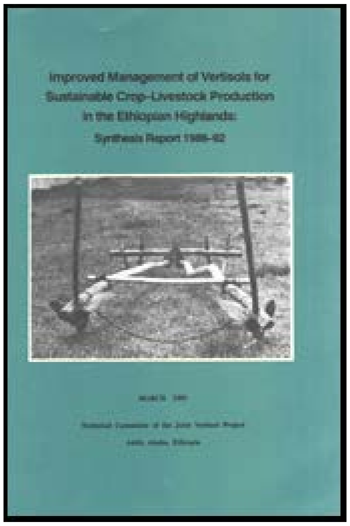
Improved management of Vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-92


Improved Management of Vertisols for
Sustainable Crop-Livestock Production
in the Ethiopian Highlands:
Synthesis Report 1986-92

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MARCH 1993

Technical Committee of the Joint Vertisol Project Addis Ababa, Ethiopia

Editors:

Tekalign Mamo
Abiye Astatke
K L Srivastava
Asgelil Dibabe

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Foreword

Any strategy for the protection, conservation and sustainable utilisation of natural resources including that aimed at the attainment of self-reliance in crop and livestock production must include, among others, research and development (R&D) plans for about 13 million hectares of dark clay soils which for convenience we collectively termed Vertisols.

Vertisols constitute over 10% of the Ethiopian land mass where unimproved traditional agricultural production practices are still rampant. This called for the establishment in 1986 of a collaborative project: The Joint Project on Improved Management and Utilisation of Dark Clay Soils which for short is known as the Joint Vertisol Project (JVP).

There is a hierarchy of interlocked subsystems pertaining to the utilisation of Vertisols. This encompasses such diverse components that an integrative research which links all levels is required for a long-term sustainable use of such a vital resource. Research and development on Vertisols inherently address complex factors and interactions among such factors relevant for resource conservation, improvement and utilisation The JVP, therefore, had to face a multidimensional challenge to be able to exploit the comparative advantages and the complementarities thereof of partner institutions for the attainment of critical mass to make agriculture and its development sustainable in the shortest time possible.

Such a challenge could be overwhelming when comprehensiveness is sought such that the efforts of several national and international institutions had to be streamlined. This was necessary because the high number of individual and correlated complex R&D issues prevent any single institution from formulating and successfully executing a blanket programme. Despite the non-conducive policy framework and a top-down commandist political system that did not encourage resourcefulness or participatory development, the JVP has come a long way in the seven years after its initiation. Needless to say, not all of JVP's efforts were success stories.

The JVP's modest accomplishments, seen in the light of the enormity and immensity of the tasks, have been due to sheer will- power and the recognition by those who saw ahead the diverse potentials of Vertisols in Ethiopia. This should act as a beacon and driving force towards greater collaboration in capability- building in research, training and extension.

The historical perspective, organisational arrangements, strategy of choice, prioritisation, task-sharing, the achievement and related issues constitute the topics of the synthesis report for the seven-year period (1986-92). We hope that this synthesis report will impetus and reference material to researchers and extension workers on Vertisols in Ethiopia and elsewhere.

This monumental task was accomplished through the untiring efforts of the JVP Technical Committee, concerned scientists from collaborating institutions, and the often unsang heroes - the Ethiopian farmers - who cooperated with the scientists in the verification of the technologies. Without the generous support of partner institutions as well as the decisive and indispensable financial assistance of the Swiss Development Cooperation (SDC), the JVP would not have accomplished what it did.

Mesfin Abebe (Dr.)
Chairman, Advisory Committee of the JVP, and

Minister, Natural Resources Development and Environmental Protection

Acknowledgements

The Editors express their gratitude to all who have contributed to the synthesis report within the short period given. We feel the work and efforts made were worthwhile. We would also like to thank the encouragements and support received from the managements of the four institutions (AUA, IAR, ILCA and ICRISAT) for finalising the publication. Special thanks are due to Drs. Mesfin Abebe, Seme Debela, Goshu Makonnen, John Walsh and James Ryan for the unlimited support given to the work. The management of ILCA deserves additional thanks for handling purchases made overseas for AUA and IAR Vertisol projects and also for channelling funds to these institutions as necessary. We take this opportunity to thank ILCA's Procurement Office, specially Ato Tekeste Berhan Habtu, for their efficient and fast services.

The work would not have been possible if it were not for the financial support from the Governments of Switzerland, Norway and Finland and non-governmental organisations (CARITAS: Swiss and Oxfam: US). Special thanks go to the Swiss Development Cooperation (SDC) for the strong financial support given to the three institutions (IAR, AUA and ILCA) involved in the Joint Vertisol Project (JVP) up to now. Special appreciation also goes to Mr. Paul Egger for his untiring support and advise to the JVP.

Finally, we should cite Dr. Samuel Jutzi, the person who, through his hard work, dedication and effort pioneered the formation of JVP. He is remembered by the JVP staff and Ethiopian agricultural scientists for directing the Project to success. The JVP is greatly indebted to him.

The Editors

1 Development of coordinated research efforts

Tekalign Mamo, MA Mohamed-Saleem and Abate Tedla

Introduction

Vertisols account for 12.7 million hectares in Ethiopia of which 7.6 minion hectares are in the Ethiopian highlands. Vertisols are generally hard when dry and sticky when wet and therefore present serious limitations to their use.

Poor internal drainage is a major problem associated with Vertisols in high rainfall as well as in irrigated areas. As a result of this, the roots of the crops are poorly aerated and nutrient uptake for growth and development impaired. Traditional farming has developed a wide range of drainage practices (construction of hand-made broadbed and furrows such as in Enewari plateaux, planting on ridges, soil burning etc) and the use of low yielding crop varieties and late planting practices to avoid waterlogging periods. Waterlogging of Vertisols is more severe in the Ethiopian highlands where rainfall is higher and evaporative demands are lower.

It has been recognised that, with the exception of the hand-made broadbeds and furrows, the technical efficiency of the traditionally applied surface drainage techniques is not sufficient to allow full use of the potentials of these soils (Mesfin Abebe, 1982; Getachew Asamenew et al, 1988; Jutzi et al, 1988). Cambered beds gave remarkable effects on crop growth and fertiliser efficiency (Mesfin Abebe, 1982). However, the economic viability of this technology in the smallholder subsistence sector proved to be questionable since no uptake by farmers was recorded.

The experience of ICRISAT with the use of Vertisols in semi-arid India (Burford, 1987; Kanwar and Virmani, 1987) indicates that the key to drastically improved productivity of Vertisols is the effective control of surface soil water which then enables rational use of the land for food and feed production. ILCA, therefore, developed and tested on-station and on-farm research in various highland Vertisol areas an animal-drawn implement for broadbed and furrow construction which was to combine technical efficiency of surface drainage construction with economic viability (Jutzi et al, 1987c). Substantial increments in grain and biomass outputs due to enhanced surface drainage were recorded along with convincing economic returns to the farm in the application of this technology.

History of the Project

The credit for the successful establishment of the improved Vertisol management project goes to Dr. Samuel Jutzi, a former staff of ILCA, who in 1984 prepared a project proposal entitled "Management of deep black clay soils (Vertisols) in sub-Saharan Africa". The project proposed the implementation of a research, training and outreach programme for improved Vertisol utilisation The programme was envisaged to focus on Ethiopian Vertisols in the first phase, as a joint ICRISAT/ILCA initiative with the involvement of the Government of Ethiopia" The project proposal was submitted for comments to the Ethiopian Ministry of Agriculture, to the Institute of Agricultural Research (IAR) and to the International Crops Research Institute for the Semi-

Arid Tropics (ICRISAT). Discussions on the project Implementation for its outreach part were pursued with the Ministry of Agriculture (MOA) and the Central Planning and Programming Department of MOA during 1985. Two implementation documents, one for the research and one for the outreach parts of the Project, were prepared in November 1985 and submitted to MOA, IAR and Alemaya University of Agriculture (AUA).

Several informal discussions between ILCA, MOA, IAR and AUA professionals and heads of institutions were then held with the purpose of exchanging information and develop mutually useful intentions and interests. This led to the official formation of the Joint Vertisol Management Project (JVMP) composed of administratively independent cells that share the goals of the Project within their respective agencies to achieve these goals.

Project objectives

- The objective of the Joint Vertisol Project (JVP) has been to develop and verify improved on-farm animal-powered Vertisol management techniques is Ethiopian highland mixed farming systems. These were:

- To develop or adapt improved animal-based Vertisol management techniques in order to improve the overall utilisation of these soils in Ethiopia.

- To develop techniques for more effective use of the water resources of the Vertisol areas by appropriate animal-powered bad-shaping and integrated watershed planning.

- To develop improved low-cost cropping systems for these physically emended soils, with particular consideration given to the legume component in order to provide reasonable soil-N levels for sustained crop production and sufficient N for the supplementation of crop residues in animal feeding, Systems to be investigated will also include agro-forestry and sylvipastoral sets.

- To design and test adapted technical means, e.g. animal-drawn implements for Vertisol cultivation and land-shaping.

- To implement necessary climatic data recording and handling systems to support improved land, water and crop management.

- To have effective means of inter-institutional coordination of Vertisol research activities.

Project rationale

1. Vertisols is high rainfall areas are agriculturally underutilised because of marked waterlogging during the growing period. They appear to be the soils with the largest gap between actual and potential production is the Ethiopian highlands.

2. Vertisols have very high waterholding capacity and high CEC due to their high clay content. They are, therefore, low-risk soils of high potential.

3. Impact of improved tillage quality on crop yields is higher on heavy clay soils than on light soils.

4. Animal power has comparative advantages over tractor power is tilling cracking clays in the wet phase. There seems to be opportunity for synergies between draught animal power (wet-soil tillage and planting) and tractor power (rough off-season ploughing).

5. Ethiopian highland agriculture has been animal-powered for centuries; animal traction knowledge is, therefore, available.

6. Acceptance of animal-powered land cultivation as an alternative to hand cultivation (human drudgery) is more likely to take place on heavy clays than on light soils.

7. Ethiopia's Vertisol area is considerable (13 in ha of which 7.6 in ha are in the highlands). Ethiopia has the largest Vertisol area in high rainfall regimes in sub-Saharan Africa.

Project strategies

The joint project adopted the following strategic positions for its programme development:

- Strict adjustment of external cost of technologies to capital/cash availabilities in target-farming systems. Since these systems are subsistence-oriented, a low external cost approach is adopted.

- Research, verification and extension of "element by element". No major effort to assemble comprehensive technological packages is undertaken.

- Bases of improved technologies are to be sought as much as possible in traditionally available elements.

- Involvement of target farmers for feedback generation and direction of the technology adoption from the start i.e. on-farm research.

- Inter-institutional task-sharing, vital for the assembling critical mass in all areas of project activity, would be practiced.

Project target areas

(a) High rainfall areas
(b) Mixed crop-livestock farming
(c) Systems with viable draught-cattle population.

Project structure and organisation

The Joint Vertisol Management Project document proposed an advisory board to give guidance to the Project and a technical committee to supervise the day-to-day execution of the Project.

The Advisory Committee (AC)

The inaugural meeting of the Advisory Committee (AC) to the joint project was held on March 28,1986 at ILCA headquarters. The composition of the Committee was endorsed as follows:

- Vice-Minister, Animal and Fishery Resources Development Main Department, Ministry of Agriculture, chairman

- General manager, Institute of Agricultural Research, member

- President, Alemaya University of Agriculture, member

- Research and Publications Officer (RPO), Addis Ababa University, member

- Director General ICRISAT, member

- Director General, ILCA, member.

The Committee's main task would be as follows:

(a) to consider policy issues associated with the Project

(b) to maintain a watching brief on its progress

(c) to ensure adequate coordination of all agencies involved

(d) to assign relative responsibilities for key actions

(e) to supervise the work of the Technical Coordinating Committee responsible for project implementation

(f) to develop and assess guidelines for resource acquisition and allocations.

Since its formation the AC met seven times and discussed a range of issues such as project emphasis, funding, membership etc. At its sixth meeting on January 27, 1991, the AC discussed the need to revise the membership list, and the following membership was approved:

- Vice-Minister, Ministry of Natural Resource Development and Environmental Protection, chairman
- ILCA Director General, member
- IAR General Manager, member
- RPO, Addis Ababa University, member
- President, Alemaya University of Agriculture, member
- Director General, ICRISAT, member
- Representative, Swiss Development Cooperation, member
- Chairman of the Technical Committee, Secretary.

It was also emphasised that other institutions such as the Relief and Rehabilitation Commission (RRC) and IBSRAM should periodically be informed about Project developments.

The Technical Committee (TC)

The AC, as its first task, appointed the Technical Committee (TC) to the Project with the following institutional composition: AUA, IAR, MOA, ICRISAT, ILCA. The Technical Committee had its first meeting on May 12,1986. It appointed Dr. Mesfin Abebe as chairman and Dr. Samuel Jutzi as secretary and agreed on its functions as follows:

(a) to preview and review research protocols of the Project

(b) to implement the Project activity jointly, thereby assuring inter-institutional flow of information and avoid duplication of efforts

(c) to assign responsibilities for specific protocols to participating agencies (supported by Project funds where feasible)

(d) to prepare complementary bases for Project activities and to generate proposals for their funding and implementation

(e) to propose mechanisms for strengthening relevant activities in national institutions

At the time of going to press, the TC had met about 30 times. The TC's division of responsibilities among the various institutions are listed in Table 1.

Table 1. Division of responsibilities between participating institutions.

