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# Conservation Agriculture Based Annual Intercropping System for Sustainable Crop Production: A review

**Yayeh Bitew and Merkuz Abera[1]**

*Amhara Agricultural Research Institute, [1]College of Agriculture and Environmental Sciences, Department Of Plant Science, Bahir Dar University, Bahir Dar, Ethiopia*
*E-mail: yayehbitew@gmail.com*

***Abstract***: The objective of this paper was to provide an inclusive view and evaluation of conservation tillage based annual intercropping, summarizing their main advantages and challenges to use as compared to conventional crop production system. Conservation tillage based intercropping (CTBI) controls soil erosion caused by conventional tillage based sole/mono-cropping as compared to conventional crop production system. Its long term effect gives higher percentage of organic matter and organic carbon as compared to conventional tillage based mono-cropping due addition of carbon input from the intercropped legumes and residues from conservation tillage. CTBI system in the long term significantly lowers the bulk density in the top layer and in turn improves the soil pore size distribution. Similarly, it resulted in higher total N, available K and Mg content than conventional crop production system. CTBI had significantly higher infiltration characteristics, soil water content, water use efficiency than continuous sole cropping and conventional tillage based intercropping. And also establishes more biodiversity into agroecosystems and reduces the addition of chemicals and gases that triggers greenhouse gas accumulation in the atmosphere. The CTBI is used as the primary means of sustainable crop production system by improving soil health, promoting diversity of diet, stability of production, reduced pests, efficient use of labor, intensification of production with limited resources, maximization of returns under low levels of technology and used as insurance against crop failure. However, in Ethiopia conservation tillage based annual intercropping system becomes effective if and only if inclusive research and extension service and appropriate land use policy over it should be implemented.

***Keywords***: Conservation tillage, Annual Intercropping, Soil fertility, Crop production

In the world the change from complex agricultural systems to less complex systems with lower species numbers was a major feature of agricultural development in the 21th century (Crews and Peoples 2003). In African, most crops are today grown continually as a monoculture and sole cropping system under conventional tillage practice (Itoa et al 2000, Lithourgidis et al 2011, Zerihun et al 2014). The improvement of crop varieties and fertilizers under intensive land cultivation has resulted in a change from rotational cropping to the continuous cropping of high yielding crops (Crews and Peoples 2003), allowing us to a large extent to ignore issues of soil fertility, crop pests (diseases, insect pests and weed infestation), yield stability and in general the issue of food and environmental security (Lithourgidis et al 2011). Thus, most present cultivation practices and cropping systems are relatively independent of internal ecological functions and are to a great degree based on the supply of inputs from the outside. In Ethiopia, little research and poor extension service on conservation tillage based annual intercrops are the main problems associated with sole cropping and mono-cropping under conventional tillage (Zerihun et al 2014, Bitew 2014). This is clearly exemplified by Ethiopian current agricultural lands decrease in soil fertility (Tadesse et al 2012), occurrence of new pests and disease and recurrent drought and long dry spells in a short interval of years (FAO 2014). Natural resource degradation and in turn slow crop productivity per hectare increment due to improper land cultivation and cropping system are the main environmental problem in Ethiopia (Tadesse et al 2012, Gebru Hailu 2015). As a result, Ethiopia loses annually 1.5 billion metric tons of top soil by erosion (Enyew et al 2013). This could have added about 1 to1.5 million metric tons of grain to the country's harvest. Furthermore, at farmer's field, teff, maize, sorghum and wheat are the dominant grain crops in the country and gave about 64.42, 69.41, 66.57 and 57.81percent less grain yield as compared to their potential yield for the last decades (CSA 2013, EIAR 2016).

Restoring on-farm biodiversity and soil fertility through diversified farming systems that mimic nature is considered to be a key strategy for sustainable agriculture (Thrupp 2002, Jackson et al 2007). On-farm biodiversity, if correctly assembled in time and space, can lead to agro ecosystems capable of maintaining their own soil fertility, regulating natural protection against pests and diseases and sustaining productivity (IIRR and ACT 2005, Sheibani and Ahmad 2013). Biodiversity in agroecosystems can be enhanced in time through conservation tillage (crop rotations cover cropping and zero tillage (Mal´ et al 2009). intercropping (Yayeh et al 2015) or through integrating conservation tillage and intercropping system (Thierfelder et al 2001, Ajayi 2015). While conventional agriculture containing intensive land preparation and sole/monocropping has brought vast increases in productivity for a short period of time, it is widely recognized that much of this may have come at the price of sustainability (Lichtfouse et al 2009).This is because this farming system implies the simplification of the structure of the environment over vast areas, replacing natural plant diversity with only a limited number of cultivated plants in extensive areas of arable monocultures and sole cropping system (Andersen et al 2007). Moreover, perhaps the most universally applicable one is that if one crop fails, or performs poorly, the other can compensate in an intercropping system under both tillage systems, such compensation clearly cannot occur if crops are grown separately in mono-cropping system (Alene Arega et al 2006, Duivenboodew et al 2000, Ouma and Jeruto 2010).

Moreover, conservation agriculture based intercropping systems are characterized by their great degree of genetic diversity in the form of multiple cropping (Lithourgidis et al 2011, Gebru Hailu 2015) and conservation tillage or an integration of the two, based on numerous varieties of domesticated crop species as well as their wild relatives (Lithourgidis et al 2011, Gebru Hailu 2015). These farming systems offer a means of improving soil fertility (Zerihun et al 2014), promoting diversity of diet and income, stability of production (Hobbs et al 2007, Preissela et al 2015) reduced insect and disease incidence, efficient use of labor, intensification of production with limited resources (Lithourgidis et al 2011) and also maximization of returns under low levels of technology (Mal´ et al 2009) and reduced climate change (Shames 2006, Kassam and Theodor 2010).Though, currently the practice like conservation agriculture as sustainable food production has been supported by international NGO's like CIMMYT (ACIAR) in Ethiopia, lack of sound agricultural policies, researches, extension packages, free grazing, intensive ploughing of cultivated land hiders the implementation of conservation tillage based intercropping system (Lithourgidis et al 20114). Only a few studies (Kassie et al 2009, Wellelo et al 2009) have reported on the status and effects of conservation tillage in the country. These studies focused on small areas of Ethiopia where drought and soil degradation are the most important agricultural constraints and high mono-cropping systems are practiced. Rockström et al (2001) presented results of on-farm trial that showed increased yields and improved water productivity using conservation farming in semi-arid and dry sub-humid locations in Ethiopia. Wellelo et al (2009) similarly reported higher on farm grain yield and biomass for teff (*Eragrostis abyssinica*) and reduced soil erosion for farms under conservation tillage in northern Ethiopia. Therefore, the objective of this paper were to provide an inclusive view and evaluation of conservation tillage based annual intercropping, summarizing their main advantages and challenges to use as compared to conventional crop production system, supported by a number of key examples from the published literature which point out its great value in the context of sustainable agricultural development in Ethiopia now and in the future.

