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Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol

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Abstract

Farmer participatory tillage trials were conducted in a highland Vertisol area of Ethiopia during the 1999 and 2000 cropping seasons. This participatory initiative clearly demonstrated that incorporating farmers' knowledge, ideas and preferences could improve the wheat production package. A traditional practice of Chefe Donsa farmers—applying ash from their homesteads to their fields to enable early-sown crops to withstand frost—led to the verification of the yield-enhancing effect of inorganic potassium fertilizer on wheat. Farmer adoption of a minimum tillage production system increased the gross margin of wheat production by US$ 132 per hectare—based on 1999 prices—relative to the traditional flat seedbed system. The minimum tillage system was characterized by a much lower level of soil manipulation relative to the traditional flat seedbed system, and, as a consequence, markedly reduced the total human labor and draft oxen requirements for wheat production. Thus, the minimum tillage system could be an effective intervention for soil conservation due to early-season vegetative cover of the soil surface. Also, the early crop harvest associated with the minimum tillage system was highly beneficial for small-holder farmers—since the early harvest coincided with the cyclical period of severe household food deficits and high grain prices in local markets.
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1. Introduction

In Ethiopia, more than 90% of the land prepared annually by small-holder farmers for crop production is tilled with the traditional ox-plow ('maresha') pulled by a pair of local zebu oxen. Three to five tillage passes with the 'maresha', with each pass perpendicular to the previous one, are required to establish a satisfactory seedbed on most types of soils. The first pass only penetrates about 8 cm into the soil profile, while the last pass can reach approximately 20 cm in depth (Astatke and Kelemu, 1993). Cropland is usually tilled in preparation for the main rainy season, extending from June to September. For tef (*Eragrostis tef*), the principal cereal crop of Ethiopia, seeds are sown during the middle of the main rains. For other crops, e.g. local wheat (*Triticum* spp.) and pulses, seeds are sown at the beginning of the main rains on light soils and close to the end of the rainy season on heavy clay soils such as Vertisols.

About 12.6 million ha of Vertisols, comprising roughly 30% of the Vertisol area in Africa, are located in Ethiopia. Vertisols cover 10.3% of the total surface area of Ethiopia, and two-thirds of the Ver-

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tisol area is located in highlands >1500 m a.s.l. (El Wakeel and Astatke, 1996). Despite their high agricultural potential, Vertisols are generally regarded as problematic soils in Ethiopia due to their characteristic hydro-physical properties, which lead to a high incidence of prolonged water-logging during the main rainy season. For this reason, most crops are sown on Vertisols towards the end of the main rainy season. Thus, the tilled soil is exposed to intense rainfall during the major portion of the rainy season; due to the lack of adequate vegetative cover, this results in a high rate of soil erosion. Furthermore, crops sown late on Vertisols in order to escape water-logging utilize residual soil moisture to mature, and inevitably experience water stress during the seed filling stage, lowering grain yield levels. Thus, improving the utilization and productivity of Vertisols could contribute immensely to solving Ethiopia's perennial problems of poor food security and human malnutrition.

To ameliorate the water-logging problem on Vertisols, a research consortium developed an animal-drawn implement named the broad bed maker (BBM) by modifying the local 'maresha' (Astatke and Kelemu, 1993). The BBM creates 80 cm wide raised seedbeds separated by 40 cm wide furrows commonly referred to as the broad bed and furrow (BBF) system. The furrows allow excess water—common during the intense main rains—to be expelled to a drain or other outlet at the bottom end of a farmer's field. This technology facilitates early sowing of crops, thereby utilizing a longer growing period and resulting in higher crop yields; soil erosion is also reduced since there is adequate vegetative cover to protect the soil during the main rains (Mohamed Saleem, 1995; Astatke and Mohamed Saleem, 1998). Crops sown in the BBF system can be harvested about 2 months earlier than those sown on traditional flat seedbeds; an early harvest is beneficial for small-holder farmers since it coincides with the period of severe household food deficit and high grain prices in the local market.

The BBF technology was tested on-farm and later disseminated by the Ministry of Agriculture and several NGOs. At present, if farmers apply the BBF system on the same plot of land during consecutive seasons, the beds are destroyed by conventional tillage and reconstructed on an annual basis. Retention of the BBF beds on a semi-permanent basis by adopting minimum tillage is a promising option for conserving natural resources. It also enables small-holders to minimize animal and human labor requirements and to reduce seed and fertilizer rates for crop production. To address this potential, additional BBM attachments have been developed for minimum tillage and row seeding on semi-permanent beds.

Subsequent to 2 years of on-station evaluation of the technical performance of the newly-developed BBM attachments, a farmer participatory trial of the BBF minimum tillage technology package was conducted in the Chefe Donsa district of Ethiopia during the 1999 and 2000 cropping seasons. Chefe Donsa—a highland Vertisol district situated above 2500 m a.s.l. in the Central Ethiopian highlands—receives annual rainfall of approximately 900 mm: 670 mm during the main rainy season extending from June to September and about 200 mm during the short rains from February to May. The mean cultivated area per household in Chefe Donsa is 2.20 ha with 0.40 ha of grazing land—similar to the majority of farms in the central highlands of Ethiopia. In this district, slightly more than 50% of the households own more than a pair of draft oxen, 40% own a pair, and the rest of the households own one or no draft oxen. Wheat is the major crop—occupying 60% of the cultivated area. At sowing time, wheat and fertilizer are mixed and broadcast by hand on soil which has been tilled by three to four passes of the 'maresha'. The broadcasting is followed by an additional 'maresha' pass to cover the seed and fertilizer and to construct ridges and furrows to drain excess water in the field. This method of sowing has little depth control, and has been shown to place 15.3% of the broadcast seed and fertilizer at a depth of 10–20 cm while 25.3% lacks adequate soil cover (Tinker, 1989). Due to this depth variation, farmers in Chefe Donsa use very high seed and fertilizer rates. Also, as a result of the runoff erosion during the main rains, there are many gullies and abandoned patches of rocky outcroppings in farmers' fields in Chefe Donsa.