Institution	**Research area**
IAR	- Soil fertility N and related micro-nutrients including BNF
	- Crop physiology/cropping systems for all crops with special emphasis on those crops on which IAR is running improvement programmes
	- Standardisation of animal-drawn implement testing
AUA	- Soil fertility P and related micro-nutrients including mycorrhiza
	- Crop physiology/cropping systems for all cop with special emphasis on those crops on which AUA is running improvement programmes (crop types different from IAR)
LUPRD	- Vertisol characterisation
ICRISAT	- Resource assessment and utilisation (agro climatology)
	- Land and water management (watershed-based land-use planning)
ILCA	- Traction animal (physiology, feeding uses)
	- Implements for soil, water and crop management and water harvesting
	- Crop-livestock interactions, crop residue utilisation
	- On-farm technology evaluation.
AUA	Alemaya University of Agriculture
IAR	Institute of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILCA	International Livestock Centre for Africa
LUPRD	Land Use Planning and Regulatory Department, Ministry of Agriculture.

In April 1987, the terms of reference of the TC were revised by the TC itself at its 4th meeting in order to address more responsibilities. This was approved by the AC in September 1987.

Terms of reference for the Technical Committee (revised)

The revised terms of reference of the Technical Committee were as follows:

1. To implement the Project as a joint activity thereby assuring inter-institutional flow of information to avoid duplication of effort

2. To propose mechanisms for strengthening relevant activities in national institutions by suggesting activities where these are inadequate or not well covered; further, to make efforts to acquire funds for the same where necessary

3. To advise on the nature, location and extent of outreach activities in the context of the Project

4. To organise information exchange and briefing sessions of staff of participating agencies to increase general awareness and commitment

5. To keep a comprehensive inventory of research protocols and development-oriented activities of participating agencies

6. To meet for follow-up and assessment at least three times per year (before season, mid-season, post-harvest)

7. To report annually to the Advisory Committee on Project progress and any other functions assigned by the Advisory Committee

8. To perform any other functions assigned by the Advisory Committee.

In 1987, the TC produced the synopsis of institutional involvement (both current and intended) in the Ethiopian project, with the understanding that no single institution can claim to have the disciplinary specialists, infrastructure and resources that are required to address the necessary study on Vertisols.

The rationale for an inter-institutional approach to research on and development of Vertisols was based on the fact that:

- Some elements of improved Vertisol technology can be rapidly brought into the extension phase. This is the primary responsibility of the Agricultural Extension Services in the Ministry of Agriculture (MOA)

- Multi-disciplinary inputs in technology research and development are required in any resource management change. Institutions with complementary mandates, therefore, preferably collaborate in these efforts

- The coordination of efforts between institutions allows:

    a) assembling of critical mass, and

    b) judicious use of scarce available funds (especially for research)

- The innovative potential of IARCs (International Agricultural Research Centres) can best be deployed if their activities are formally inserted in a national system of research and extension

- To avoid duplication of efforts

- To benefit from exchange of information, experiences and expertise input

- To achieve quick technological break-throughs.

As a follow-up of the recommendation made by the External Review Panel of the Joint Project, and the decision reached by the TC, it was necessary to limit the TC membership to active participants from the collaborating institutions. A new TC composition was suggested and later endorsed by the AC at its sixth meeting on 27/01/91 The new TC membership now had the following membership:

- AUA Vertisol Project leader
- IAR Vertisol Project leader
- ILCA Vertisol Project leader
- ICRISAT Representative
- MOA Vertisol Project leader.

Among the other recommendations made by the TC, AC, the Review Panel and the donors were that the TC operation should be raised to a level of opening a coordination office and a secretariat so that a more efficient coordination role may take place. Although a one-year budget (1992) was approved for the coordination office by SDC, it was not possible to employ a coordinator due to uncertainties of funding beyond 1992.

The Project phases and funding

The Joint Vertisol Project has passed through three project phases. The first phase was between 1986-1988 while the second phase was between 1989-1991. The last phase is 1992 which is considered as an intermediate phase, in order to continue and complete the on-going activities. During the first phase, local institutions participated in the Project although without direct funding. However, ILCA responded to some of the necessities (such as vehicle, research supplies, labour expenses etc) expressed by the NARSs (mainly IAR, AUA and MOA).

Beginning in 1989, IAR and AUA received funding assistance from SDC (based on the funding application prepared by the Technical Committee and endorsed both by IAR and AUA management). Tables 2 and 3 indicate the level of funding received by ILCA, IAR and AUA during the project phases.

Assistance by ICRISAT and IBSRAM

ICRISAT has been assisting the Joint Vertisol Project by providing expert advice in agro-climatology, soil physics, soil fertility and land/water management. ICRISAT scientists also attended regular TC meetings and together with this could interact with JVP scientists. Prior to receipt of funding by IAR and AUA, ICRISAT financed the training of some technicians at Hyderabad, India. In addition, visits by senior scientists and short-term training opportunities were arranged jointly by ICRISAT and the JVP.

Beginning in September 1990, ICRISAT seconded Mr K L Srivastava land/water engineer, to the JVP on a longer term basis (two years). He has been working closely with ILCA, AUA and IAR scientists.

IBSRAM assisted the JVP through its network: Management of Vertisols under Semi-Arid Conditions (MOVUSAC) and sponsoring participants (upto 1991) from IAR and AUA for attendance in regional Vertisol management conferences. The former coordinator of MOVUSAC, Prof. P M Ahn, visited JVP project sites and interacted with JVP scientists.

Table 2. ILCA's Vertisol management project source of funding from 1986 to 1992 (US Dollars).

Period	Donors	Amount	Total
1986	OXFAM	76000	
	CARITAS	62766	
	Norway	150000	
	Switzerland	600420	
			889186
1987	OXFAM	113280	
	CARITAS	95080	
	Norway	300000	
	Finland	148000	
	Switzerland	671141	
			1327501
1988	OXFAM	117194	
	CARITAS	198542	

	Norway	299991	
	Finland	135000	
	Switzerland	653595	
			1404322
1989	Norway	200000	
	Finland	140000	
	Switzerland	407102	
			747102
1990	Norway	150000	
	Finland	41101	
	Switzerland	498043	
			689144
1991	Switzerland	329442	
	Norway	100000	
			429442
1992	Switzerland	237000	
	OXFAM	60770	
			297770

Table 3. SDC grant for IAR and AUA (US$).

	IAR	AUA
1989	101875	70733
1990	124635	86536
1991	115271	80034
1992	115000*	63000

* Of this amount, $61 000 was allotted for the coordination office.

AUA = Alemaya University of Agriculture.
IAR = Institute of Agricultural Research.

2 Distribution and importance of Ethiopian Vertisols and location of study sites

KL Srivastava, Mesfin Abebe, Abiye Astatke, Mitiku Haile and Hailu Regassa

Introduction

Vertisols are characterised by their extensive cracking from the surface to depths of 50 cm or more with seasonal drying and also gilgai microrelief or subsoils showing slicker-sides or spheroid structures as evidence of seasonal expansion and contraction (Probert et al, 1987). These soils generally have a weak horizon differentiation.

These soils are distributed around the 45°N latitudes, mainly in the tropical and subtropical areas of the world. Driessen and Dudal (1989) report an estimated 311 million ha of Vertisols or 2.4 per cent of the global land area. Vertisols occupy about 105 million ha in Africa (Blokhuis, 1982) and about 12.6 million ha in Ethiopia.

Ethiopia can broadly be divided into highlands (areas above 1500 m altitude) and lowlands (area below 1500 m altitude). The highlands cover 40% of the land mass but account for about 95% of all cultivated land, accommodating 88% of the total human population and 70% of the total livestock population. Also 90% of the economic activity is concentrated in these areas (Constable, 1984).

This chapter describes the distribution, use and importance of Vertisols in the country and indicates the location of study sites of the Joint Vertisol Project (JVP).

Land and soil features

Parent materials and landscape features

In the central highlands of Ethiopia, the main soil parent material is olivine basalt of tertiary age. Materials of more recent age like tuffs, cinders and finer ash, mainly of basic nature are also common parent materials (Ahmad, 1983; Mitiku Haile, 1987).

The largest extents of Vertisols are found on the volcanic plateaux. Colluvial slopes and sidelopes of volcanoes are found in the central highlands, on the colluvial slopes and alluvial plains along the Sudan border and on the vast limestone plateaux of central Hararge. They are also found in sites such as granitic colluvium in basins with seasonal drainage deficiencies in southern Sidamo. Sandstone colluvium are found in valleys in Tigray and the flood plains of the Wabe Shebele and Fafen rivers in the Ogaden (FAO, 1985).

The general slope range of the landscape on which Vertisols occur is 0-8% (Berhanu Debele, 1985). They are more frequent in 0-2% slope range and are usually found in the landscapes of restricted drainage such as seasonally inundated depressional basins, deltas, alluvia/colluvial plains, pyroclastic plains, undulated plateaux, valleys and undulating sideslopes (Berhanu Debele, 1985). Vertisols are usually associated with Nitosols, Cambisols, Lithosols, Andosols and Luvisols (Mitiku

Haile, 1987). The association of Vertisols with other soils and their catenary positions are described by Fisseha Itanna (1992). Classification of some typical pedons is given in Table 1.

Soil characterisation

Soil characterisation helps in interpreting experimental results and serve as a guide to scientific soil management. Soil colour, depth-to-root-restricting layer, texture etc can be used to characterise soils.

Colour

Soil colour has been an important criterion for recognising and differentiating Vertisols by farmers and also by scientists (Kamara and Haque, 1988a; Mitiku Haile, 1991). Vertisol with a moist chrome of 1.5 or less within the upper 30 cm is grouped as pellic Vertisol; it is called a chromic Vertisol when the moist chrome is greater than 1.5. Fig. 1 shows major areas of pellic and chromic Vertisols in Ethiopia. The main study sites of JVP have also been characterised on the basis of soil colour (Table 2). Marked changes in colour as a function of topographic position, drainage and free iron content are also commonly observed (Table 3).

Texture

Vertisol profiles at several sites have been characterised by Kamara and Haque (1988a) and Mitiku Haile (1987). Table 2 includes information on clay content at nine sites.

Table 1. Classification of the pedons studied according to Soil Taxonomy and FAO/UNESCO systems.

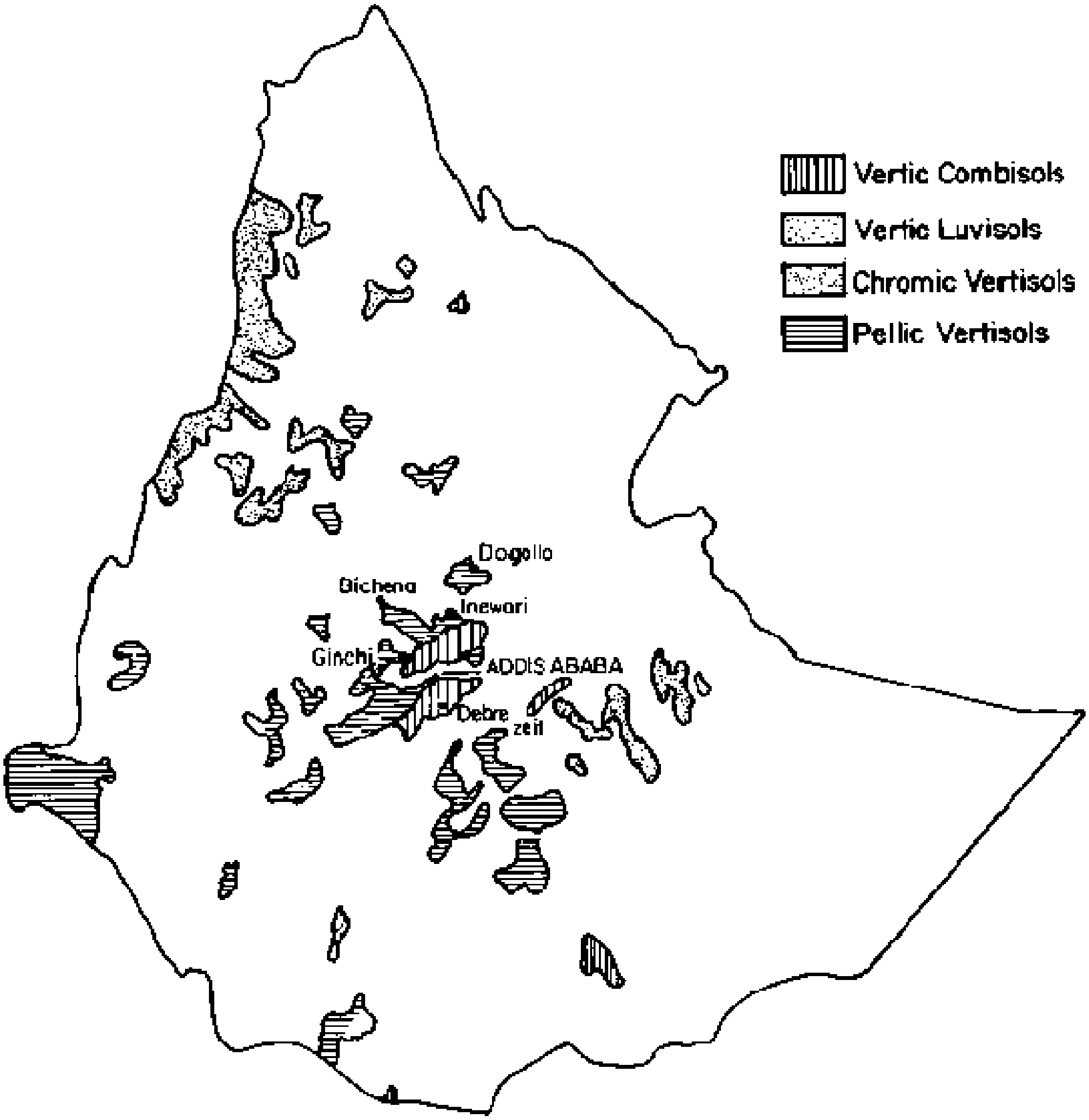
Pedon	Order	Suborder	Great group	Subgroup	Family	FAO/UNESCO
P49	Alfisol	Ustalf	Haplustalf	Udic Ultic Haplustalf	Udic Ultic Haplustalf, Clayey-skeletal, mixed isothermic	Orthi-Umbric Nitosol
Holetta	Alfisol	Ustalf	Haplustalf	Ultic Haplustalf	Ultic Haplustalf fine mixed isothermic	Haplic Nitosol
Woserbi	Alfisol	Ustalf	Rhodustalf	Udic Rhodustalf	Udic Rhodustalf, very fine mixed isothermic	Dystri-Rhodic Nitosol
P47	Entisol	Orthent	Ustortbent	Lithic Ustortbent	Lithic Ustortbent, loam mixed isothermic	Entric Regosol
P34	Mollisol	Ustoll	Haplustoll	Lithic haplustoll	Lithic Haplustoll, loamy mixed isothermic	Haplic Phaeozem
P38	Vertisol	Ustert	Chromostert	Typic Chromostert	Typic Chromostert, fine montmorillonitic isothermic	Chromi-Entric Vertisol
P102	Ustoll	Ustoll	Argiustoll	Vertic Argiustoll	Vertic Argiustoll, very fine clay mixed isothermic	Verti-Luvic Phaeozem
Sokoru	Ustoll	Ustoll	Haplustoll	Pachic Haplustoll	Pachic Haplustoll fine mixed isothermic	Haplic Phaeozem
P4	Ustert	Ustert	Chromostert	Paleustollic Chromustert	Paleustollic Chromustert fine mixed isothermic (calcaereous) isothermic	Chromi-Dystric Vertisol
P100	Ustert	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
P135	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
P148	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
P248	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
Tulu Guracha	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
P45	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol

