Limitation and potential of major soils in the highlands of West Shewa, Ethiopia

Taye Bekele

National Soil Research Center, EIAR, P.O. Box 147, Addis Abeba, Ethiopia.
Email: nsi@telecom.net.et

Abstract

A large portion of West Shewa is covered with Vertisols, Nitisols, Luvisols and Leptosols. Favorable features for the cropping of these soils with the exception of Leptosols are their extended depth, good nutrient and water retention and high cation exchange capacity. In contrast to these advantages, there are severe problems and hazards, including tillage difficulties and water logging in Vertisols, high P requirements associated with the presence of free iron oxide and soil acidity in Nitisols and shallow depth in Leptosols. The fertility and productivity of the majority of the soils of west Shewa have also reached the lowest level due to continuous cropping with little or no external inputs, removal of soil and nutrients through erosion, deforestation, soil acidity and poor drainage. Attempts are made to alleviate these problems through the use of improved technologies like chemical fertiliser, improved land preparation methods and integrated nutrient management. This paper attempts to review the fertility characteristics and results of investigations carried out to improve the fertility and productivity of these soils.

1. Introduction

West Shewa, which is part of Oromia National Regional State, is located in the western part of Ethiopia. Geographically, it is situated between latitude 80 19'-90 57' N and longtiude 350- 360 49' E. The total area is about 21,927 km^2, which means that it covers 2% of the total area of the country, which is estimated to be 1.1 million km^2.

Like in other parts of Ethiopia, the economy of the region depends very much on agricultural production. However, yield of crops on the overall is considered very low. This is mainly due to the extremely low level of plant nutrients in the soil, which does not allow the crops to express their potential yields. In the majority of West Shewa, the soils have been continuously mined for nutrients through harvests and soil erosion. As a result, the fertility and productivity of the soils have reached the lowest level. In this paper some important characteristics and research works undertaken to improve the productivity of some of the major soils found in the highlands of west Shewa are discussed.

2. Major soils of West Shewa

Available information indicates the existence of five major soil associations in West Shewa. These are Leptosols, Luvisols, Nitisols, Cambisols and Vertisols (Figure 1). Of these, Vertisols, Nitisols, Luvisols and Leptosoils comprise about 85% of the area. The Vertisols cover the flat areas with slope inclination between 0 and 8%, whereas the Leptosols predominantly occur on steep slopes and hillsides with up to 16% or more slope inclination. The Luvisols are more or less regularly distributed over flat and hilly areas and Nitisols occur on areas with slope inclination between 0 and 16%. Vertisols are important agricultural soils in the region with black to gray colour and a high content of swelling and shrinking clay. They crack when dry and swell when wet. They form gilgai microtopography. Vertisols have a poor drainage condition, which reduces their productivity. High N fertiliser application and improved drainage increase productivity. Leptosols are very thin soils on steep slopes and hilly sides.

Nitisols are deep clayey, often reddish brown soils with an argillic B-horizon. High leaching of bases occurs in Nitisols resulting in low pH. They contain a high level of Al, Fe and Mn (sesquioxides) and have a high P fixing capacity due to oxides. They allow good and deep rooting. In combination with chemical fertiliser they have a good potential for agricultural use. Luvisols are red to reddish brown in colour. They have an argillic B-horizon, but their base saturation is high. They are deep and have weatherable minerals. Phosphate is often low, while N and organic matter levels are moderate. They are weakly to moderately acidic (pH > 5.5).

3. Soil physical and chemical characteristics affecting agricultural productivity

3.1. Water-logging / poor drainage

A large portion of the area on the highlands of west Shewa is covered with Vertisols. Due to the problem of excessive water-logging, Vertisols are normally not utilised for crop production during the main rainy season. The water-logged soils on level plains are usually used as grazing grounds or for growing crops at the end of the rainy season, particularly crops such as durum wheat and chick-pea, which strive on reserve moisture in the soil during the dry season. High yields are not obtained from such waterlogged areas due to low soil fertility and shortage of moisture during the growing period. In general, insufficient drainage is the major problem in Vertisols.

3.2. Soil acidity

Soils occurring in the warm and humid areas of west Shewa, particularly those lying on well-drained landscapes are usually highly leached and highly acidic.

