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Vertisol Management for Improving Wheat and Teff Production in Ethiopia: Review

Negessa Gadisa

Ethiopian Institute of Agricultural Research,
Holeta Agricultural Research Center, P.O. Box: 2003, Addis Ababa, Ethiopia

Abstract: In Ethiopia, Vertisols account for 12.6 million hectares, of which about 7.6 million ha found in the highlands and are generally characterized by waterlogged and high clay content. This high clay content of soil is responsible for their heavy water logging in highland areas with abundant rainfall and relatively low evaporation rates. Crop production on these soils is limited due to internal drainage problems, difficulty of land preparation, soil erosion and low fertility Vertisols have considerable productive potential, but they are usually underutilized in the traditional production system. The use of animal- powered devices for surface soil drainage, planting and tillage, the development of new cropping systems, improved management for rain fed crops such as teff and bread wheat are generally grown on Vertisols and their production increased gradually with improvement in management options for crops. Evidence suggests that there would be substantial increases in yields on Vertisols if appropriate cropping practices and nutrient management were used. Integrated nutrient management and the production of short maturing wheat and teff varieties also opened an opportunity for double cropping under Vertisol.

Key words: Cropping Practices · Teff · Wheat · Vertisol · Soil · Fertility

INTRODUCTION

Vertisols are widely and intensively utilized soil types covering 11% or 12.7 million hectares (ha) of the total land mass and is the fourth important major soil group [1]. More than half (8.6 million ha) of the Vertisols are found in the central highlands with altitude of more than 1500 meters above sea level (masl). About 25 % (1.9 million ha) of the Vertisols occurring in the highlands are cultivated [2]. The crops that are commonly grown on Vertisols of Ethiopia are teff, bread wheat, chickpea, lentil and niger seed [3]. Recently, farmers in Ethiopia are using modified plough called broad bed maker (BBM) and harvesting higher yields from multiple crops on the same plot of land per season [4].

Crop production on the Ethiopian Vertisols is limited because of impeded drainage, difficulty of land preparation, soil erosion and low soil fertility [5]. Although Vertisol has a considerable productive potential, achieving sustainable and improved management of Vertisols has been a major challenge for Ethiopian farmers for many years. Realizing the potential of Vertisols in the Ethiopian agriculture, national and international agricultural research institutions have participated in developing sustainable technology to increase the productivity of crops grown on Vertisols [6]. To this effect, several management options such as developing improved animal drawn implement, the broad bed and furrow maker (BBM), varietal development for waterlogged Vertisols and a package of early planting, fertilizer application and weeding was developed to effectively and efficiently utilize these soils. Early planting of short maturing wheat and teff varieties opened an opportunity for double cropping and excess water drained from the furrows would be utilized for supplemental irrigation [6].

Wheat and Tef are mainly cultivated as mono-crops and usually involved in crop rotations (teff-wheat-food legumes). Wheat and teff show an increasing trend in terms of area coverage, which is about 2.56 and 1.42 million hector, respectively [7]. However, their corresponding productivity (1.17 and 1.63 t ha^{-1}) is very low due to poor soil fertility and traditional crop management practices. This is true especially for N and P

Corresponding Author: Negessa Gadisa, Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, P.O. Box: 2003, Addis Ababa, Ethiopia.

fertilizers because of continuous cropping of cereals and low level of fertilizer application [8]. Moreover, farmers who have the experience and resources to prepare compost to have much less than the amount required.

International and national research organizations had been collaborated to tackle the waterlogging problems of central highland vertisols for many years. But there are little success stories in the adoption of the vertisols management technologies by the small-scale farmers. The problem of slow and/or little adoption of vertisols management technologies by the small-scale farmers were confined by the lack of compatibility of the technologies with the farmers' socio-economic conditions. Regardless of lack of adoptions of improved vertisols management technologies, vertisols sustain millions of people with the centuries old traditional management techniques which became an obstacle to achieve food self-sufficiency in Ethiopia [8]. Thus, revisiting the improved vertisols management option will help to design and generate technologies compatible to the farming systems. Therefore, the objective of this paper was to review the management option of vertisols for improving productivity of wheat and teff in Ethiopian.

Vertisol Management Options in Ethiopia: Improved vertisol management technologies are the result of multi-disciplinary efforts. These efforts have dealt with agro ecological and socioeconomic resource assessment of Vertisol areal, draining excess water, improved soil management, use of organic source and inorganic fertilizers, cropping systems etc. Such diverse activities require a large degree of intra-and inter-institutional coordination.