P336	Vertisol	Ustert	Pellustert	Typic Pellustert	Typic Pellustert, very fine montorillontic (calcareous) isothermic	Pelli-Eutric Vertisol
P44	Mollisol	Ustoll	Haplustoll	Cumulic Udorthentic Haplustoll	Cumulic Udorthentic Haplustoll, fine mixed (calcareous) isothermic	Orthi-Calcaric Phaeozem
Tulu Dimtu	Inceptisol	Ochrept	Ustochrept	Vertic Ustochrept	Vertic Ustochrept, fine mixed isothermic	Orthi-Vertic Cambisol

Depth-to-root-restricting layer

Layers of bed rock, coarse sand and gravel occurring at shallow depths restrict root growth because they hold little water and few plant nutrients or offer mechanical impedance. For example, the subsoils of Were Ilu and Deneba included layers of rock, coarse sand and boulders at less than 1 m depth (Kamara and Haque, 1988a). Table 4 shows the available water capacity and soil physical characteristics of selected pedons in the central highlands.

Figure 1. Provisional soil association map of Ethiopia. Vertisols distribution and on-farm verification sites.



Source: Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia, 1984.

Table 2. Agroclimatic and general information for the main study sites of the Joint Vertisol

Project.

Site	Altitude (m asl)	Annual rainfal (mm)	Vertisol great group (based on colour)	Soil depth (cm)	Clay (%) (surface layer)	Agro-ecological zone	Physiographic region	Zone
Debre Zeit	1850	870	Chromic	>100	50	M_2	Central highlands	Central
Akaki	2250	1000	Pellic	>100	63	SH_2	Central highlands	Central
Inewari	2600	844	Pellic	60-150	60	SH_2	Central highlands	Central
Bichena	2500	1100	Pellic	>100	64	SH_2	Central highlands	North eastern
Ginchi	2200	1108	Pellic	>100	67	SH_2	Central highlands	Central
Alemaya	1980	880	Chromic	>100	65	SH_2	Hararghe highlands	Eastern
Wachu	1970	1100	Chromic	>150	70	SH_2	Chercher highlands	Eastern
Dogollo	2600	946	Pellic	60-150	60	SH_2	Central highlands	Central
Sheno	2800	900	Pellic	>100	52	SH_2	Central highlands	Central

M2 = tepid to cool, moist, mid- to high altitude.
SH_2 = tepid to cool, subhumid, mid- to high altitude.

Source: Kamara and Haque (1988a); Mitiku Haile (1987).

Table 3. Relationship between free iron, drainage class and colour of Vertisol pedons.

Pedon	Colour (Ap)	Drainage class	Free iron %
P 14	10 YR 3/2	Imperfect	5.67
P 148	10 YR 3/1	Imperfect	3.50
P 38	10 YR 3/2	Well drained	3.35
P 135	10 YR 3/1	Imperfect	2.58
P 45	10 YR 3/1	Imperfect	2.16
P 284	10 YR 3/1	Moderately well drained	2.08
P 336	10 YR 3/1	Imperfect	1.97
Tulu Guracha	5 YR 2/1	Moderately well drained	1.50
Andode	10 YR 2/1	Imperfect	1.39

Source: Mitiku Haile (1987).

Distribution

Physiographic regions

Ethiopia comprises of 12 physiographic regions (FAO, 1988), namely:

1. Chercher highlands
2. Northern rift and coastal zones
3. North-eastern escarpment
4. Abbay gorge
5. Central highlands
6. Western lowlands

7. Northern highlands
8. Ogaden lowlands
9. Central rift
10. Southern lowlands
11. Mountains and plains around Lake Tana
12. Western highlands.

The Vertisols are highly important in the central highlands and western lowlands. Significant areas of Vertisols are found in other regions also. It is estimated that 7.6 million ha of Vertisol area are located in the highlands above 1500 m asl and of this about two minion ha are currently cropped (Jutzi and Mesfin Abebe, 1986). The remaining area (over five million ha) is located at elevations below 1500 m.

Table 4. Physical properties of three pedons.

Pedon	Depth (cm)	OM (%)	Clay (%)	Bulk density g/cc	Structure	FC	WP % wt	AWC
P 4	0-20	3.8	33.10	1.36	Fine Crumb	50.16	32.20	17.96
P 135	0-50	1.7	68.20	1.74	Prismatic	50.15	34.90	15.25
Tulu Guracha	0-50	1.0	76.10	1.70	Strong Prismatic	53.90	40.20	13.70

OM = organic matter;
FC = field capacity;
WP = wilting point;
WC = available water capacity.
Source: Mitiku Haile (1987).

Agro-ecological zones

Moisture regimes of Vertisols may be characterised by the length of growing period, as defined by FAO Agro-ecological Zones Project (FAO, 1978). Based on this and other data, the Land Use Planning Regulatory Department of the Ethiopian Ministry of Agriculture has divided the country into 16 major agro-ecological zones as shown in Table 5. This zonation is designed to assist in the process of planning development strategies and research programmes for optimum utilisation of land resources for agriculture. The SH_2 zone includes vast areas of Vertisols characterised by over 180 days of growing period. The agroclimatology of several Vertisol locations was described by Belay Simane (ICRISAT, Patancheru, India, unpublished data). As an example of climatic elements, Fig. 2 shows the monthly distribution of rainfall and temperature at Ginchi station (Wagnew Ayalneh, ILCA, Addis Ababa, unpublished data).

Geographic distribution

The geographic distribution of Vertisols and associated soils is shown in Fig. 1 and Table 6. Most of the Vertisol areas are located in the central, north-western and southwestern zones.

Land use

Land use of Ethiopian Vertisols varies widely depending on climate, soil properties, population density and other socioeconomic factors.

It is rare to find extended tree vegetation on Vertisols. The predominant natural vegetation is grassland. In some areas, trees are found scattered on better drained sites. *Faidherbia albida* trees are sometimes grown by farmers in their cropped fields for obtaining fodder and fuel and to improve soil fertility (Kamara and Haque, 1992). The common grass species on Vertisols are *Andropogon*, *Sporobolus*, *Festuca*, *Eleusine*, *Hyparrhenia*, *Agrostic* and *Cynodon* (Jutzi and Mesfin Abebe, 1986).

Most of the Vertisols in Ethiopia suffer from excess water and poor workability and are also underutilised. Berhanu Debele (1985) reports that where Vertisols are cultivated, the common crops grown under rainfed conditions are teff, durum wheat, chick pea, lentils, *Vicia latyroides*, linseed etc but the crop yields are quite low (Table 7). Animal traction is commonly used in this region.

In the highlands, about 70% of the Vertisol area is uncropped and most of it is used as grazing land. In the rift valley (lowlands), about 0.1 million hectares are irrigated. Most of the lowland Vertisol area supports native vegetation of grasses, shrubs and sometimes trees. Some Vertisol areas in the western lowlands have been reclaimed for arable cropping in recent years. A major constraint to the spread of animal-powered agriculture in this area is the prevalence of trypanosomiasis. Other constraints like nutrient deficiencies, drought and frost are also important in several areas.

Study sites

The Joint Vertisol Project (JVP) decided to focus its research and technology-transfer activities in the highland areas. The highland areas are characterised by use of animal-drawn plough for crop production. JVP placed particular emphasis on the central zone which includes vast areas of Vertisols. In addition, some sites were located in the eastern and north-western zones also. Table 2 gives the agro-climatic and general information for nine study sites. These sites represent much of the highland Vertisol properties, climatic features, cropping practices and general farming systems.

Importance

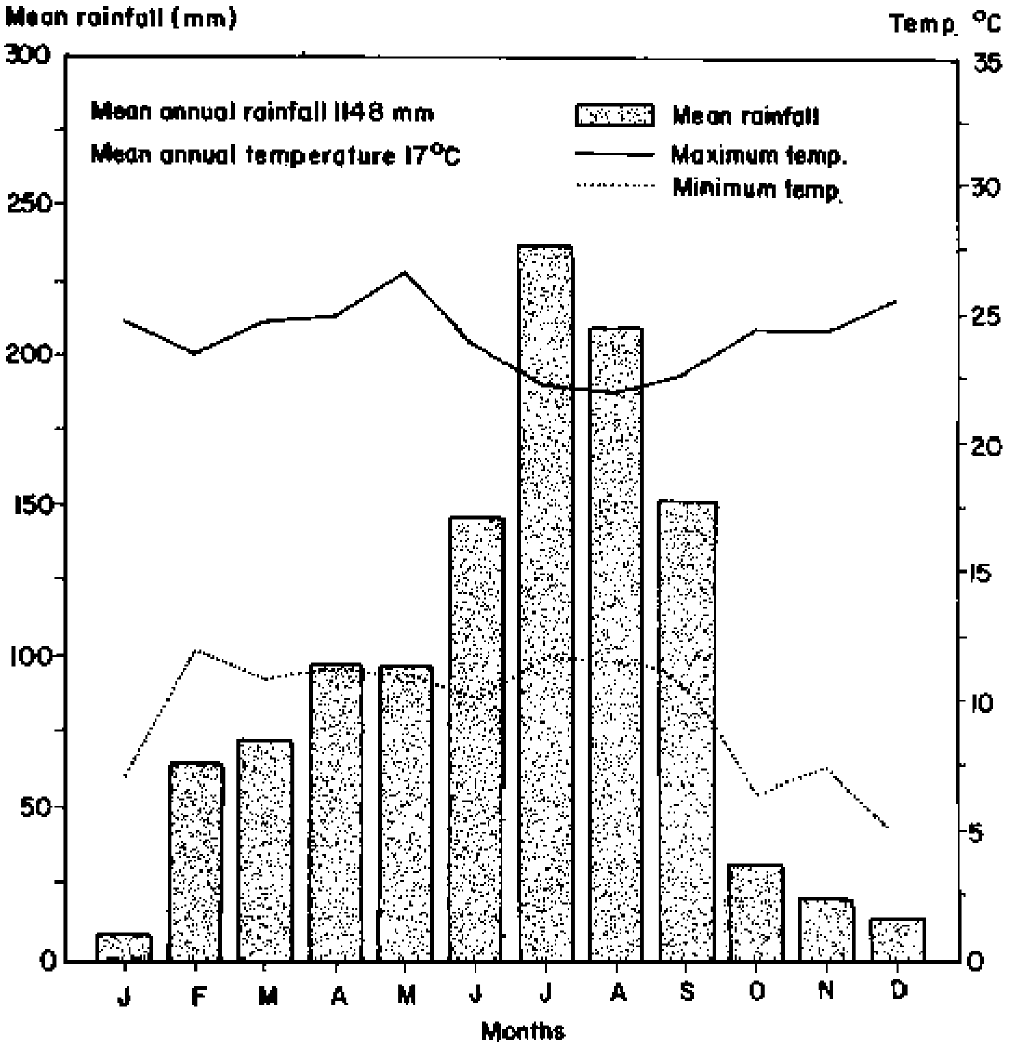
Vertisols have crucial importance for improving and sustaining food production in Ethiopia. Bull (1988) estimates that about 11.9 million ha (over 90% of total) of Vertisol area in Ethiopia are potentially arable (Table 8). Out of this, about eight million ha can provide above 150 days of growing period. Most of the Vertisol areas in the highlands of Ethiopia are traditionally planted late in the rainy season allowing only partial use of the potential growing period. Bull (1988) estimates that Ethiopian Vertisols can produce about 12 million tonnes of food grain if improved management practice could be widely adopted. This could be accomplished partly by expansion of the cropped area and partly by increasing yields per unit area At present, total grain production from Ethiopian Vertisols is probably less than two million tonnes and there is an urgent need for mounting research and development activities.

Table 5. Agro-ecological zones of Ethiopia.