Some Chefe Donsa farmers had previously adopted the BBF production package, and were familiar with its advantages and disadvantages. As an entry point to build further trust between farmers and researchers and to initiate a research process, the farmers were familiarized with two conservation tillage techniques—zero and reduced tillage systems—as options for their choice. These techniques corresponded to their priority needs, and were suggested for fur-

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ther joint testing with researchers as farmer-managed and farmer-implemented trials. This approach to research enhances the exchange of experiences among stakeholders, thus leading to a rapid refinement of the technological package as well as improving the chances of acceptance by the same end users (Bellon, 2001). Close interactions with farmers suggest that conventional research approaches have often been too restrictive; in order to optimize the development and dissemination of technological innovations, researchers should adopt a more holistic approach (Drechsel, 1998).

During the past four decades, soil and water conservation efforts in the East African highlands largely concentrated on the use of physical conservation structures such as stone terraces, soil bunds and weirs to reduce soil erosion. However, there is a growing awareness that such structures may not significantly improve the agricultural productivity of small-holder farmers. Rather, research and extension personnel need to emphasize the development of sustainable, conservation-oriented farming systems (Biamah and Rockstorm, 2000). Conservation tillage, including reduced and zero tillage practices, has been proposed as one of the most promising means of reducing soil erosion and stabilizing crop yields in the rainfed farming systems of sub-Saharan Africa (Stobbe, 1990). Conservation tillage entails a reduction in soil manipulation, thereby minimizing the energy required for tillage and maximizing the retention of crop residues on the soil surface during land preparation and seeding operations. The ultimate goal is to reduce soil nutrient and moisture losses (Kaumbutho et al., 1999).

The purpose of this paper is to describe the participatory methodology applied for testing the tillage options, and the results obtained.

2. Materials and methods

2.1. On-farm trial in 1999

Based on the results of the previous on-station tillage experiments (Astatke et al., 2002), three tillage systems (treatments) were selected for testing on-farm in the 1999 cropping season as follows: the farmers' traditional system, newly-constructed BBFs, and the use of permanent BBFs with minimum tillage. Prior to contacting volunteer farmers to host the participatory trials in the Chefe Donsa district, the following hypotheses were postulated about the possible farmer attitude towards the combination of conservation tillage with the BBF production system.

1. Farmers who had previously adopted the conventional BBF package would be more likely to volunteer to test a conservation tillage option than other farmers.
2. Farmers, regardless of prior experience with the conventional BBF system, would be reluctant to test zero tillage on their farms since farmers in Ethiopia are not accustomed to producing crops without tillage.
3. If the participatory trials of the minimum tillage package showed promising results, farmers would be more willing to test the zero tillage option in the future as a logical consequence.

Early in 1999, group consultations were held with farmers living near Chefe Donsa village to share with them the results of the previous on-station trial of the zero and minimum tillage packages, and to display the four-row planter attachment developed for the BBM. Of the farmers who participated in these discussions, 12—all of whom had used the BBF system previously—expressed an interest to learn more about the new technologies and to view the equipment in operation. These 12 farmers were transported to the ILRI Debre Zeit Research Station where the form and function of the BBM attachments were explained and demonstrated. Unfortunately, as this was an off-season period, no trial plots were available for viewing by the farmers' group. At the conclusion of the demonstration, all 12 farmers expressed interest in participating in a trial of the minimum tillage and funnel planter BBM package; none of them were willing to include the zero tillage option in the trial. Thus, their responses were consistent with the expectations of the research team as expressed in the postulated hypotheses.

However, at the beginning of the crop season, only nine farmers expressed willingness to participate in the BBF tillage trial: six of these were among the original 12 volunteer farmers; the additional three farmers had not participated in the on-station consultation, but had used the conventional BBF package during the 1998 cropping season. One farmer expressed a desire to conduct the trial on two separate plots of land, raising the number of BBF plots to a total of 10. Four neighboring farmers agreed to serve as the "controls" by following their traditional flat seedbed preparation. Thus, there were 14 plots under the three treatments, and, on each plot, which averaged 0.25 ha in area, only one tillage system (treatment) was applied. Of the 10 plots sown to the BBF systems, six plots were prepared using the traditional 'maresha', then BBFs were constructed with the BBM, and the funnel planter was used for sowing wheat. On four other plots, BBFs constructed in 1998 were retained, and minimum tillage was practiced by utilizing the attachments for weed control and the funnel planter for sowing wheat.

Except for the newly-developed BBM attachments for minimum tillage and the four-row funnel planter, the host farmers agreed to cover the cost of all other inputs required for the trial. Farmers selected varieties of durum (*T. durum*) and bread (*T. aestivum*) wheat for planting, according to their personal preferences. Wheat seed was mixed with diammonium phosphate (DAP) fertilizer and sown in four rows using the funnel planter attachment on the beds formed by the BBM. The recommended rates for seed and DAP mixed in the seed row were 100 kg and 80 kg ha^{-1}, respectively, for both BBF systems using the funnel planter. A urea top dressing was to be split applied at the rate of 50 kg ha^{-1} on the third and again on the sixth week after emergence on the BBF plots. The minimum tillage BBF plots were sown at the onset of the main rains in late June, while the newly constructed BBFs were sown during the first 2 weeks of July. The traditionally-prepared flat seedbed plots were sown near the end of the main rainy season—during late August to early September—by broadcasting seed and fertilizer at farmers' accepted rates on the prepared seedbed and covering them with a single pass of the 'maresha'.

During the growing season, the participating farmers, extension staff from the district Bureau of Agriculture, and the researchers conducted two field visits followed by group meetings to evaluate the technology packages and to recommend future improvement. More frequent informal meetings of the researchers and the participating farmers occurred when researchers visited the plots. After crop harvest and the analysis of the results, a group meeting of the participating farmers and researchers was held to discuss the results and to finalize modifications for the 2000 trials.

2.2. On-farm trial in 2000

All 10 of the BBF plots from 1999 were included in the 2000 trial by maintaining the BBFs using the previously-described minimum tillage system. One neighboring farmer who had constructed BBFs independently in 1999 requested to join the 2000 trial program and agreed to maintain his BBFs using the minimum tillage system. More than 20 additional farmers were interested to join in the 2000 trial by participating in the construction of new BBFs and using the funnel planter to sow wheat. Eventually, only 10 additional farmers with 11 plots of land were accepted as participants due to the need for clustering the trial plots. As free grazing livestock in Chefe Donsa district are traditionally not restricted from entering the fields until the first week of August, encroachment of grazing animals on the emerging wheat plots sown early on the BBFs in 1999 represented a major problem, and necessitated additional guarding by the participating farmers. As a potential solution, the farmers suggested that the participants' BBF plots should be clustered (i.e. established in close proximity) to increase the density of stakeholders in a particular area, thereby facilitating protection of the plots. Thus, four clusters, each comprising three to six BBF plots, were formed—comprising all 22 BBF plots of the 20 participating farmers. The four clusters were separated by distances ranging from 2 to 6 km. The clustering configuration essentially restricted which potential new farmers joined the trial in 2000, since the 1999 host farmers were already in place.