Improved Drainage: With an extensive area of poorly drained soils in the country, where the Vertisols (dark clay soils) alone represent over 10% of the total land area, drainage is an important soil management technique for increasing agricultural productivity. Although most vertisols on the highlands receive sufficient moisture during the rainy seasons, traditionally they are used mainly for free grazing and very little for crop production. This is mainly because of their drainage problem which makes it impossible to grow crops during the rainy seasons. To a limited extent, these soils are used to produce chickpeas and durum wheat that are planted at the end of the rainy season utilizing the reserve moisture in the soils.

At experimental level, it has been demonstrated that with the use of improved land preparation methods like camber-beds to reduce water logging problems and with the application of N and P fertilizers, cereals could be planted on vertisols and other water-logged soils at the onset of the main rain season. Following such cultural practices that are followed on the upland soils, higher yields could be obtained on vertisols. However, the preparation of camber beds for draining excess moisture from vertisols requires mechanization and could not be easily done with traditional local plow which is pulled by a pair of oxen. Some technology packages on improved land preparation methods that are within the capacity of the farmers, however, have been also tested and demonstrated to the farmers. These are the broad beds and furrows (BBF) land preparation method with specially designed tools to fit the local plow system and be pulled by a pair of oxen. With the use of this drainage technique and the application of fertilizers along with improved seeds, crop yields on Vertisols could be highly increased at the peasant farmers' level. Some tested technology package for improving the productivity of waterlogged soils and are available for use by farmers are cited below.

Use of Fertilize and Improved Seed: Replenishment of soil by organic matter is constrained by competing uses for crop residues and manure as livestock feed and fuel, respectively. The use of crop residue for livestock feeding and use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia's agricultural GDP by 7% [9] suggesting the lack of alternative fuel sources is a significant constraint for improving crop production. Besides, supply of both these materials is scarce to begin with: the average smallholder typically owns 2 or fewer cattle of the local breeds that produce very little dung. Crop residues are limited given low yields overall and for some crops this is exacerbated by off-farm processing [9].

In Ethiopia, fertilizer consumption has increased from about 1000 tons in the early 1970s to over 800, 000 tons in 2010 [10]. Although the increased fertilizer use has resulted in significant improvement in the productivity of major crops the increase in agricultural production, especially in food grain production where over 70% of the fertilizers are utilized, has not been adequate suggesting that other soil fertility constraints limit crop yield. This is attributed mainly to nutrient imbalance from the use of only DAP and urea fertilizers. Such unbalanced application of nutrients may aggravate depletion of other essential macro and micro-nutrients. In general, the continuous use of only N and P fertilizers and the introduction of high yielding varieties could result in the depletion of other important soil nutrients. Reports indicate that elements like K, S, Ca, Mg and micro-nutrients particularly Cu, Mn, B, Mo and Zn have been depleted and deficiency symptoms were observed on major crops in different areas of the country [11]. This is also supported by research findings in which fertilizers containing potassium significantly increased crop yields such [12].

Depletion of micronutrients required in small amounts for plant growth including Fe, Mn, Zn, Cu, B, Mo and Cl can lead to poor plant growth and reduced uptake of nutrients. The causes of depletion include farming without replenishing including focusing only on high analysis fertilizers, although balances are related to soil pH (acidity), salinity [13], soil moisture content and organic matter. Zinc and Cu have been found to be deficient in 65 and 89% of soil samples collected across the country, respectively. Similarly, over 75% of Vertisol were also reported to be Zn deficient. Such large-scale micronutrient deficiencies across Ethiopian soils might have been caused by long-term soil erosion and depletion of soil organic matter.

Agronomic Practices and Cropping Systems: Crop productivity on vertisols can be increased through early planting and improved surface drainage. Appropriate cropping systems are required for efficient use of the whole growing season. Some forage legumes are known to benefit food crop production by enhancing soil fertility when planted in association, or in rotation or sequence with a major food crop. Double cropping involves utilizing land for two growing seasons instead of one. This technology option helps in using the land for production for up to eight months in summer instead of four.

In vertisol areas where rainfall is greater than 750 mm year^{-1}, two crops are feasible without irrigation. Double cropping makes effective use of other fixed costs and production resources such as moisture, human labor, bullock time and cultivation tools. During on-farm testing, several new cropping systems were recommended and verified for feasibility and adaptability. Some useful cropping systems may include forage legume-cereal sequences in the off-season and main rainy season and cereal-pulse sequences in the main season [14]. Both sequential crops and intercrops that require two seasons to mature are considered options; however, farmers view moisture limitation as a major constraint to double cropping. There is, however, an opportunity to increase intensity through an intercrop [15].