## Conservation Agriculture

**Definition and principles of conservation agriculture:** The historical development of agriculture with tillage being a major component of management practices was explained by different researchers (IIRR and ACT 2005, Małecka et al 2012). Currently, agricultural productivity levels have fallen in countries like Ethiopia, due to very small cultivated land per household (less than 1ha), high population growth, (land degradation as a result of many years of erosive cultivation mainly repeated, removal of crop residue due to free grazing and declining soil fertility as farmers fail to replenish soil fertility (IIRR and ACT 2005, Derpsch 2009). For this situation, countries like Ethiopia needs capable of borne or endured, upheld, defended and maintain some important agricultural practice. Thus, conservation agriculture is the greatest soil, water and environmental conservation practice and in turn give sustainable food security to come along in the 20th century (IIRR and ACT 2005, Thierfelder et al 2015). This is an important concept in today's agriculture, since the human race will not want to compromise the ability of its future offspring to produce their food needs by damaging the natural resources used to feed the population today. According to IIRR and ACT (IIRR and ACT 2005), conservation agriculture is an approach to growing crops that strives to achieve high and sustainable productivity, quality and economic viability, while also respecting the environment. It can be defined as an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. Protecting soil and water are at the heart of this approach. It is also defined as a minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations, is a recent agricultural management system that is gaining popularity in many parts of the world (Hobbs et al 2007). Agriculture is not a rigid, formalized system, but a flexible set of guiding principles based on three interlinked principles which need to be adopted to particular cropping systems

(IIRR and ACT 2005, Hobbs et al 2007, Lane et al 2006).

**Minimum mechanical soil disturbance:** It refers to any conservation system that minimizes the total number of tillage primary and secondary operations for seed planting from that normally used on field under conventional tillage. It is also called reduced tillage because it reduces the use of tillage to minimum enough to meet the requirements of crop growth. Reduced tillage is a conservation management strategy that leaves at least 30% residue cover to minimize runoff and soil erosion, improve soil functions, and sustain crop production.

**Permanent soil cover:** Keeping a vegetative cover over the soil in the absence of a crop has an important role in protecting the soil and enhancing its properties. In annual crops this cover can be achieved by chopping and spreading the residues of the harvested crop, or by planting a cover crop which will either be incorporated or desiccated before drilling the next crop. In some instances the new crop may be drilled directly into the cover crop. These covers protect soil from the impact of raindrops and wind which lead to erosion, and enhance its properties by adding organic matter to improve its structure and fertility.

**Diversified crop rotations:** Appropriate sequences of crops will reduce the impact of weeds, pests and diseases on a single crop type and give opportunities for alternative methods of control or reduce the need for external inputs. Legume crops have bacteria associated with their roots which take nitrogen from the air and turn it into forms plants can use, hence, reducing the need for fertilizers.

**Extent of conservation agriculture:** Soils are vital for agricultural productivity and a normal rate of soil formation is estimated to be between half and one tone per hectare annually (Lane et al 2006) and may take a century or more to produce just one centimeter of new topsoil. Soil must therefore be regarded as a largely nonrenewable resource. Due to this reason conservation agriculture is widely adopted globally. However, the reliable estimates on the exact extent of all sorts of conservation agriculture practices are not available. However, there are some reliable estimates on the extent of zero-tillage, one aspect of conservation agriculture, largely adopted in different parts of the world. The estimates show that zero-tillage agriculture is adopted in an area of little more than 105 million ha (Evers 2001). The adoption of zero-tillage practices was rapid from 45 million hectare in 1999 to 95 million in 2005 and now estimated to be more than 105 million. In descending order South America (49.5 million ha and percentage of total 46.8), North America (40.1 million ha and percentage of total 37.8), Australia (12.2 million ha and percentage of total 11.5), Asia (2.5 million ha and percentage of total 2.3), Europe (1.15 million ha and percentage of total1.1) and Africa (0.37 million ha and percentage of total 0.3) showed adoption of no-tillage (Hobbs et al 2007, Derpsch 2009, Joshi 2011). Though soil conservation practices, including minimum or no tillage have long been practiced by farmers in Ethiopia, conservation tillage were introduced in 1998 by Sasakawa Global on 77 maize plots (Matsumoto et al 2004). Despite the decade old national effort to systematically disseminate conservation tillage, no empirical evidence has been presented as to what extent the technology package is being adopted, or the extent to which farm yields are being influenced (Wellelo et al 2009). In Ethiopia, agricultural services are generally focused on increasing production through short-term technical packages such as small holder intensification through improved access to modern inputs like improved seeds and fertilizers, without paying attention to sustainable food security.

## Intercropping

**Definition and principles of intercropping:** Intercropping is the simultaneous growing of more than one species in the same field to rise per unit productivity per unit time (Itoa et al 2000, Lithourgidis et al 2011, Zerihun et al 2014). Many crops have been grown in association with one another for hundred years and crop mixtures probably represent some of the first farming systems practiced as traditional agriculture (Zerihun et al 2014). Although intensive monocropping is much easier for large-scale farmers, who plant and harvest one crop, small-scale farmers, who often do not have readily access to markets and grow enough food only to sustain themselves and their families, recognize that intercropping is one good way of ensuring their livelihood (Najafi and Abbas 2014). However, at least 55 % of world farmers are resource poor mainly in Africa, Asia and Latin American (Ashenafi et al 2013). Due to this reason, today intercropping is commonly used in many tropical parts of the world particularly by small-scale traditional farmers. Traditional multiple cropping systems are estimated to provide as much as 15-20% of the world's food supply. In the tropical regions, intercropping is mostly associated with food grain production, whereas in the temperate regions it is receiving much attention as a means of efficient forage production (Zerihun et al 2014). In China, one-third of all the cultivated land area is used for multiple cropping and half of the total grain yield is produced with multiple cropping (Zhang and Long 2003). Other quantitative evaluations suggest that 89 per cent of cowpeas in Africa are intercropped, 90 per cent of beans in Colombia are intercropped and the total percentage of cropped land actually devoted to intercropping varies from as low as 17 % for India to as high as 94 per cent in Malawi (Lithourgidis et al 2011). Intercropping as greater land use intensification as well as crop diversification is a common practice in many areas of Africa as a part of traditional farming systems commonly implemented in the area due to population growth and the consequent pressure on land resources coupled with frequent crop failures due to weather, pests and diseases and food security needs (Tadesse et al 2012, Kariaga 2004). It is mostly practiced on small farms with limited production capacity due to lack of capital to acquire inputs (Ashenafi et al 2013).

