Technological Innovation, Adoption and the Management of Vertisol Resources in the Highland Ethiopia

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1. Introduction

As is the case in most developing countries, in Ethiopia agriculture is the main component the economic sector. It contributes about 55% of the GDP, 60% of the merchandise export and 80% of employment (CSO, 1996).

Vertisols (heavy black clay soils) cover some 43 million hectares comprising 19% of total land area in Sub-Saharan Africa. Nearly 30% of the Vertisols area is located in Ethiopia alone, particularly in the highland region (Mohamed Saleem, 1995). Vertisols occupy about 12.7 million hectares in Ethiopia, of which 7.6 million hectares (approximately 60 percent) are in the highlands (Tekalign et al. 1993). The highlands cover 40% of the total landmass of the country but account for about 95% of all cultivated land. Hence, the importance of Vertisols in the country is unquestionable. However, most of the Vertisols suffer from excess water and poor workability and are also underutilized, and largely used for dry season grazing (Srivastava et al, 1993). Potentially, Vertisols are productive soils, but they are not easy to cultivate due to their poor internal drainage and resultant flooding and water logging during the wet season which contribute for lower crop yields. About 2 million hectares of highland Vertisols are currently being cropped. This means presently only 25% of the 7.6 million hectares Vertisols in the highlands are cultivated. The common crops grown on Vertisols are tef (Eragrostis tef), wheat (*Triticum spp*.), barley (*Hordeum vulgare*), faba bean (*Vicia faba*), field pea (*Pisum sativum*), grass pea (*Lathyrus sativus)*, chikpea (*Cicer arietinum*), lentils (Lens culinaris), lineseed (Linum usitaissium), noug (*Guizotia abyssinica*) and fenugreek (*Trigonella foenum-graecum*). But the yields of these crops are quite low on the vertisols due to waterlogging and unavailability of improved technology.

Traditionally farmers use low yielding crop varieties adapted to poor surface drainage, ridges and furrows late planting, hand made broadbeds and furrows, and soil burning practices to solve waterlogging problems. However, previous studies indicated that with the exception of the hand made broadbeds and furrows which is commonly used in North Shewa, the traditionally applied surface drainage techniques are inadequate to allow the full realization of potential of vertisols (Mesfin and Jutzi, 1993). It was also revealed that broad beds were traditionally used since perhaps the 16th century in a limited areas of the Jirru vertisol plain in Northern Shewa (McCann, 1995).

In general the traditional system of late planting of crops has often resulting in poor crop yields and soil erosion. Experiences from countries like India and Australia, show that proper knowledge and management of Vertisols has resulted in increased yields . Hence the proper management applications of the technology for Vertisols is believed to increase productivity and food security levels in Ethiopia.

In light of this, a Joint Vertisol Project (JVP) established in 1986 as a collaborative project involving a consortium of various organization- the Ethiopian Agricultural Research Organization (EARO, the then IAR), Alemaya University of Agriculture (AUA), Ministry of Agriculture (MOA), International Livestock Research Institute (ILRI) and International Crop Research Institute for Semi-arid Areas (ICRISAT) to address the problems of Vertisols in Ethiopia. This paper attempts to investigate the contribution of technological innovation in the management of vertisol resources in the highlands of Ethiopia. It outlines the process of dissemination, adoption and future prospects.

1.1 Vertisols Technology development

Packages of vertisols technology were developed, tested and transferred in the past and some are still in the process. These technologies include, Broad Bed and Furrow (BBF) package technology based on farmers' indigenous knowledge for draining the excess water and avoid waterlogging problems, conservation tillage for conserving the resource base of the soil and increasing yield with the concept of watershed development and management.

The JVP developed a package composed of the following elements to better utilise Vertisols:

- A broad bed maker (BBM) by modifying local *mareshas* to drain excess water from vertisols plots to allow early planting compared to current practice
- Wheat variety suitable for early planting on Vertisols
- Seed rate and fertiliser rate for optimal yield
- Planting dates for optimal plant growth and yield
- Weed and pest management recommendations.

Among which the Broad Bed and furrow based (BBM) implement is the main element of Vertisols technology. The other components are improved varieties or management practices that can be used along with BBM or traditional practices that could resist water logging problems and gives higher (better) yields. There is also an improved application rate of fertilizer that could work in Vertisols areas. The whole idea of the vertisol innovation is constructing a raised based for draining excess water and improve the productivity of crops with the support of crop management technologies.

In general the use of an animal-drawn BBM to facilitate surface drainage and the use of appropriate seeds, fertilizer and early planting are some of the available Vertisols technologies which would help on one hand in increasing productivity and conserve the soil due to early planting.

1.2 Vertisols Technology Transfer

During the year 1986-1992, five major Vertisol areas with diverse farming systems were selected in the Ethiopia highlands to test and transfer of packages of Vertisol technology (BBM) package.

These areas are Debrezeit, Ginchi, Chefedonsa Eneway, Dogollo and Dejen (Getachew et.al, 1993).

