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THESIS

CONSERVATION TILLAGE OPTIONS FOR SUSTAINABLE CROP PRODUCTION SYSTEMS IN THE SEMI-ARID AND SUB-HUMID OROMIYA

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Comprehensive studies were conducted in 2003 and 2004 on conservation tillage crop productions with the overall objectives: to identify the better opportunities in soil-water conservation, soil fertility improvement, increasing crop productivity and reducing production costs. Three field experiments were carried out at Malkassa Agricultural Research Center (MARC) and Wolenchity Agricultural Research Sub Station (WARSS), both located in the dryland central rift valley of Oromiya. Assessment was done on the perception and attitude of farmers towards conservation tillage practices in six districts of the three administration zones of Oromiya. The present result revealed that the highest sorghum grain yield was recorded due to tie-ridge tillage but varied with fertilizer rate for each location. Significantly higher yield was obtained at the highest fertilizer rate of 57.4-64.4 kg N-P_2O_5 ha^{-1} than that obtained at the current recommended rate of 41-46 kg N-P_2O_5 ha^{-1}. However, further applications of fertilizer beyond 49.2-55.2 kg N-P_2O_5 ha^{-1} could give no significant yield advantage and thus, would not be economically feasible. The impact of tillage on maize crop productivity and some of soil properties revealed that soil organic matter content at a depth of 0-15 cm was significantly greater under conservation tillage (1.6%) than that under conventional tillage (1.2%). The total soil nitrogen content was increased from low (0.07%) to medium level (0.130%) on conservation tillage plot while remaining under low category on conventional tillage. A rotation system that used maize as a test crop, increased yield by 184.4% and 140% when maize followed Taaffi and haricot bean crops at Wolenchity and Malkassa, respectively. At Wolenchity, 36-110% maize grain yield increment was obtained when haricot bean was used as a precursor crop instead of Taaffi crop. Taaffi, which is a small seeded cereal and staple food crop of Oromiya was highly responsive to tillage and cropping systems. About 170.6 and 100.5 kg ha^{-1} greater Taaffi grain yields were obtained from pre-plant no-tillage with and without supplemental hand weeding than that obtained from the conventional tillage. The three options of conservation tillage systems were resulted in greater net returns of USD 15-78 ha^{-1} than the conventional tillage. Significantly higher mean grain yield of 1231 kg ha^{-1} was obtained from rotation plot than that obtained from continuous Taaffi monoculture (851 kg ha^{-1}). On-farm perception analysis also indicated that interviewed farmers had positive attitudes towards the benefits of conservation tillage systems in resource conservation, labor and time saving. However, it was observed that poor farm families could not afford to buy inputs to fulfill the requirements of conservation tillage in the rainy season when their grain is depleted from their granary. Based on the present field experimental studies, the implementation of conservation tillage and crop rotation systems can be an effective concomitant strategy for sustainable crop production in locations where soil water is limiting. Overall, adoption and selection of conservation tillage systems for crop production in semi-arid and sub-humid environment of Oromiya will likely be done based on considerations such as increasing productivity, lowering production cost, improve and sustain livelihoods and conserve natural resources.

Sombat Chinawong 14, 02, 06

Student's signature　　　　Thesis Advisor's signature

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Worku Burayu

January 2006

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INTRODUCTION

Traditional farming systems in Oromiya in the past, where the protection of natural resources were exclusively achieved by passive measures such as long fallow periods, restrictions in the use of certain tree species and extensive grazing systems, were compatible with the level of population and ecological environment. This traditional “slash and burn” or “slash and mulch” agriculture was sustainable and effective in restoring soil fertility for the prevailing level of crop yields and intensity of cropping. In the last few decades, however, the traditional shifting cultivation practice has been changed due to demographic and economic pressures, leading to permanent agriculture and frequent tillage crop production system. The introduction of frequent tillage triggered a drastic change in the farming system and in agricultural practices. This change, a sort of agricultural revolution, virtually eradicated indigenous technical knowledge in soil and water conservation and in other related farming activities.

There are several repercussions of such agricultural land use changes and intensification, the most important once being accelerated soil erosion and deterioration of soil nutrient status (FAO, 1986; Hurni, 1988, 1993; EFAP, 1994; Tekle, 1999). Soil nutrient depletion arising from continuous cropping and frequent tillage together with removal of crop residues, low external inputs and shortage of adequate soil nutrient saving technologies exacerbated the resource degradation (Bojo and Cassels, 1995; Sahlemedhin, 1999). Such progressive deterioration of biological and physical resources of the land lead to declining productivity and unsustainable yields of crops (Schwab *et al*. 1995). As a result, the output and productivity of the major cereal crops namely, Taaffi [*Eragrostis tef* (Zucc.) Trotter], sorghum [*Sorghum bicolor* (L.) Moench] and maize (*Zea Mays* L.) are significantly declined (Kidane, 1999). Moreover, poor harvest and even total crop failures are the common occurrences particularly in the semiarid areas (Birhane *et al*. 1994; Asnakew, 1994) leading to none sustainable crop production system.

On one hand, agricultural sustainability, which implies increasing productivity to meet present needs without jeopardizing future potential (Schwab *et al*. 1995), in Oromiya, is hampered with several aforementioned factors including the pressure from a rapidly growing population and diminishing natural resources (EFAP, 1994; Bojo and Cassels, 1995; Herweg and Stillhardt, 1999). On the other hand, today, more than 86% of the population is engaged in agriculture as a means of livelihood, which produces 65% of Oromiya's gross domestic product (CSA, 2004). Such strong reliance on agriculture as an economic driving force entails that natural resource of agricultural significance should be managed on a sustainable basis. Soil and water conservation are important among those natural resource concerns, and sustainability in terms of both resources implies utilization of soil and water without wastage or depletion, so that it is possible to have a continuous high level of crop production (Schwab *et al*. 1995). It can only be sustainable management of these agricultural resources base that will enable the country to achieve the desired sustainable rural and economic development goals on the basis of its agricultural economy.

To cope with such degradation of resources and productivity decline through frequent tillage and continuous cereal cropping agriculture, smallholders' farmers forced to implement some externally developed conservation measures. The focuses of soil and water conservation efforts in Oromiya during the last decades have largely been on diagnosis of crop performances under physical conservation structures such as stone terraces, soils bund and weir in the semi-arid regions and on Broad Bed Furrow (BBF) in the humid and sub-humid Vertisol soil areas. Several attempts have also been made to evaluate the effects of a component of crop management practices such as effects of tillage, fertilizer management, or cropping sequence on crops yields in different location of dryland areas (Kidane, 1999).

However, recently it was realized that the use of physical conservation structures to conserve soil and water and the outcome for a components of crop management practices might not significantly improve the agricultural productivity of smallholder farmers where the land is fragmented and land shortage is chronic constraints. There is also a greater need in Oromiya to attain agricultural sustainability than ever, especially in the fragile ecosystems and marginal lands of the semi-arid, sub humid and humid areas. Issues of agricultural sustainability in these areas, especially those relevant to soil tillage and integrated crop management practices are becoming unprecedented. Today, farmers in Oromiya also find the total costs of producing a crop exceed the income obtainable from its sale; and hence, a reduction of production cost is imperative. These particulars need a bucket of options that will focus primarily on soil and water concern as a major address of production constraints combined with maintenance of crop environments there by improves crop productivity, and reduces production costs. Cognizant to these facts, experiences of many countries have shown that a great realization of sustainability issues related to agricultural productivity has increased interest in soil and water conservation via conservation tillage crop production systems (Phillips *et al*., 1980; Hargrove and Hardcastle, 1984; Lal, 1989). Attempts and works of many other countries indicated that conservation tillage has shown positive effect to minimize nutrient losses (Shipitalo *et al*., 2000; Schillinger, 2001), increase organic matter and water storage (Unger *et al*., 1988; Malhi *et al*., 2001), and reduce production costs (Uri, 2000; Worku *et al*., 2005). The optimal conservation of water can be attained through conservation tillage methods that maximize infiltration, soil water retention, and minimize soil erosion (Stoskopf, 1985; Hammel, 1996; Papendick, 1996). Hence, research on the development of sustainable agronomic conservation oriented farming systems and integrated crop management practices emphasized in many parts of the world (Biamah and Rockstorm, 2000; Kidane *et al*., 2001). Various research results have shown that appropriate tillage systems and conservation effective technologies of soil management with proper cropping system can help attain agricultural sustainability by reversing the degradative trends and restoring the productive capacity of the soils (Schwab *et al*. 1995; Biamah and Rockstorm, 2000; Kidane *et al*., 2001; Worku *et al*., 2006b).

Despite the general recognition in restoring the productive capacity of soils and the positive impact it has on crop productivity in general, no scientific studies have been conducted in the dryland regions to provide precise quantitative information on the use of conservation tillage systems for sustainable crop production. The combined influences of conservation tillage practices, soil fertility management, and crop sequences on crop production, soil properties and profitability have also been lacking particularly in the dryland central rift valley of Oromiya. Moreover, no dependable information exists on the agronomic benefits and possible farmer attitude towards the acceptance of conservation tillage in the crop production system (Worku *et al*., 2005).

Cognizant to those facts, experiments were initiated to undertake comprehensive and in-depth study on the role of conservation tillage system options on sustainable crop production in the semi-arid and sub-humid Oromiya with the following overall and specific objectives.

OBJECTIVES

Overall Objectives

To identify the better opportunities for soil-water conservation combined with soil fertility improvement, increasing productivity and reducing production costs through different conservation tillage systems options.

Specific Objectives

The specific objectives of the four different experiments were:

1. To determine the fertilizer response of sorghum under different tillage systems,
2. To identify appropriate tillage practices for sorghum productivity,
3. To determine the impact of tillage and crop rotation systems on agronomic parameters of maize and some of soil properties,
4. To determine the role of conservation tillage and crop rotation effect on weed flora, soil properties, and Taaffi productivity,
5. To compare the economic advantages of different tillage systems,
6. To assess farmers' knowledge of conservation tillage systems and soil and water conservation practices, and
7. To assess crop management problems particularly tillage related and some of fertility problems and weed management practices.

LITERATURE REVIEW

The Importance of Cereal Crops and Constraints to Production

Regarding Ethiopia in general, cereal crops occupy the largest portion of cropped land each season in and account for over 86% of the area planted with food crops each year (CSA, 2001). Taaffi, sorghum and maize are the major food crops that occupy 28%, 20%, and 16% of the cultivated land under cereals, respectively (CSA, 2001).

Taaffi, which is a small seeded cereal crop, is an indigenous crop to Oromiya, which is consumed as a staple food crop only in the horn of Africa. In Ethiopia, it is the first in area coverage (annually cultivated on about 2 million hectare of land) and second in production, annual production being about 17 million quintal (CSA, 2003). It is mainly cultivated at an altitude of 1400-2500 m above sea level and with better performance at an altitude of 1800-2100 m, rainfall of 450-500 mm, and temperature range of 10-27^{0}C (Tesfaye *et al*., 2004). Because of its importance in the national diet of most Oromiyans and highly desirable agronomic characters it is the most preferred crop and highly valued by farmers and consumers when compared with other food crops grown in the country (Kenea *et al*., 2001). A staple diet of most people in Oromiya locally known as *Buddena,* which is thin, flat and pancake-like bread with evenly distributed eyes is made of Taaffi flour.

Sorghum is one of the leading traditional and indigenous food crops of Oromiya. Generally, it is grown in Ethiopia in 12 of the 18 agro-ecological zones. It ranks third in the country following maize and Taaffi in total production and second to Taaffi in its *Buddena* (national bread) making quality. Sorghum is grown mainly as a rain fed crop in the semi-arid areas. Depending on rainfall and other crop management practices, sorghum grain yield varies considerably from year to year and location to location. Close to one millions of hectares is developed under sorghum production and about 1.2 million tones are produced each year (CSA, 2001). Sorghum suits area receiving an average annual rainfall of about 350-800 mm. Sorghum is also staple foods for a significant proportion of the lowland rural population. Its high demands as well as its suitability for dryland areas of the country have justified the high national priority accorded to the crop (Kidane and Abuhay, 1997).

In spite of its recent introduction, maize is the first in total production (about 25 million quintal) and productivity (CSA, 2003). Maize is particularly important in West and Southwest Oromiya. It is also one of the most important cereal crops produced by smallholder farmers in the semi-arid areas of Oromiya and 40% of its production area confined to drought stressed areas of Ethiopia (CSA, 2003). It is mainly produced for food and cash and the straw is used for animal feed, domestic fuel, and construction.

The traditional tillage system for cereal crop production by the smallholder farmers' in the dryland central rift valley of Oromiya involves multiple passes (4-6 times) with an ox-plow over a 2 to 4 month period prior to planting. Earlier than these periods most crop residues used for live stock feeding or removed and other organic biomass are used for domestic purposes leaving the soil uncovered and no-organic matter is returned to the soil. During such large portion of the dry seasons (December to May) the bare soil is exposed to wind erosion. High, often intense, rainfall that usually occurs during May to August months causes water erosion.

High risk and low yield characterize such cropping systems; the national mean yields having been estimated at about 0.89, 1.2, and 2.1 t ha^{-1} for Taaffi, sorghum and maize, respectively on peasant farms (CSA, 2003) and these will continue to be the guiding principle in developing improved crop management systems in view of the socio-economic conditions of the semiarid farmers. This needs the identification and means to alleviate the underlying causes of production constraints of cereal crops. The already identified major production constraints for cereals in semiarid of the country in general are attributable to several factors including soil-water constraints, traditional farming methods and limited use of modern technologies. Among these, unreliable rainfall and moisture stress, poor soil fertility and soil erosion, weeds, lack of oxen and shortage of labor and continuous cereal cropping systems are the most productivity limiting factors in dryland of the country (Hailu and Kidane, 1988; Tilahun *et al*., 1992; Kidane and Abuhay, 1997).

The dryland area is generally characterized by high intensity but low and erratic rainfall with higher coefficient of variability, which lead to a high incidence of prolonged water stress during even the main rainy seasons (Hailu and Kidane, 1988). Hence, water stress is considered as one of the major causes for low yields and total crop failure of cereals in the semi arid areas of the country (Kidane *et al*., 2001). The increased reliance upon continuous cereal cropping even on soil with less organic matter and low inherent fertility (characteristics of semiarid), and frequent tillage practices in May, June and July aggravate the soil erosion leading to nutrient deficiency (Kidane and Abuhay, 1997). Of the nutrient, nitrogen and phosphorus are the most crop growths and yield-limiting factors ranked poor soil fertility as the second most constraint generally faced in the dryland areas (Kidane *et al*., 2001). Weeds are also some of the important crop production constraints, which resulted in sustainable loss of about 60% and 48% of sorghum and maize yield respectively, in the central rift valley of Oromiya (Kidane and Abuahy, 1997). Cost incurred and time spent to control weed is significant (Worku and Hussein, 2004; Worku *et al*., 2005). For instance, nationwide estimates of the labor required for hand weeding a hectare of Taaffi ranges 40-138 man-days (Franzel *et al*., 1989) and the cost of production and energy required to produce cereals has also been escalating.

Tillage and the Concept of Conservation Tillage

Tillage terminology

At present no national census of the crop acreage represented by conservation tillage management systems in Oromiya and Ethiopia as a whole. The term conservation tillage has been used for varied tillage practices under a range of conditions. It is difficult to obtain reliable estimates, since terms often are inconsistent or imprecisely represent the crop or farm situations that exist. The existing systems for seedbed preparation alone differ greatly among climatic zones, geographic areas, soils, and species present. The vague use of the term for differing situations has created confusion and misunderstanding. For these and other reasons much wants in the clarity and consistency of the prevailing terminology related to tillage. Thus, to avoid confusion and to promote continuity in the present dissertation paper, the terms related to tillage, which are classified to identify the kind, amount and sequence of soil disturbance during seedbed preparation (Brady and Weil 2002) are adopted and used consistently. The term tillage is a broad generic term embraces all operations of seedbed preparation that optimize soil and environmental conditions for seed germination, seedling establishment and crop growth (Lal, 1996; Brady and Weil, 2002). There is a wide range of tillage systems including conventional tillage, traditional tillage, plough-tillage and conservation tillage.

Conventional Tillage: The combined primary and secondary tillage operation normally performed in preparing a seedbed for a given crop grown in a given geographic area is usually known as conventional tillage. The system, which is based on mechanical soil manipulation of an entire field, and involves primarily cultivation based on ploughing or soil inversion followed by harrowing or discing, is called *plough-till* (Lal, 1976).

Conservation Tillage: It is any tillage sequence that reduces loss of soil or water relative to conventional tillage, which generally leaves at least 30% of the soil surface covered by residues where water erosion is important (Mannering and Fenster, 1983). Or maintaining at least 455 kg of flat, small grain residue equivalent on the surface during the critical wind erosion period, where soil erosion by wind is a primary concern (CTIC, 1992). Conservation tillage includes *minimum tillage*, *mulch tillage*, *conservation tillage*, and *ridge-tillage*.

*Conservation tillage***:** It is a procedure where by a crop is planted directly into a seedbed not tilled since harvest of the previous crop is called conservation tillage; also called *zero tillage*. The implement is only used in opening row for seed and fertilizer applications in mechanized farming; for smallholder-farming row is opening by oxen plough.

*Ridge-tillage***:** It is the practice of planting or seeding crops on ridges formed by cultivation during the growing period. The ridges may have short crossties to create a series of basins to store water is called *tied-ridges*.

Traditional tillage systems

Farmers in many different agro-ecologic zones of Ethiopia still use various traditional tillage and seedbed preparation methods (Worku *et al*., 2002). The notion of sowing seeds into untilled soils is very old. Conservation tillage is, therefore, not a novel principle in the country. Nowadays in some regions of the country the farmers practiced it by creating a hole in untilled soil with a stick, dropping seeds into the hole and then again pressing the sides together with one foot. They form mounds, beds or ridges by hand or by animal drawn with superficial soil manipulation. In some part seeds are broadcasted first then bushes and weeds are slashed manually and used as mulching. In others bushes and weeds are slashed manually and burned, seeds are sown by hand in to the hole. Several also practiced mixing and crop rotation cropping systems. Consequently, reduced tillage or conservation tillage is already in place and it is the ordinary procedure in systems using hand labor and selective animal traction in Oromiya (Worku, 2001) and in many of African countries (Biamah *et al*. 2000). Thus, Lal (1986) suggested that conservation tillage systems are compatible with existing traditional farming practices of African farmers. He further stressed that these systems can be technically and economically feasible and socially acceptable to the local communities since it has been already in place.

Risk associated with conventional tillage

Tillage was probably the most and important innovation to secure a sufficient and stable food supply. According to Arnon (1992), tillage helps in the land preparation for sowing and planting, improving the moisture regimes in the soil, nutrient status and weed control; and in the long run it helps to prevent soil erosion and maintaining soil fertility on sustainable basis. Tillage *per se* can increase infiltration; enable deeper and more uniform soil wetting, as well as deeper root penetration. Overtime, though, tillage has come to be seen as a mixed blessing- necessary at times, but capable of causing considerable damage to the soil and to the environment. Tillage can cause soil compaction, reduce soil aggregation, eliminates surface residues, and decrease infiltration. This is evidenced in conventional agriculture, in which the soils is regarded only as a substrate that provides physical support, water and nutrients to plants and finally inflict further loss of the potential productivity of crops (Unger, 1984). Conventional tillage can also increase the risk of erosion and nutrient loss associated with runoff especially if the soil surface is exposed to rain drop impact after plowing or removal of crop residues (O'Halloran, 1992). Continuous cultivation is generally taken as exploitative and involves a high risk of erosion, decline of soil organic matter and fertility, and reduced productivity (Worku *et al*., 2006c). Conventional tillage practices in the row cropping can hasten the loss of the soil or organic matter and the deterioration of soil structure (Martel and Mackenzie, 1980). Tillage induced soil erosion in developing countries can entail soil loss exceeding 150 Mg/ha annually and soil erosion accelerated by wind and water is responsible for 40% of land degradation world wide (FAO, 2001).

Time and frequency of conventional tillage

In many parts of Oromiya, farmers do not use chemicals to control weeds; tillage operations are mainly used (Worku 2002). Therefore generally, the time and frequency of tillage are influenced by the kind of weed control required. Farmers usually practice planting after two or three effective rains instead of dry planting. Shortage of draught animals and limited draft power due to shortage of dry season feed at the beginning of the season also limit the area that can be ploughed (Reddy and Kidane, 1993). According to the survey made in Ethiopia, in general the frequency and time of plowing for seed preparation varies depending on the abundance and number of weeds prevailed and also found to vary based on the type of crop species, soil type and the farming system of the localities (Pathak, 1988). Determining the timing and frequency of tillage for each area and crop type would help to improve productivity. The results of experiments done in the dryland Ethiopia to determine the timing and frequency of tillage for sorghum showed that plowing twice (just after harvest and at planting) gave better yield, although there was no significant difference among the different plowing frequencies (Reddy and Kidane, 1993).

Conservation tillage concept

The understanding of the conservation tillage concept is important not only to avoid the current confusion in Ethiopia in general like in any of the country in the world in the past two-three decades but also to make benefit out of the options in crop productivity and environmental sustainability. Some of the agricultural experts who have been working in Oromiya misconceived, as conservation tillage is only associated with chemical weed control. Some also undermine the importance of conservation tillage in the dryland of the country where there is low organic matter. Consequently, a number of them strongly resisted conservation tillage systems particularly conservation tillage for the dry land parts of Oromiya as it were evidenced on different workshops and reviews. However, literatures and the research findings prove otherwise.

Conservation tillage, a new approach that protects the soil at all times from run off loss, save energy and labor, conserve moisture and left crop residue on the soil surface was developed (Arnon, 1992). Conservation tillage has become increasingly popular and many countries have benefited from conservation tillage practices (Brady and Weil, 2002). Regarding this system Baker and Ritchie (1996) stressed "no-technique yet devised by mankind has been any where near as effective at halting soil erosion and making food production truly sustainable as conservation tillage”. World wide there is a big move away from crop production using soil preparation that invert the soil and destroy soil structure to that of reducing tillage to give a minimum soil disturbance. This is because as research in different countries of the world repeatedly showed frequent tillage operations are rarely beneficial, and frequently detrimental, in addition to being costly (Baumhard *et al*., 1985; Holland and Felton 1989; Unger and Baumhardt, 1999). Conservation-tillage system is designed in many countries to conserve resources including the minimization of soil loss by water and wind erosion. Studies in several countries indicate that conservation-tillage procedures are sound, environmentally friendly; yields are usually higher or similar to yields from conventional tillage (Baumhard *et al*., 1985; Holland and Felton 1989; Unger and Baumhardt, 1999). The value of residue in conservation efforts along with the positive economic aspects of reducing tillage operations has steadily increased the acreage of conservation tillage in many different countries (Lamound *et al*., 1991).

Because a number of factors (e.g. climate, pests, soil factors) regulate crop growth and yield response, tillage may have a positive, negative, or zero effect on crop productivity. Thus, when precipitation and soil moisture is adequate with good drainage and nitrogen is available, the types of tillage have no remarkable influence on grain yield (Baumhardt *et al*., 1985). On the one hand increased grain yields in conservation tillage systems particularly conservation tillage, compared with conventional tillage have been obtained in areas having limited precipitation and soil water (Baumhardt *et al*., 1985). On the other hand, conservation tillage resulted in lower crop yields in regions where precipitation was adequate-to-excessive, soil temperatures were low, weed control was poor, and soil drainage was poor (Hargrove and Hardcastle, 1984). Similar studies have demonstrated a yield increment from conservation tillage. According to the findings of (Unger and Parker, 1975) grain yields of sorghum and maize were significantly increased with conservation tillage than the conventional tillage at the dryland farming of USA (Bushland). Yield increases of 0.9-1.5 t ha^{-1} were recorded for no tilled sorghum as compared to cultivated sorghum in a semi-arid region of Texas, USA (Baumhard *et al*., 1985). The exact nature of appropriate tillage operations, however, depends on soil types and crops (Lal, 1986). Under some condition, conservation tillage and reduced tillage can improve crop yields (Sprague and Triplett, 1984; Lal, 1986). This has been attributed in part to the higher water contents often found in conservation tillage soils. In cool, wet soils, however, soil warming and seedling emergence may be delayed in the systems that leave high levels of surface residues (Schneider and Gupta, 1985; Hayhoe *et al*., 1993) potentially affecting yields. Higher bulk densities and penetration resistance in conservation tillage surface soils can adversely affect root growth and plant performance in some situations (Vyn and Raimbault, 1993), although tillage affects on bulk densities may be transitory (Weill *et al*., 1990). According to Lal (1976) the plough-till system in-addition to establishing the seed soil contact, it is used to alleviate soil compaction and so improve infiltration capacity, incorporate fertilizer in to the root zone and eradicate weeds.

The tie-ridge, one of the conservation tillage systems offer advantages for water conservation and yield of row crops in dry land conditions (Hulugalle, 1990), but cause yield decline due to water logging in wet conditions. The work of Kidane (1999) proved and emphasized the importance of tie-ridge in soil moisture conservation in the similar semi-arid areas. The incorporation of conservation tillage particularly conservation tillage into traditional soil and water conservation practices such as mulching, ridging, mixed cropping, and crop rotation for African's farmer was also suggested (Lal 1986). The out put of the work of other countries for the dryland also evidenced the advantage of conservation tillage where the above ground biomass is low while frequent tillage that reduces soil vegetation cover leads to soil loss (Carefoot *et al*., 1990; Hulugale, 1990).

The Effect of Conservation Tillage on Crop Growth and Yield

Tillage effects on crop growth and yield depend on cropping system, including amount and characteristics of crop residues, and on soil and climatic factors (Carefoot *et al*., 1990). Soil tillage influences sustainability at crop level through its effect on agronomic yield, at cropping system level by influencing productivity, and at farming system level by enhancing profitability (Schwab *et al.*, 1995).

The results of Holland and Felton (1989) indicated that from experimental and observational sites where sorghum grown using conservation tillage technologies out yielded the cultivated sorghum by an average of 0.5 t ha^{-1}. Wagger and Denton (1989) reported consistent yield increase of 8% to 67% in maize and 36 to 55% in soybean with conservation tillage compared to conventional tillage. They noted greater soil water availability with conservation tillage and attributed it to reduced runoff. Moschler *et al.* (1972) compared conventional and no-tilled maize on three soil types and observed that conservation tillage resulted in a 9-year average yield increase of 25.6%, a six-year average increase of 13.7% and a 5-year average increase of 39.0%. A number of on-going trials have indicating the promise of conservation tillage in Oromiya (Tesfa, 2001; Tolessa, 2001; Worku, 2001; Astatike *et al.*, 2002). The report of Food and Agricultural Organization also emphasized on the incorporation of reducing cultivation and soil manipulation in the farming systems (FAO, 1993).

Changes of Soil Properties in Different Tillage Systems

Soil properties that may be altered with changes in tillage include organic matter, erosiveness, moisture, temperature, density, and aggregation (Spargue and Triplett, 1984). According to them residue maintenance preceding and during the growing season, especially in the amount remaining on the soil surface affect accumulation of soil organic matter, soil erosiveness, soil temperature and soil moisture that in turn affect crop growth, maturity and yield. Soil organic matter resulting from the residue decomposition affects soil aggregation and soil stability. Physical soil degradation is related to changes in soil properties, which have a negative effect on crop production, farm income, and environmental quality (Lal, 1993). Decline in soil structure leads to surface sealing, crusting, compaction, hard setting, and reduction in permeability, poor aeration, and water logging (Gupta *et al.*, 1989). Rainfall often forms a surface seal or crust when the soil surface is a bare (Ewing and Gupta, 1994). According to them this seal reduces infiltration of water in to the soil and thus increases the probability of runoff, erosion, and surface water pollution. Surface sealing from rains that occurs after planting and before seedling emergence also hamper stand development. The flocculation of suspended soil colloids plays an important role in the processes of surface crust formation (Southard *et al*., 1988). Dispersed soil particles have a negative impact on soil structure and contribute to soil erosion. Lack of organic matter content and a high proportion of silt are responsible for crust formation (Goldberg *et al*., 1990). Several studies in conservation tillage especially conservation tillage system indicated that conservation tillage result in the accumulation of organic matter in the first few centimeters of the soil profile (Follet and Schimel, 1989).

The Role of Conservation Tillage in Weed Management

Weed control has been stressed to be a major factor limiting the adoption of conservation tillage system in many countries (Gebhard *et al*., 1985; Koskinen and Mc Whorter, 1986). Because of this it has been suggested that the conservation tillage techniques may be limited to areas with no numerous perennial weeds (Moomaw *et al*., 1968). De Datta *et al*. (1977) also recommended that no tillage should be considered as a special technique for special conditions. Conversely, intensive land use involving conventional tillage practices resulted in decline in crop yield, erosion hazards and irreversible loss in soil physical and chemical properties (Ball and Miller, 1993). Similarly, Seth *et al*. (1971) observed in Malaysia that the incidence of weeds in the growing crop was generally less following the use of no tillage. Heatherly *et al*. (1990) and Ball and Miller (1993) stated that pre-plant tillage is not necessary for weed control on a clay soil and weeds can be effectively controlled by use of proper herbicides. Since then in many countries the problem of weeds alleviated through combined weed management techniques. The production of broader-spectrum non-residual chemicals such as Round Up have developed and expanded the concept on conservation tillage even further. Similar findings also substantiated that in conservation tillage system weeds are controlled by herbicides and overlapping of activities can be compensated by the elimination of repeated tillage (Lamound *et al*., 1991; Chichester and Morrison, 1992; Brady and Weil, 2002).

Ridging and Tied Ridging

The method is known in various names in different countries as furrow blocking, furrow damming, furrow diking, and basin listing. Several researchers defined tied ridging as a tillage method in which a series of small dams or cross dike constructed across the furrow to prevent runoff during heavy rainstorm or to increase surface retention storage and improve infiltration (Lyle and Dixon, 1977; Unger, 1984; Jones and Stewart, 1990). Tied ridging is the formation of cross dikes within certain interval (distance) and the principle is to increase surface storage by first making ridges and furrows, then damming the furrows with small mounds, or ties. The use of tied ridges has received considerable concern in the Africa semi-arid tropics as an *in-situ* soil and water conservation system. The technique has been extensively tested and evaluated with smallholder farmers in Ethiopia, Eritrea, Zimbabwe, Kenya, Uganda, Tanzania Burkina Faso, Nigeria and else where in Africa. Even if, tied ridging technology received attention but mixed results had been reported about its performance depending on various conditions (Dagg and Macartney, 1968; El-swaify, 1983; Gerard *et al*., 1984; Kidane and Abuhay, 1997). The potential of tied ridging for improving dry land yields depends on a number of factors, including rainfall (amount, intensity, distribution), soil characteristics, and crop species. Past and recent research in Botswana, Zimbabwe, Burkina Faso, Ethiopia, Tanzania, Kenya and USA have revealed that tied ridging is effective in reducing surface runoff and increasing soil water storage (M'Arimi, 1978; Hulugalle, 1987; Krishna, 1989; Carter and Miller, 1991; Piha, 1993) and also increase grain yield (El-swaify, 1983). Whether tied ridging will increase water storage and subsequent crop yield and quality, the crop response to tied ridging varies considerably from year to year and between locations and depends on the nature of the soil character, climate related factors, slope, land slop position, soil texture and crop species. Research results from early diking experiments were generally promising in many countries (Bilbro and Hudspeth, 1977; Lyle and Dixon, 1977). The experiences in different countries of Africa indicated that under certain circumstances the system has been beneficial not only for reducing run-off and soil loss, but also for increasing crop yield (Lawes 1961; Dagg and McCartney 1968). However, during high rainfall years or in years when relatively long periods within the rainy season are very wet, significantly lower yields were reported from systems with tied ridges than from graded systems, which disallowed surface pounding of water (Lawes 1961; Dagg and McCartney 1968). Under such conditions tied ridging enhanced water logging, developed anaerobic conditions in the rooting zone, excessive fertilizer leaching, and water table rise in lower slope areas.

In other many countries there are conflicting reports, with a majority of successes. McCartney *et al*. (1971) reported that tied ridging in Tanzania gave higher maize yields not only in low but in high rainfall years as well. However, reports of success are more common in low rainfall years, for example Njihia (1979) reported from *Katumani* in Kenya that tied ridging resulted in the production of a crop of maize in low rainfall years when flat-planted crops gave no yield. Honisch (1973) reported similar result on a sandy soil in the Zambesi valley that tied ridges increased mean crop yields (maize, sorghum, and millet) over those on flat land by 168, 159 and 16 percent under seasonal rain- falls of 587, 623, and 724 mm. On Vertisols in Swaziland, mean increases for maize, cotton, and sorghum were 64 percent in a year of 508 mm and 308 percent in a year of 310 mm.

Gerard *et al*. (1984) demonstrated yield increases due to tied ridging relative to other tillage systems would occur only during years with rainfall sufficient to cause runoff, that is, when the rainstorm intensity exceeded the infiltration rate. Furrow diking has been shown to reduce or prevent runoff when dikes are in place prior to significant rainfall event (Gerard *et al*., 1984). Diking increased sorghum yields on graded and contour furrowed plots at Bush land, TX by 49 and 14% and water use efficiency by 25 and 16% respectively (Jones and Clark, 1987). The more efficient use of soil water with the furrow diking is reflected in greater sorghum grain yield and favorable response to diking was obtained with grain sorghum (Gerard *et al*., 1984; Jones and Clark, 1987). Sow *et al.* (1996) reported average grain yield with furrow dike treatment was 4840 kg ha^{-1} that was about 800 kg ha^{-1} more than with conventional tillage. The effect of tied ridges as a soil water harvesting technique is enhanced if used in combination with organic residues. For example, Kilewe and Ulsaker (1984) reported that tied ridges in combination with stover mulch conserved more water and led to higher dry matter and grain yields of maize compared to minimum tillage. Maize stover effectively controlled runoff through increased surface water storage, which in turn increased the time available for infiltration and also minimized evaporation, surface sealing and crusting. It was also reported that, when a combination of tied ridges and maize stover mulch were used, a crop of maize was realized in a season of extremely low rainfall of 171 mm, whereas no yield was obtained from the conventional tillage plots with or without farmyard manure.

Performance of animal drawn tie-ridger implement

In many countries, tied ridging is usually associated with mechanized farming. In Oromiya tied ridges are traditionally used by small farmers as *in- situ* water harvesting technique in sweet potato production system using hand hoe in the eastern part of the country in Hararghe area. This traditional practice was modified and extended through research to be used for other grain crops such as sorghum and maize (Ethiopian Agricultural Research Organization, EARO, 2000). There have been some attempts at achieving it with ox-drawn implements but the high labor requirement of the system usually makes this unpopular and less efficient with subsistence farmers (Kidane, 1999). Moreover, in practice it is more likely to depart from a true contour and to have variations in the height of the ridge, both of which will increase the risk of overtopping. Although the effectiveness of tie ridges in soil water conservation and yield increase of many field crops highlighted but it was found tedious and very time consuming, usually takes up nearly 26-30-work days ha^{-1} to construct tie-ridges by hand with a small hand hoe (Kidane, 1999). While one of the conservation tillage advantages is reducing labor cost and time this hand hoe tie ridges construction didn't payoff. To alleviate this drawback a tie-ridger attachment was invented with an oxen plow implement, which thought enables the farmer to do tie ridging four times faster than making them with hand. This tie-ridger creates tied-ridges 10-20 cm deep as micro-catchment basins and the ridges of 30-40 cm deep so that all the water that falls on them can be captured, and recommended ridge spacing is 75 cm for sorghum and maize. However, farmers' attitudes assessment toward the introduced implement in the year 1996 indicated that almost all farmers responded as the implement was too heavy and awkward for oxen to pull, especially when they are weak after dry season feed shortage, which coincides with the time of land preparation (Kidane, 1999). Preliminary results showed that both implements enabled to construct ridges with almost equivalent depth and width as compared with the manually constructed ridge in a relatively smaller time and drudgery (Wondimu and Getachew, 1998; Getachew and Wondimu, 2000).

In general tie-ridges have been found to be very efficient in storing the rainwater and lead to substantial grain yield increase in sorghum. According to the findings of Kidane and Rezene (1989), the average grain yield increase was up to 145% for sorghum compared to the traditional practices depending on soil type, slope and rainfall in some of the dryland areas. Their finding indicated that tied ridging is the most effective tillage method that increased grain yield of sorghum. Tied ridging was also found to be the most effective tillage method used to conserve soil and water in the semi-arid areas (Kidane and Rezene, 1989; Worku *et al*., 2006a). Another similar study made in the central rift valley revealed highest grain yield from crops (sorghum and maize) planted in the furrows of tie-ridges (Reddy and Kidane, 1993). However, in both studies and from the results of other similar experiments except for yield and yield components of the crop, the dependable data on how much soil-water was conserved and data on the water use efficiency of the crops have been limited.

Water Use Efficiency (WUE) and Soil Management

Water is a critical need for crop production and is often the most limiting factor to profitable yields. Even in areas with higher rainfall, lack of sufficient soil water supplies at critical growth stages causes a reduction in yield. The physiological concept of WUE, and its agronomic implication, is the yield of dry matter as a function of the total water used to produce a crop. Because it is difficult to determine the weight of roots and ignores the dry mass of the root system (typically) 10-20% of the total crop mass at maturity, only the aboveground biomass is considered (Gregory, 1988).

Soil management practices like tillage and residue management, and plant nutrient practices, like addition of nitrogen and phosphorus, have a positive impact on water use efficiency (Power, 1983; Unger and Stewart, 1983; Jones and Popham, 1997). Crop producers in water-limited areas have used water use efficiency as a method of comparing farming systems. In the higher rainfall areas, water use efficiency can be used to improve nutrient management practices across fields. The agronomic definition of water use efficiency involve two major terms: a biological component (commonly called the transpiration efficiency) that specifies the amount of dry matter produced per unit of water transpired, and a management component that specifies the fraction of the total water supply used for transpiration. For the agronomist, WUE is usually a seasonal value defined as yield per unit area per water used to produce yield. Yield is frequently expressed solely as grain yield. Thus, WUE is used in its most widely accepted form, namely the ratio of yield to water use (Y/ET); the term refers to water lost by transpiration and evaporation. For most crops only part of the dry matter produced is of economic significance to the farmer (e.g. grain crops). Therefore, the economic proportion of the total dry matter (Yec) can be substituted in the relationship and the agronomic definition of water use efficiency is defined as WUE= Yec /ET.