In subsistence economy, as the farmers in Ethiopia, uses a combination/mixture of crops on a piece of land due to scarcity of land to avoid risk of crop failure, soil conservation and labor economy (Tadesse et al 2012, Bantie et al 2014). Some of the chosen grain crop mixtures normally include cereals, pulses and/or oil seeds (Tadesse et al 2012).Though, there is lack of quantitative data on over all intercropping systems in Ethiopia, the most important grain crop mixtures commonly used by farmers are sorghum /chick pea, sorghum/faba bean, sorghum/barley, sorghum/finger millet, finger millet/rape seed, wheat /barley, pea /faba bean, maize/rape seed, maize/potato, maize/ faba bean finger millet/lupine, teff/safflower, rice/grass pea, sunflower with maize, finger millet (Bayu et al 2007). However, other traditional intercropping systems including horticultural crops are also commonly practiced by local farmers in Ethiopia. Although agricultural research originally focused on sole cropping and ignored the potential of intercropping, there has been a gradual recognition of the value of this kind of cropping system (Lithourgidis et al 2011). For instance, one of the most important progresses is use of intercropping as organic farming system even in North America and Europe who followed intensive agriculture. For organic sector, intercropping is considered an effective means of self-regulation and resilience of the organic agro ecosystems to meet environmental perturbations in the organic culture practice (Lampurlanes et al 2001). The last decades, several organic farmers are experimenting and gradually adapt intercropping systems in order to benefit from the advantages of intercropping (Entz et al 2011).

**Spatial and temporal patterns of intercropping under conservation tillage:** Intercropping is one type of multiple cropping in which growing two or more crops on the same piece of land in one cropping season (Tadesse et al 2012, Gebru Hailu et al 2015) . Several types of intercropping, all of which vary in the temporal and spatial mixture to some degree, have been described. The degree of spatial and temporal overlap in the component crops can vary somewhat, but both requirements must be met for a cropping system to be an intercrop (Bayu et al 2007, Lithourgidis et al 2011, Tadesse et al 2012). Thus, there are several different modes of intercropping, some of widely used intercropping systems according to the spatial and temporal arrangement are:

**Mixed intercropping-** is the growing of two or more crops at the same time with no distinct row arrangement. It is the intensification of cropping in space dimensions only (Lithourgidis et al 2011). Some example of mixed intercropping of annual crops are tef-sesame, tef-sesame-safflower, tef-safflower (Molla and Kemelew 2011), finger millet-lupine (Bantie et al 2014), finger millet-rape seed (FAO 2006), tef-sunflower (Bayu et al 2007) etc.

**Row intercropping-** is the growing of two or more crops at the same time with at least one crop planted in rows. It is the intensification of cropping in space dimensions only. This can be two types (Lithourgidis et al 2011).

**Alternate-row intercropping-** two or more plant species are cultivated in separate alternate rows; one crop may be planted in broadcasting or in row. An example of this type is maize/faba bean intercropping system (Lithourgidis et al 2011, Tadesse et al 2012).

**Within-row intercropping-** the component crops are planted simultaneously within the same row in varying seeding ratios. An example of this type is maize/climbing bean, intercropping system (Lithourgidis et al 2011).

**Strip intercropping**- several rows of a plant species are alternated with several rows of another plant species in enough space to allow separate crop production, but close enough for the crops to interact. It is the intensification of cropping in time and space dimensions. Examples of successful strip intercropping practices alternating strips of wheat, corn and soybean 6 rows wide each oat, corn and soybean and 6 rows of corn with 12 rows of soybean (Lithourgidis et al 2011).

**Relay intercropping-** a system in which a second crop is planted into an existing crop when it has flowered (reproductive stage) but before harvesting. The relay crop should be fairly tolerant to shade and trampling. Examples of relay crops are cassava, cotton, sweet potato and sesame with corn, chickpea, lentil and wheat with upland rice (Lithourgidis et al 2011), grass pea with rice (Bitew and Fekremariam 2014), lupine with finger millet (Bitew et al 2014) . This can be divided in two ways (Lithourgidis et al 2011),

**Short temporal separation of relay intercropping**- is the practice of sowing a fast-growing crop with a slow-growing crop, so that the first crop is harvested before the second crop starts to mature. During this time different planting dates of the component crops have differential influence of weather and in particular temperature on component crop growth.

**Long temporal separation is found in relay intercropping-** where the second crop is sown during the growth, often near the onset of reproductive development or fruiting of the first crop, so that the first crop is harvested to make room for the full development of the second crop

**Integrated Use of Intercropping and Conservation Tillage**

The tremendous research and information were investigated separately on the effects of intercropping and conservation tillage methods on crop performance, soil physical and chemical properties, labor etc. However, there is paucity of sufficient research and information on the effect of integrated use of intercropping and conservation agriculture on the above parameters (Ajayi 2015, Thierfelder et al 2015). This is due to the complexity of their interaction effects on the crops which tends to discourage researchers and these have led to loss of basic research information on the benefit of conservation tillage based intercropping system. Different researchers showed that these system gave high grain yield, land use efficiency, soil fertility, growth return as compared to sole cropping and conventional tillage practices (Zerihun et al 2014, Ajayi 2015, Thierfelder et al 2015).

In the humid tropics, maize-groundnut intercropping is often practice under conservation tillage to produce food and obtain cash income from the same piece of land (Ishaq et al 2001). The reason for using this practice is because the humid tropics are characterized by highly erosive, erratic and poorly distributed rains (Osunbitan et al 2006, FAO 2016). While many workers have advocated the use of no-tillage for the tropical soil management, the dependent of no tillage on mulch has made its adoption very slow among farmers. This is because; mulching is time consuming and requires planting, cutting, transportation and spreading to the cultivated land. Moreover, mulch availability is a challenge in the tropics due to rapid decomposition of plant left-over after cropping season due to their inclement climate. To reduce this large dependence on mulch, works in no till methods which earlier emphasized sole cropping should look into intercropping (Patil et al 2015).

**Improvement of soil physical and chemical properties through conservation tillage based annual intercropping:** In the top end exposed soil can lose 60% of the rainfall through runoff and up to 50% of soil moisture can be lost through evaporation directly from the soil surface. The greatest benefit of conservation tillage stated by many authors is the reduction in soil erosion compared with the conventional plough-based system (Landers 2007, Thierfelder and Wall 2009). Soil loss was largest on conventional tillage compared with conservation tillage based direct seeding and Rip-line seeded-legume intercrop (Thierfelder and Wall 2009, Thierfelder et al 2012) and amounted to a cumulative loss of 61.7 tons/ ha on conventional tillage after seven cropping seasons, compared with 29.2 tons /ha and 25.7 tons/ ha in the two conservation tillage cropping systems.