In Eneway broad beds of 80 cm wide separated by furrows were constructed to improve the evacuation of excess water. In other Vertisol areas planting is delayed till the soil is drained naturally at the end of the main rain. Ridges and furrows are the traditional seed beds to evacuate excess water from Vertisols in some other cases. But farmers and researchers alike acknowledge the need to replace the traditional practices because: (i) making broad-beds manually is labour intensive drudgery; (ii) part of the growing period is lost by late planting, and Vertisols deviod of vegetative cover are prone to soil erosion during the early part of the main rainy season; and (iii) the ridges and furrows are not effective drainage structures to cope with intensive rainfall and therefore result in water logging.

As a result an animal drawn BBM was designed by modifying the maresha, the traditional plough. So, use of the BBM together with appropriate seed and fertiliser became the improved Vertisol technology to be verified on-farm with farmers for the past several years (Getachew et.al.1992). The technology and approach to on-farm verification were discussed with farmers prior to the on-farm trials which began in 1986 at Debre Zeit, Dogollo/Were Ilu, and Eneway with 56 individual farmers (IFs) and three producer cooperative (PCs). With the addition of Dejen in 1987 and Ginchi in 1988, the on-farm trial sites increased to five with a total of 67 IFs and 20 PCs. As PCs dissolved in 1990, participation of individual farmers increase in the technology verification (Table 1). To compare the effectiveness of land shaping with the BBM and traditional method, farmers divided their field into two treatments on the two plots. All other inputs were kept uniform. Each farm was a replicate. Primary cultivation was made using the animal drawn maresha in all cases. Farmers were supplied with a chain and pair of wings to make a BBM by attaching them to their ploughs. Chemical fertiliser and improved seed were also provided to farmers on credit. Farmers implemented and managed the trials, while researchers provided training and monitored farmers' progress (Getachew et.al.1992).

Table 1. Number of farmers in the on-farmer technology Verification and transfer studies, 1986-1992

Year	Individual Farmers	Producer Cooperatives	Total PC members
1986	56	2	200
1987	61	7	1500
1988	67	20	6000
1989	53	25	7200
1990	158	10	2500
1991	240	None	None
1992	340	None	None

Source: Getachew Asamenew and Mohamed-Saleem (1992)

The results of wheat produced on Vertisols prepared by use of the BBM improved surface drainage and hence resulted in increased crop yields and economic returns than the traditional RF and Flat methods (Table2).

Table 2. Effects of BBM on wheat yields

Location	Grain Yield (Kg/ha)	
	Improved Vertisols technology	Traditional Vertisols technology
Debre Zeit	1442	1180
Eneway	1105	1072
Dogollo	1844	1258
Dejen	1263	918
Ginchi	1453	686

The transfer of the technology continued furtheraround Gimbichu district with a monitoring of the practices. The average yields of wheat obtained by the farmers from the use of the improved Vertisol management technology as compared to the traditional practice are shown in Tables 3 (1995) and 4 (1996) in central highlands of Ethiopia. As shown in both tables, the yield level as a result of the improved technology varied between 2.9 and 4.3t ha-1, whereas for the traditional practice the range was between 1.2 and 2t ha^{-1}. Actually, it appears that there seems to be variability in the yield at plot level. This might be due to the type of land (slope, soil depth etc) which might not be taken serious considerations at the beginning. Farmers were convinced about the advantages of the technology in increasing yield of wheat. For some areas, growing wheat was their first experience, due to an established belief that the waterlogged areas would not grow the crop. They gave such comments on a field day conducted in 1995. However, they remarked that fertiliser distribution to the area by market agencies was poor and the cost of implement was too high (Birr 225 per implement), because of economies of scale (its limited use only for short). However, since the yield level achieved by the farmers was twice as high as what they normally used to get in good harvest years following traditional practices, most farmers settled their credits as per the initial agreement.

Table 3. Wheat grain yield (t ha^{-1}) obtained from on-farm trials at Chefe Donsa (1995)

No. of farmers	Improved practice (BBF)		Traditional practice	Percent increment
	Range	Mean	Range	
6	2.5 – 3.1	2.9	1.2 – 1.8	38 – 158
10	3.2 – 3.4	3.3		78 – 183
17	3.5 – 3.8	3.7		94 – 216
11	3.9 – 4.3	4.1		116 - 258

Source: Tekalign et al., 1999

Table 4. Wheat grain yield (t ha^{-1}) obtained from on-farm trials at Chefe Donsa (1996)

No. of farmers	Improved practice (BBM)		Traditional practice	Percent increment
	Range	**Mean**	**Range**	
3	2.5 – 3.0	2.9	1.2 – 2.0	25 – 150
10	3.0 – 3.5	3.4		50 – 192
20	3.6 – 3.8	3.7		80 – 260
17	3.9 – 4.6	4.3		95 - 258

Source: Tekalign et al, 1999

In the first period (1995), the mean land holding of the participant farmer was found out to be 2.5 ha. The land holding ranged from a minimum of 0.9ha to a maximum of 5.25 ha. A sizable proportion of land was allocated to crop production. Close to 14% of the farmers rented in land and this accounted to 0.16 ha. The cropping pattern seemed to be diversified with wheat being the dominant crop in the area. Nearly all the farmers grew wheat (this occupied about 0.92 ha of the land) followed by teff (86%) and this occupies proportionally close to 0.39ha of land. Pulses were also the most important crops in the area next to cereals.