The coverage of acidic soils in west Shewa is estimated to be high. Because of high P–requirements and a deficiency of the base elements associated with soil acidity, yields of cereal crops grown on acidic soils of west Shewa are very low and the response to NP fertiliser is not satisfactory, either.

3.3. Low organic matter and total N contents

Fertiliser trials carried out in the majority of the area of west Shewa showed a high response to applied N, indicating the low organic matter and N levels of the soils. The low N content is associated with loss of organic matter, as opposed to poor drainage (denitrification loss) in Vertisol areas.

3.4. Available P

Available soil P values show high differences depending on soil type and farming system. In general, the level of available soil P has been noted to be less than 10 ppm in most soils of west Shewa. A limited number of soils, particularly those with a higher level of organic matter, are known to have available P levels in the range of 10-20 ppm (Desta 1982; Piccalo and Huluka 1986).

4. Major causes of fertility decline

4.1. Low inherent soil fertility and depletion of plant nutrients

Research outcomes have shown that the majority of cultivated lands in the highlands of west Shewa are highly responsive to N and P fertilisers because of the high exhaustion of these nutrients from the soils as a result of several decades of continuous cultivation. N and P are the two most yield-limiting nutrients. Depending on the type of soil, climatic condition, land use and cropping system, the levels of these nutrients vary from place to place.

4.2. Limited agricultural inputs

Although N and P fertilisers are known to highly increase the yields of the majority of cereal crops, little or no input through residue incorporation, or other external inputs in the form of organic and inorganic fertilisers, are being applied. The major reasons for the use of a low level of fertilisers are believed to be:

a) Limited availability of fertilisers (all imported)
b) Limitations of road infrastructure for a timely supply of fertilisers
c) Lack of know-how from the farmers' side
d) Limited extension services
e) High price of fertilisers

4.3. Inappropriate soil management practices

With the increase of population that lead to a decrease of per capita land holdings, the practice of fallowing has been gradually abandoned and the majority of the land is subjected to continuous cultivation. Moreover, the tradition of rotation of cereals with pulse and oil crops has also become less and less popular. This is because of the high demand for certain cereals on the market which force the farmers to grow a specific cereal crop year after year in order to get high market prices and be able to survive on their small piece of land. The result of the elimination of the fallow system, the complete utilisation of crop residues, less use of dung for soil fertility restoration and the low level of rotation of cereals with pulses have caused excessive soil nutrient exhaustion and low yields.

4.4. Soil erosion

The landscape as such, its unique topography, incidence of heavy deforestation, intensive rainfall and a low level of land management are causes of heavy soil erosion. The consequences are the low content of mineral nutrients and the low moisture holding capacity of soils.

5. Results of investigations carried out to improve soil productivity in the highlands of west Shewa

5.1. Mineral fertilisers (NP)

Based on the result of several field trails, the N- and P-fertiliser rates to be applied to obtain maximum yield have been established for major crops soil types. Table 1 shows NP fertiliser recommendations made for cereals, oil crops and pulses.

In addition to the determination of the optimal fertiliser rate, the timing of fertiliser application and placement that offers the highest rate of economic return to farmers has been investigated for several crops. Split application of N (half at planting and the other half at full tillering) has been found to increase the grain yield of wheat and *teff* significantly (Asnakew *et al.* 1991). The experiment on fertiliser placement indicates that band placement of phosphate is much better than broad casting. It was also demonstrated that the maximum benefit out of fertiliser application can be achieved if other natural soil conditions such as drainage and acidity are improved.

A greenhouse experiment was undertaken at Holetta to select a reliable soil test method on which the phosphorous fertiliser can be based. As can be seen in Table 2, the sodium bicarbonate extraction method of Olsen was found to be a suitable soil test method for P in Ethiopian soils. Very little work has been done with regard to N. In a field trial conducted at Ginchi, Gare Arera and Holetta, the N mean method, in which fresh soil samples are extracted with a dilute NaCl + $CaCl_2$ solution to quantify NO_{3-} and NH_{4+}, was found to be suitable for predicting the amount of N to be applied.