Integrated Soil Fertility Management: Integrated soil fertility management refers to a set of soil fertility management practices that necessarily include the use of chemical fertilizer, organic inputs and improved crop varieties combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity.

The basic concept underlying integrated nutrient management is the maintenance or adjustment of soil fertility and of optimal plant nutrient supply for sustaining the desired level of crop productivity [16]. This provides a system of crop nutrition in which plant nutrient needs are met through a pre-planned integrated use of mineral fertilizers; organic manures/fertilizers e.g., green manures, recyclable wastes, crop residues and FYM and biofertilisers. The appropriate combination of different sources of nutrients varies according to the system of land use and the ecological, social and economic conditions at the local level [17]. The combined addition of organic and mineral fertilizers, which forms the basis of integrated soil fertility management can improve crop yields and soil fertility [18].

Significance of Integrated Vertisol Management Options in Improving Yields of Wheat and Teff: The integration of organic fertilizers, such as FYM, vermicompost and conventional compost with inorganic fertilizers may improve and sustain crop yields without degrading soil fertility status. Integration of organic and inorganic fertilizers improved the crop yield compared to application of inorganic NP fertilizers alone [19]. Integrated soil fertility management plays important role in restoring soil fertility and availability of plant nutrients, enhancing crop growth and productivity [20, 21]. Significant P responses were observed for teff and bread wheat at Ginchi. For teff the maximum yield was obtained with 40 kg P ha^{-1} and for wheat 20 kg P ha^{-1} gave the highest yield. The largest yield increment for bread wheat at Holeta and barley at Sheno was observed with the lowest rate of 13 kg P ha^{-1}. Trials at Tefki, Inawari and Bichena showed that P was necessary for bread wheat, durum wheat and teff. Manure and N application was evaluated for different crops. The Manure and N application rates as well as their interaction significantly affected the grain yield of wheat and teff. Evidently, the grain yield of wheat increased with increasing N rates under all levels of Manure, but with decreasing rate as manure level increased [22, 23].

A multi-location investigation on bread wheat fertilizer response trials conducted on farmers' fields under the poorly drained vertisols of Bichena in north western Ethiopia showed high grain yield response to N and a lesser, but significant response to P According to the report, bread wheat showed a high agronomic efficiency of N response; even at 138 kg N ha^{-1}, AE exceeded 14 kg grain per kg applied N. The highest grain yield (3317 kg ha^{-1}) was obtained with the application of 138-92 kg NP2O5ha^{-1}, representing a yield increase of 2336 kg ha^{-1} over the control. However, 138-46 kg N-P2O5 ha^{-1} was the most economical NP combination for Bichena [24]. Generally, there was linear increase in all parameters as N and P rates increased. Similarly, fertilizer rates of 138-46 kg N-P2O5 ha^{-1} at Farta and 123-46 kg N-P2O5 ha^{-1} at Laie-Gaient of North western Ethiopia were also found economically feasible and bread wheat grain yield consistently increased as the rate of applied NP increased to the highest levels [25].

Wheat yield showed significant response to P and K application at Cheffe donsa and Akaki over the two cropping seasons. Thus, it can be concluded that the combined use of P with K could be beneficial to enhance productivity and nutrient uptake of wheat in central highland Vertisols of Ethiopia. Similar on-farm experiments conducted by Dawit *et al.* [26] in mid-highland Vertisols of Arsi zone revealed that the application of 92kg N ha^{-1} and 46kg P_2O_5 ha^{-1} gave optimum bread wheat yield with the AE of 13.3 kg grain per kg N applied.

Similar finding reported by Adamu [27] on grain yield response of bread wheat to N/P rates following lentil precursor on *Mererie* was significantly quadratic while responses following lentil precursor on *Bushella* and teff precursor on both types of vertisols were significantly linear. Application of the highest rate (256/80 kg N/P ha^{-1}) on wheat following lentil precursor gave grain yield of 5001 and 3407 kg ha^{-1} on *Mererie* and *Bushella* vertisols, respectively. The same rate on wheat following teff precursor gave grain yield of 4143 and 3904 kg ha^{-1} on *Mererie* and *Bushella* vertisols, respectively. The investigation conducted in in central high lands of Ethiopia for two consecutive years under vertisol condition indicated improvement in wheat grain and biological yield. Maximum grain (2745 kgha^{-1}) and biological yield (6998kgha^{-1}) was recorded by applying compost at 10 t ha^{-1} along with 69 kg P ha^{-1} fertilizer [28].

