertilizers and improved seeds and grain markets are lacking. Although farmers show increasing interest in the package of improved seeds-fertilizer, their high prices are a major limitation to their effective adoption and diffusion. For instance, the average market price for one kg of first-generation improved-hybrid maize was 1.3 US$ during the 2013/14 cropping season. During the same period, the average market price for one kg of DAP or urea was approximately 0.84 and 0.74 US$ respectively. This fertilizer price is three times higher than the average market price for one kg of maize, which is approximately 0.25 US$. Approximately three kg maize grain is required to pay for one kg of DAP fertilizer. This suggests the urgency for adaptive and efficient fertilizer application methods that use small quantities of fertilizer to enhance fertilizer use efficiency, maize productivity, profitability and reduced risk of investment in fertilizers (discussed in Papers II and III). The other constraint that makes planning of agricultural activities difficult is the volatility of the grain market price. For instance, the price for one kg maize varied approximately between 0.25 US$ at harvest and 0.37 US$ at planting. Due to financial constraints, farmers often sell out their agricultural outputs at the lowest price immediately after harvest when local markets are already saturated and they cannot wait for profitable market price peaks. Kassie *et al.* (2013) underlines the importance of addressing constraints related to technology, and market-access. Above all, the variable rainfall coupled with the absence of reliable agrometeorological forecasts halted the agronomic and economic response to the improved seed- fertilizer package. These challenges increased farmers' reluctance to use the package at planting, particularly when they are unable to get reliable forecasts on the seasonal rainfall. Thus, climate-proof strategies including better seasonal climate forecasts (Hansen *et al.*, 2007), adaptive varieties, efficient rain-water management (Biazin *et al.*, 2012), and proper agro-advisory services and input supplies (Kassie *et al.*, 2014) are critical to improving the predominantly rain-fed agriculture in the central Rift Valley. In addition, the use of small quantities of fertilizer as in microdosing can be an option that is low cost, low risk, productive and profitable to the farmers (Papers II and III). These challenges reduced the efficiency to maximize the utility of adopted technologies, leading mostly to partial adoption.

In recent years, Ethiopia has given increased attention to the extension system, improved seed, natural resource management and agricultural productivity (Byerlee *et al.*, 2007; Diao *et al.*, 2007). Apart from that, it has recently been pursuing an agricultural production intensification approach to boost crop productivity on the smallholdings through the application of modern agricultural inputs, primarily improved varieties, fertilizer technologies and improved agronomic practices (Alemu *et al.*, 2008). As part of achieving the GTP goals, the agricultural experts and the extension workers stressed that the amount of training and attention given to the extension service have recently been increased. The number of farmer unions supplying improved seeds and fertilizers has also increased. These favorable production conditions might boost the agricultural productivity in Ethiopia in the future.

9.0 Implications in the context of crop production in semi-arid Rift Valley

Fertilizer - microdosing, minimum tillage, mulching, and seed-priming are promising technologies for increasing the agronomic and economic benefits in maize production. The different packages of these technologies could be interesting for farmers since they are low-cost, low-risk, productive and profitable. The different technologies have the potential to address the major agro-ecological and socioeconomic settings in the central Rift Valley:

- The fertilizer microdosing can be a chosen method for fertilizer application as a low-cost, low-risk and profitable technology (Papers II and III).
- The high fertilizer use efficiency and low risk level with small quantities in the microdosing method can increase farmers' willingness to buy fertilizer and enhance a balanced application

of DAP and urea fertilizers. This is particularly important for farmers who are able to buy only a small quantity of fertilizers (Papers II and III).

- The seed priming technology can be practiced without any external constraints. It can be used as a strategy to cope with the impact of variable rainfall on maize production (Paper III).
- The practice of mulching is actually constrained by free grazing and competition for maize stalks for fodder and thus requires more institutional attention and future study. Yet, it can be practiced in the vicinity of homesteads (Papers I and IV).
- Minimum tillage in combination with seed priming and fertilizer microdosing can be an alternative for farmers who lack sufficient traction power (Paper III). This practice is unaffected by the uncontrolled grazing practice in the Rift Valley.
- The practice of traditional *in situ* rainwater-harvesting of ridging and furrowing can be used to cope with variable rainfall events (Paper IV).
- Intercropping of maize with pulses can be used as a strategy to cope with rainfall variability, diversify nutrition, and improve soil fertility and income (Paper IV).
- An adequate extension system and/or social network, with affordable inputs prices and delivery system, stable output market prices, and reliable agrometeorological information, among others can contribute towards enhanced technology adoption and diffusion, and efficient utilization of adopted technologies (Paper IV).

10.0 Conclusion

Maize production is rain-fed dependent and is the basis of farmers' livelihood in the central Rift Valley. It is the most important source of food and fodder. Therefore, increasing the productivity of maize is important to improve farmers' income and food security. Nevertheless, farmers are resource-poor, subsistent and operate under high rainfall variability and poor soil quality. Frequent dry spells and droughts as well as severe soil moisture stress, poor water-holding capacity, and poor fertility of the soil are the primary agro-ecological factors affecting maize production. Moreover, financial constraints to buy improved seeds and fertilizers, absence of subsidies for improved seeds and fertilizers, inadequate input delivery system and the instability of output market prices are among the socioeconomic factors affecting maize production. These hurdles have caused skepticism towards the use of expensive and high-risk technologies. Consequently, farmers prefer low-cost, low-risk and productive technologies. They prioritize technologies with immediate benefits and with prospects of alleviating the impacts of rainfall variability and poor soil quality on crop production.

Technologies are transferred to farmers through the national extension system, social networks or various combinations of these systems. Improved agronomic practices such as row sowing, row fertilizer application, intercropping and traditional *in situ* rainwater-harvesting techniques are farmers' preferences as they give higher and immediate agronomic and economic benefits. Most of these technologies do not demand complex technical skills. Among the crop species and varieties prioritized by farmers are open pollinating and hybrid maize, and haricot bean varieties.

Farmers choose maize varieties depending on the onset of the rainy season. The open pollinating varieties are extra-early and early maturing while the hybrid maize varieties are mid-maturing. The haricot bean varieties are extra-early maturing. Accordingly, extra-early and early maturing maize varieties are preferred in seasons with low rainfall, more variable or late onset of rain whereas mid-maturing maize varieties are farmers' preference in seasons with favorable rainfall conditions. The seeds of open pollinating maize are recyclable. Such recyclable seeds reduce farmers' costs because they do not have to buy seeds every cropping season. Most of the technologies that are adopted are part of the national extension system. Regardless of sources, social networks can also substantially promote the adoption and diffusion of the productive and profitable technologies. They are particularly vital for the adoption and diffusion of productive technologies that are not integrated into the extension system. Whenever possible, farmers use information from both institutions and social networks to select agricultural technologies.

The short-term agronomic and economic benefits of conservation agriculture is apparently lower than the conventional tillage. In this study too, conservation agriculture has lower yield and labor productivity than conventional tillage. Nevertheless, it may still be an interesting option for farmers lacking sufficient oxen traction power. In particular, minimum tillage gave promising agronomic and economic returns. Mulching and planting basins tended to increase soil moisture retention, which could make maize production more resilient to the recurrent dry spells and soil moisture stresses. Nevertheless, the practice of mulching and digging basins are constrained by the widely practiced open grazing on stubble after harvest. They can still be an option on small plots in the vicinity of homes, which are traditionally fenced for growing extra-early and early maturing maize varieties for supplementing severe food shortages during pre-harvest. Mulch is also constrained by competition for maize stalk for livestock fodder. Therefore, there is a need to further study how to better integrate crop residues into the maize production system. Apart from that, as this is a short-term experiment over two sites, further studies on conservation agriculture's agronomic and economic responses as well as the adaptability to the existing local settings are important. Medium to long-term studies are required in order to make a thorough assessment of its adaptability to local conditions.

Fertilizer microdosing was found more agronomically and economically efficient than the banding method. The microdosing places fertilizer more precisely adjacent to the seeds. This contributes to the high fertilizer use efficiency and high value cost ratio of fertilizer application. Farmers use row application for DAP fertilizers at planting. The row application places fertilizers in the entire row. It is waste of fertilizer, which could be a reason for its lower fertilizer use efficiency and lower value cost ratio. The recommended banding method uses a higher quantity of fertilizer than microdosing. The lowest microdosing rate that was 73% lower than the recommended rate under banding, but still gave similar maize yield as the banding method. However, it increased the profitability and reduced the risk of fertilizer application. This shows that the microdosing method may not increase yield but could increase the economic benefits of fertilizer application. It could reduce cost and risk, and make the fertilizer application more attractive for farmers. Fertilizer microdosing could be an interesting option for farmers those who can only afford to buy small quantities of fertilizers.

Different packages of minimum tillage, seed - priming, fertilizer microdosing and mulching gave promising agronomic and economic benefits in maize production. These technologies were packaged and sequenced according to the ‘ladder approach’ where the different levels of the ladder represent the different technology packages. The number of technologies or complexity of the technology packages increases with the increasing levels in the ladder. The ladder, therefore, shows the relationship between technologies and agronomic and economic responses. Production costs increased weakly with the increasing levels of inputs, while the output returns increased robustly. Gross margin and fertilizer use efficiency increased with increasing levels of inputs. The package of microdosing, seed - priming and mulching reduced the risk of fertilizer application through increasing the value cost ratio. It was also able to maintain a high value cost ratio even at the highest level of intensification. Crop establishment and reduction of time to maturity improved with increasing inputs. In this regard, the inclusion of seed - priming and mulching in the packages might have contributed substantially. As a result, the different packages, although the degree may vary, could be able to mitigate the impact of rainfall variability and soil moisture stress on maize production. The various packages of these technologies become low cost, low risk, productive, profitable and adaptive to existing agro-ecological and socioeconomic setting in the semi-arid lands.

The findings from the four papers complement each other in addressing the major local specificities affecting maize production and farmers' livelihoods in the central Rift Valley. They all emphasized increasing the productivity of the recommended early maturing maize varieties. Overall, the findings obtained from this study could have an important contribution towards intensifying the productivity of maize. The different technologies could provide promising prospects with regard to yield, profitability, fertilizer use efficiency, riskiness and adaptation potential to existing agro-ecological and socioeconomic settings in the central Rift Valley in Ethiopia. Promotion of the technical knowledge of farmers, extension workers and institutions is important for the adoption and diffusion of the technologies. These stakeholders played positive and active roles during the development of most of the technologies. There is currently a strong interest in Ethiopia in promoting agricultural productivity, particularly in relation to achieving the second five-year’s Growth and Transformation Plan (GTP) and remaining MDGs goals. The findings obtained from these studies could also attract researchers and policy makers for further investigation and/or integration of these technologies into the extension system, social networks or both.

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Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia

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ABSTRACT

In response to the intensive tillage in maize, operating under high seasonal rainfall variability, this study examined the agronomic and economic responses of tillage and water conservation management in the central rift valley (CRV) of Ethiopia. An experiment was laid out as a split plot design with conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) as main plots and mulch, no mulch and planting basin as subplots. The MT and ZT were considered as conservation agriculture (CA) plots. Results showed that CT had 13–20% higher grain yield than MT and 40–55% higher than ZT; and MT had 27–37% higher yields than ZT. Mulching had 23–33% and 14–19% higher grain yield than no mulch and planting basin respectively. The CT had 28 and 89% higher labor productivity and 6 and 60% higher gross margin than MT and ZT respectively. The MT had 37% higher gross margin than ZT. The highest yield response in CT resulted in its highest gross margin and labor productivity. This shows that regardless of water conservation management, CT yielded better agronomic and economic responses over CA. However, the practice of CT is highly constrained by the availability of draft power and the short window period for planting. Likewise, regardless of tillage management, mulching tended to be more attractive and promising in suppressing weed density and hence reducing labor demand for weeding, despite improving volumetric soil moisture content and maize yield. Yet the viability of practicing mulching is highly constrained by the widely practiced open grazing on stubble after harvest. Therefore, future studies are needed to further identify appropriate tillage and water conservation management which make maize more resilient to the high rainfall variability, and sustainably improve food security, and farmers' livelihoods in the CRV of Ethiopia.

1. Introduction

Crop production in Ethiopia is characterized by intensive tillage (Goe, 1987; Temesgen et al., 2008), low productivity due to soil degradation (Oicha et al., 2010) and inefficient use of water resources (Kassa, 2008). The high dependence of Ethiopian agricultural on rainfall makes smallholders' livelihoods highly vulnerable to climate variability (Deressa and Hassan, 2009). The soil in Ethiopia is ploughed by a traditional plough (locally called Maresha), which is pulled by a pair of oxen (Araya et al., 2012; Goe, 1987). Farmers plow their land from two to six times per planting depending on the crop that is to be planted (Aune et al., 2001). Among the major reasons for practicing intensive tillage are to prepare the seed bed, conserve soil moisture, reduce weed infestation, warm soil and increase productivity (Temesgen et al., 2008). However, repeated tillage has been reported to be the main cause of land degradation in Ethiopia (Araya et al., 2012; Nyssen et al., 2011; Temesgen et al., 2008). Complete removal of crop residues at harvest for domestic fuel and livestock fodder, and open grazing after harvest are additional factors causing land degradation (Girma, 2001). On other end, oxen rental cost for tillage is high and unaffordable to most farmers in Ethiopia (Aune et al., 2001) despite the low access to oxen particularly during peak time of planting. In the central rift vally (CRV) of Ethiopia, the repeated tillage at the shallow depths (13–16 cm) is often found to form plough pans below the plough layer (Biazin et al., 2011; Biazin and Sterk, 2013), which needs continuous manipulation (Temesgen et al., 2008; Biazin and Sterk, 2013) in order to increase infiltration and crop establishment. On other hand, intensive tillage increases evaporation of moisture from the soil surface, increasing vulnerability of crop to drought (Biazin and Sterk, 2013) particularly during dry and low rainfall season. Daily soil moisture evaporation was found to increase with the duration of cultivation with the Maresha showing that long-term Maresha cultivation, for

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instance, makes maize crop more vulnerable to drought and dry-spells in the CRV. As a result, an improved soil management and development of appropriate tillage which maximizes the rainwater use efficiency for achieving more sustainable crop production in the drought prone CRV of Ethiopia has been suggested (Biazin et al., 2011).

The CRV where this study was undertaken was previously a pastoral area covered by dense woodlands and without permanently cultivated land before the 1950s (Biazin et al., 2012; Garedew et al., 2009). In recent decades, however, it has been converted to cereal-based mixed farming system with maize as the major staple crop (Biazin and Sterk, 2013; Kassie et al., 2013). The rainfall exhibits high intra-seasonal variability with a coefficient of variation of 15–40%, and temperature increased significantly (0.12–0.54 °C per decade) over the past 30 years (Kassie et al., 2014), which imply severe challenges to the rain-fed crop production (Kassie et al., 2014; Biazin and Sterk, 2013). In response to the variable climatic conditions, this study tested early maturing, drought tolerant and nitrogen-use efficient variety of maize (*Zea mays* var. Melkassa-II) as an alternative to the mid and late maturing maize varieties used by the local farmers. Recently, due to change in the cropping calendar and variability in rainfall, the mid and late maturing maize varieties become highly vulnerable to early termination of rain in September in the cropping season (Biazin and Sterk, 2013). In the CRV, adopting the cropping calendar to the prevailing weather, and using drought-tolerant crop varieties were suggested to be among the main strategies for future adaptation to the current climate variability (Kassie et al., 2014). In experiments conducted in the Sudan Savannas in Northeast Nigeria, it was found that early-maturing cultivars of maize can escape droughts and provide yield even during years with below-average precipitation (Kamara et al., 2009). Apart from that, like in several other dry land areas in Ethiopia (Gebreegziabher et al., 2009), in response to rainfall variability, farmers in the CRV have recently started to practice *in-situ* water harvesting techniques locally called Shilshalo (Biazin and Sterk, 2013; Birhane et al., 2006). The Shilshalo is also practiced for breaking crusts or plow pans to improve infiltration (Biazin and Stroosnijder, 2012). This shows that there is a need for introducing additional *in-situ* soil moisture conservation management (mulching and planting basin in the current study) in order to complement with farmers' traditional practice of harvesting available rain water and to make maize more resilient to rainfall variability.

In this current study, conservation agriculture (CA) was evaluated for its agronomic and economic potential and for its feasibility in comparison with CT. This is because, CA has been proposed as an alternative to CT particularly in marginal agro-ecologies. Conservation agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO, 2012). It has three key elements including minimal soil disturbance (minimum tillage (MT) or zero tillage (ZT)); soil surface cover through the management of crops, pastures and crop residues (mulching); and crop rotations (FAO, 2013). The mulch gives the soil physical protection from the sun, rain and wind as well as feeding the soil biota (FAO, 2012). To reduce disease and pest problems, crop rotation is also important (FAO, 2012). Compared to CT, CA is a resource-conserving practice with the potential to increase plant available soil moisture, promote infiltration and reduce the costs of tillage operations (Hobbs et al., 2008; Thomas et al., 2007). Among the most important disadvantages of CA is the increased dependence on herbicides (Armstrong et al., 2003) and that the benefits of CA are realized gradually over long-term (Erenstein, 2003; Giller et al., 2009). Planting basin was also part of this study because conservation tillage with basin has been widely promoted in Southern Africa to be used by resource-poor farmers (Nyamangara et al., 2013) with limited access to draft power. Nyssen et al. (2011) also found permanent basins reducing oxen requirement under conservation tillage in Northern Ethiopia.

The practice of the CA concept has spread widely to many parts of the world and its area coverage has grown from 45 million hectares in 1999 to around 111 million hectares in 2009 (Derpsch et al., 2010). Conservation agriculture has been adopted in many different bio-physical environments elsewhere, however, its expansion in Africa has been limited; the area under CA on the whole African continent constitutes only 0.3% of the area worldwide (Derpsch et al., 2010). There is an ongoing debate regarding whether or not CA provides benefits for smallholder systems in Africa (Giller et al., 2009). The debate focuses mainly on how to promote CA in Africa under the existing soil, climate and socio-economic conditions (Knowler and Bradshaw, 2007; Vanlauwe and Giller, 2006). A major criticism is that the socio-economic conditions of smallholder farms are often insufficiently addressed in existing CA research. Critical constraints in its adoption appear to be the competing use of crop residues; increased labor demand for weeding; and the lack of access to, and high cost of external inputs (Giller et al., 2009). Although, FAO (2010) has proposed CA as a suitable alternative tillage practice to address the challenges of the predominantly rain-fed crop production systems of smallholder in Eastern Africa, only limited research on maize production with CA has been undertaken in Ethiopia. The CA practices were introduced to Ethiopia in 1998 by Sasakawa Global 2000 (SG 2000) on maize production (Matsumoto et al., 2004). The major findings from the limited research with regard to CA in Ethiopia are improved grain and biomass yields in *Teff*, maize and wheat (Araya et al., 2012; Kassie et al., 2009; Matsumoto et al., 2004; Nyssen et al., 2011; Rockström et al., 2009; Tadesse et al., 1996), improved water productivity (Temesgen et al., 2008), and improved soil organic matter (Nyssen et al., 2011) when practiced over medium to long-term. The central constraints in the adoption of CA packages in Ethiopia were found to be lack of farmers' awareness of CA benefits, difficulties in the incorporation cover crops, and the management of weeds (Kassie et al., 2009; Nyssen et al., 2011). The fact that socioeconomic, agronomic and environmental benefits of CA are realized gradually over long-term (Erenstein, 2003; Giller et al., 2009) may be additional challenges. Due to high risk-averse conditions in the marginal agroecologies, resource poor farmers often prefer to see immediate benefits of new technologies. In the CRV of Ethiopia, documentation with regard to short-term benefits and information regarding the agronomic and economic response, labor requirement, weed incidence, as well as ecological feasibility and viability of CA in maize production are lacking.

Therefore, we hypothesized that CT responds better than CA under similar water conservation management when practiced over short-term and that CA may be a potential alternative to CT when practiced over long-term. Farmers lacking sufficient number of oxen and female headed households (who due to cultural reasons and/or household loads can not till their farms) could be potential beneficiaries. The water conservation (capturing available rain water and retaining it for increasing water use efficiency by maize) management is principally aiming at improving volumetric soil moisture content to mitigating the impacts of rainfall variability – recurrent dry spells and droughts – in maize production. A single intervention may not increase maize production in marginal agro-ecology of the CRV of Ethiopia. In this current study, we investigated early maturing and drought tolerant maize variety (*Zea mays* L. var. Melkassa-II) under different tillage and water conservation management for its agronomic and economic responses. As an entry point, this study, therefore, examined the short-term (for two consecutive years) agronomic and economic responses from practicing CA and CT under similar water conservation management. Specifically, the effects of CT, MT, and ZT under mulching, no mulching and planting basin were evaluated according to: (1) agronomic response; (2) volumetric soil moisture content; (3) weed density; and (4) economic response as well as the potential and viability of CA over short-term practice.

2. Materials and methods

2.1. Description of study sites

The study sites were in Ziway and Melkassa in the CRV of Ethiopia (Fig. 1), which are located in the East Shoa Zone of Oromiya Regional State, Ethiopia. Ziway is located at 7°9′N latitude, 38°43′E longitude, at an altitude of 1642 m.a.s.l, 122 km south of Addis Ababa. Ziway receives a bimodal rainfall from April to October, with June–October as the main cropping season for the cultivation of early-maturing cereals and pulses. Risk-taking farmers also cultivate mid-maturing maize varieties in April, though it is affected by the cessation of rain in late May.

Melkassa is located at 8°4′N latitude, 39°31′E longitude and lies at an altitude of 1550 m.a.s.l. It is located 115 km south east of Addis Ababa. Melkassa receives a bimodal rainfall, with June–October as the main cropping season for cultivation of early-maturing cereals and pulses.

2.2. Farm characteristics

The central rift valley of Ethiopia has been identified as semiarid (Engida, 2000). Rainfall variability adversely affects agricultural production. There is a recurrent drought, dry spells and late onset and early cessation of rainfall. Serious moisture deficit in the growing seasons occurs, particularly around flowering and grain filling of maize, causing substantial yield reductions or even occasionally total harvest failure. This is a mixed farming system, where both livestock and crop farming are important agricultural practices. Cattle are important in the agricultural production system as they provide draught and threshing power, and manure to improve soil fertility and provide materials for fuel. Crop residues are used as fodder, particularly during dry seasons, as well as providing a source of domestic fuel. Mono-cropping of cereals – mainly maize (*Zea mays*), *Teff* (*Eragrostis tef*) and pulses – is a common practice in these areas. Maize is the predominant staple food crop for the rural population in the region. As in most places in Ethiopia, the region is characterized by wide open grazing after crop harvest (Belay et al., 2013; Kassie et al., 2013, 2014). The soil in the CRV is classified as Haplic Solonetz with a texture ranging between loamy sand to sandy loam (Itanna, 2005) based on FAO soil classification systems.