Consequently, the Use of the BBM together with appropriate seed and fertilizer become the improved Vertisols technology that is disseminated to various locations of the country. Employing this tilling device on Vertisols greately increases their food-producing capacity and farmers using the BBM can plant early in the rainy season and this timely planting provides soils with protective vegetative cover that reduces erosion.

During field days the on-farm trials are visited by farmers from the neighbourhood and other sites; and this was found to be a good forum for exchanging experiences and learning new techniques. Continuous farmer assessment and feedback are very helpful for technology refinement. For example farmers expressed concern that an early version of the BBM was too heavy to be pulled by their oxen, and this resulted in the refinement of the BBM.

Farmers who participate in an on-farm Verification could also play a major role in the transfer of the technology. This was observed when farmers who had previously used the technology train other farmers how to assemble the BBM, assisted in training oxen to pull the BBM.

Employing this tilling device on Vertisols greatly increases their food-producing capacity and farmers using the BBM can plant early in the rainy season and this timely planting provides soils with protective vegetative cover that reduces erosion. The Ministry of Agriculture and Global 2000 is promoting its use widely in collaboration with the research institutes of ILRI and EAROl.

BBM has been distributed widely to four major vertisol regions i.e. Oromiya, Amhara. Tigray and Benshangul Gumuz and about 2323 BBMs were distributed to woreada BOA and about 5170 farmers have used BBM between 1994-1998 in one year and/or another (Table 5).

Table 5. BBM Distribution and Sales by Region and Zone

Region	Zone	BBM Distribution and Sales			Number of BBM user farmers
		Number distributed	Number sold to farmers	Sold in %	
Oromiya	West Shewa	381	196	51.4	1985
	East Shewa	183	43	23.5	61
	North west Shewa	577	-	-	107
	Arsi	35	-	-	5
	Bale	200	-	-	-
	Sub-total	1376	239	17.4	2153
Tigray	Western	53	-	-	2
	Southern	53	Technical	-	-
	Sub-total	106	-	-	2
Amhara	South Wello	67	-	-	74
	North Wello	12	-	-	-
	North Gonder	53	-	-	26
	South Gonder	13	-	-	-
	North Shewa	98	60	61.2	342
	East Gojam	424	242	57.1	2394
	Sub-total	667	302	45.3	2836
Benshangul	Pawe	174	174	100.00	174
	Sub-total	174	174	100.00	
	Grand total	2323	715	30.8	5170

Source: Solomon et.al. 1999

1.3 Economic Returns

The economic analysis which was conducted both an on-farm and station level indicated that higher returns can be obtained from using packages of the vertisol than traditional practices of the farmers. Actually, the economic analysis here conducted reveals only partial analysis, for soil conservation benefits were not quantified at the initial phases. However, studies indicated that tremendous soil loss could be recovered by way of early planting due to early vegetative cover. This may save the cost of nutrient depletion which otherwise requires foreign exchange for the purchase of fertilizer input.

Table. 6 Returns from BBM technology in vertisol areas

Description	Inewari BBM	Inewari local	Wereilu BBM	Wereilu local	DebreZeit BBM	DebreZeit local
Revenue (EB/ha)	2015	1564	1921	785	4550	3366
Labor input (PD/ha)	38	37	46	21	65	52
Cost (EB/ha)	668	591	681	613	679	658
Gross margin EB/kg	1348	974	1240	172	3871	2708
Return to labor EB/PD	35	26	27	8	59	52

Table 6. reveals the gross margins and return to labor per hectare due to the use of BBM technology in the central highlands of vertisol areas. It is clearly observed that the return to labor, and gross margins are markedly higher for BBM technology than the traditional one.

2. Adoption of the packages of vertisol technology

The experience with vertisol technology generation, diffusion and adoption process in Ethiopia indicate that either a full package of technology may be adopted or some components of a package may be adopted depending on farmer knowledge, needs and resource conditions. To examine the issue in greater detail, adoption pattern has been considered at two levels.

2.1 Adoption pattern in on-farm research sites[1]

Since 1992, the government has gradually introduced market liberalization policies and a drive for achieving food self-sufficiency. Consequently a congenial environment has emerged for diffusion and adoption of the improved technology. During phase 2 (1990-95) of on-farm research in three sites (Inewari, Hidi and Ginchi), information on the BBM package was made accessible to all the farmers in the research villages yet it was observed that some farmers participated in the research process for different duration either continuously or discontinuously, some did not yet participate, some even did not know how the technology functioned. In the three research sites, there were 1553 households in 10 Peasant Associations (5 in Inewari, 2 in Hidi and 3 in Ginchi). Out of these, 598 (28%) households participated in on-farm research and tests during 1989-95, so they could be considered as adopters. During late 1995 and early 1996, a survey was conducted among 585 farmers: 474 adopters and 111 non-adopters.

Based on experiences in Inewari, Hidi and Ginchi, it appears that there may be significant differences between locations in terms of farmers' willingness and speed of learning and acquiring knowledge about BBM, and in terms of adoption and continuity in use. Some of the factors that may contribute to such differences are summarised in Table 1 and described below. The factors and the direction and importance of their influence are only indicative, they may not be exactly true for all circumstances. However, this experience may be helpful in identifying and targeting potential adopters by extension and other diffusion agencies.