With this method the amount of P required by wheat was calculated. For each ton expected grain yields of wheat 30kg N ha^{-1} were assumed to be necessary. Since three tons grain yield of wheat were expected, the required amount of N was calculated to be 90kg ha^{-1}. This figure minus the available amount of N in the soil gives the N-rates shown in Table 3 and 4.

5.2. Organic fertilisers and improved cultural practices

As fertilisers are costly inputs, attempts have been made to develop improved and affordable nutrient management systems, based on available organic sources such as farmyard manure, green manure and biofertiliser, for the major cereals oil crops and pulses grown at different locations in west Shewa. Results of the experiments conducted in these areas are summarised below.

5.2.1. Green manure

Short season legume crops are grown and incorporated into the soil as green manure to improve fertility through N-fixation, organic matter addition and nutrient cycling. Although limited, studies to investigate the effect of green manuring on the yield of crops have been conducted in west Shewa. The results of a study at Holetta red soil indicate that compared to wheat after wheat, the incorporation of vetch increases the wheat yield considerably. An increase in the efficiency of the applied fertiliser on the vetch incorporated field was also observed in this study (Table 5.).

5.2.2. Farmyard manure (FYM)

Experimental results have revealed that FYM has a positive effect on the improvement of soil fertility and yield, even though the magnitude is location and climate specific. In general, where there is no moisture limitation, the positive effect of FYM can easily be observed (Table 6 and 7).

5.2.3. Biological N-fixation

The N fixing symbiosis (BNF) which occurs between leguminous crops and a genus called rhizobium is the most important biological process from an economic point of view. An important feature of the BNF is that atmospheric N_2 is converted biologically with the help of microorganisms, without a great expense of energy, into forms that plants can assimilate.

The principal N fixing systems investigated are food grain legumes such as beans, peas, chickpeas and lentils. Studies have demonstrated that BNF could play an important role in increasing food production in the region. An increase in yield up to 95% as compared to the uninoculated plot was obtained.

5.2.4. Crop rotation

Some investigations have been conducted in an attempt to replace the fallow-barley system of cultivation, which is widely practiced in the region. At Bedi, for example, high barley yield of 2.8 t ha^{-1} was obtained following trifolium, as compared to 1.7 t ha^{-1} from continuous cropping of barley (IAR, 1977). In another experiment, barley yields of 2.0t ha^{-1} were obtained following both lupin and vetch (Table 9). It is interesting to note that in the plot where lupin was grown, the soil available P has decreased considerably (Table 10).

5.2.5. Lime, rock phosphate and agricultural by-products

Some experiments have been conducted to evaluate the fertiliser value of wastes from the processing of plant animal products, as well as natural occurring substances such as rock phosphate and lime. A summary of these findings is presented in table 6 to 9.

Liming to improve acidic soils

Greenhouse and field experiments were conducted on the liming of acidic soils at different locations in order to study the effect of lime with and without P fertiliser on the yield of barley, wheat, faba bean and maize. The results from such experiments indicate that lime and phosphate significantly increase the yield of crop on acidic soils (Table 11). The major problems in the practical application of these results are the large quantities of lime required per unit area of land (< 3.5 t ha^{-1}) to get the desired effects. The physical locations of the lime sources are naturally far away from the acidic soil areas, hence demanding high costs of transportation. More intensified investigation is necessary on the amendment of acid soils, which are extensively present in Ethiopia.

Rock phosphate as a source of P

The results of limited experiments conducted to compare the effectiveness of rock phosphates of different origins as a source of P for plants indicate that Gafsa rock phosphate is more effective than the local Bikilal rock phosphate on Nitisols at Holetta.

Agricultural by-products

The results of experiments conducted on the red soil at Holetta with organic materials such as hoofs and horn and dried blood show a marked increase in the yield of wheat and barley (Table 13). Similarly, mustard meal from oil seed processing when incorporated with the soil was found to be a useful source of N. The results show that the application of these material increases wheat yield significantly, beyond the level of the control plot (Table 14).

5.2.6. Improved drainage

As in other parts of the Ethiopian highlands, Vertisols in the highlands of West Shewa are traditionally used for free grazing and very little for crop production. To a limited extent, these soils are used for the production of chickpeas and durum wheat that are planted at the end of the rainy season, utilizing the reserve moisture in the soil.