Symbol	Major agro-ecological zone	LGP (days)	LGP (Types)	Temp. (°C)	Altitude (m as)
A1	Hot to warm arid/lowland	<45	Single & double	>27.5-21	<500-1600
A2	Tepid arid/mid altitude	<45	Single & double	21-46	1600-2400
SA1	Hot to warm semi-arid/low land	46-60	Single & double	>27.5-21	1300-1600
SA2	Tepid, semi-arid mid-altitude	46-60	Single & double	21-16	<500-600
SM1	Hot to warm, submoist low-land	61-120	Single & double	>27.5-21	1600-3200
SM2	Tepid to cold submoist	61-120	Single	21-11	3200-3800
SM3	Cold to very cold, sub-moist, subafroalpine to afroalpine	61-120	Single	11-7.5	500-1600
M1	Hot to warm moist lowland	121-180	Single & double	>27.5 -21	1600-3200
M2	Tepid to cool, moist mid to high altitude	121-180	Single & double	21-11	3200-3800
M3	Cold to very cold, moist	121-180	Single & double	11-<7.5	200-2400
SH1	Hot to warm, humid, lowland to mid-altitude	181-240	Single & double	>27.5-21	1600-3200
SH2	Tepid to cool, subhumid, mid- to high altitude	181-240	Single & double	21-11	1600-3200
SH3	Cold to very cold, subhumid subafroalpine to afroalpine	181-240	Single & double	11-<7.5	3200-3800
H1	Hot to warm, humid, lowland to mid-altitude	241-300	Single & double	>27.5-21	1000-2200
H2	Tepid to cool, humid, mid- to high altitude	241-300	Single & double	21-11	1600-3200
H3	Cold to very cold, humid, subafroalpine to afroalpine	241-300	Single & double	11-<7.5	3200->3800

LGP = Length of growing period.
Source: Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa.

Figure 2. Mean monthly rainfall and temperature at Ginchi (1982-90).



Source: Wagnew Ayalneh, ILCA, Addis Ababa (unpublished data).

Table 6. Distribution of Vertisols and their associations in Ethiopia (hectares).

No	Zone	Pellic Vertisols	Chromic Vertisols	Vertic Cambisols	Other Vertic Soils	Total
1	Northern	na	512100	226100	450200	1188400
2	North-eastern	174100	na	na	na	174100
3	Eastern	na	176000	831100	83600	2675500
4	Central	1607200	na	585400	576700	2769300
5	Southern	1378300	525200	237200	21000	2161700
6	North-western	433100	1579000	na	na	2012100
7	Western	1761600	25000	na	na	1786500
Total		5345300	4379600	1879800	1131500	12767600

na = nil or negligible area.
Source: Adapted from Berhanu Debele (1985).

Table 7. Grain yields of food crops on Vertisols under traditional management in the central Ethiopian highlands.

Crop	Grain yields (kg/ha)
Teff	530
Barley	860

Emmer wheat	680
Durum wheat	610
Horsebean	750
Linseed	300
Lentils	500
Chickpea	600
Field pea	730
Noug (*Guizotia abyssinica*)	290
Vetch (*Vicia latyroides*)	690

Source: Berhanu Debele (1985).

Table 8. Potential arable areas (in thousand ha) of Vertisols in the different thermal and growing period zones.

Thermal zone	Length of growing period (LGP)					Total
	L1	L2	L3	L4	L5	
T1	230	170	630	690	40	1760
T2	704	1888	613	107	119	3431
T3	182	511	1279	1588	461	4021
T4	na	77	602	1310	634	2623
T5	na	36	15	47	3	101
Total	116	2682	3139	3742	1257	11936

L_1 = < 90 days
L_2 = 91-150 days
L_3 = 151-210 days
L_4 = 211-270 days
L_5 = > 270 days
na = not available.
T_1 = < 500 m altitude
T_2 = 500-1300 m "
T_3 = 1300-2000 m "
T_4 = 2000-3000 m "
T_5 = > 3000 m "

Source: Bull (1988).

3 A survey of the farming systems of Vertisol areas of the Ethiopian highlands

Getachew Asamenew, Hailu Beyene, Workeneh Negatu and Gezahegn Ayele

Farming systems of Vertisol areas in Ethiopia - Background

With 12.61 minion ha of Vertisols (Berhanu Debele, 1985) Ethiopia ranks third in Vertisols abundance in Africa after Sudan and Chad. Of these about eight million ha are in the Ethiopian highlands and these account for 63% of all Vertisols in the country (see map in Chapter 2).

In some parts of the country, Vertisols cover large areas of several km^2 while in others they are included within other soil types. These soils are common on terrains with poor drainage such as seasonally flooded depressions, basins, deltas, alluvial plains, valleys and undulating plateaux and side slopes (Berhanu Debele, 1985).

Only about two million ha (25%) of the Vertisols in the Ethiopian highlands are presently cultivated. This area accounts for about 23% of the total Ethiopian arable land. As the rest of the Vertisols are mostly in bottom lands, they get flooded and waterlogged during the wet season and, therefore, remain uncultivated and used mainly for dry-season grazing. Grasses are the predominant natural vegetation. Trees are rare in Vertisol areas and are scattered except along river banks. Among the most prevalent grasses on Vertisols are *Agrostis*, *Cyprus*, *Sporobolus*, *Cynodon*, *Eleusine*, *Hyparrhenia* and *Digitaria* spp (Berhanu Debele, 1985).

Vertisols are fertile and in areas where they are abundant in the highlands human and livestock settlements are dense, and farm sizes are small. In the highlands, the crops grown on Vertisols include teff (*Eragrostis tef*), wheat (*Triticum* spp.), barley (*Hordeum vulgare*) faba bean (*Vicia faba*), field pea (*Pisum sativum*), grass pea/rough pea (*Lathyrus sativus*), chickpea (*Cicer arietinum*), lentils (*Lens culinaris*), linseed (*Linum usitatissimum*), noug (*Guizotia abysssinica*) and fenugreek (*Trigonella foenum-graecum*).

To understand the Vertisols farming systems of the Ethiopian highlands, informal and formal surveys were carried out at four representative Vertisol regions: Dogollo/Were Ilu (southern Wello), Ginchi (western Shewa), Inewari (northern Shewa) and Ada/Debre Zeit.

Farm surveys in some Vertisol locations in highland Ethiopia

In 1986, ILCA carried out informal surveys at Dogollo and Inewari in order to understand the farming systems. Such surveys were also conducted by the Institute of Agricultural Research (IAR) at Ginchi in 1986 and by the Alemaya University of Agriculture at Ada/Debre Zeit in 1988/89. This was followed by one-time detailed formal farm surveys at Dogollo, Inewari and Ginchi in 1988/89. The rest of this chapter mostly presents results of these formal surveys.

Objectives of the surveys

The objectives of the farm surveys were as follows:

- To understand the existing farming systems in order to develop appropriate Vertisol technologies
- To identify production constraints and opportunities for technological interventions
- To identify recommendation domain, and
- To compile baseline data in order to assist in ex-post Vertisol-technology evaluation.

The survey method

In the formal survey, sample farmers were selected randomly from representative Peasant Associations (PAs) in each study location. At Dogollo, 142 farmers were sampled from a total of 1537 farm households in three PAs: PA015, PA023, PA024 each with farm family size of 714, 402 and 421, respectively. A sample of 165 farmers were selected at Inewari from a total of 1529 families in four PAs: Wele Deneba, Tatessa, Ejersa Kubete and Bolo. The household size of each PA was 211, 356,345 and 617, respectively. The sample farmers at Ginchi were 102 from a total of 781 families in four PAs: Berdo Legebatu, Taro Legebatu, Taro Jemejem and Okote Awash. At Debre Zeit, 65 sample farmers were surveyed. The summary of the sample size is given in Table 1.

Table 1. Sample farmers surveyed at Dogollo, Ginchi and Inwari.

Locations	Sample size
Dogollo	142 farmers
Ginchi	102
Inewari	165
Debre Zeit	65

Natural resources

The study areas located in the high potential cereal livestock (HPCL) zone represent the farming systems of Vertisols areas in the Ethiopian highlands (see map in Chapter 2). Debre Zeit and Ginchi are located at 1900 m and 2200 m asl, respectively, while both Dogollo and Inewari are at an altitude of 2600 m asl. Each of these locations represents different traditional Vertisol management practices.

Soils

Vertisols, heavily textured soils dominate the survey area. Because of the high content of shrink-swell clay in these soils, cultivation is difficult when they are dry and waterlogging is a problem when they are wet. On average the clay content of Vertisols amounts to 64% at Inewari, 59% at Ginchi and 62% at Dogollo (Kamara and Haque, 1988a).

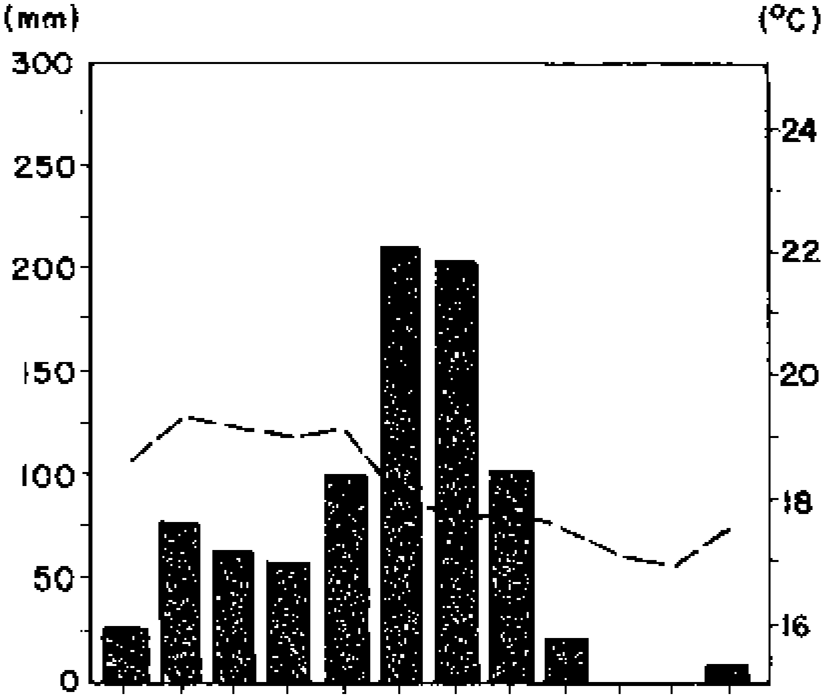
Rainfall and temperature

The rainfall in the study areas is bimodal. Up to 60 to 70% of the annual rainfall is received during the main rains (*meher*) that normally occur from June to September. The short rains (*belg*) usually start in February/March and extend into April but are inadequate for cropping in any of the study locations. In years when *belg* rains are adequate and reliable some farmers grow pulses on Vertisols. The *belg* rains are, however, useful in high altitude (2600 m asl) to grow barley on soils other than Vertisols. In Vertisol areas the belg rains are important for seedbed preparation and planting is done during the main season. The *belg* rains are also important for the regrowth of natural forages which contribute significantly to livestock production at this time of the year.

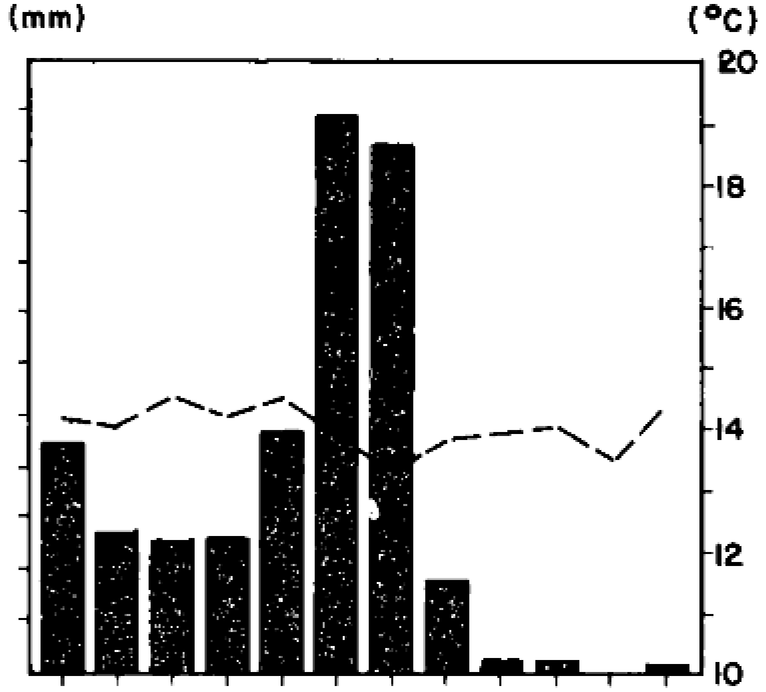
At Dogollo, Ginchi and Inewari the rainfall averages between 900-1000 mm/year. In rare cases the total amount of rainfall drastically drops below average resulting in moisture stress. But its effect is not as severe in these areas as in the lowlands or other highlands. The main rainy season normally starts in June, reaches its peak in August and gradually ceases in mid-September. Average annual rainfall and mean temperature of several years in other Vertisol locations in the Ethiopian highlands are shown in Figure 1.

Figure 1. Mean monthly rainfall and temperature at Debre Zeit, Dogollo, Ginchi and Inewari.