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[1] This section is derived from Jabbar et al. (1998) and Gezahegn et al (2000) paper presented on the work shop on International symposium on vertisol management workshop.

Area under vertisols and area with major waterlogging problem may be more important than area under cropland per se in a farmer's decision to acquire knowledge about BBM, adopt and use it continuously. This is so because the BBM is supposed to solve the problem of vertisols management, particularly major waterlogging problem. For example, average cropland per farm was 1.45 ha in Inewari, 1.75 ha in Hidi and 2.95 ha in Ginchi. Vertisols constituted 49% of cropland in Inewari, 51% in Hidi and 91% in Ginchi. However, only 19% of cropland in Inewari and 17% in Hidi faced major waterlogging problem compared to 42% in Ginchi. These differences contributed to their knowledge acquisition, adoption and use pattern. An average farmer in Inewari was more likely to acquire knowledge about BBM than in Hidi and Ginchi, but among those who had knowledge, an average farmer in Ginchi was more likely to adopt and use continuously.

Household heads with better education (primary level or over) would be normally expected to be more eager to know about BBM and adopt it (though in the three areas studied, opposite was the case). Households with larger number of work animals are more likely to acquire BBM knowledge, adopt BBM and use it continuously. The positive effect of number of work animals may be explained by the fact that a pair of animals is required to pull the BBM, so farmers with two or more animals should be more interested to know about the BBM and use it than those having one or no work animal.

Larger family size may decrease the incentive to learn about BBM and adopt it perhaps because larger family labour supply decreases the need for alternative technology. In Inewari, handmade broadbed require a lot of family labour, so larger families with a lot of labour may show less interest in BBM unless they are willing to reduce the drudgery of women and children by adopting BBM.

Table 7: Factors likely to influence acquisition of knowledge about BBM, its adoption and Continuous use

Factors	Acquisition of knowledge	Adoption	Continuity in use
Area of cropland	+	+	Neutral
Area under vertisols	++	++	+++
Area with major waterlogging	++	++	+++
Family size	-	-	Neutral
Number of work animals	+	+	Neutral
Distance from major market	-	-	-
Expected extra yield/return	+	+	-
Education	+/-	+/-	+
BBM training	NA	+++	++
Access to credit	NA	+++	++
Perception that BBM has technical problems	NA	-	-

NA Not applicable + Low importance ++ Medium importance +++ High importance

Greater distance from market (poor access to market) also decrease the incentive of learning about BBM and adopting it perhaps because the transaction costs of acquiring knowledge increase with distance and reduces potential benefits. Distance may also hinder farmers from benefiting from occasional rise in product prices. Also information to distant areas may trickle down slowly from the extension agencies.

Once acquired the knowledge about BBM, skill training in BBM use may increase the possibility of adoption and continuous use greatly. Some adopters may not actually initially acquire the skill to operate the BBM, they may hire somebody else to operate it. A typical example would be a farmer without BBM operational skill and another farmer with skill joining together with their mareshas to make the BBM.

The possibility of adoption and continuous use should be lower for farmers who perceive that the BBM has some problems or disadvantages compared to those who do not perceive such problem.

In the three survey areas, the most important problem reported by some farmers was about the heaviness of the BBM unit. The other problem mentioned by a few was the unsuitability of the BBM when the soil is too wet during heavy rains.

For many farmers cash to buy the BBM and related inputs (improved seeds, fertilizers, pesticides) may be a major constraint given their subsistence nature of production and low cash income. Therefore, access to credit for BBM package may significantly increase the possibility of adoption and continuous use among those who have acquired knowledge and skill about BBM.

The primary attraction of the package is the extra yield or return from BBM compared to the enterprise it will replace. Moderate expectation may positively influence acquisition of knowledge, adoption and continuous use, as there may be a chance of exceeding the expected target, which may raise incentive to continue. On the other hand, high expectations about extra yield/return may sometimes act negatively as actual result may fall far short of target. The extent of higher average yield expected from improved wheat compared to the traditional crop (local wheat or teff) the BBM package replaced was 418 kg for the three sites (441 kg for Inewari, 365 kg for Hidi and 441 kg for Ginchi). These were moderate expectations as actual average yields in the areas surpassed these expectations. However, yield are likely to vary between farms and location due to many factors, so while promoting the technology and educating farmers, potential benefit should be expressed in terms of a range of yield rather than a single yield figure.

2.2 Adoption pattern and related factors outside the on-farm research sites[2]

The Ministry of Agriculture along with the Global 2000 demonstrated and diffused BBM package in different parts of the country since 1994. A survey was conducted in 1996 in two weredas - Becho and Gimbichu – among 142 randomly selected farmers. Among these 85 were adopters of the BBM (used at least once) and 57 non-adopters (never used BBM). The analysis of the data included understanding of adoption of the complementary elements of the package (wheat variety, seed rate, fertiliser rate and sowing date) as well as farm level analysis of general characteristics of adopters and non-adopters.