Combination of Technologies

Conservation tillage and crop rotation

Continuous cereal monoculture is the most dominant crop production system in the dryland area. However, the results so far obtained in the dryland and sub-humid of the country indicated that yield reduction due to monoculture was the big problem (Tesfa *et al*., 2003; Worku and Hussen, 2004; Worku *et al*., 2006b). Furthermore, an ever-increasing rate in the price of inorganic fertlizer is continously becoming a challenge for crop production in the areas and these encourage the use of alternative source of fertilizer (Hussein and Worku, 2005). Alternating the choice of crops in the cropping systems as one of the approaches may help in solving such problems associated with monoculture. Crop rotations have many benefits that can influence the success of crop production enterprises both under conventional tillage and conservation tillage systems. Results of an experiment conducted in the central rift valley of Ethiopia showed an increased grain yield of cereal by rotating it after haricot bean (Lemma *et al*.,1994). Unfortunately, these results were not substantiated with data on soil nutrient changes (Worku *et al*., 2006b). Combining cropping systems and conservation tillage practices, such as conservation tillage are proven to be very effective in improving soil organic matter and yield of crops in many countries (Al-Kaisi and Hanna, 2002). These benefits of conservation tillage include less soil erosion, less water pollution, increased organic matter in the soil, lower labor costs, less time required per crop, and in some cases the possibility of an additional crop yield per year (Okoba *et al*., 1997).

Improved farm management and soil moisture conservation

Most of the soils in the semi-arid tropics are highly degraded with poor physical, chemical and biological properties. The soils have problem of shallowness, compaction, surface sealing or crusting which lead to low water infiltration and high runoff (Getachew, 1986). It is no longer appropriate to preach to farmers that they must conserve their soil before they can get better crops. By redefining the problem the philosophy underlying soil conservation becomes that of promoting improved farm management practices that benefit crop production and in so doing conserve soil and water. Under dryland farming conditions water is the number one limitation to successful crop production. In addition, soil fertility, limited choice of crops and crop varieties are the main cause to low and unstable productivity (Kidane *et al*., 2001). The quantity of water available to the crop can be increased by: (i) increasing water storage in the root zone by improving infiltration either by water harvesting and irrigation and (ii) reducing to a minimum the losses of water due to evaporation, runoff and drainage loss through management practices such as conservation tillage, fallow, mulching; weed control, planting pattern and density (Gregory, 1988; Dao, 1993).

The soils in most of Ethiopia semiarid areas are severely eroded and are relatively infertile, leading to reduced crop yields (Kidane, 1999). Soil erosion is endemic and results in a reduced volume of soil that would retain water and nutrients. Deficiencies in N and P are especially serious and organic matter content is very low, generally less than 1%. Many of the soils with low organic matter will require a parallel increase of both inorganic and organic fertilizer in order to hold nutrients in the soil and to increase biological activity. Yield and water use efficiency can be increased by: (i) improved soil and water management practices like fertilization, seedbed preparation; (ii) conservation tillage, water harvesting, etc.; (ii) improving crop management like timely plant establishment, proper cropping system, pest, disease, weed control and timely harvesting and (iii) growing high-yielding, stress tolerant and widely adapted cultivars (Tanner and Sinclair, 1983; Cooper *et al*., 1987; Hamblin *et al*., 1987). Mabbayad *et al*. (1968) found that nitrogen effects were not dependent on the degree of tillage. According to his findings there was no significant interaction between tillage methods and nitrogen fertilizer rates. Mittra and Pieris (1968) also found the timing and level of nitrogen application recommended for normal cultivation were also suited to zero-tillage. However, Boligon and Detta (1976) found that nitrogen efficiency was lower under no–tillage than under minimum and conventional tillage. There are several experimental evidence, which indicate that the combined use of soil water conservation through tied ridges and fertilizer application is more effective and resulted in sustainable increase crop production than the use of tied ridges or fertilizer use alone in semi-arid areas.

Field trials were conducted to determine the effect of moisture conservation on the yield of maize and sorghum varieties with and with out fertilizer application in semi-arid areas of Oromiya. The result from this experiment indicated that a substantial yield increase of more than 50 percent was accounted for the practice of water conservation under unfertilized condition. In the case of using fertilizer, the overall yield increase is not high (27%). However in terms of absolute yield, the combination of moisture conservation and use of fertilizer, has given the highest attainable yield. An average grain yield increase when fertilizer application was combined with water conservation practices in Alfisols and Vertisols were 110% and 49% respectively and the results from this experiment clearly showed that fertilizer application in combination with moisture conservation gives better yield than either fertilizer or moisture conservation alone (Kidane and Abuhay, 1997). The report of Kidane (1999) also indicated that grain and biomass yield increase of sorghum when tied ridges and fertilizer (nitrogen and phosphorus) were used together. From agronomic point of view it is of particular interest to determine whether conservation tillage would affect total grain matter yield and grain production in plots managed under different tillage systems. This is because; the agronomic and economic performance of conservation tillage is extremely location specific. Soil water conservation should also be integrated with other improved agronomic practices so that the soil water retained could be used effectively. It was found that the interaction between the high yielding potential of the cultivars and favorable agronomic conditions lead to substantial yield increase (Kidane and Abuhay, 1997). A recent finding by Worku *et al.* (2006a) clearly indicated the benefit of combining *in situ* moisture conservation techniques with the soil fertility management.

MATERIALS AND METHODS

To examine the effect of conservation tillage options for sustainable crop production three field experiments were conducted during the June to November main growing season of 2003 and 2004 cropping years at two locations in the semiarid central rift valley of Oromiya. To get feed back on the previous on-farm conservation tillage practices another study was also conducted. Farmers from three Districts, each in the dryland central rift valley and sub-humid high lands of Oromiya were interviewed for their perceptions of conservation tillage practices and crop management scenarios.

Experimental Sites

Field trial sites

Field trials were conducted at Malkassa Agricultural Research Center (MARC) and Wolenchity Agricultural Research Sub Station (WARSS), both located in the semiarid central rift valley of Oromiya. Based on Thermal Zones and Length of Growing Period (LGP), MARC and WARSS are generally categorized under tepid to cool sub-moist mid high lands agro-ecological zones (MOA, 1998). This agro-ecology zone is generally constrained by moisture stress, unreliable rainfall, termite problem, shallowness of soil, problem of workability, and soil erosion (MOA, 1998). Generally, soils are clay, clay loam, loam or sandy loam with little organic matter ($\leq$ 1%) and pH neutral to mildly alkaline. The area is characterized by low and erratic rainfall, averaging between 775 and 897 mm per year. Both the start and the end of the rainfall are highly uncertain. Late onset of rains, intermittent periodic dry spells, and early cessation of rains are common causes of fluctuating annual production with occasional drastic reduction in crop yields (MARC, 1996).

MARC is located 117 km East of Finfinne (the capital city of Oromiya) and 17 km southeast of Adaama town on the way to Adaama - Arsii road, at 8^{o} 24’N latitude and 39^o 12'E longitude. It receives about 775 mm annual rainfalls. The minimum temperature ranges from 10.4^oc to 16.2^oc and the maximum from 26.2^oc to 30.9^oc. About 64% and 7.2 mm relative humidity and evaporation, respectively prevail in the area. In July and August more than 80% relative humidity while in March, April and May the evaporation exceeds 8 mm. This area receives about 8.2 sunshine hours per day, and 442.5 cal per cm^2 solar radiation. It experiences high wind speed (9.7 m per second) and more soil temperature (25^oc at average). WARSS, which is 120 km East of Addis Ababa and 20 km East of Adaama, is located at 1450 m above sea level at $8^0$40' N latitude and $39^0$26' E longitude. It receives about 897 mm annual rainfalls.

Farmers' assessment sites

On top of the field experiments, the effect of the already implemented conservation tillage system was assessed in 2003 and 2004 from farmer's perception point in its practicability, and its impacts on yield and some soil properties. The assessment was done in the three administration zones of continuous maize and Taaffi growing areas of Oromiya, namely *East Shoa*, *Jimma* and *West Shoa*. The maize belt zones of Oromiya (Jimma and West Shoa) were the primarily focused areas. Hence, two districts of Jimma (*Omonada* and *Mana*) and one district of West Shoa (*Bakko-Tibbe*) where conservation tillage demonstrations have been relatively widely done on maize were considered. Taaffi, the staple food crop of Oromiya was also given special attention since frequent tillage is by far more widely used than any other cereals. In the three districts of East Shoa zone (*Ad'aa, Lume* and *Bosat*) Taaffi based cropping system is predominantly practiced and demonstration of Taaffi based conservation tillage also widely carried out and hence, assessment was done in the three districts.

Rainfall Data Analysis

The five years annual amounts of rainfall data compared with 29-years average (1977-2004) for MARC and 15 years average (1990-2004) for WARSS are presented in Table 1 and 2, respectively.

Table 1 Rainfall data from 2000 to 2004 as compared to 29 years average at MARC.

Month	2000	2001	2002	2003	2004	29-yrs average	Accounts (%)
January	0.00	0.00	39.30	16.60	50.60	19.80	2.55
February	0.00	6.80	9.00	24.20	0.40	11.88	1.53
March	8.50	96.70	53.00	128.10	92.80	70.48	9.09
April	39.70	27.00	53.50	70.80	69.20	51.25	6.61
May	77.50	137.60	45.40	4.00	0.60	52.93	6.83
June	78.20	103.00	20.20	47.90	51.20	65.43	8.44
July	262.80	221.40	71.50	197.30	202.30	190.70	24.61
August	180.00	159.40	156.90	183.80	136.70	165.62	21.37
September	64.00	50.80	40.60	158.80	103.40	83.55	10.78
October	80.40	1.40	3.20	0.00	64.30	32.82	4.23
November	42.40	00.00	1.60	1.30	19.40	12.32	1.59
December	16.90	10.70	18.40	53.10	0.00	18.18	2.35

Table 2 Rainfall data from 2000 to 2004 as compared to 15 years average at WARSS.

Month	2000	2001	2002	2003	2004	15-yrs average	Accounts (%)
January	0.00	0.00	0.00	32.10	8.03	9.89	1.10
February	0.00	13.60	0.00	32.10	11.43	12.26	1.37
March	15.50	128.00	48.90	119.60	78.00	76.58	8.54
April	18.40	20.00	61.40	152.60	63.10	60.17	6.71
May	47.90	65.90	10.00	0.00	30.95	32.91	3.67
June	58.40	76.50	18.70	61.20	94.00	62.05	6.92
July	249.20	187.10	156.20	396.20	245.75	248.45	27.71
August	249.50	271.10	231.80	321.70	172.50	240.17	26.79
September	110.90	137.90	36.00	19.50	60.00	76.75	8.56
October	96.30	63.47	0.00	0.00	43.50	44.46	4.96
November	30.50	10.00	0.00	0.00	10.00	8.79	0.98
December	6.10	0.00	97.70	28.30	32.00	24.03	2.68

MARC receives 775 mm mean annual rainfall (average of 29 years rainfall data) but with variation in distribution and amount, 65% of which occurs between the months of June and September with a peak in July and August (accounts for 46%). March to May contributes about 23% of the total rainfall. WARSS receives 897 mm annual rainfall (average of 15 years) but with much variation in distribution and amount, 70% of which occurs between the months of June and September and 19% occurs between the months of March to May with peak in July and August (accounts for 55% of the total rainfall). The rainfall data during the experimental period (June to October) for WARSS and MARC as compared to the long years average are provided in Figure 1 and Figure 2, respectively.

In general the 2003 was the good rainfall year for WARSS (Figure1) where remarkably higher rainfall was recorded in July and August as compared to the 15-years average. Rainfall in June was comparable to 15 years average but sharply reduced towards grain filling stage and totally ceased in October. In 2004 it was only in June when higher amount of rainfall than the 15 years average was recorded. Like in 2003 there was less amount of rainfall during crop grain filling stage.

At MARC there was also similar rainfall trends to that of WARSS regarding both 2003 and 2004 years (Figure 2). In 2003 year the rainfall amount in general was good and remarkably higher rainfall was recorded in August and September but ceased in October as compared to the 29-years average. As compared to the 29 years average the rainfall in July, September and October of 2004 was relatively higher but in June and August it was a bit less. Precipitation per month and rainfall distribution at 10 days interval of a month during crop growing season in 2004 at WARSS and MARC are presented in Figure3 and Fig 4. During months of July and August, the crop received about 246 and 172.5 mm rain at WARSS, and 163.6 and 136.7 mm of rain at MARC, respectively. Generally there was good amount of rainfall for WARSS when compared to MARC. However, towards crop grain filling stage and maturity the rainfall amount at WARSS was very less (Figure3) as compared to that of MARC.

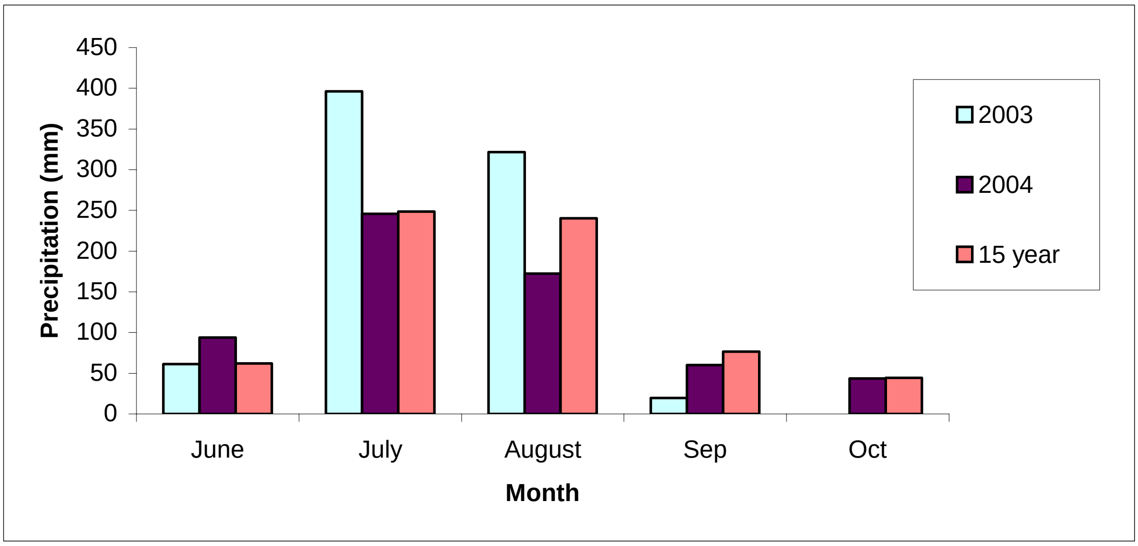

Figure 1 Monthly rainfall data during the growing seasons of 2003-2004 years as compared to fifteen years average at WARSS.

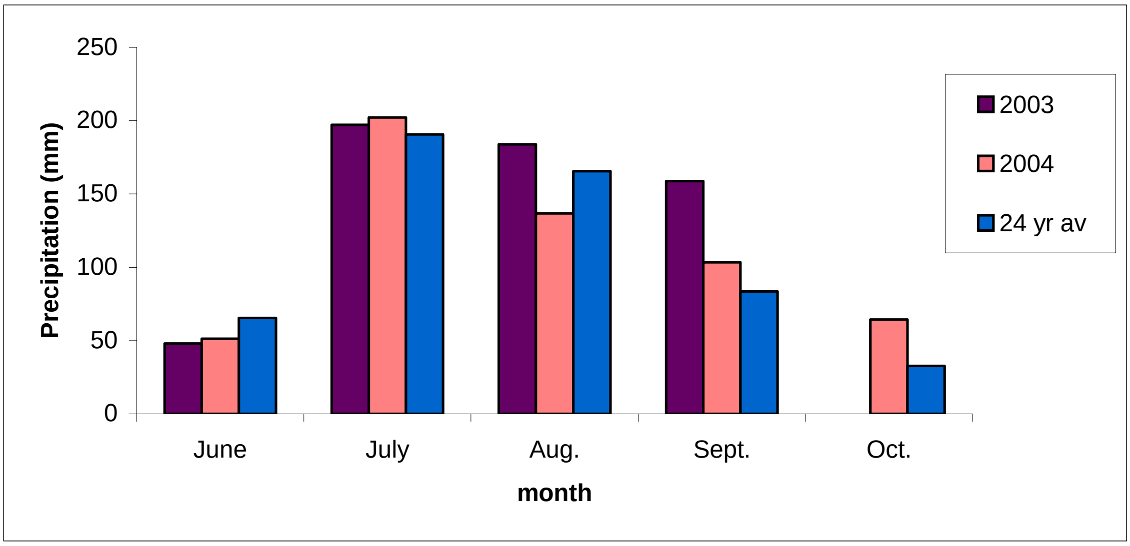

Figure 2 Monthly rainfall data during the growing season of 2003-2004 years as compared to 29 years average at MARC.

There was similar rainfall distribution in June, July, August and October for both locations while it was to opposite direction in September (Figure4).

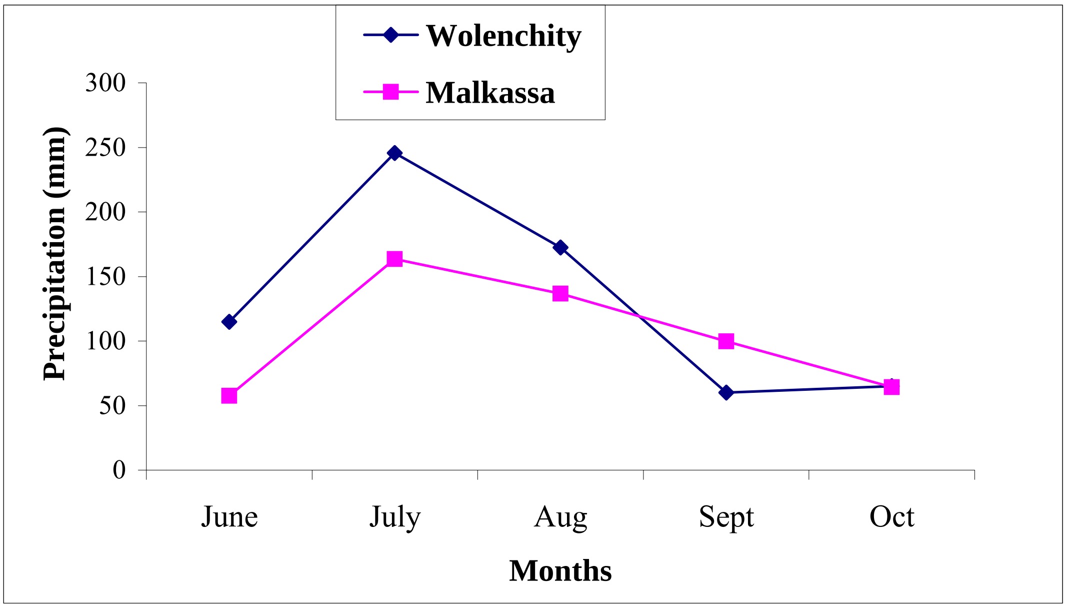

Figure 3 Precipitation during crop growing season at WARSS and MARC in 2004.

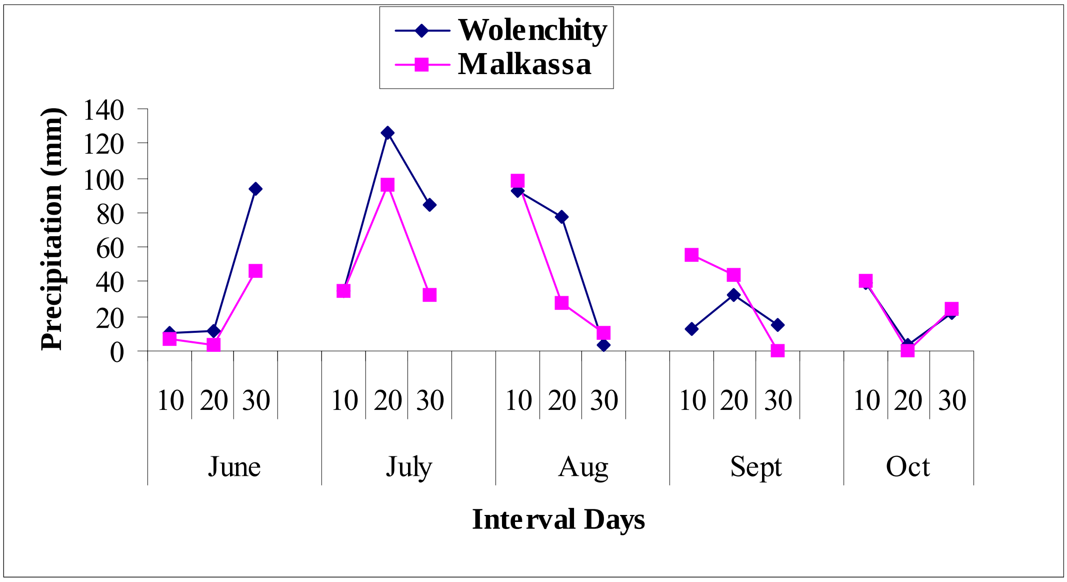

Figure 4 Rainfall distribution at 10 days interval of a month at WARSS and MARC.

The materials and methods that include the detail experimental procedures and designs are given below independently for the three field experiments as well as for the agronomic and perception analysis.

Experiment 1. Tillage System and Fertilizer Rate Effect on Sorghum Productivity

Methodology

Time and location

The field experiment was conducted during the sorghum growing seasons (July to November) in 2004 under rain fed conditions at MARC and WARSS both representing typical dryland conditions. Both experimental locations have been well described in the materials and methods sections. The soil of experimental sites are loam soil with 41% sand, 37% silt, 22% clay content and a pH of 6.41 for MARC, and loam with 46% sand, 34% silt and 20% clay content with a pH of 6.64 for WARSS.

Experimental design and treatments

The combined effects of tillage systems and fertilizer rates on sorghum productivity trial consists of 16 treatments comprising the factorial combination of four levels of tillage management (i.e., Conventional Tillage (CT), Reduced Tillage (RT), No-Tillage (NT) and Tie Ridge (TR); and four levels of fertilizer (i.e., 0-0 kg N-P_2O_5 (F_0), 41-46 kg N-P_2O_5 (F_1), 49.2-55.2 kg N-P_2O_5 (F_2), 57.4-64.4 kg N-P_2O_5 (F_3) per hectare. The experiment was laid out in a 4 X 4 spilt plot design with three replications. The four-tillage systems were initiated in main plots of 14 m ×16.5 m (231m^2), and fertilizer in sub plots of 14 m × 3.75 m (52.5 m^2). Pathways of 0.5 m, 0.75 m and 1m were placed between sub plots, main plots and replications, respectively. A row spacing of 0.75m was used.

Experimental procedures

Tillage systems

The tillage treatment that includes Conventional Tillage (CT), No-tillage (NT), Reduced-tillage (RT) and tie ridge tillage (TR) were executed as described below:

Conventional Tillage (CT): The conventional tillage system consisted of three plowings with traditional ox plow 'Maresha' (farmer's practice) to a depth of first pass approximately 8 cm and other passes perpendicular to the previous path with a final one at 20 cm depth prior to planting. In conventional tillage hand weeding first during 20-29 days after crop emergence (DAE) and second hand weeding during 40-50 DAE was executed.

No tillage (NT): It is a common practice that for no tillage system, researchers and extension agents used the already available traditional oxen plough Maresha. In the no tillage treatment no soil disturbance was made except for seeding and fertilizer application.

Reduced-Tillage Tied Furrow (RT): In the present study it was designed to use the ridger only after one pass with the ox-plow, then furrow ties were made during planting at 5m interval. Both no tillage and reduced tillage tied furrow plots were sprayed with glyphosate at a rate of 3 l ha^{-1} as pre-planting herbicides.

Tie-ridge tillage (TR): In tie ridge treatment, after three plowings with traditional oxen plow, 35 cm high ridges were constructed 75 cm apart and cross-tied with soil bunds across the ridges with tie ridger at about every 5 m ridge length.

Fertilizer

The fertilizer sources were urea (46% N) and diammonium phosphate (18% N and 46% P_2O_5). All rates of P_2O_5 fertilizer (kg of P_2O_5 ha^{-1}) and half of N fertilizer (kg of N ha^{-1}) were banded 5 cm below and 5 cm away the rows as a basal application during planting and the rest half of N fertilizer were applied 45 days after planting. Rates of different fertilizers that were applied during the study period and their time of application are presented in Table 3.

Variety

The improved sorghum variety, Meko-1, an early maturity type (60-70 days to anthesis) was used and the seeds were placed in rows and sorghum seedlings were managed based on the surrounding farmers experience except for the treatment under the considerations.

Sampling and measurements

Crop data

Data on various crop parameters were collected throughout the cropping season at different growth stages starting from seedling stage (<30 cm) until physiological maturity when 50% plants on each plot attained the respective growth stages as described by Vanderlip and Reevs (1972). Stand count before thinning and at harvesting was recorded by counting the actual number of plants from the middle three rows in each sub plot and expressed on hectare basis. Plant height for a randomly selected six plants (two plants within a 12 m segment of the three rows) per sub plot was determined. Leaf area was estimated from 10 plants per sub-plot at each growth stage using CI-202 portable leaf area meter (CI-202, CID, Inc.).

Table 3 Rate of fertilizer and time of application in 2004 cropping year.

Time of application	Fertilizer rates (kg ha^{-1})*			
	F_0	F_1	F_2	F_3
	N-P_2O_5 (kg ha^{-1})			
At Planting	0-0	20.5-46	24.6-55.2	28.7-64.4
At knee height	0-0	20.5-0	24.6-0	28.7-0
Total	0-0	41-46	49.2-55.2	57.4-64.4
	urea-diammonium phosphate (kg ha^{-1})			
At Planting	0-0	25-100	30-120	35-140
At knee height	0-0	25-0	30-0	35-0
Total	0-0	50-100	60-120	70-140

* 0-0 kg N-P_2O_5 (F_0), 41-46 kg N-P_2O_5 (F_1), 49.2-55.2 kg N-P_2O_5 (F_2), 57.4-64.4 kg N-P_2O_5 (F_3).

Leaf area index (LAI) was calculated by dividing the total area of green leaves by the ground area occupied the sampled plants. Sorghum heads and stover were harvested at the base of the lowest grain branch and at the ground surface level, respectively from areas of 13.5 m^2 (6 m × 2.25 m) at 115 days after emergence (DAE). The sorghum head height was determined, sun-dried and weighed before and after threshing. Counting 250 grains in duplicates and weighing them on two decimal electronic balance the thousand seed weight was determined. The weights thus obtained were added and multiplied by two to arrive at 1000-seed fresh weight, then oven dried at 55-60 ^oC for 24 hours and weighed again to determine moisture content and to obtain 1000-seed dry weight. Grain yield and above ground biomass per plot was determined by harvesting all plants from sub plot area. Grain yield was adjusted to 12.5% moisture content. Total above ground biomass, which included stover and whole panicles, were used to obtain biomass yield. Harvest index (HI) values were computed as the ratio of the mass of grain yield to total biomass. Fertilizer use efficiency (FUE) is defined as grain production per unit of nutrient available in the soil and calculated as grain weight divided by fertilizer supplied (FUE = Grain weight obtain by per unit of nutrient available in the soil/fertilizer supplied per unit) (Moll *et al*., 1982). In this experiment, FUE was calculated as Agronomic Efficiency (AE). AE is defined as grain yield of the fertilized sorghum in the treated plot minus grain yield of unfertilized sorghum in non-fertilized control plot over the total applied fertilizer rate per plot.

Soil data

Soil moisture at 0-15 and 15- 30 cm depths was determined gravimetrically for each plot in the central row in two replications using a core sampler. Soil water data were recorded at various growth stages from planting until the physiological maturity of sorghum crop. Gravimetric water content was converted to a volumetric basis using bulk densities of soil cores taken from each depth (Lopez *et al.*, 1996). The soil samples for chemical analysis were collected from one site in each sub plot at depths of 0-30 cm with 4 cm-diameter augur, placed in paper bags, air dried, ground, sieved to pass 2-mm size sieve screen, and stored in sealed plastic for laboratory analysis. Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were determined by using the semi-micro Kjeldahl digestion method (Bremner and Mulvancy, 1982), Olsen Method (Murphy and Riley, 1962), and the ammonium acetate extraction method (Knudsen *et al*., 1982), respectively.

Water use efficiency (WUE)

WUE is expressed as the crop dry matter or yield production per unit of water used by the plant. Because it is difficult to determine the weight of roots and ignores the dry mass of the root system, which accounts for 10-20% of the total crop mass at maturity, only the aboveground biomass is considered (Gregory, 1988). This approach is well accepted to evaluate farming practices, which could lead to improved nutrient use efficiency and more stable yield across years with variable weather (Hamblin *et al*., 1987; Cooper *et al*., 1983). For the agronomist, WUE is usually a seasonal value defined as yield per unit area per water used to produce yield. For most crops only part of the dry matter produced is of economic significance to the farmer (e.g. grain crops). Hence, yield is frequently expressed solely as grain yield. But in many dryland areas, the stover has an economic value as great as that of the grain because it is used to sustain livestock. In the context of dry land agriculture, then, yield is better expressed as the total shoot mass. In the present study grain yield, stover and aboveground were taken in to account to determine WUE of sorghum under different tillage systems and fertilizer rates. Water use efficiency (dry matter production in above ground biomass and grain yield per unit of water used) was determined using the seasonal rainfall data for the crop-growing season.

Statistical analysis

Data were subjected to General Linear Models (GLM) procedure of the SAS Statistical Software Package for analysis (SAS, 1989). Duncan’s Multiple Range Test (DMRT) and Least Significant Differences (LSD) were used for means separation at the 0.05 or 0.01 probability levels. Those variables that violated the assumption of analysis of variance were transformed using the standard procedure to equalize the variances.

Experiment 2. Tillage and Crop Rotation Effect on Soil Properties and Maize Productivity

Methodology

Site characteristics

Field studies were conducted in 2003 and 2004 at MARC and WARSS, both representing the rain fed dryland agro climatic conditions but differing mainly in the amount of annual precipitation. The soil surface at experimental site of MARC is loam in texture and contains 44, 36, and 20% sand, silt and clay, respectively with a medium soil pH (6.56). Soil test values at WARSS at the onset of the study indicated a loam soil (46% sand, 34% silt, and 20% clay) with a medium soil pH (6.64).

Previous monocropping system

The experimental site at both locations had been in a continuous maize production before 2000. Since 2000 the adjacent sites of fixed plots for maize were maintained at both locations in a continuous 3-year (2000 to 2002) monocropping system and a researcher had managed the fields under different tillage system options before the initiation of the present study.

Present rotational cropping system

In year 2002, the fixed plots divided in to two equal areas. In one side of the previous maize plot, Taaffi as a precursor crop at WARSS and haricot bean at MARC were grown while on the adjacent remaining equal areas of the same plot maize monocropping practiced. In 2003, maize was grown on previously Taaffi and haricot bean plots to examine the effect of precursor crops on the succeeding crop. The remaining equal areas of the same plots were continued with maize monocropping to observe the effect of monocropping on the test crop. The same experiment and procedures were repeated in 2004.

Tillage treatments

Three options of conservation tillage system as pre-plant no-tillage with two pre emergence herbicides and supplemental hand weeding (T1), pre-plant no-tillage with two pre emergence herbicides but no hand weeding (T2), pre-plant no-tillage with only one pre emergence herbicide and supplemental hand weeding (T3); and two options of conventional tillage system as four times plowing and one pre-emergence herbicide (T4), and four times plowing and two times hand weeding (T5) were compared. In all options of conservation tillage systems, no soil disturbances were made except for seeding and fertilizer application. Two herbicides, glyphosate [N-(phosphonomethyl) glycine] at a rate of 3 l ha^{-1} and Lasso + Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1, 3, 5 triazine) at a rate of 5 l ha^{-1} were applied 10 days before planting and at planting, respectively. The conventional tillage plot was plowed with traditional ox plow 'Maresha' following the experiences of the surroundings farmers. First and second hand weeding was done 25 and 45 days after crop emergence, respectively. Treatments combination and their descriptions are provided in Table 4.

Experimental design

The five tillage treatments were assigned as main plots and the two cropping system as sub-plots, and evaluated in a spilt plot design with three replications. Plot size was 8 m long and 6.75 m wide at WARSS and 8 m wide and 10 m long at MARC.

Table 4 Treatment combination in maize experiment during the study period.

Treatment	Tillage Systems	Treatment Combinations[a]
T1	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 5.0 l ha^{-1} LA + 1 × HW)
T2	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 5.0 l ha^{-1} LA)
T3	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 1 time HW)
T4	Conventional Tillage	Tilled (four times plowing + 5.0 l ha^{-1} LA + 1 × HW)
T5	Conventional Tillage	Tilled (four times plowing + 2 × HW)

[a]HW = Hand weeding; LA = Lasso-Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1, 3, 5 triazine); Glyphosate = N-(phosphonomethyl)glycine.

Cultural practices

Katumani maize variety was hand planted in all plots in both years. Fertilizer was applied at a rate of 100 kg ha^{-1} diammonium phosphate $(NH_4)_2HPO_4$), and 50 kg ha^{-1} urea, $[CO(NH_2)_2]$. All the diammonium phosphate and half of the urea fertilizer were applied at planting and the remaining urea applied at knee stage.

Data collection

Soil parameter

Soil samples were taken from each plot, air-dried, ground and passed through a 2 mm sieve and preserved for soil analyses. The soil properties were evaluated by measuring bulk density, soil moisture, total nitrogen, available P and exchangeable K, and soil organic matter concentrations following the method developed by (AOAC, 1960). Soil moisture at 0-15 and 15-30 cm depth was determined gravimetrically for each plot in the central row in two replications and expressed on weight basis. Soil pH was measured in the supernatant suspension of a 1:2.5 soil: water mixture by using a pH meter (model HI8521). Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were determined by using the semi-micro Kjeldahl digestion method (Bremner and Mulvancy, 1982), Olsen method using Spectrometer (Olsen and Sommers, 1982), and Morgan Extraction method using Flame photometer (model CL 378 ELICO), respectively. Organic Carbon was determined according to Walkley-Black method (Jackson, 1958).

Yield components and yield of maize

Stand count, cob number and cob weight at harvest were collected from each sub plot. The grain and straw yields of the crop were determined by hand harvesting all plants from subplots.

Statistical analysis

Data were analyzed using the SAS software statistical package (SAS, 1989) and Duncan's multiple range tests were used to examine differences between treatments means.

Experiment 3. Tillage and Crop Rotation Impact on Taaffi Productivity and Profitability

Methodology

Site characteristics

Field studies were conducted in 2003 and 2004 at MARC and WARSS, both located in the central rift valley of Oromiya but differing mainly in the amount of annual precipitation. The soil surface at experimental site of MARC is loam in texture and contains 44, 36, and 20% sand, silt and clay, respectively with a medium soil pH (6.56). Soil test values at WARSS at the onset of the study indicated a loam soil (46% sand, 34% silt, and 20% clay) with a medium soil pH (6.64).

The experimental site at both locations had been in a continuous Taaffi production before 2000. In 2000 fixed plots were maintained at both locations in a continuous 3-year (2000 to 2002) monoculture system and a researcher had managed the fields under different tillage system options before the initiation of the present study. Different tillage system that were used during the experimental period are illustrated below:

Tillage treatments

Three options of conservation tillage system as pre-plant no-tillage with pre and post emergence herbicides and supplemental hand weeding (T1), pre-plant no-tillage with pre and post emergence herbicide but no hand weeding (T2), pre-plant no-tillage with only pre emergence herbicide and supplemental hand weeding (T3); and two options of conventional tillage system as four times plowing and post-emergence herbicide (T4), and four times plowing and two times hand weeding (T5) were compared. In all options of conservation tillage systems, no soil disturbances were made except for seeding and fertilizer application. Two herbicides, glyphosate [N-

(phosphonomethyl) glycine] at a rate of 3 l ha^{-1} and 2, 4-D at a rate of 1 l ha^{-1} were applied 10 days before planting and a month after planting, respectively. The conventional tillage plot was plowed with traditional oxen plow 'Maresha' following the experiences of the surroundings farmers. In conventional tillage hand weeding first during 20-29 days after crop emergence (DAE) and second hand weeding during 40-50 DAE was executed. Combination of the treatments and their descriptions are provided in Table 5.

In year 2002, the fixed plots of each tillage systems were divided in to two equal areas. In one side of the previous Taaffi plot, haricot bean as a precursor crop at both locations were grown while on the adjacent remaining equal areas of the same plot Taaffi monoculture continued. In 2003, Taaffi was grown on previously haricot bean plots to examine the effect of precursor crops on the succeeding crop. The remaining equal areas of the same plots were continued with Taaffi monoculture to observe the effect of monoculture on the test crop.

Data collection and analysis

Weed counts and sampling

Weed density at particular experimental site of MARC was evaluated on June 2000 and abundance of each weed species was estimated. After four years elapsed, in June 2004, second weed density evaluation was made for the purpose of the present study. Population of the weeds and volunteer crops were measured using 0.25 by 0.25 m quadrants placed at four places in each plot. All the weeds from the population count area were clipped to determine the weed dry matter (WDM). The population frequency (PF) of a species was assigned the value of 0 when absent or 1 when one or greater than one plant present for each plot. Sum of the PF values for a plot across the species represented the number of weed species per plot. The number of plants was considered as the population density (PD) of a given species.

Table 5 Treatment combinations in Taaffi experiment during the study period.

Treatment	Tillage Systems	Treatment Combinations[a]
T1	Conservation Tillage	No-tillage (3 l ha^{-1} glyphosate + 1 l ha^{-1} 2, 4-D + 1 × HW)
T2	Conservation Tillage	No- tillage (3 l ha^{-1} glyphosate + 1 l ha^{-1} 2, 4-D)
T3	Conservation Tillage	No-tillage (3 l ha^{-1} glyphosate + 1 × HW)
T4	Conventional Tillage	Tilled (four times plowing + 1 l ha^{-1} 2, 4-D + 1 × HW)
T5	Conventional Tillage	Tilled (four times plowing + 2 × HW)

[a]Glyphosate = N-(phosphonomethyl)glycine; 2,4-D = (2,4-dichlorophenoxy) acetic acid; HW = hand weeding.