2.3. Experimental design and treatments

In the 2011 and 2012 cropping seasons (two succeeding years), field experiments on tillage and water conservation management were carried out at both sites. The experimental design was a split-plot with four replications. The main plots consisted of CT (four time oxen plowings), MT (one time oxen plowing during planting) and ZT (planting directly into the soil with a pointed stick (dibble stick)). Each main plot was split into three subplots: mulch, no mulch and planting basin. The planting basin (made by hand hoe) was of 0.40 m long, 0.15 m wide and 0.10 m deep. The treatments received 1.0 g DAP ($(NH_4)_2HPO_4$) per planting station (where seeds

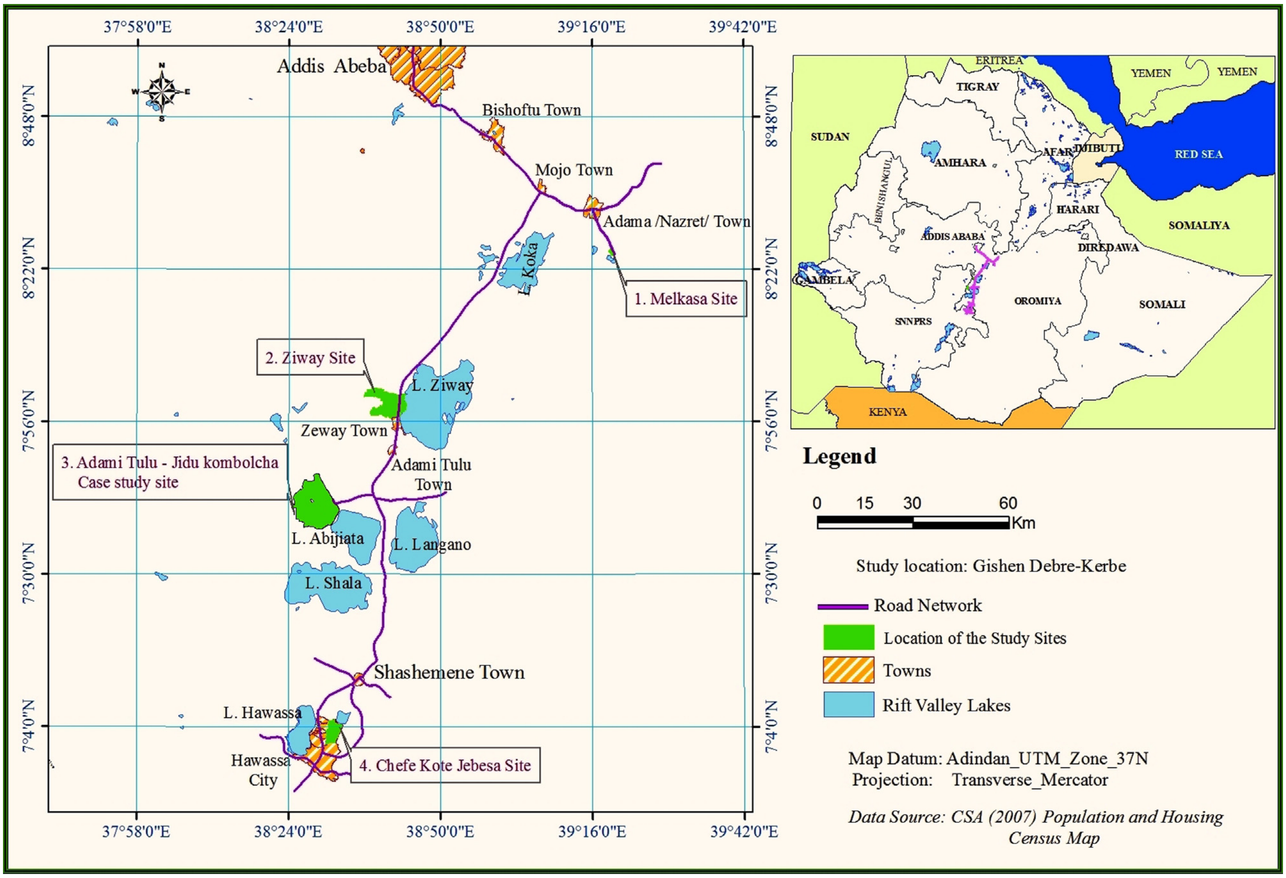

Fig. 1. Map showing the location of the study sites.

and fertilizer are placed adjacent to each other) at planting, which corresponds to 53 kg DAP ha^{-1}. One gram urea ($CO(NH_2)_2$) per planting station was also applied at knee height (40 days after planting). The plot size was 3.00 by 4.80 m (14.4 m^2). Each plot consisted of six rows with a spacing of 0.80 m between rows and 0.30 m between plants. The blocks were separated by a 1.5 m wide open space. The crop tested was maize (*Zea mays* L. var. Melkassa-II). The area for the experiment was uniformly treated before the experiment was established.

Maize stalk was applied as surface mulch to all mulched treatments, which is equivalent to 4 t ha^{-1} (approx. 60% soil cover), during the first season at both sites. During the first cropping season, maize stover was supplied from external fields. After the first harvest, the fields were fenced to retain maize residues until the next cropping season (June 2012). Permanent plots were used during the two years experimental period in order to study changes in soil moisture retention capacity as well as agronomic and economic responses. Weeds were controlled manually with a short hand hoe, commonly used in the areas.

2.4. Soil moisture measurement and rainfall data

The SM300 Soil Moisture Sensor with the Delta-T HH2 hand-held Moisture Meter (data logger) was used to measure the volumetric soil moisture content (%), with ±2.5% accuracy. The sensor can measure over 0–50% volume water in the soil. The sensor/probe (51 mm) was inserted/buried into the surface and subsurface of the soil (0–15 cm, crop root zone). Accordingly, three soil moisture measurements were recorded from the central row of the mulched, no mulched, and basin treatments. The measurements were taken systematically at different intervals the following day after rain: first week after planting, flowering, and physiological maturity. The purpose of measuring volumetric soil moisture content was to estimate the effect of mulching and no mulching, and planting basin and tillage management on soil moisture content which depicts the plant available water in the soil.

The long-term climate data and that of the experimental seasons for Melkassa and Ziway sites were gathered from the closest meteorological centers located at Melkassa and Adami Tulu Agricultural Research Centers respectively.

2.5. Weed data and measurement

Weed count data (number m^{-2}) were recorded three and six weeks following planting, just prior to manual weeding. A one meter by one meter quadrat (1 m^2) was placed randomly in three places in each plot, resulting in a total sample area of 3 m^2 plot^{-1}. The counting was conducted three (first weeding) and fifth (second weeding) weeks after planting. Additionally, before flowering and seed setting, remaining weeds were slashed to reduce weed seed banks.

2.6. Soil sampling and laboratory analysis

Twenty four composite soil samples (6 treatments per replication) were randomly collected at the depth of 0–15 cm to determine the pre-experiment physico-chemical characteristics of the soil. The soil samples were collected one week before planting and fertilization in 2011. The pH was measured on 1:2.5 soil/water suspensions with a glass electrode pH meter, organic carbon was measured using wet oxidation methods (Wakley and Black, 1934) and TN by Kjeldahl procedure (Bremner and Mulvaney, 1982). Available phosphorus (Olsen) was determined according to the Olsen method (Olsen et al., 1954). Exchangeable calcium and magnesium were determined using atomic absorption photometer, while sodium and potassium were determined by flame photometry (Black et al., 1965). Cation exchange capacity was determined (Chapman, 1965). Soil texture analysis was done using Boycous hydrometric method (Black et al., 1965). Bulk density (BD) and total porosity (TP) were determined from twenty four undisturbed cores samples (0–15 cm soil depth) which were collected by core sampler (size 5.8 cm diameter and 3.7 cm height). The BD was then determined after drying the core samples in an oven at 105 °C, 24 h while the TP (%), the percentage of bulk volume of soil not occupied by solid particles, was determined from saturated soils (Nelson and Sommers, 1982).

2.7. Agronomic data and measurement

The agronomic data collected include percent pocket germination (two seeds were placed in each planting station to increase percent seed germination), seedling vigor (rated 1–5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous), lodging count, plant height (cm), and grain and stover yield (kg ha^{-1}). Plants fallen, inclined or with broken stalk were considered as lodging. Plant height (cm) was measured from the ground level to the base of the tassel for five randomly selected plants per plot. Stover weight was measured after sun drying the stover for nine days when no change in the stover weight was observed between consecutive measurements. Maize cobs were harvested, shelled, weighed, grain moisture measured and eventually corrected for moisture content at 12.5% by a multi-grain digital moisture meter. Yield was extrapolated and then reported on a hectare basis. To avoid border effects, the agronomic data were collected from the four central rows, with a net plot size of 9 m^2.

Field observations were carefully recorded and informal discussions were held with farmers, development agents and government institutions to create awareness about the interventions and to identify challenges and opportunities for practicing CT and CA in the study sites.

2.8. Economic data and analysis

Standard enterprise budgeting techniques were used to estimate production costs and profitability. Total revenue (TR) was calculated based on grain yield and grain prices obtained from the local market. The local market grain price used was

Table 1
Physical and chemical properties of soils at Ziway and Melkassa, collected one week prior to the experimentation in 2011.

Site	Physical and chemical property											
	K	Ca	Mg	Na	CEC	TP	BD	pH	EC	OC	TN	Av. P
Ziway	2.42	25.10	4.35	7.47	34.74	25.30	1.01	8.40	0.17	3.21	0.25	18.20
Melkassa	2.30	15.19	3.60	0.43	26.40	25.63	1.13	7.42	0.16	1.70	0.14	19.20

Key: Exchangeable cations (potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na)) organic carbon (OC (%)) and total nitrogen (TN (%)), electrical conductivity (EC (ds m^{-1})), bulk density (BD (g cm^{-3})) and total porosity (TP (%)).

0.23 US\$ kg^{-1} (1 US\$ = 18.24 Ethiopian Birr (ETB)). Total variable cost (TVC) was estimated from labor and input cost. Labor cost was estimated from labor incurred for seedbed preparation, planting, fertilization, mulching, weeding, harvesting and threshing. Rental cost for oxen was obtained from farmers. Input cost was determined from the cost of fertilizers (DAP and urea) and seeds. Local market seed, DAP and urea prices per kilogram were 1.14, and 0.82 and 0.63 US\$ respectively. Labor cost was estimated at 1.64 US\$ person^{-1} day^{-1} (30 ETB person^{-1} day^{-1}). Locally, for one time ploughing of a hectare of land, the rental cost of a pair oxen including human labor is 10.96 US\$ (at 200 ETB). For each treatment, the time spent for each activity (seedbed preparation, planting, fertilization, mulching, planting basin making, thinning, weeding, harvesting and threshing) was recorded. Time use for the different activities was observed in all the plots of the experiment for the two years across both sites. In addition, the time spent when farmers worked as a group on the plots was observed. The average for each treatment was calculated. Costs of seeds, fertilizers, harvesting and threshing were considered to be the same for all treatments. Family labor was used as the major source of labor to increase farmers' participation, knowledge and attitudes for easy use of the technologies.

Gross margin (GM) for each treatment was determined as the difference between TR and TVC. Finally, labor productivity (LP) of each treatment was estimated as a ratio between maize grain (kg ha^{-1}) and the total amount of labor required (day ha^{-1}).

2.9. Statistical analyses

The General Linear Model of the ANOVA of SAS System Version 9.3 of SAS Institute Inc. (SAS, 2011) was used to determine treatment effects on agronomic, weed density, volumetric water content and economic responses. Means comparisons were conducted using the least significant differences (LSD), established at 5% significance level (P-value < 0.05). The data was analyzed as a split plot. Only significant effects were discussed unless otherwise presented in the text. Descriptive statistics were used for the qualitative data obtained from field observation and informal discussions with stakeholders.

3. Results

3.1. Soil physical and chemical properties

Table 1 presents physical and chemical soil properties. The soils at Ziway had lower available phosphorous (P) and bulk density (BD) than the soils at Melkassa. There were slightly more favorable conditions in the chemical properties (electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), exchangeable cations including potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg), and cation exchange capacity (CEC) in Ziway soils than in Melkassa soils. The soils at both sites had moderately alkaline pH. The soil texture at Ziway was clay loam (40% sand, 32% silt and 28% clay) and that of Melkassa was loam (37% sand, 41% silt and 23% clay). Total porosity (TP) was similar in both sites. Based on FAO soil classification systems, Itanna (2005) classified the soil in the CRV with texture ranging from loamy sand to sandy loam as Haplic Solonetz.

3.2. Rainfall, waterlogging, and dry spells

Fig. 2 presented the cumulative rainfall (mm) at Ziway and Melkassa during the experimental period from first of June to November of 2011 and 2012. The average total annual rainfall at Ziway over the past 12 years ranged from 518 to 1002 mm (average 815 mm), with an average maximum and minimum air temperature of 28 °C and 13 °C respectively. The total amount of rainfall received over 2011/2012 and 2012/2013 was 598 and 856 mm respectively. The total amount of rainfall received during the experimental period of the same years (June–October) was 442 and 732 mm respectively, which constitutes 74% and 86% of the total annual rainfall respectively. The average relative humidity during the experiment was 60%. The average maximum and minimum air temperature during the same period was 28 °C and 14 °C. The average total annual rainfall for Melkassa over the past 12 years ranged from 548 mm to 1093 mm (average 877 mm), with an average maximum and minimum air temperature of 29 °C and 14 °C respectively. The total amount of rainfall received over 2011 and 2012 was 923 and 924 mm respectively. The total amount of rainfall received during the experimental period of these two years (June–October) was 685 and 822 mm respectively. The average relative humidity for the experimental period was 62%. The average maximum and minimum air temperature during the same period was 29 °C and 12 °C.

Across sites and years, frequent waterlogging with durations of 3–5 days was observed during early growth of maize in July and early August. The treatment ZT was particularly affected, as well as mulching and basin treatments. Waterlogging occurred mainly in July, between planting and maize knee height. Treatments with waterlogging had yellow leaves and stunted growth. There were also periods with dry spells during the season. No mulch treatments in CT were particularly affected by the dry spells.

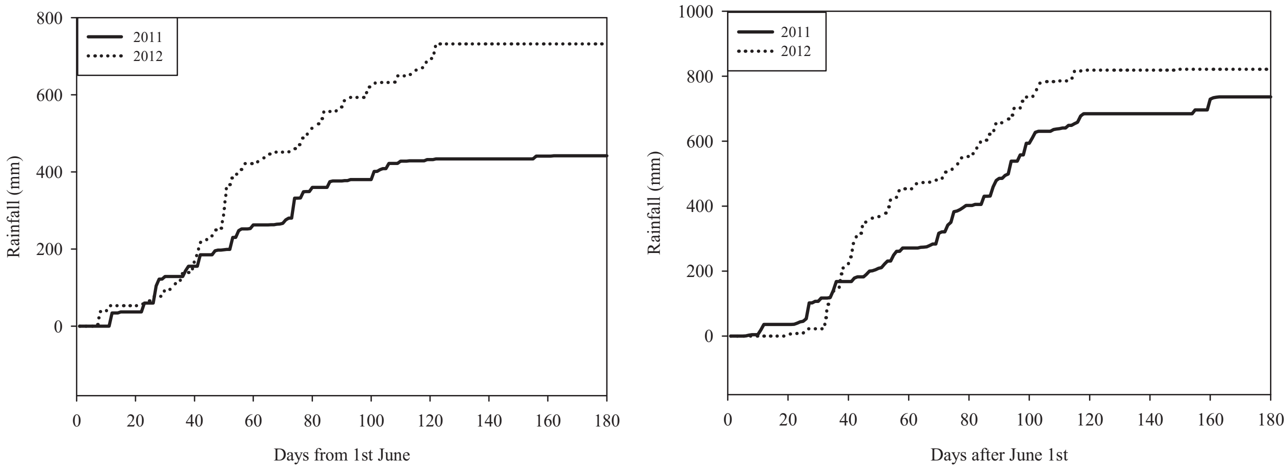

Fig. 2. Cumulative rainfall (mm) at Ziway (left) and Melkassa (right) during the experimental period from first of June to November of 2011 and 2012.
Source: The sources of the rainfall data for Ziway and Melkassa sites are Adami Tulu and Melkassa Agricultural Research Centers respectively.

Table 2
Average yield characteristics in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

	Ziway						Melkassa					
Treatment	PSG (%)	UF	SV	LC	PH (cm)	SCH	PSG (%)	UF	SV	LC	PH (cm)	SCH
CT	98.1a	3.7a	3.8a	2.3a	191.5a	47.3a	98.9a	3.8a	3.5a	2.1b	211.5a	47.5a
MT	97.4a	3.4a	3.7a	2.4a	184.4a	46.9a	98.3a	3.3b	3.4a	2.3b	206.0b	47.6a
ZT	95.6a	2.5a	2.5a	3.9a	175.9a	45.5a	94.6a	2.1c	1.8b	3.4a	200.6c	45.8a
LSD	3.05	1.19	1.69	4.83	22.07	2.55	5.71	0.38	1.02	0.51	2.58	2.60
Mulch	97.8a	3.8a	3.8a	2.1b	191.75a	47.2a	97.7a	3.7a	3.7a	2.1a	213.09a	47.5a
No mulch	96.4a	2.7b	2.7b	3.9a	178.71b	46.1b	96.7b	2.5c	2.8b	3.4a	198.89a	46.5a
Basin	97.0a	3.2ab	3.5ab	2.7ab	181.33b	46.5ab	97.4ab	3.0b	2.3c	2.3a	206.3a	46.8a
LSD	2.83	0.89	0.96	1.30	9.06	0.73	1.02	0.15	0.39	2.21	21.46	0.96

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: PSG (%): percent pocket seed germination; UF: uniformity; SV: seedling vigor; LC: lodging count; PH (cm): plant height and SCH: stand plant count; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

The dry spells caused temporary wilting in the CT treatments without mulching. Dry spells ranging between 5 and 10 days were more frequent in Ziway (double the frequency) than in Melkassa. There were dry spells occurring at flowering and physiological maturity. Most of the dry spells ranged between 4 and 7 days. Cessation of rainfall was observed in September across years and sites (Fig. 2).

3.3. Effects of tillage and water conservation management on characteristics of yields

Unlike at Ziway, tillage management of CT and MT improved seedling uniformity, seedling vigor, lodging and plant height at Melkassa compared to ZT. The CT also improved seedling uniformity and plant height compared to the MT at Melkassa. At Ziway, among the water conservation management mulching improved seedling uniformity and vigor, lodging, plant height and plant stand at harvest compared to no mulching as well as plant height compared to planting basin. Mulching also improved percent pocket seed germination, seedling uniformity and vigor compared to no mulching and planting basin at Melkassa. Plant basin improved seedling uniformity and seedling vigor compared to no mulching at Melkassa (Table 2).

3.4. Effect of tillage and water conservation management on average maize grain and stover yields

Across locations and sites, average grain yield improved in the order of CT > MT > ZT. The CT increased average grain yield by 13–20%, and 44–55% over MT and ZT respectively across sites. Similarly, MT increased average grain yield by 27–30% over ZT across sites (Table 3).

Effects on stover yield followed the same trend as the grain yields. The average stover yield across years and sites was 8092, 7343 and 6250 kg ha^{-1} for CT, MT and ZT respectively.

Across locations and seasons, mulching improved grain yield over basin and no mulch. During the second season across locations, basin improved grain yield over no mulch (Table 3).

The effect on stover yield followed the same trend as the grain yields. The average stover yield across years and sites was 8118, 6534 and 7138 kg ha^{-1}, for mulch, no mulch and basin respectively. Overall, over locations and seasons, the interaction between tillage and water conservation management on the grain and stover yields was not significant.

3.5. Effect of tillage and water conservation management on average weed density

The weed suppression effect between tillage management was insignificant. At Melkassa, CT suppressed second weed density compared to MT and ZT, so did MT compared to ZT. Weed density tended to increase with ZT and no mulch as follow ZT > MT > CT and with no mulch > basin > mulch. Across sites and seasons, there was less weed infestation in the mulched plots. Mulching suppressed first weed density at Ziway and second weed density at Melkassa compared to basin and no mulch (Table 4). The interaction between tillage and water conservation management was not significant.

3.6. Effects of tillage and water conservation management on average volumetric soil water content

The effect of tillage management on volumetric soil moisture content (plant available water) tended to increase towards the late growth stage of maize at flowering and physiological maturity at Ziway. At Ziway ZT had higher soil moisture capturing capacity compared to CT at flowering and physiological maturity (Table 5). There was no significant effect of tillage management on soil moisture capturing capacity at Melkassa.

Similarly, the effect of mulching on volumetric water content tended to increase towards the end of the growing season (Table 5). Mulching was able to improve soil moisture content more than no mulch and planting basin at planting, flowering and physiological maturity at Ziway. At Ziway, planting basins were also possible to improve soil moisture content more than no mulch at flowering and physiological maturity. At Melkassa, mulching was able to improve soil moisture content at physiological maturity.

Table 3
Average maize grain yield (kg ha^{-1}) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

TM	Ziway		Melkassa		WCM	Ziway		Melkassa	
	2011	2012	2011	2012		2011	2012	2011	2012
CT	5356a	6419a	5547a	6027a	Mulch	4847a	6804a	4743a	5911a
MT	4544b	5860b	4396b	5259b	No mulch	4171b	4741c	4131b	4517c
ZT	3358c	4816c	3195c	4248c	Basin	4239b	5550b	4265b	5106b
Mean	4419	5698	4379	5178	Mean	4419	5698	4379	5178
LSD	499	432	299	482	LSD	357	394	262	320

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Table 4
Average weed density (number m^{-2}) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

TM	Ziway		Melkassa		WCM	Ziway		Melkassa	
	FWD	SWD	FWD	SWD		FWD	SWD	FWD	SWD
CT	130a	48a	24a	18c	Mulch	100b	30a	17a	15b
MT	148a	54a	33a	22b	No mulch	170a	70a	43a	27a
ZT	160a	67a	45a	27a	Basin	168a	69a	42a	24a
Mean	146	56	34	22	Mean	146	56	34	22
LSD	34.41	20.75	35.17	3.10	LSD	57.52	63.53	31.72	5.08

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; FWD: first weed density; SWD: second weed density; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Overall, soil moisture capturing capacity tended to be higher in ZT and MT and mulch treatments. The variation in moisture retention capacity among treatments was higher in Ziway, with lower rainfall and more dry spells, than in Melkassa. The interaction between tillage and water conservation management in volumetric water content was not significant.

3.7. The economic assessments of tillage and water conservation management

Gross margin increased with CT compared with other tillage practices as follow CT > MT > ZT (Table 6). Rental cost increased with CT as follow CT > MT > ZT; whereas, labor demand for weeding increased with ZT compared with other tillage practices as follow ZT > MT > CT. Farmers on average spent 40, 44 and 54 days ha^{-1} of labor with CT, MT and ZT respectively.