Group meetings and discussions with the participating farmers resulted in several additional changes to the 2000 trials.

1. The major change involved the inclusion of an additional comparison, i.e. zero versus applied K_2SO_4 in factorial combination with the three tillage systems. Farmers in Chefe Donsa district generally apply dung cake and wood ash from their homesteads to plots of land designated for planting faba bean (*Vicia faba*) and barley (*Hordeum vulgare*) crops. These two crops are traditionally sown early in July and are expected to withstand an October frost—if it occurs—due to the application of ash (i.e. which contains potassium) to

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the fields. Due to a severe shriveling of wheat seed observed in October 1999, it was decided, after discussion with the participating farmers, to apply 50 kg K_2SO_4 ha^{-1}—the only potassium fertilizer available in the local market at the time. In order to assess the effects of K, each trial plot was sub-divided: one-half received K_2SO_4 while the other half did not. For the early-planted BBF plots, 25 kg K_2SO_4 ha^{-1} was applied at planting and an equal amount was applied three weeks after planting, i.e. concurrent with the first urea top dressing. For the traditional tillage system, 11 interested farmers each with 0.25 ha plots were selected for K_2SO_4 application at 50 kg ha^{-1}—with all other inputs as per the host farmer's conventional practice—to compare with another 11 farmers' traditional plots without K application.

2. In 1999, due to the 20 cm row spacing used on the funnel planter, the four rows of wheat effectively occupied only 60 cm of the 80 cm seedbed formed by the BBM, resulting in a wide gap of 60 cm (including the 40 cm furrow) between the outer rows of wheat on consecutive beds. Since farmers greatly disliked the 60 cm gaps, and to maximize the soil surface under crop cover, the rows of the funnel planter were reset at a wider spacing of 25 cm to fully occupy the 80 cm BBF beds.
3. The standard 40 cm BBF furrow width was reduced to 30–35 cm when farmers substituted their local narrower 'maresha' wings on the BBM.
4. The target date of planting on permanent BBFs was postponed to the first week of July in contrast to planting in mid to late June as in 1999.
5. The recommended seed rate for wheat sown with the funnel planter was raised to 115 kg ha^{-1} from an actual mean seed rate of about 100 kg ha^{-1} in 1999.

As in 1999, the participating farmers, district extension agents, and researchers conducted two field visits and group meetings during the 2000 growing period. There were also frequent informal discussions among researchers and individual participating farmers during field visits in the cropping season. A post-harvest meeting was conducted in February 2001 to discuss the performance of the BBF packages in comparison to the traditional system.

2.3. Data collection and analysis

During the 1999 and 2000 cropping seasons, actual seed and fertilizer rates applied, the oxen time required for seedbed preparation and planting, the wheat varieties used, and the time spent on hand weeding for the different tillage systems were monitored for all participating farmers. The precursor crop grown during 1999 was also recorded during the 2000 cropping season. Farmers planted wheat varieties according to their preference, and Kilinto (durum), ET-13 (bread), Kubsa (bread) and Cocorit (durum) were the principal varieties used. The application rates for wheat seed, urea, and DAP varied from recommended rates in both years. Over the two seasons, the actual wheat seed rate applied with the funnel planter was 119 ± 19 kg ha^{-1} for new BBFs and 114 ± 7 kg ha^{-1} for permanent BBFs. In the traditional broadcast system, the actual wheat seed rate was 211 ± 47 kg ha^{-1}. The higher seed rate with broadcast planting in the traditional system is associated with an inappropriate depth of seed placement by the 'maresha' and a consequent lower germination rate (Tinker, 1989). Rate of urea application was 141 ± 20, 113 ± 28 and 115 ± 26 kg ha^{-1} for the traditional, new and permanent BBF systems. DAP application rates appeared to vary in a discrete manner, and there were four clusters grouped around 50, 65, 80 and 100 kg ha^{-1}.

At harvest, four randomly selected 1.2 m^2 samples were collected from each plot to estimate grain and straw yields. Grain and straw samples were collected from 14 plots in 1999 and 66 plots in 2000 (i.e. 33 plots each sub-divided into two for the K treatments).

Combined analyses of variance, using the crop cut data bulked at the plot level, were conducted to compare the effects of the three tillage systems in both cropping years. For the 2000 cropping season, the analysis of variance included the effect of K_2SO_4 on the wheat crop, and also considered the effects of precursor crops and wheat varieties. Due to the unbalanced number of treatments, the GLM procedure for SAS (1988) was used for these analyses.

Since the experiments were not fully controlled in the real-farm situation, apart from tillage systems, several other factors varied between farms and plots, and these might have influenced yields, input use rates, costs and returns. Thus, a general linear model incorporating several factors and covariates was also used

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to analyze the data. For this model, rather than bulking the crop cuts at the plot level, the individual harvest samples were used as the unit of analysis. This increased the experimental degrees of freedom, and facilitated the evaluation of both within and between plot variation.

Since K was not applied in 1999, analysis of pooled data appeared problematic due to this imbalance in the experimental design. To address this issue, first, all the plots from 1999 and the plots without K from 2000 were combined for analysis to determine if year was a significant factor; it was found that year was not significant. Second, all of the plots for 2000—with and without K—were analyzed to see if K was a significant factor; it was found that K was significant. Therefore, the final analysis pooled data for both years but excluded year as a factor in the model.