To integrate the results of PF and PD measurements, relative abundance (RA) of the individual weed species was obtained following the procedure proposed by Thomas (1985), as the sum of their relative frequency (RF) and relative density (RD). The RF was calculated as the ratio of the PF for the individual species to the total number of species in a given plot. Corresponding PD values were used to estimate the RD. Accordingly, the PD and PF of a given species weighted equally in the RA. Analysis of variances (ANOVAs) was used to test the effect of different tillage systems on the aboveground weed populations. Statistical analysis of the PD, PF, and RA data was performed for each major species. Analysis of the PD data was done after addition of 0.5 to each observation and taking square root of the total (Little and Hills, 1978). Mean comparisons were conducted on the transformed data and these means were then back transformed for presentation.

Yields

The grain yields of the crop at MARC were determined by hand harvesting the whole area of each plot and data from the four years (2000, 2001, 2002, 2003) were combined. For WARSS, no combined analysis was attempted since no grain yield was obtained in 2002 due to drought. In 2004, the grain and straw yields of the crop were determined at both locations by hand harvesting all plants from subplots. Harvest Index (HI) of Taaffi was calculated as grain yield over the aboveground biomass.

Soil parameter

Soil samples were taken from each plot, air-dried, ground and passed through a 2 mm sieve and preserved for soil analyses. The soil properties were evaluated by measuring bulk density, soil moisture, total nitrogen, available P, exchangeable K, and soil organic matter content following the method developed by (AOAC, 1960). Soil moisture at 0-15 and 15-30 cm depth was determined gravimetrically for each plot in the central row in two replications and expressed on weight basis. Soil pH was measured in the supernatant suspension of a 1:2.5 soil: water mixture by using a pH meter (model HI8521). Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were determined by using the semi-micro Kjeldahl digestion method (Bremner and Mulvancy, 1982), Olsen method using Spectrometer (Olsen and Sommers, 1982), and Morgan Extraction method using Flame photometer (model CL 378 ELICO), respectively. Organic Carbon was determined according to Walkley-Black method (Jackson, 1958).

Economic analysis

Collecting secondary data with other cost of production and price of produce, simple partial budget analysis (CIMMYT, 1988) was done. The total cost of production in the economic analysis includes land preparation, seeds and seeding, herbicide and its application cost, hand weeding, fertilizer and its application costs, and cost for harvest and transport to market. The average prices of the three years were estimated at Ethiopian currency Birr 260 and 4 per 100 kg of grain and straw yields, respectively. At a moment 8.68 Ethiopian currency (Birr) could buy 1 USD (Birr 8.68 = $ 1.0).

Cultural practices

With the exception of the factors being tested, all other field activities and fertilizer application were carried out in accordance with the recommendations for the

Taaffi crop production. *DZ-cross-37* Taaffi variety was hand broadcasted in all plots in both years. 40-60 kg N-P_2O_5 ha^{-1} applied each year with the entire P_2O_5 and half of N fertilizer at planting and the other half of N as split application at tillering stage.

Experimental design and statistical analysis

For grain yield and straw, aboveground biomass and HI of Taaffi, the five tillage treatments were considered as main plots and the two cropping system as sub-plots, and evaluated in a spilt plot design with three replications. Plot size for each tillage treatment was 8 m long and 6.75 m wide at WARSS and 8 m wide and 10 m long at MARC. For most of the data collected, data were analyzed using the SAS software statistical package (SAS, 1989) and Duncan's multiple range tests were used to examine differences between treatments means.

Experiment 4. Agronomic and Perception Analysis in the Existing Conservation Tillage Practices

Prior to implementing the analysis in the specified districts, the following hypotheses were postulated about the agronomic benefits and possible farmer attitude towards the acceptance of conservation tillage in the crop production system: 1) Farmers who had previously adopted the conservation tillage system would more likely response in favor of the system than who had not. 2) Farmers would be more reluctant to test conservation tillage on their farms for more than two years since farmers in the area are not accustomed to produce crops with conservation tillage using chemicals. 3) If the trials of the conservation tillage system showed promising results in production, costs and benefits; farmers would be more willing to adopt conservation tillage options in the future as a logical consequence. 4) From agronomic point of view the past conservation tillage system would accumulate more organic matter in the soil surface and improves the hydro-physical properties of the soil as compared to conventional tillage system.

Methodology

The study was started in 2003 to assess the perception and attitudes of farmers towards the practices of conservation tillage in different maize and Taaffi growing zones of Oromiya. Late in 2003, group interviews and discussions were conducted in order to get an overview and opinion of the communities in general. Aspects such as indigenous knowledge in crop management and tillage systems, constraints of crop production, and its control and treatment of those were covered during group interviews.

Sampling procedure

To generate the overall tillage systems information the process started with a brain storming session to construct a set of sub questions, which would be used as the basis for the questionnaire. These are: 1) what had been the fundamental purpose of plowing through the ages? 2) Were there valid reasons for repeated tillage? 3) What are the existing levels of knowledge, skill and attitude amongst farmers towards the practices of conservation tillage? 4) What practices are farmers used in order to reduce erosion? 5) What factors enhance or constrain the use of conservation tillage as a system of crop production? Based on these research questions, interviews were designed for the purpose of quantifying and clarifying important aspects in the respective systems. The sample size is small due to the nature of the research work. Hence, purposive non-random sampling method was employed to obtain information about those members of the population who undertaken the conservation tillage program. Of the participated farmers for discussion, those who had used on-farm conservation tillage trials previously for more than two years were selected from three administration zones (East Shoa, Jimma and West Shoa) of Oromiya. For the individual or face-to-face interviews, a group of 5-13 people were selected in each site based on their experience and knowledge of conservation tillage with the assistance of extension officers and village leaders in that particular village and accordingly interviewed. Data were collected using a semi-structured interview (SSI) with open and focused questions. As questionnaires were structured with the research question in mind, questions were very specific and direct in the objectives they were trying to achieve. To generate relevant knowledge the following data were collected:

Conservation tillage and crop management perception

Farmers and expertise perception and attitudes towards conservation tillage from water and wind erosion, crop production and cost of production standpoint were sought. Importance of different tillage system, methods of erosion control, soil fertility and weed management issues identified. Based on their perceptions, the details of cropping system and management problem identified, ranked, and details of their solutions in face of risks and uncertainties from conservation tillage and crop management system were solicited for each environment. Some participatory rural appraisal (PRA) techniques such as participatory matrix ranking of cropping constraints were employed. For matrix ranking, a checkerboard was drawn on a large piece of paper. Separate groups of farmers (for each district) were asked what they considered to be the major constraints for crop production. Accordingly, the farmers identified different constraints for crop production. Then the farmers were asked to rank the major constraints by putting seeds in the corresponding square. Each farmer added an arbitrary number of seeds according to his own perceptions.

Secondary information and review

Secondary information on demography, climate, soil types, soil-water-crop management-related problems, and source of inputs (seed, fertilizer and herbicide) and uses were collected. Throughout the study, physical observations were made on the identification of local knowledge used by farmers for various purposes in crop production. To verify that information and to determine changes in the soil as a result of adjusted tillage patterns, soil samples from two plots (conservation and conventional tillage plots) of each district were taken. Determination of organic carbon, total nitrogen, available P, exchangeable K, pH and the textural class of the soil were done following the method developed by A.S.O.C (1955) under the Department of Soil laboratory of Oromiya Agricultural Research Institute (OARI) located at Baatu township of East Shoa Zone. Useful and precise information were gathered on conservation tillage perceptions from non-governmental organization, ministry of agriculture (MOA) staff and researchers from respective research center. All site documentation, government records, organizational reports and geographic document records; university and research organization studies were reviewed.

Statistical analysis

Descriptive statistics such as means, frequency and percentage were used in this study using SPSS (1999) 11.5 statistical soft ware.

RESULTS AND DISCUSSION

Experiment 1. Tillage System and Fertilizer Rate Effect on Sorghum Productivity

Stand count

Stand count of sorghum varied significantly between location, different tillage system, and the interaction between tillage and fertilizer rate (Appendix Table 1). An estimated mean stand count of sorghum at WARSS was significantly lower than that observed at MARC (Table 6). In the present study the overall mean initial and final stand counts during the seedling and harvesting time averaged over two locations were only 60952 and 58643 plants per hectare, respectively. The research results in Oromiya, however, indicated that based on the available resources particularly soil water, nutrients and the variety under use, about 88,888 stand counts per hectare (15 x 75 cm) were considered optimum for sorghum production (Kidane *et al*., 2001). Although the maximum limit of the recommended seed rate for row planted sorghum crop (10 kg ha^{-1}) was used during planting the stand establishment was not to the desired population in both locations on all plots due to poor seedling emergence and stand establishment, which is partly attributed to the inherent problem with this sorghum variety and partly to lower soil moisture during the on set of the experiment. When the data for the different fertilizer rates and both locations were combined the stand count from conventional tillage and reduced tillage was significantly higher than that obtained from either the no-tillage or tie-ridge tillage systems (Table 7). Poor seedling performance was observed particularly on the no tillage plots at WARSS and tie ridge plots at MARC. An experiment by Omer and Elamin (1997) in the western Sudan showed that ridges without tying increased plant stand by 48% over no till but the increment in percent of plants with heads was not significantly different.

Table 6 Location and tillage effect on stand count (plant ha^{-1}) of sorghum.

Tillage System*	Location	
	WARSS	MARC
CT	64143	70952
RT	63214	70863
NT	52333	57292
TR	43261	47083
Mean	55738	61548

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge

Table 7 Main effect of tillage and fertilizer rate on sorghum stand count (plant ha^{-1}).

	Tillage System*				
Fertilizer Rate**	CT	RT	NT	TR	Mean
F_0	56595	78202	61595	42321	59679
F_1	59167	72881	45726	42702	55119
F_2	83321	51607	56607	57643	62295
F_3	71107	65464	55321	38023	57479
Mean	67548a	67039a	54813b	45173c	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare. Means followed by the same common letter within row was not significantly different at 5 % probability level of significance.

Dabney *et al*. (2000) reported 15% reduction in sorghum stand density with conservation tillage. Similarly, Tewodros (2004) reported about 5% greater plant population at maturity on the conventional tilled as compared to tied ridged and zero tilled treatments. In the present study, at seedling growth stage conventional tillage and reduced tillage had relatively higher soil moisture content than no tillage and tie ridge plot which could probably the reason for the higher stand count of the former two tillage systems. How ever, despite the higher stand count the productive tillers (percent of plants with heads) for the two tillage systems were less as its was evidenced by lesser sorghum head height and lower harvest index on conventional and reduced tillage plots. The main effect of fertilizer rate did not affect the stand count of sorghum. However, when the mean for all tillage systems were combined higher final stand count was observed with plot that received 49.2-55.2 kg N-P_2O_5 per hectare. This rate of fertilizer resulted in higher stand count particularly on conventional and tie ridge plot. But the result was showed inconsistence trend for the other two tillage systems. The impact of fertilizer on stand count of sorghum has been well documented in the dryland Oromiya (Kidane *et al*., 2001).

<u>Plant height</u>

Differences were observed in plant height between location, among different rates of fertilizer application and the interaction between location and fertilizer, and between tillage system and fertilizer rate (Appendix Table 2). Unlike the stand count of sorghum the greater plant height was obtained at WARSS as compared to that obtained at MARC. The unfertilized plot had significantly lower plant height than that obtained at any fertilized plots (Table 8). Among the three rates of fertilizer (F_1, F_2, F_3) there was no significant difference in plant height. When different rates of fertilizer were combined there were no significant differences among tillage systems (Table 9). The interaction between tillage systems and fertilizer rates indicate that there were no significant differences among fertilizer rates on conventional plots and on tied ridge plot while there were significant differences on the reduced and conservation tillage plots.

<u>Leaf area index (LAI) and leaf dry matter (LDM)</u>

Generally, leaf area index was greater for no tillage and reduced tillage during the growing season while it was lower for tie ridge tillage particularly from 60 days after planting on wards at MARC (Figure 5). At early growing season the difference was not remarkable among tillage systems. Mid and late in the growing season the LAI for tie ridge was remarkably inferior to the rest of treatments. Comparing conventional tillage to no tillage, Azooz *et al*. (1995) found greater LAI in no tillage during the drought in 1998 and it was attributed to the higher moisture content of no tillage. In the present study, however, the differences could not be attributed to soil moisture content differences as tie ridge had higher content.

Table 8 Influence of fertilizer on plant height (cm) with varied locations.

Fertilizer Rate*	Location		
	WARSS	MARC	Mean
F_0	148.73	137.13	142.93b
F_1	149.40	146.88	148.13a
F_2	151.08	145.55	148.31a
F_3	160.58	146.38	153.48a
Mean	152.45	143.99	

* F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare. Means followed by the same common letter within row was not significantly different at 5 % probability level of significance.

Table 9 Main effect of tillage and fertilizer rate on plant height (cm).

Fertilizer Rates**	Tillage System*			
	CT	RT	NT	TR
F_0	146.75abc	136.6d	138.05cd	150.30ab
F_1	154.90a	147.95ab	144.90abcd	144.75bcd
F_2	149.05ab	146.00abc	150.60ab	147.60abc
F_3	151.35ab	154.70ab	151.15ab	146.70abc
Mean	150.51	146.31	146.18	147.33

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare. Means followed by the same common letter within row was not significantly different at 5 % probability level of significance.

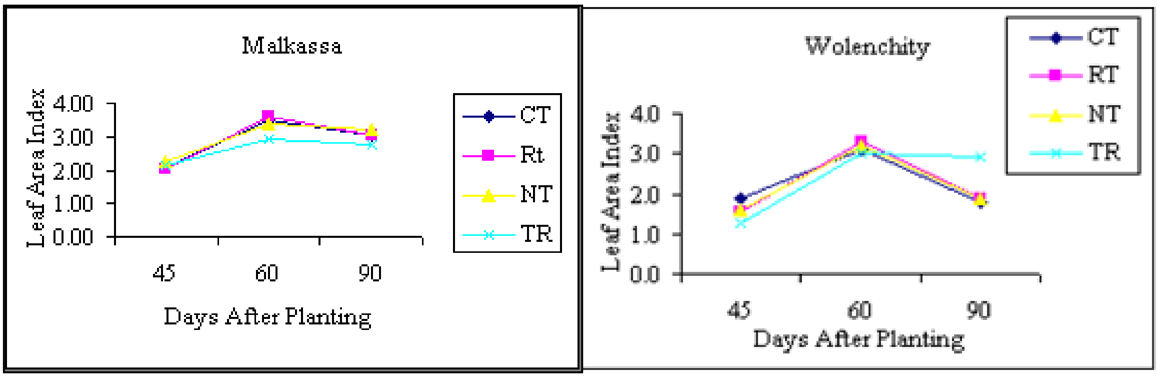

Figure 5 Leaf area index as a function of days after planting for conventional tillage (CT), reduced tillage (RT), no tillage (NT) and tie ridge (TR) at MARC and WARSS.

At WARSS, leaf area index was not significantly different among treatments at mid in the growing season, the time when there was no moisture stress (Figure3). However, early and late in the growing season the time when there was moisture deficit, LAI was significantly different among treatments; it was significantly greater in conventional tillage and tied ridge at early and late growing season, respectively as compared to other tillage treatments. The greater the moisture content of tied ridge at late in the growing season might have been contributed to higher extended crop canopy formation that lead to greater leaf area index. For other tillage systems there was sharp decline in LAI towards 90 days after planting. During maximum leaf area index formation (60 days after planting) reduced tillage had greater LAI as compared to the three other treatments.

Watson (1947) applied the concept of the leaf area as a measure of plant productive potential to field crops by defining a leaf area index. Leaf area index (LAI), measured as a ratio of crop canopy to ground covered by the crop, is an important agronomic and physiological parameter to judge crop performance in a given environment. Leaf area index and fraction of photosynthetically active radiation intercepted are the two important biophysical variables determining the biomass production. Light interception was recorded to maximum up to LAI 3-4 and further increase in LAI was shown to have little effect on light interception (Muchow, 1989). In the present study, sorghum LAI was at the ranges of 3-4 at vegetative growth stage. Leaf area index was increased at slow rate until 45 days after planting and to peak at 60 days after planting (boom stage) followed by decline to 90 days. This is in agreement with the findings of Hammer *et al*. (1987) who found sorghum LAI to peak at boom stage followed by decline up to maturity. This decline was expected due to mobilization of assimilate to the grain and leaf senescence. Muchow (1989) found that biomass yield at maturity is closely related to leaf area development and maintenance. About 49% reduction in yield due to reduced LAI of sorghum grown under different moisture regimes had been reported (Chaudhuri and Kanemasu, 1982).

Leaf dry matter at early and late growing season was not significantly different among tillage systems at MARC. At 45 days after planting, leaf dry matter accumulation was more or less comparable due to conventional tillage and tied ridging. At boom growth stage it was remarkably lower for tie ridge (Figure6). Dry matter for tie ridge at early and mid growth stage was less than for other treatments at WARSS because of depressed early growth and delayed emergence. However, remarkably higher dry matter was obtained at late the growing season due to tied ridge. Total dry matter production of a plant is a function of the rate of net photosynthetic production, which in turn is mainly dependent on the function, and efficiency of the photosynthetic tissue and its duration (Muchow and Davis, 1988). Others have reported similar total dry matter accumulation at early stage in comparing tillage practices (Horn *et al.,* 2000; Messersmith *et al.,* 2000) while Rao and Dao (1996) reported less dry matter accumulation with no tillage as compared to conventional. At MARC during grain filling stage (90 days after planting), the effect of tillage system was not significant for leaf dry matter, but the non-significant tillage effects followed the same trend as at vegetative growth stage (60 days after planting) where the highest leaf dry matter accumulation was observed on conventional tillage followed by the no tillage and the least with the reduced tillage. However, at WARSS, leaf dry matter was higher for the tie ridge plots during grain filling stage but was least during seedling and vegetative growth stage.

Head height

The main factors, namely location, tillage system, and fertilizer rate had no significant influence on head height of sorghum although the interaction between location and tillage had significant effect at alpha = 0.05 (Appendix Table 5). It was only reduced tillage that was varying across location and had significantly higher head height at MARC than the corresponding tillage at WARSS (Table 10). Otherwise, similar mean head weight was obtained at both locations.

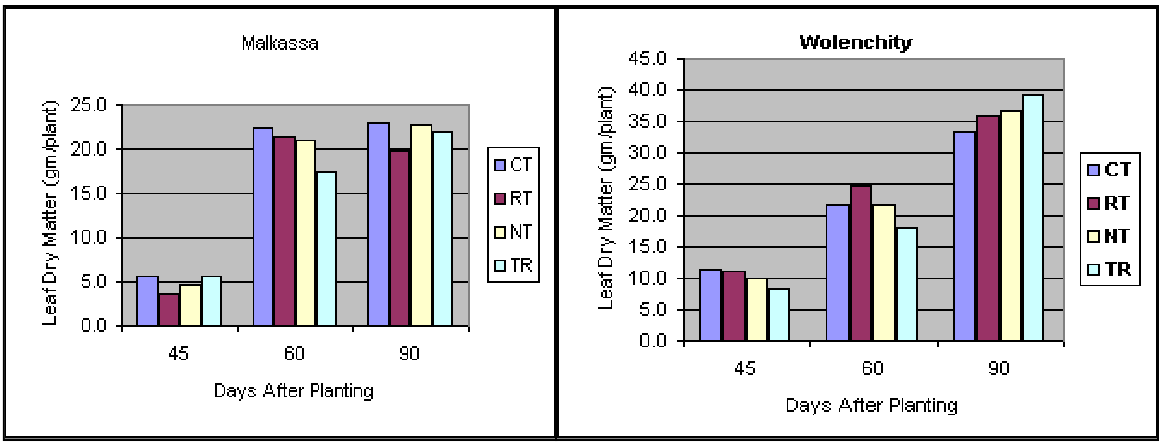

Figure 6 Leaf dry matter (gm/plant) as a function of days after planting for conventional tillage (CT), Reduced tillage (RT), no tillage (NT) and tie ridge (TR) at MARC and WARSS.

1000 seed weight

The 1000-grain weight of sorghum was significantly affected only by location (Appendix Table 6). Significantly higher 1000 seed weight was obtained at WARSS as compared to that obtained at MARC. The highest seed weight was observed on the tie ridge treatment with highest rate of fertilizer application for WARSS and no-tillage treatment for MARC at the same rate of fertilizer (Table 11). Sorghum grain weight reflects the crop growing conditions during the grain filling period. A desired characteristic of sorghum is to be able to compensate for the effects of early stress by producing larger grain upon withdrawal of stress (Blum *et al.*, 1989). The greater the seed weight at WARSS than at MARC may have happened due to mild water deficit during grain filling at the latter location.

Grain yield

The sorghum grain yield obtained at WARSS was significantly higher (Table 12) than that obtained at MARC. The greater grain yield at WARSS could be attributed to the higher precipitation and fairly distribution of rainfall at interval of ten days particularly during anthesis and head formation.

Table 10 Influence of tillage system on head height (cm) with varied locations.

Tillage System*	Location		
	WARSS	MARC	Mean
CT	23.25ab**	23.25ab	23.25
RT	20.13b	24.25a	22.19
NT	23.38ab	23.20ab	23.29
TR	23.29ab	23.28ab	23.29
Mean	22.51	23.50	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; **Means followed by the same common letter are not significantly different at 5% probability level of significance.

Table 11 Influence of tillage and fertilizer rate on sorghum 1000 seed weight (gm).

Tillage System	Fertilizer Rate			
	F_0	F_1	F_2	F_3
WARSS				
CT	27.55 abc	27.50 abc	31.15 ab	24.70 cd
RT	27.10 abc	24.70 cd	28.60 abc	24.65 cd
NT	26.75 abc	25.25 bcd	28.80 abc	19.60 d
TR	26.20 bc	26.50 abc	25.25 bcd	32.65 a
Mean	26.90	25.99	28.45	25.40
MARC				
CT	11.40 efg	6.50 fg	11.00 efg	11.85 ef
RT	7.05 efg	5.20 g	7.05 efg	6.45 fg
NT	7.80 efg	7.05 efg	10.65 efg	13.20 e
TR	7.85 efg	10.45 efg	6.55 fg	6.30 fg
Mean	8.53	7.30	8.81	9.45
Grand mean	17.72	16.65	18.63	17.43

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; Means followed by a common letter within a column do not differed significantly at 5% probability level of significance.

As a consequence, remarkably greater percentage of soil moisture content was observed in the top 0-15 cm soil layer at WARSS through out the growing season that lead to higher grain yield. Non-significant difference in grain yield was observed among tillage systems at each location. However, the greatest yield was obtained due to tie ridge followed by conventional tillage at WARSS while it was the reverse order at MARC.

Table 12 Influence of tillage system and fertilizer rate on grain yield.

Tillage System*	Fertilizer Rate**				Mean
	F_0	F_1	F_2	F_3	
WARSS (kg ha^{-1})					
CT	2438	2343	2533	2533	2462
RT	1714	2343	2171	2286	2129
NT	2381	2191	2476	2476	2381
TR	2381	2400	2762	2667	2553
Mean	2229	2319	2486	2491	
MARC (kg ha^{-1})					
CT	1643	1833	1857	2036	1842
RT	1476	1762	1798	2143	1795
NT	1381	1417	1679	1691	1542
TR	1667	1655	1774	2143	1810
Mean	1542	1667	1777	2003	
Grand Fertilizer Mean	1885 c	1993 bc	2131 ab	2247 a	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare. Means followed by the same common letter within row was not significantly different at 5 % probability level of significance.

The differences in mean grain yield among fertilizer rates was highly significant (P<0.01). Generally, grain yield was increased at increasing fertilizer rates. When the data from all tillage systems and both locations were combined the mean grain yield at the highest fertilizer rate of 57.4-64.4 kg N-P_2O_5 ha^{-1} were significantly higher than that obtained at the current recommended rate of 41-46 kg N-P_2O_5 ha^{-1} and with no fertilizer application. Although at the highest rate of fertilizer (57.4-64.4 kg N-P_2O_5 ha^{-1}) higher grain yield was obtained the increment of yield between this highest rate and the next immediate down rate (49.2-55.2 kg N-P_2O_5 ha^{-1}) was not significantly different. This implying that applications of fertilizer beyond 49.2-55.2 kg N-P_2O_5 ha^{-1} could give no significant yield advantage in the present study. This was particularly true for WARSS where increments of 8.2-9.2 kg N-P_2O_5 ha^{-1} could only give 5 kg ha^{-1} extra grain yield. The highest sorghum grain yield was recorded due to tie-ridge tillage but varied with fertilizer rate for each location The yield obtained due to tie-ridge and reduced tillage tied furrow was equal at MARC. There were many other results, which validated this findings, as it is evident from the extensive published data on tillage that affect crop yield, differs with soil conditions and environment (Lal, 1986; Triplett, 1986; Arnon, 1992; Dao, 1993; Radford *et al.*, 1995). There are several experimental evidences, which indicate that the combined use of soil water conservation through tied ridges and fertilizer application is more effective and resulted in sustainable increase crop production than the use of tied ridges or fertilizer use alone in semi-arid areas of Africa. For Example, in farmer managed trial in Burkina Faso; higher sorghum grain yield was obtained with fertilizer and tied ridges than with either fertilizer or tied ridge alone (Nagy *et al*., 1990). In Zimbabwe sorghum yields were increased from 118 to 388 kg ha^{-1} using 1.5-m tied ridges and this value escalated to 1071 kg ha^{-1} when 50 kg ha^{-1} N was applied to tie ridges during below average rainfall season (Nyakatawa 1996). Kidane (1999) also found increased grain and biomass yield of sorghum and maize when both tie ridges and fertilizer were used together. In the semi-arid areas of Oromiya tied ridges have been found to be very efficient in storing the rain water and lead to substantial grain yield increase in some of the major dryland crops. Kidane and Rezene (1989) reported that maize, sorghum wheat and mung bean yields were higher when grown with tied ridges regardless of the different planting patterns used compared to the flat seed-bed (farmers practices). The average grain yield increased ranges from 75 to 145% compared to the traditional practice depending on soil type, slope, rainfall and the crop grown in some of the dryland central rift valley areas.

Stover and aboveground biomass

Contrary to the grain yield, significantly higher ($P<0.05$) stover and biomass yield of sorghum were obtained at MARC than that obtained at WARSS. Stover and aboveground biomass yield were not affected by tillage systems, fertilizer rates, and the interaction between them at the desired level of probability (Appendix Table 8 and 9). When fertilizer rates were combined the mean stover and above ground biomass due to tie ridge were remarkably higher as compared to other tillage systems just similar to grain yield (Table 13). Thus, tie ridge tillage systems not only resulted in grain yield increases but also in more stover, which is important as animal feed. This character of tie ridge is very beneficial in the central rift valley of the country since smallholder-farming systems include both livestock and crops.

Table 13 The effect of tillage on sorghum stover and above ground biomass.

Location	CT*	RT	NT	TR	Mean
			Stover (kg ha^{-1})		
WARSS	3392.86	3166.67	2916.67	3273.81	3187.50
MARC	4997.04	4648.81	4708.33	5491.07	4961.31
Mean	4194.94	3907.74	3812.50	4382.44	
			Above ground biomass (kg ha^{-1})		
WARSS	5854.76	5295.24	5297.62	5826.19	5568.45
MARC	6839.29	6443.45	6250.00	7300.60	6708.33
Mean	6347.02	5869.35	5773.81	6563.39	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge.

When the mean of tillage systems and locations were combined it was F_2, which gave higher mean stover and biomass yield (Table 14). But when locations were considered F_3 and F_2 were resulted in higher stover and biomass at WARSS and MARC, respectively (Table 15). The result also indicated that aboveground biomass yield of the crop was generally following the same trend as stover yield, as most of the component was mainly attributed by the stover of the sorghum crop. Unlike grain yield, there was inconsistency in stover and biomass production under different fertilizer and tillage management. Regarding fertilizer by tillage reactions, F_2 with tie ridge was the best combination that resulted in highest stover and above ground biomass (Table 15).

Table 14 Effect of fertilizer rate on sorghum stover and above ground biomass (kg ha^{-1}).

Location	F_0**	F_1	F_2	F_3	Mean
			Stover (kg ha^{-1})		
WARSS	3214.29	3142.86	3142.86	3250.00	3187.50
MARC	5071.43	4952.38	5315.48	4505.95	4961.31
Mean	4142.86	4047.62	4229.17	3877.98	
			Above ground biomass (kg ha^{-1})		
WARSS	5442.86	5461.91	5628.57	5740.48	5568.45
MARC	6613.10	6619.05	7092.26	6508.93	6708.33
Mean	6027.98	6040.48	6360.42	6124.70	

** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

Table 15 Effect of tillage and fertilizer on sorghum stover and above ground biomass.

Tillage System*	Fertilizer Rates** F_0	F_1	F_2	F_3	Mean
			Stover (kg ha^{-1})		
CT	4136.91	3964.29	4964.29	3714.29	4194.94
RT	3964.29	3875.00	3922.62	3869.05	3907.74
NT	4065.48	3964.29	3505.95	3714.29	3812.50
TR	4404.76	4386.91	4523.81	4214.29	4382.44
Mean	4142.86	4047.62	4229.17	3877.98	
			Above ground biomass (kg ha^{-1})		
CT	6177.38	6052.38	7159.52	5998.81	6347.02
RT	5559.52	5927.38	5907.14	6083.33	5869.35
NT	5946.43	5767.86	5583.33	5797.62	5773.81
TR	6428.57	6414.29	6791.67	6619.05	6563.39
Mean	6027.98	6040.48	6360.42	6124.70	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

Harvest index (HI)

Harvest index of sorghum varied significantly with location (P<0.05) and fertilizer rates (P<0.01), and followed the same pattern as the grain yield of sorghum (Appendix Table 10). The HI at WARSS was significantly higher than that at MARC (Table 16). Thus, the attributive factors for grain yields could probably hold true for HI of sorghum. Indeed, HI is the relationship of grain yield to total above ground biomass. It measures dry matter partitioning to the grain (Huda *et al.,* 1987; Powell *et al.,* 1991).

At increasing fertilizer rates HI was generally increased; the unfertilized plot produced significantly lower harvest index than that obtained at highest fertilizer rates. There was no significant difference among the remaining fertilizer rates (Table 17). Although harvest index was not affected by tillage, and their interaction, it was greatest with no tillage followed by tied-ridges. As it is evident in (Figure 3), the no tillage and tied-ridges plots had higher soil moisture content at the grain filling growth stage that could probably the reason for higher HI of both tillage systems.

Table 16 Influence of fertilizer rates on sorghum harvest index under varied locations.

Fertilizer rate*	WARSS	MARC	Mean
F_0	0.407	0.234	0.321 b
F_1	0.425	0.252	0.340 ab
F_2	0.442	0.256	0.349 ab
F_3	0.434	0.316	0.375 a
Mean	0.427	0.265	

* F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare. Means followed by the same common letter within row was not significantly different at 5 % probability level of significance.

Table 17 Effects of fertilizer and tillage system on harvest index of sorghum.

	Tillage Systems*			
Fertilizer rate**	CT	RT	NT	TR
F_0	0.335	0.294	0.324	0.330
F_1	0.349	0.355	0.328	0.338
F_2	0.322	0.343	0.381	0.349
F_3	0.377	0.375	0.369	0.378
Mean	0.346	0.342	0.351	0.349

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

Agronomic efficiency (AE)

The agronomic efficiency increment at different fertilizer rates at WARSS and MARC is provided in Figure7. For both locations, maximum agronomic efficiency increment was obtained between the F_1 (41-46 kg N-P_2O_5 ha^{-1}) and F_2 (49.2-55.2 kg N-P_2O_5 ha^{-1}) treatment. Minimum AE increment was obtained between F_2 and F_3 (57.4-64.4 kg N-P_2O_5) treatment. By the results above it was observed that higher rate of increment in AE for both locations could be detected under medium rate of nitrogen application (F_2). AE increment (the rate of increment) was sharply decreased at the highest rate of fertilizer application at both locations. This implies that there was increment in AE but the increment was at a decreasing rate after maximum was obtained at medium fertilizer rate.

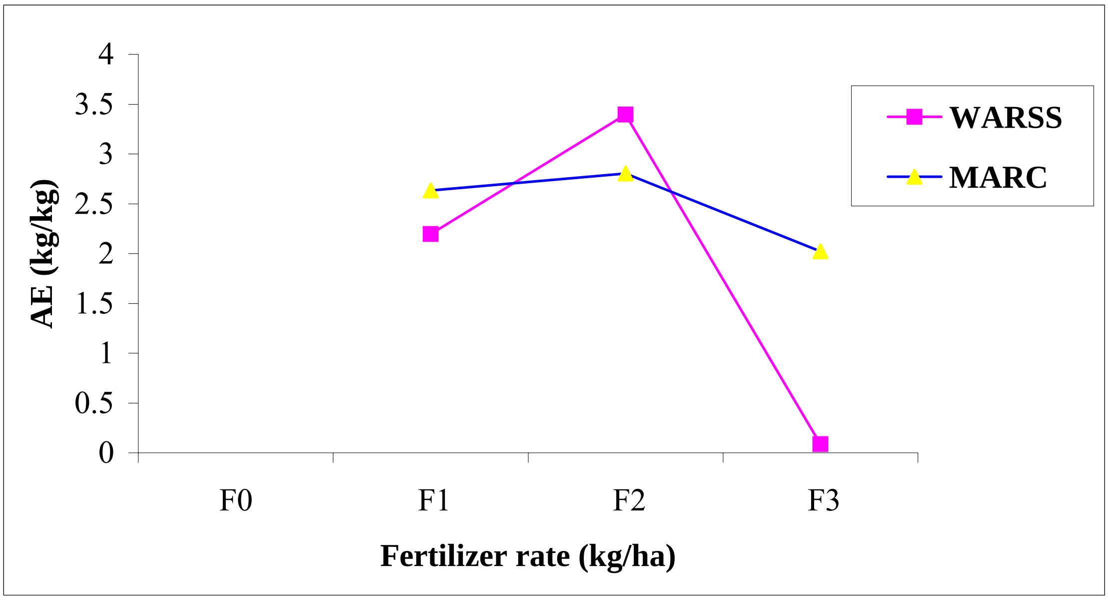

Figure7 Effect of fertilizer rate on sorghum agronomic efficiency increment.

Low efficiency of fertilizers particularly nitrogen in dryland sorghum is related to ammonia volatilization, denitrification, leaching, ammonium fixation, immobilization, and runoff (Savant and De Datta, 1982). Fertilizer N losses in surface runoff range between 1% (Blevins *et al.*, 1996) and 135% (Chichester and Richardson, 1992) of total N applied, and are generally lower under no tillage. Many ^{15}N recovery experiments have reported losses of fertilizer N in cereal production from 20% to 50% (Olson and Swallow, 1984; Sanchez and Blackmer, 1988; Francis *et al.*, 1993; Wienhold *et al.*, 1995; Karlen *et al.*, 1996) when these factors were not measured separately.

Dynamics of soil water content

During months of July and August, the crop received about 246 and 172.5 mm rain at WARSS, and 163.6 and 136.7 mm of rain at MARC, respectively. Generally there was good amount and distribution of rainfall for WARSS, therefore none of the management systems brought about significant difference in the soil water content through out the soil-sampled plots. Tied- ridging was relatively better to augment more soil moisture content due to the enhanced infiltration rate of water to the deeper soil layer than other tillage treatments (Figure 8). The differences in soil water contents in the top 0-15 cm soil depth at 30 days after emergence were related to differences in the amount of water infiltrated. The increase in soil water content stored was presumably related to the effect of tillage, which might have improved bulk density and increased porosity, and also related to furrow tying to effectively capture rainfall and prevent any possible loss of water in the form of runoff and thus increased the time of ponding and amount of water to be infiltrated (Krishna, 1989; Carter and Miller, 1991; Piha, 1993), despite little differences due to treatments was observed. At 60 days after crop emergence (Sep. 12), the same trend of soil moisture pattern was evident, but some of the moisture had already depleted as reflected in low soil moisture content at WARSS while a bit higher moisture observed at MARC as the result of higher rainfall (56 mm) 24 hours before the soil moisture sampling date. The soil water at this time at the depth of 0-15 cm for the tie ridge and reduced tillage tied furrow treatments were higher but was extremely low at the same depth for no-tillage and conventional tillage treatments. At the late growth stage of the crop (90 days after emergence) minimum and the same trend of soil water content was observed at both locations in the presence of small but equal amount of October rainfall (65 mm). Minimum amount of soil water was extracted at this stage of the crop growth as expected since the sorghum crop was near physiological maturity.

Grain, stover and aboveground biomass water use efficiency

During the growing season (July to October), the crop received about 545 and 364 mm rainfall at WARSS and MARC, respectively. Remarkable differences in WUE values for grain production were observed by fertilizer rates and the interaction due to fertilizer and tillage (Table 18). When all tillage and fertilizer rates were combined, greater grain WUE was recorded at MARC (4.80 kg ha^{-1} mm^{-1}) than at WARSS (4.37 kg ha^{-1} mm^{-1}). When the mean for fertilizer rates were combined tie ridge at WARSS; tie ridge and conventional tillage at MARC gave the highest WUE. WUE values for grain production increased from 3.91 kg ha^{-1} mm^{-1} due to reduced-tillage to 4.68 kg ha^{-1} mm^{-1} due to tied ridging at WARSS.