4. Discussion

4.1. Tillage management and maize agronomic responses

Under similar water conservation management, CT was able to improve maize agronomic responses over CA. The performance in yield characteristics in the CA plots were generally lower than the CT plots, for instance at Melkassa. The CT increased average grain yield by 13–20% and 44–55% over MT and ZT respectively across sites. Similarly, MT improved average grain yield by 27–30% over ZT across sites. Field observations indicated rigorous waterlogging (temporary) and yellow leaved and subtly grown maize stands in MT and ZT plots. Moreover, there was a faintly increasing weed tendency in the same plots. Therefore, the generally lower performance in yield characteristics, higher waterlogging and slightly increasing weed infestation and the short duration of the experimentation might be the most likely reasons for the yield depression in the MT and ZT plots. Several reports indicated waterlogging under higher rainfall season in CA causes yield depression (Giller et al., 2009; Rockström and Barron, 2007; Rusinamhodzi et al., 2011). Absence of tillage can result in higher run-off and lower infiltration leading to lower yields (Tadesse et al., 1996). Biazin and Sterk (2013) also reported temporary waterlogging in maize fields the central rift valley in Ethiopia. Maize is moderately sensitive to waterlogging that reaches anaerobiosis point when the root zone soil moisture status is at about 5–10% below the saturation point (FAO, 2009). In contrast to CA, no waterlogging problem was observed under conventional tillage, which signifies the reasons for increasing the frequency of tillage for crop production in Ethiopia. Temesgen et al. (2008) reported similar reasons in Ethiopia for increasing ploughing frequency to improve infiltration, minimize run-off and reduce evaporation of water from soil surface. Increased weed competition and waterlogging (under poor drainage conditions) can impact crop production negatively in CA (Giller et al., 2009) when practiced over short-term. Conservation tillage reduces crop yields through limiting soil physical properties, increasing weeds and decreasing fertilizer efficiency (Murillo et al., 1998). According Giller et al. (2009), despite the fact that CA can result in yield benefits in the long-term, yield losses or no yield benefits are likely in the short-term practice (which may need up to 10 years). Yet several studies have also found higher maize yields in conservation than conventional tillage from experiments conducted over three to four years in Ethiopia (Ito et al., 2007; Rockström et al., 2009) and 3–10 years in Malawi (Ngwira et al., 2012). Several other reports indicated that it takes some years before the yields benefits become evident in CA practices. Increased retention of mulch, soil moisture, improved soil structure and biotic activity could increase long-term crop yields in conservation tillage (Fowler and Rockström, 2001; Ito et al., 2007).

4.2. Water conservation management and agronomic responses

Irrespective of tillage management, mulching improved most of the agronomic responses far more than no mulching. In the central rift valley of Ethiopia, despite the high intra and inter seasonal variability in rainfall (Biazin and Sterk, 2013; Kassie et al., 2013, 2014), maize production has always been considerably affected by late on setting and early cessation of rainfall in the study sites which usually happens during flowering and/or physiological maturity (Biazin and Sterk, 2013). In this study, the better soil moisture condition under mulching is the most likely condition to improve most of the agronomic parameters; namely seedling vigor,

Table 5
Average volumetric water content (%) in the 0–15 cm soil depth in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

Site	Growth stage	TM				WCM			
		CT	MT	ZT	LSD	Mulch	No mulch	Basin	LSD
Ziway	Planting	31.1a	30.6a	32.0a	4.3	33.6a	29.0b	30.9b	2.3
	Flowering	27.0b	27.9ab	28.9a	1.9	30.8a	25.5c	27.4b	1.3
	Maturity	26.3b	26.5ab	26.9a	0.5	27.4a	25.9c	26.5b	0.3
Melkassa	Planting	26.9a	26.5a	26.6a	3.9	28.5a	24.5a	26.9a	5.1
	Flowering	32.8a	33.3a	32.8a	2.4	35.3a	30.8a	32.8a	9.3
	Maturity	27.1a	27.4a	27.6a	1.4	28.3a	26.7b	27.1b	0.5

Means in the same row with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Table 6
Total revenue, total variable costs, gross margin and labor productivity (in US$) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

Item	Unit price (US$)	CT				MT				ZT			
		Mulch	No mulch	Basin	Mean	Mulch	No mulch	Basin	Mean	Mulch	No mulch	Basin	Mean
1. Revenue													
Maize grain (kg ha^{-1})		6375	5605	5534	5838	5616	4475	4954	5015	4740	3091	3883	3905
Total revenue (US$ ha^{-1})	0.23	1466	1289	1273	1343a	1292	1029	1139	1153b	1090	711	893	898c
2. Input cost													
Maize seed (US$ ha^{-1})	1.14	30	30	30	30	30	30	30	30	30	30	30	30
DAP (US$ ha^{-1})	0.82	44	44	44	44	44	44	44	44	44	44	44	44
Urea (US$ ha^{-1})	0.63	34	34	34	34	34	34	34	34	34	34	34	34
Total input cost (US$ ha^{-1})		107	107	107	107	107	107	107	107	107	107	107	107
3. Labor use (day ha^{-1})													
Weeding		4	9	6	6c	7	15	12	11b	14	23	19	19a
Others (planting, mulching, fertilization, etc.)		31	28	44	34	30	26	45	34	31	27	47	35
Total labor (day ha^{-1})	1.64	35	37	50	40	37	41	57	44	45	50	66	54
Total labor cost (US$ ha^{-1})		57	61	82	66	61	67	93	72	74	82	108	89
Rental cost (US$ ha^{-1})	10.96	44	44	44	44	11	11	11	11	0	0	0	0c
Total variable costs (US$ ha^{-1})		209	212	233	217a	179	186	212	190a	181	189	216	196a
4. Returns													
Gross margin (US$ ha^{-1})		1257	1077	1040	1126a	1113	843	927	963b	909	522	677	702c
Labor productivity (kg day^{-1})		182	151	115	146a	152	109	93	114b	105	62	67	77c

Means in the same row with same letter are not significantly different at P-value < 0.05.
Key: CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

uniformity, plant height, lodging, and plant population at harvest under mulching. These improved agronomic characteristics would have positive effect on overall maize yield. As a result, mulching increased average grain yield by 23–33% and 14–19% over no mulch and planting basin respectively. Previous studies indicated that mulching increased biomass and grain yield of maize by 54 and 56% respectively (Tenaw et al., 2002) in the moisture stressed areas in Ethiopia. Several previous studies indicated that mulching increased yields in maize (Adeniyan et al., 2008), *Teff* (Tulema et al., 2008) and grains (Thomas et al., 2007) under conservation agriculture.

Therefore, the overall promising performance of mulching over the short-term, particularly during the second season across sites, is suggestive of its higher long-term potential in improving maize production in the region. During the second season across sites, mulching was able to improve maize yields over no mulching and planting basin. This is favored by the finding that productivity benefits in CA accumulate over time as mulching gradually improves the physico-chemical and biological properties of soils (Erenstein, 2003). As a result, regardless of tillage management, mulching appears to be an appropriate method for mitigating the negative impact of the frequent inter and intra seasonal dry spells on maize yields in the region. It may importantly contribute towards achieving climate-resilient and sustainable maize production in the region. However, due to the open grazing on fields after harvest, currently mulching cannot be practiced on open fields. Therefore, for farmers who would like to operate on fenced small fields around homesteads, mulching could be the best option. Yet there is a need to study how to better incorporate crop residues as mulching into maize production in the region.

Compared to no mulching, the yield benefits of basin become higher during the second season across sites. Planting basins were also able to capture more water than no mulch at flowering and physiological maturity at Ziway. Planting basins may therefore be an option for farmers lacking oxen and operating higher dry spells and droughts. There is a tradition of planting early-maturing maize on fenced small plots around homesteads in order to offset food shortages during the pre-harvest, and to generate income from selling green cobs. The CA with basin has been widely promoted for resource poor farmers in Southern Africa (Nyamangara et al., 2013). The cost of oxen rental in the study sites is high (11 US$ ha^{-1} for one time passage) and is a pressing challenge for farmers lacking sufficient draft power. Farmers without oxen should work for oxen owners for 2–3 days in return for hiring oxen for one day. Another option for such farmers is to practice sharecropping or renting out farm lands to others. It was reported that permanent basins decreased oxen requirement under CA in northern Ethiopia (Nyssen et al., 2011).

4.3. Tillage and water conservation management and volumetric soil moisture content

Although the agronomic responses were lower, CA plots tended to retain more soil moisture towards later growth of maize than CT in Ziway, with lower seasonal rain fall and more dry spells. This result could, therefore, suggest the long-term potential of CA practices as an alternative system in maize production operating under recurrent dry spells and drought occurring in the study sites. Thierfelder and Wall (2009) also reported higher soil moisture levels throughout the season in CA than in conventional tillage. In addition, the same authors suggest that CA has high potential for increasing rain water productivity and; therefore, to reduce the risk of crop failure, particularly during the later growth stage of maize in Zambia.

Among the water conservation management, mulching became so inconsistent in its moisture conservation potential across sites. Compared to no mulching, mulching was able to conserve more volumetric soil moisture for the entire growth period at Ziway. Mulching improves soil moisture and enhances water infiltration (Adeniyan et al., 2008; Thomas et al., 2007; Tulema et al., 2008). Ziway had relatively lower seasonal rainfall as well as more dry spells and intra and inter-seasonal rainfall variability. Mulching was also able to retain more soil moisture at physiological maturity at Melkassa, one of the critical stages in maize growth demanding considerable amount of soil moisture. Mulching is therefore likely to work well in areas with more dry spells and rainfall variability. It might have improved infiltration and minimized water evaporation in soil (Rockström et al., 2009). The higher capacity of mulching in conserving more water at planting, flowering and physiological maturity, critical stage in maize growth demanding high water, in particular will have remarkable importance in making maize production more resilient to the recurrent rainfall variability. In the semiarid regions, mulching was found to be effective in reducing risk of crop failure due to better water retention capacity of available rainfall (Scopel et al., 2004). Planting basin tended to increase soil moisture content.

4.4. Water conservation management and weed density

Mulching was inconsistent in its weed suppression effects. It was also able to suppress the first weed density at Ziway and the second weed density at Melkassa. Overall, weed density tended to decline with mulching across sites. The lower weed density under mulching might have reduced the competition of weeds for soil moisture and nutrients and have contributed to the higher yield under mulching. The suppression of weed incidence by mulching corresponds with the results reported on *Teff* production in Ethiopia (Tulema et al., 2008). Effective weed suppression by mulch in maize production has been documented (Essien et al., 2009; Uwah and Iwo 2011). Therefore, besides minimizing financial outlays for farmers, weed control through mulch appears to be eco-friendly as the need to use herbicides is reduced. This could also help farmers free some labors investing on other farm and socioeconomic activities. Planting basins tended to reduce weed density but tended to increase maize yields indicating its high potential particularly for farmers lacking oxen. Conservation tillage with basin has been widely promoted in Southern Africa to be used by resource-poor farmers with limited access to draft power (Nyamangara et al., 2013). Nyssen et al. (2011) reported permanent basins increasing the need for weeding in the first years under conservation tillage in Northern Ethiopia.

4.5. Tillage and water conservation management and economic response

The CT increased labor productivity by 28 and 90% compared with MT and ZT respectively. MT increased labor productivity by 48% compared with ZT. The CT became the most profitable, increasing gross margin by 17 and 60% over MT and ZT respectively. The MT increased gross margin by 37% compared with ZT. Tulema et al. (2008) also indicated that zero tillage resulted in lower gross margin in *Teff* production than conventional tillage. MT yielded an average gross margin and labor productivity, between CT and ZT. The cost for seedbed preparation was lower in MT and ZT, but weeding costs constituted a major source of the increased costs of production in MT and ZT. As a result, farmers spent a higher number of days in MT and ZT (with the highest weed density) than in CT. The higher weeding costs in MT and ZT might attribute to the fact that herbicides were not used in this study. Tulema et al. (2008) report minimum tillage improves farm productivity by reducing tillage costs and allowing partial replacement of oxen with cows. Thomas et al. (2007) also reported reduction in costs to tillage operations in conservation agriculture. Lower cost for seedbed preparation is the immediate benefits of conservation tillage (Fowler and Rockström, 2001). A reduction in cost of production under conservation tillage practices than conventional tillage (Govaerts et al., 2009) when herbicides are used. Although higher input costs for herbicides were incurred, farmers got better agronomic benefits and income from conservation tillage experiments conducted over three years (1999–2003) season under maize production in Ethiopia (Ito et al., 2007). In conservation tillage, several investigators indicated that weed control is often laborious and costly suggesting a higher demand for herbicide use than manual weeding (Wall, 2007); use of herbicides substantially decreases the hand-weeding labor costs (Tulema et al., 2008); and excluding herbicides from conservation tillage increases the labor requirements for weeding (Giller et al., 2009; Ngwira et al., 2012). The exclusion of herbicide in this study assumes higher costs for purchasing herbicides, hiring herbicide application equipment or sprayers, accessibility, and negative environmental impacts.

Regardless of tillage management, mulching reduced weed density and labor costs for weeding; which complies to previous studies (Thomas et al., 2007; Tulema et al., 2008). The lower cost for seedbed preparation is an immediate benefit of CA (Fowler and Rockström, 2001). This current study also found similar results where the rental cost for seedbed preparation was 75% less in MT compared with CT. Owing to the reduction in tillage costs and economic responses, MT may be an interesting option for farmers with a shortage of oxen and in female households who due to either cultural reasons or house loads cannot use intensive tillage. There is high rental cost for oxen in Ethiopia (Aune et al., 2001) and conventional tillage is expensive to farmers without oxen (Tulema et al., 2008). This indicates that farmers who lack oxen could benefit from practicing CA due to reduction in the requirement for oxen.

Mulching is a difficult option in the central rift valley due to low crop biomass, alternative use of mulch as livestock fodder, free grazing, and the low awareness of the importance of recycling crop residues. In this regard, shortage of crop residues, prioritization of crop residues for livestock fodder and lack of sufficient information as major concern that virtually challenge adoption of conservation tillage practice in most SSA countries (Giller et al., 2009), and lack of farmers' awareness of CA benefits (Araya et al., 2012; Kassie et al., 2009) in Ethiopia. The wide free grazing after crop harvest in the region remains a major challenge to practicing mulching on open fields even under high yields. According to Valbuena et al. (2012) in areas with relatively high feed pressure, there is need to have a strategy of increasing biomass production and developing alternative sources to alleviate the opportunity cost of leaving crop residues as mulch. The abandonment of stubble grazing which has environmental benefits like soil conservation is a pre-requisite for implementing resource-conserving technologies in Ethiopia (Oicha et al., 2010).

5. Conclusions

The results from the two years of field experiments have demonstrated that conventional tillage provides greater agronomic and economic benefits compared with minimum tillage and zero tillage. Conventional tillage improved maize yields, gross margin and labor productivity far more than minimum tillage and zero tillage. The most likely reasons for the yield depression and lower economic response in CA can be related to the generally lower performance in yield characterisics, temporary waterlogging, increasing tendency of weed density and short duration of experimentation. Minimum tillage performed much better than zero tillage and it can be a potential option for farmers lacking sufficient oxen for plowing and for female headed households. Regardless of tillage management, mulching improved agronomic and economic benefits compared to no mulch and planting basins. Planting basins also tended to perform higher than no mulching and proved to show its potential. Despite the inconsistency, mulching was able to improve volumetric soil moisture content for efficient plant use, and reduced weed density and the labor requirement for weeding. However, owing to free grazing on open fields after crop harvest (realized from field observations and interaction with local communities and administration), mulching seems feasible only on small plots around homesteads where famers have fenced plots for growing early-maturing maize. Despite lack of easy access to oxen principally during peak time of planting, the oxen rental cost for intensive tillage is expensive to farmers lacking sufficient oxen and having financial constraints. Intensive tillage is also a challenge to female headed households who due to either cultural reasons or house loads cannot till their farms. Considering the short-term agronomic and economic potential of conservation agriculture (particularly minimum tillage) and the existing challenges in conventional tillage, we suggest further study (based on long-term) on how to sustainably integrating conservation agriculture to the widely practiced conventional tillage for the potential beneficiaries. On other end, sustainable integration of appropriate water conservation management (mulching) and adapting maize varieties (early maturing and drought tolerant maize) into the farming system in the central rift valley might further promote the existing traditional methods (Shilshalo and ridging) and make maize production more resilient to rainfall variability to improve food security and farmers livelihoods in the region.

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Article

Maize Response to Fertilizer Dosing at Three Sites in the Central Rift Valley of Ethiopia

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Abstract: This study examines the agronomic response, efficiency and profitability of fertilizer microdosing in maize. An experiment with the following treatments was conducted: control without fertilizer, microdosing treatments, with the rate of 27 + 27, 53 + 53 and 80 + 80 kg ha^{-1}, and banding of fertilizer with 100 + 100 kg ha^{-1} of di ammonium phosphate (DAP) + urea, applied at planting and jointing, respectively. The treatments were arranged in a randomized complete block design with four replications. The experiment was conducted during the 2011/2012 and 2012/2013 cropping seasons at Ziway, Melkassa and Hawassa in the semiarid central rift valley region of Ethiopia. Compared to the control, the fertilizer treatments had higher yield and fertilizer use efficiency (FUE) profitably. The 27 + 27 kg ha^{-1} fertilizer rate increased the grain yield by 19, 45 and 46% at Hawassa, Ziway and Melkassa, respectively, and it was equivalent to the higher rates. The value cost ratio (VCR) was highest with the lowest fertilizer rate, varying between seven and 11 in the treatment with 27 + 27 kg ha^{-1}, but two and three in the banding treatment. Similarly, FUE was highest with the lowest fertilizer rate, varying between 23 and 34 kg kg^{-1} but 7 and 8 kg kg^{-1} in the banding treatment. The improved yield, FUE, VCR and gross margin in maize with microdosing at the 27 + 27 kg ha^{-1} of DAP + urea rate makes it low cost, low risk, high yielding and profitable. Therefore, application of this particular rate in maize may be an option for the marginal farmers in the region with similar socioeconomic and agroecological conditions.

Keywords: fertilizer dose; fertilizer application method; maize yield; semiarid Ethiopia; value cost ratio

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1. Introduction

Land degradation in the form of soil erosion and soil nutrient depletion are critical challenges to agricultural production and economic growth in Ethiopia. On farm lands, in particular, there is a continuous decline in soil quality resulting from reduced fallows and the sub-optimal use of input [1]. At the national level, fertilizer is applied to only 45% of the total crop area [2,3]. Factors that limit the use of chemical fertilizer by smallholder farmers are the high cost, lack of access to credit, price risk of fertilizers and lack of technology [4].

The central rift valley of Ethiopia, where this study was undertaken, is characterized by a general decline in fallow periods and the increasing use of marginal land, with consequent land degradation [5–7]. As a result of the increasing land degradation, agricultural productivity has decreased, thus exacerbating food insecurity and poverty [7]. The Ethiopian rift valley, which covers a huge proportion of the vast semi-arid areas in Ethiopia, covers 301,500 km^2 (27% of the country) and represents the crop production zone suffering from serious moisture stress [8]. This study was undertaken in three sites with different land use and management systems and, therefore, possibly having spatial variability in soil quality and, thus, maize yield responses to fertilizers. In this respect, it was reported that different land management systems were found to affect soil quality and agricultural production differently in Ethiopia [1]. There can be a spatial variability in soil nutrients even within farms, due to different soil management [9], and such variability affects nutrient use efficiency and crop productivity [10]. In this respect, there is a need for considering soil fertility gradients and nutrient management to improve resource use efficiency and crop production on smallholder farms [9,10]. Apart from that, the existence of high temporal and spatial variability in rain and high variability in the length of growing season (late onset and early termination) between years was reported to affect crop production in the central rift valley [11,12]. A spatial and temporal variation in crop responses to climate variability has also been reported in East Africa [13]. Several other previous studies have also reported that although the agricultural extension program in Ethiopia has promoted fertilizer use over the last few decades, its success in increasing agricultural productivity has been constrained principally by unpredictable rainfall patterns [14,15]. Therefore, spatial variability in soil quality and rainfall could be among other factors influencing maize yield responses to fertilizer application in the three study sites in the central rift valley.

The important nutrients limiting crop production in the dry land areas of Ethiopia, including the central rift valley, are nitrogen (N) and phosphorus (P) [16]. The cation exchange capacity (CEC) of the soils ranges from a medium to a high level (20.00–39.00 meq/100 gram of soil). The high exchangeable potassium (K) level (2.05–4.03 meq/100 gram of soil) indicates that a response to K fertilizer is unlikely for cereals [17]. Hence, for increased grain/biomass yield, yearly application of N and P fertilizer is required. The easiest way to increase soil N and P is the addition of inorganic nutrients, such as urea and di-ammonium phosphate (DAP). With the available fertilizer application methods that use high fertilizer rates, however, this may be difficult for smallholder farmers in the study sites, due to the high fertilizer cost, lack of credit and insufficient training in the use of fertilizers.

The microdose method of applying fertilizers is an alternative to the banding method that has been recommended through the national extension system. Microdosing consists of the application of small quantities of fertilizer in the planting station at planting, or as a top dressing three to four weeks after emergence. Microdosing fertilizer enhances fertilizer use efficiency and improves yields, while minimizing input cost (requiring low financial risk and low cash outlay) and improving return on investment [18–20]. This is an efficient way to apply fertilizer, because the fertilizer is applied adjacent to the seeds, thereby ensuring a high uptake. Microdosing of fertilizers was found to increase yields by 44% to 120% and farmers' income by 52% to 134% compared to traditional application methods [18]. It is an effective fertilizer application method for sorghum and pearl millet production in Mali and Sudan [19] and in Sudan [21].

There is no documentation on the use of fertilizer microdosing in Ethiopia. The most common fertilizer application methods in Ethiopia are broadcasting, top dressing or banding. National research institutes primarily recommend the banding method, while farmers use the broadcasting method for broadcasted crops and banding for row-planted crops. Maize, which is staple crop in the study sites and the test crop in this study, is an ideal crop for row planting. Presently, the Ethiopian government is promoting the row planting and banding methods of fertilizer application for the major cereal crops to improve crop productivity, food security and farmer income. However, due to the high fertilizer rates with the banding method of fertilizer application, an alternative fertilizer application method, such as the microdose method, is therefore imperative.

Farmers do not generally follow the national fertilizer recommendation rates (for instance, the application of 100 DAP + 100 urea kg ha^{-1} at planting and jointing, respectively, for maize), due to high fertilizer cost, fertilizer supply shortages and insufficient training in fertilizer use [2,4,22]. Due to the high price of fertilizer, the use of urea is limited [22]. Moreover, the effect of fertilizers is marginal, due to applications being below the recommended rates [22,23] and the failure to use DAP and urea in proper combinations [22]. These effects are further exacerbated, because fertilizer recommendations from the early 1990s [24] are largely out-of-date and not tailored to the agro-ecology, soil type and climate [4,24]. Such low technical efficiency leads to non-optimal fertilization [4] and marginal effects on crop production [22]. This study therefore examines the agronomic response, fertilizer use efficiency and fertilizer profitability of variable rates of DAP and urea applied through microdosing and banding methods in maize production in the central rift valley. Specifically, the variable fertilizers rates to be investigated for their agronomic and economic responses in maize were 27 + 27, 53 + 53 and 80 + 80 kg ha^{-1} of DAP + urea under the microdosing method and 100 + 100 kg ha^{-1} DAP + urea under the banding method.