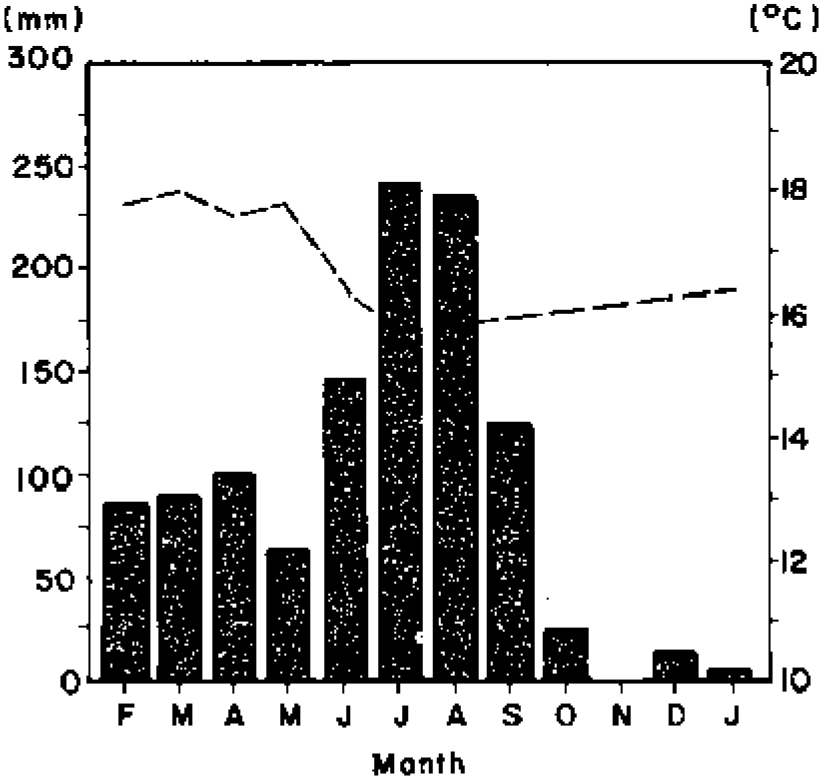
Debre Zeit: Mean rainfall & temp. 1977-91



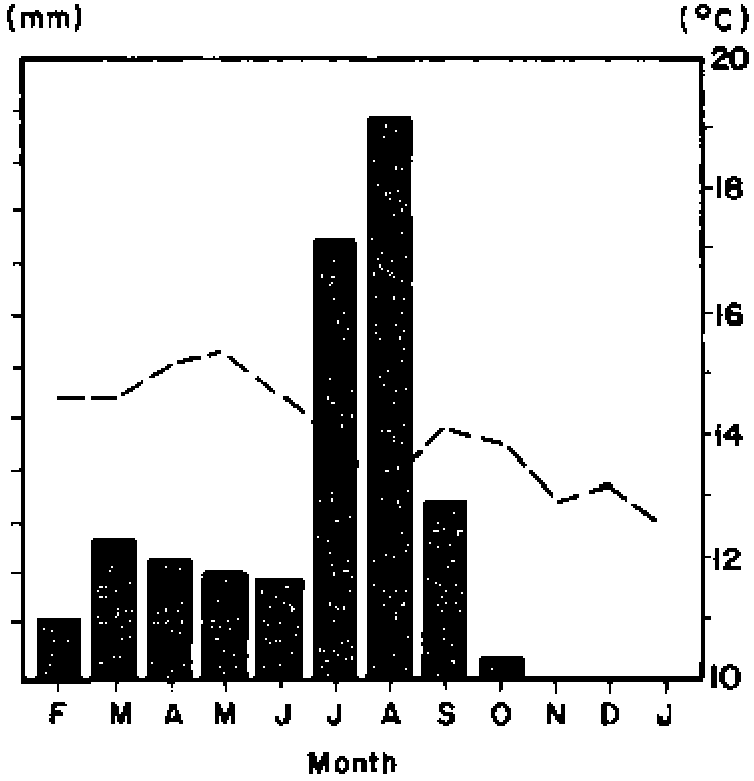
Dogollo: Mean rainfall & temp. 1986-88



Ginchi: Mean rainfall & temp. 1986-91



Inewari: Mean rainfall & temp. 1986-89



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Source: Compiled from weather stations of ILCA and MOA.

In general, daily temperature is moderate in the survey locations. On average the minimum temperature does not fall below zero, and hence frost damage to crops is uncommon as in areas above 2600 m asl. October to February are normally the coldest months.

Farm resources

Land

The survey locations being densely populated, farm sizes are on the average small with some variations within and between the survey locations. The land size allotted to individual farmers by a Peasant Association (PA) as per the Land Reform Declaration of 1975, depended on family size, fertility of the land, the number of PA members and the total land area available within the PA. Hence farm sizes varied within and between PAs and between locations. Average farm sizes at Dogollo, Ginchi and Inewari are shown in Table 2.

Table 2. Average farm sizes (ha) and land use at Dogollo, Ginchi, Inewari and Debre Zeit.

Land class	Dogollo	Ginchi	Inewari
Cultivated	1.7	2.6	1.9
Pasture land[1]	0.2	0.5	0.1
Total	1.9	3.1	2.0

[1] Does not include communal grazing areas.

In the highlands, arable Vertisols are extensively cropped. Over 90% at Dogollo and Inewari and 84% of the land at Ginchi is cultivated.

Farm sizes being generally small while family sizes are large, land is hardly left fallow. Fallow land, on the average, accounted for less than 1% of the total land holdings in all the survey locations. For example, if a farm family is unable to till all the cultivable land because of shortage of inputs particularly labour and draught animals, the land is normally leased.

Individually owned pasture lands are quite small. Farmers mostly depend on communal pasture lands to graze livestock but these lands are heavily stocked and overgrazed.

There is a high variation in the distribution of land holdings among farmers of the three sites considered as shown in Table 3. At Ginchi the distribution tends to be skewed to the right. Here, 41% of the farmers own 3.5 ha or more, and 24% own over 4 ha. About 5% of the farmers own less than 1.5 ha.

The land holdings of about 54% of the farmers fall between 1.5 ha to 3.5 ha. Contrary to that at Ginchi, farm land holdings at Dogollo, is extremely skewed to the left with 52% of the farmers owning less than 1.5 ha. The proportion of farmers owning between 1.5 ha and 2.5 ha accounts for 25%. At the time of the survey only 2% of the farmers owned over 2 ha. Allocation of land holdings at Inewari is normally distributed compared to Ginchi or Dogollo, Twenty-one per cent of the farmers own less than 1.5 ha, and 61% of the farmers own between 1.5 ha and 2.5 ha. Only 5% of the farmers owned over 3 ha.

Land holdings are highly fragmented. The average number of plots per farm at Dogollo, and Inewari is 4.4 and 6.3, respectively.

Table 3. Distribution of land holdings at Dogollo, Ginchi and Inewari, 1988/89.

	Percentage of farmers		
Farm sizes (ha)	**Dogollo**	**Ginchi**	**Inewari**
Less than 1	34.5	-	-
1 to 2	31.7	24.5	61.8
2.1 to 3	23.9	29.4	33.9
3.1 to 4	8.5	22.6	3.6
Over 4	1.4	23.5	0.6
Total	100	100	100

Source: Getachew Asamenew (1991).

Farm household and labour

In general family sizes per farm are large, and it amounts to five persons at Dogollo, and 5.6 persons at Ginchi and Inewari. The family is the major source of farm labour and most of it comes from members of 15 to 65 years of age. Children over the age of eight years also contribute labour, particularly to livestock tending. The proportion of the active adult family members contributing to the total work force per farm in the three survey locations is nearly equal (76% at Dogollo, and 74% at Ginchi and Inewari).

There is division of labour by sex and age. Women and children contribute to weeding, harvesting, threshing and transporting grain. Livestock husbandry activities (feeding, milking, herding, barn-cleaning, dung cake-making and forage collection) are shared among the household members. The responsibility of women includes milking cow (at times assisted by men), barn-cleaning and dung cake-making. Men are involved in forage collection and feeding livestock. Herding of livestock is mostly the responsibility of children. Ploughing is done by men and in general farming is their responsibility.

Some family members engage in other non-farm activities during the dry and the main rainy season. Hence, all of the family members are not available for farming.

Children between eight and 14 years old are also involved in farming during the main rainy season. They contribute to the manual construction of broadbeds furrows (at Inewari) to oxen-handling, weeding and transportation.

The available labour for farming is restricted by religious holidays and tradition. As most farmers in the Ethiopian highland Vertisol locations are followers of the Coptic Orthodox church, they observe a number of religious holidays on which they are customarily prohibited to undertake any cropping activities. Hence on average only some 15 days a month are used for such activities. This constrains labour available for cropping during the peak demand period. Fencing and livestock husbandry activities are permitted to be undertaken on religious holidays.

Additional labour is acquired through exchange labour between families (locally known as *debo*) or hired. The local wage ranges between EB 1.00 to EB 3.00 per day.

Livestock

Cattle are the most important livestock species in Ethiopian agriculture. Their principal contributions include draught power for cultivation, threshing and to provide manure.

The cattle owned are the shorthorn zebu breed and they are mainly kept to produce draught oxen. Milk production is secondary because of absence of regular market. Hence except around Addis Ababa, where milk markets are available, in all other Vertisol areas crossbred cattle are rare. Other livestock on farm are small ruminants and equine.

The number of oxen accounts for 38%, 29% and 36% of the cattle herd at Inewari, Dogollo, and Ginchi, respectively, generally the stocking rate/ha is high. Individually owned grazing lands are quite small (Table 2) and communal grazing lands are not available to all farmers, and when available it is usually overgrazed.

Sheep are economically important in the highlands. Farmers keep sheep for various reasons. They are a significant source of investment, security end cash. They are easily sold off at times of economic difficulties. In normal years too, sheep are sold and purchased according to the needs of farmers. Two or three sheep are slaughtered per household per year on average in the Vertisol areas. They also provide manure. During the dry season manure collected from the pens is mixed with cattle manure and prepared into dung cakes to be used as household fuel. During the rainy season however, the sheep manure collected is often wet and mixed with mud which makes it difficult to use as fuel. It is then used to fertilise crop land.

Breeding ewes above one year old make up the highest proportion within the flock: up to 57% at Dogollo, and 54% at Inewari.

Crop and livestock interaction

Crop and livestock subsystems are highly integrated. Crop residues provide a major share of the livestock feed while milk, meat, hides, manure and income are major livestock outputs. Livestock also serve as stored wealth in the form of physical animal number, and therefore serve as an asset and security. The major contribution of livestock to smallholder farming is provision of draught power for cropping. Figure 2 illustrates the crop/livestock interaction in the Ethiopian highlands mixed farming systems.

Oxen are used for cultivation, planting and threshing, generally oxen are preferred for cultivation, but whenever there is a shortage of draught power bulls are paired with oxen under the same yoke. In all instances cultivation is traditionally done with paired animals. The Inewari and Dogollo, areas are two of the few areas in Ethiopia where the use of horses for ploughing is very common. Horses are paired either with each other or with oxen and, in some instances, with bulls under the same yoke. Horses tend to be faster than oxen but can tee used for shorter intervals (four hours on average compared to 6-7 hours for oxen) because they get tired more quickly. However, the area covered per day is similar to that of paired oxen. Oxen can also be resold when they are unable to pull the plough or at any time in case of economic difficulties. Hence, oxen are more valued than equine.

In the Vertisol areas farmers who own less than two oxen overcome the problem of inadequate draught power by the following arrangements:

1. *Mekenajo*, a farmer with one ox pair his ox with that of a neighbour farmer's who also has only one ox

2 *Yegeleba shiyach* is an arrangement whereby a farmer without oxen borrows a pair of oxen to cultivate his land and repays with his straw harvest to the oxen owner at the end of the cropping season

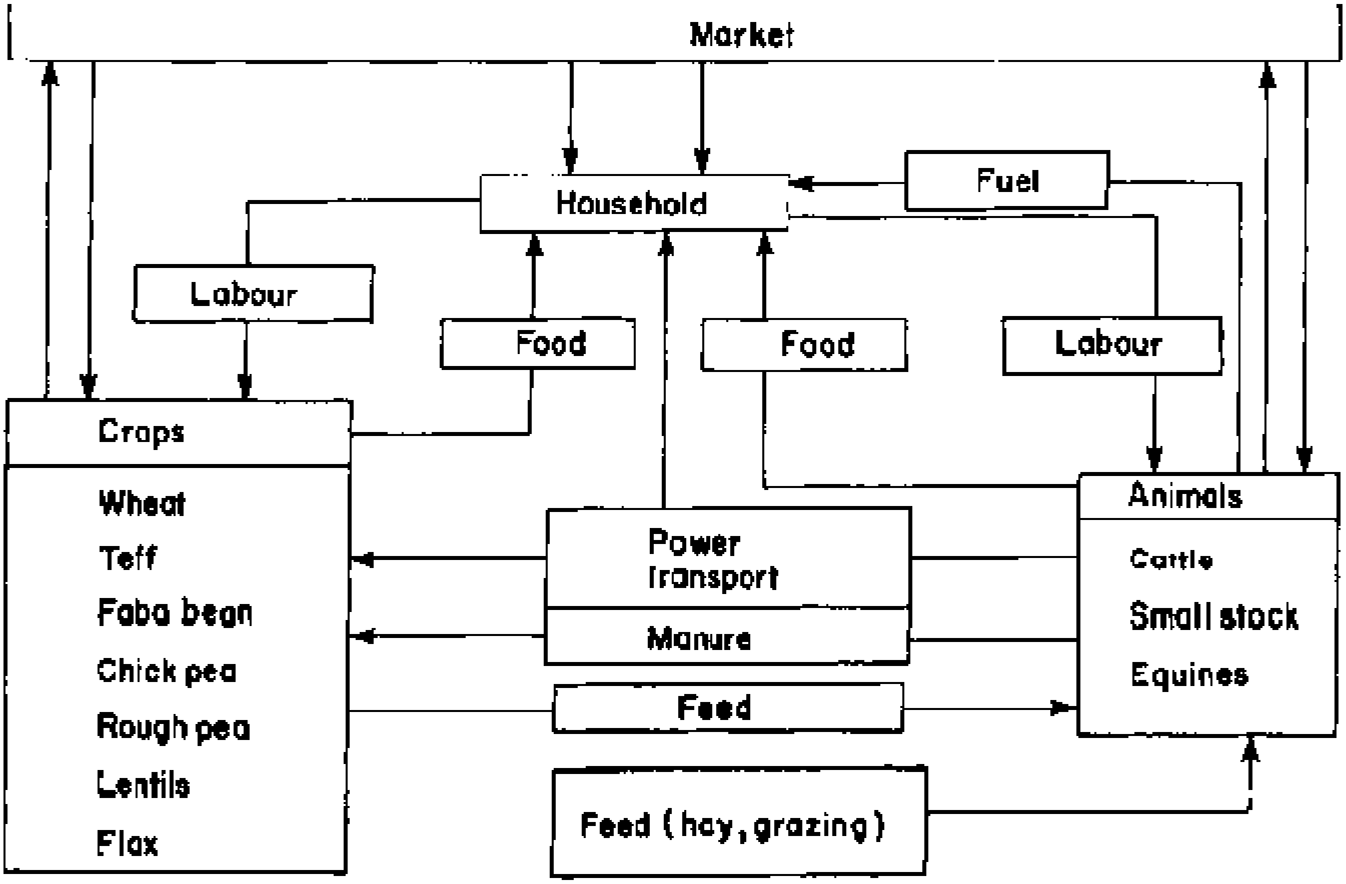
3. *Hiring oxen* for cash. The rent for a pair of oxen with a harness in Inewari and Dogollo, is EB 5.00 per day.