Thierfelder et al (2012) showed that bulk density at conservation tillage based maiz-cawpea intercropping system was significantly lower in the top soil, which confirms previous results of Mal´ et al (2009), although some other studies showed few, or inconsistent trends (Logsdon and Karlen 2004). Porosity is a measure of the total pore space in the soil and is measured as a volume or percent. The amount of porosity in a soil depends on the minerals that make up the soil and the amount of sorting that occurs within the soil structure. The air-filled porosity in conservation tillage based intercropping was 29.6% at the 0 to 0.01 m depth, this decreased by 27.3% in conventional tillage and for the 0.01-0.02 m depth, it decreased by 7.8% (Logsdon and Karlen 2004). Improved soil pore size distribution in the conservation tillage and intercropped plots indicates the ability of the soil to improve water supply to the plant. It also signifies improved soil utilization of precipitation leading to reduced run-off and less soil erosion (Logsdon and Karlen 2004, Thierfelder et al 2012).

The infiltration is one of the most immediate benefits of conservation tillage systems especially when measured on rotational plots (Thierfelder and Wall 2009, Nyagumbo 2008) and reveals the potential of a soil to utilize water instead of losing it to run-off (Rockström et al 2001). The reduction or absence of soil tillage has an impact on water conductivity and the infiltration rate. Conservation tillage based intercropping and conservation tillage based sole cropping had significantly higher infiltration characteristics than intercropping and sole cropping under conventional tillage (Fig. 1). Intercropped plot of conservation tillage (605mm) had significantly higher infiltration characteristics compared with intercropped plot of conventional tillage (248mm). Similarly, infiltration on three conservation agriculture (direct seeding, Rip-line seeded-legume intercrop and Rip-line seeded in descending order) was 145–331% higher than one conventionally ploughed system measured on plots with continues maize monocropping and maize-sun hemp rotation (Thierfelder et al 2012) and this reveals the potential of a soil to utilize water instead of losing it to run-off (Rockström et al 2001 (Figure 1). Zerihun et al (2014) conducted a long year research on conservation tillage based maize-legume intercropping system and observed that the lowest pH value was recorded when maize was continuously produced under conventional tillage. In addition maize and haricot bean in permanent plots showed significantly lower pH value as compared to bean-maize rotation and maize-bean intercropping and even to the initial soil pH value. This result in agreement with other findings indicated that legume crops reduce soil pH since the crops absorb high concentration of base cations and available nitrogen in the form of nitrate by releasing $H^+$ into rhizosphere, which leads to soil acidification (Crews and Peoples 2003). Repeated application of acidic inorganic fertilizer could also enhance soil acidity, particularly in convectional system. Nitrification is more enhanced in much disturbed soil than minimum tilling so that nitrate leaching might be aggravated and leads to high concentration of $H^+$ in the soil solutions (Zerihun et al 2014). A permanent vegetative soil cover, using intercrop or green manure under no till, can strongly reduce nitrate losses. Similar to soil pH, CEC of the soil was increased in crop rotation and intercropping systems in combination with minimum tilling due to addition of soil organic carbon (Govaerts et al 2007, Zerihun et al 2014). Sole maize with conventional practice and conservation tillage practices significantly reduced nitrogen content whereas better improvement was observed in crop rotation and intercropping systems. The reduced nutrient availability under tilled may be due to removal of crop residue, higher decomposition rate of organic matter, and rapid leaching of the nutrients (Tesfay et al 2011, Zerihun et al 2014).

Tesfay et al (2011) showed that higher percentage of organic carbon was in maize-bean intercropping, sole haricot bean and haricot bean-maize rotations under conservation tillage. However, farmers' practices considerably reduced the organic carbon content. The carbon content in the 0–30 cm soil profile showed the largest amount of soil carbon in conservation tillage based maize-cowpea intercropping (24.7 Mg $ha^{-1}$) and the smallest in conventional tillage (18.4 Mg $ha^{-1}$), suggesting additional carbon input from the intercropped legumes. Carbon accumulates mostly in the first horizons on the conservation tillage based sole and intercropping system suggesting some stratification, as highlighted by (Thierfelder et al 2012).

According to the long term study by Ajayi (2015), gravimetric soil water content showed that conservation tillage based sole and intercropping had higher soil water content in all cropping treatments than conventional tillage in both sole and intercropping conditions (Fig. 2). In the tillage treatments, higher soil water content was observed with no-tillage in all cropping methods than conventional tillage. In general, intercropped plots under conservation and conventional tillage had significantly higher soil moisture content than the sole crops of maize and groundnut under conservation and conventional tillage. The additional surface soil protection in maize-groundnut intercrop enhanced soil and water conservation and with careful selection of intercrops, competition for water under intercropping may be reduced (Preissela et al 2015). Available soil moisture (mm) was higher and increased under conservation tillage based