The GLM procedure of SPSS was applied to analyze the data (SPSS, 1999). The general form of the model may be written as $\boldsymbol{Y} = \boldsymbol{F}(\boldsymbol{Q}, \boldsymbol{C}) + \boldsymbol{e}$, where $\boldsymbol{Y}$ is the observed dependent variable (yield, input use, or return), $\boldsymbol{Q}$ is a set of qualitative (discrete) variables or factors each with more than one category, $\boldsymbol{C}$ is a set of quantitative variables (covariates), and $\boldsymbol{e}$ is an error term. Interaction variables may also be incorporated. The partial derivative of the estimated function with respect to a covariate is the implicit marginal value of the attribute. Factors are represented by dummy variables, and the estimated parameters measure the impact of the presence or absence of the attribute. Bonferroni confidence intervals were used in the hypothesis tests in order to reduce the likelihood of false rejection of null hypotheses. The advantage of this procedure compared to linear regression is that the results can be interpreted more directly and easily to compare differences between categories of a factor, as the estimated parameters indicate both the direction and absolute value of the differences from a base category.

3. Results and discussion

3.1. Results of combined analysis of variance

The data on draft oxen time reflected differences both among treatments and between years (Table 1). In both years, four passes with the ox-drawn BBM with the blade and tine harrow attachments and a fifth pass with the BBM with the funnel planter were required to maintain and sow wheat on the permanent BBFs. This conservation tillage package utilized a similar total oxen time in both seasons; however, the total oxen time used in maintaining and sowing wheat on the permanent BBFs was roughly one-third to one-half of the total time required for either the newly-constructed BBFs or the traditional flat seedbed each season. In 1999, the oxen time required for the permanent BBFs was significantly lower than either the newly-constructed BBFs or the traditional flat seedbed; the latter two treatments did not differ from each other. In 2000, the oxen time requirements for each treatment were ranked in the following order of significance: flat > new BBFs > permanent BBFs.

Table 1
Draft oxen time used for land preparation and planting for the three tillage systems in the on-farm tillage trials at Chefe Donsa in 1999 and 2000

Tillage system	Draft oxen time ($h\,ha^{-1}$) 1999	Draft oxen time ($h\,ha^{-1}$) 2000	L.S.D.$_{(0.05)}$
Traditional flat	71.60 (4)	57.30 (22)	13.90
Newly constructed BBFs	60.56 (6)	41.70 (11)	8.90
Permanent BBFs	25.70 (4)	23.90 (11)	NS
L.S.D.$_{(0.05)}$	26.30	4.50	

Figures in brackets refer to the number of plots for each treatment. NS: not significant ($P > 0.05$).

Year effects were also apparent for oxen time used in the flat and new BBF treatments (Table 1). For both treatments, there was a significantly higher oxen time requirement for tillage in 1999 compared to 2000. The failure (i.e. absence) of the small rains during February to April of 1999 forced farmers to commence tillage at the onset of the main rains—much later than is customary. As a consequence, three tillage passes in close succession prior to seeding were required to break the soil clods and to prepare a satisfactory seedbed in 1999. In contrast, the 150 mm of precipitation received during the small rains of 2000 enabled farmers to prepare a satisfactory seedbed with one final tillage pass prior to sowing wheat. Despite the failure of the small rains in 1999, the minimum tillage package on the permanent BBFs not only facilitated earlier planting, but also reduced the draft power requirement since the system only disturbs the upper 4 cm of soil.

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In 1999, the labor requirement for in-crop weeding of the minimum tillage plots, which primarily involved harvesting the weeds growing in the furrows with a sickle, was 10 person-days ha^{-1} and did not differ significantly from the mean weeding time for the traditional plots of 8 person-days ha^{-1}. However, the newly-constructed BBFs that were sown in mid-July required 32 person-days ha^{-1} for in-crop weeding—a significantly higher labor requirement than the other two systems. In 2000, the time for weeding the three tillage systems did not differ—averaging 10 person-days ha^{-1}. The higher intensity of weeding required on the new BBF plots in 1999 could be attributed to the narrower crop row spacing and resultant wider gaps between beds. The high weed density in the newly-constructed BBFs in 1999 could also be attributed to the early planting date in conjunction with the failure of the small rains that year, resulting in copious weed emergence during the main rains. On the traditionally-prepared plots, the last tillage pass—late in the rainy season—destroyed the germinated annual weed seedlings, thereby reducing the labor requirement for weeding. Detailed studies on weed emergence dynamics in relation to tillage have revealed that the density of some weed species is exacerbated by conservation tillage practices, while other species are either unaffected or even reduced in density (Girma et al., 1996; Taa and Tanner, 1998).

In both cropping seasons, all of the minimum tillage BBF plots were harvested by the second week of November, while the harvest of the newly-constructed BBFs extended into mid-December. The traditional flat seedbed wheat plots were harvested during the end of January and early February. Thus, the early harvest possible with the minimum tillage BBF intervention could contribute to improved food security as farmers in Vertisol areas such as Chefe Donsa generally experience food shortage at the end of the main rainy season. Also, higher prices are received for early-harvested crops—an additional benefit associated with early planting.

Wheat grain and straw yields reflected significant effects of year, tillage system and K application (Tables 2 and 3). The lowest grain yields for all three tillage systems were recorded in 1999 (Table 2): for the traditional flat system, the 1999 grain yield was only significantly lower than the 2000 grain yield with K applied; however, for both BBF systems, the 1999 grain yield was lower than the 2000 grain yields either with or without K application. Differences in straw yield were less dramatic (Table 3); however, for the permanent BBF treatment, the 1999 straw yield was lower than the 2000 straw yields with or without K, while, for the new BBF treatment, the 1999 straw yield was lower than the 2000 straw yield with K applied. In general, the lower grain and straw yields of 1999 can be at least partially attributed to the lower rate of nitrogen (N) application from urea that season relative to 2000. Studies of wheat response to N on Ethiopian Vertisols have reported high and profitable wheat grain and straw yield responses to fertilizer N (Tanner et al., 1999a; Tarekegne et al., 2000).

Table 2
Grain yield of wheat for the three tillage systems in the on-farm tillage trials at Chefe Donsa in 1999 and 2000 (with and without K_2SO_4 in 2000)

Tillage system	Grain yield ($t\,ha^{-1}$)			L.S.D.$_{(0.05)}$
	K_2SO_4 not applied		K_2SO_4 applied[a]	
	1999	2000	2000	
Traditional flat	2.21 (4)	2.44 (11)	2.76 (11)	0.52
Newly constructed BBFs	1.46 (6)	2.32 (11)	3.37 (11)	0.57
Permanent BBFs	1.54 (4)	2.09 (11)	2.64 (11)	0.43
L.S.D.$_{(0.05)}$	0.48	NS	0.50	

Figures in brackets refer to the number of plots for each treatment.
[a] Application rate: 50 kg K_2SO_4 ha^{-1}.