2. Materials and Methods

2.1. Characteristics of Study Sites

The research sites, Ziway, Melkassa and Hawassa, are situated at 7°9′ N and 38°43′ E, 8°4′ N and 39°31′ E, and 7°4′ N and 38°31′ E latitude and longitude, respectively, at 1642, 1550 and 1675 m.a.s.l. in the central rift valley of Ethiopia. Ziway and Melkassa are characterized as semi-arid agro-ecological zones; whereas Hawassa is a moist mid-highland zone. Ziway has a well-drained clay loam soil (40% sand, 32% silt and 28% clay), with pH = 8.40, 3.21% organic carbon (OC), 0.25% total nitrogen (TN) and 18.20 mg kg^{-1} available P. The average total annual rainfall in Ziway over the past 12 years ranges from 518 to 1002 mm (average 815 mm), with an average maximum and the minimum air temperature of 28 °C and 13 °C, respectively. Melkassa has a loam soil (37% sand, 40% silt and 23% clay), with pH = 7.42, 1.7% OC, 0.14% TN and 19.20 mg kg^{-1} available P. The average total annual rainfall for Melkassa over the past 12 years ranges from 549 mm to 1093 mm (average 877 mm), with an average maximum and minimum air temperature of 29 °C and 14 °C, respectively. Hawassa has a well-drained loam (46% sand, 28% silt and 26% clay), with pH = 7.1, 2.3% OC, 0.19% TN and 46.40 mg kg^{-1} available P. The average total annual rainfall for Hawassa over the past 12 years ranges from 776 mm to 1145 mm (average 988.1 mm), with an average maximum and minimum air temperature of 26.6 °C and 13.7 °C, respectively.

2.2. Farm Characteristics

Farmers in the study sites practice mixed farming; characterized by a strong integration between crop and livestock production. Livestock provides draft and threshing power, manure to improve soil fertility and materials for fuel. Crop residues are used as fodder, particularly during dry seasons, as well as providing a source of domestic fuel. Mono-cropping of cereals, mainly maize (*Zea mays* L.); and teff (*Eragrostis tef* (Zucc.) Trotter), and pulses, such as haricot bean (*Phaseolus vulgaris* L.), is a common practice in the region. Maize is the predominant cereal crop and staple food. Increasing food demand in the region, driven by considerable population growth, has increased pressure on the fragile land system [6,7,25].

There are two overlapping seasons for crop production in the study sites. The first season usually extends from April to September, while the second season, which is the main rainy season, extends from June to October. July and August are the wettest months. Mid-maturing maize is the main crop for the first (and longer) season; while haricot bean, wheat and teff are the main crops for the second season. Early-maturing maize is cultivated during both seasons. When the rain starts late, farmers cultivate early-maturing maize varieties during the second season, usually in early June. In recent times, at Ziway and Melkassa, due to the shifting seasons, farmers have started to use the second season for most of the crops. Early-maturing maize is usually cultivated to fill the severe food shortage during pre-harvest. The government also encourages farmers to cultivate early and plant drought-tolerant varieties of maize in these areas. Fertilizer and improved seeds are supplied to farmers through the farmers' cooperative union and agricultural departments; however, delays in supply are frequent. Farmers sell their agricultural produce at local markets. There is broad fluctuation in the input and output market prices.

2.3. Treatments, Experimental Design and Procedures

An experiment was conducted at Ziway, Melkassa and Hawassa during the 2011/2012 and 2012/2013 cropping seasons using the following treatments:

1. Control without fertilizer;
2. Microdosing 26.6 kg DAP at planting and 26.6 kg urea ha^{-1} at maize jointing. This corresponds to applying 0.5 g DAP and urea per planting hill;
3. Microdosing with 53 kg DAP ha^{-1} at planting and 53 kg ha^{-1} urea at maize jointing. This corresponds to applying 1 g DAP and urea per planting hill;
4. Microdosing with 80 kg DAP ha^{-1} at planting and 80 kg ha urea at maize jointing. This corresponds to applying 1.5 g DAP and urea per planting hill;
5. Banding with 100 kg DAP ha^{-1} at planting and 100 kg urea at maize jointing (national recommendation rate).

The microdose rates represent a reduction in the fertilizer rate compared to the recommended rates of 73, 47 and 20% of DAP or urea. In microdosing, the fertilizer is placed adjacent to seeds; whereas, in banding, the fertilizer was dressed in the entire central surface of furrows and covered afterwards with soil at planting. The experiment used di-ammonium phosphate (DAP) ($(NH_4)_2HPO_4$) and urea ($CO(NH_2)_2$); both commonly used fertilizers in Ethiopia. The plot size was 3 m by 4.5 m (13.5 m^2) with six rows. The population was around 53,000 maize plants ha^{-1}. The spacing was 75 cm between rows and 25 cm between plants. The seed rate was 27 kg ha^{-1}. The required microdose rate of DAP was placed together with seeds (two seeds per planting station) in the planting station at planting, while urea was top dressed and covered with the soil immediately to avoid its loss to the air through evaporation in the fifth week when plants were at jointing with approximately a 60-cm plant height. In the microdosing treatment, to save time, a small cap produced from available plastic material was cut into different sizes in order to accurately measure the different fertilizer rates. The treatments were arranged as a randomized complete block design in four replications. The blocks were separated by a 1.5 m-wide open space. Hand weeding was undertaken using a local hand hoe three weeks and six weeks after planting.

2.4. Agronomic Data Collection and Measurement

The major agronomic data collected include pocket seed germination, seedling vigor (rated 1 to 5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous), lodging count, plant height, grain yield and stover yield. Plants fallen, inclined or with broken stalks were considered as lodging. Plant height was measured from the ground level to the base of the tassel for five randomly selected plants per plot. Stover weight was taken after sun drying for 9 days when almost no change in weight was observed between consecutive measurements. Maize cobs were harvested, shelled, weighed, grain moisture measured and eventually corrected for moisture content at 12.5% by a multi-grain digital moisture meter. Yield was extrapolated and then reported on a hectare basis. To avoid border effects, yield data were collected from the four central rows, with a net plot size of 9 m^2.

2.5. Fertilizer Use Efficiency

The fertilizer use efficiency (FUE) of each treatment was computed as the difference in yield (kg ha^{-1}) between each treatment and the control divided by the amount of fertilizer applied (kg ha^{-1}).

$$FUEt = \frac{Yt - Ct}{Ft} \tag{1}$$

where *FUEt* is the agronomic fertilizer use efficiency of treatment *t*; *Yt* is the grain yield of treatment *t*; *Ct* is the grain yield of the control treatment; and *Ft* is the rate of fertilizer used for treatment *t*.

Standard enterprise budgeting techniques were used to estimate production costs and profitability. Total variable cost (TVC) was estimated from the input costs of labor, fertilizer and seed. Input costs for fertilizers and seeds; and average labor costs for planting, fertilizer application, weeding and harvesting were estimated. Price per kg (averaged over 2011 and 2012) of maize seeds, DAP and urea were 1.14, and 0.82 and 0.63 US$ kg^{-1}, respectively, at the local market at Ziway and Melkassa. Both Ziway and Melkassa are close to fertilizer markets, and the price is therefore the same. The market price for output is also similar. At Hawassa, price per kg (averaged over 2011 and 2012) of maize seeds and DAP and urea fertilizer were 1.19, and 0.84 and 0.64 US$, respectively. The market price of the grain per kilogram was estimated at 0.23 US$ at Ziway and Melkassa and 0.22 US$ at Hawassa. Rental cost was estimated at 10.96 US$ ha^{-1} for one time passage with oxen. Labor cost was estimated at 1.64 US$ $person^{-1}day^{-1}$ across the sites. Gross income (GI) was estimated from grain yield multiplied by grain price. Gross margin (GM) was calculated as the difference between GI and TVC. Monetary values related to cost and income were converted from Ethiopian Birr to US$ at the exchange rate of one US$ to 18.24 Ethiopian Birr.

2.6. Economics of Fertilizer Use

The economic returns of the treatments were calculated based on the GM and value cost ratio (VCR).

For each treatment, the GM was calculated as follows:

$$GMt = GIt - TVCt \tag{2}$$

Where *GMt* denotes gross margin of treatment *t*, *GIt* denotes the gross income from treatment *t* and *TVCt* denotes the total variable cost for treatment *t*.

For each treatment (compared to the control), *VCR* was calculated as follows:

$$VCRt = \frac{(Yt - Yc) \times Gt}{CFt} \tag{3}$$

Where *VCRt* denotes the value cost ratio for treatment *t*, *Yt*−*Yt* denotes the incremental grain yield resulting from fertilizer use in treatment t and control *c*, *PGt* denotes the grain price per kg and *CFt* denotes the cost of fertilizer per hectare in the treatment, *t*.

2.7. Statistical Analyses

For both agronomic and economic data, analyses of variance were carried out using SAS for Windows 9.3 [26]. Wherever there were significant differences, mean separations were carried out using least significant difference (LSD). Significant differences between means of treatments were determined at the 5% significance level ($p < 0.5$). The statistical analyses and presentations for the agronomic and economic data were based on the average of the two seasons' data. The agro-ecologies and socioeconomic conditions at Ziway and Melkassa are assumed to represent most semiarid areas in the rift valley of Ethiopia. Therefore, the findings obtained from this study can be extrapolated to other areas in the rift valley with similar agro-ecological and socioeconomic conditions.

3. Results

3.1. Yield Characteristics and Responses to Fertilizer Microdosing and Banding

Across sites, the highest fertilizer rate (80 + 80 kg ha^{-1} DAP + urea) in microdosing had significantly depressed pocket seed germination. Seedling vigor, however, did not show a considerable response to fertilizer rates. Unfertilized plots had a higher lodging count than fertilized treatments. The plant population at harvest was considerably lower in the treatment with the highest microdosing rate. On average, the fertilizer rate in banding (100 + 100 kg ha^{-1} DAP + urea) was found to have similar effects as the two lower fertilizer rates (27 + 27 and 53 + 53 kg ha^{-1} DAP + urea) in microdosing on seed germination and plant population at harvest (Table 1). Generally, most of the yield characteristics did not vary with fertilization and non-fertilization.

Table 1. Average maize yield characteristics of fertilizer rates in microdosing and banding methods of fertilizer application at Hawassa, Ziway and Melkassa sites over the 2011/2012 and 2012/2013 cropping seasons. DAP, di-ammonium phosphate.

Site	Application Method	Fertilizer rate (DAP + urea) (kg ha^{-1})	Seed Germination (%)	Seedling Vigor	Lodging Count	Plant Height	Stand Count Harvest
Hawassa	Microdose	0	97 a	3.6 a	2.0 a	197 a	46 a
		27 + 27	96 ab	4.1 a	1.0 ab	199 a	47 a
		53 + 53	96 b	3.9 a	1.0 ab	200 a	47 a
		80 + 80	92 c	3.8 a	1.6 ab	202 a	44 b
	Banding	100 + 100	97 ab	4.0 a	1.6 ab	204 a	47 a
		LSD	*1.07*	*0.54*	*1.08*	*28.34*	*1.29*
Ziway	Microdose	0	98 a	2.9 c	2.9 a	203 a	47 a
		27 + 27	98 a	3.5 bc	1.0 b	203 a	48 a
		53 + 53	98 a	4.8 a	1.0 b	212 a	48 a
		80 + 80	97 b	3.4 bc	1.0 b	204 a	46 b
	Banding	100 + 100	98 a	3.9 b	1.0 b	204 a	48 a
		LSD	*1.05*	*0.81*	*1.34*	*11.37*	*0.83*

Table 1. *Cont.*

Site	Application Method	Fertilizer rate (DAP + urea) (kg ha^{-1})	Seed Germination (%)	Seedling Vigor	Lodging Count	Plant Height	Stand Count Harvest
		53 + 53	96 b	3.9 a	1.4 ab	217 a	47 ab
		80 + 80	93 c	3.8 a	1.3 b	219 a	45 c
	Banding	100 + 100	97 ab	4.0 a	1.1 b	215 a	47 a
		LSD	*1.07*	*0.54*	*0.85*	*7.32*	*1.19*

Means in the same column with same letter are not significantly different at $p < 0.05$.

3.2. Maize Yield Responses to Fertilizer Microdosing and Banding

Across the sites, although all of the variable fertilizer rates were able to improve yield significantly over the control, there was no significant difference in yields between the fertilizer treatments. However, maize yield tended to decline with increasing fertilizer doses in microdosing. In microdosing, the maximum yield was recorded in the treatment with the minimum fertilizer rate of 27 + 27 kg ha^{-1} at Hawassa; whereas at Ziway and Melkassa, the maximum yield was found in the treatment with the 53 + 53 kg ha^{-1} fertilizer rate. Across the sites, the microdosing treatment with the 80 + 80 kg ha^{-1} fertilizer gave a consistently lower yield than all other treatments in microdosing and banding. Despite its higher doses, the banding method gave similar yields as the variable doses in microdosing (Table 2).

Table 2. Average maize grain and stover yield in relation to microdosing and banding methods at the Hawassa, Ziway and Melkassa sites over the 2011/2012 and 2012/2013 cropping seasons.

Application	Fertilizer Rate	Grain Yield (kg ha^{-1})			Stover Yield (kg ha^{-1})		
Method	(DAP + urea kg ha^{-1})	Hawassa	Ziway	Melkassa	Hawassa	Ziway	Melkassa
	0	6334 b	4054 b	3649 b	7416 b	6404 b	5610 b
Microdosing	27 + 27	7539 a	5864 a	5320 a	8850 a	8133 a	7375 a
	53 + 53	7222 a	6042 a	5542 a	8391 a	8283 a	7500 a
	80 + 80	7086 a	5743 a	5221 a	8265 a	8042 a	7167 a
Banding	100 + 100	7636 a	5815 a	5226 a	8896 a	7999 a	7375 a
	LSD	*608*	*300*	*339*	*671*	*800*	*406*

Means in the same column with same letter are not significantly different at p-value <0.05.

3.3. Fertilizer Use Efficiency, Value Cost Ratio and Profitability

FUE decreased with increasing fertilizer rates in microdosing across sites. The FUE varied between 23 and 34 for the lowest microdosing rate. Except at Hawassa, the banding method had lower FUE than the microdosing method. Regardless of fertilizer rates and the methods of fertilizer application, Ziway and Melkassa had higher FUE than Hawassa (Table 3). Equally, VCR declined with increasing fertilizer rates in microdosing across sites. The maximum VCR was recorded in microdosing treatments with the lowest fertilizer rate across the sites. Across sites, the banding method generally had a lower VCR compared to the microdosing treatment of 27 + 27 and 53 + 53 kg ha^{-1} fertilizer.

Except at Hawassa with a higher VCR, the banding method had the same VCR as the highest fertilizer rate in microdosing (Table 3).

Table 3. Average fertilizer use efficiency (FUE) and value cost ratio (VCR) of fertilizer rates in microdosing and banding methods at the Hawassa, Ziway and Melkassa sites over two seasons.

Fertilizer application		**Hawassa**		**Ziway**		**Melkassa**	
Method	**rate**	**FUE ($kg\ kg^{-1}$)**	**VCR**	**FUE ($kg\ kg^{-1}$)**	**VCR**	**FUE ($kg\ kg^{-1}$)**	**VCR**
	0	-	-	-	-	-	-
Micro-dosing	27 + 27	22.6	6.6	33.9	10.6	31.3	9.8
	53 + 53	8.4	2.5	18.8	6.0	17.9	5.7
	80 + 80	4.7	1.4	10.6	3.3	9.8	3.1
Banding	100 + 100	6.5	1.9	8.8	2.8	7.9	2.5

The labor demand (man-day $hectare^{-1}$) varied with fertilizer application techniques. The microdosing and banding methods required 4.8 and 2.3 man-day $hectare^{-1}$, respectively. The labor demand for microdosing was therefore twice that of banding.

Corresponding to yields, microdosing of the 27 + 27 kg ha^{-1} fertilizer rate generated the maximum GM at Hawassa, increasing GM by 13% compared to the control; whereas at Ziway and Melkassa, microdosing of 53 + 53 kg ha^{-1} fertilizer generated the maximum GM, increasing GM by 53 and 42%, respectively, over the control. All of the remaining fertilizer rates also increased GM considerably compared to the control at Ziway and Melkassa. Overall, lower fertilizer rates in microdosing were more economically attractive than the highest rates, as there was no significant improvement in GM with increasing fertilizer rates (Table 4). The banding method also improved GM over the control. At Hawassa, the banding method did not significantly increase GM compared to the control, but increased GM over the 80 + 80 kg ha^{-1} fertilizer in microdosing. At Ziway and Melkassa, banding increased GM by 43% and 29%, respectively, over the control.

Table 4. Average gross income (GI) and gross margin (GM) of fertilizer rates in the microdosing and banding methods at the Hawassa, Ziway and Melkassa sites over the 2011/2012 and 2012/2013 cropping seasons.

Fertilizer	**Hawassa**		**Ziway**		**Melkassa**	
rate	**GI (US\$ ha^{-1})**	**GM (US\$ ha^{-1})**	**GI (US\$ ha^{-1})**	**GM (US\$ ha^{-1})**	**GI (US\$ ha^{-1})**	**GM (US\$ ha^{-1})**
0	1393 b	1272 bc	932 c	813 c	839 c	719 c
27 + 27	1659 a	1442 a	1346 ab	1132 a	1224 ab	1009 a
53 + 53	1589 a	1333 abc	1396 a	1143 a	1275 a	1022 a
80 + 80	1559 a	1263 c	1327 b	1036 b	1178 b	887 b
100 + 100	1680 a	1400 ab	1344 ab	1069 b	1202 ab	928 b
LSD	*134*	*133*	*55*	*56*	*73*	*74*

Means in the same column with same letter are not significantly different at *p*-value <0.05.

4. Discussion

4.1. Maize Yield and Yield Characteristics Response to Fertilizer Microdosing and Banding

Irrespective of differences in agro-ecological conditions in the three study sites, all of the fertilizer rates in microdosing and the fertilizer rate in banding increased yields compared to the control. This shows that there is a need for applying fertilizer in maize production at all of the study sites. A fertilizer application method that is efficient with a smaller amount of fertilizer is what is most important for marginal farmers in the central rift valley. Such a method will have high potential to increase farmers' interest, economic viability and sustainability with respect to applying fertilizer in maize. In this respect, results from this study showed that the microdosing method of fertilizer application was found to improve maize yields with smaller quantities of fertilizer. The 27 + 27 kg ha^{-1} fertilizer rate, the lowest fertilizer rate, in microdosing was able to improve maize yield more than the higher rates in microdosing and banding across the three sites. It increased yield by 19%, 45% and 46% at Hawassa, Ziway and Melkassa, respectively, compared to the control. Previous studies have also shown similar effects that lower fertilizer rates increased crop yields more than the higher rates in microdosing [19–21] in sub-Saharan countries.

On top of that, the lower yield response in maize to the highest fertilizer rate (80 + 80 kg ha^{-1} fertilizer) in microdosing indicated that there is a limit to the dose of fertilizer that can be applied through microdosing. In this respect, the 80 + 80 kg ha^{-1} fertilizer rate in microdosing was found to depress pocket seed germination and lower plant population at harvest. These negative effects on maize performances might be attributed to the burning effects of high doses of fertilizer in the microdosing method of application. These effects are favored by a previous report that higher doses of fertilizer in the microdosing method of application may have a burning effect on seed germination and other growth stages [19]. A similar result was also obtained with spot application of fertilizer at Hawassa in maize [27]. However, the higher dose of fertilizers (100 + 100 kg ha^{-1}) in the banding method was found to have less burning effects than the variable doses of fertilizer in the microdosing method. This might be accredited to the pattern of placement of fertilizers and seeds, which affects the dose of fertilizers coming in contact with the seeds. In the microdosing method, to increase the fertilizer use efficiency, fertilizer is more precisely placed adjacent to seeds, only in the planting stations. In the banding method, however, fertilizers are placed in the entire furrows, leaving some of the fertilizer outside planting stations, which reduces the dose of fertilizers coming in close contact with seeds. As a result, the microdosing method of fertilizer application becomes more efficient in increasing maize yields than the banding method of fertilizer application. This might be due to the fact that placing fertilizer close to the seed in soils increases fertilizer uptake by crops [19,20,28].

Apart from that, a declining tendency in maize yields with increasing fertilizers doses in microdosing corresponds to an earlier report that maize agronomic responses declined beyond 46 kg ha^{-1} phosphorous fertilizer under spot application in Hawassa [27]. Although the recommended fertilizer rate (100 + 100 kg ha^{-1}) in banding was able to improve yield in maize (compared to no fertilizer application), it has a high cash outlay and is therefore more risky for the resource poor farmers, increasing their reluctance in applying fertilizers. This high rate can be one of the reasons why farmers in Ethiopia generally apply lower rates of fertilizer than national recommendations [23]. Other reports [29] also indicated that the average amount of fertilizer rate used by farmers in Ethiopia is 21 kg N ha^{-1}, which is much lower than the national recommendation rate of 60 to 100 kg N ha^{-1} [30]. The result from this study therefore revealed microdosing of fertilizers at 27 + 27 kg ha^{-1} (which corresponds to a reduction of 73% of DAP or urea compared to the national recommendation at 100 kg ha^{-1} DAP or 100 kg ha^{-1} urea) to be a low cost, low risk and an efficient dose of fertilizer across sites. Therefore, if the farmers are practicing microdosing, they can obtain a good yield at a low rate of fertilizer application. Yet, further study based on long-term data is imperative to rectifying optimum fertilizer rates for the different sites depending on soil quality and other governing agro-ecological conditions.

In relation to sites, the spatial variations in yield responses to fertilizers doses may be attributed to differences in agro-ecological conditions among the sites, namely in soil quality, degree of variability of seasonal rainfall, length of growth period and land use and land management systems. There is spatial variation between Hawassa and the other two sites (Ziway and Melkassa) in these agro-ecological conditions and land use and land management systems. Hawassa has better soil quality (for instance, higher OC, P, as well as well-drained loam soil with slightly acidic pH suitable for maize), owing to better land use and management systems, as well as higher rainfall and length of growing seasons. Among other factors, it was reported that different land management systems were found to differently affect soil quality and agricultural production in Ethiopia [1]. There was spatial variability in soil nutrients even within farms, due to different soil management systems [9], and such variability affects nutrient use efficiency and crop productivity [10]. In this respect, therefore, there is a need for considering soil fertility gradients and nutrient management to improve resource use efficiency and crop production on smallholder farms [9,10]. The lower maize yield response to fertilizer application at Hawassa (with better soil quality) can also be supported with the report that yield response to fertilization decrease with increasing soil quality [10,31].

The average total annual rainfall in Ziway, Melkassa and Hawassa over the past 12 years ranges from 518 to 1002 mm (average 815 mm), 549 mm to 1093 mm (average 877 mm), 776 mm to 1145 mm (average 988.1 mm), respectively. Apart from that, Hawassa lies in the mid-altitude zones in Ethiopia with longer growing seasons. The seasonal variability in rainfall is also lower compared to Ziway and Melkassa. Therefore, despite the better soil quality, better rainfall conditions at Hawassa might be the likely reasons for the higher maize performances, but with lower responses to fertilizer doses. Similarly, the existence of more similar agro-ecological conditions in the other two sites might be the reasons for their similarity in maize performances and responses to fertilizers. An association between spatial and temporal variation in crop responses to climate variability has been observed in East Africa [13]. The high spatial variability in rain and the high variability in the length of the growing season (late onset and early termination) between years was reported to affect crop production in the central rift valley [11,12]. Several previous studies have indicated that although the agricultural extension program in Ethiopia has promoted fertilizer application over the last few decades, its success in increasing agricultural productivity has been constrained principally by unpredictable rainfall patterns [14,15]. Moreover, in this study, Ziway and Melkassa were assumed to have similar agro-ecologies, which can represent most other semiarid areas in the Ethiopian rift valley. Therefore, the findings obtained from this study can be extrapolated to other areas in the central rift valley with similar socioeconomic and agro-ecological conditions.