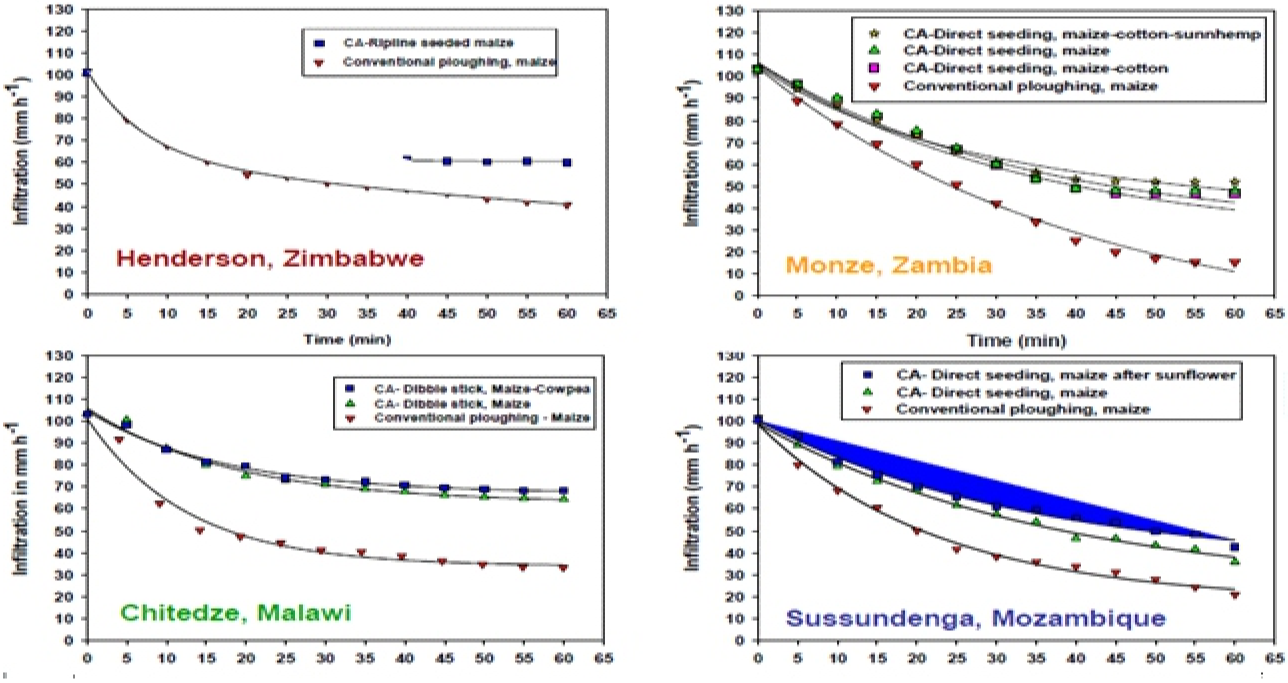

**Fig. 1.** Effect of conservation agriculture based intercropping system on infiltration (Thierfelder and Wall 2009, Thierfelder et al 2012)

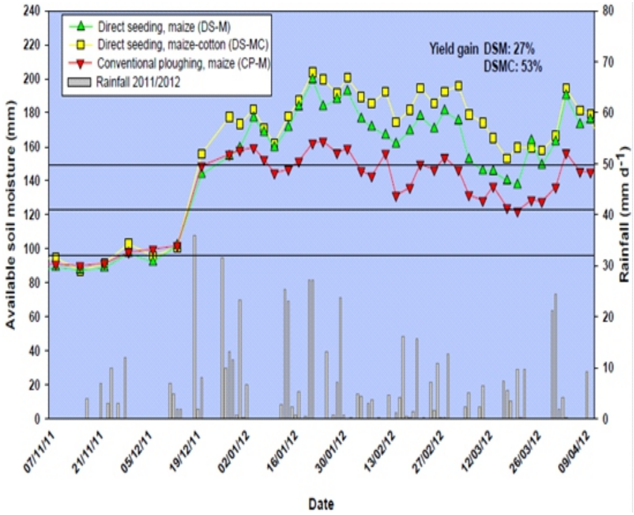

**Fig. 2.** Effect of Conservation agriculture based intercropping on soil moisture content (Thierfelder et al 2012)

maize-cotton intercropping system followed by conservation tillage based sole maize as compared to conventional ploughing based sole maize (Doets et al 2000).

Conservation tillage based intercropping systems considerably increased water use efficiency as compared to crop rotation or continuous production in conservation tillage or conventional tillage (Zerihun et al 2014). Ajayi (2015) observed soil moisture content of 0.01 m, 0.01-0.02 m and 0.02-0.03 m soil layers under tillage and cropping methods showed that higher soil water content and earthworm population were observed with no-tillage in all cropping methods than conventional tillage. The same author indicated that intercropped plots in both tillage methods had significantly higher soil moisture content than the sole crops of maize and groundnut.

**Production of stable yields and incomes with reduced production costs:** Maize-haricot bean intercrops under conservation tillage ensured risks free or avoidance in case of variable and short rainfall (West and Post 2002, Zerihun et al 2014). Zerihun et al (2014) confirmed that more than 38-41% in unfavorable season and 44-47% during favorable season of additional yield were obtained without significant reduction of the main crop in conservation tillage based maize-haricot bean intercropping. Ajayi (2015) investigated that the yield of sole maize under conservation tillage>conservation tillage based intercropping>conventional tillage based intercropping>conventional tillage based sole maize. Similarly, for groundnut, the trend in grain yield was conservation tillage based groundnut>conservation tillage based intercropped>conventional tillage based sole groundnut>conventional tillage based intercropped. The experiment conducted by Adet agricultural research Centre (AARC) on conservation tillage based maize legume intercropping system for three years (2012-2014) at two districts (13 sites) of high maize production areas of Western Amhara region showed that maize productivity and production were highest in conservation tillage (both sole and intercropping) as compared to conventional tillage (sole cropping) at all locations and sites. This experiment also showed that maize production under conservation tillage based maize-haricot bean rotation (6.4 tons/ha) > conservation tillage based maize-haricot bean/cow pea intercropping (5.4tons/ha) > conservation tillage based sole maize (5.1 tons/ha) > conventional tillage based sole maize (4.8 tons/ha) (AARC 2015) (Fig. 3). Similarly, longer term experiment (8 years) on conservation tillage based-cropping system conducted at Malawi by CIMMYT showed that conservation tillage based maize-legume intercropping gave maximum yield next to conservation tillage based sole maize as compared to conventional (Thierfelder et al 2015). Thierfelder et al (2012) showed that it is more advantageous to grow crops under conservation tillage than conventional tillage: There are marked yield benefits in rotating crops (11–64% higher yield) or intercropping (10–35% higher yield) compared with continuous maize cropping under

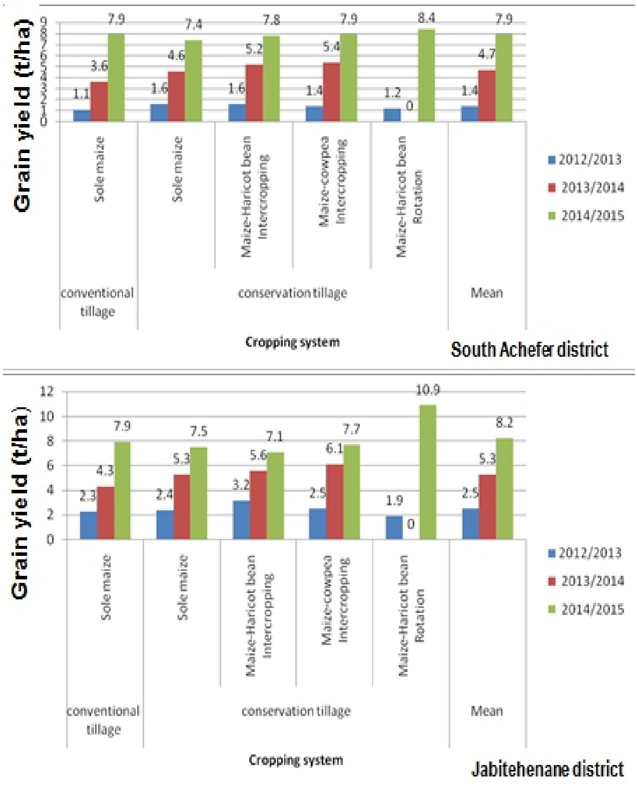

**Fig. 3.** Effect of Conservation agriculture based cropping system on maize grain yield (AARC 2015)

conventional tillage in Zimbabwe.

