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Low-cost Animal drawn implements for Vertisol management and strategies for land use intensification[1]

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The main aim of land preparation is to modify and manipulate the land features so as to create favorable environment for seed establishment and crop growth. The research and development in this field must take into account the traditional practices used by the farming community. This paper gives a brief description of farmers' management of Vertisols and soils with 'vertic' properties and the development of the low cost broadbed maker (BBM) for facilitating surface drainage. Other attachments like planters and cultivators to the BBM for minimum tillage system which are going to be tested on-farm are also discussed.

Importance of Vertisols in the East African highland

From an estimated global 300 million ha of Vertisols, 43 million ha are located in tropical Africa. An additional 80 million ha of soils with 'vertic' properties require similar management as Vertisols for exploiting its agricultural potential (Virmani, 1988).

Most of Africa is generally characterized by marginal rainfall but the highland areas of east African with altitudes above 1500m above sea level occupy a special positions in providing cooler temperatures and high rainfall. Where soils are deep, the growing period is prolonged more than 180 days and are suitable for a variety of crops and livestock (Morgan, 1972). Ethiopia has 50 million ha of land in the highlands representing about 62% of the East African highlands. Of this area, 16% is estimated to be Vertisols, and about an equal amount has vertic properties. These soils are generally found on the lower side of the landscape on slopes not exceeding 8% making them agriculturally attractive. However, the inherent management problem occurs due to waterlogging caused by the slow percolation rates of these soils coupled with low evaporation for tapping their agricultural potential in the highlands. Compared to the drainage problem, erosion caused by the runoff from the higher landscape and from draining off the excess water can exacerbate soil erosion, specially gully erosion, which is another major problem of these soils in the highlands.

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Traditional management of Vertisols and land use types

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[1] In: In: J K Syers, F W T Penning de Vries and P Nyamudeza (eds) (2001) The Sustainable management of Vertisols. CABI in association with IWMI.. pp. 189-202.

During the main growing period, the severity of waterlogging varies from area to area depending on the clay content of the soil, amount of rainfall and the soil temperature which also depends on the moisture content. Farmers in the Vertisol areas realize the adverse effects of waterlogging on crop productivity and have developed traditional methods for overcoming them.

One of the traditional methods practiced for overcoming the waterlogging problem is planting crops late in the season after the excess water has naturally drained away to grow on the residual moisture. The varieties of these crops like wheat, chickpea, roughpea etc have a short growing period of not more than three months. *Eragrostis tef*, which mildly tolerates waterlogging, is planted during the middle of the rainy season. Traditional practice does not fully exploit the growing period and enhance erosion due to lack of vegetation ground cover during the rainy season. Crop yields in this traditional practice are low averaging 0.8 t/ha (Debele, 1985). In the last 10 years, highland rice being grown on Vertisols around lake Tana in the north western part of the country has expanded, and is said to give better yields with the traditional practice than other indigenous crops grown in the area.

In the high altitude areas of Ethiopia, i.e. above 2400m a s l, a unique practice called 'guie' is adopted for growing barley on Vertisols after leaving the area fallow from 5-8 years (Tesema and Yirgou, 1973). The farmers plough the land three to four times during the dry season, heap the soil at irregular spacing and burn it with dry manure, grass and weeds. The soil is then spread back on the fields (Debele, 1985). After the onset of the following rains in mid June, the fields are ploughed again and barley is grown. The planting of barley continues for two to three seasons and the land is then left fallow again. The burning of the soil changes the top soil structure producing more coarse texture which facilitates better water movement and drainage, and increases available phosphorous (Tesema and Yirgau, 1973).

Different cultivation techniques are also practiced using the 'maresha' to minimize the waterlogging problem on Vertisols. Flat seedbed preparation is common on gentle slopes except for the fact that outside ditches are sometimes dug to control flooding. This method is common in drier regions and crops such as faba bean, field peas, barley, linseed and sorghum are planted (Tedla and Mohamed Saleem, 1992).

In some parts of the central highlands of Ethiopia, drainage furrows are made with the 'maresha' on the flat seedbed after seding. These furrows are made across the contour at distances ranging from three to seven meters. These drainage furrows have an average 20 cm width and 15 cm depth. The area taken by the drainage furrows from the crop areas can be 10-15% (Westpal, 1975). In high rainfall areas, it is common making ridges and furrows using the 'maresha' at an interval of 40 to 60 cm. In this traditional ridge and furrow system, the furrows take up 40-50% of the crop area.