4. *Minda* is renting of one or two oxen in exchange for grain or human labour.

5. *Debo* is another arrangement whereby relatives and friends with oxen assist in cultivation, free of charge except for the lunch provided to them.

In the Ethiopian highlands the majority of farmers own oxen. Farmers who own at least one ox account for 60% at Dogollo, 83% at Ginchi, 76% at Inewari and 91% at Debre Zeit.

Figure 2. Crop/livestock interactions in the Ethiopian highland Vertisols.



Source: Getachew Asamenew (1991, adapted from McDowell, 1985).

Cropping details

Cereals, pulses and oil seeds are food crops grown in Vertisol areas in the Ethiopian highlands. The importance of each crop type in terms of area covered varies from location to location. Wheat is the major crop at Dogollo, and Inewari covering 50.4% and 40% of all cultivated land, respectively. Nearly all farmers grow wheat at Dogollo, (99.1%) and Inewari (98.2%). The percentage of farmers growing various crops at Dogollo, Ginchi and Inewari is shown in Table 4.

Table 4. Percentage of farmers growing various crops at Dogollo, Ginchi and Inewari.

Crops	Percentages		
	Dogollo	Ginchi	Inewari
Wheat	99.1	61.8	98.2
Teff	86.2	97.1	83.6
Faba bean	72.4	-	80.6
Rough pea	30.2	68.6	63.6
Lentils	29.3	2.9	15.8
Chickpea	2.6	64.7	68.0

Source: Getachew Asamenew (1991).

Teff (*Eragrostis tef*) is the second most important cereal crop grown by 86.2% of the farmers on about 21% of the cultivated area at Dogollo, (Table 4). Here, other cereal crops like maize, sorghum and barley (*Hordeum vulgare*) have minor importance in the cropping systems and together they account for less than 2% of the cultivated area. Faba bean (*Vicia faba*) is the main pulse crop occupying about 14% of the cultivated land. Rough pea/grass pea (*Lathyrus sativus*) and lentils (*Lens culinaris*) are other important pulse crops at Dogollo, The major oil crops grown are linseed (*Linum usitatissimum*) and noug (*Guizotia abyssinica*).

At Inewari teff (*Eragrostis tef*) is the third important crop in terms of the area it covers (15%) and grown by 83% of the farmers. Although some oats and barley are also grown, land area devoted to these crops is insignificant (Table 4). Faba bean is the major pulse crop, and it is grown by 80.6% of the farmers on 17.3% of the total cultivated area. Other important pulse crops in the area are chick pea (*Cicer arietinum*) and rough pea (*Lathyrus sativus*) (Table 5).

At Ginchi teff is the major crop, grown by 97% of the farmers on an average of 1.31 ha/farm (cv 46%) and occupying 49.2% of the total cultivated land. Wheat is the second important crop. Other cereals grown at Ginchi include maize, sorghum and barley. Chick pea (*Cicer arietinum*) and rough pea/grass pea (*Lathyrus sativus*) are grown by over 60% of the farmers and each occupies 9.6% and 10.9%, respectively. Noug (*Guizotia abyssinica*) is also grown at Ginchi (Table 5).

Cropping techniques calendars

In general cereals require finer seedbed preparation than pulses and hence more cultivations are carried out before sowing cereals. As specified earlier, seedbed preparation for planting begins normally with the belg rain in March/April. Cultivation generally continues up to May depending on the soil moisture, and resumes in mid-June when the main rain commences. Traditionally, farmers without adequate number of draught animals take advantage of the long ploughing period to share them with others.

Table 5. Crop combinations (ha) on average-sized farms at Dogollo, Ginchi and Inewari.

Crop	Dogollo	Ginchi	Inewari
Wheat	0.86	033	0.73
Teff	0.36	1.33	0.28
Dura	0.01	0.12	-
Maize	-	0.06	-
Sorghum	-	0.06	-
Oats	-	-	0.01
Barley	-	0.06	0.02
Faba bean	0.23	-	0.32
Rough pea	0.09	0.25	0.20
Lentils	0.07	0.01	0.03
Chickpea	0.01	0.28	0.21
Field pea	-	-	0.02
Noug	0.01	0.17	-
Linseed	0.03	-	0.03
Others	0.02	0.04	0.03

Note: Dashes indicate crops not grown in the area.
Source: Getachew Asamenew (1991).

Farmers have various ways of overcoming the problem of waterlogging in Vertisols. The traditional Vertisol management practice at Inewari is more efficient compared to other sites, all crops except teff are grown on manually constructed broadbeds and furrows (BBF) at Inewari. To make these BBF, the fields are cultivated several times (at least twice), using pairs of oxen or horses or pairing one with the other. Then the fields are sown with crops. Next, narrow furrow lines, approximately 80 cm apart, are demarcated with the use of well-trained oxen. Following these furrow lines, the farmer's family members scoop up the soil from either side of the line to construct the BBF by hand. The distance between the furrows at the deepest points averages 120 cm (broadbed of 80 cm and two midpoints on the furrows on either side measure 40 cm).

At Dogollo, furrows and ridges locally known as *shurube* are the conventional seedbeds in Vertisols which are constructed with the use of oxen. Furrows are shallow and the ridges are narrow (30-50 cm). Therefore, the drainage is less effective compared to BBF. At Ginchi crops grown on Vertisols are traditionally on flat fields after excess water has been drained off.

Since teff tolerates waterlogging, it is sown awing the wettest part of the rainy season, i.e. from late July to mid-August. The seedbed for teff is commonly puddled and trampled. Planting of crops that require better-drained soils at the time of planting is delayed until August/September after the fields are drained off naturally. The disadvantages of this practice are that the full length of the growing period is not utilised, and that soil degradation occurs since the cultivated fields are exposed to erosion awing the early part of the growing season. Vertisols on higher slopes drain faster and hence crops can be planted relatively earlier. Faba bean and barley are the main crops grown on higher slopes.

The general cropping calendar for the Ethiopian highland Vertisols is illustrated in Figure 3. Most farm activities often overlap. As the Vertisol fields get puddled when wet, weeding is done after the end of the main rains. This is also a busy period for planting pulses like chickpea and rough pea/grass pea. In high altitude Vertisol areas, weeding extends from mid-September to the beginning of November. In lower altitude Vertisol areas e.g Debre Zeit, planting is done early and the growing period is short. Harvesting of cereals (teff and wheat) starts in November compared to higher Vertisol areas where most crops are planted late and harvested in January and February.

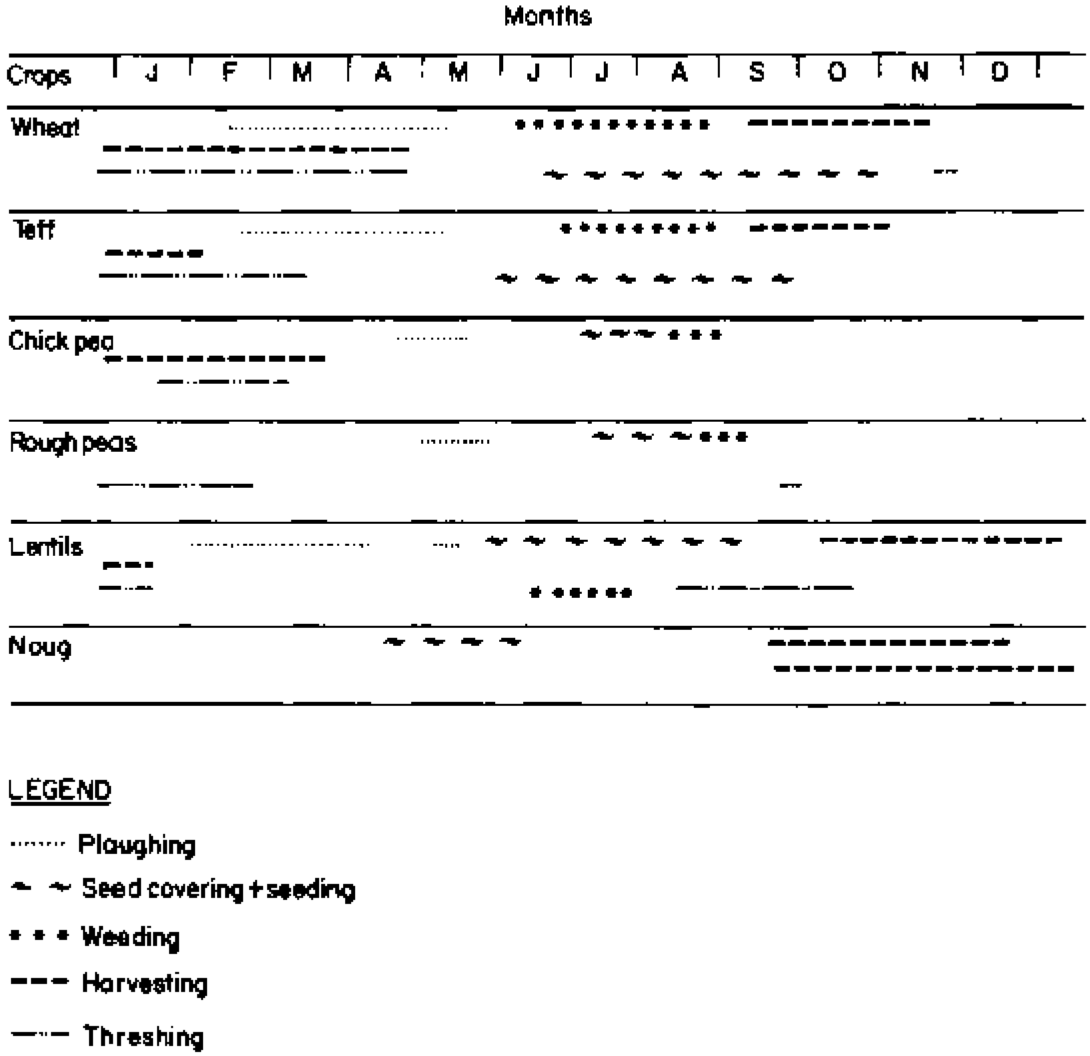
Crop inputs

Inputs to cropping in the Ethiopian highlands differ between areas. Unavailability and high costs are among the main limiting factors to the wide use of purchased inputs. Pesticides are not usually available, but required occasionally to control pests. The same constraints apply to the use of herbicides by smallholders Di-ammonium phosphate (DAP, 18% N 46% P) and urea (46% N) are the commonly used inputs. These fertilisers are sold to farmers on credit or cash by the Ministry of Agriculture (MOA) through Peasant Service Cooperatives. Farmers usually apply fertiliser on cereals: teff, wheat and barley. Its use on other crops is very rare.

At the time of the survey, 35% of the farmers at Dogollo, 76.5% at Ginchi and 673% at Inewari used fertiliser. Quantity of fertiliser used per farm was small (Table 6).

At Debre Zeit farmers' modal fertiliser application rates were: DAP 87-100 kg/ha and Urea 30-38 kg/ha (Workeneh Negatu and Gezahegn Ayele, Debre Zeit Research Center, Ethiopia, unpublished data). In general very little manure is returned to the soil. As manure is the main household fuel source little is spared for use as fertiliser. But in some instances sheep manure and ashes are used on garden plots.

Figure 3. A general cropping calendar in the Ethiopian highland Vertisols locations.



Seeds used commonly are the local variety. The seeding rate is high. In general seeds used are not clean and the rate of germination is low. Sowing is done by broadcasting.

Table 6. Per cent of farmers using fertiliser, quantity of fertiliser used, number of plots and size of area fertilised, 1988/89.

Description	Dogollo	Ginchi	Inewari
% farmers using fertiliser	35	76.5	67.3
Fertiliser/farm (kg)[1]	47	62.5	75.0
Mean no. of fertilised plots	1.6	1.2	2.0
Mean area fertilised (ha)	0.204	0.33	0.22

[1] Mean of farmers using fertiliser.
Source: Getachew Asamenew (1991).

Crop yields

Crop yields on Vertisols in the Ethiopian highlands are low. As shown in Table 7, all types of crops yielded less than one ton per hectare at Inewari. The average yields per farm in a good year are just adequate to meet the household food requirements. The variations in crop yields are quite high.