Zerihun et al (2014) showed that crop rotations had reduced by 15-27% labors as compared to continuous maize or legume production under conservation tillage practices**.** The highest growth return was obtained from maize-soybean intercropping under conservation tillage where as sole maize production with conventional tillage practice recorded the highest total variable cost. Minimum tilling with crop residue retention could reduce labor requirement up to 50-60% at a critical time of agricultural calendar (Doets 2000, Ken et al 2014). Intercropping practices with conservation tillage by far reduced from 29% to 52% of total time required for weeding as compared to conventional practice with both sole and intercropping system since there might be highly smothering effect on weed that might largely reduce its competitions effects (Zerihun et al 2014). Similar result was also reported that energy cost of crop production with conventional tillage and direct seeding estimated that the total inputs are about 40-50% lower for conservation agriculture and the increase net income ranged from 50% to more than 60% (Lange et al 2005).Thierfelder et al (2014) showed that returns to investment in sole maize under conservation were increased from about 11 $USD to 14 $USD while returns to investment maize/legume intercropping under conservation tillage were increased from 10 $USD to18 $USD.

**Weeds and conservation tillage based intercropping:** The control of weeds, pests and diseases by means of a suitable crop rotation significantly reduce the pesticides use and decreases the risk of pollution. A number of conservation agriculture practices designed to replace continuous maize/bean intercropping in the region intend to introduce nitrogen fixing cover crops, reduce soil disturbance and retain surface crop residues (Giller et al 2011). However, adoption of conservation agriculture is often hindered by farmers' limited understanding of the changes in weed control practices and crop performance during the transition period (Ngwira et al 2013). Long term intercropping under conservation tillage can smother weeds (Odhiambo et al 2014, Muoni and Mhlanga 2014). Thierfelder et al (2014) observed that conservation tillage based maize/legume intercropping (250 plants/ha) followed by conservation tillage based sole maize (850 plants/ha) had high striga control as compared to conventional control (3500 plants/ha) (Fig. 4). Muoni et al (2014) submitted that under conservation tillage based sole and intercropping system weed density was decline over time. The greatest declines of more than 50% were observed at minimum tillage and zero tillage in maize, bean and mucuna planted in a strip intercropping arrangement and continuous maize/bean intercropping and maize cropping systems as compared to conventional tillage (Odhiambo et al 2014). Corresponding costs of weed management were reduced by $148.40/ ha in minimum tillage based continuous maize/bean intercropping and maize, bean and mucuna planted in a strip intercropping arrangement and $149.60/ha in no till based continuous maize/bean intercropping and maize, bean and mucuna planted in a strip intercropping arrangement compared with conventional tillage (Muoni and Mhlanga 2014).

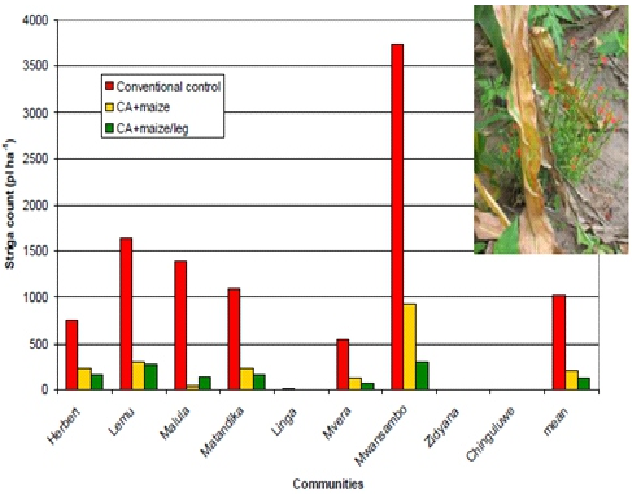

**Fig. 4.** Effect of Conservation agriculture based intercropping on weed infestation (Thierfelder and Wall 2009)

**Environmental benefits of conservation tillage based intercropping increasing biodiversity:** Maintaining soil cover in conservation tillage based intercropping will reduce erosion, loss of soil fertility, soil compaction, and, eventually, landscape change (IIRR and ACT 2005). One aspect of conventional agriculture is its ability to change the landscape. The destruction of the vegetative cover affects the plants, animals and microorganisms. Most organisms are negatively affected and either they disappear completely or their numbers are drastically reduced. With the conservation of soil cover in conservation agriculture based intercropping a habitat is created for a number of species that feed on pests, which in turn attracts more insects, birds and other animals. The rotation of crops and cover crops restrains the loss of genetic biodiversity, which is favored with mono-cropping (Govaerts et al 2007, Ikuenobe and Anoliefo 2003, Odhiambo et al 2014). Soil organisms are important elements for preserved ecosystem biodiversity and services (IIRR and ACT 2005). One of the main threats to soil biodiversity occurred by mechanical impacts by soil tillage in agricultural management. Soil microorganisms regulate carbon and nitrogen cycling and provide nutrients to plants. Bacteria and fungi are critical for the production of soil aggregates and the conversion of plant residue to soil organic matter that increases aggregate stability, cation exchange capacity, and water holding capacity, water infiltration and soil porosity (IIRR and ACT 2005, Salles et al 2006). Several recent studies have focused on the effects of agricultural practices on the community diversity of soil microorganisms. Soil microbial activity is affected negatively by soil tillage (FAO 2008, Henle et al 2008, Shaxson et al 2008, Médiène et al 2011). No-till or reduced tillage systems can reduce the erosion level of a soil, which is not a renewable resource (Papendick et al 2004).

The decrease of organic matter as a result of tillage in the soil can cause decreases in soil microbial activity (Kladivko 2001, Sagar et al 2001, Thierfelder and Wall 2010). Earthworms incorporate organic matter into the soil, stimulating decomposition, humus formation, nutrient cycling and the development of soil structure (Lane et al 2006). Thierfelder and Wall (2010), investigated a long-term trial in Zambia, observed significantly larger earthworm numbers in conservation tillage treatments, especially in rotations of cotton and sun hemp, which suggests that residue retention and crop rotations apart from no-tillage play a significant role in the increase in biological activity. In descending order, increased earthworm activity was observed in conservation tillage based intercropping and conservation tillage alone as compared to conventionally plowed fields in Zambia (Thierfelder et al 2014).

Intercropping under conservation tillage is one way of establishing more biodiversity into agro ecosystems and results from intercropping studies indicate that increased crop diversity may increase the number of ecosystem services provided (Hauggaard-Nielsen et al 2001, Lithourgidis et al 2011, Gebru Hailu 2015). Higher species richness may be associated with nutrient cycling characteristics that often can regulate soil fertility (Russell 2002), limit nutrient leaching losses (Hauggaard-Nielsen et al 2008) and significantly reduce the negative impacts of pests (Willey et al *2015)* including that of weeds (Mal´et al 2009). Intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment.