At Inewari, in the central highlands of Ethiopia, surface drainage of Vertisols is facilitated with the use of manually formed broadbeds and furrows. The seedbed is made by making 3-4 passes with the maresha. In the middle of the rainy season, the seeds are broadcast and furrows made with the 'maresha' at an interval of 0.8 to 1 m. Using family labour, the soil is then scooped up from the furrows and dumped on the beds. By using this method they do not only form the broadbed and furrow but also cover the seeds. Grass drainage channels are also constructed to carry the water from the crop fields. This practice of constructing broadbeds and furrows manually requires hard work from the family. In the last two years, this method of manually constructing broadbeds and furrows have been extended to neighboring Vertisol areas which were previously using the ridge and furrow system.

The traditional implement 'maresha'

The maresha being pulled by a pair of oxen has been used in Ethiopia for millenium. There are certain pockets of the country where hoe cultivation is still practiced but by and large, cultivation is carried out by a pair of oxen pulling the maresha. In some areas of the country, horses and mules occasionally pull the maresha, but generally, oxen provide the main traction force.

The 'maresha' consists of a metal point or tine, which in turn is fastened to wooden neck yoke as shown in Figure 1. At each side of the metal point are two wooden wings which push the soil aside. The complete traditional plough is a light implement ranging from 17 to 26 kg with the yoke (Goe, 1987) which makes it possible to be transported to and from the field over difficult terrain by one person. Except for the metal tine, which the farmer has to buy from the blacksmith, the rest is home made. Depending on the crop types, three to four cultivation are required by the maresha before a field is ready for planting.

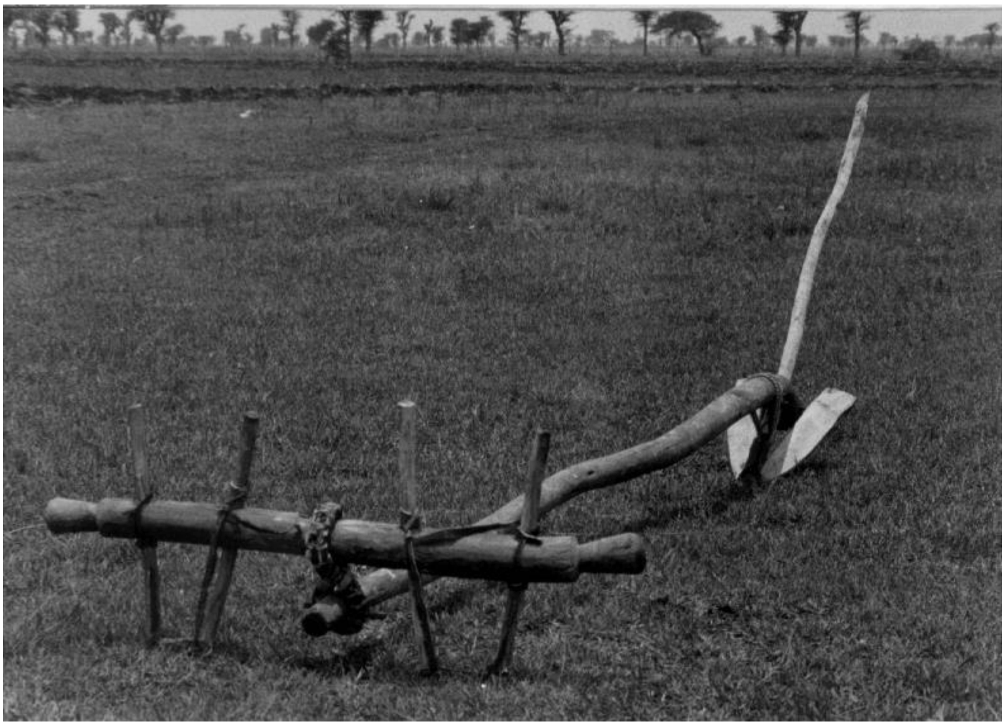

Figure1. Ethiopian ‘maresha’ plough.

Each cultivation pass is made perpendicular to the previous one so as to disturb the whole soil. The depth of the first plough ranges from 5 to 8 cm while with the last pass upto 20 cm could be attained. For land preparation and seed covering with the 'maresha', on an average 100 hr/ha and 150 hr/ha are required for Vertisols and light soils respectively (Astatke and Mathews, 1982). The power developed by a pair of local Zebu oxen, each weighing not more than 300 kg, ranges between 0.50 to 0.90 kw (Astatke and Mathews, 1982).