Seasonal waterlogging in Vertisols, pest damage, use of local variety seed and a low amount of fertiliser are some of the factors for low yields.

Table 7. Yields of grain from traditional cropping at Inewari, 1988/89.

Crop	Yield (kg/ha)
Wheat	797
Teff	885
Chickpea	814
Rough pea	554
Lentils	346
Fenugreek	594

Source: Getachew Asamenew (1991).

Livestock management

The traditional livestock husbandry practiced across the Ethiopian highlands is similar. Livestock are kept in a 'kraal' during the night. During the day time, they are herded on communal pasture, private grazing lands or in a stubble depending on the season. Livestock of mixed species are herded together during most of the day. The movement of livestock is closely monitored to avoid crop damage.

There is a seasonal pattern in the use of grazing lands. From February to early June most grazing is on bottom-land pastures and on crop stubble. Stubble grazing takes place mostly after the harvest, i.e the end of November in lower altitudes and December in higher altitudes generally extending up to January/March. Since the bottomlands get flooded during the rainy season, all grazing takes place higher up where the land is better drained. Animals are moved to the hill sides to graze.

Feed production and livestock feeding

Feed production

In the Ethiopian highland Vertisol areas fodder supply is erratic and seasonal. On-farm supply of fodder depends on:

- The cropping pattern
- Harvesting practices
- Weeding intensity and frequency
- Access to private pasture land
- Access to communal pasture land and productivity
- Stocking rates
- Road-side grazing, and
- In a few instances, purchases of straw and hay.

Cereal straw being the most common animal feed, the proportion of cereals in the cropping pattern determines feed availability on the farm. Generally, straw yields on the Ethiopian highland Vertisols are low. Table 8 confirms this.

The low yield, particularly at Dogollo, is due to the critical waterlogging during the growing period. At that location in a normal wet year, excess water results in extremely low growth so that the average crop residue yield amounts to only slightly higher than one ton DM/farm. Although the problem of waterlogging is better controlled by planting crops on manually made

BBF at Inewari, yields of straw are still low. The average yield per farm amounts to about two tons DM.

Table 8. Straw yields at Dogollo, and Inewari, 1988.

Crop	Dogollo kg/ha	Inewari kg/ha
Wheat	611	1042
Teff	514	972
Oats	-	907
Barley	892	854
Rough pea	639	624

Source: Getachew Asamenew (1991).

The availability of fodder from individual farms and communal lands depends on the rainfall distribution. Almost all the fodder production is rain-dependent and occurs between June and September.

Due to the variation in the climatic conditions feed supply within a given year fluctuates considerably. Three feeding periods may be identified: (1) the main rainy season or the *meher* (July-September) with abundant plant regrowth, (2) the dry period with scarce native pasture, and (3) the short rainy season, the 'belg' that normally occurs between February and April. As the start and end of the *meher* season varies from year to year, the beginning of the subsequent feeding periods also shifts. Natural grazing is the main source of livestock feed but its availability can vary particularly during the dry season. As pasture areas are extremely small, hay-making is not a common practice. Hay making begins as early as September in some cases and continues up to the beginning of November. Some farmers use communal grazing land throughout the year except when it is flooded but not all farmers have access to communal pasture lands in every Peasant Association.

In the Ethiopian highlands, natural pasture can produce 6 tons DM/ha but when continuously grazed it yields only 2.5 tons DM/ha (Jutzi et al, 1987a). As frequent grass outtake leads to a reduction in DM yield upto 50%, yield from heavily grazed pasture may not exceed 1.5 t DM/ha (Jutzi et al, 1987a).

On average, the available feed per farm in the Vertisol areas only meets the body maintenance requirements of the animals. Very little is left over for growth and production. The estimated available feed per farm per year at Inewari, Ginchi and Dogollo, is 27%, 30% and 37% less than the annual requirements, respectively.

Feeding of livestock

Teff and wheat straws are important sources of livestock feed in the highland Vertisol areas. Barley and oat straws are also important in areas where they are produced. Only cereal straw has commercial value. As pulse straw is stocky and rough, it is commonly used for household fuel and floor cleaning. When pulse straw is fed to animals, it is mixed with cereal straw. Straw supplementation is commonly restricted to work-oxen and lactating cows. However, farmers who are well-supplied with feed also supplement calves and working equine. But grass hay is commonly fed to working oxen and milking cows during the dry season. Feed supplementation is commonly done when the animals are at the homestead. Oxen engaged in work have priority for most feed supplementation. The amount of straw fed depends on the work expected from the ox. During the peak period, on average 5 to 10 kg of straw is fed to an ox each day.

Weight of straw is locally expressed in *kurbet*, which is roughly the size of a hide for packing straw when transporting on donkey. A small *kurbet* weighs about 30 kg, while medium and large sizes weigh 40-50 kg. In a normal year, the price of one kg of cereal straw, on average, amounts to EB 0.10 in Vertisol areas like Debre Zeit and Inewari. Grass hay which is used for making hay is cut between September and October. Hay becomes available in the market from December upto August. As straw is available after the crop harvest, i.e. from December to April, the price of hay also drops during this period. The price goes up again between June and August when straw is highly in demand because during this time all stored feed on-farm is depleted and natural grass is inadequate. This is also a peak working period for oxen.

Like for other classes of livestock, the main source of feed for sheep is native pasture and stubble grazing. In general hay, straw or other feeds are supplemented only during severe feed stress. Although sheep fattening is fairly common throughout the highland Vertisol areas, supplementation is not common except in the Inewari area. A number of farmers are engaged in sheep-fattening activity. At the time of the survey, 32% and 27% of the farmers at Inewari and Dogollo, respectively, are reported to have fastened sheep.

The major reasons cited for not fattening sheep are shortage of capital and feed. Traditionally sheep fattening takes 4-8 months, and is usually targeted for consumption at Ethiopian Christmas and Easter (January and April).

Constraints to production

Farmers' view of constraints to their farm production can give a good insight into the opportunities for technological intervention. Constraints to agricultural production in the Ethiopian highlands are summarised in the following subsections. This summary is a compilation of farmers' responses, discussions with informants, and application of observations and analyses of the farming systems.

Crop production constraints

Constraints to crop production in the Vertisol study sites include waterlogging, shortages of land, land degradation, improved inputs, working capital, animal draught power and labour as well as weeds, pests and diseases.

Waterlogging

Seasonal waterlogging is a general constraint in the Ethiopian highland Vertisol areas. As a result yields of grain and crop residue are low (Tables 7 and 8). The severity of this constraint vary from location to location depending on the availability of rainfall during the growing period, the degree of temperature that affects evapo-transpiration, and the tillage practice to overcome waterlogging. Farmers in all the Vertisol areas surveyed realise the negative effect of poor drainage on food and feed 'production. They also know that solution to waterlogging could increase farm productivity.

Shortage of land

In the highland Vertisol areas farm sizes are' small averaging less than 0.5 ha per family member (Table 2). However, they have to support large families and livestock. The situation is further aggravated by the low farm productivity. This is a critical problem in view of the ever-growing population and decline in yields.

Soil degradation

Due to poor management end shortage 'of land sloppy lands are continuously cultivated and natural vegetations are denuded. Hence the rate of soil erosion is high.

Shortage of improved inputs

The commonly used fertilisers: Di-ammonium phosphate (DAP) and urea are not widely used by farmers because of their unavailability, irregularity in their delivery and the financial inadequacy to purchase them. At the time of the survey fertiliser was sold to farmers in some Peasant Associations (PAs) mostly on a loan basis by the Ministry of Agriculture through Service Cooperatives (SCs). SCs required that all other farmers who took fertiliser loans should repay the cost immediately after their crop harvest in order to be eligible for the next loan. A farmer would not be eligible for a loan until all farmers in a given PA repaid their debts. This was reported to be a critical constraint to those farmers who regularly settled their debts promptly.

Although farmers in general are aware of the positive effects of chemical fertilisers on crops, the rate used per farm is quite low (Table 6) because of the reasons listed above

The seeding rate is high because of the impurities and low germination rate of local variety seed. Although there are some, IAR-released varieties of wheat in the country, they are not yet readily 'available to all farmers.

Hence, the constraints' on the use of fertiliser and improved seed are more institutional in nature.

Draught animal shortage

The uneven distribution of work-oxen has been a critical problem in the farming systems of the Vertisol areas. As most crops are planted after several cultivations with draught animals, farmers without these animals are at a disadvantage to plant the most profitable crop mixes on time. The traditional draught-animal exchanges are no relief because animals become available only after cultivation of land of the owner of the animals is completed. This was a problem for 79% of the farmers at Dogollo, 42% at Ginchi, 73% at Inewari as they had none or only one ox.

Weeds

The reason for several cultivations before planting most cereals in the Vertisol locations is to control weeds. In spite of several cultivations weed infestation is extremely high in these areas. The major weeds in the Ethiopian highland Vertisol areas are: 'asendabo' (*Phalaris paradoxia*), 'borecho' (*Scorpiurus muricatus*), 'wortebet' (*Plantago lanveolata*), 'wajema', (*Medicago polymora*) etc. Use of impure local seed largely contributes to the proliferation of weeds. The weeding operation that normally starts after the Vertisols are drained off naturally in September/October is highly labour-intensive. It takes 28-35% of the labour required by the crops. Moreover, early manual weeding is difficult in waterlogged soils. Generally use of selective herbicide is limited.

On the other hand, as farm sizes in most areas shrink and shortage of animal feeds becomes critical, weeds will be an important feed source in many of the Vertisol farming systems.

Pests and diseases

Sometimes a short dry spell following onset of the main rains, insects (mainly grasshoppers) attack crops in the lower and medium-altitude highlands such as at Debre Zeit and Ginchi. Insects such as aphids cause considerable damage to wheat even in high altitude Vertisol areas. Faba bean is frequently attacked by the stalk borer. The main crop diseases are chocolate spot, rust and smut.

Livestock production constraints

Animal nutrition

Livestock feed supply is erratic and seasonal. There is severe shortage during the dry season and at the beginning of the main rains. The most critical period is between April and the beginning of July, when all feed resources are virtually depleted. Conservation of straw and, in a few instances of hay is inadequate. Whatever is conserved is preferentially fed to draught animals. Additional feeds are required awing ploughing and planting. The high energy demand of working animals is not met and hence their condition deteriorates rapidly awing this period.

Individually owned pasture lands are small and rare in some areas. Due to land shortage grazing lands are being encroached for crop production. The stocking rate on available communal lands is high. There is no restriction on the number of livestock tended on the communal grazing lands. Consequently, every individual farmer tries to maximise the feed intake by his livestock, causing overgrazing and land degradation. Farmers maximise the number of animals in their herd because (1) work oxen are frequently replaced (2) livestock are regarded as a very important asset of wealth and security, and (3) individual benefits are higher from larger herds since grazing is communal property.

The commonly used feedstuffs (i.e. pasture straw and hay) in the Ethiopian highlands have low digestibility (Mukassa-Mugerwa, 1981). The protein content is below the required level. Hence the feed available can at most meet the maintenance requirements of livestock. As a result animals suffer from low growth rates, poor fertility and high calf mortality (Gryseels, 1988).

Marketing

Although output of livestock products particularly of milk is low, there is no ready market for livestock products in the Vertisol areas away from Addis Ababa, since they are not served with milk collection centres. This forces farmers to process milk into butter which is normally sold to merchants and occasionally to local consumers.

Animal health

In general the main livestock diseases reported in the case study areas were: (1) internal parasites e.g. fascioliasis, lung worms, ascaris etc (2) bacterial diseases e.g. sheep pasteurellosis (3) blackleg and (4) anthrax Mostly local medicines are used since modern veterinary services are not widely available.

Shortage of working capital

Farm cash income is extremely low with almost no surplus available for reinvestment on the farm itself. This had partly hindered the wide use of purchased inputs. Credit to individual farmers is not widely and readily available.

Researchable areas

An understanding of traditional farming systems can enable one to design appropriate technology options for on-farm research. Technologies can be introduced from elsewhere and be adapted. Technologies in the target area can also be modified or refined to solve constraints. The desired characteristics are that technologies should be (a) simple, low-cost and quickly comprehensible by farmers; b) be within users' reach and c) compatible with overall extension objectives and policies.

The Ethiopian highland Vertisol locations have common socio-economic characteristics. Land

and capital are scarce. Available farm resource has to sustain large farm families and livestock. Hence, appropriate technologies are required to increase productivity using the scarce farm resources. Vertisols in the target areas are known to have high agricultural potential. As there is a high livestock and crop interaction, intervention in one of the subsystems directly or indirectly affects the other. Improvement to the livestock subsystem could, in turn, improve the crop subsystem or vice versa.

Improved Vertisol management

Appropriate technologies to better manage Vertisols is a desirable intervention in the Ethiopian highland Vertisol farming systems. A better Vertisol management can be brought about by improving the surface drainage. The positive effects of surface drainage on agricultural productivity of Vertisols have been widely documented. Few of the improved techniques suggested to solve the problem of surface drainage in these soils include the use of the wheel-tool carrier by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) in India and the formation of cumberbeds with the use of tractors by the Institute of Agricultural Research (IAR) in Ethiopia.

As these techniques require a high financial investment, they can be adopted only within the recommendation domain that has the means to procure them. When resource-poor smallholder farms are the target group, farm technologies have to be simple and cheap. Where farms are subsistent-oriented with low annual farm cash income as in Ethiopia, research on simple, low-cost and easily adoptable surface drainage technologies are needed. An effective surface drainage technique does exist locally at the Inewari plateau in central Ethiopia. But as already pointed out, human drudgery in constructing the BBF can be replaced by animal draught power, thus increasing social welfare. The development of an animal-drawn implement for this purpose becomes a priority research area. The formation of broadbeds and furrows (BBF) with the use of an appropriate animal-drawn implement is basic to solve seasonal waterlogging in Vertisols.