4.2. Fertilizer Use Efficiency, Value Cost Ratio and Profitability of Fertilizer Microdosing and Banding

Microdosing of fertilizers gave higher FUE (kg kg^{-1}), VCR and GM (US$) compared with the recommend rate. The FUE varied from five to 23 at Hawassa, 11 to 34 at Ziway and 10 to 31 at Melkassa for the microdosing fertilizer rates, respectively. For the banding rate, the FUE value was 7, 9 and 8 at Hawassa, Ziway and Melkassa, respectively. Other studies in Ethiopia have found that nutrient use efficiency (kg yield per kg nutrient) of maize ranges between nine and 17 [32]. This indicates that the application of the smallest microdosing rate is more efficient than the highest microdosing rate.

In microdosing, VCR ranged from one to seven at Hawassa, three to 11 at Ziway and three to 10 at Melkassa. Except for the 53 + 53 and 80 + 80 kg ha^{-1} at Hawassa, the VCR was the above the recommended level. A VCR above two and preferably above four is needed under conditions of risk as in the Sahelian region [33]. Studies from Mali and Sudan in pearl millet and sorghum have shown that the VCR of microdosing is generally very favorable [19,21]. In Ethiopia, previous reports showed VCR for fertilizer maize ranging between 2.5 to 9.0 between the 1980s and 2000s [34]. In Ethiopia, case studies conducted on Sasakawa Global 2000 (SG 2000) fertilizer promotion programs have shown VCR of 9.0 in maize in the mid-1990s [35]. In Ethiopia, the return to the recommended fertilizer application rate has been generally positive in recent years, with VCR around the threshold of two [36].

In this study, microdosing with lower fertilizer rates was able to improve VCR beyond the threshold, thereby minimizing the financial risk for farmers. The optimum rates in microdosing were able to improve VCR above the threshold. The VCR obtained from banding at 100 + 100 kg ha^{-1} was around the threshold. The microdosing rate at 80 + 80 kg ha^{-1} had similar VCR to banding. The VCR at the threshold value is likely to give an unfavorable VCR in years with low rainfall or unfavorable market conditions. As a result, the banding rate is less attractive to farmers, due to high risks and high cash outlays. Microdosing of a small amount of fertilizer may be a better option for resource-poor smallholding farmers at the study sites [19–21]. The lower rate at 27 + 27 kg ha^{-1} will normally be preferred by farmers, because of its higher VCR. This study shows that microdosing can reduce farmers' cash outlay and risk; thereby making the use of fertilizer more attractive. Previous studies in the Sahelian region also confirmed that crop productivity can be increased at a low cost and very moderate risk to farmers [21].

The lowest microdosing rate at 27 + 27 kg ha^{-1} generated a higher GM than the 80 + 80 kg ha^{-1}, banding rate (except at Hawassa) and control. The application of small quantities of fertilizer with the microdosing method becomes more profitable than the application of large quantities of fertilizers with either the microdosing or banding methods. The maximum increase in GM over the control was 13%, 53% and 42%, at Hawassa, Ziway and Melkassa, respectively. Corresponding to yield responses, the higher GM with small quantities at 27 + 27 kg $ha^{-1}$of fertilizer under microdosing may attract farmers toward applying fertilizers in maize. Unlike at Ziway and Melkassa, the banding method did not improve GM over the control at Hawassa, having a lower response to fertilizer. This may be related principally to the better soil quality, seasonal rainfall and the length of the growing season at Hawassa.

This indicates that under a better soil management system and favorable seasonal rainfall conditions, farmers can still get reasonable yields from crops.

Although the labor demand in microdosing (4.8 man-days ha^{-1}) is nearly twice that in banding (2.3 days ha^{-1}) for the application of fertilizers, the microdosing method still appears attractive and viable. Like in several other areas in Ethiopia, the opportunity cost for labor is low in the central rift valley.

4.3. Limitations and Opportunities in Using Fertilizers

The unpredictable climatic conditions in timing and severity—drought and prolonged dry spells—in the central rift valley escalate the risk-averse conditions of the marginal farmers and inhibit investment in high cost fertilizers and technologies [11,12], because the downside risk for marginal farmers is extremely high. Therefore, the microdose method appears to be particularly interesting to farmers having access to only small quantities of fertilizer in risk-prone areas and to the poorest farmers. For the poorest farmers, it is far less risky to use microdosing than the banding method. Particularly, it appeared attractive for boosting the productivity and incomes of maize by using fertilizer rates that are 73% lower than the recommended rate. On top of that, as the use of the microdosing method brings entire changes to the existing fertilizer application methods, there is a need for a strong linkage among researchers, farmers, and policy makers. The knowledge transfer would be more productive if it becomes part of the national agricultural extension system.

5. Conclusions and Recommendations

Microdosing in maize is an interesting option for farmers, because it gives a high yield, VCR and FUE; as well as favorable gross margins. Both fertilizer microdosing and banding improves yields. The lowest fertilizer rates improve yields as much as higher rates under both microdosing and banding. At Hawassa, the gross margin in microdosing was similar to banding, but it required 47% to 73% less fertilizer. However, at Ziway and Melkassa, these lower fertilizer rates under microdosing gave higher GM than higher rates under microdosing and banding. The higher FUE in microdosing shows that it is more efficient than banding, which may increase farmers' interest in applying fertilizer with the microdosing method. Microdosing has a higher VCR than banding and is therefore a less risky and more affordable method for farmers. In conclusion, lower fertilizer rates under microdosing are more productive and profitable than higher rates under microdosing or banding methods. Based on the results from these experiments, application of 27 kg DAP ha^{-1} at sowing and 27 kg urea ha^{-1} at jointing in maize could be an option for the marginal farmers across the sites. Yet, as the findings from this study are based only on two years of data, we suggest further investigation (based on long-term data) for rectifying the optimum rates for the microdosing method of fertilizer application in the study areas.

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Author Contributions

Getachew Sime was responsible for planning, designing, site selection and executing all the experiments, analysis and interpretation of results. He has prepared the first draft of the paper and wrote the final version in collaboration with Jens B. Aune, he also had substantial contribution in the planning, analysis and interpretation of results. He visited all the experiments at Ziway and Melkassa in Ethiopia. Overall, he was the main supervisor of this paper.

Conflicts of interest

The authors declare no conflicts of interest.

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Paper III

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SEQUENTIAL EFFECTS OF MINIMUM TILLAGE, SEED PRIMING, FERTILIZER MICRODOSING AND MULCHING IN MAIZE, SEMIARID CENTRAL RIFT VALLEY OF ETHIOPIA

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SUMMARY

Intensification of maize production is imperative to improve food security for the rising population in the central rift valley (CRV) of Ethiopia, whose livelihood is principally based on rainfed maize that operates under shrinking landholding and high seasonal rainfall variability. This study examined different levels of intensification options in maize production by sequentially introducing minimum tillage and seed priming, phosphorus (P) fertilizer microdosing, surface mulching and nitrogen (N) fertilizer microdosing. Field experiments were conducted with five treatments, steps or levels consisting of conventional tillage (farmers practice as a control); minimum tillage + seed priming, unfertilized (step 1); step 1 + microdosing 53 kg ha^{-1} P (step 2); step 2 + 4 ton ha^{-1} maize stover as surface mulch (step 3) and step 3 + 53 kg ha^{-1} N (step 4). These steps represented increasing levels of intensification. Except at the lowest level (step 1), agronomic and economic responses improved with increasing levels of inputs. Relative to the very high and increasing gross margin, production costs were low but slowly increased with increasing levels of inputs. Except at the lowest level, the value cost ratio was above 4 even at the highest levels of inputs, demonstrating that such kind of intensification can be achieved with low risk. Likewise, the fertilizer use efficiency was quite high even at the highest of levels of inputs signifying the efficiency of the pocket application of fertilizer through the microdosing method. The improvement in maize establishment and yield and the reduction in the days to maturity could contribute to make maize production more adaptive to the existing seasonal rainfall variability. Depending on the affordability to the external inputs and their feasibilities, the different technology packages in the intensification ladder may give different choices for the farmers to improve maize production in the CRV of Ethiopia.

INTRODUCTION

In Ethiopia, 97% of agricultural production depends on rainfed systems and the variability in rainfall makes farming risky (Blocka *et al.*, 2008). Agricultural technologies which can mitigate the impact of the high seasonal rainfall variability on crop production in Ethiopia are imperative to improve the livelihoods of marginal farmers (Biazin and Stroosnijder, 2012; Kassie *et al.*, 2013; Sime *et al.*, 2015). The heavy dependence on low external inputs (Conway and Schipper, 2011; Demeke *et al.*, 2011) and widespread land degradation have further impaired the agricultural practice in Ethiopia (Haileslassie *et al.*, 2005; Nyssen *et al.*, 2008).

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The central rift valley (CRV) region in Ethiopia, where this study was conducted is one of the most climatically vulnerable areas with arid and semiarid land and frequent droughts (Garedew *et al.*, 2009; Meshesha *et al.*, 2012). Increasing population and livestock pressures on limited resources, traditional farming system and poverty are major factors causing increased land use, changes in vegetation cover and severe degradation in the region (Garedew *et al.*, 2009; Meshesha *et al.*, 2012). The expanding land degradation has decreased agricultural productivity, which further exacerbated food insecurity and poverty in the region (Garedew *et al.*, 2009; Meshesha *et al.*, 2012).

Despite the marginal agroecological conditions, farmers in the region are resource-poor and have financial constraints to use increased external inputs like fertilizers and improved seeds in crop production (Kassie *et al.*, 2013). Low cost, low risk and environmentally friendly technologies could motivate farmers to use external inputs in maize production. Such technologies could include decreasing certain inputs; for example, the microdosing method which is the use of more effective application of small amounts of fertilizer in the pocket beside seeds, and the use of row sowing method that saves the expensive seeds and fertilizers (Sime and Aune, 2014), and better targeting early maturing and drought tolerant varieties of maize (Sime and Aune, 2014; Sime *et al.*, 2015). Each of these technologies were reported to yield a promising significance in the agronomic and economic responses in maize production (Sime and Aune, 2014; Sime *et al.*, 2015). Furthermore, such technologies have been identified as promising low-cost methods for increasing agricultural productivity in dryland areas of the Sahel (Aune and Bationo, 2008). In the current study, these technologies were differently packaged, designed and sequenced to further improve the agronomic and economic responses in maize while making maize productive more adaptive to the prevailing seasonal rainfall variability in the region. The ‘ladder approach’ can be considered as a way to provide such technology options in agricultural systems (Aune and Bationo, 2008). The ‘ladder approach’ shows the relationship between increasing levels of inputs and outputs. Various packages of these technologies at different levels of a ladder may intensify the productivity of maize and hence the economic benefits of farmers. The objective of this study was therefore to examine the additional productivity of maize that can be obtained by sequentially introducing the technologies of minimum tillage and seed priming, pocket application of phosphorus (P) fertilizer, surface mulching and application of nitrogen (N) fertilizer.

MATERIALS AND METHODS

Description of the study sites

The research sites, Ziway and Melkassa, are situated at 7°9′N and 38°43′E and 8°4′N and 39°31′E respectively, at 1642 and 1550 m.a.s.l. in the CRV of Ethiopia. They are characterized as semi-arid agro-ecological zones (Garedew *et al.*, 2009; Meshesha *et al.*, 2012). The soil in the CRV of Ethiopia is poor in fertility (Biazin and Stroosnijder, 2012; Temesgen *et al.*, 2008) and is shallow soil with frequent crusting and plow pans (Biazin and Stroosnijder, 2012). The rainfall condition exhibits high intra-seasonal variability with a coefficient of variation of 15–40%, and temperature increased significantly (0.12–0.54°C per decade) over the past 30 years (Kassie *et al.*, 2014).

Ziway has a well-drained clay loam soil (Sime *et al.*, 2015). The total amount of rainfall received over 2011 and 2012 was 598 and 857 mm respectively. The total amount of annual rainfall received during the experimental period of the 2011/2012 and 2012/2013 cropping seasons (June to October) was 434 and 732 mm, which is 73 and 85% of the total annual rainfall received, respectively. Melkassa has a well-drained loam soil (Sime *et al.*, 2015). The total amount of annual rainfall received over 2011 and 2012 was 923 and 924 mm, respectively. The total amount of rainfall received during the experimental period (June to October) for the same years was 685 and 822 mm, which is 74 and 89% of the total annual rainfall received respectively.

The rainfall data were obtained from meteorological stations at the Adami Tullu (in Ziway) and Melkassa Agricultural Research Centers for the Ziway and Melkassa experiments, respectively.

Crop production, mainly rainfed, cereal-based production systems and modest livestock rearing are the mainstays of livelihoods for farmers in the CRV. Maize is the major crop cultivated with significant role in the livelihoods of smallholders in the CRV (Biazin and Stroosnijder, 2012). There are two overlapping seasons for crop production. The first season usually extends from April to September depending on the onset of rain while the second season, which is the main rainy season, extends from June to October. July and August are the wettest months. Mid-maturing maize (*Zea mays* L.) is the main crop for the first (and longer) season while haricot bean (*Phaseolus vulgaris* L.), wheat (*Triticum aestivum* L.) and *teff* (*Eragrostis tef* (Zucc.) Trotter) are the main crops for the second season. Early-maturing maize is cultivated during both seasons.

Treatments, experimental design and procedures

On-station and on-farm experiments of maize were conducted for two successive years. The on-station experiments were undertaken in Ziway and Melkassa for the cropping seasons of 2011/2012 and 2012/2013. During the same cropping seasons, the on-farm experiment was conducted at Ziway in three villages with nine farmers.

There were five steps, levels or treatments both in the on-station and on-farm experiments:

1. **Farmers practice as a control (CTc)**: CT (4 passes with plough) + non-primed maize seed + no fertilizer.
2. **Step 1 (MP)**: Minimum tillage (1 pass with plough) + primed maize seed + no fertilizer.
3. **Step 2 (MPM)**: Minimum tillage + primed maize seed + 53 kg ha^{-1} P fertilizer applied at planting.
4. **Step 3 (MPMM)**: Minimum tillage + primed maize seed + 53 kg ha^{-1} P fertilizer applied at planting + 4 ton ha^{-1} mulch.

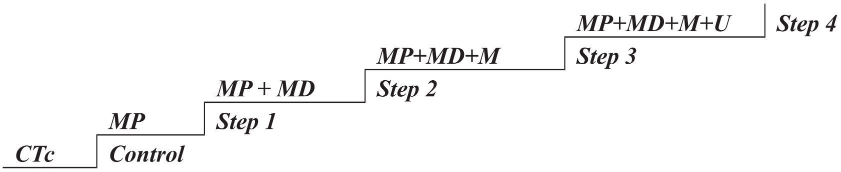

Figure 1. A ladder showing different level of inputs as package of technologies.
Key: CTc: conventional tillage (CT) as a control (c); MP: minimum tillage (M) and seed priming (P); MD: microdosing of DAP fertilizer; M: surface mulching with maize stover; and U: microdosing of urea fertilizer.

5. **Step 4 (MPMMU)**: Minimum tillage + primed maize seed + 53 kg ha^{-1} P fertilizer applied at planting + 4 ton ha^{-1} mulch + 53 kg ha^{-1} N fertilizer applied at maize knee height.

The sources of P and N fertilizer were diammonium phosphate (DAP) and urea respectively.

The first level in the ladder represented farmers practice, whereas the other steps were used to give farmers different technology options in maize production (Figure 1). Most of these technologies are cost-saving technologies besides their potential to mitigate the effects of seasonal rainfall variability on maize production. Except seed priming, the individual effects of these technologies on maize production were studied in the same sites during the same period (Sime and Aune, 2014; Sime *et al.*, 2015). At the same time, the same research team was interested to investigate the sequential effects of these technologies as a package on the agronomic and economic responses in maize. The choice of technologies was based on the major production constraints in the study area. They were packaged and sequenced in the order of the production costs, importance of inputs and level of availability of inputs. Minimum tillage was introduced as an option to conventional tillage with more tillage requirement and rental costs (Aune *et al.*, 2001; Sime *et al.*, 2015). In Ethiopia, fertilizer is expensive to most farmers, despite its unavailability and traditional way of application (CSA, 2008; Spielman *et al.*, 2010). Due to high prices, the use of urea is limited as a result, there is a failure to use DAP and urea in proper combinations (Endale, 2010). This was the reason for the introduction of the fertilizer microdosing method, the pocket application of fertilizers beside seeds, which saves fertilizers besides increasing crop fertilizer use efficiency (Aune and Bationo, 2008; Sime and Aune, 2014). The other constraint to maize production in relation to the impact of rainfall variability include poor seed germination, seedling establishment and partial or complete crop failure, that was the reason for the introduction of on-farm seed priming as an option for dry seed sowing. Seed priming is cheap and does not add any expenditure to farmers (Aune and Bationo, 2008) and improves maize establishment and yields in semiarid agriculture (Harris *et al.*, 1999). Yield losses or no yield benefits are likely in the short-term practice of conservation tillage, which may need up to 10 years (Giller *et al.*, 2009). This was the reason for cofounding minimum tillage with seed priming. Mulching was used earlier than urea, because it is cheaper and more available to most farmers which otherwise would have been brought to the end of the ladder. It was introduced as

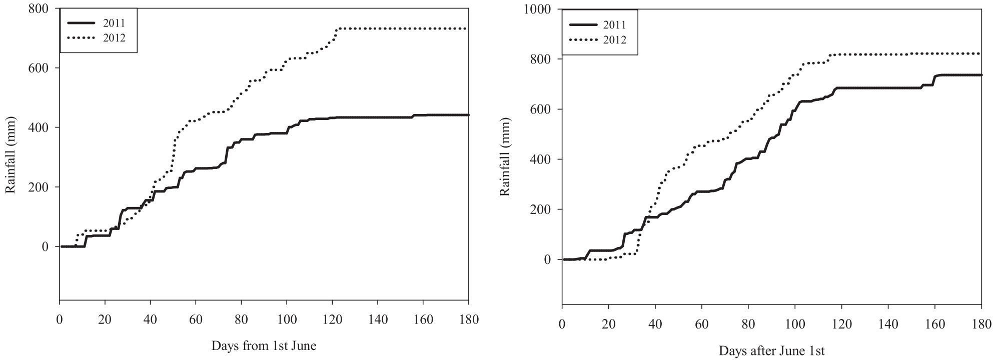

Figure 2. Cumulative rainfall (mm) at Ziway (left) and Melkassa (right) during the experimental period from first of June to November of 2011 and 2012.

Source: The sources of the rainfall data for Ziway and Melkassa sites are Adami Tulu and Melkassa Agricultural Research Centers repectively.

part of the technologies to mitigate the effect of seasonal rainfall variability on maize production. In this regard, mulching was reported to give a promising significance to maize production in the region (Sime *et al.*, 2015).

The crop tested was drought tolerant early maturing variety of maize (*Z. mays* L. var. Melkassa-2). Maize seed was primed by soaking in water for 12 hours, then surface drying for 2 hours on dry cloth and being kept under shade and sowed immediately. Fertilizer and seeds were applied in two separate operations.

The plot size was 3 m× 4.5 m (13.5 m^2). The spacing was 75 cm between rows and 25 cm between plants. The seed rate was 27 kg ha^{-1}. The treatments were arranged in a randomized complete block design with four replications. The blocks were separated by a 1.5 m wide open space. Hand weeding was undertaken using a local hand hoe three and six weeks after planting. Permanent plots were used for the entire period of the experiments. Mulched treatments retained their maize stalks as mulching. A 4 ton ha^{-1} mulch was applied based on Matsumoto et al. (2004) to control weed and increase soil moisture in the drylands of Ethiopia.

The different treatments presented above can be considered as different levels in the ladder approach (Aune and Bationo, 2008). There were four levels in the ladder to intensify the productivity of maize. The inputs were successively added to the first, second, third and fourth level in the ladder (Figure 2).

Farmers at the study sites actively participated in the planting, weeding and harvesting; providing the main source of labour. The on-farm experiments were managed mainly by farmers and partly by researchers, following jointly agreed protocols.

Agronomic data measurements

The major agronomic data collected include days to emergence, pocket seed germination (50%), seedling vigour (rated 1–5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous), days to tassel (50%) and to physiological maturity

(75%), lodging count, plant height (cm), and grain and stover yield (kg ha^{-1}). Plants fallen, inclined or with broken stalk were considered as lodged. Plant height was measured from the ground level to the base of the tassel for five randomly selected plants per plot. Biomass weight was taken after sun drying for 8 days. Threshing was done manually. To avoid border effects, data of all the parameters were taken from the four central rows, thus, the net plot size was 9 m^2. After harvesting cobs, for each treatment, cobs were shelled, weighed and grain moisture content was measured immediately by a multigrain digital moisture meter. Eventually, the grain yield weight was adjusted at 12.5% moisture level. Yield was extrapolated and then reported on a hectare basis.

Economic data measurements

The agronomic efficiency, risk and profitability of using fertilizers were assessed by calculating the fertilizer use efficiency (FUE), value cost ratio (VCR) and gross margin (GM).

Agronomic fertilizer use efficiency

The agronomic FUE of each treatment was computed as the difference in yield (kg ha^{-1}) between each treatment and control divided by the amount of fertilizer applied (kg ha^{-1}).

$$FUE = \frac{Yt \times Ct}{Ft},$$

where *FUE* is the agronomic fertilizer use efficiency of treatment *t*; *Yt* is the grain yield of treatment *t*; *Ct* the grain yield of the control treatment; and *Ft* is the rate of fertilizer used for treatment *t*.

Economics of fertilizer use

Standard enterprise budgeting techniques were used to estimate production costs and profitability. GM and VCR were used for the analysis of profitability of each treatment. Average labour cost for the various farm activities of planting, fertilizer application, mulching, weeding and harvesting was estimated as $person^{-1}$ day^{-1}. Oxen rental cost for one pass was estimated at 11 US$ ha^{-1}. The input costs of maize seeds and fertilizer DAP and urea kg^{-1} was estimated at 1.14, and 0.82 and 0.63 US$ respectively at the local market. The price of grain, averaged over 2011 and 2012, was estimated at 0.23 US$ kg^{-1} at local markets. Gross income (GI) was calculated from grain price. Labour cost was estimated at 1.64 US$ $person^{-1}$ day^{-1} across the sites (the average rate paid by research institutions and private organizations). The study sites have similar input and output markets. Total variable cost (TVC) was calculated as the sum of labour and input costs. Monetary values related to costs and incomes were converted from Ethiopian Birr at the exchange rate of one US$ to 18.24 Ethiopian Birr.