A serious disadvantage of the maresha is its inability to cover seeds adequately. In the traditional cultivation method, seeds of all the cereal crops and pulses after broadcast before the last pass which then is used to cover the seeds. The exception is *Eragrostis tef* which is broadcasted and left . Thus, the depth of the coverage varies from seeds not covered at all to the maximum depth which the 'maresha' tine penetrates. This might be the reason why farmers tend to use high seed rates as germination rates could be low. In some pockets of the central highlands, it is common to use wheat seed rate of 250 kg/ha, which could be 15 to 25% of the expected total production.

The broad bed maker and its evolution

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), based in India, developed an animal-drawn implement in the mid 1970s for making broadbeds and furrows to improve surface drainage of Vertisols. This implement proved functionally effective but it required more power than a pair of zebu oxen could generate. It was also expensive, more expensive than the Indian subsistence farmers could afford. So adoption was very poor. When the equipment was tested in Ethiopia, farmers felt the same about it.

In 1986, the International Livestock Centre for Africa (ILCA), now the International Livestock Research Institute (ILRI), the Ethiopian Agricultural Research Organization (previously the Institute of Agricultural Research), Alemaya University of Agriculture and ICRISAT formed a consortium, called the Joint Vertisol Project (JVP), to develop low-cost technologies to improve the management and productivity of Vertisols. Ethiopian highland farmers have limited cash income, so any improvement of tools and farming methods must take this into consideration and make economy a priority. Implements and technologies designed, therefore, must cost minimally so that farmers can afford them.

From the beginning, researchers consulted farmers on design. Test conducted on-farm and farmer suggestions derived from such tests have been invaluable for refining the implement. As researchers took the implement beyond the areas where it was tried on-farm, they realized they needed to refine it further to tailor it to specific farmer circumstances.

The first land-shaping implement that the project developed had a wooden wing that functioned as a mouldboard, replacing the traditional flat wings of the maresha. After loosening the soil (which took three or four passes with the maresha), the implement lifted and heaped the soil to form a bed. However, it was no faster than the maresha in making the raised beds, and an untrained person using the new implement found it difficult to make a seedbed of good quality. Hence, farmers rejected this modification of the maresha as well.

The second version was a broadbed maker (BBM) made from the maresha (Figure 2). The main beams of the maresha were shortened to about 90 cm and were connected with a simple wooden frame. Mouldboard-shaped wings, two bigger ones throwing the soil to the centre and two smaller wings throwing it outside, forming beds and furrows, replaced the two flat maresha wings. This implement could be used only for shaping the land, and therefore the field had first to be ploughed three or four times with the maresha. The implement weighed about 35 kg, depending on the type of wood used. The average power required to putll it was 0.7 kw—the same as the power required to do the first ploughing with the maresha (Jutzi et al, 1986). However, when farmers tried it out in the field, they found it too heavy to handle and too bulky to carry to and from the field. Also, finding a spanner and 12 bolts to put together the wooden BBM frame was not easy in the rural areas. So researchers literally went back to the drawing board to redesign the implement.

Figure 2. Second version broadbed maker

The present version of the BBM is widely recommended, the implement having proved effective and acceptable in several years of on-farm trials. It is based on the traditional wooden frame plough, to which is attached the maresha metal plough-share with its land-shaping mouldboard. Two mareshas are connected in a triangular structure, mounted about 120 cm apart on a crossbar (Figure 3). The top ends of the maresha beams are tied together and connected to the yoke as in the traditional method. To maintain the distance of 1.2 m between the mareha tips, a crossbeam is tied between the two maresha poles at a metre from their lower edges. A steel mouldboard wing is attached on each of the inner flat wings.