About 70% of adopters of used the recommended seed rate of 150 kg/ha, while 30% of non adopters follow the recommended date of sowing (dry planting) and seed rate. Both the adopters and non-adopter groups have used the improved variety. In Gimbichu area, the non-adopter group used almost the same level of improved variety. More than 60% of the farmers have applied the recommended rate of fertilizer, although nearly all the farmers in the study area are applying fertilizer. There is no significant difference in the use of fertilizer between adopters and non-adopter groups (Table 8). This trend shows that the use of fertilizer is a long time experience among the farmers in the survey region. The use of improved variety is relatively a short time experience as compared with fertiliser.

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[2] This section has been derived from Gezahegn Ayele (1999).

Table 8: Average intensity use of technology components

	Adopters N=85	Non-Adopters N=57
Fertilizer use (kg/ha)		
for wheat- urea	105	85
DAP	110	105
Tef- urea	102	100
DAP	150	120
- improved seed -wheat (kg/ha)	136	114
- local –wheat (kg/ha)	123	130
- improved tef (kg/ha)	30	20***
- local tef (kg/ha)	57	40
Sowing date (% of farmers)		
- wheat - end June-mid July	85	60
- tef - early July	63	60
Share of wheat area on total farm land (%)		
Gimbichu (N=72)	48	40**
Becho (N=70)	14	7*

*, **, *** significant at 1%, 5% and 10% respectively
Source : Field survey

Factors affecting adoption: The benefits obtained from the technology differ across the sample farms. With sub-optimal use of the BBM technology, the yield advantage decreases, hence leading to lower benefit derived from the technology. Generally, there is evidence that the economic advantage is much higher for the adopters than the non-adopters group.

The household level analysis demonstrated a spectacular increase of yield as a result of early planting using the BBM package as compared to traditional practices of the farmers. The results confirm that there is marked marginal increment from the use of the BBM technology at the household level for those who used full package. Although there seems to be variability in the average yield obtained from the use of the BBM technology, the overall yield has almost more than doubled over the traditional one on the same soil type.

The variability of output on the same soil could be attributed to different levels of efficiency in implementing the BBM package, specially improved drainage which in turn depends on the skill of individual farmer in using the BBM and shaping the land. In addition to this, the optimum time of using the implement determines the efficiency of the BBM in draining the excess water.

Following a multitude of theoretical and empirical works of adoption and diffusion models, in general, it was hypothesised that economic, demographic, environmental factors and those of the technology characteristics influence farmers’ response to an innovation. This analysis clearly indicated that, the adoption pattern and speed of adoption varied among individual farmers. As a result, farmers in the study villages responded differently to the technology package. Some adopted the technology in the first period and continued to use it, others adopted it at different times and discontinued practising it while others heard about it but were found reluctant to adopt and use it. Analysis of the sampled farmers confirmed that age factor has negative effect on the adoption of the BBM technology. As age increases probability of adoption tended to decrease indicating that old farmers were more reluctant to adopt the technology than younger farmers. As is often the case young farmers are fast enough to respond to new technology. It is equally true that distance from main road affected adoption negatively. The implication is that market access and proximity to the infrastructral facilities increase the probability of adoption of the technology with anticipation of better market and profitability.

Other factors such as access to farm resources were observed to affect the probability of adoption positively and significantly. In this connection, farm size and number of bulls owned were a surrogate to induce adoption of the farm technology as expected. As the farm holdings of the household increased the probability of adoption increased tending to expand the farm land under the improved technology. This is especially true for Gimbichu farmers who operate limited land under various risk situations such as unreliable rainfall, unpredictable weather change and variation of topography. Similarly, number of bulls owned affects the farmer's decision to adopt positively. Animal drawn drainage equipment requires at least a pair of oxen to draw the implement and prepare the raised bed to let the water flow out of the farm.

Training facilitates method of developing the skill of the farmer and raising the awareness. This is especially true during the initial phase of the transfer process when farmers require training on land shaping methods and proper use of the hardware component of the BBM. Most of the farmers who appreciated the use of the BBM have received intensive training from MOA or Global 2000 as well as research centers. Most of the farmers at Gimbichu got the exposure and training from the Debre Zeit research centre located in the vicinity.

Others factors, like credit greatly affect the adoption of technology. Adopters received Birr 437 as credit compared to 227 Birr by non-adopters. Not only availability of credit is a sufficient condition, but also the type, amount and availability in time is a necessary condition. In a situation where cash is a constraining, the question of acquiring BBM is closely linked with economies of scale. Farmers buy at a high cost and use it only once for preparing the land and its use is limited only for a specific period and purpose. Instead under this situation farmers adopt modified BBF, or some may rent in the BBM itself just for a while. Some have been observed when renting out the BBM. This might be helpful for resource poor farmers under a situation where supply is not a constraint. There are also additional categories of constraints which were not mentioned by farmers: sociocultural and policy like the question of sharing BBMs between households and conflict in community watershed management.