Reduced tillage in experiments conducted in the central highland vertisols with high rainfall have shown higher yield, although it was not statistically significant [29, 30]. A similar study in the Adigudom Vertisol also showed promising results for the use of minimum tillage for teff growth [31]. However, most of these studies stress only crop parameters and the gross margin of teff. There is little information on the effect of tillage practices on soil physical quality. The finding reported by Mebratu *et al.* [32] in western Shoa under vertisol condition showed that use of new teff variety (DZ-01-196) in combination with 50% FYM and 50% recommended N fertilizer rate resulted in optimum grain yield of the crop. Similarly, Mirustse *et al.* [33] also reported optimum teff yield (1.631t ha^{-1}) by applying 46 kg N ha^{-1}N and 69 kg in Tigrai region. Therefore, the result of this study has clearly indicated that it is possible to fairly produce teff through integrated nutrient application approach, rather than applying nutrient from one source. Ayalew [34] indicated that teff has showed significance response to the integrated soil fertility management containing both organic and inorganic forms under farmers? field condition that they could be considered as alternative options for sustainable soil and crop productivity in Ethiopia. Interaction effect of seed rate and fertilizer rate significantly ($P< 0.01$) affected the grain and biomass yield of teff but not significantly affects plant height, panicle length and number of fertile tillers per plant [35]. Optimum teff grain yield (2239.1kgha^{-1}) was obtained using 20kgha^{-1} teff seeding rate and 69kg Nha^{-1} with 60kg Pha^{-1} fertilizer rate. Study conducted by the authors in central high lands of Ethiopia for two consecutive years under vertisol condition indicated that the highest teff grain yield (3144.8kg ha^{-1}) was obtained from the applications of half doses of vermicompost (4.8t ha^{-1}) when combined with half dose of the recommended (34.5kg Nha^{-1}) and half dose of the recommended (30kg Pha^{-1}) fertilizer.

Integrated use of organic fertilizer in conjunction with inorganic fertilizer improved Teff grain yield than individual application of these fertilizer sources. According to Girma and Gebreyes [36] Combined application of inorganic and organic nutrient sources either alone or in combination had a significant effect on grain yield, biomass yield and panicle length of teff. The highest teff grain (3144.8 kg ha^{-1}) and biomass yield (12562 kg ha^{-1}) were obtained from the application of 50% VC and half the recommended rate of N and P followed by full dose of recommended rate of N and P from inorganic fertilizer resulting in 2846 kg ha^{-1} grain and 11833 kg ha^{-1} biomass yields respectively, where there are no significance differences between the two treatment effects. The application of 50% CC with 50% N and P has also given comparable grain and biomass yield as compared to application of full dose of N and P from inorganic fertilizer.

Crop production in the highland vertisols area of Ethiopia is highly constrained by the soil physical and hydrological properties. Land preparation is constrained by the hardness of the soils when dry and their stickiness when wet and their very slow internal drainage with infiltration rates between 2.5-6.0 cm day^{-1} [37].

Table 1: Interaction effect of compost and P on grain, straw and biomass yield of wheat

Compost (tha^{-1})	P-rate ($kgha^{-1}$)	Gy ($kgha^{-1}$)	SY ($kgha^{-1}$)	BY ($kgha^{-1}$)
0	0	2485^{e}	3947^{f}	6432^{f}
	46	2512^{de}	3999^{ef}	6511^{ef}
	69	2520^{de}	3977^{d}	6497^{ef}
	92	$2578c^{de}$	4014^{c-f}	6592^{d-f}
	115	2650^{bcd}	4037^{c-f}	6687^{c-f}
	138	2607^{b-e}	3984^{d-f}	6592^{d-f}
10	0	2660^{b-d}	4101^{b-f}	6761^{b-e}
	46	2646^{bcd}	3978^{def}	6624^{d-f}
	69	2745^{b}	4253^{ab}	6998^{ab}
	92	2693^{be}	4138^{a-e}	6832^{b-d}
	115	2601^{b-e}	4061^{c-f}	6661^{ce}
	138	2608^{b-e}	4154^{a-d}	6762^{b-e}
20	0	2608^{b-e}	4052^{c-f}	6659^{c-f}
	46	2707^{bc}	4248^{ab}	6955^{a-c}
	69	2649^{b-d}	4027^{c-f}	6675^{c-f}
	92	2705^{bc}	4139^{a-e}	6844^{b-d}
LSD (%5)		157.9	176.7	305.6
CV (%)		3.6	2.6	2.7