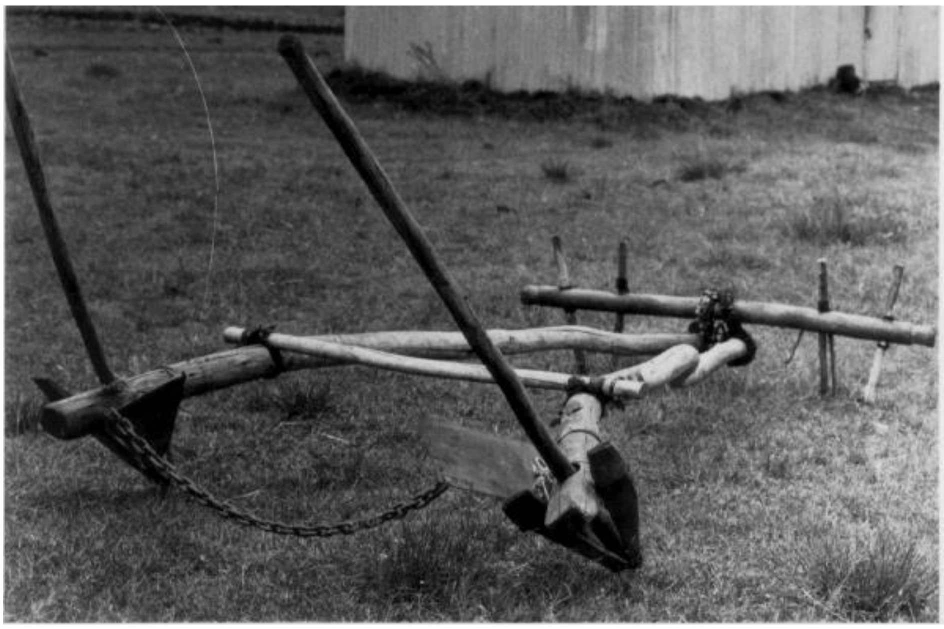

Figure 3. The latest version of the broadbed maker.

As a pair of animals pulls the BBM through the soil, it makes two parallel cuts. The wings scoop the soil toward the middle and mound it, forming the broadbed and furrow. The chain attached at the edge of the metal wings that connects the wing not only shapes the beds evenly, it also covers the sown seeds. Seeds are broadcast as early as June. The result is a series of broad, raised and seeded beds 15 cm high by 80 cm wide, separated by 40 cm-wide furrows.

The power requirement of 0.62 kw for this new BBM is lower than it was for the wooden BBM, as the frictional force of the metal wings passing through the soil is less than that of the wooden wings. In 6 working hours, the area shaped into broadbeds and furrows with this BBM pulled by a pair of oxen was 1.2 ha compared with only 0.4 ha when a wooden BBM was used.

The potential effect of this tilling device on Vertisols and their food-producing capacity is immense. Benefits will be long lasting. Early planting helps establish a vegetative cover early in the season and thus reduces soil erosion. In Vertisol areas, the BBM technology package has been found to double crop yields, triple fodder yields and increase the productivity of farm labour by 50 to 75%. (Asamenew, G. et al, 1988). In 1995 cropping season, wheat grain yields from the 50 farmers that used the BBM and its package on half ha each at Gimbichu, in central highlands of Ethiopia, more than double their grain yields compared to the traditional average yield of 1 Mg ha^{-1} as shown in Table 1. Replacing local wheat with ET-13 on BBF land systems increased grain energy output from 6.3 GJ ha^{-1} to 13.2 GJ ha^{-1} (Mohamed Saleem and Astatke, 19960).

Table 1. On farm wheat grain yields (MG h^{-1}) at Gimbichu using the BBM packagein 1995 cropping season.

No. farmers	Range	Mean
3	2.5 – 3.0	2.9
10	3.0 - 3.5	3.4
20	3.5- 3.8	3.7
17	3.8- 4.6	4.3

Source: ILRI,1996.

At present several thousand farmers are using the BBM with its package to grow wheat on highland Vertisols. Adoption pathways followed by farmers in the on-farm research sites are described by Jabbar et al.(1998) and factors influencing adoption in selected areas outside the research sites are described by Ayele and Heidhues, 1998). These studies also reported some problems mentioned by farmers in using BBM. In the on-farm research sites, some farmers reported that the equipment was heavy in relation to the capacity of their animals (this could be partly because of feed problem as the time for planting with BBM also coincide with the end of the heavy cultivation period and low feed stock) and others mentioned that it cannot make effective channel and cover seed properly when the soil is too wet. Outside the research sites, the principal problems mentioned for nonadoption are lack of training, too expensive equipment and inputs, lack of knowledge about the benefits of the equipment, and shortage of land to use the package. But by and large 80-90% of adopters have expressed their satisfaction with the results obtained.

Other problems observed during a rapid surveyconducted by the JVP are that some farmers have used the BBM with their traditional late planting method, requiring higher amount of power and affecting the quality of the beds constructed. This is also reported by some of the government extension agencies still distributing fertilizer in the middle of the rainy season as in the traditional system. The period of using BBM is short, optimum dates ranging from 10-15 days after the start of main rainy season thus limiting its use. In some instances, the field drains constructed by the BBM are taken as the main drainage network without the construction of primary and secondary channels for proper diversions for controlling runoff, affecting the evacuation of the excess water from the fields. Early planting with BBM is not without its problems. As not many farmers adopt in the beginning, more pests are harboured by few BBM plots in a field specially if there are dry spells. In some cases, better field drainage by the BBF is said to have caused more weed infestation which would mean more labour input for weeding.