3. Watershed Management

Since the drainage resulting from BBM use effects the whole of the watershed this required community participation and can result in disputes over excess water "down stream". Hence managing resources in a watershed approach becomes an important development pathway. Thus recently, the research approach followed and moved from farm level to a concept of watershed management approach to efficiently and optimally use the vertisol resources of a country although much work has not been done. Watershed is defined as land area in which water drains to a given point, and soils, water and vegetation, livestock's are the primary natural resources which sustain the environment. Within the watershed approach, conservation tillage technology was added to the existing innovation with a major objective of introducing conservation practice into smallholder's farming system.

3.1 Conservation tillage technology: An option for resource management

One of the vertisol technologies that could be an alternative to traditional land management practices is the conservation tillage technique. Tillage is any seed bed preparation technique that utilizes machine, animal traction, hoe, hand etc. to disturb the soil. According to the paradigms of tillage system, traditional soil cultivation methods in the tropics with intensive soil tillage practice end in soil degradation and loss of crop productivity. Ultimately use and management of soil have to change in new ways of farming that considers tillage as such not the necessary factor for crop production. Soil erosion is a two way process, accomplished by agents that cause detachment and transporting of the soil particles. Unlike the traditional tillage methods which applies several passes of plowing for loosening the soil, top soils keep intact as it is when the minimum tillage practice is applied. The latter makes difficulty in transporting (eroding) the soil since detachment of the top soil is not actually occurred at the inception. Crop residues at least 20-30%, when left on the soil surface can serve as mulch to prevent wind and soil erosion and slows down evaporation losses (Kurt, 1998). Many research results also indicates that by preventing splash the erosion from bare soil can be dramatically reduced. This is the most important aspect of soil conservation if combined with crop management, simply because it has the greatest effect. It is thus possible to make sustainable increase soil organic matter, improve water infiltration in to the soil, prevent wind and water erosion and ultimately raise soil productivity.

In this situation, initially the innovation of Broad Bed Maker (BBM) has an essence of shaping broad bed and furrows to overcome problems related to surface drainage of vertisols in areas where intensity of rainfall is high. At the initial phase of the technology, farm land is repeatedly plowed with traditional ox plough before shaping the surface with BBM. Consequently, loosening and turning the upper layers of soil and burial of crop residues due to the several passes of ox plough makes to create conducive condition for soil erosion, however improvement in drainage system is observed. Later, the introduction of conservation tillage in these phenomena is regarded to be an alternative solution to combat both soil drainage and erosion problems. That is, both BBM implement and minimum tillage technology are sequentially combined as a two in one practice. This could be implemented, in the first case, by constructing Broad Bed and Furrows (BBF) by an animal drawn Broad Bed maker (BBM). Once the BBF constructed, it could be maintained for several cropping seasons with the minimum tillage practice. In making the land for subsequent seasons with the same practice, BBF will have to be rehabilitated, with additional attachments to the BBM. Retaining the BBFs for repeated use with minimum tillage is a promising option. In addition to this a planter-other; additional attachment is provided with the capacity of sowing seed and fertilizer, optimizing input use, with out making any damage on the previously established BBF and covering it in the same operation. The planter makes technically, row seeding rather than broadcasting, reduces seed rates by placement of seed uniformly at optimum soil depth and also reduces fertilizer rate by improving nutrient uptake. In addition, crop residues remains on the soil surface as mulch and the soils get permanent soil cover so as to reduce the extent of land degradation and promote sustainable natural resource management.

3.2 Economics of Conservation tillage

As part of the Joint Vertisol Project (JVP) program, the minimum tillage technology verified for farmers in the vertisol areas is the central focus of an on-farm technology verification and transfer. The general framework prerequisites, such as environmental suitability, economic viability and social acceptability are considered to be important criteria in an evaluation of on-farm technology. The performance of minimum tillage technology on these criteria are evaluated based on agro-ecological prerequisites, incentive brought for farmers and perception of farmers regarding to the technology.

The agro-ecological framework conditions, which could be the most favorable conditions for the application of minimum tillage practices, exist where mean annual rainfall is more than 1000mm. Consequently, minimum tillage practice in the highlands of vertisol areas is well performed to the given agro-ecological parameters for effective protection of the soil against erosion by water and wind and then promotes life of the soil.

3.3 Economic incentive

Compared to the traditional land shaping methods there is an increment of yields in minimum tillage. The on station trial showed that the grain and straw yields of plots that were prepared using minimum tillage averaged 1.4t/ha and 3.37t/ha respectively compared to significantly low corresponding yields of 0.91t/ha and 2.36t/ha respectively from conventionally tilled plots (JVP Progress report-No.9).

Minimum tillage has also an important economic appeal making incentives to farmers in terms of reducing production costs particularly expenditure on purchased input and labor in different agricultural operations. The reduction of the amount of labor, time and energy expended on soil cultivation and subsequent farming operations attracted the attention of smallholder farmers for conservation tillage in the vertisol farming systems.

Table 9. Comparison of input required and output produced for different tillage practices, Gimbichu, 1999.