Table 3
Straw yield of wheat for the three tillage systems in the on-farm tillage trials at Chefe Donsa in 1999 and 2000 (with and without K_2SO_4 in 2000)

Tillage system	Straw yield ($t\,ha^{-1}$)			L.S.D.$_{(0.05)}$
	K_2SO_4 not applied		K_2SO_4 applied[a]	
	1999	2000	2000	
Traditional flat	3.48 (4)	3.29 (11)	3.83 (11)	NS
Newly constructed BBFs	2.59 (6)	8.25 (11)	6.47 (11)	4.96
Permanent BBFs	3.06 (4)	4.90 (11)	5.84 (11)	0.78
L.S.D.$_{(0.05)}$	NS	3.93	0.83	

Figures in brackets refer to the number of plots for each treatment.
NS: not significant ($P > 0.05$).
[a] Application rate: 50 kg K_2SO_4 ha^{-1}.

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Grain and straw yields did not show a consistent effect of tillage system across years and K levels. In 1999, the traditional flat system produced a significantly higher grain yield than the two BBF systems, which did not differ from each other; in 2000 without K application, all three tillage systems produced equal grain yields; in 2000 with K application, the new BBF system produced a higher grain yield than the other two tillage treatments, which did not differ from each other (Table 2). In 1999, the three tillage systems produced equal straw yields; in 2000 without K application, the new BBFs produced more straw than the other two treatments, which did not differ from each other; in 2000 with K application, straw yield followed the significance ranking new BBFs > permanent BBFs > traditional flat (Table 3). Taa et al. (2001) also reported inconsistent effects of conservation tillage on wheat grain yield over multiple seasons on two non-vertic soils in Ethiopia. The tendency for higher grain and straw yields on the newly constructed BBFs in the current study may have been associated with a higher inclusion of alternate crops—primarily legumes and tef—in the crop rotation during the 1999 season prior to establishing the new BBFs.

With the application of 50 kg ha^{-1} of K_2SO_4, grain yields increased in the 2000 season by 320 (NS), 550 kg ha^{-1} ($P < 0.05$) and 1050 kg ha^{-1} ($P < 0.05$) in the traditional flat, and the permanent and newly-constructed BBF systems, respectively (Table 2). The application of K_2SO_4 significantly increased straw yield, by 940 kg ha^{-1}, but only for the permanent BBF system (Table 3). The exceptionally high responses to the K_2SO_4 applied in the current study are surprising, particularly since there is no previous record in the literature of a response of wheat yield to either applied K or S in Ethiopia. Although a wheat crop yielding 2–3 t ha^{-1} of grain may be expected to remove approximately 200 kg K_2O ha^{-1} per year (California Fertilizer Association, 1995), one would anticipate that the Ethiopian Vertisols with their high native K content (Mamo and Haque, 1988) would be able to supply this rate of K extraction for many years without exhibiting signs of deficiency. Remarkable crop yield responses to K_2SO_4 have been reported elsewhere, but generally for crops in the *Cruciferae* family which are known to have a high S requirement (Beringer and Mutert, 1991). Definitely, the response observed in the current study must be verified in follow-up on-farm trials in the Chefe Donsa district.

Table 4
The effect of previous crop on the grain yield of wheat with and without K_2SO_4 in the on-farm tillage trials at Chefe Donsa in 2000

Previous crop	Grain yield (t ha^{-1})		L.S.D.$_{(0.05)}$
	K_2SO_4 not applied	K_2SO_4 applied[a]	
Legume	2.24 (6)	3.34 (8)	0.52
Tef	2.40 (6)	3.25 (4)	NS
Wheat	2.27 (22)	2.67 (20)	0.30
L.S.D.$_{(0.05)}$	NS	0.60	

Figures in brackets refer to the number of plots for each treatment. NS: not significant ($P > 0.05$).
[a] Application rate: 50 kg K_2SO_4 ha^{-1}.

In the 2000 trials, a significant interaction was observed between K_2SO_4 application and the crop grown in the previous year. Without K_2SO_4 application, the effect of the precursor crop was non-significant (Table 4). However, with the application of 50 kg K_2SO_4 ha^{-1}, a significant precursor crop effect was noted: wheat following a legume precursor crop—primarily faba bean—produced a 670 kg ha^{-1} higher grain yield relative to wheat following wheat; wheat following tef was intermediate in grain yield and not significantly different from wheat in the other two cropping sequences. In response to the application of 50 kg K_2SO_4 ha^{-1}, wheat grain yield increased by 400 kg ha^{-1} ($P < 0.05$), 850 kg ha^{-1} (NS) and 1100 kg ha^{-1} ($P < 0.05$) following wheat, tef and legume precursors, respectively. Thus, there was an apparent synergism resulting from the application of K_2SO_4 to wheat following a legume precursor crop. Faba bean is capable of fixing from 139 to 210 kg of atmospheric N ha^{-1} in the Ethiopian highlands in conjunction with indigenous non-inoculated strains of *Rhizobium* spp. (Gorfu et al., 2000). The beneficial rotation effect of a faba bean precursor crop—partly due to its pronounced N-fixation capacity—has produced grain yield increments in succeeding wheat crops ranging from 36 to 121% relative to continuous wheat across several site–season combinations in south-eastern Ethiopia (Tanner et al., 1999b). Similar to the effect of interaction between K_2SO_4 application and crop rotation on wheat grain yield in the current study, there have been previous reports of synergism between rotation with faba

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Table 5
The effect of K_2SO_4 application on the grain yield of the four principal wheat varieties included in the on-farm tillage trial at Chefe Donsa in 2000

Variety	Grain yield ($t\,ha^{-1}$)		L.S.D.$_{(0.05)}$
	K_2SO_4 not applied	K_2SO_4 applied[a]	
Kilinto (durum)	2.02 (4)	2.93 (5)	NS
Cocorit (durum)	2.25 (13)	2.89 (12)	0.32
ET-13 (bread wheat)	2.47 (10)	3.18 (9)	0.60
Kubsa (bread wheat)	2.37 (5)	2.65 (5)	NS
L.S.D.$_{(0.05)}$	NS	NS	

Figures in brackets refer to the number of plots for each treatment.
NS: not significant ($P > 0.05$).
[a] Application rate: 50 kg $K_2SO_4\,ha^{-1}$.