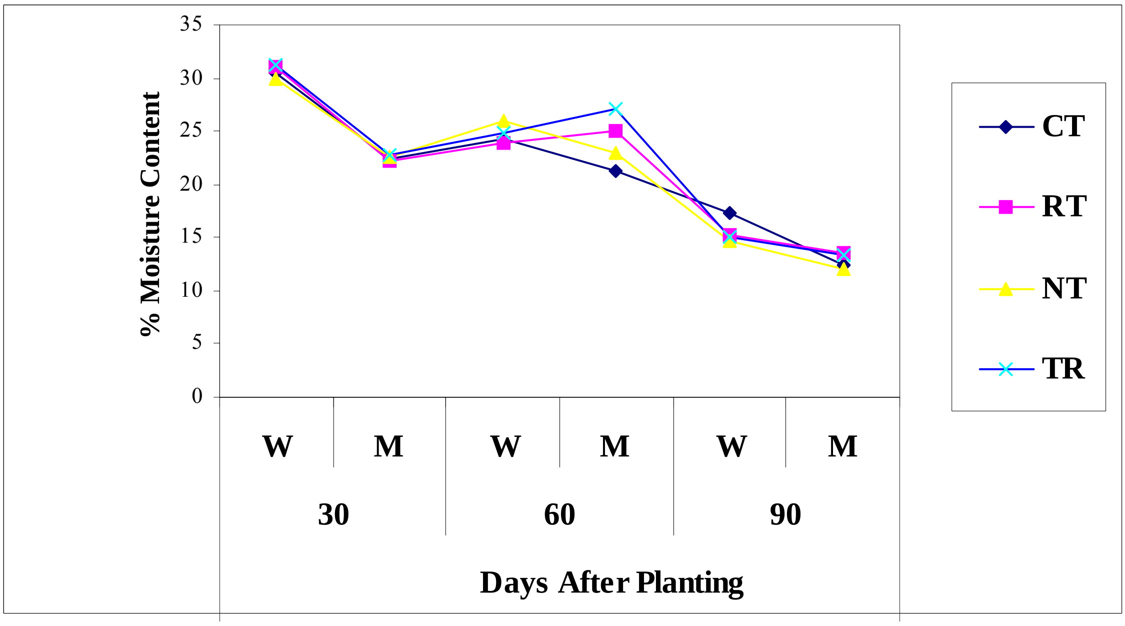

Figure 8 Soil moisture content at 0-15 cm depth for conventional tillage (CT), reduced tillage (RT), conservation tillage (NT), and Tie-ridge (TR) at WARSS (W) and MARC (M).

Table 18 Effect of tillage systems and fertilizer rates on grain water use efficiency.

Tillage System*	F_0**	F_1	F_2	F_3	Mean
		WARSS (kg ha^{-1} mm^{-1})			
CT	4.47	4.30	4.65	4.65	4.52
RT	3.14	4.30	3.98	4.19	3.91
NT	4.37	4.02	4.54	4.54	4.37
TR	4.37	4.40	5.07	4.89	4.68
Mean	4.09	4.26	4.56	4.57	
		MARC (kg ha^{-1} mm^{-1})			
CT	4.51	5.00	5.00	5.59	5.00
RT	4.05	4.84	4.94	5.89	4.93
NT	3.79	3.89	4.61	4.65	4.24
TR	4.58	4.59	4.87	5.89	5.00
Mean	4.24	4.58	4.88	5.50	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

At MARC it was increased from 4.24 kg ha^{-1} mm^{-1} due to no tillage to 5 kg ha^{-1} mm^{-1} each due to tie ridge and conventional tillage. WUE was decreased in tie ridged and conservation tillage at WARSS and MARC probably due to higher utilization of water because of relatively higher rainfall year as compared to lesser rainfall years when the water supply is limited and transpiration (T) might be increased relative to other pathways of loss. If the total water supply is increased, WUE will only be increased if T is increased proportionally (Gregory *et al*., 1984; Dick and Van Doren, 1985; Gregory, 1988; Griffith *et al*, 1988; Sharma and Acharya, 2000) or it could be due to some undesirable factors imposed on no-tillage which is liable to yield reduction especially at first few years as reported by many workers (Dick and Van Doren, 1985; Griffith *et al.,* 1988). On other hand, when the mean of all tillage systems were combined, at increasing fertilizer rates, the grain WUE was increased. Increased WUE was observed as the fertilizer rate was increased from no application to the highest level of fertilizer application from 4.09 kg ha^{-1} mm^{-1} to 4.57 kg ha^{-1} mm^{-1} of WUE at WARSS, respectively. At MARC it was increased from 4.24 kg ha^{-1} mm^{-1} with no fertilizer to 5.50 kg ha^{-1} mm^{-1} with the highest fertilizer rates. The rate of increment was, however, differed. At WARSS, the rate of increment in grain water use efficiency followed the same pattern as the agronomic efficiency of the crop where by 27 and 26% grain WUE was due to F_2 and F_3 fertilizer rates. Like wise, at MARC the rate of grain WUE was enhanced by 29% at the highest fertilizer rates (F_3) followed by the F_2 (25%) fertilizer rates. The combination of fertilizer with moisture conservation techniques such as tie ridge was increased the crop water use efficiency. As indicated in Table 18, at any fertilizer rate application (F_1, F_2, and F_3) tie ridge resulted in higher WUE of grain at WARSS. Where there was no fertilizer application (F_0) it was on conventional tillage plot that higher grain WUE was recorded. At MARC the crop grown on tie ridged and reduced tillage plots with the highest rate of fertilizer (F_3) had the greatest grain WUE.

The WUE for both stover yield and total dry matter were influenced by the main effect of tillage systems and fertilizer rates (Table 19 and 20). The stover and biomass of sorghum WUE generally followed the same trend at that of grain yield. It was at MARC the highest stover and biomass WUE was achieved. Combined over two locations tie ridge enhanced the WUE of both stover and biomass.

Table 19 Stover and aboveground biomass WUE at varied tillage system.

Location	CT*	RT	NT	TR	Mean
		Stover (kg ha^{-1} mm^{-1})			
WARSS	6.23	5.81	5.35	6.01	5.85
MARC	13.73	12.77	12.9	15.09	13.63
Mean	9.98	9.29	9.14	10.55	
		Above ground biomass (kg ha^{-1} mm^{-1})			
WARSS	10.74	9.72	9.72	10.69	10.22
MARC	18.79	17.70	17.17	20.06	18.43
Mean	14.77	13.71	13.46	15.37	

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge.

Table 20 Stover and aboveground biomass WUE as influenced by fertilizer rate.

Location	F_0*	F_1	F_2	F_3
		Stover (kg ha^{-1} mm^{-1})		
WARSS	5.90	5.77	5.77	5.96
MARC	13.93	13.61	14.60	12.38
Mean	9.92	9.69	10.18	9.17
		Aboveground biomass (kg ha^{-1} mm^{-1})		
WARSS	9.99	10.02	10.33	10.53
MARC	18.17	18.18	19.48	17.88
Mean	14.07	14.10	14.91	14.21

* F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

For WARSS higher stover and biomass WUE was observed on conventional tillage plots. At MARC, however, tie ridge resulted in higher stover and biomass WUE. It was at the F_2 rate (49.2-55.2 kg N-P_2O_5 ha^{-1}) that the stover and biomass WUE was remarkably enhanced when the means over locations were combined (Table 20). At this rate of fertilizers, the stover and biomass of sorghum crop achieved the highest WUE at MARC while it was at the highest fertilizer rate at WARSS. The different responses in WUE for dry matter production due to main effects of tillage and fertilizer and their interaction suggested that some additional growth occurred on the tie ridged plots and the conventional plots as progressively the fertilizer application was raised to the higher level at both locations. Additional higher precipitation accompanied with greater water conservation level due to tie ridge during critical grain filling stages might have improved grain yields in such tillage systems. Consequently, these treatments resulted in greater WUE values. Cooper *et al.* (1987) reported that reduction of evaporation (E) by no-tillage could not be possible in dryland environments because of poor ground cover by the crop especially during early stage of the crop. Gibson *et al.* (1992) also reported the reduction in WUE associated with lesser evapotranspiration (seasonal water use) during cropping season of the crop as the result of lower soil water storage at early growth stage. However, several research results from the long-term field experiment demonstrated the advantage of conservation tillage from improved grain yields and greater water use efficiency in regions receiving annual precipitation of more than 250 mm (Aase and Pikul, 1995). As it was clearly known from studies in the areas of semi-aid regions, much was not expected from the no-tillage system during the first one to three years particularly when the precipitation reasonably ample or increased (Hammel, 1995). Linear and curvilinear relationships between crops yield and water use reported in many studies (Arkley, 1963). It is generally stated that yield is a function of seasonal water use, but the different variability among the growing season especially associated with the amount and distribution of the seasonal rainfall, rate of evaporation at different stages and other prevailing environmental factors make it difficult to trace the relationship between these variables (Cooper *et al.,* 1987; Hamblin *et al.,* 1987).

Soil chemical properties under different tillage systems and fertilizer rates

The soils of WARSS where sorghum productivity trial under different tillage systems and fertilizer rates was conducted had loam soil type with 46, 34, and 20% sand, silt and clay content, respectively. Very low organic carbon as well as low NP was obtained at WARSS (Table 21). Basic cations were high to very high category. Extractable K, and exchangeable Ca were very high while Mg and Na were high. Cation exchange capacity of the soil and pH was at high level. There was no significant different among various tillage system. However, slightly higher organic carbon was obtained due to no tillage and tie ridge. Total soil nitrogen and available P was remarkably higher due to reduced tillage tied furrow and tie ridge tillage systems probably due to higher water content of both tillage systems.

Table 21 Soil properties at WARSS's sorghum experimental site.

Tillage	Soil Chemical Properties									
	OC (%)	N (%)	P mg kg^{-1}	K	Ca	Mg	Na	CEC	pH (1:2.5)	EC (1:2.5,d S/M
				Meq/100 gm Soil						
Tillage System*										
CT	1.55	0.114	8.25	2.69	24.06	5.84	1.45	36.07	8.07	0.087
RT	1.54	0.126	8.70	2.79	23.51	5.98	1.76	36.10	8.10	0.096
NT	1.61	0.113	8.30	2.75	22.33	5.66	1.76	34.45	8.00	0.091
TR	1.60	0.120	8.74	2.67	22.43	5.66	1.74	34.44	8.05	0.087
Fertilizer Rates**										
F_0	1.58	0.114	7.71	2.74	23.07	5.62	1.64	35.05	8.04	0.088
F_1	1.57	0.116	8.92	2.68	23.20	5.84	1.60	35.32	8.03	0.092
F_2	1.55	0.121	9.14	2.74	23.37	5.91	1.76	35.80	8.11	0.089
F_3	1.58	0.122	8.22	2.75	22.69	5.77	1.72	34.89	8.04	0.092

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

Regarding different fertilizer rate, at higher rate of fertilizer the level of total nitrogen was increased while other soil properties were exhibited inconsistency in their content against fertilizer rates. The soil type of MARC is loam with textural class of 41, 37, and 22 % sand, silt and clay, respectively. This site is also characterized by very low organic carbon, low nitrogen, medium phosphorus but very high potassium content and medium pH (Table 22). Neither the main effect of tillage systems and fertilizer rates nor the interaction between them differed significantly.

Table 22 Soil chemical properties at MARC's sorghum experimental site.

Tillage System	Soil Chemical Properties					
	OC (%)	N (%)	P mg kg^{-1}	K Meq/100gm	pH (1:2.5)	EC (1:2.5,d S/M)
Tillage systems*						
CT	0.75	0.063	10.78	2.26	6.38	0.121
RT	0.83	0.033	10.68	3.80	6.29	0.234
NT	0.65	0.053	19.45	3.46	6.61	0.069
TR	0.83	0.043	16.64	3.43	6.32	0.082
Fertilizer rates**						
F_0	0.83	0.040	11.53	3.91	6.48	0.245
F_1	0.78	0.060	13.00	2.68	6.42	0.085
F_2	0.72	0.036	17.58	2.72	6.38	0.078
F_3	0.72	0.056	15.44	3.63	6.32	0.099

* CT = Conventional tillage, RT = Reduced tillage, NT = Conservation tillage, TR = Tie ridge; ** F_0 = 0-0 kg N-P_2O_5, F_1 = 41-46 kg N-P_2O_5, F_2 = 49.2-55.2 kg N-P_2O_5, F_3 = 57.4-64.4 kg N-P_2O_5 per hectare.

Experiment 2. Tillage and Crop Rotation Effect on Soil Properties and Maize Productivity

Bulk density (BD)

The effect of tillage and cropping system on soil bulk density is presented in Table (23). In both systems (tillage and cropping), the values of bulk densities were in the desirable category. The mean soil BD (average of the two cropping systems) was 1.16 gm cm^{-3} each at 0-15 cm and 15-30 cm soil depth for conservation (T1) and 1.09 and 1.22 gm cm^{-3} for conventional (T5) tillage, respectively. Regarding cropping system it was observed that the mean soil BD (average of two tillage systems) was 1.13 gm cm^{-3} and 1.11 gm cm^{-3} at a depth of 0–15 cm for continuous and rotational cropping plots, respectively. The same BD value was observed between the two cropping system at 15-30 cm soil depth. There was no evidence that conservation tillage causes compaction even in continuous monocropping for five years and the bulk density in continuous cropping of conservation tillage (1.21 gm cm^{-3}) was slightly higher than that of conventional tillage (1.05 gm cm^{-3}). When rotation was used this difference was rather reversed and the bulk density of the soil was higher from the conventional tillage (1.12 and 1.28 gm cm^{-3}, respectively at 0-15 and 15-30 cm) than that of the conservation tillage (1.10 and 1.10 gm cm^{-3}), probably indicating the importance of crop rotation to avoid compaction. Similar to the present findings, in many countries a non-significant effect of tillage treatments on soil BD observed (Unger, 1984; Hill, 1990). In the present study the value of BD ranges 1.05 to 1.28 gm cm^{-3} in conventional tillage and 1.1 to 1.21 gm cm^{-3} in conservation tillage. These values of bulk density were below the range of 1.4–1.5 gm cm^{-3} reported by Griffith *et al*. (1977) as affecting root growth. Changes in soil physical properties due to use of conservation tillage depend on several factors including differences in soil properties, weather conditions, history of management, intensity, and type of tillage (Mahboubi *et al*., 1993).

Table 23 Tillage and cropping system effect on soil bulk density (gm cm^{-3}).

Tillage System	Cropping System			
	Rotation		Continuous	
	0-15 (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)
Conservation	1.10	1.17	1.21	1.10
Conventional	1.12	1.28	1.05	1.15

Several authors found greater soil bulk density under conservation tillage than conventional tillage (Hammel, 1989 and Ferreras *et al*., 2000), while others did not find differences (Hill and Cruse, 1985 and Chang and Lindwall, 1989), or obtained lower values of bulk density under soils with a residue layer on the surface (Edwards *et al*., 1992 and Lal *et al*., 1994). Different observation also indicate that what compaction might occur is rapidly reversed by the mass of roots growing near the soil surface (Blevins *et al*., 1977). Several authors described a higher bulk density in soils under conservation tillage systems (Hill *et al*., 1985; Pelegrín *et al*., 1990; Moreno *et al*., 2000) during the complete agricultural cycle or at least for part of it. These changes are associated with weather fluctuations in conservation tillage systems (Rachman *et al*., 2003) and with disking in other cases.

Increased bulk density is associated with soil compaction and changes in total porosity and pore geometry (Horton *et al*., 1989). Soils under conservation tillage systems appear to have a larger proportion of small pores in relation to conventional tillage (Hill *et al*., 1985). The increase in the porosity of these systems is restricted to the ploughed horizons because a pan develops underneath it (Josa-March *et al*., 2002). The increased bulk density markedly altered the water retention curves and lowered saturated and unsaturated conductivity rates; the most compacted areas remained wetter during the drying-out cycle than did other areas (Reicosky *et al*., 1981).

<u>Precipitation and soil moisture content</u>

At early growing season, WARSS had higher precipitation (Figure3) that contributed to its higher soil moisture content. However, during the grain filling stage, starting from half of August MARC received remarkably higher precipitation that contributed to its higher water content at late growing season (Figure9). Available soil water content on dry weight basis in the top 0-30 cm soil layer was remarkably greater under T1 (conservation) than under T5 (conventional) during the growing season.

Effects of tillage on soil chemical properties

While tillage did not show remarkable effects on soil physical properties, the effects on soil chemical properties were apparent after a short time (Table 24). After five years cropping season (2000 to 2004) the NPK of the soil increased on both conventional and conservation tillage probably because of continuous fertilizer use of 50-100 kg urea-diammonium phosphate per hetare.

Total Soil Nitrogen (TSN)

Though there was no significant difference between the two tillage systems, the nitrogen content was higher on conservation tillage (T1) than that on the conventional tillage (T5). Hence, nitrogen increased from low to medium amount on conservation tillage while remaining under low category in conventional tillage.

Available Phosphorus

Available phosphorus concentration of 9.47 mg kg^{-1} in the surface layer at the start of the experiment in 2000 increased to 14.42 and 19.44 mg kg^{-1} in conventional and conservation tillage, respectively probably due to continuous use of 100 kg ha^{-1} diammonium phosphate fertilizer in each year. Lal (1997) also reported that P increased with cultivation duration due to application of phosphate fertilizers.

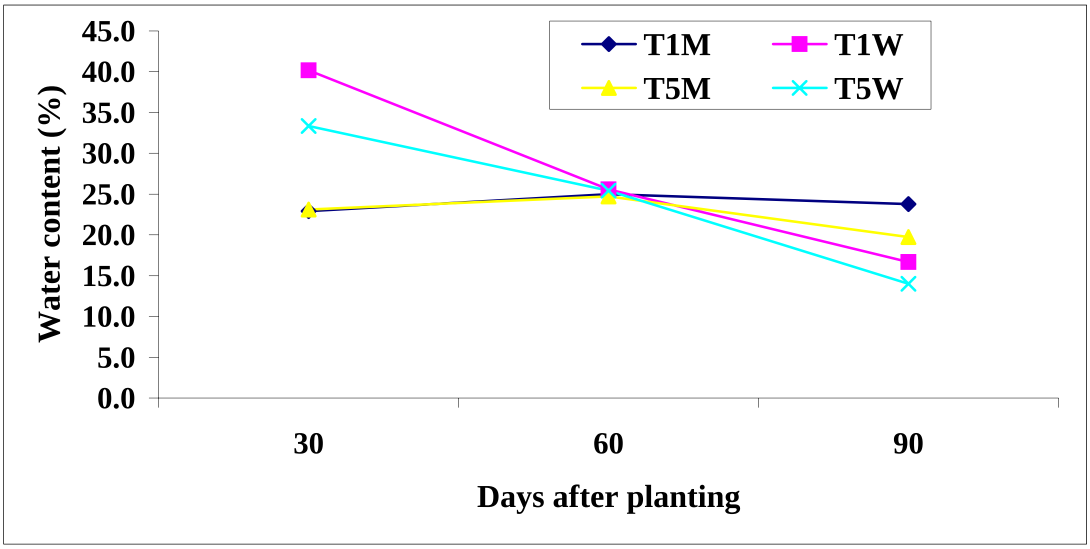

Figure 9 Soil moisture content at 0-30 cm depth for conservation tillage (T1) and conventional tillage (T5) at MARC (M) and WARSS (W).

Table 24 The effect of tillage systems on some soil chemical properties.

Soil properties	June 2000 (Initial)	June 2003	
		Conservation	Conventional
N (%)	0.051	0.130	0.070
P (mg kg^{-1})	9.47	19.44	14.42
K (mg kg^{-1})	272	633	597
pH (1:2.5)	6.64	6.58	6.34
OM (%)	1.02	1.6	1.2

P stress is always worse under dry soil conditions, so much so that P deficiency is often called " dry weather" disease. Therefore, one-way of improving P availability is to increase the soil water content, which is done under conservation tillage. The present high available P can be attributed to the higher water content of the soil under conservation tillage system.

Exchangeable potassium (K)

The exchangeable K level which was 272 mg kg^{-1} in the plough layer at the initiation of experiment in 2000 was very high, and increased to 633 and 597 mg kg^{-1} for conservation tillage and conventional tillage, respectively indicating that tillage and balanced fertilizer application enhanced soil K content with higher value for conservation tillage. In agreement with the present findings, under tropical conditions where distinct wet and dry rainfall regimes occur, Lal (1982) reported higher levels of potassium under conservation tillage when compared to plowed land while the pH levels remained about the same. This is probably a result of the marked increase in cation exchange capacity (CEC) due to increased organic matter under conservation tillage (Lal, 1982).

Soil organic matter (SOM)

The effect of tillage on soil organic matter in the surface 15 cm of the soil was very remarkable. Soil organic matter was increased on both conservation (T1) and conventional (T5) tillage plots. The use of recommended fertilizer rate might bring about the increment on conventional tillage. Remarkably more organic matter was found on conservation tillage (1.6%) than the contents on conventional tillage (1.2%). Because soil was disturbed so little under conservation tillage and erosion was reduced, the level of soil organic matter tended to rise in conservation tillage. Similarly, many authors reported that conservation tillage systems, especially no-till, result in the accumulation of organic matter in the first few centimeters of the soil profile (Follett and Schimel, 1989; Karlen *et al*., 1991).

Acidity

As it is evidenced in the table 24 the effect of frequent tillage on the pH of surface 0-15 cm was greater than the effect of conservation tillage. However, theoretically with conservation tillage one can expect a lower pH because of the tendency toward loss of bases in the soil surface, already alluded to, and because of the increase in CO_2 content of the soil air due to increased water content and (presumably) to a higher organic matter content. In many countries the known damaging effect of conservation tillage is a rapid lowering of soil surface pH when nitrogen fertilizers are applied which was not the case in the present study. In conformity to the present findings, Lal (1982) stated that a marked tendency toward the acidification of the upper part of the soil with conservation tillage is not the case in the tropics unlike in the temperate regions. According to him, the apparent reason this does not occur in the tropics is that there are longer dry periods during which salts of basic cations are brought back to the surface by plant roots.

Effect of monocropping on previous crop yield

The results of the previous three years continuous monocropping indicated that grain yield decreased from year to year even with the application of recommended fertilizer rate (Table 25) regardless of tillage systems. Maize grain yields in 2000, a year of adequate rainfall; 2001, a very dry year; and 2003, a relatively good rainfall year (Figure 10), for conservation tillage (T1) were 2800, 970 and 750 kg ha^{-1}, respectively. The corresponding yields of the conventionally tilled (T5) treatments were 2700, 850, and 410 kg ha^{-1}, respectively. In 2002, a year of drought and famine in the country, no grain yield was produced. In spite of a relatively good rainfall year in 2003 the decline in maize grain yield clearly indicated that continuous monocropping is a factor contributing to the reduction of yields. In conservation tillage (T1), about 65.4 and 22.7% yield reduction was observed from 2000 to 2001 and from 2001 to 2003, respectively. The corresponding yield reduction during the same year in conventional tillage (T5) was 68.5% and 51.8%, respectively. By the end of 2003, yield reduction in conventional tillage (T5) was more than by double to that of conservation tillage (T1) indicating more adverse effect of monocropping on conventional tillage. There was no significant difference among tillage systems within each year in grain yield of maize. However, the higher mean grain yield in the three options of conservation tillage (T1, T2, T3) clearly indicate that conservation tillage practices even with continuous cropping have a remarkable positive impact to obtain high grain yield. One major advantage of conservation tillage in row crop production, which is the conservation of soil water and accumulation of soil organic matter that resulted in its higher yield, was confirmed in the present study.

Table 25 Effect of tillage on maize grain yield (kg ha^{-1}) in continuous maize cropping.

	Cropping Year				
Treatment [a]	2000	2001	2002	2003	Mean
T1	2800	974	-	750	1508
T2	3300	661	-	417	1459
T3	2800	775	-	653	1409
T4	2000	613	-	722	1112
T5	2700	853	-	472	1341
Mean [b]	2720 a	775 b		602 b	

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 5 l ha^{-1} LA herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no LA herbicide application, T4 = Conventional tillage with four times plowing and 5 l ha^{-1} LA spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding. [b] Means followed by a different letter differ at the 0.05 probability level.

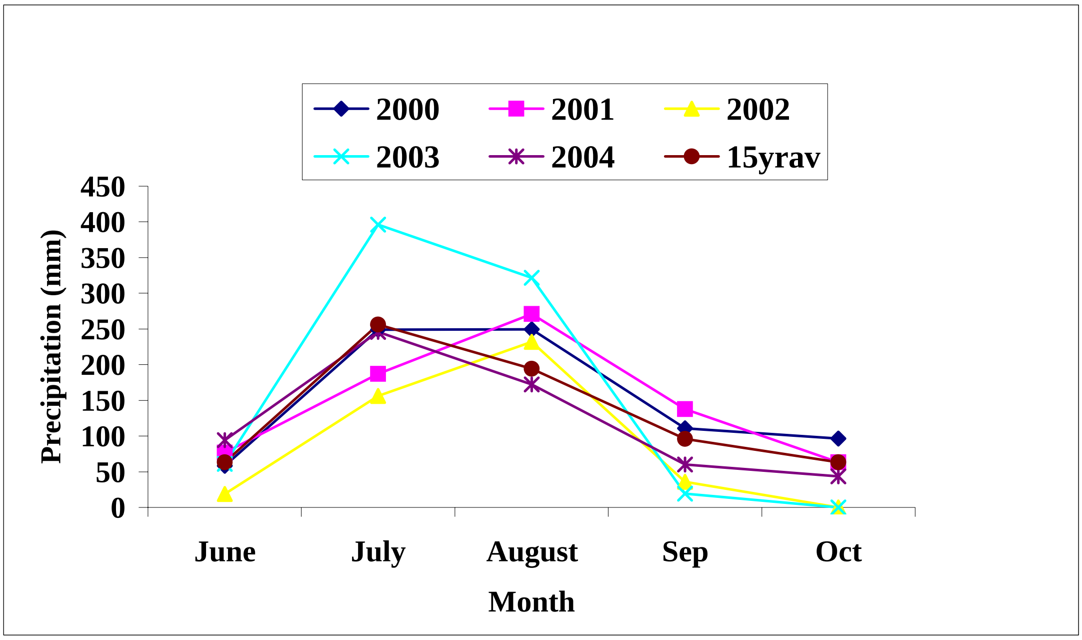

Figure10 Precipitation during maize growing period and 15 years average at WARSS.

Effects of crop rotation on maize yield component

Stand Count

Number of plants significantly ($P<0.01$) affected by location, cropping system and the interaction of both (Appendix Table 11). Significantly greater number of stand counts observed at WARSS than at MARC, and plants grown after rotation had significantly higher number than that grown on monocropping plot (Table 26).

Cobs number and weight

Number of cobs significantly ($P<0.01$) affected by cropping system (Appendix Table 12) and plots of rotation had significantly higher cob number than the monocropping plots. When rotation was used the cob number was higher at MARC while when monocropping was practiced the cob number was higher at WARSS (Table 27).

Table 26 Stand count of maize affected by location and cropping system.

	Stand count (plant ha^{-1})		
Location	Rotation	Monocropping	Mean
WARSS	66229.65 a[1]	52994.73 b	59612
MARC	65018.52 a	33711.11 c	49365
Mean	65624	43353	

[1]Means followed by different letter are significantly different at 5% level of significance.

Table 27 Effect of cropping system on maize cob number (No ha^{-1}).

	Cropping System		
Location	Rotation	Monocropping	Mean
WARSS	41880.80	33331.35	37606.07
MARC	42814.82	29422.22	35118.52
Mean[1]	42347.81	31376.79	

The effect of location, cropping system and the interaction of both on cob weight was very highly significant (Appendix Table 13). Thus, significantly higher cob weight was obtained from MARC than that obtained from WARSS. The cob weight that was recorded from rotational plot was significantly higher than that of monocropping plot (Table 28). In both cropping system MARC had greater cob weight; and at both locations the cob weight from rotational plot was significantly higher than that of the monocropping plot.

Effects of crop rotation on yield

Grain and straw yields of maize were significantly (P<0.01) affected by cropping system (Table 29). The straw and grain yield (average of all tillage systems) on rotational plot were significantly higher than that obtained from continuous cropping system for both locations.

Table 28 Cob weight of maize affected by location and cropping system.

Location	Cob weight (kg ha^{-1})		
	Rotation	Monocropping	Mean
WARSS	234 c[1]	134 d	184
MARC	793 a	487 b	640
Mean	513	311	

[1]Means followed by different letter are significantly different at 5% level of significance.

Table 29 Effect of cropping system on grain and straw yield of maize.

Location	Grain and straw Yield (kg ha^{-1})			
	Grain	Straw		
	Rotation	Continuous	Rotation	Continuous
WARSS	1846.1 B[1]	1060.9 C	4422 A	1825 C
MARC	2553.7 A	1064.5 C	2852 B	1942 C
Mean	2199.9 a[1]	1062.6 b	3637 a	1884 b

[1]Means followed by different uppercase letter within grain and straw yield in the table, and means followed by different lowercase letter within furrow are significantly different at 5% level of significance.

Regarding locations, grain yield obtained from MARC was significantly higher than that obtained from WARSS. Un like the grain yield, significantly higher mean straw yield of maize was obtained from WARSS than that obtained from MARC. MARC and WARSS had significantly higher grain and straw yield, respectively under rotation while no significant difference was observed between the two locations under continuous cropping system. The higher precipitation that WARSS (Figure1) received at the earlier growing season contributed to its higher soil moisture content (Figure 2) that resulted in higher straw yield of maize production. During the grain filling stage, however, MARC received remarkably higher precipitation and had higher soil moisture content that contributed to its greater grain yield. This indicated that the higher the rainfall during the first two months might have been beneficial for vegetative growth while relatively the higher rainfall during grain filling could contributed to the greater grain yield.

Combined effects of tillage and cropping system on crop yield

The positive impact of rotating crops one after the other on maize yield is presented in (Table 30 and 31). Thus, the overall mean maize grain yield obtained from crop grown on previous Taaffi crop exhibited 184.4% yield advantage over the yield that was obtained from continuous maize cropping at WARSS. The advantage of crop rotation for the three options of conservation tillage plots ranges form 169.2 to 228.5%, and for the two options of conventional tillage plots ranges from 133.4 to 245.3% over the continuous cropping. At MARC, the advantage obtained from leguminous crop (haricot bean) rotation was also remarkable and 70-183% yield increment was recorded over the continuous cropping for the different tillage system; and the overall mean yield increment for rotational cropping was 140% over the monocropping system. The maize grain yield increment in the present study when Taaffi was used as a precursor crop over the continuous monocropping of maize could probably attributed to (i) the crop management practices that were carried out to reduce weed population and the usage of herbicide that kills broad leaf weed on previous Taaffi plot resulted in decreasing seed bank of weeds that reduced weed

Table 30 Tillage and cropping system effect on maize grain yield (kg ha^{-1}) at WARSS.

Tillage System	Cropping System: Continuous	Rotation (Taaffi[1])	% Increment
T1	750	2019	169.2
T2	417	1370	228.5
T3	653	1852	183.6
T4	722	1685	133.4
T5	472	1630	245.3
Mean	602	1712	184.4

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 5 l ha^{-1} LA herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no LA herbicide application, T4 = Conventional tillage with four times plowing and 5 l ha^{-1} LA spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding. [1] Taaffi was used as a precursor crop at WARSS.

Table 31 Tillage and cropping system effect on maize grain yield (kg ha^{-1}) at MARC.

Tillage System [a]	Cropping System: Continuous	Rotation (HB[2])	% Increment
T1	1322	2972	125
T2	1022	2759	170
T3	933	2555	174
T4	888	2518	183
T5	1155	1962	70
Mean	1064	2553	140

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 5 l ha^{-1} LA herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no LA herbicide application, T4 = Conventional tillage with four times plowing and 5 l ha^{-1} LA spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding; [2]HB = Haricot bean was used as a precursor crop at MARC.

infestation on maize, and (ii) shallow rooting depth of Taaffi leave the soil below the rooting depth in a state of unacknowledged fallow which can be reached by deep rooted crops such as maize. This is in agreement with the report of Hailu and Kidane (1988) that stated a rotation system that used maize as a test crop, increased yield by (60%) when maize followed haricot bean or Taaffi crops. Results of several experiments in other countries also provide evidence of an increased productivity of subsequent non-legume crops. Ahlawat *et al*. (1981) have shown an increased grain yield of maize in India by a previous crop of legume crop. Kumar Rao *et al*. (1983) also reported a yield increase of maize by 57% and total plant dry matter by 32% following pigeonpea. The increased in grain yield of the succeeding cereal crop is believed to be due to the contribution of preceding legume crop which improved the soil fertility through atmospheric N-fixation (Kumar Rao *et al*., 1983). Table 30 and 31 further indicate that the higher grain yield was obtained from conservation tillage plot (T1) as compared to that obtained from conventional plot (T5) at both locations. The greater ability of conservation tillage (T1) to store more water and accumulate higher organic matter might have resulted in its higher grain yields. Increased grain yields in conservation tillage systems compared with conventional tillage have been obtained in areas having limited precipitation and soil water (Baumhardt *et al*., 1985). In agreement with the present findings, results from other country revealed that conservation tillage resulted in higher yields due to its higher soil water contents (Blevins *et al*., 1977).

Effects of different precursor crops on grain yield

A remarkable advantage and the overall mean of 75.6% maize grain yield increment was obtained when haricot bean was used as a precursor crop than Taaffi crop. For all tillage system, at the range of 36-110% yield increment was obtained when haricot bean was used as a precursor crop over the yield obtained when Taaffi crop was used at WARSS (Table 32).

Table 32 Maize grain yield (kg ha^{-1}) at different precursor crop at WARSS.

Tillage System [a]	Precursor crop Taaffi	Haricot bean	Difference	% Increment
T1	1097.11	1976.32	879.21	80
T2	1078.85	1470.86	392.01	36
T3	873.08	1841.68	968.60	110
T4	1233.65	2032.76	799.11	65
T5	1021.59	1909.08	887.49	87
Mean	1060.86	1846.14	785.28	75.6

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 5 l ha^{-1} LA herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no LA herbicide application, T4 = Conventional tillage with four times plowing and 5 l ha^{-1} LA spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding.

Experiment 3. Tillage and Crop Rotation Impact on Taaffi Productivity and Profitability

Initial weed spectrum

Major weed species in the whole experimental site with their estimated value during the onset of the experiment at MARC are presented in Table 33. The top seven weed species widely distributed in the whole experimental site during the onset of the experiment (June 2000) according to their importance were, *Cyperus spp, Digitaria scalarum, Cynodon dactylon, Sorghum arundeanance, Eragrostis aspera, Convolvulus arvensis* and *Bidens pilosa.* Thirty-days after Taaffi emergence just before 2,4-D post-emergence herbicide application, weeds that were less or no importance during the first observation were found scarcely distributed in all plots. These late emerging and scarcely distributed weed species almost in all plots were, *Ageratum conyziodes, Tribulus terestires*, *Galinsoga parviflora* and *Eracastrum arabicum*.

Weed spectrum after four years

Occurrences of weed species among the five tillage systems at Melkassa Agricultural Research Center during the present study are presented in Table 34. Four years after the initiation of the experiment, 32 weed species in 16 families were recorded from all plots in which, species of Poaceae followed by Asteraceae were the most common. Similar to the present findings available survey records indicated that there are about 64 species in 24 plant families known to be problematic weed species for Taaffi, out of which species of Poaceae are the most common followed by Asteraceae and Cyperaceae (Rezene and Zerihun, 2001). About 21, 19, 13, 16 and 13 weed species were found in T5, T4, T3, T2, and T1, respectively (Table 34).

Table 33 Weed species during the initiation of the experiment (June 2000) at MARC.

Scientific name	Common name	Percent
Cyperus spp	Nut grass	30
Digitaria scalarum	Blue couch grass	20
Cynodon dactylon	Bermuda grass	15
Sorghum arundianaceum	Wild sorghum	10
Eragrostirs aspera	Birds foot	5
Convolvulus arvensis	Bind weed	3
Bidens pilosa	Black jack	3
Ageratum conyziodes	Goat weed	2
Tribulus terestires	Puncture vine	2
Galinsoga parviflora	Gallant soldier	2
Eracastrum arabicum	Milky weed	2
Ipomea eriocarpa	-	1
Xanthium stramarium	Cocklebur	1
Launaea maizeuta	Wild lettuce	1
Amaranthus spp	Pig weed	1
Others	-	2
		100 %

Table 34 Weed species among the five tillage systems at MARC (June 2004).

No	Weed species	Family	Tillage systems T1[b]	T2	T3	T4	T5
1	*Cynodon dactylon*	POACEAE	1[a]	0	0	0	1
2	*Corchorus pseudocapsularis*	TILIACEAE	1	1	1	0	1
3	*Galinsoga parviflora*	COMPOSITAE	1	1	1	1	1
4	*Oxygonum sinuatum*	POLYGONACEAE	1	1	1	0	0
5	*Euphorbia hirta*	EUPHORBIACEAE	1	0	0	0	0
6	*Convolvulus arvensis*	CONVOLVULACEAE	1	1	1	1	1
7	*Brassica oleracea*	BRASSICACEAE	1	1	1	1	1
8	*Tribulus terrestris*	ZYGOPHYLLACEAE	1	0	0	1	1
9	*Digitaria ternate*	POACEAE	1	1	1	1	1
10	*Panicum maximum*	POACEAE	1	1	0	0	0
11	*Echinocloa colona*	POACEAE	1	1	1	1	1
12	*Cyperus esculentus*	CYPERACEAE	1	1	0	0	1
13	*Amaranthus spinosus*	AMARANTHACEAE	1	1	1	0	1
14	*Hyparrhenia spp.*	POACEAE	0	1	0	1	0
15	*Digitaria milanjiana*	POACEAE	0	1	0	1	1
16	*Hibiscus meeusei*	MALVACEAE	0	1	0	1	1
17	*Tagetes minuta*	ASTERACEAE	0	1	1	1	1
18	*Euphorbia heterophylla*	EUPHORBIACEAE	0	0	1	0	0
19	*Corchorus olitorius*	TILIACEAE	0	1	0	0	0
20	*Xanthium strumarium*	ASTERACEAE	0	1	0	1	0
21	*Senecio abyssinicus*	POACEAE	0	0	1	1	1
22	*Parthenium hysterophorus*	ASTERACEAE	0	0	1	0	1
23	*Argemone mexicana*	PAPAVERACEAE	0	0	1	0	1
24	*Solanum nigrum*	SOLANACEAE	0	0	0	1	1
25	*Oxalis obliquifolia*	OXALIDACEAE	0	0	0	1	1
26	*Alternanthera punges*	AMARANTHACEAE	0	0	0	1	0
27	*Triumfetta annue*	TILIACEAE	0	0	0	1	0
28	*Boerhaavia diffusa*	NYCTAGINACEAE	0	0	0	1	0
29	*Gutenbergia rueppellii*	ASTERACEAE	0	0	0	1	0
30	*Lactuca serriola*	ASTERACEAE	0	0	0	1	1
31	*Digitaria scalarum*	POACEAE	0	0	0	0	1
32	*Conyza bonariensis*	ASTERACEAE	0	0	0	0	1
Total number of weed species			13	16	13	19	21

[a] 1 = presence and 0 = absence

[b]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 1 l ha^{-1} 2,4-D herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no 2,4-D herbicide application, T4 = Conventional tillage with four times plowing and 1 l ha^{-1} 2,4-D spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding.