For each treatment, the GM was calculated as follows:

$$\mathrm{GM} = \mathrm{GI} - \mathrm{TVC}$$

The VCR was calculated as follows:

$$\mathrm{VCR} = \frac{\Delta Y \times p}{Cf},$$

Where ΔY denotes incremental grain yield resulting from treatment, p denotes grain yield price kg^{-1}, and Cf denotes fertilizer cost ha^{-1}.
The VCR for each treatment measures the increase in revenue relative to the increased cost of fertilizer compared to the control treatment.

Statistical analyses

The SAS System (Version 9.3) from SAS Institute Inc. (SAS, 2011) was used for the statistical evaluation of treatment effects on maize yield and yield characteristics compared to the control. To determine statistical significances between differences in means of the treatments, analyses of variance were carried out. Wherever there were significant differences, mean separations were carried out using least significant difference (LSD). Significant differences between means of treatments were determined at 5% significance level (p *value* < 0.05). Unless mentioned in the text, only significant differences between means of treatments were reported.

RESULTS

Increasing levels of inputs, yield characteristics and yield in maize

Different levels of input use were tested according to the ladder approach (Aune and Bationo, 2008). It was found that increasing levels (Figure 1) of intensification improved crop characteristics and maize yields (Tables 1 and 2), FUE and VCR (Table 3) and economic profitability (Tables 4 and 5). Dry spells and end of season drought could also affect maize yields (Figure 2).

Step 1: Addition of seed priming and minimum tillage

Compared to farmers' practice, the package of minimum tillage and seed priming improved days to emergence (DEM), pocket seed germination (GERM), while reduced days to physiological maturity (DMAT) in on-station experiments at both sites as well as days to tassel (DTAS) at Melkassa. This package improved DEM and seedling vigour (VIG) and reduced DMAT in on-farm experiment (Table 1).

Step 2: Addition of P fertilizer to step 1

Compared to farmers' practice, the package of minimum tillage, seed priming and application of P increased DEM, GERM and VIG and reduced DTAS and DMAT in on-farm and on-station at Ziway as well as improved VIG in on-station at Ziway and reduced plant lodging (LODG) at Melkassa. It increased VIG and reduced DMAT in on-station at Ziway compared to the preceding step (Table 1). This technology package also improved maize yields both in on-station and on-farm

Table 1. Average maize yield characteristics in response to minimum tillage, seed priming, fertilizer microdosing and mulching.

Site	Treatment	Days to emergence	Seed germination (%)	Seedling vigour (scale)	Days tassel	Days maturity	Lodging count (scale)	Plant height (cm)
Ziway (On-station)	CTc	7a	96b	1.9b	68a	129a	4a	199b
	MP	5b	99a	2.3b	66ab	125b	3a	200b
	MPM	5b	98a	3.9a	63bc	121c	3a	206ab
	MPMM	5b	98a	4.4a	61c	118d	1b	207ab
	MPMMU	5b	98a	3.9a	60c	116d	1b	212a
	LSD	*0*	*1.2*	*0.8*	*3.8*	*2.2*	*1.6*	*11.9*
Ziway (On-farm)	CTc	7a	95.9c	1.9c	68a	128a	6a	195a
	MP	5b	96.4bc	2.8b	68a	126b	5ab	197a
	MPM	5b	97.1ab	3.3ab	66a	125b	4bc	200a
	MPMM	5b	97.6a	3.6a	63b	122c	3c	205a
	MPMMU	5b	97.0ab	4.0a	60c	120d	3c	205a
	LSD	*0*	*1.0*	*0.8*	*2.9*	*0.8*	*1.3*	*10.9*
Melkassa (On-station)	CTc	7a	96b	2.1b	71a	128a	3a	194b
	MP	5b	98a	3.1b	65b	125b	2a	195b
	MPM	5b	97a	3.6ab	63bc	122bc	2a	207ab
	MPMM	5b	98a	3.9ab	62bc	120cd	2a	211a
	MPMMU	5b	98a	4.4a	61c	118d	1a	217a
	LSD	*0*	*1.2*	*0.6*	*3.3*	*2.9*	*1.7*	*15.7*

Means in the same column with same letter are not significantly different at p value < 0.05.

Key: CTc = conventional tillage with no priming, farmers practice; MP = minimum tillage with seed priming, MPM = minimum tillage, seed priming and microdosing of DAP; MPMM = minimum tillage, seed priming, microdosing of DAP; and mulching and MPMMU = minimum tillage, seed priming, microdosing of DAP, mulching and urea.

Seedling vigour (1–5 scores where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous).

Lodging count refers to number of plants fallen, inclined or with broken stalk.

Table 2. Average maize grain and stover yields in response to minimum tillage, seed priming, fertilizer microdosing and mulching.

	On-station				On-farm	
	Grain yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Ziway	
Treatment	Ziway	Melkassa	Ziway	Melkassa	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CTc	3794d	3798d	6456d	5971d	3314d	5386c
MP	3878d	3906d	6620d	6042d	3370d	5472c
MPM	4583c	4533c	7438c	6886c	4047c	6108b
MPMM	5101b	4909b	7964b	7639b	4464b	6431b
MPMMU	6093a	5597a	8974a	8395a	5024a	7028a
LSD	*443*	*338*	*483*	*421*	*210*	*366*

Means in the same column with same letter are not significantly different at p value < 0.05.

Key: CTc = conventional tillage with no priming, farmers practice; MP = minimum tillage with seed priming; MPM = minimum tillage, seed priming and microdosing of DAP; MPMM = minimum tillage, seed priming and microdosing of DAP and mulching; and, MPMMU = minimum tillage, seed priming and microdosing of DAP, mulching and urea.

Table 3. Average agronomic fertilizer use efficiency (FUE) and value cost ratio (VCR) in response to fertilizer microdosing.

	On-station experiment				On-farm experiment	
	FUE (kg kg^{-1})		VCR		Ziway	
Treatment	Ziway	Melkassa	Ziway	Melkassa	FUE (kg kg^{-1})	VCR
MPM	15	14	4	4	14	4
MPMM	25	21	7	6	22	6
MPMMU	22	17	7	5	16	5

Key: MPM = minimum tillage, seed priming and microdosing of DAP; MPMM = minimum tillage, seed priming and microdosing of DAP and mulching; and, MPMMU = minimum tillage, seed priming and microdosing of DAP, mulching and urea.

Table 4. Average gross income and gross margin in response to minimum tillage, seed priming, fertilizer microdosing and mulching.

	On-station experiment				On-farm experiment	
	Ziway		Melkassa		Ziway	
Treatment	Gross income (US$ ha^{-1})	Gross margin (US$ ha^{-1})	Gross income (US$ ha^{-1})	Gross margin (US$ ha^{-1})	Gross income (US$ ha^{-1})	Gross margin (US$ ha^{-1})
CTc	873e	784d	874e	785d	762d	642d
MP	892d	801d	898d	808d	775d	677d
MPM	1054c	894c	1043c	882c	931c	763c
MPMM	1173b	1018b	1129b	973b	1027b	894b
MPMMU	1401a	1207a	1287a	1093a	1156a	988a
LSD	*18*	*17*	*22*	*23*	*20*	*57*

Means in the same column with same letter are not significantly different at p value < 0.05.
Key: CTc = conventional tillage with no priming, farmers practice; MP = minimum tillage with seed priming; MPM = minimum tillage, seed priming and microdosing of DAP; MPMM = minimum tillage, seed priming and microdosing of DAP and mulching; and, MPMMU = minimum tillage, seed priming and microdosing of DAP, mulching and urea.

compared to farmers' practice and the package in the preceding step. The addition of P fertilizer to the previous step further improved maize yields in on-farm and on-station (Table 2).

Step 3: Addition of surface mulching to step 2

Compared to farmers' practice, the package of minimum tillage, seed priming, application of P and mulching improved all the average maize yield characteristics except plant height (PH) in on-farm and on-station at Ziway. At Melkassa, likewise, this package improved all these characteristics except VIG and LODG in on-station. Compared to the package in step 1, VIG, DTAS, DMAT and LODG were improved in on-station and on-farm with improved GEM in addition to in on-farm at Ziway. Likewise, DTAS, DMAT and PH were improved in on-station at Melkassa. Compared to the package in step 2, DMAT and LODG in on-station experiments and DTAS and DMAT in on-farm were improved at Ziway (Table 1). This technology package also improved maize yields both in on-station and on-farm

Table 5. Average production cost, gross margin and labour in response to the sequential use of minimum tillage, seed priming, fertilizer microdosing and mulching over sites and experiments.

Treatment	Labour cost (day ha^{-1})	Production cost (US$ ha^{-1})	Gross margin (US$ ha^{-1})
CTc	29d	89d	737d
MP	40c	91d	762d
MPM	43b	155c	846c
MPMM	45a	161b	962b
MPMMU	46a	194a	1096a
LSD	*1.7*	*0.8*	*58*

Means in the same column with same letter are not significantly different at p value < 0.05.

Key: CTc = conventional tillage with no priming, farmers practice; MP = minimum tillage with seed priming; MPM = minimum tillage, seed priming and microdosing of DAP; MPMM = minimum tillage, seed priming and microdosing of DAP; and mulching and MPMMU = minimum tillage, seed priming and microdosing of DAP, mulching and urea.

compared to farmers' practice and all packages in the preceding steps (Table 2). Compared to the previous step, the addition of mulching had further improved maize yields in on-farm and on-station.

Step 4: Addition of N fertilizers to step 3

Compared to farmers' practice, the addition of N to the variable inputs in step 2, i.e., the package of seed priming, P fertilizer application and mulching, improved most of the maize yield characteristics in both in on-station and on-farm except PH in on-farm and LODG at Melkassa. Compared to the package in step 1, VIG, DTAS, DMAT, LODG and PH in on-station at Ziway, VIG, DTAS, DMAT and LODG in on-farm and VIG, DTAS, DMAT and PH in on-station were improved at Melkassa. Compared to the package in step 2, this package improved DMAT and LODG at Ziway and DMAT at Melkassa in on-station and DMAT in on-farm. Similarly, the package in this step improved DTAS and DMAT in on-farm (Table 1). This technology package also improved maize yields both in on-station and on-farm compared to farmers' practice and all other packages in the preceding steps (Table 2). The addition of N to the technology packages in the preceding step further improved maize yields both in on-farm and on-station compared to the technology package in the preceding step (Table 2).

Compared to farmers practice, the improvement in maize establishment (DEM, GERM and VIG) and the reduction in DTAS, DMAT and the improvement in yields appeared to favourably affect farmers' livelihood by making maize production more adaptive to the prevailing seasonal rainfall variability. Farmers frequently suffer poor crop establishment and re-sowing. There was frequent short-term dry spells occurring during the growing seasons (Figure 2). For instance, earlier maturity would help plants to avoid the end of season drought in September (Figure 2).

Fertilizer use efficiency and economic responses

The package of seed priming, minimum tillage and application of 53 kg ha^{-1}, P fertilizer generated an FUE value ranging from 14 to 15 across experiments (Table 3). The VCR value was 4 across experiments. The FUE and VCR were further increased with the application of mulching in step 2. The FUE value was between 21 and 25 in on-station experiments and was 22 in on-farm. Similarly, the VCR value was between 6 and 7 in on-station and 6 in on-farm. The application of 53 kg ha^{-1} N fertilizer in the final level of the ladder resulted in a FUE value ranging between 17 and 22 in on-station and was 16 in on-farm. The VCR ranged between 5 and 7 in on-station and was 5 in on-farm (Table 3).

Except at the lowest level, GM increased with increasing levels of intensification (Tables 4, 5). The cost of maize seed, DAP and urea was 31, 44 and 34 US$ ha^{-1} respectively. The oxen rental cost for minimum tillage and CT was 44 and 11 US$ ha^{-1} respectively. Thus, compared to CTc, minimum tillage reduced oxen rental costs by 75%. The difference in GM between fertilized and non-fertilized levels also extends to labour cost for fertilizer application.

DISCUSSION

Agronomic responses

Although the first level in the ladder of intensification did not significantly improve yields of maize, it had improved yield characteristics such as DEM, GERM, VIG, DTAS and maturity. The improvements in these yield characteristics most likely infer to seed priming. Previous studies indicated seed priming (soaking seeds in water) promotes GERM, yield and yield attributes (Aune and Ousman, 2011; Harris *et al.*, 1999). Seed priming can be used as a strategy to mitigate the impacts of climatic variability on maize production (Harris *et al.*, 1999). Seed priming will normally increase yields under dryland conditions (Harris *et al.*, 1999). In this step, minimum tillage was combined with seed priming to avoid the risk of yield penalty. This is because yield losses or no yield benefits are likely in the short-term practice of conservation agriculture (Giller *et al.*, 2009). Other studies from the same region have shown that minimum tillage alone will not increase yield over short-term practice when compared with farmers practices (Sime *et al.*, 2015). Minimum tillage was therefore introduced as a cost saving technology for oxen traction power, which is expensive in Ethiopia (Aune *et al.*, 2001; Sime *et al.*, 2015) and environmentally friendly technology in terms of land degradation and soil moisture conservation (FAO, 2013).

In the following step, most of the yield characteristics improved almost in a similar way as in the preceding step compared to farmers practice but with further improvements in most of the yield characteristics. There was an apparent increase in yield which appeared due to the application of P. Previous studies also indicated that fertilizer microdosing in combination with seed priming is an efficient way to improve crop productivity in dryland agriculture (Aune and Ousman, 2011; Aune and Bationo, 2008; Aune *et al.*, 2007). Microdosing, which consists of applying a small amount of fertilizer in the planting pocket has been found to increase yields at a low cost (Aune and Bationo, 2008; Aune and Ousman, 2011; Aune *et al.*, 2007; Sime and Aune, 2014). Therefore, the introduction of fertilizer microdosing method could be an opportunity for the marginal farmers in the CRV who due to high fertilizer prices and lack of technologies are unable to apply fertilizer in maize. Previous studies in the same sites showed similar advantage of fertilizer microdosing over farmers practice and national recommendation which apply high fertilizer rates (Sime and Aune, 2014).

Then in step 3, the package in this step further improved most of the yield characteristics and yields. These agronomic improvements therefore signified the importance of mulching. Mulching was reported to have high potential in improving maize yields in the CRV (Sime *et al.*, 2015).

In the final step, like in the preceding steps there was increase in the yield characteristics and yield. The increase in maize grain yield by 47 to 61% and stover yields by 30 to 41% signified the importance of applying N in maize production in the region. In Ethiopia, due to the high costs of fertilizers and lack of sufficient training, the application of N in cereal production is low compared to the application of P (Dorosh and Rashid, 2013). Therefore, the high agronomic responses to applying small amounts of N fertilizer combined with package of minimum tillage, seed priming, P fertilizer and mulching may motivate farmers to apply N in maize production. Most of these technologies are cost saving and yield increasing. Therefore, such package of technology can be an available option for farmers.

Overall, the various packages of minimum tillage, seed priming, application of *P*, mulching and the application of N fertilizer substantially improve crop establishment, and grain and stover yields. The introduction of the different options of farming systems in the region may be used as a mitigation strategy for the increasing climatic variability (Kassie *et al.*, 2014) that are worsening agricultural productivity and the livelihoods of farmers in the region. Therefore, the different levels give different options for farmers depending on their preferences based on their economic capacity, expected seasonal rainfall or both.

Fertilizer use efficiency and economic responses

A VCR above 4 is required in order to have an acceptable level of risk in dryland areas, such as the Sahel (Koning *et al.*, 1998). In this regard, it is economically attractive for farmers to use the different levels of intensification. Normally, there is a clear drop in VCR as the level of intensification increases, but in this study it was possible to maintain the VCR above the acceptable level of 4, an effect which might be mainly achieved through the introduction of mulch. In Ethiopia, despite the considerable use of inputs and efforts for intensification, low technical efficiency in the application of fertilizer is a factor affecting agricultural productivity (Spielman *et al.*, 2010). Fertilizer application may be yielding negative returns for many farmers, limiting its further intensification (Byerlee *et al.*, 2007). Our current study shows that it is possible to circumvent the problem of negative response to fertilizer by applying fertilizer as microdosing in pockets beside seeds. Our previous studies also indicated a similar

VCR response to smaller rates of fertilizer microdosing without combining it with the technologies in the current study (Sime and Aune, 2014).

Except at the lowest level, the GM increased with increased levels of inputs in an almost similar way as to the yields. The GM responses might therefore be better explained in terms of the yield benefits each level of intensification contributes. Likewise, except at the lowest level, production cost increased with increasing levels of intensification. The major differences in production costs between the different levels relate to the cost of fertilizer, oxen rental cost and labour requirements for tillage, fertilization and weeding. Labour cost tended to increase with increasing levels of intensification.

Constraints and opportunities for the intensification of maize production

Increasing land degradation (Garedew *et al.*, 2009; Meshesha *et al.*, 2012) and rainfall variability (Kassie *et al.*, 2014) are major factors driving the need for an alternative farming system in the CRV of Ethiopia. Shrinking landholdings as well as rising human and livestock populations are additional factors. The technologies tested in this study appeared to improve the resilience to seasonal rainfall variability of maize production by improving crop establishment, reducing time to maturity and lodging and improving yields.

Seed priming and microdosing were identified as simple and low-cost technologies for increasing yields. The high labour demand in fertilizer microdosing method appeared to be a constraint to its uptake, but the labour demand can be reduced either through using a home-made measuring cup or the two-finger approach. Sime and Aune (2014) later reported a lower rate of fertilizer microdosing, 27 + 27 kg ha^{-1} of DAP + urea rate, as possible optimum rates in maize production in the same study sites. This smaller fertilizer rates may motivate farmers to apply fertilizers in maize. Although the practice of mulching is greatly constrained by free grazing after harvest in the region (Sime *et al.*, 2015), it can be used in maize production around homesteads which are traditionally fenced and protected from free roaming of livestock (Sime *et al.*, 2015). Such kind of maize cultivation is practiced widely by most farmers for filling critical food shortage often encountering during pre-harvest. Yet, in this regard more research is quite required to better integrate mulch into the wide open farming systems in the region.

CONCLUSION

Maize is the most important source of food and fodder. There is high seasonal rainfall variability; dry spells and droughts are frequent, which makes crop production risky. Farmers are resource-poor and cannot use high-cost technologies for the intensification of maize production. This study focused on the intensification of maize production through sequentially adding technologies: minimum tillage, seed priming, fertilizer application through the microdosing method and mulching. Except at the lowest level, production costs increased with increasing levels of inputs, while agronomic and economic return increased substantially. Gross margin and FUE increased with increasing levels of intensification. Seed priming did not add any financial outlay for farmers, but microdosing required the investment in fertilizer at a small cost. Mulching minimized the risk of fertilizer use as the VCR increased when used in combination with microdosing. Mulching was able to maintain a high VCR even at the highest levels of inputs. Increasing levels of inputs with the technologies tested in this study also appeared to improve resilience to seasonal rainfall variability as there was improved crop establishment and reduced time to maturity.

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Paper IV

Getachew Sime and Jens B. Aune (2015). Exploring agricultural technologies, and their adoption and diffusion in the central Rift Valley, Ethiopia. Submitted to Journal of Development Studies

Agronomic technologies, and their adoption and diffusion in the central Rift Valley, Ethiopia

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Abstract

This study identifies agricultural technologies introduced to farmers and assesses their attributes, adoption and diffusion patterns, and the challenges and opportunities for adoption and diffusion. The viewpoints of stakeholders, namely farmers, agricultural extension workers and experts, were collected from a series of focus group discussions and key informant interviews, supplemented by a series of field observations. Results showed that technologies reach farmers through the national extension system, social networks, or both. Improved early-maturing maize varieties and improved practices such as row sowing, banding fertilizer, intercropping and traditional rainwater - harvesting, are among the technologies adopted and disseminated through the extension system. Row sowing, banding fertilizer and traditional water harvesting methods are also promoted through the social networks. Technologies can also spread even when they are not part of the extension system. This was observed for hybrid maize and haricot bean varieties. These crops were adopted because they give high yield and have a high market price. Once technologies have been adopted, they may later be disadopted if they lack institutional support. This was observed for seed priming, microdosing, harvesting at physiological maturity and cultivation of finger millet and sorghum varieties. Although most of the adopted technologies accommodate farmers' priorities, improved seeds and fertilizer are expensive and become a challenge for technology adoption and diffusion. Under these production conditions, farmers use negligible quantities of fertilizer or none at all, or replace improved seeds with local varieties or recycled seeds. In order to help farmers exploit the full potential of adopted technologies, constraints related to inadequacy of the extension system, financial constraints, and provision of reliable agrometeorological information need to be addressed. Moreover, for rational adoption and diffusion, technology development and extension system requires a strong link between institution-researcher-extension worker-and farmer.

Keywords: adaptive seeds; fertilizer application; financial constraints; institutions; adoption–diffusion; semi-arid; Ethiopia

Introduction

Marginal rural livelihoods with increasingly vulnerable agro-ecological conditions need low cost, low risk and adaptive technologies (Sime and Aune, 2015; Aune and Bationo, 2008). In response to the increasing population and decreasing landholding of the rural population, the current government of Ethiopia gives high priority to agricultural development. To intensify smallholder productivity, the government is implementing ambitious plans to develop and provide new seeds, chemical fertilizers, new crops, and new natural resource management practices. It has also made substantial investment in roads and agricultural extension services (Dorosh and Rashid, 2013; Dercon and Hill, 2009) and has endorsed ambitious socio-economic plans (Pörtner *et al.*, 2012). Agricultural intensification is based on the assumption that increased total farm production and productivity on small land size can ensure food security and improve farmers' livelihoods.

Like most sub-Saharan African countries, Ethiopia is heavily dependent on agriculture, which contributes to approximately 50% of the national GDP, supplies 73% of the raw materials to agro-industries, generates 88% of the export earnings (Deressa *et al.*, 2009) and employs over 85% of the population. Yet agriculture is also the most volatile sector, mainly because it is heavily dependent on rain and is highly vulnerable to recurrent seasonal rainfall shocks (Biazin and Sterk, 2013; Demeke *et al.*, 2011; Conway and Schipper, 2011; Segele and Lamb, 2005), low external input use (Conway and Schipper, 2011; Demeke *et al.*, 2011), and widespread land degradation (Nyssen *et al.*, 2008; Haileslassie *et al.*, 2005). Furthermore, the absence of appropriate technologies is impairing agricultural production in Ethiopia (Spielman *et al.*, 2011).

Although the government has ambitious plans and practices to develop and extend new agricultural technologies, there are a number of factors limiting agricultural technology adoption and diffusion in Ethiopia. High cost of inputs, insufficient credit services and high financial costs are critical constraints on the adoption of the available seed–fertilizer technology packages (Spielman *et al.*, 2011). Farmers' insufficient knowledge and inadequate extension systems (Alemu *et al.*, 2008), insufficient supply of seeds, limited choice of new varieties (Kassie *et al.*, 2013) and market and institutional failures (Alemu *et al.*, 2008) are other important factors limiting the adoption and diffusion of agricultural technologies.