Table 6
The effect of K_2SO_4 application on the straw yield of the four principal wheat varieties included in the on-farm tillage trial at Chefe Donsa in 2000

Variety	Straw yield ($t\,ha^{-1}$)		L.S.D.$_{(0.05)}$
	K_2SO_4 not applied	K_2SO_4 applied[a]	
Kilinto (durum)	10.61 (4)	5.84 (5)	NS
Cocorit (durum)	4.98 (13)	4.74 (12)	NS
ET-13 (bread wheat)	4.92 (10)	6.52 (9)	0.90
Kubsa (bread wheat)	3.42 (4)	4.17 (4)	NS
L.S.D.$_{(0.05)}$	5.73	NS	

Figures in brackets refer to the number of plots for each treatment.
NS: not significant ($P > 0.05$).
[a] Application rate: 50 kg $K_2SO_4\,ha^{-1}$.

bean and the application of phosphorus (P) fertilizer on wheat in south-eastern Ethiopia (Tanner et al., 1999b).

Also in the 2000 trials, a significant interaction effect on wheat grain yield was observed between K_2SO_4 application and the wheat variety grown. The four principal wheat varieties selected by the host farmers for the 2000 cropping season trials were Kilinto (durum), Cocorit (durum), ET-13 (bread) and Kubsa (bread). At each level of K_2SO_4 application, the four wheat varieties did not differ in grain yield (Table 5). The application of 50 kg $K_2SO_4\,ha^{-1}$ resulted in a mean wheat grain yield increment of 646 kg ha^{-1}, representing a mean response of 13 kg grain per kg of $K_2SO_4\,ha^{-1}$. However, perhaps partly due to the small sample size for Kilinto and Kubsa, the variety-specific yield increment was only significant for Cocorit and ET-13. In fact, the recently-released bread wheat variety Kubsa has previously been shown to be generally more responsive to fertilizer than most of the older Ethiopian wheat varieties (Tanner et al., 1999a).

Wheat straw yield also exhibited a significant interaction between K_2SO_4 application and the wheat variety grown. The variety Kilinto produced a higher straw yield than the other three wheat varieties without the application of K_2SO_4 (Table 6); however, with the application of K_2SO_4, there was no significant difference among the four wheat varieties. Only the bread wheat variety ET-13 exhibited a significant response to the addition of 50 kg of $K_2SO_4\,ha^{-1}$ (Table 6).

3.2. Results of factor and covariate model analysis

This analysis focused primarily upon the effects of tillage systems and other production factors on wheat grain and straw yields, input use intensity and economic returns. The hypothesis tested was that there were no differences among the three tillage systems in terms of these outcomes. Since it was anticipated that other production factors and covariates could also affect these outcomes, the effects of such factors and covariates were accounted for in the model, and were thereby controlled in the overall comparison of the performance of the three tillage systems.

Grain was considered the main production output, but straw is a joint product, and the grain to straw ratio may vary among varieties and due to other factors. Therefore, we estimated: a grain yield function with several factors and covariates, but without straw yield as a covariate (model 1 in Table 7); a straw yield function with the same factors and covariates (model 2 in Table 7); and a grain yield function with the same factors and covariates plus the inclusion of straw as a covariate (model 3 in Table 7). For grain yield, model 3 (i.e. including straw yield as a covariate) resulted in the best fit in terms of explanatory power, and the remaining interpretation of treatment effects is based on this model. The results of model 3 revealed that, everything else being equal:

(a) the traditional flat and the newly-constructed BBF tillage systems gave significantly higher grain

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Table 7
Determinants of wheat grain and straw yield (kg ha^{-1}) and thousand kernel weight (TKW) in the on-farm tillage trial at Chefe Donsa in 1999 and 2000

Independent variable	Dependent variable			
	Grain yield (model 1)	Straw yield (model 2)	Grain yield (model 3)	TKW (g) (model 4)
Intercept	993 (588)	4589* (1282)	−369 (459)	25.1* (4.7)
Factors				
Tillage system				
Traditional	1417* (532)	1575 (1160)	949* (408)	0.5 (4.1)
New BBFs	938* (131)	809* (287)	698* (102)	4.1* (1.0)
Permanent BBFs	0	0	0	0
Variety				
Kilinto	−9 (304)	−418 (662)	115 (232)	1.6 (2.4)
Cocorit	−130 (295)	−1075 (642)	189 (226)	4.0 (2.3)
Kubsa	550 (289)	91 (630)	523* (221)	−4.6* (2.2)
ET-13	0	0	0	0
Previous crop				
Wheat	−77 (103)	−227 (224)	−9 (79)	1.2 (0.8)
Tef	−134 (112)	−430 (243)	−7 (86)	1.2 (0.9)
Legume	0	0	0	0
K_2SO_4 status				
Applied at 50 kg ha^{-1}	646* (67)	1105* (147)	318* (57)	1.6* (0.6)
Not applied	0	0	0	0
DAP (kg ha^{-1})				
100	−806* (342)	−3505* (746)	234 (272)	2.8 (2.8)
80	118 (387)	−1852* (843)	668 (298)	1.4 (3.0)
65	485 (396)	−1380 (857)	894* (304)	2.6 (3.1)
50	0	0	0	0
Covariates				
Seed rate (kg ha^{-1})	2.77 (3.03)	6.41 (6.61)	0.87 (2.32)	0.04 (0.02)
Urea (kg ha^{-1})	6.44 (4.87)	7.81 (10.61)	4.13 (3.72)	0.03 (0.04)
Weeding labor (days ha^{-1})	−4.41** (1.51)	−8.01* (3.29)	−2.03 (1.17)	0.001 (0.01)
Cultivation time (h ha^{-1})	−9.43* (3.91)	−10.10 (8.52)	−6.44* (2.99)	−0.001 (0.03)
Straw yield (kg ha^{-1})	–	–	0.30* (0.02)	0. 00 (0.00)
N	292	292	292	292
R^2	0.56	0.65	0.74	0.70
Adjusted R^2	0.53	0.63	0.73	0.68