Five weed species namely; *Galinsoga parviflora, Convolvulus arevensis, Brassica oleracea, Digitaria ternate* and *Echinochloa colona* were appeared in all the five tillage treatments. The former two weed species were also the major weeds during the initiation of the experiment probably indicating the dominance of those species during four years experimental period and their tolerance to different controls methods. The two (*Digitaria scalarum* and *Conyza bonariensis*) were observed exclusively in T5 that might have been indicating the importance of herbicide to control those weeds. Two (*Parthenium hysterophorus* and *Argemone* m*exicana)* were found only in T3 and T5; both treatments had no 2, 4-D herbicide application and revealed the importance of 2, 4-D to control both weeds.

Mean population density (MPD) and relative density (RD) of weeds

Tillage effects on density of weeds were found to be species specific (Table 35). For example, highest MPD of *Cyperus escalentus* (40 m^{-2}), *Galinsoga prviflora* (35.67 m^{-2}), *Digitaria scalarum* (11.0 m^{-2}), *Convolvulus arvensis* (10.67 m^{-2}) and *Hibiscus meeusei* (4.67 m^{-2}) was observed under the conventional tillage system (T5). *Cyperus escalentus* is one of the most hard to pull perennial weed that is difficult to control, and *Galinsoga parviflora* is considered as a known noxious weeds by farmers, around the central rift valley (HARC, 1999). But *Digitaria ternate*, *Cynodon dactylon* and *Corchorus pseudocarpsularis* had their highest MPD under the different options of conservation tillage (T1, T2 and T3). The highest MPD of the former two weed species in conservation tillage systems might have been indicated their tolerance to the herbicides and a shift in weed species from broad leaf to grass weeds. The latter annual broad leaf weed may be better adapted to less disturbed environments.

Table 35 Tillage effects on population density (PD) and relative density (RD) of weeds.

Weed species	Tillage Systems[a]					
	T1	T2	T3	T4	T5	
	Mean Population Density (no m^{-2})					RD (%)
Galinsoga parviflora	1.00	3.33	5.67	2.33	35.67	18.50
Cyperus esculentus	1.33	3.67	0.00	0.00	40.00	17.30
Corchorus pseudocapsularis	9.67	5.00	13.00	0.00	0.67	10.90
Digitaria ternate	11.00	4.67	8.33	3.33	0.33	10.60
Convolvulus arvensis	3.33	2.67	1.00	0.67	10.67	7.10
Hibiscus meeusei	0.00	0.33	0.00	7.33	4.67	4.70
Echinocloa colona	0.33	1.67	1.33	7.00	1.33	4.50
Digitaria scalarum	0.00	0.00	0.00	0.00	11.00	4.20
Amaranthus spinosus	1.33	1.00	4.67	0.00	2.33	3.60
Brassica oleraceae	0.33	1.33	4.00	2.00	1.00	3.40
Tagetes minuta	0.00	0.33	2.00	5.00	0.33	3.00
Cynodon dactylon	5.33	0.00	0.00	0.00	0.33	2.30
Digitaria milanjiana	0.00	1.67	0.00	3.00	0.33	1.90
Oxygonum sinuatum	1.33	1.00	1.67	0.00	0.00	1.50
Senecio abyssinicus	0.00	0.00	1.00	0.67	1.33	1.20
Tribulus terrestris	1.00	0.00	0.00	0.33	1.00	0.90
Parthenium hysterophorus	0.00	0.00	1.00	0.00	0.67	0.60
Oxalis obliquifolia	0.00	0.00	0.00	1.33	0.33	0.60
Lactuca serriola	0.00	0.00	0.00	0.67	1.00	0.60
Euphorbia hirta	1.00	0.00	0.00	0.00	0.00	0.40
Panicum maximum	0.33	0.33	0.00	0.00	0.00	0.30
Hyparrhenia spp	0.00	0.33	0.00	0.33	0.00	0.30
Xanthium strumarium	0.00	0.33	0.00	0.33	0.00	0.30
Argemone mexicana	0.00	0.00	0.33	0.00	0.33	0.30
Solanum nigrum	0.00	0.00	0.00	0.33	0.33	0.30
Boerhaavia diffusa	0.00	0.00	0.00	0.33	0.00	0.10
Euphorbia heterophylla	0.00	0.00	0.33	0.00	0.00	0.10
Corchorus olitorius	0.00	0.33	0.00	0.00	0.00	0.10
Alternanthera punges	0.00	0.00	0.00	0.33	0.00	0.10
Triumfetta annue	0.00	0.00	0.00	0.33	0.00	0.10
Gutenbergia rueppellii	0.00	0.00	0.00	0.33	0.00	0.10
Conyza bonariensis	0.00	0.00	0.00	0.00	0.33	0.10
Total plant density(no m^{-2})	37.31	27.99	44.33	35.97	113.98	

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 1 l ha^{-1} 2,4-D herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no 2,4-D herbicide application, T4 = Conventional tillage with four times plowing and 1 l ha^{-1} 2,4-D spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding.

Relatively higher density of *Galinsoga parviflora*, *Cyperus escalentus, Corchorus pseudocapsularis, Digitaria ternate* and *Convolvulus arvensis* were found as compared to other species of weeds. The previous research results revealed that the former two weed species were the most abundant around MARC (Nigussie, 1995). Many farmers in the central rift valley also reported that *Convolvulus arvensis* is becoming the most problematic weed since recent years (HARC, 1999).

Category of weed flora and weed dry matter (WDM)

The identified weed category and the determined weed dry matter are presented in Table 36. In general the higher populations of broadleaf weeds were observed as compared to the grass weeds. The WDM production was significantly greater under T5 and T4 than the different conservation tillage options (T1, T2 and T3). Higher WDM under conventional tillage than the conservation tillage is in agreement with Teasdale *et al*. (1991) who observed very high amounts of WDM in conventional tillage. In spite of its higher weed number as compared to T1 and T2, the less WDM in T3 indicate the presence of relatively younger plants and likelihood of delayed emergence, which suggest that it may be appropriate to consider 2, 4-D herbicide for less intensive systems of tillage. The higher WDM of grass weeds in T5 probably indicate that proportion of the late emerged broad leaf weeds in the same tillage plot was higher.

Grain yield in the previous four years

Averaged over all tillage treatments, a significant yield differences was observed among the years (Table 37). In 2003, the mean Taaffi grain yields were significantly higher as compared to the mean grain yields obtained from other years. In 2000 grain yields were also higher as compared to the yields obtained either in 2001 or in 2002.

Table 36 Category of weeds and weed dry matter (WDM) at MARC (2004).

	no m^{-2}			WDM ($gm\ m^{-2}$)		
Tillage system[a]	Broad leaf	Grass weed	Total	Broad leaf	Grass weed	Total
T1	55	55	110	129.30	74.20	203.50
T2	47	37	84	141.30	69.00	210.30
T3	100	34	134	112.00	13.10	125.10
T4	69	41	110	159.90	93.00	252.90
T5	182	160	342	138.10	143.30	281.40
Total	453	327	780	680.60	392.6	1073.2

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 1 l ha^{-1} 2,4-D herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no 2,4-D herbicide application, T4 = Conventional tillage with four times plowing and 1 l ha^{-1} 2,4-D spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding.

Table 37 Taaffi grain yield (kg ha^{-1}) as affected by tillage system (2000 to 2003).

	Cropping Year				
Treatment[a]	2000	2001	2002	2003	Mean[b]
T1	1360 bc	340 g	850 de	1570 ab	1030 a
T2	740 def	270 g	1090 cd	1720 a	960 ab
T3	750 def	270 g	720 ef	1560 ab	820 b
T4	800 de	430 fg	890 de	1480 ab	900 ab
T5	980 de	420 fg	700 ef	1310 bc	850 b
Mean[b]	920 B	350 C	850 B	1530 A	

[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 1 l ha^{-1} 2,4-D herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with only 3 l ha^{-1} glyphosate and one time hand weeding, T4 = Conventional tillage with four times plowing and 1 l ha^{-1} 2,4-D spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding. [b] Means within a row (mean of a year) followed by a different uppercase letter differ at the 0.05 probability level. Means within a column (mean of tillage) followed by a different lowercase letter differ at the 0.10 probability level.

The 2002 cropping season was a drought and a famine year with very less amount of rainfall and poor distribution that lead to the most crop stress condition during pollination and grain filling stage and contributed to low yields that affected the life of more than 14 million people in Oromiya. The lower yields in 2001 partly attributed to the low yield potential of the local variety used in that year. Mean grain yields averaged across 4 years were significantly ($P \leq 0.10$) different among tillage systems. A significantly ($P \leq 0.10$) higher mean grain yields were obtained from T1 than T3 and T5. Both T3 and T5 treatments excluded the use of 2, 4-D herbicide and thus, affected by broad leaf weeds in the early crop growth, which was probably resulted in lower yield of the same treatments. In deed, because of its least cost and easily availability, 2, 4-D herbicide is the only widely used chemical among the farmers to control broad-leaved weeds in Taaffi production system. In 2000, Taaffi grain yields were significantly ($P \leq 0.10$) highest in T1. However, in 2001, when farmer's local Taaffi variety was used, T4 and T5 were resulted relatively in the higher grain yields. This is probably suggesting the requirement of improved planting material with improved management to implement conservation tillage practices. In 2002 and 2003 significantly higher grain yields were obtained from T2 than that obtained from T5. In 3 of the 4 years study, 2000, 2002 and 2003, one or all of the conservation tillage systems (T1, T2 and T3) out yielded conventional tillage. The general trend of increasing yields with decreasing tillage frequency suggested that the beneficial effect of conservation tillage on crop production proved its implementation at this site.

Grain yield, straw and aboveground biomass in 2004

There was highly significant ($p<0.01$) differences in mean grain yield between the two cropping system (Table 38); significantly higher mean grain yield was obtained from rotation plots as compared to the grain yield obtained from continuous Taaffi monoculture.

Table 38 Effect of tillage and cropping system on Taaffi grain yield (kg ha^{-1}) in 2004.

Tillage System	Cropping System[1] Rotation	Monocropping	Mean
T1	1225.96 ab[2]	1004.81 bc	1115.38
T2	1048.98 bc	922.40 cd	985.69
T3	1325.59 a	758.87 d	1042.23
T4	1322.63 a	733.95 d	1028.29
T5	1231.33 ab	832.56 cd	1031.95
Mean	1230.90	850.52	

[1] mean grain yields were average of two locations; [2]means followed by the same letter are not significantly different at 10% probability level of significance

The increased in grain yield of the succeeding cereal crop is believed to be due to the contribution of preceding legume crop which improved the soil fertility through atmospheric N-fixation (Kumar Rao *et al*., 1983). An increased grain yield of cereal was obtained in India by a previous crop of legume crop (Ahlawat *et al*., 1981). In agreement with the present findings research results from the central rift valley of Oromiya showed an increased grain yield of cereal by rotating it after haricot bean (Lemma *et al*.,1994).

The differences in grain yield among tillage systems and the interaction of tillage to cropping system were not significant at 5% level of significance. However, at 10% level of probability there was significant difference in grain yield due to interaction of tillage by cropping system (Table 38). The variation in yield was more pronounced between the two cropping system when T3, T4, and T5 tillage system were used. All these systems were produced significantly higher grain yield under rotation as compared to monocropping system. Similar yields were obtained from the two cropping system when the two conservation tillage treatments (T1 and T2) were used. This implies that rotation had more impact on conventional tillage than it did on conservation tillage when grain yield was considered.

Very highly significant differences ($P<0.01$) in mean straw and aboveground biomass yields were observed between the two cropping system (Table 39 and 40). Like grain yield the mean straw (Table 39) and above ground biomass yields (Table

40) that obtained from rotation plot were significantly higher than that obtained from continuous monoculture plot. Results of several experiments in other countries also provide evidence of an increased productivity of subsequent non-legume crops. Previous experience has shown that yields of cereal crops are usually higher when the crop is rotated with some other crop rather than grown continiously (Giri ans De, 1979; Baldock *et al*., 1981; Lemma *et al*., 1994). A yield increase of maize by 57% and total plant dry matter by 32% following pigeonpea was also reported (Kumar Rao *et al*., 1983).

Harvest index (HI)

HI was significantly affected by location (P<0.01), and by the interaction between location and cropping system (Table 41). Harvest index at WARSS was significantly higher than that at MARC. HI varies with cropping system of the two locations and significantly higher HI obtained from monoculture of WARSS than that obtained from rotational plot of the same location, which can hardly justified. Although harvest index is an easy measurement, it is not a reliable indicator of yield and should not be used without at least an understanding of the development of yield (Seetharama and Soman, 1990). HI that was obtained from either of the cropping system at WARSS was significantly higher than that obtained from the corresponding yield at MARC. But there was no significant variation between the two cropping system at MARC.

Table 39 Cropping and tillage system influence on Taaffi straw yield (kg ha^{-1}) in 2004.

Tillage System	Cropping System[1]		
	Rotation	Monoculture	Mean
T1	2438.07 abc	1920.02 cd	2179
T2	2277.99 bc	2283.69 bc	2281
T3	2723.59 ab	1925.14 cd	2324
T4	3022.27 a	1591.27 d	2307
T5	2707.43 ab	1795.76 cd	2252
Mean	2633.87	1903.18	

[1]means followed by the same letter are not significantly different at 1% probability level of significance.

Table 40 Cropping and tillage system effect on biomass yield of Taaffi (kg ha^{-1}).

Tillage System	Cropping System		
	Rotation	Monoculture	Mean
T1	3664.03 abc[1]	2924.83 cde	3294.43
T2	3326.98 bcd	3206.09 bcd	3266.53
T3	4049.18 ab	2684.01 de	3366.60
T4	4344.91 a	2325.22 e	3335.06
T5	3938.76 ab	2628.33 de	3283.54
Mean	3864.77	2753.70	

[1]means followed by the same letter are not significantly different at 1% probability level of significance.

Table 41 Influence of cropping system on Taaffi harvest index at varied location.

Cropping System	Location	
	WARSS	MARC
Rotation	0.358 B[1]	0.291 C
Continuous	0.401 A	0.254 C
Mean	0.379	0.272

[1]means followed by the same letter are not significantly different at 1% probability level of significance.

Tillage and cropping system on some soil properties

The impact of tillage and cropping system on some of soil properties at MARC is presented in Table (42). The amount of soil organic matter and total soil nitrogen was remarkably higher in no tillage as compared to the value on conventional tillage. The soil organic matter content increased significantly near the soil surface (0-15 cm) in no tillage. When values of cropping systems averaged, increases in soil organic matter for conservation tillage over conventional tillage were 0.30 and 0.28% at 0-15 cm and 15-30 cm soil profile depths, respectively. Total soil nitrogen increases in conservation tillage were 0.03% at each of two depths over conventional tillage. Available P results were variable but differences could not be attributed to tillage. Available potassium was generally very high for all tillage system and cropping system. Soil depth and tillage type did not have much effect on soil pH and EC. Soil organic matter and total soil nitrogen remarkably increased in rotation plot than in continuous monoculture plot within the same tillage system. The impact of cropping system was greatly observed in conventional tillage than the corresponding no tillage. This might have been attributed that no tillage had the ability to increase soil nutrients equally in continuous and rotation plots. The continuous Taaffi monoculture had the lowest soil organic matter and total soil nitrogen concentrations under conventional tillage. The C/N ratio of whole soil (C/N = 15.5) was impacted by tillage and cropping system. The average C/N ratio of the no tillage (C/N = 12.75) was lower than the average ratios of the conventional tillage (C/N = 18.32). The C/N ratio for the average of two tillage systems was lower under rotation (C/N = 14.37) than under continuous cropping (C/N = 16.71). However, the lowest (C/N= 11.88) and the highest ratio (C/N = 21.53) were found for continuous cropping under conservation tillage and conventional tillage, respectively. The higher the C/N ratio for the conventional tillage implies the less N nutrients in the soil. Bulk density for continuous Taaffi monoculture was found under desirable category at both 0–15 and 15–30 cm soil depth (Table 42) and was impacted by tillage system.

Table 42 Effect of tillage and crop sequence on soil properties at MARC.

	No tillage				Conventional Tillage			
	Rotation		Monoculture		Rotation		Monoculture	
Soil property	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
OC (%)	0.90	0.90	0.90	0.67	0.80	0.77	0.74	0.56
TN (%)	0.07	0.07	0.07	0.07	0.05	0.05	0.03	0.03
P (ppm)	13.23	11.90	6.66	8.94	9.12	10.81	19.70	11.49
K (meq/100gm)	481.28	409.60	363.88	363.88	471.50	391.02	426.21	497.70
PH (1:2.5)	6.33	6.43	6.33	6.39	6.41	6.40	6.55	6.34
EC (1:2.5)	0.11	0.09	0.08	0.07	0.09	0.13	0.11	0.08
OM (%)	2.05	2.05	2.05	1.53	1.83	1.76	1.68	1.27
BD (g cm^{-3})	-	-	1.16	1.20	-	-	1.09	1.10
Moisture (%, w/w)	-	-	7.42	13.26	-	-	6.68	13.63

Bulk density increased with depth, ranging 1.09 g cm^{-3} at 0–15 cm to 1.2 g cm^{-3} at 15–30 cm. The bulk density of no tillage at 0-15 cm (1.16 g cm^{-3}) and 15-30 cm (1.20 g cm^{-3}) was higher than that of conventional tillage for both soil depths (1.09 g cm^{-3}) and (1.10 g cm^{-3}), respectively. However, there was no indication of compaction as the observed bulk densities were below the ranges that affect crop growth (1.4-1.5 g cm^{-3}) in both tillage systems. This might have been attributed to low effect of animal traction to compact soil. After harvesting it was found that at both soil depths the moisture content of both tillage system was at par.

The effect of tillage and cropping system on some soil properties at WARSS is given in Table 43. Soil depth, tillage type and cropping system have only slight effect on soil total nitrogen, exchangeable potassium and pH at WARSS. Total N was similar for each tillage type and each cropping system except possibly more soil N at the 0-30 cm depth with rotational plot under conventional tillage than with other tillage practices. Available P was generally higher for no tillage and less at greater depth for rotational plot of both tillage systems, this could be due to the relatively immobile nature in the soil and so remains concentrated more near the site of application on the top of the soil.

Table 43 Effect of tillage and crop sequence on soil properties at WARSS.

Tillage System	Depth (cm)	TN (%)	Av. P (ppm)	pH (1:2.5)	EC (1:2.5)	OM (%)
	Taaffi Continuous Monoculture					
No Tillage	0-15	0.13	11.18	8.09	0.08	1.70
	0-30	0.11	11.84	8.26	0.19	1.45
Conventional Tillage	0-15	0.12	11.20	8.16	0.09	1.68
	0-30	0.13	7.36	8.29	0.19	1.42
	Taaffi Rotation (after Haricot bean)					
No Tillage	0-15	0.12	12.40	8.09	0.10	1.72
	0-30	0.12	12.00	8.19	0.20	1.39
Conventional Tillage	0-15	0.12	9.04	7.98	0.09	1.66
	0-30	0.14	7.68	8.12	0.21	1.43

But available P results were variable for continuous cropping in which lower value was obtained in conventional tillage at a greater soil depth (30 cm) while no remarkable difference was observed in no tillage. Soil organic matter was greatly reduced with increment of depth for all tillage system and cropping system. An increase in organic matter gradient generally occurred under conservation tillage, with much of the concentration at the surface and much decreases with depth. However, organic matter is fairly distributed through out the plough layer in conventionally tilled plots.

In agreement with the present findings it has been shown in various studies that conservation tillage can increase soil organic matter (Al-Kaisi and Hanna, 2002). With 8 years of experiment, increases in soil organic matter and nitrogen storage were observed at 0–5 cm soil depth in no tillage (Ortega *et al*., 2002). Conservation tillage is considered the most effective conservation system for improving soil organic matter due to no soil disturbance (Triplet, 1986). This characteristic of conservation tillage is extremely beneficial because surface residue and soil organic matter are left undisturbed, slowing decomposition and maximizing soil organic matter gains. In addition to increased water holding capacity, soil organic matter helps create soil conditions that improve water infiltration and reduce surface runoff. Overall, soil organic matter is a necessary component for improved soil and water quality. It has been well documented that increased tillage intensities can reduce soil organic matter in the topsoil due to increased microbial activity and carbon oxidation (Al-Kaisi and Hanna, 2002).

Economic impact

Total production costs were lower in T3, T2 and T1 as compared to the production costs of T5 and T4. However, gross returns were higher in T1 and T2 (Table 44). Net returns for T1, T2 and T3 were also greater than to that of T5. This could be attributed to greater yields and to lower production costs of the conservation tillage systems.

Table 44 Effects of tillage systems on Taaffi production costs and economic returns[1]

	Tillage System [a]				
Indicator	T1	T2	T3	T4	T5
Grain Yield (kg ha^{-1})	1260	1190	1010	1060	1000
Straw Yield (kg ha^{-1})	4030	4230	4290	4190	4260
Grain (Birr 260 / 100 kg)	3276	3094	2626	2756	2600
Straw (Birr 4 / 100 kg)	161	169	172	168	170
Return (Birr ha^{-1})	3437	3263	2798	2914	2770
Production Cost (Birr ha^{-1})	2568	2539	2478	2664	2576
Net Benefit (Birr ha^{-1})	869	704	320	250	194
Net Benefit (USD ha^{-1})	99	81	37	29	22

[1]average of three years (2000, 2002, 2003).
[a]T1 = Conservation tillage with 3 l ha^{-1} glyphosate and 1 l ha^{-1} 2,4-D herbicide application and supplemented by one time hand weeding, T2 = Similar to T1 except no hand weeding, T3 = Conservation tillage with 3 l ha^{-1} glyphosate and one time hand weeding but no 2,4-D herbicide application, T4 = Conventional tillage with four times plowing and 1 l ha^{-1} 2,4-D spray and supplemented by one time hand weeding, T5 = Conventional tillage with four times plowing and two times hand weeding.

Experiment 4. Agronomic and Perception Analysis in the Existing Conservation Tillage Practices

Site descriptions and demographic information

Oromiya, the land of the Oromos, is amongst the largest with reference to its economy size as indicated by population, geographical area and production in Africa (Gadaa Melbaa, 1988). Oromos, a very ancient race, the indigenous stock, perhaps, on which most other peoples in this part of eastern Africa have been grafted" (Bates, 1979) are one of the most original inhabitants of what is today known as Ethiopia and the Horn of Africa (Prouty *et al*., 1981). The population of Oromiya estimated more than 30 million (World Fact Book, 2005) and accounted for more than 51 percent of the total production (CSA, 2004; ESPO, 1999) in the now day Ethiopia. Out of the 50 nations of Africa only four have larger population than Oromiya. Their language, Afaan Oromo is the third most widely spoken language in Africa - after Arabic and Hausa (Gadaa Melbaa, 1988).

The rural population of Oromiya comprises about 89 percent and the economically active population is estimated at 81% of the 15 to 64 ages group (ESPO, 1999). The export of agricultural products originating from this region such as coffee, hides and skins, pulses and oil seeds make up the lion's share of the country’s foreign exchange earnings. Oromiya has a wide range of agro-ecological diversity that is favorable for producing several varieties of crops. Most of the arable and cultivated land is located between 500 and 2,500 meters. This range of climate is suitable for growing tropical and sub-tropical crops as well as crops of temperate climate. Most parts of the region receive sufficient and reliable rainfall during the main rainy season. It receives heavy rainfall up to 2600 mm in the Western, 680-1700 mm in the middle and about 200 mm in the Eastern and Southern boarder (Girma *et al*., 2001). Areas with erratic rainfall are not more than 20 percent of the region (ESPO, 1999). Due to its favorable climate, Oromiya grows diverse of the crops such as cereals, pulses, oilseeds, vegetables and root crops in order of importance. Cereals occupy an important position in the agrarian economy of Oromiya accounting for 82 percent of each of the cropped area and production (CSA, 2001). Taaffi, maize, wheat, barley and sorghum are the major food crops of Oromiya, of those crops the former three crops accounting for 59 percent of the crop area and 60 percent of the production (CSA, 2001). About 5.9 million tons of crop residues are annually produced in the region with cereal straws accounting for 95 percent and legume haulms for the remaining 5 percent (ESPO, 1999). Maize stover, Taaffi straw and sorghum stover each account for nearly one-third of the total residue. Farm sizes are quite small and average only 1.2 hectare per household. Although three systems of agricultural mechanization (manual power, animal-drawn implements and motorized power) are currently in use, techniques of production involve mostly simple implements, and traction is limited to draught animals. The traditional plough and hand tools such as the hoe, machete, pickaxe, shovel, sickle, etc are the most widely used implements by smallholder farmers. The use of high yielding seed varieties is insignificant and farmers use traditional methods, which are broadcast. In general, land, soil, forest, and water resources of Oromiya and its diverse climatic conditions make it one of the best naturally endowed regions, which considered it the break basket of the country. However, Oromiya's economic potentialities are in stark contrast to the abject poverty of its population and not been harnessed for the benefit of Oromiya due to many political, economical and social factors. Almost 90 percent of the population lives off the land eking out miserable existence with an abysmally low standard of living (ESPO, 1999).

The three administration zones of Oromiya, namely East Shoa, Jimma and West Shoa, where the present study was conducted, conservation tillage practices have been widely exercised on different crops and cropping systems. In three districts of East Shoa zone (*Ad'aa, Lume* and *Bosat*) Taaffi based cropping system is predominantly practiced and demonstration of Taaffi based conservation tillage also widely carried out. Where as in two districts of Jimma (*Omonada* and *Mana*) and one district of West Shoa (*Bakko-Tibbe*) conservation tillage demonstrations have been relatively widely done on maize as compared to other zones and on other crops.

Eastern Shoa zone

Eastern Shoa is one of the 12 zones in Oromiya. There are 1.8 million people in the zone; 72% is living in rural areas, the rest live in urban areas. The area of the zone covers 1.4 million ha and the land-use consists of: 11.2% covered by water, 38.4% agricultural land, 14.3% used for grazing, 14.5% forest, 3.8% not cultivated. The altitude ranges from 900 to 2400 m above sea level and the annual rainfall ranges between 700-1400 mm (SPM, 1999). The farming systems in the area consist mostly of mixed farming, with only one district in the lowland being dominated by semi-nomadic activities. In the mixed farming system, crops such as maize, Taaffi, wheat, sorghum, haricot bean, barley, pulses, and fruit and vegetables are cultivated. The present study in the three villages (*UUdee* of Adaa, *Dibandiba* of Lume and *WARSS* of Bosat districts) of Eastern Shoa zone included about 32 farmers. The study revealed that those who experienced conservation tillage practices have several years of experiences in farming (15-44 years) with all being in the active age range of 30-60 years old. Only, 46.2% can read and write but with low grade of formal education (only 15.4% with 5-7 grade). About 15.4% of the household headed with female and the rest 84.6% male headed with one wife. Although there is a large amount of cultural variation, small farmers in the three districts, have some general characteristics. The average farm size varies 0.5-3.5 ha per family. The average family size is 2 – 10 per household. About 53.8% have more than two oxen and 92.3% have at least one ox. About 92.3% of the farmers characterized their land as not bad and the major crops during 2003/2004 cropping year were Taaffi, Wheat, haricot bean and sorghum. However, only 7.7%, 53.8% and 15.4% of the respondent could produce enough crops for yearly, 3/4th of the year and half of a year for food and income generation, respectively while the remaining 23.1% had enough produce for less than half of a year. Out of the 32 interviewed farmers (ethnically 30 being Oromos and 2 Amharas) only the two Amhara farmers had improved agricultural implements such as tie-ridger and planter, in spite of their closeness to the agricultural research centers. Other farmers used traditional implements such as Maresha, Hoe, Pickaxe, and Machete to grow crops. Almost all of the farmers responded that labor is not enough during crop production particularly at weeding and harvesting time out of which 76.9% stressed as labor is a big problem at all times while 23.1% responded that it is a problem at some times. Although labor is considered not enough for crop production all except one farmer responded that they do not want either to adopt or to continue with the new technology of conservation tillage practices with the present cost of herbicide (Birr 70-80 per litter round up). However, 30% of the farmers who exercised introduced conservation tillage for more than three years wanted to continue with the technology on part of their farms if the present cost of the chemical reduced down to Birr 40-50 per litter. If the roundup cost reduced down to less than Birr 40 all farmers responded to continue conservation tillage practices.

Soil types and land preparation

Farmers categorized the soil in to three types based mainly on color of the soil and from management point of view. Accordingly, *Koticha*, *Carrii*, and *Gonboree* are the major soils in the three districts (Table 45).

Farmers view

Black soil called 'Koticha' is mainly used for Taaffi and chickpea while red soil called Gonboree is allocated for Taaffi and wheat production but not used for chickpea production since it is easily dried and has no residual moisture; the third “Carrii” black soil mostly has high sand content thus why it is called carrii meaning pure. The latter is exposed for drought since its water holding capacity is very less. Water logging is occasionally occurring mainly on flat 'Kotichaa' black Vertisol. Yields obtained from different soil types ranges from 800-2000 kg ha^{-1}. According to farmers about 1400, 1300, and 1000 kg ha^{-1} average Taaffi grain yield could be obtained from Ganboree, Koticha, and Carii soil, respectively. The relative productivity of soil is based on rainfall pattern and distribution. When there is sufficient and fair distribution of rain, Koticha soil is the best yielder. When rainfall is unusually higher and with the extended period, Gonboree soil is better yielder due to its higher percolation. Carii (Cabaree) is highly affected by content of sand, when sand content is higher it is the least yielder but when the soil is found with slightly flat land (Bolee soil) it is some what good yielder. Comparing conventional tillage to conservation tillage, farmers experienced much more moist and swelling of the Koticha soil when they walked in their conservation tillage plots than the corresponding conventional tillage of the same site.

<u>Table 45</u> Farmers' evaluation on some soil properties and characteristics.

Parameter	Koticha	Carri	Ganboree
Color	Black	Brown (mixed)	Red
Slope	Flat	Medium	Sloppy
Percolation	Very less	High	Very high
Soil moisture	Very high	Less	Very less
Erosion	Less	High	Very high
Water logging	Very high	Less	No
Vegetation cover	Mixed	Argemone mexicana	High A. mexicana
Fertilizer (urea-dap, kg ha^{-1},)	100-100	75-100	50-100
Crop	Cheak pea, Taaffi	Wheat, Taaffi	Taaffi, wheat
Cropping	T-T-T-P-T-T-T T-T-T-W-T-T-T	T-W-T-W W-W-T	T-T-W T-T-B
Soil fertility	Very high	Medium	Less
Constraints	Logging	Deficit, weed	Deficit, erosion
Workability	Not good	Good	Very good
Cracking	Very high	High	No
Plowing	4-5 times	3-4 times	3 times
Good season	Less rainfall	High rainfall	High rainfall

T = Taaffi, W = Wheat, P = Pulse, B = Barley; dap = diammonium phosphate.

<u>Expertise view</u>

Black or Koticha soils are comparatively fertile and have clay contents between 35 and 60%. In the present study Koticha soil types constitutes from clay loom to clay soil types with the clay content about 48%. This high clay content and type of clay largely determine the specific physical properties of these soils. Due to the high clay content, the water holding capacity is high, the infiltration rate is low, and the internal drainage is low. This often leads to water logging during the main rainy season. At low soil moisture levels these black soils shrink, forming cracks up to 10 cm wide, and they became hard. At higher moisture level the soils become wet and swell and then plastic and cohesive. The soils are heavy thus, hard to work manually. Red (Gonboree) soils are common at relatively higher altitude, and on slopping, eroded terrain. This type is well drained with a low fertility level. Constitutes more than 50% sand; it is sandy loam soil type. Red soils have the potential to be suitable for a variety of crops though their potential is not as high as that of the brown soils. Brown (Carii) soils have a low clay percentage as compared to Koticha, relatively well drained but locally prone to water logging. These soils are mostly loam in type with 30% silt and 24% clay. Have favorable fertility parameters and thus, have good capability for growing a variety of crops. The data in textural class and its corresponding local name in Table (46) support the perception of farmers and the attitudes of expertise in that Ganbore constitute high sand proportion while Koticha soils composed of high clay content and Carii soil types are in between the two.

Farmers prepare seedbed using an ox-mounted single plough (*Ginddi* and *Ordda*); the tip is known as the *maresha* and the wings, *babatee*. The number of tillage depends on the crop to be grown, the field type, the soil type, the number of oxen owned, the start of rain and the distribution pattern. Farmers seem to have established a desired procedure and quality of tillage to be followed for a given crop and cultivar. Generally the same procedure for land preparation is carried out in the three districts on the same soil type. Before starting land preparation, farmers test the conserved soil moisture, known as *nish*, by inserting the maresha to a depth of approximately 25-30 cm. If the soil sticks to the point, it means soil moisture is sufficient to start land preparation. They may also test soil moisture by hand. If the soil binds together when held in the hand then the soil has good *nish*. Then they will not sow immediately but instead wait for the *nish* to reduce a little. The conventional procedure for Taaffi seedbed preparation depending on the coming of rain (April to May) is 4-5 times plowing but if the rain is late only 3-4 times. The conventional operations and sequence of activities with their local descriptions for Taaffi production are given in Table (47).

Table 46 Soil textural class and its local name around Adaa and Lume district.

Proportion (%)				
Sand	Silt	Clay	Textural class	Local name
53	36	12	Sand-Loam	Ganboree
46	30	24	Loam	Carrii
28	24	48	Clay	Koticha

Table 47 Cultural practices and period of operation for Taaffi production.

Operation	Local description	Month of Activities
1st tillage	Baqaqssa	April 8-25
2nd tillage	Irra-deebii	May 8-23
3rd tillage	Keesa-deebii	24-29 May
4th tillage	Dirdaroo	June-July
5th tillage	Bulleessu	July 18
Planting	Facaasuu	July 20-1 August (white Taaffi-red Taaffi)
Fertilizing	Xaa'oo keenuu	July 20
1st weeding	Arama duraa	August 5-10
2nd weeding	Arama lamesso	Sept 11-26
2, 4-D	Sumii Arama	August 10
Threshing plot	Ofdii qopheesuu	September-October
Harvesting	Aamuu	October-November
Threshing	Dhaa'uu	December-January

The plowing frequency for Taaffi production depends on soil types. Taaffi plowed 5, 4, and 3 times for Kotichaa, Carrii and Gonbore soil types, respectively. If the rain comes in February 1st, 2nd, 3rd and 4th plowing is executed on March, April, May and June, respectively. Third and fourth plowing is done for the purpose of moisture conservation. The first land preparation usually performed at the beginning of March is locally known as *Baqaqssa* (meaning splitting). This first tillage operation encourages weeds to emerge and increases the moisture holding capacity of the soil. In general, farmers reported that dry plowing is not preferred as the soil forms clods and weed seeds are less exposed and may become a potential problem. Hence, farmers normally wait for the first 2-3 rain showers before they start tilling their fields. The second plowing known as *Irra Deebii* (second tillage) is performed perpendicular to the first cut to help destroy the emerging weeds and to retain soil moisture. Perpendicular to the second, the third plowing is carried out. The fourth tillage operation called *Dirdaroo* opens up the furrows and serves to warm-up the soil and also to conserve soil moisture if the rains are good. It is performed using the wooden wing of the *Orddaa* known as *babatee*. After harvesting water, farmers plough their fields to close the furrow and reduce evaporation. Farmers then wait for rains to cease before sowing, so that the seedlings will be able to grow in relatively weed free environment. A fifth plowing may or may not take place based on soil types. Farmers may reduce or increase the number of land cultivations not only in response to the season, but also because of other constraints such as access to oxen and labor. Generally, farmers use urea and diammonium phosphate (dap) fertilizers for their crop production particularly for Taaffi and wheat. Fertilizer rate was 100-100 kg urea-diammonium phosphate fertilizers ha^{-1} for soils considered non-fertile, while 50-100 kg urea-diammonium phosphate ha^{-1} for relatively fertile good land. By mixing both fertilizers they broadcast during planting. This has been adopted through farmers' trial and errors experience; neither recommended from ministry of agriculture nor from any research center. But they need proper proportion of such mixing from both organizations. Farmers recognized that some inputs such as Round up (Birr 70-80/l), fertilizer (Birr 355 for 50-100 kg urea-dap ha^{-1}) is too expensive to afford. A Taaffi variety DZ-Cr-37, which was released in 1984, is grown almost by all farmers. Farmers usually control weeds before sowing by practicing as much tillage as possible, assuming there are rains in April and May and if resources (access to oxen and labor) are not limiting. Some farmers may slash and burn weeds before they begin tillage. Farmers who have the resources to plough their Taaffi land six or seven times are able to control weeds better prior to sowing. Taaffi is weeded two weeks after sowing. Farmers who could only do two cultivations have to hand weed at least three times. Other farmers may only need to weed once or twice. According to farmers frequent tillage is advantageous to control weeds, improve air circulation and fertility, and for good crop emergence but perceived as it is time consuming and labor requiring activity. Almost all farmers used 2, 4, D herbicide since it is cheap but effective to control broad leaf weeds.