Description	Traditional Tillage[3]	Conventional Tillage[2]	Minimum Tillage[1]
INPUT			
Implements used for cultivation (hr/ha)			
- Maresha	8.95 (3.84)	6.26 (1.43)	-
- BBM	-	0.66 (0.07)	0.63 (0.18)
- Row planter	-	0.64 (0.10)	1.28 (0.68)
Labor used for cultivation/cleaning (Manday/ha)	2.79 (1.12)	2.88 (1.15)	0.52 (0.12)
- First cultivation	2.46 (0.92)	3.39 (0.55)	0.63 (0.18)
- Second cultivation	0.75 (1.50)	0.66 (0.07)	-
- Third cultivation	0.69 (1.38)	-	-
- Fourth cultivation	2.26 (0.82)	0.64 (0.10)	1.28 (0.68)
- Planting			
Oxen used for cultivation (Manday/ha)	2.79 (1.12)	2.88 (1.15)	-
- First cultivation	2.46 (0.92)	3.39 (0.55)	0.63 (0.18)
- Second cultivation	0.75 (1.50)	0.66 (0.07)	-
- Third cultivation	0.69 (1.38)	-	-
- Fourth cultivation	2.26 (0.82)	0.64 (0.10)	1.28 (0.68)
- Planting	187.50	88.00 (11.24)	109.89
Seed rate (kg/ha)	(47.87)		(14.85)
Fertilizer rate (kg/ha)		72.37 (10.08)	
- DAP	95.83 (8.33)	56.67 (18.27)	72.52 (8.64)
- UREA	95.83 (8.33)	7.42 (2.61)	54.65 (11.73)
Labor used for weeding (Manday/ha)	3.09 (0.99)		3.50 (0.71)
OUT PUT			
Grain Yield (kg/ha)	2208.43 (348.39)	1455.20 (382.29)	1536.77 (166.55)
Straw yield (kg/ha)	3483.16 (1173.32)	2587.77 (868.90)	3060.66 (631.71)
Weed used as feed (kg/ha)	334.53 (122.18)	905.60 (381.82)	1146.61 (212.61)

(..): Figures in parenthesis are standard deviation

[1] *Minimum tillage = Use of BBM to rebuilt the already existed BBFs followed by row placement of wheat seeds mixed with fertilizer with the planter*

[2] *Conventional tillage = Use of BBM to form new BBFs followed by row placement of wheat seeds mixed with fertilizer with the planter.*

[3] *Traditional tillage = Wheat seeds and fertilizers broadcasted and covered with maresha (ox-plough) to make ridge and furrows*

On-farm verification of minimum tillage practice on wheat which is carried out in one of the vertisol area showed that there is remarkable improvement in the requirement of labor and draft power. Not only this, but also the amount of purchased inputs such as seed and fertilizer used is lower. The demand for labour in land preparation in the case of minimum tillage is only for cleaning the land with tines, rebuilding the already existed BBFs with BBM and seed and fertilizer planting with row planter.

As opposed to conventional and traditional tillage practices labor is required for loosening and turning the upper layer soil for minimum tillage practice is non existed. In addition to this the amount of labour required for planting with planter in minimum tillage practices is by half lower than the labour required in traditional system for the same operation. Essentially minimum tillage practices could be an options for evening out peak labour loads for soil preparation and subsequent farming operations which provides wide opportunity for timely operation of the activities.

As compared to traditional and conventional tillage systems, peasant households who employs a family labor for minimum tillage has an advantage of reducing the opportunity cost of labour for cultivation by 178% and 136% respectively. Similar economic advantage is also present in minimum tillage practices with regard to the requirement of draft power for land preparation and labor for weeding. Apart from the reduction of implicit oxen rent cost, the reduced time requirements for seed bed preparations and evened out of ploughing is crucially important. This applies significantly for those low income groups who suffers with shortage of oxen. The oxen traction time required to manage one hectare of land is on average 368% less than that required for the traditional method and 296% less for the conventional tillage practice. More over, the great interest in minimum tillage practices is also founded in the reductions of the need for purchased agricultural input such as seed and fertilizer. Considering minimum tillage as a minimum input cost technology, the application of lower rate of seed (109.89kg/ha) and fertilizer (72.52kg/ha DAP and 54.65kg/ha Urea) will save farmers to incur 70% and 45% additional cost respectively as compared to the traditional tillage system. Recent studies on this issues indicated that reductions of input cost is supposed to be continued further in the following cropping seasons as protection of the soil and the build up of soil organic matter increased soil productivity. As a whole given the least cost technological components of minimum tillage practices, the total cost combinations of such practice is significantly different at $p<0.05$ both from the conventional and traditional cultivation system.

Table 10. Comparison of costs incurred and benefits earned for different tillage practices, Gimbichu, 1999.