At Ginchi, 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 fertilisers, higher yields of cereals can be obtained on Vertisols. It can be seen from Table 15 that additional yield gains of 560, 303 and 500 kg ha^{-1} of wheat, *teff* and chickpeas from fertiliser application as a result of improved aeration of the soil or by improved drainage alone. However, the preparation of camber-beds for draining excess moisture from Vertisols requires mechanisation and could not be easily done with a traditional local plough, which is pulled by a pair of oxen.

Some technology packages on improved land preparation methods that are within the capacity of the farmers have also been tested and demonstrated to the farmers. This is the broad–beds and furrows (BBF) land preparation method with specially designed tools to fit the local plough system and to be pulled by a pair of oxen. With the use of this drainage technique and the application of fertilisers (NP), along with improved seeds, the crop and straw yields on Vertisols were increased substantially at the peasant farmer level.

6. Conclusions and recommendations

The potential for improving the productivity of soils of West Shewa through the application of fertiliser or liming and surface drainage has been realised through laboratory, greenhouse and field experiments. With the use of these technologies, the currently less productive soils of the region could easily be converted into highly productive soils. Nevertheless, despite the numerous fertiliser trail data available in different parts of the country, it was not possible to establish a soil test based fertiliser recommendation scheme.

This was mainly due to the inappropriateness of the method and design of the experiments used and the absence of adequate soil test data on soils. Without information on soils, the fertiliser trial results could not be extrapolated to similar areas or be used to give a site-specific recommendation. Studies are needed that can provide adequate and reliable data on the amount of available nutrient in the soil, nutrient removal and fertiliser requirements. Soil test calibration studies must also be initiated on a nationwide scale for different nutrients / crops / climatic conditions, as a means to develop site-specific fertiliser recommendation schemes for the country. In order to make fertiliser application profitable it is also essential to consider factors other than soils, including time of planting, plant population, disease, insect and weed control and other improved cultivation practices. Furthermore, for an efficient utilisation of organic residues, the importance of storage and application techniques deserves consideration. Finally, greater effort must be made to promote the utilisation of technologies generated from research through intensive demonstration trials.

References

Asnakew W. (1989) The role of soil fertility management in crop production. In: *Proceedings of the First Natural Resource Conservation Conference.* IAR, Addis Ababa: pp. 65-72.

Asnakew W., Tekalign M., Mengesha B. and Teferra A. (1991) Soil fertility management studies on wheat in Ethiopia. In: Hailu G.M., Tanner D.G. and Mengistu H. (eds) *Wheat research in Ethiopia: IAR/CIMMYT*.

Balesh, T. (1993) *Evaluation of mustard meal as a source of nitrogen.* Paper presented at the annual conference of the Crop Science Committee of Ethiopia. (Unpublished).

Desta, B. (1982) Diagnosis of phosphorus deficiency in Ethiopian soils. *Soil Science Bulletin* No 3, IAR. Addis Ababa.

FAO (1984) *Assistance to land-use planning* (AG=DP/ETH/82/010). Field documents. Geomorphology and soils of Ethiopia. Ministry of agriculture, Addis Ababa.

FAO (1986) *Highland reclamation study*, Ethiopia. AG:VTF/ETH/037, Vol. 1 and 2, FAO, Rome.

Getachew A. and Taye B. (2005) On-farm integrated soil fertility management in wheat on Nitisols of central Ethiopian highlands. *Ethiopian J Nat Resour*, 7(2): pp. 141-155.

Getachew A., Taye B. and Agajie T. (2005) Phosphorus fertiliser and farmyard manure effects on the growth and yield of faba bean and some soil chemical properties in acidic Nitisols of the central highlands of Ethiopia. *Ethiopian J Nat Resour*, 7(1): pp. 23-29.

Hiruy B. (1986) The effect of drainage system, drainage, spacing and fertiliser on seed yield and other characters of wheat, teff and chickpea on heavy clay soils of Ginchi. *Ethiopian J Agric Sci*, 8(2): pp. 85-95.

IAR (1977) *Holetta–Genet research station progress report for 19775/76*. Addis Ababa, Ethiopia.