Sources: [29]

Table 2: Effect of inorganic and organic nutrient sources on yield and yield components of Teff

Treatments	PH (cm)	PL (cm)	BY ($kgha^{-1}$)	Gy ($kgha^{-1}$)
Recommended NP	114.17	42^{a}	11833.3^{ab}	2846^{ab}
Conventional Compost (CC)	98.3	39.7^{abc}	7979.2^{d}	1941^{de}
Farmyard manure (FYM)	92.67	38.3^{c}	8250^{d}	1920^{e}
Vermi-Compost (VC)	102.17	39.17^{bc}	9020^{cd}	1904.7^{e}
50% VC + 50% CC	101.5	40^{abc}	8500^{cd}	2027.3^{de}
50% VC + 50% FYM	103.17	40.5^{abc}	8750^{cd}	1933.5^{de}
33% VC + 33% CC + 33%FYM	100.83	39.17^{bc}	9145.8^{cd}	2293^{cd}
50% VC + 50% NP	111.5	41.17^{ab}	12562.5^{a}	3144.8^{a}
50% CC + 50% NP	108	41^{ab}	10208.3^{bc}	2516.7^{bc}
50% FYM + 50% NP	103.5	38.17^{c}	9687.5^{cd}	2420^{c}
DMRT 0.05	6.7	2.33^{**}	1940.2^{**}	368.02
Y x T	NS	**	**	*
CV (%)	5.12	5.6	16.6	13.9

Sources: [36]

Table 3: Effect of land preparation methods on the grain yield of wheat lentil and teff

	Wheat			Lentil			Teff		
Land preparation methods	1998	2001	Mean	1999	2002	Mean	2000	2003	Mean
BBF	438	1763	1101	2732	532	1632	1260	1333	1296
GM	1940	1621	1780	1704	144	924	1194	1373	1284
RF	1209	2187	1698	1787	271	1029	1139	1409	1274
RT	1819	1904	1862	1482	212	847	1315	1443	1379
Mean	1352	1869		1926	290		1227	1389	
LSD (0.05)		217			193			NS	
Year		196			255			NS	
Year*L		307			273			NS	
CV (%)		10.73			13.85			9.5	

Source: [38]

Methods of Land preparation namely as BBF, RF (ridge and furrow), RT (reduced tillage) and GM (green manure) was evaluated on Chefe-Donsa under vertisol condition. The test crops were wheat, teff and lentil and rotated following traditional cropping sequence. The planting dates were varied with the treatment and crop types, as well as on the onset of rain. The effect of land preparation methods on grain yields varied with crops (Table 3).

The grain yield and straw yields of wheat and lentil were significantly increased by the land preparation methods and their interaction with year. Broad bed and furrow (BBF)significantly affected lentil grain yield which was improved by about 59 % relative to control plot. On the other hand, the highest mean grain yield of wheat was obtained due to RT (10 %) higher than the control. BBF significantly reduced the grain yield of wheat (35%) less than the control. Land preparation methods seem to be sensitive to rainfall with respect to wheat. The grain yield of wheat increased from 1988 to a high in 2001 under all the land preparation methods, but grain yield in response to the increased total rainfall during the cropping season. On the other hand, BBF performed best both under favorable and unfavorable weather conditions. Regarding runoff and soil loss, the highest runoff drained 13, 30 and 16 % of the rainfall in 1988, 1999 and 2000, respectively.

Teff planted on flat bed resulted in 2000, the highest runoff of 30 and 16 % as compared to the previous year. BBF drained more proportion of water as the total rainfall increased, which makes it not only efficient but also dynamic with respect to surface drainage. RT resulted in the highest soil loss followed by BBF. It can be concluded that, treatment effects and rainfall intensity can aggravate soil erosion [38].

CONCLUSION

Improved management systems which increase land productivity and maintain environmental quality are increasingly global issue. Covering about 8 million ha, in Ethiopia vertisols are among the high potential soils, where significant increase in productivity is likely. However, their productivity is constrained by physical and hydrological properties, which manifested by hardness when dry and stickiness when wet, hence imped land preparation. The traditional management systems led neither to increased productivity nor to enhanced soil quality in country. Thus, the use of improved cereal variety particularly wheat and teff has opened an opportunity for double cropping under vertisol. Substantial increases in crop yields on vertisols when appropriate cropping practices and nutrient management utilized had been observed. Integrated use of vertisols management options in improving the whole farming systems of small-scale farmers and bring radical change to their life and livelihood thereby sustainable development of the country could be enhanced.

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