Farmers' attitude towards conservation tillage

Farmers perceived that conservation tillage is easy to implement and needs to open land only for seed placement and fertilizer application. However, since the land is left untouched it is very rough to plow once even for seeding particularly when soil moisture is less. A pair of oxen can plow $1/4^{th}$ of the hectare in 8 hours during the last land preparation in conventional tillage but conservation tillage needs 12 hour to plow once. Continuous Taaffi after Taaffi for three years or even more years is a common practice. Regarding time, they perceived that conservation tillage saves time and labor but it is costly. Farmers don't take in to cost account their family labor, but to implement conservation tillage particularly in the first phase, input is a must which farmers unlikely to have afford. In general they need location specific fertilizer rate and management of improved variety to be reassessed.

Land ownership

Farmers are not sure of their land and always in doubt that the land may be sold to investor. There are conflicts in land use resulting from competition among different systems. A common competitive situation is between agricultural and urban/suburban development in the three districts. Most urban centers in the East Shoa zone are established on fertile agricultural land. It was observed that during the survey made on agricultural constraints (2004 year) particularly around the central Oromiya where cereal production shows number one priority, suburban development are expanding at the expense of agricultural development. Farmers around these zones driven off from their lands and some without prior consultation (e.g., Aqaaqii, Ada'aa, Lume, Burraayyu, Sabbata and Sandaafa districts) and with no compensation; those with compensation were allocated on depleted soil or more marginal lands conversely where construction could have been done. This being the case almost all of the farmers responded that they do not want to practice any medium and log term strategies in resource conservation, and do not need to plant some plantation crops and showed no need to invest even on short-term crop rotation cropping systems. If they are sure of their land they ought to do a forestation, soil conservation and plant some perennial crops.

Problem Identification and Participatory matrix ranking of cropping constraints

Separate groups of about 13, 13 and 6 farmers from Adaa, Lumee and Bosat identified 7, 6 and 5 major Taaffi production constraints, respectively. The results of participatory ranking for Taaffi crop production constraints that were carried out in the villages of Udee (Adaa), Dibaandib (Lumee) and WARSS (Bosat) are presented in Table (48). The numbers in each cell are the total amounts of seeds put in that cell by all the participating farmers. Row sub totals are shown to facilitate inter comparison among the constraints of the three districts. According to the total ranking (total column), moisture deficit due to unreliability of rainfall and uneven distribution is perceived as the number one Taaffi cropping constraint for all farmers in the three districts. Farmers perceived that the rainfall distribution is more important than the amount. During planting and at flowering stage the amount and distribution of rainfall is unreliable. Because of such event most of the time farmers could not produced enough food for their family for year round. Farmers express their perceptions of rainfall in the crop varieties they plant and the amount of crop they harvest. They described 2001/2002 and 2003/2004 as bad years.

Table 48 Participatory ranking for Taaffi production constraints in East Shoa zone.

Constraint	District			Total	Ranking
	Adaa	Lume	Bosat		
Moisture deficient	10	10	10	30	1
Water logging	9	7	-	16	5
Poor soil fertility	8	6	9	23	2
Rust disease	7	8	-	15	6
Insect pest	4	9	5	18	4
Weed pest	6	5	8	19	3
Soil erosion	5	-	-	5	8
Labor shortage	-	-	7	7	7

For instance, in the year 2002 almost no yields were obtained and in the 2003/2004 cropping year most farmers (86%) produced only 600 kg out of the expected 1200 kg of Taaffi per hectare. This is in agreement with several researches; a finding that revealed unreliability of rainfall is number one crop production constraints particularly during planting and grain filling stage in the central rift valley of Oromiya (Kidane *et al*., 2001). According to farmers from the three villages, crop failure and food shortages are caused by a change in the nature of rainfall. Rains have become erratic and contributing to crop failures. Farmers believe that the change in rainfall is caused by deforestation and mismanagement of natural resources. They expressed their fear this will continue in the coming years too. They describe good years as good rains suitable for crop production. In good years farmers could harvest enough crop to last for the whole season. Farmers indicated that now days there is a crop failure every two to three years contrary to the common long years believe that crop failure occurs eight to ten years.

For other constraints the one, which was mentioned as the second important in one district, was mentioned as third or fourth in other districts. For instance, Adaa farmers ranked water logging second, while Lumee and Bosat farmers' ranked insect and poor soil fertility problem second, respectively. Poor soil fertility (depletion of nutrients) was ranked as the third major problems for Adaa farmers, while rust disease, which is very similar to matured (red) grained pepper has been recently occurred was the third major problem confronting crop production particularly during flowering period in Lumee, and weeds were ranked third major constrains for Taaffi production in the districts of Bosat. There is striking difference among the districts: water logging and rust disease are seen as no problems at all for the Bosat district farmers while as a major problems for farmers of Lumee and Adaa districts. This appears logic given the higher flat lands with Vertisol soil and thus higher water logging in Lumee and Adaa. During participatory problem identification only Bosat farmers mentioned labor as a major problem. However, during group discussion labor was mentioned as one of the major constraints for crop production during harvesting.

Practically, in the three districts with out hired labor the harvest could not be successfully accomplished.

Although the effect of insect on Taaffi production is relatively lower as compared to other cereal crops nowadays insect also became problematic. Farmers perceive that this insect has been prevalent since 1991. It is very minuet that cannot be easily controlled. Farmers complained that crop rotation could not been a remedy for such insect although they don't know the source. Farmers of Dibandiba village (Lumee district) reported that with the last three to four years the insect problems has become very significant where by some times farmers could not get their produce. They categorized these insects in to three types based on their color. These are green, black and gray. According to them the gray type is very difficult to control as it has protecting shale like structure on its body and thus, even the chemicals cannot control this insect. It starts feeding on September on the stalk from inside and finally the crop die. It feeds during the night and hidden during the day making the control mechanism very difficult.

According to farmers weed is not out of their control on Taaffi field since they used 2, 4 D herbicide and others pulled by hand. Heavy rainfall is occurred once in July and August per annum leading to flush of weeds. However, farmers are aware of weeding operation that it is time consuming and significantly affects yield of crops if left untouched in the field. Taaffi needs three times weeding if no herbicide is used. If 2,4 D is used only one time weeding is necessary. They need herbicide that control *Setaria pumila*, locally known as “Miggira Saree”. According to their belief, frequent tillage is advantageous for weed control and for good emergence of crops. The most important weeds identified by the farmers and their rankings are given in Table (49). According to the row ranking the three most important weed species are *Setaria pumila*, *Xanthium strumarium* and *Sorghum arundianaceum*. *Setaria pumila*, which is difficult to control by hand due to its resemblance to Taaffi, is by far the most constraint for the production of Taaffi in all areas. Both *Setaria pumila* and *Xanthium strumarium* were mentioned as notorious weeds in the three districts. However, there were perception differences in responses for what they considered the most important weeds that constrained their crop production. For instance, *Setaria pumila, Convolvulus arvensis*, and *Xanthium strumarium* were ranked by Adaa farmers as first, second and third most important weeds. For Lume farmers, *Setaria pumila, Sorghum arundianaceum* and *Amaranthus spinosus* are the three major weeds that affect Taaffi production. *Parthenium hysterophorus*, s*etaria pumila,* and *Sorghum arundianaceum* according to their importance are the major weeds for Bosat districts. Farmers perceived that weeds such as *Argemone mexicana*, *Xanthium strumarium* and *Xanthium spinoses* are very spiny and difficult to pull by hand, once established even difficult to control by chemicals. However, the former weed is emerged at the late growing period when crop nearly reached maturity and immediately after harvesting they flush out. Because the bare land covered by such weed and protected from wind erosion during the dry season farmers have positive attitude towards this weed. They perceived also that evaporation is low under the soil covered by such weed thus the soil stayed moist and the formation of clogging by tillage operation is minimized. The effect of weed is greater in August and September. Recently introduced weeds are *Parthenium hysterophorus* and *Convolvulus arvensis* (white flowers binding weeds). Farmers perceived that the source of *Parthenium hysterophorus* weed is modern road construction as it is widely seen along the main road. The *Convolvulus arvensis* weed is found mainly around the then occupation of Italy camp.

Table 49 Participatory ranking for the most important weeds in East Shoa zone.

		District				
Weed Species	Local name	Adaa	Lumee	Bosat	Total	Rank
Setaria pumila	Miggira Saree	10	10	9	29	1
Guizeta scabra	Cuqii	6	-	-	6	8
Convolvulus arvensis	Xaaxxo	9	-	-	9	6
Xanthium strumarium	Baandaa	8	7	5	20	2
Amaranthus spinosus	Raafu Oromoo	7	8	-	15	4
Xanthium spinoses	Xoreseeraawit	-	-	6	6	8
Sorghum arundianaceum	Qiloo	-	9	8	17	3
Parthenium hysterophorus	Faaramsiisaa	-	-	10	10	5
Argemone mexicana	Nechleebash	-	-	7	7	7
Erucastrum arabicum	Senaafich	-	-	4	4	10

Copping strategies for agricultural production constraints

In WARSS of Bosat, Dibandiba of Lumee and Uude of Adaa, the community and individual households have a number of strategies to cope with moisture stress. To over come the problem of water stress farmers used their local knowledge. One means is changing crop and variety sequence of planting. As a solution for moisture stress due to insufficient rainfall, they planted vegetables around riverbank and tried to use supplemental irrigation. If the rain comes late, farmers' plant pulses such as chickpea and haricot bean instead of Taaffi and wheat, and some farmers also sow early variety of Taaffi such as red Taaffi. Some farmers exercised dry planting for some crops like sorghum and maize on limited plots of land 6-8 before rain expectation.

Erosion is at its most impact during June and early July when the land is bare and is not covered by emerged crop. Plowing against the slope is the only means farmers used to control erosion. To remove water logging opening ditch from the upper side of the land is exercised but not intensively used since most of the land is flat. According to farmers' perception crops exposed to water logging shows stunted growth and the color of the leaf changed to yellow indicating symptoms of nitrogen deficiency so that additional 25 kg of urea is given by farmers. When the land becomes too rough and compact to plow (locally called as *Fafee* land) they hired tractor by Birr 260 to plow a hectare of land. They do sub soiling after which twice oxen plow practiced to make the seed bed suitable for crop emergence. Fertility is improved with rotation of pulse crops particularly chickpea and haricot bean. Chickpea is mainly used as a crop rotation to rejuvenate the soil fertility but farmers around that community not widely used crop rotation fearing that the land may be allocated for other purposes by the government. Animal waste is rarely utilized for adding nutrient to the field. Although they know the importance of manuring, animal dung is mainly used for fuel purpose and sold for the same, the remaining dung used for the field nearest to the dwellings (homestead). The average amounts of cattle an individual owned is about 3-5 and this amount is very minimal to apply waste utilization of the cattle on their field. Based on the fertility of the soil 100-100 kg ha^{-1} urea-dap fertilizers applied to both crops. This blanket recommendation is recently implemented (only one year) as opposed to 50-100 kg ha^{-1} rate used for several past years (for more than 25 years) for every soil types of continuous Taaffi or wheat cropping system. When chickpea was considered as precursor crop only 50-100 kg urea-dap per hectare is applied. The same rate is also applied for the soil considered relatively fertile. For all weeds the major control measure is hand weeding followed by 2,4 D herbicide. Farmers perceived the problem of rust is remarkable on dry soil and when there was no sufficient rainfall. To prevent rust farmers experienced planting crops on moist soil. They believed yearly planting of new seed of crop reduces to some extents the problem.

Community sharing arrangements

To over come the problem of labor shortage, it is evident that social sharing arrangements for labor and oxen are extremely important in the community and hence the livelihood system. Many households rely on the social networks through which these sharing arrangements take place as this means they have a wider pool of assets to draw from. *"Daboo"* which is a practice of mobilizing community labor has significant importance in alleviating labor shortage. At peak times in the agricultural year, or when a farm household is short of labor, they call on some of their community members to volunteer their labor for completing land preparation on time, weeding crops like Taaffi and harvesting, transport and threshing crops. Farmers offer the laborers with food, drinking water and local behaverage. Such an arrangement is vital for households who cannot afford to pay for hired labor. In general, farmers need due research attention for the crop to build up resistance to disease, pest, and abiotic factors. The farmers also need a combination of technologies that conserve water and soil accommodating their experience such as *Dirdaroo* (plowing land side to side to conserve water) and sequence of crop planting.

Changes in soil properties and advantages obtained from conservation tillage

The effects of conservation tillage on soil chemical properties were apparent after a short time (Table 50). The initial soil chemical properties data were obtained only for WARSS site. At this site, after five years, the pH of the soil at 30 cm depth under conservation tillage was slightly lowered from 6.64 to 6.58 compared to 6.34 under conventional tillage when an annual rate of 46 kg N ha^{-1} was applied. Total soil nitrogen, available phosphorus and exchangeable potassium were increased in both tillage systems probably because of continuous urea and dap fertilizer uses. Available phosphorus was high under conventional tillage at both sites. Probably because phosphorus is made insoluble in the soil, there is very little movement from the point of application thus, lowered at higher depths (> 20 cm) in conservation tillage. Study by Singh *et al*. (1966) showed that uptake of fertilizer phosphorus applied to the soil surface was greater than when the phosphorus was mixed with the soil. Apparently this method is used successfully by most conservation tillage farmers resulting in high levels of phosphorus at the soil surface but declined rapidly with depth.

Table 50 Changes in soil properties under conservation and conventional tillage systems.

Soil parameter	2000	WARSS (2004)		Adaa (2004)	
	Initial	Conservation	Conventional	Conservation	Conventional
N (%)	0.051	0.085	0.062	0.095	0.050
P_2O_5 (mg kg^{-1})	9.466	14.420	19.438	8.197	10.930
K (mg kg^{-1})	271	633	597	296	378
pH (1:2.5)	6.64	6.580	6.340	6.840	6.340
OM (%)	1.02	1.700	1.240	1.900	1.000

Organic matter content was significantly higher under conservation tillage both at WARSS and Udee sites. The higher organic matter is probably associated with retention of good soil structure.

Jimma zone

Located in southwestern Oromiya, Jimma zone consists of more than 2.6 million populations with 19300.5 km^2. The zone found between 880-3340 m above sea level. The thirteen districts in the zone mainly categorized in 20.5, 64.6, and 14.9% as high land (*Baddaa*), mid altitude (*Badda-Daree*) and low land (*Gamoojji*), respectively.

Omoo Nadda district

Omoo Naaddaa, one of the thirteen districts in Jimma zone, is located 72 km southeast away from Jimma town and 301 km southwest far away from Finfinee (capital city of Oromiya). It is found at latitude of $7^0$8'-$7^0$49' N and longitude of $37^0$00'-$37^0$28' E. The range of the altitude in the district is between 880 m (*Odaabulii*) to 3344 m (*Mayii guddo*) above sea level. It comprises 13.58% low land 62.76% mid land, and 23.63% high land. Maximum and minimum temperature is 26.8 and 11.8^{0}C with annual rainfall ranges between 900-1600mm. The population estimated 243717 with the land area of 1589.4 km^2 (158,940 ha). *GilgalGibee*, *Beeyyam*, *Naaddaa Guddaa*, *Naaddaa Xinna*, *Oomoo*, and *Gojab* are the known rivers used for different economic purposes. Cereal occupies 89.8% of the total crop production out of which 39.5%, 33%, and 14.7% occupied by maize, Taaffi, and sorghum with grain yields of 2700, 760, and 750 kg ha^{-1}, respectively.

Manna district

Manna is 18 km far away northwest of Jimma town and consists of 47981 ha of land with altitude of 1400-2000 m. Annual rainfall is 1467 mm, with 24.8 and 13.1^{0}C maximum and minimum, respectively. About 5.3 and 4.4 member/household at rural and town found, respectively in the district. About 72% of the total households, their livelihood depends on coffee production. Land is occupied by 31.96% perennial, 19.7% annual, 2.65% forestry, 2.7% grazing land, 37.7% cultivated land, 0.7% uncultivated land. Farmers in both districts of the specific research sites are at active agricultural age of 25-55 years (90%) with the 80% being at the farm experience of 20-35% years. Although 50% of the respondent could read and write only 20% have formal education of 3-6 grades. About 70% and 30% of the household is male headed with one and two wife, respectively. The family size ranges from 2-14 of which 70% of the farmers have 8-14 family size. The farm size varies from as low as 0.5 to greater than 2.5 ha, and 50% of the farmer have more than 2.5 ha of land.

Cropping system

In most cases farmers around the two districts have followed one or more of the following cropping sequence: maize-maize-Taaffi-maize-maize (this is most widely used); maize-maize-pepper-sorghum-Taaffi; maize-maize-sorghum-pepper; maize-maize-pepper-maize; and maize-maize-sorghum-Taaffi-maize. Because of fear in yield reduction, farmers never use more than two years maize after maize cropping. What so ever, maize is never grown after sorghum. This is because farmers perceived sorghum is heavy nutrient feeder so that Taaffi is the best follower.

Participatory problem identification and matrix raking

Crop production constraints that were identified and the average results (because of similarity in ranking) of matrix ranking of the two districts during the study are presented in Table (51). Farmers identified the total of six crop production constraints. As number of seeds provided for each crop was equal, column subtotals are not shown. Hence, to facilitate inter comparison between the constraints and between the different crops only row sub totals are shown. According to the row totals, poor soil fertility perceived as the number one cropping constraint (more seeds were added in the corresponding square to show the more serious the constraint is), followed by weeds and moisture deficit. For maize production and productivity poor soil fertility, moisture deficit and insects are the three major constraints. Poor soil fertility, weeds and soil erosion are the three major constraints for Taaffi production.

Table 51 Participatory matrix ranking of cropping constraints around Jimma zone.

Constraints	Maize	Taaffi	Sorghum	Sub-total	Rank
Poor soil fertility	6	6	2	14	1
Weeds	2	5	6	13	2
Soil erosion	1	4	3	8	5
Moisture deficit	5	2	4	11	3
Insects	4	1	5	10	4
Disease	3	3	1	7	6

These appear logic given the higher rainfall and rugged topography of the area where Taaffi production is done. Farmers perceived that due to poor soil fertility maize and Taaffi productivity significantly affected than sorghum crop. For sorghum, weeds are perceived as priority cropping constraint followed by insects and soil moisture deficit. In spite of high rainfall in the area (900-1600 mm for Naaddaa and 1467 mm for Manna) moisture deficit is perceived as one of the priority constraints for maize and sorghum production in both districts. In vast proceedings and literature it has been indicated that Jimma zone and its surroundings is categorized as reliable and high rainfall areas. But for farmers the unreliability of rainfall in its distribution particularly during flowering and grain filling stage is considered as top priority to produce maize and sorghum. Despite the fact that poor soil fertility perceived number one constraints all farmers considered their land is not bad in fertility status. However, the findings of Tesfa (2003) showed that the area is found to be at lower fertility level because of continuous maize monocropping and unabated soil erosion. Advantages and changes in soil chemical properties due to conservation tillage systems are presented in Table (52).

It is indicated that some of the soil properties from continuous monocropping undisturbed soil around the experimental site showed deficient or lower. A great advantages and remarkable increase in organic matter, total nitrogen, available phosphorus and exchangeable potassium were observed due to conservation tillage in both sites. Tesfa (2003) reported that retained crop residue on the soil surface checked soil erosion and the decomposition of crop residue lead to organic matter build up. Further more, during group discussion it was pointed that fertilizer cost, availability,

<u>Table 52</u> Soil properties change in different tillage systems at sites of Jimma zone.

Soil properties	Cropping Years		
	2000*	2004	
Manna (15% slope)			
	Undisturbed	Conventional	Conservation
pH (1:2.5)	5.0	5.2	5.0
OM (%)	2.34	2.13	2.50
Total N (%)	0.230	0.211	0.250
Available P (mg kg^{-1})	3.20	5.54	6.85
Exchangeable K (mg kg^{-1})	330	355	430
Omo Naaddaa (10% slope)			
pH (1:2.5)	5.5	5.48	5.45
OM (%)	2.15	2.13	2.37
Total N (%)	0.170	0.150	0.191
Available P (mg kg^{-1})	5.60	7.99	9.81
Exchangeable K (mg kg^{-1})	190	200	370

* Source Tesfa (2003)

and marketing are the main problem. In spite of expensiveness (dap, which was Birr 260 and urea Birr 135), these fertilizers were not available either at market or from ministry of agriculture and most farmers planted maize in 2004 main cropping season with out fertilizers and they fear this will affect the yield significantly. About 60% of the respondent could produce enough food for only one year and 40% for $3/4^{th}$ of the year. For 20 and 80% of the respondent labor are not a problem and only some times a problem, respectively. Weed is perceived one of the major bottlenecks to produce crop production in the area. There are different weed species in the experimental sites and only the major weed species identified by farmers at Naaddaa and Manna is summarized in Table (53).

The weed flora is similar at both locations probably because of the similarity in existing climatic conditions. Based on row total ranking the major weeds confronting the production of maize crops at both districts are *Guizota scabra*, *Ageratum convoides*, *Commelina benghalersis* and *Galinsoga parviflora*. For Omoo Naaddaa *Guizota scabra*, *Commelina benghalersis* and *Galinsoga parviflora* are the three major weeds significantly affect maize production. *Guizota scabra*, *Ageratum convoides* and *Elucine indica* weeds are the most important weeds affecting maize

Table 53 Participatory ranking of major weed species at two locations of Jimma zone.

Weed species	Omoo Naaddaa	Manna	Sub total	Rank
Guizotia scabra	10	10	20	1
Ageratum conyoides	5	9	14	2
Commelina benghalersis	9	4	13	3
Galinsoga parviflora	8	3	11	4
Elusine indica	-	8	8	5
Cynodon spp	-	7	7	6
Polygonum spp	7	-	7	6
Digitaria spp	-	6	6	8
Nicandra physaloides	6	-	6	8

growth and productivity at Manna. The major weed identification and ranking of farmers had similarity with the research findings of Tesfa (2003) who found *Commelina benghalensis*, *Galinsoga parviflora* and *Guizota scabra* as the major weeds at Naaddaa while *Ageratum conyzoides*, *Guizota scabra* and *Elucine indica* as the major weeds at Manna. Farmers indicated that weeds such as *Digitaria* and *Cynodon* spp have recently became problematic weeds in their farm. Because of the existing favorable environment coupled with saturated weed seed bank in the soil, weed emergence and growth is fast, dense and continuous for a prolonged period of 8-9 months resulting in severe weed competition in these districts (Tesfa, 2003).

About 60% and 20% of the farmers wanted to adopt or continue the conservation tillage technology if the chemical is provided freely and the cost reduced by half, respectively. The remaining 20% did not want either to continue or to adopt the technology as they have ample labor and their land is also considered fertile and not degraded. These farmers have a large number of cattle and more than three hectare of land. Un like East Shoa zone they use animal dung for manuring purposes.

Copping strategies

Farmers usually grow sorghum when there is shortage of rainfall and when fertilizer is not accessible. Criss-cross plowing is used mainly to control weeds. *Babbaqaa* is inter-row cultivation used by farmers to control weed, water logging, for good air circulation and moisture conservation. Crop rotation and manuring used to rejuvenate soil fertility.

West Shoa zone

Bakko-Tibbe district

Farmers in the specific on-farm research site were between the ages of 28-60 years (63.6%) about which 91.9% have more than 10 years farm experiences. Some can read and write (44.5%) out of which only 9.1% have had greater than six grades. The entire household is headed with male and 90.9% are with one wife, and 9.1% with two wives. Average family number is 7 out of which 4 and 3 are female and male, respectively. However, about 55% of the farmers have 7-9 family members. About 72.7% of the farmer have greater than 2.5 ha and 81.8% have greater than 5 cattle. Although all farmers use fertilizer for their crop production only 9.1% of the farmers have enough produce for their family and to generate income year round while for the 45.5% of the farmers the produce is enough only for 3/4th of the year, and the remaining 45.4% have enough produce for ½ a year. About 60% of them have labor problem for farming activities, and farmers have labor shortage particularly during weeding (20%), planting (24%) and harvesting (16%). Only 20% said that they have sufficient time to plow, while for the remaining (20%) only some times they have time constraints.

Agricultural activity

All farmers involved in both crop and livestock production; and the most important crop are maize followed by Taaffi and pepper. The crops are important both for food and to generate cash. For maize, BH660 is the sole maize variety grown from 2000-2004. Farmers identified this variety as having the merit of high yield, disease resistant, and high market value; but needs more fertilizer rates. The type and frequency of land preparation varies depending on soil type, crop grown, tillage system and the rainfall pattern. The type and frequency of land preparation activity during the agricultural operation around Bakko-Tibbe district is provided in Table (54). As it is indicated in the Table, farmers plow 4-5 times including planting for maize, 2-3 weeding, once inter row cultivation in conventional tillage. The frequency of tillage remarkably decreased in conservation tillage, and this leads to the reduction of labor requirement and significant cost of production decrease. All farmers perceived that due to less frequent tillage germination of a crop is a problem particularly on grassy land. Thus, frequent plowing of land is advantageous for them to control weeds, to make seedbed fine and for good germination. They used traditional inter-row cultivation known as Babbaqaa to control weed, to make soil easy for fertilizer application, for good aeration, to obtain adequate population, and to conserve moisture. All farmers said conservation tillage is good but the availability and the cost of chemicals are the two problems for wider use. Although they exercised this technology for more than two years they responded that they do not have any training regarding the technology. Thus, it has not been easy to implement the technology because it is very difficult to properly weigh and mix chemicals, and to apply herbicide properly to the plots of land.

All farmers perceived row planting fit to conservation tillage, and intercropping such as haricot bean and pepper is also possible. Only 40% of the farmers considered fertilizing crops at knee height in conservation tillage is a problem because of no inter-row cultivation. They perceived that it is advantageous for saving time, control weed, and to have good seedbed preparation but costly, not possible to

Table 54 Type and frequency of agricultural activity in Bakko-Tibbe district.

Type of Activity	Frequency of Activity Conventional tillage	 Conservation tillage
Plowing	4	1
Planting	1	1
Fertilizer	2	2
Weeding	3	-
Cultivation	1	-
Harvesting	1	1

plant as early as possible and high prevalent of insects are considered as bottlenecks. All preferred the technology but only when the chemical cost is cheap. Farmers want to diversify crops, to rear livestock, and for some social commitments if they have ample time due to it. If cost of production is very less due to conservation tillage, farmers wants to extensive crops, to rear animals, to train their children, to pay their debits, and to settle their social affairs.

All farmers used local implements to plow their farm. About 36 and 8% of the farmers have had the opportunity to adopt some times and very often the recommended practices, respectively. However, 56% of the respondents had no opportunity to adopt. The most important reason for no adoption is the recommended practices are not easily available when they are in need (90%) some of them too expensive (fertilizer) to afford (10%). Only 10%, 50%, and 40% gets fertilizer easily, with some difficulties, and cannot get easily, respectively. The former 10% are those who have more than 20 cattle thus, can sell and buy in time. Some farmers had access to fertilizer or seed credit facilities and 45% of them settled debt when they are asked to do so. For some, this time is not the proper time to pay because it is the busiest time while there is no money to pay (36%), for some it is when crop produce is not in their hand (36%), and for others, this time makes them sell their cattle to pay the credit (18%), but 10% responded it is a proper time. About 71% wanted to continue to have credit always, the remaining for some times. All farmers responded that the technology need some modification such as means not to wait until weeds emerged in order not to lose a good sowing time, means to control grass weed before emerging since grass weed was not efficiently controlled, and means how to use also during sunny days not to wait moist or wet condition. Thus, the necessary conditions for adoption according to farmers are reduction of herbicide cost, credit facility, adequate training, availability of herbicide at a right time and proper site. If those preconditions are fulfilled about 60% farmers wanted to continue with the technology. And 40% wanted to use it interchangeably with the conventional tillage. Although the farmers want to continue with it but none of them ready to buy herbicide on cash basis, and they want to get on credit basis. They also recommended the technology for others but with intensive training and credit facility. The economic evaluation of tillage systems on maize grain yield indicated that the highest net benefit was obtained from conservation tillage (Birr 4008 per ha) than from conventional (Birr 3145 per ha) tillage system (Tolessa, 2003). He concluded that farmer could gain more benefit from practicing conservation tillage than the conventional tillage systems of production, even with fluctuating maize market price and herbicide cost.

Production constraints around Bakko-Tibbe

In general, out of the six identified maize crop production constraints, moisture deficit, poor soil fertility and weeds are amongst the major constraints for crop production around the Bakko-Tibbe district. However, out of these three major constraints in the same district of different villages, the relative importance of crop constraints varies based on farmers' perception of specific village (Table 55). According to the present participatory ranking, poor soil fertility is the number one constraint confronting the production and productivity of maize around *Odaa Gibee*, *Tarkkanfataa Gibee* and *Odaa Haroo* villages. For *Haanxxe* and *Diimaa* farmers' moisture deficit perceived as the most maize production limiting factors. The importance of moisture is recognized particularly at tasseling and grain-filling stage thus, when there is moisture stress there is no heading. Some times there is less moisture during planting too. May, September, and October are perceived as top three months at which water shortage occurs. According to farmers crop is not emerged due

<u>Table 55</u> Participatory ranking of cropping constraints in Bakko-Tibbe district.

Constraints	Odaa Gibee	Tarkkanfataa Gibee	Haanxxee	D/Diimae	Odaa Haroo	Total	Rank
Poor soil fertility	6	11	7	4	11	39	2
Weeds	3	8	9	4	6	30	3
Soil erosion	2	4	3	2	6	17	5
Moisture deficit	4	11	12	5	10	42	1
Insects	2	3	3	2	3	13	6
Diseases	3	3	6	3	4	19	4

to water shortage. They perceived water stress is mainly manifested on black soil while poor soil fertility observed on red sloppy soil. All farmers plant or sow maize on moist soil; no dry planting is practiced as opposed to what is done by the farmers of eastern Shoa zone.

On the other hand about 90% of the farmers reported row sowing is time consuming but they appreciated the row maize crop. Farmers also reported frequent tillage is time consuming and perceived that long years soil fertilization brought about land drought. No-farmers indicated the problem of water logging as the topography of their farmland is sloppy mostly greater than 10%. Almost all farmers perceived (80%) that runoff is a problem and much water and soil is lost due to runoff. During May, after fine seedbed prepared but no crops emerged runoff is a big problem. There is heavy rainfall from July to Sept leading to a serious runoff problem. It is true that under the present conventional tillage system there are high erosion hazard since the land is bare and this leads to deteriorating soil properties in western Oromiya. However, conservation tillage, which advocates retention of some crop residues on the soil surface could tackle the erosion problem and brought the positive impact in soil chemical properties.

Changes in some chemical properties of soil are presented in Table (56). In general, all soil chemical properties except organic carbon in conventional tillage and soil pH in conservation tillage were enhanced in both tillage systems. This might have been accounted for a five years continuous use of inorganic fertilizers (urea and dap)

Table 56 Changes of soil properties under two tillage systems in Bakko Tibbe district.

Soil Properties	Cropping Years		
	2000*	2004	
	Initial	Conventional	Conservation
pH (1:2.5)	5.60	5.65	5.4
OM (%)	2.18	2.11	3.25
Total N (%)	0.10	0.12	0.16
Available P (mg kg^{-1})	8.40	8.50	9.55
Exchangeable K (mg kg^{-1})	324.00	325.00	425.00

* Source Tolessa (2003)

in both tillage systems. However, a comparison of soil fertility before cropping and after five years cropping revealed that conservation tillage significantly increased organic matter from 2.18% to 3.25% and total soil nitrogen, available phosphorus and exchangeable potassium were enhanced by 0.06%, 1.15 mg kg^{-1}, and 101 mg kg^{-1}, respectively. Soil pH was decreased as time goes from 2000 to 2004 on conservation plot while it was remained about the same on conventional plots. The decomposition of organic residues by microorganisms resulted in acid release to the soil that might have been contributing to the lowering of soil pH in conservation tillage.

The negative impact of weeds on maize production is also perceived as the major constraints in all villages of the district. The major weed species in Bakko-Tibbe district identified by farmers are presented in Table (57). *Guizotia scabra* is the number one weed that densely found in every farmers field and affects crop yield. *Spilanthes mauritiana*, *Snowdenia polystachya* and *Bidens pilosa* are also the major weeds confronting the production of maize in the area. *Snowdenia polystachya* is mainly found around homestead or occurred on fields with animal manure. *Datura stramonium* considered by many farmers as notorious weed. In one of the village, farmers reported that the weed called *Abbaqooratti (Nicandra physaloides)* is recently introduced probably from the coffee growing areas through animal wastes, particularly that of Donkey's. Since donkey used for transportation of coffee from different areas it may consume such weeds and passed through its disposal as the seed of the weed is evidenced in the wastes of Donkey.

Table 57 Major weed species and their local name around Bakko-Tibbe district.

Scientific name	Local name
Guizotia scabra	Tufoo (Cuqii)
Spilanthes mauritiana	Gororssa
Snowdenia polystachya	Muujja
Bidens pilosa	Keeloo
Datura stramonium	Asengra
Nicandra physaloides	Abbabalobloa or Abbaqooratti

According to the research findings of Tolessa (2003) *Guizotia scabra*, *Datura stramonium* and *Bidens pilosa* are the common weed species around Bakko-Tibbe district, which is in agreement with the farmers' perception.

Copping strategies

To minimize the effects of poor soil fertility they practiced crop rotation such as using "Noug" (*Guizotia abysinica*) for black soil, add farm yard manure for red soil, allowing fallow for one-two years for red-soil (only 20% of the farmer). When there was a moisture stress during planting, farmers' exercised to plant Taaffi or other crops such as sorghum instead of maize. To conserve soil and to control erosion they exercised plowing against slop and open waterway along the field. Allowing fallow period for some time and opening *boraatii lolaa* (waterway) are the common practices to reduce runoff. July and August are the two months when weeds became more problematic. Hand weeding is the major methods used to control weeds. Babbaqaa and slashing is also carried out for the late emerged weeds. Pickaxe is the main implement used to control weeds. They overcome labor shortage partly by exchange of labor. Farmers enumerated some of the solutions to get higher yield namely, early planting and weeding, using of animal manure, crop rotation, using quality seed, land fallowing and conserving soil. Only 36% of the interviewed farmers used all organic, urea and dap fertilizers for the crop while 64% use only urea and dap fertilizers. Those who have a large number of cattle's used animal manure for some parts of their fields and the remaining fields applied with inorganic fertilizer.

Some common features and diversity observed in all study sites

The study locations differ greatly in terms of topography, traditional groups, rainfall pattern, minimum and maximum temperatures, vegetation and soils (Appendix Table 22). Cereals are the dominant and most important crops in all production systems. In addition to cultivating annual crops, farmers keep livestock on their farms for various economic and social reasons. The main reasons for keeping cattle are prestige or sign of wealth, income, social security, dowry, draught power (in most of the study areas), milk, meat and manure. The conservation tillage crop production system has been promising and agronomically suite to all the studied areas. From agronomic point of view the past conservation tillage system was enhanced organic matter content in the soil surface and improves the hydro-physical properties of the soil as compared to conventional tillage system.

During the present study, the respondents revealed that there is a progressive decline in the yield of cereals resulting from unreliable rainfall, poor soil fertility, weeds, insects and diseases such as rust. Moisture stress, poor soil fertility and weeds are perceived the three most crop yield limiting factors in all most all areas. Rainfall is unreliable both in the high rainfall and less amount areas for the last two years. It is low, erratic and often occurs as big storms in the semi-arid. Temperatures and direct sun light is very high in the semi-arid and aggravates soil moisture loss. Thus, soil moisture is priority constraints to be tackled both in maize and Taaffi based production system. Low soil fertility as a result of centuries of cultivation and improper management of natural resources (forest, soil and water) is the second most important constraints in both Eastern and Western parts of Oromiya. Although farmers are well aware of the benefits of applying manure on their field, they do not always have the means to do so due to shortage of materials, use of dung for fuel and income generation purposes.

Farmers exhibited differences in their produce and capability in food self-sufficiency. Those at specific sites in Jimma zone produce enough production for their yearly food and income generations as compared to farmers in the East and West Shoa zones. The growing of coffee for cash earning purpose and cereals for food in Jimma zone of specific locations probably contributing for higher proportion of farmers to produce yearly enough food for their lively hood and to generate cash. Those interviewed farmers both from East and West Shoa zone are food in secured in spite of their closeness to main road and market facility as well as wide usage of fertilizers as compared to Jimma zone. East Shoa is one of the drought-affected zones of Oromiya. The labor shortage in East Shoa zone may not be contributed to lesser family size rather those families with active agricultural age migrate to town in need of job although the opportunity to get job is almost impossible.

Indigenous knowledge in soil conservation tillage systems

There have been many traditional soil conservation tillage systems evolved by farmers over the course of time to suit certain environmental conditions. These indigenous soil conservation systems may be agronomic, vegetative or physical in nature and some of these systems, which were noted during our physical observations, are discussed below.

Agronomic and vegetative techniques

Agronomic techniques include practices such as crop rotations, mixed cropping and trash lines. Crop rotations and mixed cropping are traditional systems that are widely practiced in the study areas. Good crop rotations such as maize followed by legumes facilitate the conservation and addition of organic matter, restoration of soil structure and fertility and reduction of pests and diseases. In mixed cropping, two or more crops are grown in the same field in the same season. In most cases grains and leguminous crops are mixed. The fast growing legumes provide soil cover early in season, shielding the impact of raindrops, fix nitrogen too, and thus help to maintain soil fertility. In slopping hillsides, maize stover is sometimes used to make trash lines (Jimma, West Shoa), which help in slowing down the flow of runoff, and traps eroded soils. The technique is used both for erosion control and fertility improvement.

Physical tillage techniques

In some parts of East Shoa zone earth bunds are used for slowing down runoff in maize and sorghum fields where they are usually constructed along the contour after planting the crop. A few used stone bunds at regular intervals along the contour. Stone bunds retain or slow down run off and hence control erosion.

Traditional ditches

Traditional ditches are constructed using a 'maresha' *orddaa* plough pulled by oxen and made to disposes excess water and drain out of cultivated land, to the side of an artificial or natural waterway. A ditch may sometimes be dug on the upper side of the cultivated land (West Shoa and Jimma) or as a criss-cross (West and East Shoa) to act as a cut off drain to protect the field from the runoff coming from the higher land. Thus, traditional ditches drain excess water from the field, protect the soil from being washed away by runoff and reduce surface runoff generated within the cultivated land.