Within factors: single asterisk in superscript indicates that the coefficient of the relevant category is significantly different from the base category in that factor, based on joint univariate at the 0.95 Bonferronic confidence interval. For covariates: single and double asterisks indicate that the coefficient is significant at the 1 and 5% levels, respectively. S.E. values are given in brackets.

yields compared to the permanent BBF system, but there was no difference between the traditional flat and the newly-constructed BBF systems;

(b) the Kubsa bread wheat variety produced a significantly higher grain yield compared to ET-13, while there were no significant differences among ET-13, Kilinto and Cocorit;

(c) the previous crop grown on a farmer's plot prior to planting wheat in the current study had no apparent effect upon grain yield in the model;

(d) the application of 50 kg K_2SO_4 ha^{-1} significantly increased wheat grain yield;

(e) the application of DAP at 65 kg ha^{-1} significantly increased grain yield cf. 50 kg ha^{-1}, but no ad-

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ditional yield increment was observed with rates higher than 65 kg ha^{-1}, indicating a diminishing response to the rate of DAP application.

Among the covariates, grain yield declined significantly with greater usage of labor for cultivation, and increased significantly in tandem with straw yield.

The results of the model for straw yield (i.e. model 2) revealed that, everything else being equal:

(a) the newly-constructed BBF tillage system gave significantly higher straw yields compared to the permanent BBF system, but there was no difference between the traditional flat and the permanent BBF systems;
(b) varieties did not differ significantly for straw yield;
(c) the previous crop grown on a farmer's plot prior to planting wheat in the current study had no apparent effect upon straw yield in the model;
(d) the application of 50 kg K_2SO_4 ha^{-1} significantly increased wheat straw yield;
(e) the application of DAP at 80 and 100 kg ha^{-1} significantly decreased the straw yield cf. 50 kg ha^{-1}, perhaps reflecting the greater amount of crop lodging that occurred at higher rates of DAP application.

Among the covariates, straw yield declined significantly with greater usage of labor for hand weeding.

A model was also run using 1000 kernel weight as the dependent variable to assess which factors influenced seed size—as a proxy indicator of grain quality and potential market price (model 4 in Table 7). It appears that, other things being equal, the new BBF system resulted in significantly larger grains compared to the other two tillage systems, that the variety Kubsa produced significantly smaller seeds compared to the other three varieties (although producing the highest grain yield), and the application of K_2SO_4 significantly improved seed size compared to no K application. None of the other factors or covariates significantly influenced seed size.

Differences among the three tillage systems in terms of mean seed rate and urea application were described earlier. However, because of the influence of other factors on these production inputs and on weeding and cultivation labor use rates, it was considered appropriate to explore these differences within a functional framework (Table 8). It appears that, other things being equal, seed rate was, as expected, significantly higher for the traditional flat tillage system in contrast with the other two tillage systems. Seed rate was also significantly lower for ET-13 than for the other three wheat varieties, but the difference between Kilinto and Kubsa was not significant. Seed rate was also significantly higher for farmers' plots receiving K_2SO_4 fertilizer.

In the case of urea, other things being equal, the application rate was significantly higher for the traditional flat tillage system compared to the other two tillage treatments, significantly lower for Kilinto variety compared to the other three wheat varieties, significantly lower on wheat plots following a previous crop of tef, and significantly higher for farmers' plots receiving K_2SO_4 fertilizer.

In the case of cultivation time, other things being equal, the time input for cultivation was significantly reduced for the permanent BBF system compared to the traditional flat and the new BBF tillage systems. The traditional flat system required significantly more cultivation time than the new BBF system. Neither the wheat variety grown nor the previous crop grown on the plot affected cultivation time. Significantly less time was required for farmers' plots receiving K_2SO_4 fertilizer.

For weeding labor, other things being equal, the traditional flat and the new BBF tillage systems required significantly higher labor inputs than the permanent BBF system; there was no difference between the traditional flat and the new BBF systems. Kilinto variety required significantly more weeding labor than the other varieties, wheat plots following a previous crop of tef required significantly more weeding labor, and plots receiving K_2SO_4 fertilizer required significantly less.

In summary, the permanent BBF tillage system required significantly lower rates of all the major inputs measured in the current study.

Cost, revenue and gross margin functions were estimated following the same principles (Table 9). However, only tillage system and wheat variety were used as factors in the model, since the measured inputs were included in the cost estimate as a dependent variable: otherwise, the inclusion of these inputs as factors or covariates in the model would have created a problem of endogeneity. Cost, revenue, and gross margin were estimated using the prices of inputs and outputs

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Table 8
Determinants of input use rates in the on-farm tillage trial at Chefe Donsa in 1999 and 2000

Independent variable	Dependent variable			
	Seed rate (kg ha^{-1})	Urea (kg ha^{-1})	Cultivation time (h ha^{-1})	Weeding labor (days ha^{-1})
Intercept	40.6* (6.2)	121.4* (7.2)	24.3* (3.2)	19.2 (11.1)
Factors				
Tillage system				
Traditional	114.1* (3.4)	21.3* (4.0)	37.3* (1.8)	26.0* (6.2)
New BBFs	−0.9 (3.7)	2.0 (4.3)	17.2* (1.9)	29.6* (6.6)
Permanent BBFs	0	0	0	0
Variety				
Kilinto	71.8* (4.7)	−26.4* (5.4)	2.5 (2.5)	25.2* (8.4)
Cocorit	86.1* (4.1)	−2.6 (4.8)	−5.1 (2.2)	−8.4 (7.4)
Kubsa	67.9* (4.6)	−10.1 (5.3)	2.7 (2.4)	1.3 (8.3)
ET-13	0	0	0	0
Previous crop				
Wheat	−2.4 (3.6)	−0.4 (4.1)	0.4 (1.9)	8.4 (6.4)
Tef	−2.9 (3.7)	−10.4* (4.3)	2.8 (2.0)	15.2* (6.7)
Legume	0	0	0	0
K_2SO_4 status				
Applied at 50 kg ha^{-1}	8.2* (2.2)	15.2* (2.6)	−4.1* (1.2)	−15.0* (4.0)
Not applied	0	0	0	0
N	292	292	292	292
R^2	0.89	0.44	0.72	0.27
Adjusted R^2	0.88	0.42	0.71	0.25

S.E. values are given in brackets.