**Climate change adaptation and reduced vulnerability:** Reduced vulnerability to effects of drought, less erosion, and lesser extremes of soil temperatures represent a managed adaptation of conservation tillage systems based intercropping to climate change effects (ICRISAT et al 2006). In Ethiopia, agriculture is highly sensitive to variability and change in climate. For instance, multiple severe impacts are likely to result from climate changes in future which are likely to cause lack of food for more than 10.4 million farmers and pastoralists (FAO 2015). Currently, agriculture and other forms of land use contribute 32 % to the world's greenhouse gas emissions (Lal et al 2006). Moreover, each ton of carbon lost from soil adds approximately 3.7 tons of $CO_2$ to the atmosphere. The same author suggested that by adopting improved management practices on agricultural land (use of conservation tillage), food security would not only be enhanced but also offset fossil fuel emissions at the rate of 0.5 Pg C/ year (Hobbs et al 2007).Landers (2007) reported that a six fold difference was measured between infiltration rates under conservation tillage (120 mm/ hour) and traditional tillage (20 mm/ hour). Conservation tillage thus, provides a means to maximize effective rainfall and recharge groundwater as well as reduce risks of flooding. Due to improved growing season moisture regime and soil storage of water and nutrients, crops under conservation tillage require less fertilizer and pesticides to feed and protect the crop, thus leading to a lowering of potential contamination of soil, water, food and feed. In addition, in soils of good porosity, anoxic zones hardly have time to form in the root zone, thus avoiding problems of reduction of nitrate to nitrite ions in the soil solution (ICRISAT 2006).

Conservation tillage reduces the unnecessarily rapid oxidation of soil organic matter to $CO_2$ that is induced by inappropriate tillage practices (Preissela et al 2015, Lane et al 2006). Together with the addition of mulch as a result of saving crop residues in- situ as well as through root exudation of carbon compounds directly into the soil during crop growth (Jabro et al 2009). Thus, there is a reversal from net loss to net gain of carbon in the soil, and the start of long term processes of carbon sequestration. In the total balance, carbon is sequestered in the soil, and turns the soil into a net sink of carbon. This could have profound consequences in the fight to reduce greenhouse gas emissions into the atmosphere and thereby help to forestall the calamitous impacts of global warming. Making use of the above ground crop residues, the root organic matter (higher under conservation tillage because of the larger root systems) and the direct rhizospheric exudation of carbon into the soil represents the retention of much of the atmospheric carbon captured by the plants and retained above the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown (though still with useful attributes in soil), and represents net carbon accumulation in soil, eventually leading to carbon sequestration (Lane et al 2006, FAO 2008, Baig et al 2009). Tillage however, results in rapid oxidation to $CO_2$ and loss to the atmosphere (Lane et al 2006, Baig et al 2009). Similarly, results from long term trials over a 20 year period, have shown the soil under traditional practice (stubble burnt and traditional tillage) was losing carbon at a rate of 400 kg/ ha/year compared to conservation tillage (Heenan et al 2004). According to ICRISAT (2006), soil carbon content increased by 47% in conservation tillage based maize–lablab system, and by 116 % in conservation tillage based maize–castor bean system, compared to the fallow–maize cropping system which was taken as a reference. Baker et al (2007) Found that crop rotation systems in conservation tillage accumulated about 11 tons/ha of carbon after nine years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 tons/ha/ year of $CO_2$ (FAO 2001). In other words conservation tillage means that soils can sequester carbon until a new equilibrium is reached to counter balance greenhouse gas emissions. Thus, carbon dioxide fluxes from soils are directly related to the volume of soil disturbed. The ability of conservation tillage soils to sequester carbon presents farmers with additional business opportunities to enter carbon trading schemes. For instance, in 2005, Canadian no-till farmers could earn almost € 10/ha to help offset Canada's greenhouse gas emissions (Lane eta al 2006).

Conservation tillage can also help reduce the emissions for other relevant greenhouse gases, such as methane and nitrous oxides, if combined with other complementary techniques. Both methane and nitrous oxide emissions resulted from poorly aerated soils, for example, from permanently flooded rice paddies, severely compacted soils, or from heavy poorly drained soils. Conservation tillage improves the internal drainage of soils and the aeration and avoids anaerobic areas in the soil profile (FAO 2015). Methane emissions that have a warming potential of 21 times that of $CO_2$ are common and significant in puddle anaerobic paddy fields and also when residues are burnt. This greenhouse gases emission can be mitigated by shifting to aerobic, direct seeded or conservation tillage rice system (Joshi 2011).

Nitrous oxide has 310 times the warming potential of carbon dioxide and its emissions are affected by poor nitrogen management (Lane et al 2006, ICRISAT 2006, Hobbs et al 2007). The soil is a dominant source of atmospheric $N_2O$. In most agricultural soils biogenic formation of nitrous oxide is enhanced by an increase in available mineral nitrogen which, in turn, increases the rates of aerobic microbial nitrification of ammonia into nitrates and anaerobic microbial reduction (denitrification) of nitrate to gaseous forms of nitrogen (ICRISAT 2006, Lane et al 2006**)**. The rate of production and emission of $N_2O$ depends primarily on the availability of a mineral nitrogen source, the substrate for nitrification or denitrification on soil temperature, soil water content, and the availability of labile organic compounds. Addition of fertilizer nitrogen, therefore, directly results in extra $N_2O$ formation as an intermediate in the reaction sequence of both processes that leaks from microbial cells into the atmosphere. In addition, mineral nitrogen inputs may lead to indirect formation of $N_2O$ after nitrogen leaching or runoff, or following gaseous losses and consecutive deposition of $N_2O$ and ammonia. Conservation tillage generally reduces the need for mineral nitrogen by 30–50%, and enhances nitrogen factor productivity (ICRISAT 2006). Thus, overall, conservation tillage has the potential to lower nitrogen leaching and nitrogen runoff, $N_2O$ emissions and mitigates other greenhouse gases emissions (ICRISAT 2006, Metay et al *2007,* Baig and Gamache 2009).