This study was undertaken in the central Rift Valley of Ethiopia. Earlier studies conducted in the central Rift Valley have attempted to address problems in agricultural production related to seasonal rainfall variability (Belay *et al.*, 2013; Kassie *et al.*, 2013; Kassie *et al.*, 2014; Sime *et al.*, 2015), adverse land degradation (Belay *et al.*, 2013; Biazin and Sterk, 2013; Garedew *et al.*, 2009), vulnerability to environmental shocks such as droughts (Kassie *et al.*, 2013; Meshesha *et al.*, 2012; Biazin and Sterk, 2013), inadequate provision of improved and adaptive seeds (Alemu *et al.*, 2008; Kassie *et al.*, 2013), and absence of appropriate fertilizer application methods and fertilizer rates (Sime and Aune, 2014). This study identifies the agricultural technologies transferred to farmers and assesses their characteristics, adoption and diffusion patterns, along with their challenges and opportunities. The viewpoints of key stakeholders –

namely farmers, extension workers and experts from the agricultural offices – were collected from a series of discussions and interviews, supplemented by a series of field observations.

Materials and methods

Description of the study sites

The study site, Ziway, is located in the East Shoa Zone of Oromiya Regional State in the central Rift Valley region in Ethiopia. The study targeted three villages, namely Ellilan Ababo, Denbe Adansho and Chitu Getu, with 758, 680, and 764 households, respectively. The district is located at 7^0 9' north latitude, 38^0 43' east longitude, at an altitude of 1,643 m.a.s.l, and is between 136 and 148 km south of the capital, Addis Ababa. According to the Central Statistical Agency (CSA) of Ethiopia, the population size in the district is 164,234 in an area covering approximately 1,094 km^2 with an average population density of 150.1 individuals km^{-1} (CSA, 2012). The rainfall conditions in the central Rift Valley exhibit high intra-seasonal variability with a coefficient of variation of 15 to 40%, and a significantly increased temperature (0.12–0.54^o C per decade) over the past 30 years (Kassie *et al.*, 2014). The soil has poor fertility (Biazin and Stroosnijder, 2012; Temesgen *et al.*, 2008). The average family size ranges from 5.3 to 7.5 individuals (Ayenew, 2004; Jansen *et al.*, 2007). Kassie *et al.* (2013) report that the average household landholding size ranges between 0.75 and 2.5 hectares (ha) in the central Rift Valley.

Rain-fed and cereal-based crop production is combined with modest livestock production (Kassie *et al.*, 2013). The increasing inter-seasonal rainfall variability and intra-seasonal dry spells associated with increasing temperature cause severe challenges to rain-fed crop production (Kassie *et al.*, 2013; Biazin and Sterk, 2013). The main crop is maize (*Zea mays* L.), but teff (*Eragrostis tef* (Zucc.) Trotter) and haricot bean (*Phaseolus vulgaris* L.) are also widely cultivated. Livestock include cattle, sheep, goats, equines and poultry. Oxen are primarily kept as a source of draft power while equines, donkeys and mules are used for transportation and packing. The livestock provide a source of manure and domestic fuel. Crop residues are the main source of feed for livestock, particularly during the dry season. Livestock graze freely on the crop residues after crop harvests (Biazin and Stroosnijder, 2012; Sime *et al.*, 2015).

The process of technology adopting and diffusion

This study used the adoption and diffusion theory to assess the processes of technology adoption and diffusion. Central to this is Everett Rogers' 'technology adoption and diffusion' theory. Rogers (1995) defines an innovation as 'an idea, practice or object that is perceived as new by an individual or other unit of adoption'. An innovation is not necessarily better, nor does it necessarily mean that the new idea is more beneficial to an individual. Adoption theory examines the individual and the choices an individual makes to accept or reject a particular innovation. Adoption theory focuses not only on the whole, but also on the pieces that make up the whole (Rogers, 2003). Following Rogers (2003), the decision making process in adoption is seen as a linear sequence of five stages, starting from the knowledge stage in which a potential adopter gains a basic information, understanding and knowledge about an innovation such as what it is and how it works. This is followed by a persuasion stage in which a potential adopter forms an attitude towards the innovation, which could be a positive or negative impression. Following the persuasion stage comes the decision phase in which an actual decision is made to adopt or not to adopt the innovation. At this stage, all exposed adopters must make a decision about whether to accept or reject the innovation. The implementation stage then occurs when there is an actual decision taken to use the innovation. The implementation stage may involve adapting or reinventing the innovation to suit the local conditions. The final stage is the confirmation stage where the adopter seeks further information about the innovation in order to decide to either continue if he/she is satisfied with the outcomes of implementation, or to discontinue the use of the innovation if dissatisfied.

By contrast, diffusion theory describes how an innovation spreads through a population across time. Rogers (2003) argues that diffusion is the process by which an innovation is communicated through certain channels over time among the participants in a social system. Rogers proposes that four main elements influence the spread of a new idea: the innovation itself, communication channels, time, and a social system. This process relies heavily on human capital. The innovation must be widely adopted in order to self-sustain. During the adoption process, there is a point at which an innovation reaches a critical mass. Diffusion manifests itself in different ways in various cultures and fields and is highly subject to the type of adopter and to the innovation–decision process. Rogers' innovation–diffusion theory holds that access to information about an innovation is the key factor that determines adoption and diffusion (Rogers, 2003).

Rogers (1995) also proposes a set of five attributes to predict when and where the adoption occurs under given social circumstances. These are relative advantage, compatibility, complexity, trialability, and observability. Accordingly, relative advantage examines the degree to which an innovation is perceived as better than the existing practice it is replacing. The relative advantage includes the potential for increased profit, improved social status and a decrease of personal discomfort. Compatibility is the measure of the degree to which an innovation suits the current potential adopters' conditions. When adopters have the option of using the innovation on a trial basis without large upfront investments of time or financial resources, this increases the trialability of the innovation. Many potential adopters also like to see the innovation in use by their peers and understand its benefits before they choose to adopt. This quality is known as observability. The final attribute is complexity, which measures the degree to which an innovation is perceived as relatively difficult to understand and use.

Adoption of an innovation is seen as a social process in which learning about new practices occurs both in formal and informal settings through sharing information, observation, imitation, or as a normative action (Rogers, 1995). The appropriateness of an innovation is taken as given, and the problem of technology adoption is reduced to communicating information on the technology to the potential end users. Networks, values and norms, structures in society and human agency all influence the process of social learning and adoption of innovations (Rogers, 1995; Rogers, 2003).

Methodology

Primary data related to technology, agro-ecological and institutional characteristics were collected from key informant interviews, focus group discussions, informal discussions, and field observations. The viewpoints of stakeholders pertaining to technology variables, extension services, and the market system in relation to the adoption and diffusion of transferred technologies were assessed in line with the adoption and diffusion theory of Rogers.

Focus group discussions, each with nine farmers, were held in each of the three villages. The selection of the discussant farmers was based on purposive sampling in order to obtain comprehensive information about the farming systems and livelihoods in the villages. Selection by the researcher took place with the assistance of extension workers and village leaders based on previously set criteria. The selected farmers were village headmen, lead farmers, and leaders of local farmer organizations who have a decent community acceptance and exercise leading roles in the agricultural activities. These participants belonged to different social status, age and sex groupings and their ages ranged from 32 to 75 years. Six of the discussants were female, two in each village. Predetermined semi-structured questions were developed and asked. Trust was built and consensus of valuing information was reached. The same discussion was held in each village for crosschecking of the information to increase the validity and reliability of the information. McHugh *et al.* (2007) report that repeated discussion and interaction with various stakeholders helps to obtain comprehensive knowledge about agricultural production and livelihoods of farmers.

Similarly, at each village a separate group discussion was held with a group of three agricultural extension workers. This discussion focused on the following points: the identification of transferred technologies and their characteristics; the adequacy of agricultural extension services; the availability of external inputs such as adaptive seeds at farmer capacities, subsidy and credit arrangements; the stability of input and output market prices; and the suitability of the technologies to the existing agro-ecological settings (such as rainfall events, soil quality such as fertility, water holding capacity and traditional harvesting systems). Most of these issues were also raised during the focus group discussions with farmers and during key informant interviews.

Key informant interviews were held with agricultural experts from the district agricultural office who were directly engaging in input supply, management of technology transfer and policymaking. Three experts with competence in crop, livestock and environmental management were interviewed in depth. Issues related to institutions and policies were also highlighted. The extension system is the institutional agency through which technologies are channelled to farmers.

A series of field observations were also carried out before harvest (seedbed preparation, planting, weeding and harvesting) and after harvest (threshing, storing, and marketing of crops). These field observations were made for three consecutive years, from the 2011/12 to the 2013/14 cropping seasons. During the field observations, interactive discussions were held with farmers and extension workers. During these narratives, various issues were explored to confirm the viewpoints collected from the different stakeholders. These were the information sharing system, agronomic practices, agricultural extension service sessions, technologies in practice, virtual farmers' challenges, opportunities for technology adoption and diffusion, external input supply system, and agricultural activities and marketing procedures. Particularly the last narratives conducted in 2013/14 along with the interviews and discussions held with stakeholders were used principally for crosschecking information.

Since this study was based on the crosschecked stakeholders' viewpoints, specific stakeholders are not indicated in the text unless otherwise mentioned for specific purposes. While conducting the discussion, interviews, and field observations, comprehensive notes were taken by the researcher and an assistant.

As all the information collected is qualitative, a crosschecking method was used for ensuring the validity and reliability of the information. A comparison analysis was used to assess common themes and subthemes in reaching data saturation. Finally, every theme and subtheme was described.

Results

Transferred technologies, institutions and their characteristics

Technologies reached farmers through research projects, national extension systems, or social networks. Public universities, agricultural research centres and non-governmental organizations delivered technologies to farmers in collaboration with the agricultural office and extension system. This study reported technologies transferred to farmers through a research project and national extension system during the 2006/07 and the 2010/11 cropping seasons.

Technologies introduced in the 2006/07 cropping season include improved varieties of haricot bean (*Phaseolus vulgaris* L.), finger millet (*Eleusine coracana* L.), extra-early maturing and early maturing maize (*Zea mays* L.), and sorghum (*Sorghum bicolor* L.). Among the introduced improved practices are row sowing, harvesting at physiological maturity, conservation tillage, seed priming, intercropping of maize with haricot bean, and banding and microdosing methods of fertilizer application (see Tables 1 and 2 below). By the end of the project life in the 2009/10 cropping season, of the 64 farmers who hosted the technologies on their farms, 42 had adopted most of the technologies. Nevertheless, conservation tillage and cultivation of the extra-early maturing maize and early maturing sorghum varieties were abandoned after one cropping season, in 2007/08. These technologies were supported by the Eco-farm project of the Dryland Co-ordinating Group (DCG) of Norway and Hawassa University. The project was terminated at the end of 2009/10 cropping season after conducting upscaling of some best farmers' practices.

The remaining technologies presented in Tables 1 and 2 were transferred through the national extension system. They were improved varieties of early maturing maize and improved practice including row sowing, intercropping, banding of fertilizer application, *in situ* rainwater - harvesting practices, locally called *Dirdaro* and *Shilshalo* and the use of compost and manure as organic fertilizer. These technologies were transferred to farmers in the 2011/12 cropping season as part of Ethiopia's five-year Growth and Transformation Plan (2010/11 to 2014/15). Most of these technologies were launched once at the community level. Early maturing maize varieties, intercropping, row sowing and banding fertilizer were among the DCG technologies that were reintroduced.

Hybrid maize and haricot bean varieties were introduced and promoted by social networks and were not integrated into the national extension system. They received a widespread adoption and diffusion as a result of higher yields and market values. DCG technologies that were not integrated into either the national extension system or social networks were disadopted following the termination of the project (see Table 2 below).

The transferred technologies of crop species and varieties, the improved agronomic practices, and the key variables for their adoption and diffusion or disadoption are presented in Tables 1 and 2 below.

Table 1. Adopted and diffused improved crop species and varieties, agronomic practices, and their key characteristics for adoption and diffusion

Species	Improved Variety	Improved Practice	Key characteristics and reason(s) for adoption and diffusion
Maize	Early maturing open pollinating, namely Melkassa-2, 6Q, Awassa-511		▪Early maturing and more adaptive to low seasonal rainfall and intra-seasonal rainfall variability, gives moderate yields with no or low fertilizer application *Lower yields compared to hybrid maize varieties
	Mid maturing hybrids, such as BH-540 and 543		▪Higher yields than early and local varieties under optimum seasonal rainfall events and high grain market prices *Seeds cannot be saved and recycled, inaccessibility of first generation seed, which is supplied only by government institutions or certified agencies, less adaptive to intra-seasonal rainfall variability and is more vulnerable to end of the season cut off of rainfall or to dry spells
Haricot bean	Early maturing, such as Awash-1 and Awash Melka		▪Early maturing and adaptive to low and variable rainfall, high yields even with no or low fertilizer application, high market prices for outputs, seeds can be saved and recycled ▪Low labour for weed control and low oxen energy for tillage (minimum tillage is usually used) ▪After harvest, haricot bean fields used as pasture; high grass weeds from minimum tillage and less weed control ▪Used as a partial or entire replacement in failed maize fields (from low or prolonged dry spells) and is ideal as an intercrop with maize ▪Grown in July when farmers have less fair time and seasonal rainfall variability is minimal
		▪Row sowing method, for maize and haricot beans	▪High yields; saves seeds and fertilizer; eases agronomic practices such as weeding, thinning and traditional rainwater - harvesting, *Shilshalo* and *Dirdaro* that make ridges and furrows – compatibility with other practices ▪Replaced the predominant low yielding broadcasting method of seed sowing practice, which is less compatible with other practices
		▪Intercropping, for maize intercropped with haricot bean	▪Increases nutritional diversity and incomes, increases resilience to rainfall variability and lessens food shocks because maize and haricot bean are differently affected by dry spells ▪Increases soil nutrient restoration
		▪Banding method of fertilizer application	▪High yields, high labour demand, substantially saves on fertilizers ▪Replaced lower yielding and less efficient broadcasting method of fertilizer application in practice
		▪Traditional practices of *Dirdaro* and *Shilshalo*	▪Efficient practices in *in situ* rainwater - harvesting for enhanced agronomic performance under low seasonal rainfall events but under high rainfall events may cause waterlogging that might affect plant growth and yield ▪*Dirdaro* is practised mainly for making ridges and furrows for rainfall harvesting while *Shilshalo* is practised for multiple purposes: weed controlling, thinning and removing the surface crust to facilitate infiltration ▪Both *Dirdaro* and *Shilshalo* practices are implemented with a traditional plough that uses oxen energy and eases labour loads
		▪Organic fertilizer, such as compost and manure	▪Low cost; low risk; prepared from locally available inputs, can increase yield for at least two to three years once applied to farm and environmentally friendly *Embedding demands high labour and inadequate information on preparation, application and utilization

* denotes constraints with the particular technology

Table 2. Improved crop species, varieties, and agronomic practices and their key characteristics for disadoption

	Improved		Key characteristics and reason(s) for *_disadoption_
Species	**Variety**	**Practice**	
Maize	Extra early-maturing maize varieties, namely Katumani, Melkassa-1, Awassa-511		▪Earliness (Katumani, Melkassa-1) Adaptation to low and intra-seasonal rainfall variability; drought tolerant (Awassa-511) *_Low grain and stalk yields_ *V_ulnerability to attack by dogs, birds and other wildlife_
Finger millet	Early maturing, such as Tadesse and Paddet		▪Adapting to the variable rainfall; high yield even with no or low fertilizer application; seeds can be recycled ▪Low labour for weed control and low oxen energy for tillage (minimum tillage) *_Lack of adequate information on grain market and consumption value; lack of support from institutions or social networks (neither integrated into the extension system nor adequately promoted and assimilated into social networks)_
Sorghum	Early maturing, such as Teshale, Seredo, Melko-1		▪Adapting to the variable rainfall; high yields even with no or low fertilizer application ▪Lower labour for weed control and oxen energy (minimum tillage) *_High vulnerability to bird attack and total harvest loss (Teshale and Melko-1)_ *_Low food value, low palatability from high tannin content despite its high use value in making local drinks (Seredo_, which is less vulnerable to bird attack)
		▪Seed priming, for example maize, finger millet, haricot bean	▪High yields; needs no external input and no risk *_Lack of adequate information and lack of support from institutions or social networks (neither integrated into the extension system, nor adequately promoted and assimilated into social networks)_
		▪Microdosing method of fertilizer application, for example phosphorus and nitrogen fertilizer in maize	▪High yields; high labour demand (labour is not a problem in most households); saves fertilizers *_Lack of adequate information on optimum fertilizer rate; lack of support from institutions or social networks (neither integrated into the extension system nor adequately promoted and assimilated into social networks)_
		▪Conservation tillage, such as zero and minimum tillage with mulching	▪Reduces oxen energy; ideal for farmers lacking oxen; more adaptable to rainfall variability *_Low yields over short-term practice; high weed density; high labour demand for weeding when herbicides not used_ *_Crop residues cannot be kept in open fields due to free grazing of animals it demands an entire change to the existing intensive tillage and the free grazing system_
		▪Rainwater - harvesting, for example small artificial ponds	▪Store water for small-scale vegetable production adjacent to home and livestock; increased resilience to rainfall variability *_Lack of inputs (plastic bags) and high labour demand for digging ponds and maintenance_

* denotes reason(s) for disadoption of the particular technology

Discussion

Technologies reach farmers through the national extension system, research projects, social networks or various combinations of these systems. The adopted technologies hold high adaptability to rainfall variability. Most of the technologies that are adopted are part of the national extension system. Integration into the national extension system ensures more institutional support such as the provision of extension services and input supply. However, technologies spreading through the social system are also adopted. Adaptability to the existing rainfall conditions, as well as accessibility and affordability to the inputs and profitability of grain market are important factors determining adoption and diffusion. Regardless of sources, social networks could substantially promote the adoption and diffusion of the adaptable and profitable technologies. They are particularly vital for the adoption and diffusion of productive technologies that are not integrated into the extension system. Whenever possible, farmers use information from both institutions and social networks in order to select agricultural technologies.

Technologies, adoption and diffusion

Most of the technologies reaching farmers aim to improve soil quality and resilience to the impact of variable rainfall. Most farmers have an increased interest in technologies involving fertilizers, improved seeds, intercropping of maize and haricot bean and *in situ* rainwater - harvesting practices. These technologies are popular because they increase agricultural productivity for both human and livestock consumption.

Before the 2004/05 cropping season, the agricultural production system in the villages being studied had been dominated by the traditional mono-cropping of a late maturing maize variety (referred to as ‘local variety’ in this paper) and the broadcasting of seeds and fertilizers. Since then, a number of technologies have been introduced to the study villages through the national extension system, social networks or research projects. Regardless of source, the most important technologies delivered to farmers have been: the banding and microdosing methods of fertilizer application; row sowing; adaptive haricot beans, sorghum and finger millet; the very-early maturing, early maturing and mid maturing maize varieties; and the diversification of crop production such as intercropping of maize with a pulse. Most of these technologies were delivered by the DCG project. The ultimate purpose of these interventions has been to improve food security and livelihood on smallholdings by increasing farmers’ income and reducing vulnerability to rainfall variability. However, a number of constraints hamper the adoption, diffusion, and sustainability of these technologies.

Adopted and disseminated technologies

Adopted technologies include improved crop species and varieties, and agronomic practices. Examples of adopted improved crop species and varieties include haricot beans and early- and mid-maturing maize. Row sowing, row fertilizer application, *in situ* rainwater - harvesting practices, and organic fertilizers are among the adopted improved practices in the study villages.

Improved crop species and varieties

Maize. Although maize is the major crop and is the mainstay of the livelihood of farmers in the villages, its production is highly constrained by soil moisture stress, intra- and inter-seasonal rainfall variability and dry spells (Belay *et al.*, 2013), and poor soil fertility (Biazin and Stroosnijder, 2012). In response to these climatic characteristics, the use of improved early-maturing maize varieties is an interesting option for farmers. Institutions promote open pollination (OPVs) maize varieties; they mature early and are more adaptive to dry spells or drought. As a result, such varieties of maize are widely adopted. Equally, though the central Rift Valley is outside their area of adaptation, mid maturing maize varieties were also widely adopted. As a result of their higher yield advantage over early-maturing varieties, mid maturing hybrid maize varieties are spreading principally via social networks. The extension workers in the central Rift Valley do not provide advice on hybrid maize production as they are institutionally recommended for high moisture areas (Beshir and Wegary, 2014). Beshir and Wegary (2014) report that the production of these hybrids is currently expanding in the central Rift Valley with farmers using both hybrids and OPVs. The OPVs are the farmers' choice when there is late onset of rainfall or more intra-seasonal rainfall is expected; their earliness in maturing enhances the resilience to the unfavourable rainfall events. In this regard, the *Melkassa* varieties in particular are less vulnerable and have been widely adopted. In years with early onset of rainfall, which is an indicator of a good year, farmers mostly prefer mid maturing hybrid maize varieties with a high yield such as BH-540 and 543. Previous studies indicated that mid maturing maize was more productive where growing conditions were relatively favourable (Nigussie *et al.*, 2001).

The challenges with hybrid maize varieties are the higher seed costs (high production cost), shortage of supply and the necessity to purchase seeds every year. Because of genetic segregation, hybrid seeds are not recyclable, and this increases farmers' dependency on institutional provision of the seeds, resulting in higher production costs. These characteristics of the seeds create scepticism, particularly among the economically poorest farmers. Planting hybrid maize seeds for two seasons is a common practice in the villages. In Ethiopia, farmers plant recycled hybrid seed, despite significant losses in vigour (Alemu *et al.*, 2008). Alemu *et al.* (2008) further indicate that such practices are the result of farmers' insufficient knowledge about the need to renew the seed on a regular basis in combination with inadequate access to the credit needed to purchase new seeds. In addition to this, the hybrid maize seed market is characterized by limited competition among the few breeders, insufficient supply of seed relative to demand, limited choice of varieties that are available, and high seed costs (Kassie *et al.*, 2013). Hybrid maize seeds are only supplied by public institutions or certified companies (Beshir and Wegary, 2014). Unlike the hybrid seeds, local seeds are reproducible and can be used for successive seasons without appreciable reduction in yields. In addition, the seeds of OPVs maize varieties can be recycled for two to three seasons.

Improved OPVs give better yield than the local varieties under low or variable seasonal rainfall. Bedru (2007) reports that the Melkassa - II OPVs maize variety showed a 22.7% average yield advantage under poor rainfall conditions in the 2006/07 cropping season over the local varieties in the Rift Valley in Ethiopia. An assessment from the stakeholders' viewpoints indicated that the average grain yields of local, OPVs and hybrid maize varieties range from two to three, three to four and four to five ton ha^{-1} respectively under varying farmer conditions. The average yield obtained from OPVs was 2.3 ton ha^{-1} while that of hybrids was 3.7 ton ha^{-1}, indicating that hybrids had more than 50% yield advantage over the OPVs of varying farmer conditions in the central Rift Valley (Beshir and Wegary, 2014). A study of OPVs maize in the central Rift Valley reported an average grain yield of three to four and five to six ton ha^{-1} of grain yields on-farm and on-station respectively (Sime and Aune, 2014). Farmers reported that they do not frequently apply fertilizer to local varieties because of the low yield. They also apply less (or no) fertilizer to OPVs than to hybrid maize. This corresponds with earlier reports that farmers do not apply fertilizers and incur costs to local maize varieties because of low yield and low profit margin (Abakemal *et al.*, 2013; Beshir and Wegary, 2014). Farmers also advised that local varieties can cope with intra-seasonal dry spells and are as adaptive to these conditions as the OPVs are. However, the frequent dry spells and end of season cut off rainfall from September onwards are the key challenge with local varieties. Local varieties used to be planted in April as they mature late. Recently, however, there has been a shift in the cropping calendar from planting in April to planting maize in early June; this shortens the length of the cropping season, which makes the production of local varieties more vulnerable. Kassie *et al.* (2013) report similar challenges to crop production in the central Rift Valley. Farmers responded to these challenges with crop and variety choice and adjustment of the cropping calendar. Yosef and Asmamaw (2015) indicate that information on seasonal rainfall events is essential for planning and managing agricultural practices in vulnerable areas in Ethiopia.