* Indicates that the coefficient of the relevant category is significantly different from the base category in that factor, based on joint univariate at the 0.95 Bonferronic confidence interval.

prevailing in the Chefe Donsa village in 1999, so that any effect of yearly price fluctuation was not captured. However, using a constant price facilitated the measurement of the real effects of physical inputs and outputs in this study.

Other things being equal, cost per ha was significantly higher for the traditional flat and the new BBF tillage systems compared to the permanent BBF system, while the traditional flat system cost significantly more than the new BBF tillage system. The Kilinto wheat variety cost significantly more to produce than the other three wheat varieties. Revenue was lowest for the traditional flat tillage system—reflecting the lower market price for the late-harvested grain despite the higher grain yield level in this system—but was significantly higher for the new BBF system compared to the permanent BBF system. Kubsa gave a significantly higher revenue compared to the other three wheat varieties—reflecting its pronounced grain yield advantage. As a consequence of these relative differences in cost and revenue, the traditional flat tillage system gave a significantly lower gross margin while the new BBF system gave a significantly higher gross margin relative to the permanent BBF system. The variety Kilinto gave a significantly lower gross margin relative to the other three wheat varieties—among which there were no differences.

3.3. Potential impact on soil erosion

One of the expected benefits of minimum tillage is a reduction in soil erosion. Furthermore, the BBF system employed in the current experiment is also expected to minimize erosion because of early planting and enhanced vegetative cover during the main rains in contrast to the traditional flat seedbed system in which tilled soil is bare during the first months of the main rains rendering the soil surface vulnerable to ero-

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Table 9
Determinants of cost, revenue and gross margin by tillage system and variety in the on-farm tillage trial at Chefe Donsa in 1999 and 2000

Independent variable	Dependent variable		
	Cost (Birr ha^{-1})	Revenue (Birr ha^{-1})	Gross margin (Birr ha^{-1})
Intercept	710.83* (73.49)	3577.44* (283.31)	2866.62* (318.62)
Factor			
Tillage system			
Traditional	728.53* (50.94)	−330.17 (196.37)	−1058.70* (220.84)
New BBFs	348.68* (45.94)	944.01* (177.11)	595.33* (199.19)
Permanent BBFs	0	0	0
Variety			
Kilinto	332.79* (74.22)	−415.31 (286.15)	−748.10* (321.82)
Cocorit	53.67 (65.84)	37.04 (253.84)	−16.63 (285.48)
Kubsa	136.04 (73.55)	687.80* (283.54)	551.77 (318.88)
ET-13	0	0	0
N	292	292	292
R^2	0.49	0.24	0.28
Adjusted R^2	0.48	0.23	0.27

S.E. values are given in brackets. Note: prices prevailing in Chefe Donsa village in 1999 were used in the estimation of cost and revenue: cultivation labor 27 Birr for one pair of oxen and one person per day; human labor 9 Birr person per day; wheat seed 1.60 Birr kg^{-1}; urea 1.55 Birr kg^{-1}; DAP 2.40 Birr kg^{-1}; potassium sulfate 2.00 Birr kg^{-1}; wheat grain from November harvest (BBF systems) 1600 Birr t^{-1}; from January harvest (traditional system) 1200 Birr t^{-1}; wheat straw dry weight 55 Birr t^{-1}; US$ 1 = 8.00 Birr in 1999.

* Indicates that the coefficient of the relevant category is significantly different from the base category in that factor, based on joint univariate at the 0.95 Bonferronic confidence interval.

sion. For effective soil conservation, it is important to maintain vegetative cover throughout the rainy season. High rainfall incidence coupled with a bare soil surface exacerbates erosion (for an extensive review of soil erosion and related factors in Ethiopia see Tefera et al., 2002).

Actual erosion rates were not monitored on the trial plots. However, several qualitative observations were made concerning the effects of the different tillage systems on erosion. During the 1999 and 2000 main rains, a total precipitation of approximately 800 and 750 mm was recorded, respectively, in the study area; thus, rainfall during both seasons exceeded the long-term average of 670 mm. In both years, there were highly erosive rainfall events. In the 1999 main season, heavy soil losses were observed on the traditional flat seedbed plots—which were bare of vegetation at that time—due to 70 mm of rain received on 11 August. On the nearby Chefe Donsa research site, a soil loss of 18 t ha^{-1} was recorded during August 1999 on traditionally prepared cropland (EARO, 2000). During the 2000 main rains, two erosive rainfall events occurred on August 5 and 21: 31 and 46 mm of rain, respectively, fell before the traditional flat seedbed plots were sown, contributing to the formation of a number of new gullies. In both years, the BBF plots exhibited much less erosion due to vegetative cover during the main rains.

4. Conclusions

The farmer participatory trials conducted during 1999 and 2000 clearly demonstrated that small-holder farmers in Ethiopia are extremely interested in analyzing their farming circumstances, and are keen to incorporate their own ideas and preferences into the on-farm research process. Although the participatory approach implies that researchers surrender control over some aspects of trial design and treatment structure, the researcher-developed BBF-based minimum tillage package has been substantially improved through the active involvement of farmers. Further benefits could be attained with laboratory analyses of potassium, sulfur and other soil nutrients to enable farmers to use fertilizers more efficiently.

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The minimum tillage BBF system required 50% less draft power than the traditional system, resulted in less soil disturbance, and facilitated earlier planting of crops in the current study. All of these factors are anticipated to yield economic advantages at both the micro- and macro-levels in Ethiopia. In addition, the new technology can conserve natural resources by lowering soil losses and reducing the oxen herd size required to cultivate a given district. The early harvest of crops from the minimum tillage BBF package coincides with the severe food deficit period in the Vertisol areas, and will improve the food security status of the rural population of Ethiopia. Furthermore, the funnel planter attachment for the BBM should appeal to farmers because of its potential to increase the efficiency of seed and fertilizer use, in addition to reducing the human labor required for hand weeding. Unfortunately, there was no consistent yield advantage for the permanent BBF technology in the current study. It may be necessary to conduct the research over a longer time period in order to capture more of the beneficial effects of conservation tillage on farmers' fields.

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