IAR (1989) *Effect of Rhizobia inoculants on yield of grain legumes in Ethiopia*. Progress Report, Addis Ababa, Ethiopia.

Piccolo A. and Huluka G. (1986) *Phosphorus status of some Ethiopian soils*, Trinidad. *Trop Agr* 63: pp. 137-142.

SWRP (1990) *Soil and water research strategy document*. Ethiopian Agricultural Research Organization. Addis Ababa, Ethiopia.

Taye B. and Hoefner W. (1993) Effect of different phosphate fertilisers on the yields of barley and rape seed on reddish-brown soils of Ethiopian Highlands. *Fert Res*, 34: pp.243-250.

Taye B. and Hoefner W. (1990) Comparison of eight extraction methods on ten reddish brown soils of the Ethiopian highlands. In: *Giessener Beiträge zur Entwicklungsforschung*, Series I, vol. 18, Wissenschaftliches Zentrum Tropeninstitut, Justus–Liebig–Universität, Giessen: pp. 175-193.

Taye, B. (1994) *Effect of lime on the growth and biomass yield of barely*. Annual Report, Holetta Research Center, Holetta, Ethiopia.

Taye, B. (2001) *Developing alternative for barley cropping system in western Shewa*. Annual Report. Holetta Research Center, Holetta, Ethiopia.

Taye, B. (2002) *Evaluation of soil test based N-fertiliser recommendation methods under field conditions.* Annual Report, Combating Nutrient Depeletion Project (CND). Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Table 1: Fertiliser recommendation for cereals, pulses and oil crops.

Location	Soil type	Crop	Fertiliser rate kg ha^{-1}	
			N	P
Holetta	Nitosol	Bread wheat	60	26
Holetta	Nitosol	Barley	60	26
Holetta	Nitosol	Tef	40	26
Holetta	Nitosol	Horse bean	23	20
Holetta	Nitosol	Field pea	23	20
Holetta	Nitosol	Linseed	23	20
Holetta	Nitosol	Rape seed	23	30
Ginchi	Vertisol	Bread wheat	90	40
Ginchi	Vertisol	Tef	60	26
Ginchi	Vertisol	Noug	23	20

Source: SWRP (1990)

Table 2: Correlation coefficient (*y*) between dry matter yield and P (extracted by soil tests).

Soil test	1st harvest of *y*	Wheat ranks	2nd harvest of *y*	Wheat ranks	Average rank
Olsen	0.698***	2	0.683***	1	1
Saunder	0.562***	8	0.636***	7	8
Truog	0.706***	1	0.662***	4	2
Bray 1	0.601***	6	0.680***	2	4
Bray 2	0.642***	3	0.628***	8	6
Mehlich 1	0.590***	7	0.647***	6	7
Mehlich 2	0.631***	4	0.670***	3	3
Egner	0.615***	5	0.658***	5	5

Table 3: Comparison of N rate recommendation methods for wheat on homestead soils (mean of four sites) at Gare Arera, west Shewa, Ethiopia.

Treatments	N applied (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
N applied based on yield goal*	50.5	3.01	4.93
N applied according to site recommendation	60.0	2.76	4.64
Control, without N application	0.0	1.88	3.59
CV (%)		1.27	2.04
LSD (0.05)		2.80	7.70

Source: Taye (2002)
Available N kg ha^{-1} (N-mean method)=54.5; estimated yield (t ha^{-1})=3.5; N uptake per dt of dry matter of wheat = 30 kg; N required based on expected yield (kg ha^{-1})=105 (35*30); N fertiliser applied= N required based on expected yield-available N in the soil.

Table 4: Comparison of N rate recommendation methods for wheat on Nitisols (mean of four sites) at Gare Arera, West Shewa, Ethiopia.

Treatments	N applied (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
N applied based on yield goal*	66.2	2.90	5.92
N applied according to site recommendation	60.0	2.47	4.37
Control, without N application	0.0	1.14	2.71
CV (%)		12.9	19.4
LSD (0.05)		2.4	7.3

Source: Taye (2002)
Available N kg ha^{-1} (N-mean)=38.8; estimated yield (t ha^{-1})=3.5; N uptake per dt of dry matter of wheat=30 kg; N required based on expected yield (kg ha^{-1})=105 (35*30); *N fertiliser applied= N required based on expected yield-available N in the soil.