No primary till or pot holing

This is essentially a dry planting, slashing and burning systems. It involves slashing of the vegetation; allow it on the ground to dry and burning it to leave a clean seedbed. Sowing is then done without disturbing the soil, except for the planting holes that may be done with the pointed stick, followed by very early weeding using the slashes, a few days after the emergence of the crops (maize, sorghum, oat, wheat). The practice is common in Jimma and West Shoa zones.

Mulching

It involves sowing the crop on stand vegetation then slashing the vegetation leaving it on the ground to dry and to be rotten. Mulch farming maintains surface residues on tilled land. Plant residues are useful in conserving the soil, controlling water runoff, improving soil physical conditions and increasing soil fertility. *In situ* mulching was fairly commonly practiced in Jimma and West Shoa areas. The practice has declined as a result of other competitive use of the crop residues such as feed for livestock, fuel and building materials in East Shoa zone. Mulching, however, is still practiced in oat, wheat and coffee areas and in horticultural crops, in areas of high rainfall.

The *Dikee* system

This is a crop management system practiced where by nutrients add to the soil by animal dung. Cattle is enclosures in the typical Oromoo barn during the night from three to seven days based on the number of cattle (large number less days, small number more days), season (during June, July and August only 2-3 days, during dry season 4-7 days), topography (flat land less days, sloppy land more days) and fertility status of the soil (relatively fertile soil less days). In such area, manure from stall fed cattle is incorporated into soil only by one time plowing. The frequency of the tillage is decreased remarkably (mostly one to two times plowing) when using this system. This practice is still widely used in many districts of West Shoa, Jimma and some parts of East Shoa zones. In some districts of East Showa this system is rarely practiced due to shifting of the purpose of animal dung to fuel instead of manuring.

Indigenous knowledge in copping crop production constraints

Farmers have developed a range of indigenous coping strategies, through trial and error, to combat their problems and constraints. They have been changing crops and cultivars according to the type of season and follow a number of tillage practices to conserve soil moisture, and control weeds. Some important strategies include: as soon as soil moisture is sufficient, farmers start practicing a number of tillage to ensure moisture infiltration and to encourage weeds to germinate. Farmers in Eastern Showa zone adjust the sowing time according to the crop, cultivar, and soils type and moisture availability. Drought tolerant crops are grown as early as possible (in April and May) in low-lying areas that receive run-off. Sowing is delayed on drought prone soils such as *Gombore* until sufficient moisture is conserved. Farmers sow early in the morning or late in the evening to avoid soil moisture loss. In May, during the hottest period of the year, they try to prevent livestock walking on the fields to avoid loss of conserved moisture by evaporation. Some farmers divert run off into established (sown) fields whenever possible, especially at the flowering stage.

Constraints and challenges of indigenous knowledge

Traditional or indigenous conservation tillage has been a major pre-occupation of subsistence farmers since time immemorial. While indigenous soil conservation methods still play an important role, they are highly location specific. Some of these measures are labor intensive and are difficult to mechanize, thus severely limiting the cropped land. Physical conservation practices alone have not been very effective where land is fragmented and labor shortage is chronic problem. Agronomic and vegetative measures alone have not been very effective where marginal lands like steep slopes are put under cultivation as a result of land pressure.

Limits to adoption of conservation tillage

Despite the reported successes in Oromiya with conservation tillage, the following have been identified as the problems faced in the adoption.

Risk avoidance

Leaving a legacy of better land for future generations is one thing, but the short-term reality of feeding the present generation and making a living is quite alarming and unprecedented in current Oromiyan condition. An important reason for the poor adoption of new techniques in general is the inability of the subsistence farmers to take risks. The essence of farming is trying to improve the odds in the gamble against weather, pest, and disease. The peasant has no risk capital to gamble with, so his whole strategy is geared to safety and reality to feed the present generation. Not unreasonably, short-term reality usually took priority. Certainly there have been good and even excellent conservation tillage crops particularly in maize production but there has also been failure particularly in the dryland areas during the drought year (2002 cropping year). And it is the failure, which take prime position in the minds of all but the most forward-looking or innovative farmers. Farmers would rather want to use his traditional farming system with a low-yielding variety, which gives some yield every year than a new tillage system with improved variety and recommended fertilizer management, which will give an increased yield most years, but none at all in the bad year (e.g. 2002 drought year in Oromiya). Even if the chance of an increased yield is nine years out of ten, it is still not an acceptable gamble for the small subsistence farmer. In the tenth year, the year of failure, his family will starve. It is neither stupidity nor lethargy when he sticks to his traditional management and old variety; it is accepting the realities of life. Thus, the perception of risk is probably the single biggest factor governing the implementation of conservation tillage, and it is likely to remain so far for a long time.

The absence of farmer groups and associations

This is regarded as major problem. In practice the vast majority of farmers are fragmented, disorganized and geographically dispersed. The absence of genuine, cohesive and well-organized farm groups is the significant constraint facing the development of smallholder agriculture in the area. The transaction costs in dealing with a disorganized farming community is prohibitive whether it is for the provision of loans, extension services, markets, or the dissemination of appropriate technologies.

Continuity

Sasakawa Global 2000 works with demonstration farmers for maximum of three years on the same site in order that the medium term benefits can be realized. Because of the higher skill needed and the high cost of herbicides, only few of the demonstration farmers wanted to continue with the technologies by their own support. This means that with the drop of demonstration farmers, the conclusion of other farmers will mean obliteration in the demonstration programmed.

Limited target group

The benefits of past conservation tillage in Oromiya were limited for farmers who could not afford input and have one or no ox to plow. Non-assisted farmers will not necessarily follow the complete package of measures. However, some of these farmers have large number of cattle and volunteer to adopt conservation tillage.

Shortage of information

As any agricultural research and development in the country previously the emphasis of conservation tillage research and development has been on making the best use of good soils and good climates and little attention was given to marginal environments. One result of this uneven spread of effort is a lack of information about the less favored semi-arid areas. A combination of lack of interest, low research commitment, shortage of information and the complexities of the problem in dryland area result in a shortage of technology that can be applied to improving agriculture in semi-arid regions.

Lack of access to agricultural input

The non-availability and untimely supply of agricultural inputs destructs farmers’ time lines in agricultural activity. Lack of access to improved technologies particularly to agricultural machinery and implements by the large majority of peasant farmers is considered the main problem for crop production. As perceived by farmers, the common ox-plough is not a good implement to use for conservation tillage. They need an implement that can break up pans and that does not lead to soil clog during land preparation.

Insecure land ownership

Lack of guarantee in land ownership discourages them to invest on soil and water conservation strategies. All interviewed farmers in the Eastern Shoa zone were reluctant to practice any medium to log-term conservation strategy and even the short-term crop rotation measures to rejuvenate soil fertility fearing that their land can be sold at any time of the year for investor by the government.

Lack of credit facility and marketing infrastructure

Lack of credit facility for them to purchase agricultural inputs and farm implements aggravates the problem. Inadequate marketing infrastructure to enable peasant farmers to sell their produce and buy what they need without traveling long distances coupled with low agricultural prices became a bottleneck for further crop production, hence to adopt conservation tillage systems.

CONCLUSION AND RECOMMENDATION

Conclusion

The study of conservation tillage options for sustainable crop production in the semi-arid and sub-humid Oromiya is concluded as follows:

Combined effects of tillage and fertilizer on sorghum productivity

The present result revealed that the highest sorghum grain yield was recorded due to tie-ridge tillage but varied with fertilizer rate for each location. At the highest fertilizer rate of 57.4-64.4 kg N-P_2O_5 ha^{-1} significantly higher yield obtained than at the current recommended rate of 41-46 kg N-P_2O_5 ha^{-1}. However, further applications of fertilizer beyond 49.2-55.2 kg N-P_2O_5 ha^{-1} could give no significant yield advantage and thus, would not be economically feasible. The results from tie-ridge and reduced tillage tied furrow were encouraging but need further investigation to incorporate in to sorghum cropping system.

Tillage and crop rotation effect on soil properties and maize productivity

Application of conservation tillage to sandy loam and loam soil type in the dryland, central rift valley of Oromiya for five years, markedly improved organic matter content, N concentrations, and soil moisture content. Gains of up to 0.4% in organic matter are relatively modest, but are consistent with organic matter gains observed in hot climates where conservation tillage has been adopted. The measurable gains in organic matter and N content suggest a balanced improvement in soil fertility is underway. The greater soil organic matter content, total soil nitrogen content and more stored water in conservation tillage in turn, resulted in increased maize grain yield as compared with conventional tillage. Such characters of conservation tillage have important implications for the biological, chemical, and physical processes that continually occur in the soil. In both locations, crop rotation had significant effect in increasing biological yields of maize crop. The present findings also confirmed that Taaffi can be used as a precursor crop for maize and a great advantage can be accrued in the absence of leguminous crop. Based on the present study, it can be said that conservation tillage and crop rotation system is a win-win crop management options for sustainable maize production in the dryland, central rift valley of Oromiya, where soil water is most limiting.

Effects of tillage and crop rotation on Taaffi productivity and profitability

The present findings indicate that the higher frequency, mean density, and greater dry mass of weeds were found in conventional tillage than in conservation tillage systems. The yield of Taaffi increased with decreasing tillage frequency and yield differences among tillage systems has become more pronounced at the last year (2004) of the experiment with continuous Taaffi production. Significantly higher mean grain yield was obtained from rotation plot as compared to that obtained from continuous Taaffi monoculture. The same trend as grain yield was observed for straw and aboveground biomass yields. Soil organic matter and total soil nitrogen storage were increased in no tillage surface soils. Crop rotation increased soil organic matter and total nitrogen compared to the Taaffi monoculture system. Overall, the conservation tillage systems resulted in lower labor and time requirements, reduced production costs and greater net returns. Based on these results, selection of a tillage system for the central rift valley semiarid environments of Oromiya will likely be done based on considerations such as energy conservation, lowering production costs, profitability, and overall economic returns, rather than on mere yield potential. The implementation of conservation tillage and crop rotation can be an effective concomitant strategy in improving soil properties and increasing yield of Taaffi without adverse impact on the environment.

Agronomic and perception analysis

Farmers were appreciating the benefits of conservation tillage systems. However, the unlikely response of poor farm families to adopt conservation tillage system is that they could not afford to buy chemicals (herbicide and fertilizer) to fulfill the requirements of conservation tillage in the rainy season when their grain is depleted from their granary. Whereas, the rich ones (both in farm size and income) considered conservation tillage crop production system as a time and labor saving that could enable them to diversify other crop production management practices and use the surplus time for some social commitments. Despite these differences in the degree of satisfaction, rich farmers wanted to continue on relatively large hectares if the cost of Ropundup and Lasso Atrazine reduced to Birr 40-50 from the present cost of Birr 70-80 per liter compared to the poor ones. As the purchasing power of poor farmers is very less, many farmers need to adopt conservation tillage technology if the present herbicide cost reduced to less than Birr 40. This necessities the provision of credit facility and good marketing infrastructure which in turn encourages farmers to sell their produce with reasonable price and to escalate the purchasing power of them.

Recommendation

Worldwide interest in conservation tillage research and application has been well underway. One feature that makes conservation tillage so popular is its adaptability and social acceptability. It has application for the large commercial farming in highly developed countries as well as for the small subsistence farmers in developing countries. It should be recognized that the conservation tillage system as it is known in its present form is less than a decade years old in Oromiya, while conventional tillage systems are a centuries old. Moreover, although studies of conservation tillage have several times shown great promise, but have been too brief, or too local, or restricted to demonstration plots and experiment stations, and as a result they generate neither the depth and breadth of understanding of the technique nor the impetus and general interest that might sustain it through a long programme of wider testing, adjustment, and retesting under practical farming conditions. Research in conservation tillage in its context, however, needs a long time span to reduce the effect of seasonal variations, and coverage over a wide area to reduce the effect of local variations. The ability to control perennial weeds, cost and availability of chemicals, changes in economics of crop production, increasing environmental concern for degradation control, cost and availability of energy and Oromiya's need for food self secure will dictate the percentage of crops grown under conservation tillage and the rate of change from traditional methods. It has been said that no single tillage system is best suited for all soil types and soil conditions. A high percentage of Western Oromiya soils suitable for row crop production have well-drained, medium textured class and is sufficiently slopping to have water erosion as the major limiting factors. The soils in the central rift valley of Oromiya have potential drought characteristics that have wind erosion as the major limiting factor. As it is already shown in many countries the conservation tillage system of crop production is well adapted to such well drained and moderately well drained, medium-textured soil types when compared to conventional tillage management. The acceptance and adoption of conservation tillage production has also been most successful on similar soil type and soil conditions. Observations of conservation tillage Taaffi production on the imperfectly drained soils showed less response than the well-drained soils, requiring more refined management inputs. Thus, additional research and development work that accommodate farmers' indigenous knowledge is needed on the imperfectly drained soils to determine whether management techniques can be sufficiently refined for successful conservation tillage use.

As the use of animal traction is countrywide, then the incorporation of appropriate soil moisture conservation measures, fertility improvement means and proper agricultural implements in such systems are important so as to ensure sustainable crop production. These measures should be integrated into the normal crop-livestock husbandry concept, where care and improvement of land resources comes first and control of degradation is part of the caring and improvement process. The coping strategies that farmers set out to cope with natural resource conservation measures and crop related risks are valuable from agricultural development aspects. For instance, farmers' knowledge of soil moisture conservation means, soil fertility improvement strategies and removal of water logging measures provide a basis for building a technology that accommodates farmers' indigenous knowledge. Participatory community based approaches involving the stakeholders in planning and implementation are necessary in order to create a higher ownership attitude. Clear messages on conservation tillage should be included in the normal extension packages and training of both village extension workers and farmers should be emphasized so as to improve their understanding and skills. The land policy and livestock "free for all" range management system should be revisited so as to increase personal responsibility on the land and increase investment on soil conservation activities. Conservation tillage tends to be more acceptable to farmers if it serve multiple objectives and help to increase production. Indeed, for many smallholder farmers, resource conservation cannot be an end in itself, but it is an integral part of efforts to improve and sustain livelihoods. Improving productivity is then the underlying rationale. Finally, if farmers' strategies and decisions can be better understood so that every development workers can work in harmony with farmers, the ultimate target group may better accept the technologies.

LITERATURE CITED

Aase, J.K. and J.L. Pikul. 1995. Crop and Soil response to long-term zero-tillage practices in the Northern Great Plains. **Argon. J.** 87: 652-656.

Ahlawat, I.P.S., A. Singh and C.S. Saraf. 1981. Effects of winter legumes on the nitrogen economy and productivity of succeeding cereals**. Experimental Agric**. 17:57-62

Al-Kaisi, M. M. and H. M. Hanna. 2002. Resource conservation practices: Consider the strip-tillage alternative. **Iowa Cooperative Extension Service Bulletin**, PM 1901c.

Arkley, R.T. 1963. Relationship between plant growth and transpiration. **Hilgardia** 34: 559-584.

Arnon.1992. **Agriculture in dry lands**: principles and practice. Elseiver Science Publisher, Amesterdam, The Netherlands.

Asnakew. W. 1994. Soil fertility and management in the dryland. *In*: Reddy, M.S and G. Kidane (ed.). Development of Technologies for the dryland farming areas of Ethiopia. **Proceedings of the first workshop on dryland farming research in Ethiopia.** IAR and FAO, Addis Ababa, Ethiopia.

Association of Official Agricultural Chemists (AOAC). 1960. **Official Methods of Analysis pp** 12-13. Washington, D.C

Astatke, A. and F. Kelemu. 1993. Modifying the traditional plough `maresha' for better management of Vertisols. *In*: Mamo, T., A. Astatke, K.L. Srivastava and A. Dibabe (eds.). Improved Management of Vertisols for Sustainable Crop-Livestock Production in the Ethiopian Highlands: 85-102. **Synthesis**

Report 1986–1992. Technical Committee of the Joint Vertisol Project. ILRI, Addis Ababa, Ethiopia.

Astatke, A., M. Jabbar and D. Tanner. 2002. Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian high land vertisol. **Soil and Tillage Research:** 68: 153-160

Avery, B.W. and C.L. Bascomb. 1974. Soil survey laboratory methods. **Soil Survey Technical Monograph** No. 6, Harpenden.

Azooz, R.H., B. Lowery, T.C. Daniel. 1995. Tillage and residue management influence on maize growth. **Soil and Tillage Research** 33: 215-227

Baker, C.J. K.E. Saxton and W.R. Ritchie. 1996. **No-tillage Seeding, Science and Practice**. CAB International, Wallingford, Oxon, UK, 158 pp.

Baldock, J.O., P.L. Higgs, P.L. Paulson, J.L. Jackson and W.D Shrader. 1981. Legume and mineral N effects on crop yields in several crop sequence in the upper Misissipi Valley. **Agron.J**. 73: 885 - 890.

Ball, D.A. and S.D Miller. 1993. Cropping history, tillage, and herbicide effects on seed flora composition in irrigated maize. **Agron. J**. 85: 817-821.

Baumhardt, R.L., P.W.Unger, B.A. Stewart. 2000. Long-term dryland grain sorghum and winter wheat production using stubble-mulch and conservation tillage residue management. *In* Mechanized Dryland and Water-saving Farming for the 21st Century, N. Dun, ed. **Proceedings of the China International Conference on Dryland and Water-saving Farming**: 199–209, Beijing, PR China.

Baumhardt, R.L., R.E. Zartman and P.W. Unger. 1985. Grain sorghum response to tillage method used during fallow and to limited irrigation. **Agron. J**. 77: 643-646.

Biamah, E.K., J. Rockstorm. 2000. Development of sustainable conservation farming systems. *In* Conservation Tillage for Dryland Farming, E.K. Biamah, J. Rockstorm, G.E. Okwach, eds. **Regional Land Management Unit (RELMA) and Swedish International Development Agency (Sida)**, Nairobi, Kenya, pp. 27–35.

Bilbro, J.D. and E.B. Hudspeth, Jr. 1977. Furrow diking to prevent runoff and increase yields of cotton. **Texas Agric. Exp. Stn**. PR-3436.

Birihane, B., T. Neggusie and A. Habtamu. 1994. Appropriate cultural practices for dryland farming areas of Ethiopia. *In* Development of Technologies for the dryland farming areas of Ethiopia, M.S. Reddy and G. Kidane eds. **Proceedings of the first workshop on dryland farming research in Ethiopia,** IAR and FAO, Addis Ababa, Ethiopia.

Blevins, D.W., D.H. Wilkison, B.P. Kelly, and S.R. Silva. 1996. Movement of nitrate fertilizer to glacial till and runoff from a clay pan soil. **J. Environ. Qual**. 25: 584-593.

Blevins, R.L., L.W. Murdock, and P.L. Maizeelius. 1977. Influence of conservation tillage and nitrogen fertilization on certain soil properties after five years of continuous maize. **Agron**. J. 69: 383-386.

Blum, A.J. Mayer and G. Golan. 1989. Agronomic and physiological assessment of genotypic variation for drought resistance in sorghum. **Aust. J. Agric. Res**. 40:49-61.

Boligon, F.R. and S.K. DeDatta. 1976. Minimum and zero tillage in lowland rice. International Rice Research Institute (IRRI), Satudry Seminar, December 18, 1976. Losbanos, laguna. Philippines.

Brady, N. C. and R. R. Weil. 2002. The nature and properties of soils 13th ed. New Jersy.

Bremner, J.M. and C.S. Mulvancy. 1982. Total nitrogen. *In* **Methods of soil analysis, part II**. Chemical and microbial properties. C.A.Black (ed.).

Carefoot, J.M., M. Nyborg and C.W.Lindwall, 1990. Tillage induced soil changes and related grain yields in a semi-arid region. **Can.J.Soil Sci**. 70:203-214.

Carter, D.C and Miller.1991. Three years of experience with a uniform macro catchments water harvesting system in Botswana. **Agric. Wat. Manage.**19: 191-203.

Carter, M.R. 1990. Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. **Can. J. Soil Sc.** 70: 425-433.

Central Statistics Authority (CSA). 1996. **Agricultural sample survey** 1995/1996, Volume I. Report on area and production of major crops. Addis Ababa, Ethiopia.

Central Statistics Authority (CSA). 2001. **Agricultural sample survey** 2000/2001, Volume I. Report on area and production of major crops. Addis Ababa, Ethiopia.

Central Statistical Authority (CSA). 2003. **Agricultural sample survey** 2002/2003, Volume I. Report on area and production of major crops. Addis Ababa, Ethiopia.

Central Statistical Authority (CSA). 2004. **Agricultural sample survey** 2003/2004, Volume I. Report on area and production of major crops. Addis Ababa, Ethiopia.

Chang, C. and C.W. Lindwall. 1989. Effects of long-term minimum tillage practices on some physical properties of a chernozemic clay loam. **Can. J. Soil Sci.** 69: 443–449.

Chaudhuri, U.N. and E.T. Kanemasu. 1982. Effect of water gradient on sorghum growth, water relations and yield. **Plant Sci.** 62: 599-607.

Chichester, F.W. and J.E. Morrison. 1992. Agronomic Evaluation of Fertilizer Placement Methods for Conservation tillage Sorghum in Vertisol Clays. **J. Prod. Agri**. Vol. 5, no. 3, 1992.

Chichester, F.W., and C.W. Richardson. 1992. Sediment and nutrient loss from clay soil as affected by tillage. **J. Environ. Qual**. 21: 587-590.

Clark R. N. and O.R. Jones. 1981. Furrow dams for conserving rainwater in a semiarid climate. *In* **Proc. Am. Soc. Agric. Eng. Conf.** on crop production with conservation in the soil: 198-206. Chicago, Illinois.

Cooper, P.T.M., J.D. H. Keatinge and G.Hughes. 1983. Crop evapotranspiration-a technique for calculation of its components by field measurements. **Field Crops Res**. 7: 299-312.

Cooper, P.T.M., P.J. Gregory, D.Tully and H.C. Harris. 1987. Improving water use efficiency in rain fed conditions in northen Syria. **Field Crops Res.** 16: 67-84.

CTIC. 1992. Conservation Tillage Information Center (CTIC, 1992).

Dabney, S.M., J.D. Schreiber and C.S. Rothrock, J.R. Johnson. 1996. Cover crops affect sorghum seedling growth. **Agron. J.** 88: 961-970.

Dagg, M. and J.C McCartney, 1968. The agronomic efficiency of N.I.A.E Mechanized the ridge system of cultivation. **EXPL Agric**. 4: 279-294.

Dao, T.H. 1993. Tillage and winter wheat residue management effects in water infiltration and storage. **Soil Sci. Soc. Am.** *J*. 57:1586- 1595.

De Detta, S.K., F.R. Bolton and W.L. Lin. 1977. **Prospect for using minimum and zero tillage in tropical low land rice.** The 8th annual conference of the pest control council of the Philippines, Bacicold city, May 18-20.

Dick, W.A. and D.M Van Doren. 1985. Continuous tillage and rotation combinations effects on maize, soybean and oat yields. **Agron. J**. 59:375-381.

EARO, 2000. EARO (Ethiopian Agricultural Research Organization), 2000. Resource Management for Improving and Sustaining Crop Livestock Production on Highland Vertisols in Ethiopia. **Progress Report** No. 11. EARO, Addis Ababa, Ethiopia, 36 pp.

Edwards, J.H., C.W. Wood, D.L. Thurlow and M.E. Ruf. 1992. Tillage and crop rotation effects on fertility status of a Hapludult soil. **Soc. Sci. Soc. Am. J.** 56: 1577–1582.

El-Swaify, S.A.1983. Conservation effective farming system in semi arid tropics. **Soil physics and conservation.**

ESPO. 1999. Economic Study Program Office of Oromiya (ESPO). **The Economy of Oromiya.** A Perspective for Development, Finfinne, September 1999.

Ewing R. P. and S. C. Gupta. 1994. Pore-scale network modelling of compaction and filtration during surface sealing. **Soil Sci. Am. J**. 58: 712-720.

FAO. 1993. Food and Agricultural Organization of United Nation (FAO). Soil Tillage in Africa: Needs and challenges. **FAO soils Bulletin** No. 69. FAO, Rome, Italy.

FAO. 2001. Food and Agricultural Organization of United Nation (FAO). Conservation Agriculture: Case studies in Latin America. **FAO Soils Bulletin** No.70. FAO, Rome, Italy.

Ferreras, L.A., J.l. Costa, F.O. García and C. Pecorari. 2000. Effect of conservation tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern "Pampas" of Argentina. **Soil Tillage Res.** 54: 31–39.

Follet, R. F. and D.S. Schimel. 1989. Effect of tillage practices on microbial biomass dynamics. **Soil Sci. Soc. Am. J.** 53: 1091-1096.

Francis, D.D., J.S. Schepers, and M.F. Vigil. 1993. Post anthesis nitrogen loss from maize. **Agron. J.** 85: 659-663.

Franzel, S., M. Mekuria and C. Yirga. 1989. Smallholder weed problem and weed control practices: Information from four case studies. *In* Problem and priorities for weed science in Ethiopia, A. Sharief, C. Parker, A. Stroud and F. Rezene (eds). **Proceedings of the First Weed Science Workshop in Ethiopia, Addis Ababa, Ethiopia**. pp 25-46.

Gebhardt, M.R., T.C. Daniel, E.E Schweizer and R.R. Allmaras. 1985. Conservation tillage. **Science.** 230: 625-630.

Gerard, C.J., P.D. Sexton and D.M. Conover. 1984. Effect of furrow diking, sub-soiling, and slope position on crop yields. **Agron. J**. 76:945-950.

Getachew A. 1986. A review of soil and water management research in the semi-arid regions of Ethiopia. *In* **Food grain production in semi-arid areas**. J.M. Memonya, J. Bezuneh and A. Youdeowei (eds.). Addis Ababa, Ethiopia.

Getachew, A. and B. Wondimu. 2000. On farm Evaluation of animal drawn tied-ridger in semi-arid areas of Wello. **Ethiopian J. of natural resources** 2 (2): 227-236.

Gibson, G., B.J. Radford and R.G.H. Nielsen.1992. Fallow management, soil water, plant-available soil nitrogen and grain sorghum production in south west Queens land. **Aust .J .Exp. Agric**. 32:473-482.

Giri, G. and R. De. 1979. Effect of Preceding grain legumes on dry land pearl millet in India, **Experimental Agric**.15:169-172

Girma, A., W. Mosisa, B. Dereje, G. Abdissa and K. Demissew. 2001. Analysis of Off-Season Maize Production in East and West Wellega Zones of Oromiya Region. **Research Report** No. 37. Ethiopian Agricultural Research Organization, Addis Ababa, pp 29.

Goldberg, S., B.S, Kapoor, and Hoodes. 1990. Effects of alluminium and iron oxides and organic matter on flocculation and dispersion of arid zone. **Soil sci**. 150: 588-593.

Gregory, P.J. 1988. Plant and management factors affecting the water use efficiency of dry land crops. pp171-175. *In*: challenges in dry land Agriculture. **Proceedings of International Conference on Dry land Farming.** Amarillo/ Bush land, TX.

Gregory, P.J., K.D. Shephenol and P.T. Cooper. 1984. Effects of fertilizers on foot Growth and water use of barley in northern Syria. **J. Agri. Sci**. 108:429-438.

Griffith, D.R., J.V. Mannering, H.M. Galloway, S.D. Parsons and C.B. Rickey. 1973. Effect of eight tillage-plant systems on soil temperature, percent stand, plant growth and yield of maize on five Indiana soils, **Agron. J.** 65: 321–326.

Griffith, D.R., E.J., Mannering, T.D. West and S.D. Parsons. 1988. Long term tillage and rotation effects on maize growth and yield on high and low organic matter, poorly drained soils. **Agron. J.** 80: 562-599.

Gryseels, G. 1988. Role of livestock on mixed smallholder farms in Ethiopian highlands. A case study from the 'Baso" and "Worena" "Woredas" Near "Debre Berhan". **Ph.D. Dissertation**, Agricultural University, Wageningen.

Gupta, S. C., P.P Sharma, S.A. Defrachi. 1989. Compaction effects on soil structure. **Adv. Agronomy** 42: 311-338.

Hailu, G. and G. Kidane. 1980. Sustaining crop production in the semi-arid areas of Ethiopia. Ethiopia **J. Agric. Sci**.10: 99-107.

Hailu, G. and G. Kidane. 1988. Sustaining crop production in the semi-arid areas of Ethiopia. **Conference papers**, Addis Ababa. Ethiopia.

Hamblin, A.P, D. Tennunt and M.W. Perry. 1987. Management of soil water for wheat production in western. **Aus. J. Soil Use and Manage**. 3: 63-69.

Hammel, J.E. 1989. Long-term tillage and crop rotation effects on bulk density and soil impedance in northern Idaho. **Soil Sci. Soc. Am. J.** 53: 1515–1519.

Hammel, J.E. 1996. Long-term tillage and crop rotation effects on winter wheat production in northern Idaho. **Agron. J.** 87: 16-22.

Hammer, G.L., K. Hill and G.N. Schrdter. 1987. Leaf area production and senescence of diverse grain sorghum hybrids. **Field Crops Res.**17:305-317.

HARC. 1999. **Progress Report of Holeta Agricultural Research Center for 1998/1999**. Holeta, Ethiopia.

Hargrove, W. L. and W.S. Hardcastel. 1984. Conservation Tillage practices for winter wheat production in the Appalachian Piedmont. **J. Soil water Conservation**. 39: 324-326.

Hayhoe, H.N., L.M Dwyer, D. Balchin, and J. L. B Culley. 1993. **Soil and Tillage Research** 26: 45-53.

Heatherly, L. G., C.D. Elmore and R.A. Wesley. 1990. Weed control and soybean response to preplant tillage and plating time. **Soil and Tillage Research**. 17:199-210.

Hill, R.L 1990. Long term conventional and conservation tillage effects on selected soil physical properties. **Soil Sci. Soc. Am. J.** 54: 161-166.

Hill, R.L. and Cruse, R.M., 1985. Tillage effects on bulk density and soil strength of two Mollisols. **Soil Sci. Soc. Am. J.** 49: 1270–1273.

Holland, J.F. and W.L. Felton. 1989. Effect of tillage practice on grain sorghum production in Northern NewSouth Wales. **Grains Research and Development Corporation** (GRDC, 1989).

Honisch, O. 1973. Water conservation in three-grain crops in the Zambazi valleys. **EXPL. Agric**. 10: 1-8.

Horn, C.P., C.T. Birch, R.C. Dala and J.A. Doughton. 2000. Sowing time and tillage practice affect chickpea yield and nitrogen fixation, dry matter accumulation and grain yield. **Aus. J. Exp. Agri.** 36: 695-700.

Horton, R., R.R. Allmaras and R.M. Cruse, 1989. Tillage and comparative effects on soil hydraulic properties and water flow. *In* **Mechanics and Related Processes in Structured Agricultural Soils**, W.E. Larson, ed. pp187–203.

Huda,A.K.S., M.U.K. Sivakumar, Y.V. Srirama, J.G. Sekaran and S.M. Virmani. 1987. Observed and simulated responses of two sorghum cultivars to different water regimes. **Field crops Res.** 16: 323-335.

Hulugalle, N.R. 1987. Effect of tied ridges on soil water content, evapotranspiration, root growth and yield of cowpeas in the Sudan savannah of Burkina Faso. **Field Crops Res**. 17:219-228.

Hulugalle, N.R., 1990. Alleviation of soil constraints to crop growth in the up land alfisols and associated soil groups of the West African Sudan savanna by tied ridges. **Soil Tillage Research** 18: 231-248.

Husssein H. and B. Worku. 2005. The role of conservation tillage on crop production under dryland conditions. *In* **Proceedings of the Workshop on Conservation Tillage in Ethiopia (June 2004).** pp 24-29. Malkassa Agricultural Research Center, Ethiopia.

Jackson, M.L. 1958. **Soil chemical analysis.** Prentice-Hall, Englewood Cliffs, NJ, pp 498.

Jackson, M.L., 1967. **Soil chemical analysis.** pp183-204. Prentice Hall of India, private limited, NewDelhi.

John H, Sanders and Della E. Macmillan, 2001. Agricultural Technology for the semi-arid Africa Horn. Country Study. Ethiopia. Country report (revised) from **INTSORMIL publication** 01-4 Volume 1.

Jones, 1971. Soil testing and plant analysis for fertilizer recommendations. **Quick Bibliography Series** no. QB96-12.

Jones, O.R and Stewart.1990. Basin tillage. **Soil & Tillage Res**. 18: 249-265.

Jones, O.R. and T.W. Popham. 1997. Cropping and tillage systems for dryland grain production in the southern High Plains. **Agron. J**. 89: 222-232.

Jones, O.R.and R.N. Clark. 1987. Effect of furrow dikes o water conservation and dryland crop yields. **Soil Sci. Soc. Am. J**. 51:1307-1314.

Josa-March, R., A. Hereter-Quintana, I. Queralt and A. Verdú-González. 2002. Efectos de una precipitación intensa sobre los suelos de una cuenca agrícola: Cartografía de las áreas afectadas y comportamiento del horizonte Ap. In: A. Pérez-González, J. Vegas and M.J. Machado, Editors, **Aportaciones a la Geomorfología de España en el Inicio del Tercer Milenio** vol. 1**,** pp. 277–282.

Karlen, D.L., E.C. Berry, T.S. Colvin and R.S. Kanwar. 1991. Twelve-year tillage and crop rotation effects on yields and soil chemical properties in Northeast Iowa. **Plant Annal.** 82: 1985-2003.

Karlen, D.L., P.G. Hunt, and T.A. Matheny. 1996. Fertilizer ^{15}nitrogen recovery by maize, wheat, and cotton growth with and with out pre-plant tillage on loamy sand. **Crop Sci** 36: 975-981.

Kaumbutho, P.G., G. Gebresenbet, T.E Simalenga. 1999. Overview of conservation tillage practices in East and Southern Africa. *In* Conservation Tillage with Animal Traction, Kaumbutho, P.G., and T.E Simalenga eds. **A Resource Book of the Animal Traction Network for Eastern and Southern Africa** (ATNESA). pp1–21.Harare, Zimbabwe.

Kenea, Y., G. Ayele and W. Negattu. 2001. Farming systems research on tef: Smallholders' production practices. pp 15-22. *In* Hailu T., G. Belay and M. Sorrells (eds). Narrowing the rift. Tef research and development. **Proceeding of the International Workshop on tef Genetics and Improvement"**, DebreZeit, Ethiopia. 16-19 October 2000.

Kidane ,G. 1982. The influence of tillage methods and spacing on soil moisture regimes and their effect on growth and development of sorghum in the semi-arid region of Ethiopia. **MSc. Thesis**, Addis Ababa University.

Kidane, G. 1999. Improved crop and crop management practices for sustaining crop production in the semi-arid areas of Ethiopia. Nazereth, Ethiopia, **Institute of Agricultural Research.**

Kidane, G. 2002. **Dryland sorghum agronomy**. Training Workshop on striga resistant sorghum seed production, May 14-17, 2002. Melkassa Agricultural Research Center, Ethiopia.

Kidane G. and F. Rezene. 1989. **Dry land research priorities to increase crop productivity**. Paper presented at the 21st. 1989 NCIC. Addis Ababa, Ethiopia.

Kidane, G. and T. Abuhay. 1997. **Resource base, constraints, and available dryland farming technologies for sustaining in the dryland areas of Ethiopia**, Addis Ababa, Ethiopia, EARO.

Kidane, G., John H. S, Della E. M, Eliud O. O, and Thomas W. 2001. Agricultural Technology for the semi-arid Africa Horn. Country Study. Ethiopia. Country report (revised) from **INTSORMIL publication** 003 volume 2.

Kilew,A.M. and L.Ulsaker. 1984. Topographic modification of land to concentrate and redistribute runoff for crop production. **E. Afi.. agric. For. J**. 44: 254-265.

Knudson, D.M., Peterson, GA. and Pratt, P.F. 1982. Lithium, Sodium and Potassium. In: **Methods of soil analysis part 2**. Chemical and microbial properties. C.A.Black (ed.).

Koskinen, W.C. and C.G. McWhorter, 1986. Weed control in conservation tillage. **J. Soil Water Conservation** 41:365-370.

Krishna, J.H.1989. Modelling the effects of tied ridging on water conservation and crop yields. **Agric. Wat. Manage**.16: 87-95.

Kumar Rao, J.V.D.K., P.J. Dart and P.V.S.S Sastry. 1983. Residual effects of Pigeon pea (*Cajanus cajan*) on yield and Nitrogen response of maize. **Experimental Agric.**19:131-141.

Lal, R.1976. Conservation tillage effects on soil properties under different crops in Western Nigeria. **Soil Sci. Soc. Am. J.** 40: 762-768.

Lal, R.1982. Management of clay soils for erosion control. **Trop. Agric.** (Trinidad) 59: 133-138.

Lal, R.1986. Influence of six years of zero-tillage and conventional plowing on fertilizer response of maize on Alfisol in the tropics. **Soil Sci. Soc. Am. J.** 43: 399-40.

Lal, R.1989. Agroforestry systems and soil surface management of a tropical Alfisols: Water infilterablity, transmittivity and soil water sorpitivity. **Agroforestry Syst.** 8: 217-238.

Lal, R. 1993. Tillage effects on soil degradation, soil resilience, soil quality and sustainability. **Soil Till. Res.** 27: 1–8.

Lal, R. 1996. Axle load and tillage effects on crop yields on a Mollic Ochraqualf in northwest Ohio. **Soil Till. Res**. 37: 143–160.

Lal. R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2 enrichment. **Soil Till. Res.** 43: 81-107.

Lal, R., A.A Mahboubi and N.R. Faussey. 1994. Long-term tillage and rotation effects on properties of a Central Ohio soil. **Soil Sci. Soc. Am. J.** 58: 517–522.

Lamound, R.E, D.A Whitney, J.S. Hickman, and L.C. Bonczkowski. 1991. Nitrogen Rate and Placement for Grain Sorghum Production in Conservation tillage System. **J. Prod. Agri**. Vol.4, no.4, 1991.

Landon, J.R. 1991. **Booker Tropical Soil Manual**. Longman Scientific and Technical Publ., UK.