Additional attachments to the BBM for improving tillage efficiency and resource conservation

Early planting resulting in higher yields than traditional late planted crops is the main advantage of BBM package. It has other advantages as well, e.g. the BBM crop is harvested early during the severe food deficit period, so it contributes to food security. The price may be higher at this early stage so higher cash income from any sale is another advantage. However, the JVP diversified its its research effort to make the equipment more versatile, so that its technical and economic efficiency may be further improved.

Currently, the broad beds are ploughed and reconstituted if the BBM package is to be used in the next season. The possibility of retaining the broad bed for repeated use with minimum tillage was considered. This will save animal and human lobour for various tillage operations. Along with this the possibility of line seeding rather than broadcasting was considered because the traditional method of broadcasting seeds and covering with 'maresha' has been shown to mix 15.3% of broadcast wheat seed to a depth of 10 to 20 cm yet leaving 25.3% within the top 2.5 cm (Tinker, 1989). Due to this variation of coverage depth germination rate is low which is the main reason why farmers use high seed rates. The BBM is better than traditional plough in covering seeds but more efficiency can be gained by line sowing. This could reduce the required seed rate by improving germination rate and also reduce required fertilizer rate by improving nutrient intake by plants. Further advantages could be better control of weeds (making weeding easier and less labour demanding) and stubble incorporation into the soil thereby partially filling the cracks thus reducing moisture loss and help the following crop.

Several options to achieve the above goals were considered and modification of the BBM with additional attachment(s) have been designed and tested. First, a version that has proved technically efficient in on-station trials over two years aimed at minimum tillage is a blade harrow consisting of a metal blade 4 mm thick fixed on both sides of the 'maresha' tines. This blade harrow uniformly cuts the soil on the BBF at about 5-8 cm below the surface thus slicing weeds at the rooting level when the soil condition is moist, during the small rains, or at the beginning of the main rains. This was used for post-harvest cultivation, then the broad beds are left until the early rains for planting with minimum of soil disturbance. At this period, the power requirement for the implement is drastically reduced. The time for land preparation and reconstruction of BBF will not be required every year if minimum tillage is used.

Second, a planter attachment to the BBM has been developed for line seeding/planting. This is similar to the traditional planter used by the Afars in the eastern part of Ethiopia, which is a simple hand-metered seeder made of calabash and bamboo that mounts on the 'maresha'. This has been redesigned to be attached to the BBM with a sheet metal funnel and four connecting tubes. A set of plain tines and tines of leading and trailing coulter units at $45/15^{o}$ penetrating angle to the horizontal soil surface is used. The funnel consists of a circular hopper Ø 100 with a disked bottom drilled with four equally spaced Ø 25 mm holes to which coulter tubes are attached. A centre tube supports 4 baffle plates with a Ø 70 mm shallow cone placed above which have now been changed to double layered cone as it provided better uniformity in seed distribution. The holes inside the hopper could be blocked off according to the new arrangement. The seeder is supported by a bar clamped to the tine bar.

The blade harrow and the planter can be used either together or separately depending on the choice of the user. Trials conducted in 1997 and 1998 have shown that the time required for seedbed preparation with the minimum tillage system was 15 hrs/ha, one fourth of what was required by the traditional system for the production of wheat plots. Even though in 1998 season wheat grain yield was generally lower by 30% than normal years due to the unexpected rains during the flowering stage of the wheat growth, the mean grain and straw yields under the minimum tillage were significantly higher than the conventional tillage system (Table 2). Inputs of seed and fertilizer rates were reduced on average by 25% and 30%, respectively by using the funnel seeder.

Table 2. Effect of different tillage systems on height at harvest, grain and straw yields (Mg ha-1) of durum wheat variety

Tillage systems	Planting methods	Height at harvest (cm)	Grain yield	Straw yield
Minimum	funnel planter [†]	106.6ab	1.35a	3.09ab
Conventional BBM	funnel planter	100.4bc	1.01b	2.61bc

Traditional	broadcast	95.8c	0.90b	2.34c

† seed and fertilizer mixed

Source: EARO, 1999

In a separate on-station trial, zero tillage (with herbicide) was compared with traditional tillage on both flat and broadbed plots. Results showed no significant differences between tillage methods, so zero tillage will save all the expenses related to seedbed preparation.