Table 5: The effect of green manuring on wheat yield (kg ha^{-1}) at Holetta.

Fertiliser sub-plot	Wheat after vetch	Wheat after wheat	Mean
N_0P_0	2840	940	1890
N_0P_{26}	3050	990	2020
$N_{20}P_0$	2910	1040	1980
$N_{30}P_{26}$	3630	1830	2730
$N_{60}P_0$	3120	1530	2330
$N_{60}P_{26}$	4550	1960	3260
Mean	3350	1380	2365
	NP means	Crop means	
LSD (0.05)	800	1590	

Source: Asnakew (1989)

Table 6: Inorganic N and P fertilisers and FYM effects on grain yield (GY), biomass yield (TBY) and thousand-kernel weight (TKW) of wheat from 2003 to 2004 on Nitisols of Welmera area, west Shewa.

	Medium fertility			Low fertility		
Treatment (T)	GY (t ha^{-1})	TBY (t ha^{-1})	TKW (g)	GY (t ha^{-1})	TBY (t ha^{-1})	TKW (g)
N/P/FYM (kg ha^{-1})						
9/10/0	2.63c†	7.10c	39.22	1.63c	5.06c‡	41.00
9/10/8000	3.05b	8.56b	39.03	2.15b	6.23b	39.62
32/10/4000	3.27ab	9.18ab	39.37	2.29b	6.37b	40.55
32/10/8000	3.44a	9.77ab	38.57	2.59a	7.45a	41.03
64/20/0	3.46a	10.06a	37.27	2.78a	8.18a	39.25
F-probability						
Year (Y)	NS	NS	**	NS	NS	**
Treatment (T)	***	**	NS	***	***	NS
Y×T	NS	NS	NS	NS	NS	*
LSD (0.05)	0.34	1.38	NS	0.23	0.96	NS
CV (%)	8.79	12.77	5.24	8.43	11.93	3.94

Source: Getachew and Taye (2005)
†Means in a column with different letters are significantly different at $P \leq 0.05$.
*, **, *** Significant at $P \leq 0.05$, 0.01 and 0.001 probability level, respectively; NS = Not significant

Table 7: The interaction effect of FYM and P fertiliser on faba bean seed yield (kg ha^{-1}) in 2003.

	Farmyard manure†		
P (kg ha^{-1})	0 (t ha^{-1})	4 (t ha^{-1})	8 (t ha^{-1})
0	606g	1022ef	1589bc
13	896ef	1254d	1471c
26	827f	1579bc	1640bc

Source: Getachew *et al.* (2005)

† Means in a column followed by the same letter are not significantly different at P≤0.05.

Table 8: Effect of Rhizobium strains on yield of grain legumes in Ethiopia.

	Yield t ha^{-1}		
Crop	Non-inoculated	Inoculated	Increase%
Faba bean	1.02	1.90	86.2
Soybean	1.52	1.86	22.4
Field pea	1.00	1.95	95.0
Chickpea	2.18	2.36	8.3
Lentil	1.38	1.49	8.0

Source: IAR (1989)

Table 9: Effect of precursor crops and fallowing on grain and straw yields (kg ha^{-1}) of food barley at Siga Meda, west Shewa.

Precursor	Mean Grain yield (kg ha^{-1})		Mean straw yield (kg ha^{-1})	
Crops	Unfertilised	Fertilised	Unfertilised	Fertilised
Fallow	1583	2154	6474	7494
Lupin	1960	2229	7216	7828
Trifolium	1435	2247	6288	7716
Barley	1721	2167	6955	7481
Vetch	2035	2199	7171	8033
Oat/Vetch mixture	1772	1925	6756	6955
Mean	1751	2154	6810	7585

Source: Taye (2001)

Table 10: Available P and pH of Nitisols after food and forage legumes, barley and natural fallow in siga Meda, west Shewa.

Crop	pH (1:1) H_2O	Available P (ppm) Olsen
Fallow	4.61	6.3
Lupin	4.71	4.8
Trifolium	4.66	6.5
Barley	4.91	8.0
Vetch	4.52	8.5
Oat-vetch mixture	4.69	8.2

Source: Taye (2001)

Table 11. Effect of lime on the grain and biomass yields (dt ha^{-1}) of barley on a farmer's field at Adaberga, Central Ethiopia.