Laws, D.A, 1961. Rainfall conservation and the yield of cotton in Northern Nigeria. **Emp. J. EXPL. Agric.** 29: 307-318.

Lemma, Z., M.S. Reddy, A. Habtamu, B. Berhane, H. Tsegaye and G. Etagegnew. 1994. Maize Agronomic Research to alleviate moisture stress, low soil fertility and weed problems in the dryland areas of Ethiopia . *In* **Proceedings of the fourth Eastern and Southern Africa Regional Maize Conference**, D..V.Jewell, S.R.Waddington, J.K.Ransom and K.V.Pixley eds. Harare, Zimbabwe pp242-247.

Little, T.M. and F.J. Hills. 1978. Transformation. *In* **Agricultural manual.** Completely revised edition. Mexico, D.F. pp139-165. **Experimentation Design and Analysis.** John Weiley and Sons, New York.

Lopez, M.V, J.L. Arrue and V. Sanchez Giron.1996. A comparison between seasonal changes in soil water storage and penetration resistance under conventional and conservation tillage systems in a Ragon. **Soil & Tillage Res**.37: 251-271.

Lyle, W.M. and D.R. Dixon. 1977. Basin tillage for rainfall retention. **Trans ASAE** 30: 143-147.

M' Arimi, A.M. 1978. The effects of tillage methods and cropping systems on rainfall conservation in a semi-arid area of Eastern Kenya. *In* **Soil and water conservation in Kenya.** IDS, Occasional Paper No. 27. Nairobi, Kenya, University of Nairobi pp. 74-86.

Mabbayad, B.B., B.N. Emerson and E.L Aragon. 1968. Further tests on minimum tillage and rates of nitrogen in transplanted rice. **Philippines Agric.** 55: 216-220.

Mahboubi, A.A., Lal, R. and Faussey, N.R., 1993. Twenty-eight years of tillage effects on two soils in Ohio. **Soil Sci. Soc. Am. J.** 57: 506–512.

Mannering,J.V. and C.R. Fenster.1983.What is conservation tillage?. **Soil & Water cons**. 38: 141-143.

MARC. 1996. **Melkassa Agricultural Research Center Profile.** Melkassa, Ethiopia.

Martel, Y.A., and A.F. Mackenzie. 1980. Long-term effects of cultivation and land use on soil quality in Quebec. **Can. J. Soil Sci.** 60:411-420.

McCartney, J.C., P.J Northwood, M. Dagg and R. Dawson, 1971. The effect of different cultivation techniques on soil moisture conservation, the establishment and yield of maize at the Central Tanzania. **Trop.Agric.** 48: 9-17.

Messersmith, D.T., W.S. Curran, G.W. Roth, N.C. Hartwig and M.D. Orzolek. 2000. The effect of tillage and herbicide effect bure cucummber management in maize. **Agron. J.** 92:181- 185

Mittra, M.K. and J.W.L. PIERIS. 1968. Paraquat as an aid to paddy cultivation. **Proc. 9th British weeds conference.** P 668-672.

MOA (Ministry of Agriculture). 1998. **Agro-ecological zones of** Ethiopia. Natural Resources Management and Regulatory Department. Addis Ababa.

Moll, R.H., E.J. Kamprath and W.A Jackson. 1982. Analysis and interpretation of factors, which contribute to efficiency to nitrogen utilization. **Agrn. J.** 74: 562-564.

MooMaw, J.C., S.K. DeDatta, D.E. Seanan and P. YoGaratnam, 1968. New direction in weed control research in tropical rice. **Proc., 9th British weed control conference** pp675-681.

Moreno, F., F. Pelegrin, J.E. Fernández, J.M. Murillo and I.F. Girón. 2000. Influence of climatic conditions on soil physical properties under traditional and conservation tillage. *In* Subsoil Compaction, Distribution, Processes and Consequences, R. Horn, J.J.H. van den Akker and J. Arvidsson, eds. **Advances in Geoecology,** 32: 295–304.

Moschler, W.W., G.M. Shear, D.C Martens, G.D. Jones, and R.R Wilmouth. 1972. Comparative Yield and Fertilizer Efficiency of Conservation tillage and Conventionally Tilled Maize. **Agron. J**. 64: 229-231.

Mrabet, R. 2000b. Long-term conservation tillage influence on soil quality and wheat production in semi-arid Morocco. *In* **Proceedings of the 15th ISTRO conference**. Tillage at the threshold of the 21st century: Looking ahead, J.E Morrison eds. Fort Worth, TX, July 2-7, 2000.

Muchow, R.C. 1989. Comparative productivity of maize, sorghum and pearl millet in semi-arid tropical environment I. Yield potential. **Field Crops Res**. 20:207-219

Muchow, R.C. and R. Davis. 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in semi-arid tropical environment II. Radiation interception and biomass accumulation. **Field Crop Res**. 18: 17-30.

Murata, Y. and Y. Togari. 1975. Crop productivity and solar energy utilization in various climates in Japan. **Jpn. Com. Int. Biol. Progr**, University of Tokyo Press, 11: 1-36.

Murphy, J. and J. W. Holmes. 1994. A modified single solution method for determination of phosphate in natural waters. **Anal. Chem Acta.** 27: 31-36.

Nagy, J.G., H.W. Ohm and S. Sawadogo. 1990. Farmer Researcher Collaboration in Developing Cropping Practices that Involve the Complementary use of

Mechanical Tie-ridge and fertilizer technology for sorghum in Burkina Faso. **Exp. Agric**. 26:161-169.

Nelson, D.W. and L.E Sommers. 1982. Total carbon, organic carbon and organic matter. *In* Methods of Soil Analysis part 2. **Chemical and Microbial Properties**. C.A.Black ed.

Nigussie, T. 1995. Cropping systems research status and future trends in the rift valley. Weeds, Insect Pests and Diseases. *In* **Proceedings of the 25th Anniversary of Nazareth Agricultural Research Center:** 25 years of experiences in lowland crops research, A. Habtu eds. Nazareth, Ethiopia. pp 22-27.

Njihia C.M. 1979. The effect of tied ridges, stover mulch, and farmyard manure on water conservation in a medium potential area, Katumani, Kenya. *In* **Soil Tillage and Crop Production**, R. Lal R. (ed). IITA, Ibadan, Nigeria. pp 295-302.

Nyakatawa, E.Z. 1996. Rain water and soil fertility management for sustainable cropping on sandy soils in semi-arid South-East Lowveld of Zimbabwe. **J. Sustain. Agric**. 7:19-34.

O'Halloran, I.P. 1992. Effects of tillage, fertilization, and continuous maize production on maize yield and soil organic matter content. **Macdonald J**. 53(l): 10-11.

Okoba B. O., S.J. Twomlow and C.R. Mugo. 1997. Evaluation of Indigenous Soil and Water Conservation Technologies in Semi-arid Mbeere District, Kenya. *In* Modern methods from traditional technologies. **Proceedings, Land Management Workshop**, Kabale - Uganda.

Olsen, R. S. and L. E. Sommers. 1982. Phosphorus. PP 403-427. *In* **Methods of Soil Analysis, part II** 2nd eds, A. L. Page, R. H. Miller and D. R. Keeney (eds.), ASA, Madison.

Olsen, R.V., and C.W. Swallow. 1984. Fate of labeled nitrogen fertilizer applied to winter wheat for five years. **Soil Soc. Am. J**. 48: 583-586.

Ortega, R.A., G.A. Peterson and D.G. Westfall. 2002. Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems, **Agron. J. 94** (2002), pp. 944–954.

Pathak, B.S. 1988. Agricultural Mechanization Options for Ethiopia. Ethiopian **J. Agri. Sci.** 10: 1-2.

Pelegrín, F., F. Moreno, J. Martin-Aranda and M. Camps, 1990. The Influence of tillage methods on soil physical properties and water balance for a typical crop rotation in SW Spain, **Soil Tillage Res.** 16: 345–358.

Pickett, J., 1991. **Economic development in Ethiopia**: Agriculture, the market and the state. Paris, OECD.

Pieri, C. and K.G Steiner. 1997. **Agric. Dev. Rural** 1: 23-26.

Piha, M.J. 1993. Optimizing fertilizer use and practical rainfall capture in a semi-arid environment with variable rainfall. **Expl. Agric**. 29: 403-415.

Power, J.F. 1983. Soil management for efficient water use: Soil fertility. *In* Limitations to efficient water use in crop production, H.M. Taylor *et al*. eds. ASA, Madison, WI. pp 461-470.

Rachman, A., S.H. Anderson, C.J. Gantzer and A.L. Thompson, 2003. Influence of long-term cropping systems on soil physical properties related to soil erodibility, **Soils Sci. Soc. Am. J. 67** (2003), pp. 637–644.

Radford, B.J., A.J. Dry, L.N. Robertson, and B.A. Thomas.1995. Conservation tillage increases soil water storage, soil animal population. **J. Soil Water Consv.** 40: 466-470.

Rao, S.C., and T.H. Dao. 1996. Nitrogen placement and tillage effects on dry matter and nitrogen accumulation and distribution in winter wheat. **Agrn. J**. 88(3): 365-371.

Reddy, M.S., and G. Kidane. 1993. **Dryland farming in** Ethiopia: Review of the past and thrust in the nineties, Addis Ababa, Ethiopia: Institute of Agricultural Research.

Reddy, M.S. and G. Kidane. 1994. Development of Technologies for the Dryland Farming Areas of Ethiopia: **Proceedings of the First National Workshop on Dryland Farming Research in Ethiopia**. IAR and FAO, Addis Ababa, Ethiopia.

Reicosky, D.C., W.B. Voorhees and J.K. Radke. 1981. Unsaturated water flow through a simulated wheel track. **Soils Sci. Soc. Am. J. 45** (1981), pp. 3–8.

Rezene, F. and Z. Tadale. 2001. Weed Research in tef. *In* narrowing the rift. Tef research and development. **Proceeding of the International Workshop on tef Genetics and Improvement,** Hailu T., G. Belay and M. Sorrells eds. DebreZeit, Ethiopia. pp 40-46.

Sanchez, C.A., and A.M. Blackmer. 1988. Recovery of anhydrous ammonia-derived nitrogen-15 during three years of maize production in Iowa. **Agron. J.** 80: 102-108.

SAS (Statistical Analysis System). 1988. User's guide. SAS Inc., Cary, NC, USA, 1686 pp.

Savant, N.K. and S.K. De Datta. 1982. Nitrogen transformationin wet land rice soils. **Adv. Agron**. 35: 241-302.

Schlesinger, W. H. 2001. Carbon sequestration in soils: some cautions admit optimism. **Agric. Ecosyst. Environ.** 82 (2000), pp. 121-127.

Schneider, E.C. and S.C. Gupta. 1985. Maize emergence as influenced by soil temperature, matrix potential, and aggregate size distribution. **Journal of the Soil Science Society of America**. 49: 415-422.

Seetharmaa, N. and P. Soman. 1990. Fitting crop genotypes to Abiotic stress environment. *In* Trends in crop improvement: **Proceeding of regional seminar on innovative ideas in plant research**. Behl, R.K. and N. Maherchandani eds. New Delhi, India. pp 138-145.

Seth, A.K., C.H. Khaw and J.M.Fua, 1971. Minimum and zero tillage techniques and post planting weed control in rice. **Proc. 3rd Asian-Pacific weed science. Soc. Conf.**, Kuala Lumpur, Malaysia.

Sharma, P.K., and C.L. Acharya. 2000. Carry-over of residual soil moisture with mulching and conservation tillage practices for sowing of rain fed wheat (*Triticum aestivum* L.) in northwest India. **Soil & Tillage Res**. 57: 43-52.

Singh, T.A., G.W. Thomas, W.W. Moschler, and D.C. Martens. 1966. “Phosphorus uptake by maize under no tillage and conventional practices.” **Agron.J**.58: 147-148.

Southard, R. J. and S. W. Buol. 1988. Subsoil blocky structures formation in some North Carolina Paleudults and Paleaquults. **Soil Sci. Soc. Am. J**. 52: 1069-1076.

Sow, A.A., L.R. Hossner, P.W. Unger and B.A. Stewart.1996. Effects of furrow diking and tillage on water storage, plant water use efficiency and yield of sorghum. **African Crop Sci. J**. 4: 433-440.

Spargue, M. A. and G.B. Triplett. 1984. **Conservation tillage and surface tillage agriculture**. The tillage revolution. Johon Willey and Sons Publications.

SPSS, 1999. SPSS (Statistical Package for Social Sciences), 1999. SPSS Base 10. User's Guide, 1999 ed. SPSS Inc., Chicago, IL, 537 pp.

Strategic Planning and Management (SPM). 1999. The strategic planning of Oromiya Rural and Agricultural Development Supreme Office (RADSO) for 2004-2006. 76 p.

Stobbe, M.E. 1990. Conservation tillage. *In* **Proceedings of the 6th Regional Wheat Workshop for Eastern, Central and Southern Africa**, D.G. Tanner, M. van Ginkel, and W. Mwangi eds. CIMMYT, Mexico, D.F., Mexico, pp 120–132.

Stroud, A. 1989. Weed management in Ethiopia. An extensition and training manual. **FAO, Technical Cooperation Programe**, Rome. 237 p.

Stwart, J.lan. 1987. Response farming: A scientific approach to ending starvation and alleviating poverty in drought zones of Africa. **Proc.African Agricultural**

Development Conf., California State polytechnic University, Pomonia. May 28- June 2, 1986 pp 50-52.

Taylor and Jackson 1965. Soil temperatue. *In* **Methods of Soil Analysis part 2**. Chemical and Microbial Property. C.A.Black ed.

Teasdale, J.R., C. E. Beste and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. **Weed Sci.,** 39: 195-199.

Tesfa, B. 2001. Conservation tillage in Jimma Zone. *In* **Proceedings of the first Conservation Tillage Workshop in Ethiopia**. Feb 28-march 1, 2001. Melkassa agricultural research center, Ethiopia.

Tesfa, B., L. Tullu and E. Tadesse. 2003. Conservation tillage in Jimma Zone. *In* **Proceedings of the workshop on conservation tillage in Ethiopia**. April 4, 2002. MARC Agricultural Research Center, Ethiopia. pp 10-14.

Tilahun, M., T. Regassa and A. Kefyalew. 1992. Farming system of Nazaret area. *In* **Research with farmers: Lesson from Ethiopia.** S. Franzel and H. Van Houten (eds). C.AB International UK.

Tolessa, D. 2001. Conservation tillage in Bakko area. *In* **Proceedings of the first Conservation Tillage Workshop in Ethiopia.** Feb 28-march 1, 2001. Melkassa agricultural research center, Ethiopia.

Tolessa, D. 2003. Conservation tillage in Bakko area. *In* **Proceedings of the workshop on conservation tillage in Ethiopia**, April 4, 2002. MARC Agricultural Research Center, Ethiopia. pp 4-9.

Triplett, G.B. 1986. Crop management practices for surface-tillage systems. *In* **Zero-tillage and surface-tillage agriculture.** The tillage revolution, M.A. Sprague and G.B. Triplett (eds.) John Wiley, New York. pp 149-182.

Unger, P.W. 1984. Tillage and residue effects on wheat, sorghum, sunflower grown in rotation. **Soil Sc. Soc. Am. J.**, 48: 885-891.

Unger, P.W. and R.L. Baumhardt. 1999. Factors related to dryland grain sorghum yield increases: **Agron. J**. 91: 870–875.

Unger, PW and J.J. Parker. 1975. Tillage Effects on dryland wheat and sorghum production in the Southern Great Plains. **Agron. J.** 86: 310-314.

Unger, P.W., and B.A. Stewart. 1983. Soil management for efficient water use. An overview. *In* **Limitations to efficient water use in crop production**, H.M. Taylor *et al*. (eds.) ASA, Madison, WI. Pp 419-460.

Vanderlip, R.L. and H.E. Reevs. 1972. Growth stages of sorghum (*Sorghum bicolor* (L.) Moench). **Agron. J**. 64:13-16

Vyn, T.J. and B.A. Raimbault. 1993. Long-term effect of five tillage systems on maize response and soil structure. **Agron. J**. 85: 1074–1079.

Wagger, M.G. and H.P. Denton. 1989. Tillage Effects on Grain Yield in Wheat, Double-Crop Soybean, and Maize Rotation. **Agron. J**. 81:493-498.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops 1. Variation in net assimilation rate and leaf area index between species and varieties and within and between years. **Ann. Bot**. 11: 41-76.

Weill, A.N., C.R. De Kimpe and B. Mckyes., 1988. Effect of tillage reduction and fertilizer on soil macro and micro aggregation. **Can. J. Soil Sci**. 69: 489-500.

Wienhold, B.J., T.P. Trooien, and G.A. Reichman. 1995. Yield and nitrogen use efficiency of irrigated maize in the northern Great Plains. **Agron. J**. 87: 842-846.

Williford, J.R., O.B. Wooten and F.E. Fulgham. 1972. Tractor mounted field penetrometer. **Trans. ASAE** 15: 226–227.

Wondimu B. and A. Getachew. 1998. Soil Management and Crop Technologies for improved Crop production in marginal rainfall areas of Wello. *In* Agricultural Research and Technology Transfer attempts and achievements in Northern Ethiopia, S. Beyene and D. Aberra (eds.). **Proceedings of the Fourth Technology Generation, Transfer and Gap Analysis Workshop**. 18-21 March 1997, Bahir Dar, Ethiopia.

Worku, B. 2001. Observation trials on conservation tillage practices at Malkassa Agricultural Research Center. *In* **Proceedings of the first Workshop on Conservation Tillage in Ethiopia,** Feb 28-march 1, 2001. Malkassa Agricultural Research Center, Ethiopia.

Worku, B. 2002. Observation trials on conservation tillage practices in the dryland, central rift valley of Ethiopia. *In* **Proceedings of the Workshop on Conservation Tillage in Ethiopia (April 4, 2002).** pp 15-22. Malkassa Agricultural Research Center, Ethiopia.

Worku, B., M. Tewodros, M. Hussein, D. Tollesa, and M. Birtukan. 2002. A review of tillage management research on maize in Ethiopia. *In* **Proceedings of the second national maize workshop of Ethiopia,** N. Mandefro, D.G. Tanner, and S. Twumasi-Afriyie (eds.). pp 12-16. Addis Ababa, Ethiopia, Ethiopia

Agricultural Research Organization (EARO) and International Maize and Wheat Improvement Center (CIMMYT).

Worku, B. and H. Harun. 2004. The role of conservation tillage on crop production under dryland conditions. *In* **Proceedings of the Workshop on Conservation Tillage in Ethiopia (June 4, 2003).** pp 36-39. Malkassa Agricultural Research Center, Ethiopia.

Worku B. and C. Sombat. 2005. Conservation Tillage-Alternative Systems of Tef (*Eragrostis tef*) Production for a Semi-Arid, Central Rift Valley of Ethiopia. Kamphaengsaen Acad. J. 3 (3): 1-10.

Worku B., C. Sombat, S. Rungsit, M. Thongchai, and J. Sunanta. 2006a. Tillage System and Fertilizer Rate Effects on Sorghum Productivity in the Central Rift Valley of Ethiopia. Kasetsart J. (Nat. Sci.) 40 (1).

Worku B., C. Sombat, S. Rungsit, M. Thongchai, and J. Sunanta. 2006b. Conservation Tillage and Crop Rotation: Concomitant Systems to Harmonize Tef [*Eragrostis tef* (Zucc.) Trotter)] Production with Sustainability in the Drylad Oromiya. Kasetsart J. (Nat. Sci.) 40 (2).

Worku B., C. Sombat, S. Rungsit, M. Thongchai, and J. Sunanta. 2006c. Conservation Tillage and Crop Rotation: Win-Win Options for Sustainable Maize Production in the Dryland, Central Rift Valley of Ethiopia. Kamphaengsaen Acad. J. (in press).

APPENDIX

Appendix Table 1 Analysis of variance table for sorghum stand count.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	Sum of Square (SS)	Mean of Square (MS)	F Value	Prob
1	Replication	1	16576519.820	16576519.820	81.0009	0.0704
2	Factor A	1	540009023.827	540009023.827	2638.7440	0.0124
-3	Error	1	204646.233	204646.233		
4	Factor B	3	5534460169	1844820056.347	6.1304	0.0294
6	AB	3	36240072.490	12080024.163	0.0401	
-7	Error	6	1805583222.331	300930537.055		
8	Factor C	3	450874496.930	150291498.977	1.1425	0.3520
10	AC	3	24615918.346	8205306.115	0.0624	
12	BC	9	4364884288.186	484987143.132	3.6868	0.0051
14	ABC	9	182514809.878	20279423.320	0.1542	
-15	Error	24	3157138817.956	131547450.748		
	Total	63	16113101985.039			
Coefficient of Variation: 19.56%						

Appendix Table 2 Analysis of variance table for sorghum plant height.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	0.681	0.681	0.0125	
2	Factor A	1	1144.131	1144.131	21.0354	0.1367
-3	Error	1	54.391	54.391		
4	Factor B	3	290.572	96.857	0.5803	
6	AB	3	997.356	332.452	1.9919	0.2167
-7	Error	6	1001.413	166.902		
8	Factor C	3	348.207	116.069	2.3009	0.1028
10	AC	3	347.772	115.924	2.2980	0.1031
12	BC	9	1329.306	147.701	2.9279	0.0171
14	ABC	9	357.491	39.721	0.7874	
-15	Error	24	1210.695	50.446		
	Total	63	7082.014			
Coefficient of Variation: 4.83%						

Appendix Table 3 Leaf area index of sorghum at WARSS (W) and MARC (M).

Tillage System	Days After Planting 45		60		90	
	WARSS*	MARC	WARSS	MARC	WARSS	MARC
CT	1.87 a	1.92	2.47 ab	6.19 ab	2.02 b	6.44
RT	1.68 a	1.66	2.85 a	7.12 a	2.05 b	5.72
NT	1.59 a	1.95	2.61 ab	6.51 ab	1.93 b	5.87
TR	1.27 b	1.90	2.14 b	5.51 b	2.76 a	5.45
MSE	0.1278	0.614	0.3600	2.331	0.453	2.149
LSD	0.2973	0.658	0.499	1.269	0.559	1.219
CV	22.29	42.22	23.83	24.12	30.69	24.97

* Means followed by the same letter are not significantly different at 5% probability level.

Appendix Table 4 Sorghum leaf dry matter (gm/plant) at WARSS (W) and MARC (M).

Tillage	Days After Planting 45		60		90	
	WARSS*	MARC	WARSS	MARC	WARSS	MARC
CT	11.15 a	5.93 a	21.61 ab	21.99 ab	33.44 a	25.08 a
RT	11.03 a	3.79 a	24.79 a	25.68 a	35.72 a	21.64 a
NT	9.92 ab	4.68 a	21.54 ab	20.97 ab	36.68 a	22.88 a
TR	8.24 b	5.56 a	17.99 b	17.32 b	39.09 a	22.03 a
MSE	4.93	7.37	30.96	33.40	87.91	41.06
LSD	1.85	2.25	4.62	4.81	7.80	5.33
CV	21.84	54.38	25.90	26.89	25.87	27.97

* Means followed by the same letter are not significantly different at 5% probability level.

Appendix Table 5 Analysis of variance table for head height of sorghum.

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	58.141	58.141	12.8754	0.1730
2	Factor A	1	6.891	6.891	1.5260	0.4332
-3	Error	1	4.516	4.516		
4	Factor B	3	10.922	3.641	0.8837	
6	AB	3	66.172	22.057	5.3540	0.0392
-7	Error	6	24.719	4.120		
8	Factor C	3	20.547	6.849	0.8381	
10	AC	3	44.297	14.766	1.8069	0.1728
12	BC	9	48.391	5.377	0.6580	
14	ABC	9	34.391	3.821	0.4676	
-15	Error	24	196.125	8.172		
	Total	63	515.109			
Coefficient of Variation: 12.52%						

Appendix Table 6 Analysis of variance table for sorghum seed dry weight.

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	11.056	11.056	30.7101	0.1137
2	Factor A	1	5278.022	5278.022	14661.1854	0.0053
-3	Error	1	0.360	0.360		
4	Factor B	3	55.378	18.459	0.6621	
6	AB	3	54.154	18.051	0.6475	
-7	Error	6	167.279	27.880		
8	Factor C	3	32.338	10.779	1.0500	0.3886
10	AC	3	29.566	9.855	0.9600	
12	BC	9	86.778	9.642	0.9392	
14	ABC	9	188.182	20.909	2.0367	0.0794
-15	Error	24	246.385	10.266		
	Total	63	6149.499			
Coefficient of Variation: 18.20%						

Appendix Table 7 Analysis of variance table for grain yield of sorghum.

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	23584.178	23584.178	0.6582	
2	Factor A	1	6429847.757	6429847.757	179.4589	0.0474
-3	Error	1	35829.078	35829.078		
4	Factor B	3	679458.572	226486.191	1.2155	0.3822
6	AB	3	576964.222	192321.407	1.0321	0.4429
-7	Error	6	1117996.070	186332.678		
8	Factor C	3	1199538.121	399846.040	8.1953	0.0006
10	AC	3	120853.122	40284.374	0.8257	
12	BC	9	434115.642	48235.071	0.9886	
14	ABC	9	192165.492	21351.721	0.4376	
-15	Error	24	1170958.102	48789.921		
	Total	63	11981310.355			
Coefficient of Variation: 10.70%						

Appendix Table 8 Analysis of variance table for stover yield of sorghum.

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	347257.607	347257.607	1.2949	0.4590
2	Factor A	1	50342398.906	50342398.906	187.721	0.0464
-3	Error	1	268176.025	268176.025		
4	Factor B	3	3292587.971	1097529.324	1.8362	0.2411
6	AB	3	1243268.116	414422.705	0.6934	
-7	Error	6	3586238.814	597706.469		
8	Factor C	3	1087018.081	362339.360	0.7464	
10	AC	3	1741780.095	580593.365	1.1959	0.3324
12	BC	9	3412626.780	379180.753	0.7810	
14	ABC	9	2277139.377	253015.486	0.5212	
-15	Error	24	11651503.298	485479.304		
	Total	63	79249995.069			
Coefficient of Variation: 17.10%						

Appendix Table 9 Analysis of variance table for sorghum aboveground biomass.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	551836.696	551836.696	5.1115	0.2651
2	Factor A	1	20789255.647	20789255.647	192.5663	0.0458
-3	Error	1	107958.972	107958.972		
4	Factor B	3	6871351.812	2290450.604	2.9179	0.1225
6	AB	3	685070.968	228356.989	0.2909	
-7	Error	6	4709846.652	784974.442		
8	Factor C	3	1140183.812	380061.271	0.7912	
10	AC	3	976125.148	325375.049	0.6773	
12	BC	9	3683320.489	409257.832	0.8520	
14	ABC	9	2179919.769	242213.308	0.5042	
-15	Error	24	11528836.332	480368.181		
	Total	63	53223706.295			
Coefficient of Variation: 11.29%						

Appendix Table 10 Analysis of variance table for harvest index of sorghum.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	1	0.000	0.000	0.0142	
2	Factor A	1	0.422	0.422	392.0224	0.0321
-3	Error	1	0.001	0.001		
4	Factor B	3	0.001	0.000	0.0554	
6	AB	3	0.017	0.006	1.7562	0.2550
-7	Error	6	0.020	0.003		
8	Factor C	3	0.024	0.008	4.6477	0.0106
10	AC	3	0.011	0.004	2.0742	0.1303
12	BC	9	0.014	0.002	0.8945	
14	ABC	9	0.008	0.001	0.4932	
-15	Error	24	0.042	0.002		
	Total	63	0.561			
Coefficient of Variation: 12.12%						

Appendix Table 11 Analysis of variance for maize stand count.

K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	174237013.343	87118506.672	0.2154	
2	Factor A	1	1575129595.269	1575129595.269	3.8937	0.1872
-3	Error	2	809065361.533	404532680.767		
4	Factor B	4	194812085.301	48703021.325	1.1417	0.3725
6	AB	4	281784530.993	70446132.748	1.6514	0.2102
-7	Error	16	682515770.285	42657235.643		
8	Factor C	1	7440069708.039	7440069708.039	69.7023	0.0000
10	AC	1	1224806275.545	1224806275.545	11.4746	0.0029
12	BC	4	63396601.788	15849150.447	0.1485	
14	ABC	4	272095841.067	68023960.267	0.6373	
-15	Error	20	2134813819.669	106740690.983		
	Total	59	14852726602.833			

Coefficient of Variation: 18.96%

Appendix Table 12 Analysis of variance for maize cob number (cob/ha).

K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	4867706.558	2433853.279	0.0204	
2	Factor A	1	33192301.657	33192301.657	0.2788	
-3	Error	2	238077626.280	119038813.140		
4	Factor B	4	40709520.701	10177380.175	0.1419	
6	AB	4	113306444.588	28326611.147	0.3950	
-7	Error	16	1147380045.847	71711252.865		
8	Factor C	1	1805449129.037	1805449129.037	24.2533	0.0001
10	AC	1	87960240.320	87960240.320	1.1816	0.2900
12	BC	4	73755882.579	18438970.645	0.2477	
14	ABC	4	75590640.058	18897660.015	0.2539	
-15	Error	20	1488826446.040	74441322.302		
	Total	59	5109115983.666			

Coefficient of Variation: 23.41%

Appendix Table 13 Analysis of variance for maize cob weight (kg/ha).

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	919.507	459.753	0.0232	
2	Factor A	1	3108312.981	3108312.981	156.7405	0.0063
-3	Error	2	39661.910	19830.955		
4	Factor B	4	103356.447	25839.112	1.2936	0.3141
6	AB	4	128240.258	32060.064	1.6050	0.2214
-7	Error	16	319602.528	19975.158		
8	Factor C	1	617762.607	617762.607	41.4711	0.0000
10	AC	1	159095.052	159095.052	10.6802	0.0038
12	BC	4	38275.259	9568.815	0.6424	
14	ABC	4	30774.218	7693.554	0.5165	
-15	Error	20	297924.059	14896.203		
	Total	59	4843924.825			
Coefficient of Variation: 29.62%						

Appendix Table 14 Analysis of variance for grain yield of maize.

A N A L Y S I S O F V A R I A N C E T A B L E						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	71136.220	35568.110	0.1385	
2	Factor A	1	1896528.450	1896528.450	7.7646	0.0083
-3	Error	2	513735.919	256867.959		
4	Factor B	4	824854.461	206213.615	1.0171	0.4280
6	AB	4	850425.559	212606.390	1.0486	0.4133
-7	Error	16	3243978.070	202748.629		
8	Factor C	1	19400813.930	19400813.930	70.2427	0.0000
10	AC	1	1858404.972	1858404.972	6.7286	0.0174
12	BC	4	409366.737	102341.684	0.3705	
14	ABC	4	786525.316	196631.329	0.7119	
-15	Error	20	5523934.420	276196.721		
	Total	59	35379704.053			
Coefficient of Variation: 32.22%						

<u>Appendix Table 15</u> Analysis of variance for stover yield of maize.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	2239562.714	1119781.357	1.2970	0.4353
2	Factor A	1	7918760.346	7918760.346	9.1723	0.0939
-3	Error	2	1726669.250	863334.625		
4	Factor B	4	2137760.915	534440.229	0.8356	
6	AB	4	4096530.264	1024132.566	1.6012	0.2223
-7	Error	16	10233416.143	639588.509		
8	Factor C	1	46126981.244	46126981.244	110.8881	0.0000
10	AC	1	10684429.057	10684429.057	25.6851	0.0001
12	BC	4	1865272.550	466318.138	1.1210	0.3745
14	ABC	4	943537.583	235884.396	0.5671	
-15	Error	20	8319551.845	415977.592		
	Total	59	96292471.910			
Coefficient of Variation: 23.37%						

<u>Appendix Table 16</u> Analysis of variance for aboveground biomass of maize.

ANALYSIS OF VARIANCE TABLE						
KValue	Source	df	SS	MS	F Value	Prob
1	Replication	2	3150457.586	1575228.793	0.5830	
2	Factor A	1	7718318.403	7718318.403	2.8566	0.2331
-3	Error	2	5403860.046	2701930.023		
4	Factor B	4	6831971.559	1707992.890	0.9004	
6	AB	4	8103479.562	2025869.890	1.0680	0.4045
-7	Error	16	30351408.753	1896963.047		
8	Factor C	1	153310506.064	153310506.064	104.4767	0.0000
10	AC	1	518225.717	518225.717	0.3532	
12	BC	4	5406670.989	1351667.747	0.9211	
14	ABC	4	4025313.460	1006328.365	0.6858	
-15	Error	20	29348268.705	1467413.435		
	Total	59	254168480.843			
Coefficient of Variation: 24.54%						

<u>Appendix Table 17</u> Analysis of variance for harvest index of maize.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	0.004	0.002	10.8067	0.0847
2	Factor A	1	0.001	0.001	7.8235	0.1076
-3	Error	2	0.000	0.000		
4	Factor B	4	0.002	0.000	0.1923	
6	AB	4	0.011	0.003	1.2800	0.3189
-7	Error	16	0.035	0.002		
8	Factor C	1	0.001	0.001	0.3133	
10	AC	1	0.122	0.122	47.0821	0.0000
12	BC	4	0.009	0.002	0.8456	
14	ABC	4	0.003	0.001	0.3029	
-15	Error	20	0.052	0.003		
	Total	59	0.239			
Coefficient of Variation: 15.37%						

<u>Appendix Table 18</u> Analysis of variance for grain yield of Taaffi.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	322421.592	161210.796	14.5690	0.0642
2	Factor A	1	46600.272	46600.272	4.2114	0.1766
-3	Error	2	22130.634	11065.317		
4	Factor B	4	106036.203	26509.051	0.3189	
6	AB	4	227629.584	56907.396	0.6845	
-7	Error	16	1330214.447	83138.403		
8	Factor C	1	2170330.646	2170330.646	45.4447	0.0000
10	AC	1	43499.007	43499.007	0.9108	
12	BC	4	504652.188	126163.047	2.6417	0.0641
14	ABC	4	271941.343	67985.336	1.4235	0.2626
-15	Error	20	955153.212	47757.661		
	Total	59	6000609.129			
Coefficient of Variation: 21.00%						

<u>Appendix Table 19</u> Analysis of variance for Taaffi straw yield.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	730007.555	365003.777	0.3257	
2	Factor A	1	12270185.376	12270185.376	10.9493	0.0805
-3	Error	2	2241272.558	1120636.279		
4	Factor B	4	156309.369	39077.342	0.0818	
6	AB	4	2699948.924	674987.231	1.4134	0.2745
-7	Error	16	7641069.624	477566.852		
8	Factor C	1	8008711.672	8008711.672	32.9349	0.0000
10	AC	1	295787.692	295787.692	1.2164	0.2832
12	BC	4	3345792.677	836448.169	3.4398	0.0270
14	ABC	4	223943.729	55985.932	0.2302	
-15	Error	20	4863361.703	243168.085		
	Total	59	42476390.878			
Coefficient of Variation: 21.74%						

<u>Appendix Table 20</u> Analysis of variance for aboveground biomass of Taaffi.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	1847728.874	923864.437	0.6825	
2	Factor A	1	10804443.675	10804443.675	7.9823	0.1058
-3	Error	2	2707103.116	1353551.558		
4	Factor B	4	79927.458	19981.865	0.0246	
6	AB	4	4476163.048	1119040.762	1.3798	0.2850
-7	Error	16	12975805.871	810987.867		
8	Factor C	1	18517280.588	18517280.588	42.6806	0.0000
10	AC	1	112425.791	112425.791	0.2591	
12	BC	4	6145939.099	1536484.775	3.5415	0.0243
14	ABC	4	867068.520	216767.130	0.4996	
-15	Error	20	8677144.143	433857.207		
	Total	59	67211030.183			
Coefficient of Variation: 19.90%						

Appendix Table 21 Analysis of variance for harvest index of Taaffi.

ANALYSIS OF VARIANCE TABLE						
K Value	Source	df	SS	MS	F Value	Prob
1	Replication	2	0.011	0.005	0.5264	
2	Factor A	1	0.172	0.172	16.5879	0.0553
-3	Error	2	0.021	0.010		
4	Factor B	4	0.005	0.001	0.5294	
6	AB	4	0.004	0.001	0.4172	
-7	Error	16	0.035	0.002		
8	Factor C	1	0.000	0.000	0.0758	
10	AC	1	0.024	0.024	12.2754	0.0022
12	BC	4	0.007	0.002	0.8688	
14	ABC	4	0.005	0.001	0.6043	
-15	Error	20	0.039	0.002		
	Total	59	0.322			
Coefficient of Variation: 13.56%						

Appendix Table 22 Summary of perception analysis.

Parameter	East Shoa	Jimma	West Shoa
Yearly food and income generation (%)	7.7	60	9.1
Enough produce only for 3/4th of a year (%)	53.8	40	45.5
Enough produce only for ≤ ½ of a year (%)	38.5	0	45.5
Labor shortage all the time (%)	76.9	0	60
Labor shortage for some time (%)	23.1	80	20
No labor shortage (%)	0	20	20
Active age (year)	30-60	25-55	28-60
Farm experiences (year)	15-44	20-35	12-45
Formal education (%)	15.4	20	9
Farm size (ha)	0.5-3.5	0.5-5.0	2.0-5.0
Family size (number)	2-10	2-14	7-9
Have a pair of oxen (%)	53.8	100	80
Have at least one ox (%)	92.3	100	100
Farm characterization as not bad (%)	92.3	100	95%
Adopt conservation tillage if herbicide cost Birr 70-80/l (%)*	3%	0	0
Adopt conservation tillage if herbicide cost 40-50 Birr (%)	30	20	60
Adopt conservation tillage if herbicide cost < 40 Birr (%)	67	40	100
Adopt conservation tillage if free (%)	100	80	100
Need not adopt conservation tillage (%)	0	20	0
Possess improved agricultural implement (%)	3	0	0
Major constraints for crop production**	M-F-W	F-W-M	M-F-W
Population	2321510	2622847	3115057
Land (km^2)	13624	18412	21551

*At a moment 8.68 Ethiopian currency (Birr) could buy 1 USD (Birr 8.68 = $ 1.0); ** M = Moisture stress, F = Poor soil fertility, W = Weeds.

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