These options will be tested on-farm for 2-3 years beginning from 1999 crop season. The test will be conducted at a site where farmers have adopted BBM package so are familiar with the functional mechanism and advantages and disadvantages of the packag. In conducting the test and selecting volunteers for participation in on-farm test, based on theories and practices in adoption of technologies, it is hypothesised that

(a) although , on-station, zero tillage performed similar to traditional tillage with benefits of labour savings, farmers or at least all farmers may not like to test them alongside minimum tillage. There may be a need to test these options separately and in a stepwise manner.
(b) farmers who adopted BBM package are more likely to volunteer for testing the minimum tillage equipment and/or the planter than farmers who are yet to adopt the BBM package, because adopters being confident about the benefits of BBM package may like to test the possibility of enhancing that gain.
(c) farmers, with or without BBM experience, may be reluctant to test zero tillage in the beginning as no till cultivation is not consistent with traditional practice.
(d) if the on-farm tests with minimum tillage and/or planter show promising results, farmers are more likely to volunteer for testing zero tillage as a logical sequence. Farmers experiencing good results from participating in minimum tillage and/or planter trial are more likely to volunteer for zero tillage tests than those who are yet to test minimum tillage and/or planter.

Consultation meetings were held with farmers in a selected research village to share the findings of the on-station trials on zero and minimum tillage and the planter attachments to BBM. Then volunteers were sought to participate in one or more of the trial components. Out of 15 farmers participating in these discussion meetings, 12 expressed willingness to know more about these trials and see the equipment and the way they function. These farmers were then invited to the research station where the equipment and their functional mechanisms were explained and demonstrated, though the trial plots could not be shown as this was off-season. Eventually all 12 farmers expressed interest to participate in the on-farm trial with minimum tillage and the planter but none was willing to include zero tillage in the trial. In case of loss of crop or failure of the experiment, trial farmers will be compensated but even compensation was not adequate for motivating farmers to test zero tillage. Thus so far farmer behaviour appear to be consistent with the hypothesis postulated earlier.

Land use intensification opportunities

It is projected that smallholder farming conditions will worsen as per capita land holding is expected to decline from 1.76 ha in 1985 to 1.11 and 0.66 in year 2000 and 2015, respectively (IUCN, 1990) due to rapid population growth. Hence, high potential and more resilient land need to be used more intensively to meet human and livestock needs.

Vertisols and soils with 'vertic' properties which are potentially productive are spread across the moderate slopes and flat areas of the highland landscape. None the less, farmers in the Ethiopian highlands underutilize the Vertisols, using them for only part of the season for growing low yielding cereals such as *Eragrostis tef*, local wheat and few pulses. Also farmers are able to grow only a single crop of tef or pulses in a year on vertisol plots because fields become waterlogged early in the season. Even in areas where farmers make their broadbeds by hand, they do not plant early, because the soil is too hard for them to work up. The BBM can help intensify the use of vertisols in three ways. First, early planting of high yielding wheat or tef allows utilization of longer growing period giving higher yields. This has already been shown successfully and farmers are rapidly adopting this option. Second, experimentally, it has been shown that wheat can be intercropped with forage legumes, which improve the quality of the harvested fodder for livestock, without diminishing the yields of the food grain. Combined with crossbred dairy cows, the economic benefits can enhanced further (Kassi et al., 1999). Using BBM also provide opportunity for more capacity utilization of draught oxen. Third, the early planting of short duration crops could allow an early harvest making a second crop possible on the residual moisture (Astatke and Mohamed Saleem, 1998). If water can be conserved in ponds or reservoirs, a sequential crop would be feasible in the same cropping season through minimal supplementary irrigation at planting time to secure germination. The same furrows of the BBFs that evacuated the excess water during the rainy season would be used as furrows for irrigation. This could be further intensified and natural resources sustained with the use of minimum tillage and seed/fertilizer row seeding devices.

The traditional practice of ploughing early and planting late brings on wide-scale soil erosion. But early planting helps establish a good ground cover, which minimizes the direct impact of rain on the soil and, compared with late-planted plots, reduces soil erosion by more than 100%. If food and fodder production per unit of land area can be increased by combining better drainage with sequential or rotational cropping of legumes during most of the year, then people should be able to meet their basic needs for food and fodder. This farming system can also bring about a positive effect on the entire landscape and the environment. The upper, steeper slopes can be spared from overuse, reversing the ultimate negative impact that overuse makes on land and biodirersity. Both the farm family and the environment benefit.

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