**Insurance against crop failure:** One important reason for which intercropping is popular in the developing world including Ethiopia is that it is more stable not only during normal seasonal conditions but also adverse conditions than mono-cropping (Lithourgidis et al 20111; Najafi and Abbas 2014); FAO 2015).Using risk as a criterion for evaluating stability of intercropping systems, (Waddington et al 2007) showed that the probability of reaching a given income level was higher in an intercrop when compared to sole crops of the same component species. Furthermore, intercropping is more extensively practiced by small scale or subsistence farmers (Waddington et al 2007**)**. Risk, as it applies to subsistence farmers, relates more to net production and less to market forces. The stability under intercropping can be attributed to the partial restoration of diversity that is lost under mono-cropping (Lithourgidis et al 2011; Mal´ eta l 2009). If a single crop may often fail because of adverse conditions such as frost, drought, flood, or even pest attack, farmers reduce their risk for total crop failure by growing more than one crop in their field. Lithourgidis et al (2015) thought that for intercropping to be risk advantageous, the components of the crop association needed to have different environmental requirements or contrasting habits. Long year experiment on ninety four experiments on mixed cropping of sorghum/pigeon pea showed that for a particular 'disaster' level, sole pigeon pea crop would fail one year in five, sole sorghum crop would fail one year in eight, but intercropping would fail only one year in thirty six (Lithourgidis et al 2011) (Fig. 5). Lithourgidis et al (2011) concluded that if one crop fails, or grows poorly, the other can compensate; such compensation clearly cannot occur if crops are grown separately. In India intercropping is effective for yield stability in erratic rainfall environments (Willey et al 2015).

Intercropping maize with beans reduced nutrient decline and raised household incomes compared with monocropping of either of the two crops. Regularly intercropped pigeon pea or cowpea can help to maintain maize yield when maize is grown without mineral fertilizer on sandy and in turn no dependent on chemical fertilizer

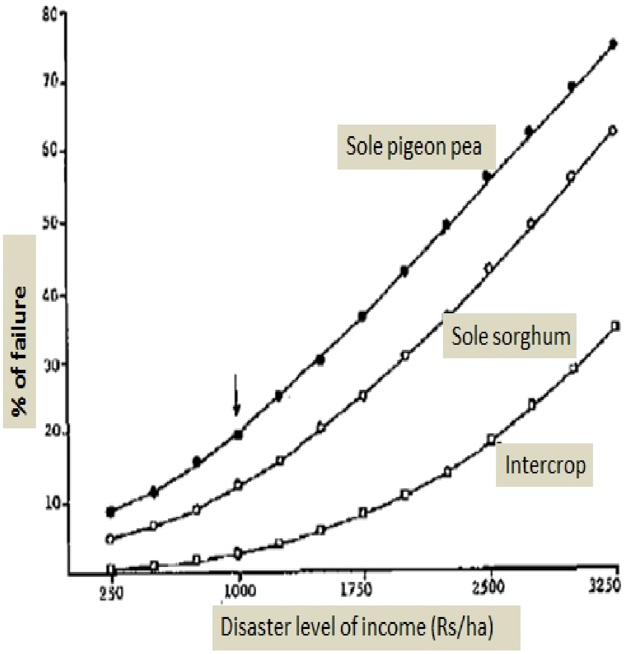

**Fig. 5.** Yield stability of sorghum and pigeon pea in sole cropping and intercropping: The probability of crop failure (Lithourgidis et al 2011)

(Waddington et al 2007). Kariaga (2004) showed that poor fertility land was returned to production under intercrop of maize with other low growing legumes like cowpeas and beans. During the past two decades studies in several years in semi-arid environments showed that intercropping has been advocated to increase crop yield and improve yield stability in environments where water stress occurs (Lithourgidis et al 2011, Kariaga 2004).

Combinations involving crops with slightly differing growth duration, e.g. millet and sorghum or mixtures of early and late maturing cultivars of the same species are used in areas with growing seasons of variable length to exploit the occasional favorable season yet insure against total failure in unfavorable seasons (Lithourgidis et al 2011, Najafi and Abbas 2014, Gebru Hailu et al 2015).This included intra species diversity such as different colors of maize with different maturation times. On average, late maturing cultivars of groundnut and sorghum gave higher dry pod and grain yield, respectively, when intercropped with early maturing cultivars of the associated crops (Tefera and Tana 2003). If the growing season is long, the late maturing type takes advantage of the abundant resources, whereas if the growing season is short, the early-maturing type can provide a reasonable yield. Differing growing seasons may thus lead to reversals of success in such intercrops, giving more stable yield in intercropping when measured over a run of seasons (Lithourgidis et al 2011).

## Barriers to Implementing Conservation Agriculture in Ethiopia

Conservation based intercropping may not be readily adopted by policy makers and farmers in Ethiopia because it conflicts with conventional farming practices. Some barriers to promoting and implementing conservation agriculture based intercropping systems arise from deep rooted socio-cultural beliefs and the downgrading of indigenous farming methods which are poorly supported by researches over past decades. Some examples are given below (Shames 2006; Kassie et al 2009; Wellelo et al 2009; Salami et al 2010; Anderson and Elisabeth 2015) :

1. Research activity and research-extension linkage: Lack of strong research activity, and research-extension linkage on the impact of conservation based intercropping system on soil health, agricultural production, biodiversity and economic benefit in Ethiopia
2. Ploughing: For many years' higher Politian's, agricultural experts (excluding researchers) and farmers in Ethiopia have been taught that ploughing is essential for crop production because it makes the soil soft and enables roots to penetrate easily, when in fact the opposite is true.
3. Clean fields and free grazing: This barrier of cattle free grazing, burning or collecting stubble is promoted by extension officers and strengthened by the notions that a 'good farmer' has a clean field and that organic matter should be ploughed in fact mulch on the soil surface allows more rain to infiltrate and promotes fertility better.
4. Land ownership and tenure policy: This is an economic and political issue as well as a cultural and social one. The land in Ethiopia is owned by both government and the people. If the land is owned by the government or communally, individual farmers may have little incentive to improve it through conservation tillage based cropping system.
5. Agricultural production by Conservation tillage may not be profitable at the beginning rather after four years of implementation. This may disfavor the farmers to use Conservation tillage based intercropping system. However, the loss occurred at the beginning of conservation tillage could be compensated by adding intercropping system.

## CONCLUSION

Conservation tillage based annual intercropping (CTBI) controls soil erosion and biodiversity loss caused by conventional crop production system. Its long term effect causes higher percentage of organic matter and organic carbon pool compared to conventional tillage based monocropping due to addition of carbon input from the intercropped legumes and residues from conservation tillage. Besides, CTBI system in the long term significantly lowers the bulk density in the top-soil layer and in turn improves the soil pore size distribution. Similarly, it resulted in higher total N, available K and Mg content than conventional crop production system. CTBI had significantly higher infiltration characteristics, soil water content and water use efficiency than continuous sole cropping and conventional tillage based intercropping. CTIB also establishes more biodiversity into agroecosystems and reduces the addition of chemicals and gases that triggers greenhouse gas accumulation in the atmosphere. In conclusion, CTBI is used as the primary means of sustainable crop production system by improving soil health, promoting diversity of diet, stability of production, efficient use of labor, intensification of production with limited resources maximization of returns under low levels of technology and insurance against crop failure due to drought and frost. However, in Ethiopia conservation tillage based annual intercropping system becomes effective if and only if inclusive research and extension service and appropriate land use policy over it should be implemented.

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