Description	Traditional Tillage (RF)	Conventional Tillage (CT)	Minimum Tillage (MT)
Grain Sale (Birr/ha)	3754.34^{a}	2764.88^{a}	2919.86
	(592.25)	(726.36)	(316.45)
Straw Sale (Birr/ha)	1044.95	776.33	918.20
	(351.99)	(260.67)	(189.51)
Total Gross Benefit (Birr/ha)	4799.28^{a}	3541.21^{a}	3838.05
	(889.69)	(917.20)	(470.24)
Cost of labor for cultivation (Birr/ha)	89.48^{a}	75.69^{b}	32.13^{ab}
	(38.41)	(14.14)	(6.16)
Cost of labor for weeding (Birr/ha)	30.94^{a}	74.17^{ab}	35.00^{b}
	(9.87)	(26.11)	(7.07)
Oxen rent (Birr/ha)	268.44^{a}	227.08^{b}	65.57^{ab}

	(115.23)	(42.42)	(16.84)
Cost of Seed (Birr/ha)	412.50^{ab}	193.60^{a}	241.76^{b}
	(105.32)	(24.73)	(32.66)
Cost of fertilizer (Birr/ha)	378.54^{ab}	262.46^{a}	259.83^{b}
	(32.92)	(41.76)	(30.20)
Total cost that vary (Birr/ha)	1179.90^{a}	833.00^{a}	634.28^{a}
	(147.04)	(18.93)	(69.45)
Gross Margin (Birr/ha)	3619.39	2708.21	3203.77
	(930.98)	(905.12)	(415.69)

* Price information

- Grain price (Birr/kg) = 1.90 (for MT & CT) and 1.70 (for RF)
- Seed price (Birr/kg) = 2.20
- Fertilizer price (Birr/kg) : DAP = 2.46 ; UREA = 1.49
- Oxen rent (Birr/ day) = 30.00
- Labor price (Birr/day) = 10.00
- Straw price (Birr/kg) = 0.30

** Figures followed by the same letter are significant at the 0.05 probability level

Though not significant, the yield that the farmer harvested and consequently the return that the farmers earned, in the case of minimum tillage practice, is shown as slightly lower than the one being used with the traditional tillage system. The reasoning of several studies on this line is that the pivotal objective of minimum tillage is conservation of natural resources through overcoming loss of soil caused by different agents. And reduction of requirement of labor and oxen time and expenditures on purchased inputs are considered to be as a subsidiary effect of the practice. Through time as the soil is well maintained and organic matter of the farm is improved, yield is expected to be stabilized, implying that an on-farm activity should be continued to validate the long run effect of the technology, albeit, in this study the impact on soil degradation and nutrient depletion is not yet fully investigated. This demands further study by employing multi-criteria analysis.

Subjective preference and perceptions of farmers in the character, implementation and consequent effect of the technology paves the way for a better process of dissemination and/or a further refinement of the technology. Likewise, participating and neighbouring farmers in the vertisol area allowed evaluating the process and consequences of minimum tillage practices in relation to the other traditional practices. The technology is distinguished primarily in to different attributes. Cultivation patterns and the discussion of technological characteristics of minimum tillage system among participating farmers illustrates a point which regarded as information on technological choice and adaptation.

Among the three tillage practices verified to them, farmers attitudes towards land saving through minimum tillage practice is considered as positive attribute. The number of furrows to which seed is not placed is increased proportional to the number of ridges. This premise supposed to suggest that as farmers increase the number of ridges and furrows to avoid drainage problems, the land with out crop is also increased, ultimately wastage of land comes on the negative picture.

Farmers also highly perceived on labor saving for plowing and sowing in minimum tillage. This is simply because of the mere absence of frequent ox plowing and requirement of less time for rebuilding the BBFs.

With regard to weeding, there is a controversial and mixed perception, among farmers in the study area. Weeds grown in the area are classified in two faces, those economically beneficial that serve as animal feeds and those which are not. In order to feed for their animals, some farmers spent more time to rouge the weeds, however it is in their spare time. But the problem associated with weeding is that, weeds used for feed are weeded late after it reduces the growth and yield potential of the crops. Due to the absence of plowing operations in minimum tillage practice, labour could be free for other tasks. The labor competition effect of minimum tillage practice is low either due to the exclusion of some farming operation like plowing or performing at the slack period of farmers' time. .

4. Conclusion and future direction

Lesson learnt from the past in general indicated that vertisol are potential resources and will continue in the future to support both crop and livestock production system and contribute to the food security in the country. On the other hand there are also conflicting nature in the development and use of this resource and hence has not been fully exploited to the extent of its potential. Technological innovation was developed to support the management of the vertisol resources and shown some positive impact. The conflicting interest specially the issue of managing excess water drained from the farms created further problem on the community and this lead to follow watershed approach to better managing the resources. The addition of conservation tillage to the BBM technology contributes to better conserve vertisols and increasing of yield. The contribution of the innovation can be evaluated both indirectly and directly.

1. Reducing labor time required to prepare land
2. Allows farmers to plant more farm land
3. Provides farmers an opportunity for sustainable production system thereby contributing to ecosystem
4. Provides oxenless farmers with opportunity to minimize oxen cost and input cost

It will be clear that Ethiopia to meet the demand for food and feed its population, it has no other option except to maintain its resource base. Every effort should be exerted to conserve the soil and water of the farmland. Without innovation supporting the resource base of the vertisols and use of the excess water in the Ethiopian highland, the use of external input such as fertilizer alone may not be a sustainable option for development. For future direction and development, it is necessary to integrate the resource management of a vertisol in a watershed context and able to optimally use resources, see to it impacts of alternative technologies. In this line of thought it is also essential to consider relevant policy options related to land resource management, conflicting objectives of smallholder in management of natural resources and implication at the watershed level. The integration of crop-livestock system should also be considered as an issue of research agenda within the watershed research approach.

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