Treatments	Total biomass yield	Grain yield	Soil pH	
			Before application	After application
Lime (3 t ha^{-1})	19.2	8.4	4.63	5.46
Lime + recommended rate of fertiliser	42.9	12.6	4.73	5.28
Recommended rate of fertiliser	28.6	10.6	4.65	4.76
Control (no lime, no fertiliser)	11.0	3.7	4.62	5.41
CV (%)	13.35	26.04		
LSD 5%	6.05	4.59		
1%	9.25	6.53		

Table 12: Direct and residual effects of different sources of P on the yield of barley and rape seed.

Source of P	P rate (kg ha^{-1})	Direct effect (Mg ha^{-1})		Residual effect (Mg ha^{-1})
		Barley	Rape	Rape
Control	0.0	2.80	0.20	0.28
Bone meal	26.4	3.22	1.28	0.83
	52.8	3.73	1.48	1.04
	105.6	4.23	1.58	1.19
Tomas Phosphate	26.4	3.58	0.97	0.59
	52.8	4.39	1.04	0.78
	105.6	4.86	1.68	1.25
Gasfa Phosphate	26.4	3.64	0.92	0.69
	52.8	3.98	1.14	0.88
	105.6	4.47	1.84	1.31
Ethiopian Rock Phosphate	26.4	2.34	0.45	0.05
	52.8	1.64	0.82	0.21
	105.6	1.44	1.13	0.57
Triple Super Phosphate	26.4	3.64	1.20	0.50
	52.8	3.79	1.44	0.96
	105.6	4.99	1.38	0.86
LSD 0.05		0.26	0.35	0.32

Source: Taye and Hoefner (1993)

Table 13: Effect of different sources of plant nutrient on the grain yield of wheat in kg ha^{-1}.

Treatments	Mean (kg ha^{-1})	Mean yield (% of control)
Check	1492	100
50 kg DAP ha^{-1}	1996	134
100 kg DAP ha^{-1}	2938	197
150 kg DAP ha^{-1}	2177	146
100 kg Bone meal ha^{-1}	1942	130
200 kg Bone meal ha^{-1}	2502	168
300 kg Bone meal ha^{-1}	1973	132
200 kg Blood meal ha^{-1}	2061	138
400 kg Blood meal ha^{-1}	2326	156
600 kg Blood meal ha^{-1}	1944	130
600 kg FYM ha^{-1}	1965	132
1200 kg FYM ha^{-1}	2728	182
1800 kg FYM ha^{-1}	2941	197

Source: IAR (1977)

Table 14. Effect of mustard meal on the growth and yield of wheat (kg ha^{-1}) on Nitosol at Holetta.

NP rates	Years		
	1990	1991	1992
N_0P_{26}	285	389	240
$N_{60}P_{26}$	1203	986	1172
$N_{90}P_{26}$	2328	1722	1333
$N_{120}P_{26}$	2543	1766	1813
$N_{180}P_{26}$	3422	2339	3620

Source: Balesh (1993)

Table 15: The influence of fertiliser on the grain yield of wheat, *teff* and chickpea grown under un-drained and drained conditions at Ginchi.

		Un-drained		Drained		
Crop	Variety	F_0	F_1	F_0	F_1	Variety mean
			(t ha^{-1})			
Wheat	Enkoy	0.40	0.78	0.79	1.77	0.94
	Local	0.32	0.56	0.64	1.29	0.70
	Mean	0.36	0.67	0.72	1.53	0.82
Teff	DZ-01- 354	0.69	1.09	0.85	1.46	1.02
	Local	0.79	1.18	0.82	1.47	1.07
	Mean	0.74	1.14	0.84	1.47	1.05
Chickpea	41 B	0.93	0.93	1.40	1.40	1.17
	Local	0.76	0.86	1.03	1.39	1.01
	Mean	0.85	0.90	1.22	1.40	1.09

Source: Hiruy (1986)
F_0 and F_1 denote 'unfertilised' and 'fertilised' respectively.