Other constraints to the adoption and diffusion of adaptive maize, as highlighted by discussant farmers, are low seed quality (broken seeds) and weed seeds. The broken seeds reduce seed germination and cause wastage to fertilizers. Farmers are sometimes forced to re-sow because of the poor quality of seeds. Using seeds of low quality also makes the use of banding of fertilizer less efficient and less profitable.

Haricot bean. The second major crop in the study villages is the haricot bean. It is under wide adoption and dissemination. Different varieties were introduced to neighbouring villages by the Melkassa Agricultural Research Centre in the 2004/05 cropping season. Later, two high yield potential and adaptable varieties, namely *Awash-1* and *Awash Melka,* were introduced to the villages by the DCG in the 2006/07 cropping season. Haricot bean production appears to match farmers' preferences as the crops possess the adoptable attributes important for adoption as identified by Rogers (1995). The most important attractive adoptable attributes of haricot bean production are the low requirement for labour and traction power, high yield, early maturity, drought tolerance, high output market value, and high soil fertility restoration capacity (as a replacement for fallowing). The crop is also appreciated for its high straw yield with high fodder nutritive values, and the possibility of its production as either a sole or an intercrop and its suitability for replanting in failed maize fields (as a result of dry spells or droughts). It can be used for the diversification of livelihood shocks resulting from unfavourable rainfall events.

Improved practices

Row sowing of seeds. Broadcasting was the most popular and widely practised method of sowing maize in the central Rift Valley and elsewhere in Ethiopia. As an alternative to broadcasting seeds, row sowing was originally introduced by the DCG to farmers in the study villages in the 2006/07 cropping season. However, only very few farmers used to practise row sowing in maize, until it became a national agenda in the 2011/12 cropping season and was re-introduced to the farmers as part of the national extension system. Since then it has been widely adopted and disseminated. Presently, row sowing has become the most widely practised method for sowing maize in the study villages. The information gathered from the discussant farmers and field visits confirmed that the adoption rate of row sowing achieved 80 to 90% and 15 to 20% for maize and bean respectively. The transition to row sowing has been fast owing to its attractive attributes. The viewpoints of stakeholders and farmers in particular indicated that row sowing enables aeration in maize stands, improves seedling vigour, and eases manual weeding (uprooting weeds with hands) and hoeing (with local tools) for weed control. Unlike the broadcasting method, row sowing is convenient for practising the traditional soil and water conservation methods of *Dirdaro and Shilshalo.* These structures are established with the help of the traditional ard plough, pulled by a pair of oxen. This ard is a locally made farm tool that farmers use for tillage as well. Earlier studies reported that Ethiopian farmers use the ard for intensive tillage, traditional ridging and making furrows for water harvesting, weeding and thinning purposes (Nyssen *et al.*, 2011; Biazin and Stroosnijder, 2012).

Observation from field visits indicated that the *Dirdaro* practice makes ridges and furrows for *in situ* rainwater - harvesting at sowing times. The ridges and furrows are made between every two planting rows. The ridges harvest rainwater, reduce runoff and enhance infiltration (Nyssen *et al.,* 2011; Biazin and Stroosnijder, 2012; Temesgen *et al.,* 2008). Row sowing also enables the traditional weeding and rainwater-harvesting method called *Shilshalo*, which is practised four to five weeks after sowing. It removes the surface crust and promotes infiltration (Biazin and Stroosnijder, 2012; Temesgen *et al.*, 2008). *Shilshalo* is commonly practised on the furrows that were made by *Dirdaro*. Biazin and Stroosnijder (2012) report that *Shilshalo* is used for water harvesting and breaks the surface crust formed through intensive tillage. By contrast, the broadcasting of seeds and *Shilshalo* are incompatible as the method causes substantial damage to the maize stands sown by the broadcasting. Therefore, row sowing has made the methods of *Dirdaro* and *Shilshalo* more feasible in maize. Farmers and extension workers stated that the use of the traditional *in situ* rainwater - harvesting system can increase maize yields and reduces its vulnerability to dry spells or droughts. A previous study indicated that *in situ* rainwater - harvesting techniques have significantly improved soil moisture and runoff and increased agricultural production in the semiarid areas in Ethiopia, which in turn reduces risk (Yosef and Asmamaw, 2015). However, the furrow and ridges made by these techniques may cause waterlogging during heavy rainfall. This situation can affect plant growth and yield as both maize and haricot beans have been found to be vulnerable to prolonged waterlogging.

Farmers claimed that row sowing saves seeds (50 to 65 kg ha^{-1} for broadcasting compared to 26 to 31 kg ha^{-1} for row sowing), reducing the seed rate approximately by 50% in favourable cropping seasons. Experts and extension workers found that row sowing has the potential of reducing the seed rate with more than 50%. Moreover, although experts and extension workers claim more benefits, farmers argued that row sowing increases maize yields twofold to threefold compared to the broadcasting method. Yet, because of the high risk of crop failure in relation to the very unpredictable seasonal rainfall, a low plant stand in row sowing may have problems. In seasons with low rainfall or high rainfall variability, farmers prefer a high seed rate to ensure adequate crop establishment. A previous study indicated that varying planting density according to the rainfall pattern has been shown to improve water and crop productivity in dryland rain-fed systems (Tsubo and Walker, 2007). Farmers also mentioned that too low plant density under limited rainfall conditions could lead to low utilisation of available soil water due to evaporation from the surface of the soil. When adequate establishment is ensured, the surplus maize plants are usually thinned for fodder two to three weeks following planting. This is the time the first weeding is usually carried out. Farmers can exploit the fullest potential of row sowing if optimum fertilizer rate is provided under favourable rainfall conditions.

Banding method of fertilizer application. Fertilizer was traditionally applied by the broadcasting method. Together with row sowing, the banding of fertilizer was introduced by the DCG as an alternative to the broadcasting method in the 2006/07 cropping season. However, only a few farmers practised this method until it was launched at national level during the 2010/11 cropping season. There is compatibility between the banding of fertilizer and row sowing, as both use rows. As a result, its adoption and diffusion rate has been very high, particularly among farmers who used to apply fertilizer to maize. The practice of these technologies together was reported to give high agronomic and economic returns in maize in the central Rift Valley (Sime and Aune, 2014). The agricultural experts and extension workers argued that the banding method increases maize yields by approximately 60 to 70% compared to the broadcasting method. Banding fertilizers therefore have a ‘relative advantage’ (Rogers, 1995) as compared to the broadcasting method. Despite the high costs of fertilizer, the number of farmers applying fertilizers has substantially increased in recent years. For instance, in one of the villages (Denbe Adansho), the official documents indicated that 35% of the farmers in the village applied nitrogen and phosphorus fertilizer (DAP) and 18% applied nitrogen fertilizer (urea) in maize in the 2013/14 cropping season. However, only 13% of the farmers had applied DAP and none had applied urea fertilizer in the preceding cropping season in maize. The yield advantage of row sowing and banding fertilizer is the major reason for the increased interest in fertilizer application.

Official documents revealed that only 5 to 9% of the farmers in Denbe Adansho village followed the national recommendations (100 kg DAP ha^{-1} + 100 kg urea ha^{-1}) in the 2013/14 cropping season in maize. In the same cropping season and village, the average fertilizer rate applied to maize varied between approximately 45 to 50 kg ha^{-1}, which is roughly half of the national recommendation. Instead of following the national recommendations, farmers apply a small quantity of fertilizer over a large area. They perceive that such a practice gives more agronomic and economic benefits than applying the same amount of fertilizer over a smaller area. This is referred to locally as *Urgesu*. The high fertilizer prices and unpredictable rainfall pattern in the villages inhibit farmers from following the recommendations. Previous studies indicated that although the agricultural extension programme in Ethiopia has promoted fertilizer application over the last decades, its success in enhancing agricultural productivity has been constrained mainly by unpredictable rainfall patterns (Fufa and Hassan, 2006; Gebremedhin *et al.*, 2009). Abegaz and van Keulen (2009) report that farmers in Ethiopia, as in many parts of Africa, generally apply less fertilizer than the recommended amount. Average fertilizer in Ethiopia is reported to be 21 kg ha^{-1} which is much lower than the nationally recommended rate of 60 to 100 kg ha^{-1} (Debelle *et al.*, 2001). Therefore, the high price of fertilizer, absence of optimum fertilizer, lack of adequate information and the highly variable rainfall are the underlying factors determining fertilizer application. A study conducted in the central Rift Valley has confirmed that attractive agronomic and economic benefits can also be obtained with reduced amounts of fertilizer, provided that this is applied using microdosing (Sime and Aune, 2014).

The higher labour requirement is potentially a limitation for the banding method. However, the fact that most households consist of large families, labour appears not to be a limiting factor for most households. Children do not normally engage in fertilizer application and instead carry out other agronomic activities such as weeding. Another limiting factor is the lack of a recommended optimum fertilizer rate, which makes its adoption more difficult particularly among the poorest farmers. And because there is no measurement tool, the amount of fertilizer used within and between rows varies with the person applying fertilizer. As a result, there is a risk of applying too little or too much fertilizer to the planting hills.

On the other hand, in addition to causing a remarkable wastage of fertilizers, the broadcasting method of fertilizer application gives lower yields. With the broadcasting method, the association between the fertilizer and seed varies markedly, reducing the efficiency of fertilizer. Field observations indicated that broadcast fertilizer was not well covered by the soil, exposing the fertilizer to heat, and hence to melting and evaporation. The nitrogen fertilizer (urea) was observed to be more vulnerable to evaporation than the phosphorus fertilizer (DAP). A previous study reported that about 30 to 70% of the applied nitrogen may be lost as ammonia within seven to ten days after application due to lack of proper management (Debelle *et al.*, 2001). The only advantage of fertilizer broadcasting is the lower labour requirement for its application.

Disadopted technologies and their characteristics

The disadopted technologies are seed priming, fertilizer microdosing, harvesting maize at physiological maturity, and different varieties of finger millet and sorghum, among others. They were introduced by the Eco-farm project of the DCG. About 29% of the farmers who hosted the technologies on their farms ended up adopting most of the technologies during the project's lifetime. However, after the project was phased out, the adopted technologies were also abandoned. The project ended before the adopted technologies were integrated into the national extension system or thoroughly taken up by the social networks. Thus, the further adoption and dissemination of these technologies was unsuccessful because of the absence of support from institutions or from social networks.

Seed priming and microdosing proved to be agronomically sound and profitable technologies (Sime and Aune, 2015). Studies conducted in the central Rift Valley indicated that a dose of fertilizer at 27 kg DAP ha^{-1} + 27 kg urea ha^{-1} applied as microdosing was able to produce the same yield as the 100 kg DAP ha^{-1} + 100 kg urea ha^{-1} applied as banding. The microdose dose is approximately 73% less than the recommended banding rate (Sime and Aune, 2014). Such a fertilizer technology can increase affordability and encourage farmers to apply fertilizers (Sime and Aune, 2014), while seed priming does not incur any external cost to farmers (Sime and Aune, 2015). These technology options are particularly important for the poorest farmers. Most stakeholders indicated that they lacked adequate information about microdosing and seed priming. Discussant farmers, however, stated that microdosing and seed priming were discontinued primarily because of the absence of support from institutions and social networks. These farmers also stated that microdosing and seed priming have attractive adoptable attributes. Seed priming is cheap and does not add any external expenditure for farmers (Aune and Bationo, 2008) and improves crop establishment and yields in semi-arid agriculture (Harris *et al.*, 1999; Harris, 2006; Chivasa *et al.*, 2000).

Conservation tillage was disadopted because it requires an entire change in the tillage and grazing system, increases weed infestation and offers low yields. Free grazing on stubble after harvest is not compatible with conservation agriculture, which includes retaining crop residues as a mulch (Biazin and Stroosnijder, 2012; Sime *et al.*, 2015). However, conservation tillage is still an option in the central Rift Valley in the vicinity of the household where it is possible to prevent free grazing with traditional fences (Sime *et al.*, 2015).

Extra-early maturing maize varieties were disadopted as a result of very low yield potential and high vulnerability to dogs, birds and other wildlife. These varieties mature far earlier than all other crops. Sorghum varieties were disadopted due to high vulnerability to bird attack, as in the case of *Teshale,* or because of low palatability for consumption and market values, as with *Seredo*. Finger millet varieties were disadopted because of inadequate information on food values, absence of market for grains and absence of institutional support. It was scarcely promoted or assimilated into the social networks. The crop has high yield and good quality of grain and straw. Artificial ponds for rainwater - harvesting were discontinued because of lack of inputs, high labour for digging the ponds, leakage and high maintenance costs. They were used for domestic consumption for both humans and livestock and for small vegetable production. Similar challenges in the semiarid areas in Ethiopia have been reported by Yosef and Asmamaw (2015).

It is clear that no single reason that can explain the disadoption of the technologies. However, one common denominator is the lack of integration of these technologies into the national extension system and social network.

Institutions, the extension system, and technology adoption and diffusion

Institutions channel agricultural technologies to farmers through an agricultural extension system. Extension workers represent the front line of extension services. The national extension system does not comply with the process in technology adoption and diffusion developed by Rogers (2003). He describes technology adoption as a linear sequence of five stages, these being knowledge, persuasion, decision, implementation and confirmation. In the study sites, the existing technology adoption and diffusion process starts commonly with the implementation and proceeds with the confirmation. Technologies reach farmers in the community concurrently in the form of campaigns which neglect the understanding of how farmers adopt new technologies (Rogers, 2003). In such a system, no distinction is made between adoption and diffusion.

Earlier studies, however, indicated that although adoption and diffusion are closely interrelated, they are conceptually distinct. The unit of analysis in adoption study is an individual decision-maker, whereas diffusion is the cumulative adoption path or distribution of adoption (percentage of farmers, percentage of the area) over time or space with the community, region, nation or other geographical scale as the unit of analysis (Rogers, 2003).

It appears that most of the technologies reaching farmers through the extension system suffer from limited information. Rogers (2003) indicated that sufficient information is a key to technology adoption and diffusion. The extension workers are often given only limited training on how to assist farmers in adopting technologies. This inadequate knowledge of the extension workers has been found to lead to a large yield gap between the prescribed and actual fields of the farmers. Such inefficiencies have fostered risk-averse behaviour in farmers, together with reluctance and scepticism concerning technology adoption and diffusion. Earlier studies indicated that communicating adequate information to potential technology adopters is key to promoting adoption behaviour (Bandura, 1977; Rogers, 1995; Rogers, 2003; Adesina and Zinnah, 1993). The use of extension system, media and local opinion leaders or visits to experimental stations combined with on-farm trials, could foster rational technology adoption and diffusion (Adesina and Zinnah, 1993) by providing adequate information. The existing extension system could be improved through making extension workers and farmers active participants in the technology development and decision-making process.

Agricultural research centres and universities also work on technology extension and development. They usually collaborate with district agriculture departments, extension workers and farmers. Such technology development and extension systems are based on farmer fields and up-scaling of best farmers' practices. Such a technology development apparently follows the five stages in technology adoption and diffusion developed by Rogers (2003). As this approach makes farmers and extension workers active participants, it enhances their knowledge. However, the link to the national extension system is poor and the technologies developed by these institutions are barely integrated into the national extension system. In recent years, Ethiopia has given increased attention to extension systems, improved crops, natural resource management and agricultural productivity (Byerlee *et al.*, 2007; Diao *et al.*, 2007). An agricultural production intensification approach has been pursued to boost crop productivity through the application of modern agricultural inputs, primarily improved varieties, fertilizers and improved agronomic practices. The agricultural experts and the extension workers consulted during this study confirmed that the amount of training and attention given to the extension services has been increasing in recent times. This suggests a favourable scenario for agricultural development in Ethiopia in the future.

Most of the technologies reaching farmers match their priorities, except that they are high-input and need further refinements. Based on the interviews with farmers, it appears that their views about promising technologies correspond with the five technology attributes (relative advantage, compatibility, complexity, trialability, and observability) developed by Rogers (1995).

Farmers are unable to exploit the full potential of adopted technologies for various reasons. Affordability of inputs is one key constraint to technology adoption and diffusion. For instance, although farmers show increasing interest in their utilisation, high prices are among the major limitations to the adoption and diffusion of fertilizer and improved seeds. Spielman *et al.* (2011) indicate that the high cost of inputs and insufficient credit services are among the most critical constraints farmers face in adopting the seed–fertilizer technology packages. For example, the average market price for one kg of first generation improved hybrid maize was 1.3 US$ during the 2013/14 cropping season. During the same period, the average market price for one kg of DAP or urea (as per the national recommendation) was approximately 0.84 US$ and 0.74 respectively. This price is approximately more than four times higher than the average market price for one kg of maize, which is approximately 0.25 US$. Around four kg of grain are required to pay for one kg of DAP fertilizer.

Institutions need to work together with farmers in order to increase the efficiency of fertilizer use. The variable rainfall and unreliable agro-meteorological services impose negative impacts on yields and force farmers to desist from fertilizer application. Thus, climate-proof strategies, including better seasonal climate forecasts (Hansen *et al.*, 2007), use of adaptive varieties, efficient rainwater management (Biazin *et al.*, 2012), proper agro-advisory services and input supply (Kassie *et al.*, 2014) are critical for improving the predominantly rain-fed agriculture in the central Rift Valley of Ethiopia.

Another constraint that makes planning of agricultural activities difficult is the volatility of output market prices. For instance, the maize price for one kg varied from approximately 0.25 US$ at harvest to 0.37 US$ at planting, during the study period. Another challenge is that farmers often sell out their agricultural outputs at the lowest price after harvest when local markets are already saturated, and without waiting for profitable market price peaks. As for inputs, institutional support such as credit or subsidy arrangements for outputs, is absent. Having such arrangements in place can help farmers waiting for profitable markets. Kassie *et al.* (2013) discuss similar challenges with the marketing procedures in the central Rift Valley. The same study suggests that to enable farmers to increase agricultural productivity, constraints related to technology, institution, and market-access need to be settled (Kassie *et al.*, 2013).

However, despite these weaknesses in the national extension system, it seems that this system is inefficient in promoting new technologies that are introduced to farmers through various agencies. Technologies not promoted by the national extension system have less chance of being adopted by farmers.

Social network for information sharing

Farmers acquire informal information from social networks of various kinds, such as peers, neighbours, relatives and media. This is a traditional information sharing system for social learning. Technologies are frequently discussed in social gatherings in the villages. Social learning was the underlying reason for the extensive adoption and diffusion of haricot bean and mid maturing hybrid maize varieties, while these crops were hardly supported by the extension system. For acquiring adequate information on technologies, farmers integrate informal and formal information whenever possible. It is this information that enabled the widespread adoption and diffusion of row sowing, banding fertilizer application, early-maturing maize varieties and traditional *in situ* rainwater - harvesting practices. Although farmers used to practise the broadcasting method for both seed sowing and fertilizer application, they were originally very sceptical about fertilizers for row sowing and banding, primarily due to inadequate information. They were also sceptical about the haricot bean production because of the lower palatability of the new varieties compared to the local varieties. Nevertheless, they had gradually become positive as they received adequate information from a combination of formal and informal sources.

Farmers use the market place and their free time in the late afternoon and holidays, as well as funeral and wedding ceremonies, to share information. Most of these social gatherings give plenty of opportunity to discuss information about new technologies. People at such gatherings may come from different places and have different experience with or exposure to technology. This is in agreement with earlier reports that farmers have a tradition of listening to each other; they use different network values and norms to gain confidence in new technologies (Rogers, 2003; Rogers, 1995). Most of the farmers' behaviour also fits the social learning perspectives reported in previous studies (Rogers, 1995; Rogers, 2003; Bandura, 1977). Farmers are also influenced by observing other farmers' fields, as reported by Rogers (2003). Such information sharing also occurs in the study villages, particularly when social gatherings take place during the cropping season, when the performance of technologies on farmers' fields can be observed. Adoption of an innovation is seen as a social process in which learning about new practices occurs both in formal and informal settings by sharing information, observation, imitation, or as a normative action (Rogers, 1995).

It could be seen from a discussion held with extension workers and farmers that farmers differ in their understanding of technologies, especially when supported by information from social networks. The likely reasons could be the quality and strength of observation of the adopter, and the level of understanding, experience and knowledge of the receiver of the information (Bandura, 1977). It was also understood that the quality of such information varies with the degree of the knowledge of the person sharing the information. It was found that, as a result of absence of optimum seed and fertilizer rate, the banding method, row sowing and improved seeds gave different benefits to different adopter farmers in the villages. Such differential knowledge may minimise the potential utility of the adopted technologies.

Conclusion

Technologies reach farmers via national extension system, local social networks or research projects. When technologies are integrated into the extension systems, social networks or both, the likelihood for their adoption and diffusion is enhanced. The study area has undergone major changes during the last ten years. The cropping system in the area was previously based on the broadcasting and mono-cropping of maize, and the limited use of improved crop varieties and mineral fertilizers. Farmers mostly prioritize technologies that are low cost, and have low risk and high adaptability to the existing rainfall variability. Because of the variable rainfall and financial constraints, the expensive improved seeds and fertilizers have high-risk potential and therefore need careful management. Farmers use various strategies such as adjusting the cropping calendar and selecting appropriate crop species and varieties suiting to seasonal rainfall, and application of smaller quantities of fertilizer than the recommendation, or none at all. Yield potential and market prices for outputs are also among the key variables that attract farmers' interests. Row sowing, banding fertilizer and traditional *in situ* rainwater - harvesting practices are widely practiced because they give high return and are compatible with farmers' priorities. These technologies are quickly disseminated because they have been integrated into the national extension system. Haricot bean and mid maturing hybrid maize varieties have not been part of the national extension system, but have been widely adopted and disseminated through the social networks. These crops and varieties have high yield potential and fetch good market prices. Seed priming, fertilizer microdosing and cultivation of finger millet and sorghum were first adopted but were later disadopted. These technologies also have good agronomic and economic benefits, but were disadopted because they lacked support from institutions or social networks. Such an outcome is common for technologies developed through research projects when such projects are insufficiently connected to the extension system or social networks. Technologies which cause significant change to existing practices and do not give immediate benefits, encounter scepticism and reluctance among farmers. Conservation tillage was abandoned as a result of such challenges. Even though farmers have adopted new technologies, the full benefit of these technologies may not be realised due to inadequate information and imprecise recommendations for fertilizer application methods, and optimum fertilizer and seed rates. Challenges related to input supply, output market, financial constraints and the provision of reliable seasonal agro-meteorological information are still limitations, which affect the full package adoption of these technologies.

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