On-farm verification and transfer of such a technology are discussed at length in Chapter 8.

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4 Nutrient management

I Haque, Mesfin Abebe, Tekalign Mamo and Asgelil Dibabe

Introduction

Vertisols are used for both crop production and animal grazing. In the highlands, crops such as cereals (teff, oats, barley, durum wheat, finger millet, sorghum), pulses (horse beans, chickpeas, lentils, field peas, rough peas, fenugreek) and oil crops (linseed, noug and safflower) are often produced on well-drained Vertisols. Grazing is the dominant use of the poorly drained valley bottoms and depressions (Westphal, 1975; Berhanu Debele, 1985).

The traditional highland farming system is confronted with several major problems and limitations. The poor drainage of Vertisols restricts farming operations awing the rainy season, especially if rainfall is excessive and the slope of the land is steep. The cultivars of traditional crops grown on Vertisols have limited yield potential and little ability to respond to fertilisers (Berhanu Debele, 1985).

The most serious problem of the traditional fallow system awing the rainy season in most of the highland Vertisol areas is soil, water and nutrient erosion. Nitrogen and P deficiencies are the major constraints to crop production and will become increasingly important with high yielding crops and cropping systems (Kamara and Haque, 1988; Tekalign Mamo et al, 1988; Haque, 1992).

The highland farmers use little fertiliser. For power, they use animal and human resources (Jutzi and Goe, 1987). The general crop yields at the farm level are low (Berhanu Debele, 1985; Getachew Asamenew et al, 1988). Thus the traditional system of Vertisol utilisation gives low yields and promotes soil, water and nutrient erosion resulting in low productivity.

Considering the large available moisture capacity (Virgo and Munro, 1978; Kamara and Haque, 1988) and relatively high natural fertility of Vertisols, it is unfortunate that these soils are underutilised. There is sufficient evidence that Vertisols are capable of producing many times more food and feed than they do today provided they are adequately and properly managed.

Physico-chemical characteristics

Soils differ in their physical chemical and mineralogical properties and hence their suitability for different forages and crops. Determining the soil physico-chemical characteristics and relating these to known plant requirements can indicate the potential fertility of the soil and ascertain whether sites are useful for screening certain plant groups (ILCA, 1988).

Morphology and characteristics of soils of the central highlands of Ethiopia are described by Kamara and Haque (1988) and Mitiku Haile (1987) while the physical properties of Vertisols and their implications for management are reviewed by Kamara and Haque (1988). These aspects are reviewed separately in this report, while only chemical properties will be highlighted in this Chapter.

Chemical properties

A generalised statement of the chemical properties of Ethiopian Vertisols is that they have low organic matter total nitrogen, are near neutral or alkaline with high exchangeable bases, Ca being the most dominant. They have a high CEC. The chemical properties of Ethiopian Vertisols from four study sites are shown in Tables 1 and 2.

Mineralogy

The clay mineralogy of highland Vertisols has been studied by Mitiku Haile (1987), Sahlemedhin Sertsu (1987), Fisseha Itanna (1992) and Ahmad and Haque (unpublished data). The main conclusions can be drawn as follows:

- The dominant clay mineral in most of the Vertisols is the 2:1 expanding smectite. This, coupled with high a clay content, is the main reason for the high water-holding capacity of Vertisols.
- Illite is present in small quantities as a smectite/illite intergrade.
- Mica is present in some profiles as a smectite/mica intergrade.
- Amorphous (non-crystalline) materials increase with depth and there is a virtual absence of kaolinite and illite at these deeper depths. The amorphous material includes imogolite like allophane as the predominant mineral (Table 3).
- The x-ray diffraction intensity values in Table 4 show the devastating effect of high temperature on crystallinity of most of the clay minerals from cover to the burned layer.
- After spreading and mixing the "*guie*" mounds, the crystallinity of almost all the minerals at Sheno and Chekie were highly reduced.
- On the third year after "*guie*", the x-ray diffraction impulse values of most of the clay minerals approached those of the "non-*guied*" soils.

Table 1. Chemical properties of Ethiopian Vertisols of eastern Ethiopia

Depth (cm)	**(a) Alemaya Vertisol**			
	0-25	**25-50**	**50-100**	**100-150**
OM (g/kg)	19.5	18.5	12.2	11.1
Total N (g/kg)	1.03	1.18	1.11	0.72
C/N	11.0	6.54	6.35	8.90
pH	7.93	7.46	7.58	7.18
Exch. bases (mMc/kg)				
Na	5.57	4.64	3.13	3.70
K	3.05	3.60	9.53	5.38
Ca	300	295	271	258
Mg	146	80.6	80.8	74.7
Cation exch. Capacity	455	384	364	391
Depth (cm)	**(b) Wachu Vertisol**			
	0-25	**25-50**	**50-100**	**100-150**
OM (g/kg)	19.0	18.8	18.3	16.9
Total N	0.96	1.04	0.73	0.49
C/N	11.5	10.5	14.5	20.0
pH	6.16	6.39	6.90	6.60
Exch. bases (mMc/kg)				
Na	3.49	4.49	5.01	5.81
K	4.11	3.09	2.52	3.58
Ca	266	240	244	183
Mg	67.9	103	141	112
Cation exch. capacity	342	351	393	304

Source: Ali Yimer (1992).

Table 2. Chemical properties of Ethiopian Vertisols of central Ethiopia.

Depth (cm)	(a) Debre Zeit			
	0-25	**25-50**	**50-100**	**100-150**
OM (g/kg)	18.6	17.3	16.3	12.2
Total N (g/kg)	0.63	0.5	0.62	0.51
C/N	17.1	20.1	15.30	13.9
pH	6.38	6.67	06.82	7.09
Exch. bases (mMc/kg)				
Na	15.40	6.21	8.91	8.78
K	3.04	3.15	6.95	7.49
Ca	187	187	179	178
Mg	88.5	117	141	131
Cation exch. capacity	293	313	337	325
Depth (cm)	**(b) Akaki**			
	0-25	**25-50**	**50-100**	**100-150**
OM (g/kg)	12.7	12.0	11.6	10.6
Total N (g/kg)	0.52	0.47	0.41	0.32
C/N	14.2	14.8	16.4	19.2
pH	7.52	7.79	8.10	8.09
Exch. bases (mMc/kg)				
Na	11.8	13.6	9.81	12.1
K	5.76	5.92	6.68	8.01
Ca	583	595	675	666
Mg	211	216	184	183
Cation exch. capacity	812	830	875	879

Source: Ali Yimer (1992).

Phosphorus management

Available phosphorus

Next to N. P is the most limiting nutrient element in the highland Vertisols of Ethiopia. Available P seems to be low (Olsen, Bray I & II) in most of the surface soils. Using the Olsen method, which is often regarded as the most appropriate for Ethiopian soils (Tekalign Mamo and Haque, 1991), the maximum P content was observed in Wereta soil and the minimum in soils at Shola.

Higher values of Bray II extractable P were observed at lower depths than at the surface for each of the profiles (Tekalign Mamo et a, 1988). This may be due to the abundance of Ca-P and the dissolution of Ca-P by the Bray II extractant at lower depths. Similar trends were also observed by Piccolo and Gobena Huluka (1986) in their P studies of seven Ethiopian soils.

The status of available P in soils is normally related to the different active inorganic P forms (Al-P, Fe-P and Ca-P). Based on the results of 15 Vertisols (Tekalign Mamo et al, 1988), the low Al-P and the Ca-P contents reported in the surface soils are indicative of the limited capacity of the inorganic forms to act as a liable pool to supply available P to the plants.

In another survey of nutrient availability, 350 surface soil samples in the Shewa region of Ethiopia, Pulschen (1987) found that the mean Olsen extractable P in 165 Vertisols or soils with vertic properties was 11.6 ppm but less than that in light soils (16.9 ppm) and reddish brown soils (13.9 ppm). Presence of P deficiency in Ethiopian soils is also reported by Desta Beyene (1982).

Guie (soil burning)

In the high altitude areas of Ethiopia a cultural practice, called *'guie'*, is followed for growing barley on Vertisols (Mesfin Abebe, 1981; Roorda, 1984). Although it is very labour-intensive, it initially gives good crops, considerably above those that can be achieved using alternative cultural practices. During the process, which involves burning dung within heaps of soil, available P and K in the soil are increased and the structure of the surface horizon is altered facilitating better water movement in the plough layer. Using fertilisers permits yields to be sustained for longer periods, but farmers continue to prefer their traditional method which seems likely to continue as long as land is plentiful enough to afford the long fallow period (10 - 15 years) (Mesfin Abebe, 1981 and 1982; Sahlemedhin Sertsu, 1987). Some chemical properties of guied samples are given in Table 5.

Table 3. Oxalate (o) and pyrophosphate (p) extractable sesquioxides of Debre Zeit Andosols.

Depth (cm)	Sio	Alo	Feo	Alp	Alo-Alp	Alo-Alp/sio	Allophane
	Per cent						
DZ-I Summit (Vitric Andosol)							
0-15	0.11	0.27	0.39	0.005	0.26	2.4	1.23
15-55	0.11	0.29	0.34	0.005	0.28	2.5	1.28
22-32	0.12	0.26	0.35	0.003	0.26	2.2	1.23
32-40	0.12	0.25	0.34	0.005	0.24	2.0	1.12
DZ-II Shoulder (Mollic Andosol)							
0-15	0.11	0.23	0.48	0.020	0.21	1.9	0.98
	0.11	0.24	0.62	0.025	0.21	1.9	0.98
DZ-III Backslope (Mollic Andosol)							
0-16	0.11	0.26	0.57	0.023	0.24	2.2	1.13
16-58	0.11	0.24	0.57	0.020	0.22	2.0	1.02

Source: Fisseha Itanna (1992).

Table 4. The x-ray diffraction impulses of different minerals in Ca-saturated, glycerol-solvated clays from the different layers of a "*guie*" mound at Sheno.

"*Guie*" treatments	Kaolinite (7.15 Å)	Illite (9.9 Å)	Transition minerals (10-14 Å)	Al-chl (13.8 Å)	Transition minerals (14-18 Å)	Smectites (17-6 Å)	Total
Cover layer	14	96	16	19	108	271	524
Heated layer	13	85	9	4	84	218	413
Carbonised layer	3	72	12	13	80	171	351
Burnt layer	1	64	5	2	23	54	149

Source: Sahlemedhin Sertsu (1987).

Table 5. Exchangeable bases and cation capacities of soil within burnt heap and soils of "*guie*" area after different periods of fallow.

Sample	mM_c/kg soil						
	Na	K	Mg	Ca	CEC	TN[1]	Av.P[2]
1	7.6	16.8	33.9	131	190	0.2	ND
2	7.3	17.6	29.8	127	143	0.25	35.0
3	7.3	20.0	26.7	87.5	120	0.06	ND
4	8.4	7.7	70.9	170	234	0.19	ND
5	8.1	9.7	72.1	181	227	0.24	ND
6	7.5	10.3	75.2	192	261	0.23	ND
7	7.9	13.2	76.5	187	276	0.25	ND
8	8.3	9.8	78.2	179	286	0.26	3.21
9	8.6	9.1	73.1	196	275	0.27	2.63
10	6.8	8.6	65.1	187	252	0.28	2.33

1 = Total N (g/kg).
2 = Available Phosphorous (mg/kg).
ND = Not detrmined.

Samples:

1 = Heated.
2 = Carbonised.
3 = Ashed.
4 = Bottom.
5 = One year after "*guie*".
6 = Two years after "*guie*"
7 = Five " " "
8 = Ten " " "
9 = Fifteen " " "
10 = Twenty " " "

Source: Ali Yimer (1992).

Phosphorus nutrition of forage legumes and crops

Phosphorus is the most important nutrient in the successful establishment of legumes. Phosphorus often increases dry matter, modulation, nitrogen fixation, P uptake and protein yields of legumes (Haque et al, 1986).

Effect of TSP and Egyptian rock phosphate (ERP) was compared on clovers grown on highland Vertisols. The cumulative effect of TSP and Egyptian rock phosphate on clover dry-matter production over six years showed linear and quadratic increases with increasing rates of TSP and ERP, respectively (Haque, 1992).

The efficiency of unacidulated and partially acidulated rock phosphates was compared with that of TSP when applied on *Trifolium quartinianum* (ILCA 6301) on a highland Vertisol. Application of TSP significantly increased dry-matter yield relative to the control (1273 kg/ha). Clover dry-matter yield showed a quadratic response to TSP. Applying 50% acidulated rock phosphate (50% ARP) significantly increased dry-matter yield relative to the control at all rates of application; dry matter yield increased linearly with increased rates of 50% ARP applied. Applying 25% acidulated rock phosphate (25% ARP) also significantly increased dry matter yield relative to the control, except at 20 kg P/ha. Dry-matter yield showed a linear increase with increasing rates of 25% ARP application. Applying untreated rock phosphate did not have a significant effect on clover yield, indicating the non-reactivity of this P source on the Vertisol (Haque, 1992).

In a greenhouse trial, the effect of management (P. rhizobium and their combination) was investigated on *Sesbania goetzei* grown on highland Vertisol. Phosphorus application and inoculation with an effective rhizobium significantly increased shoot, root and total dry matter relative to other treatments. Highest N derived from fixation was achieved with P and rhizobium treatment as compared with other treatments (Luyindula and Haque, unpublished data).

In another greenhouse experiment the effect of management (rhizobium, P and N) was investigated on the growth and N fixation by *Leucaena paniculata* and *L*. *leucocephala* on highland Vertisol. Unacidulated plants at 0-10 mg N/kg and all inoculated without P had poor growth compared to other treatments. Leucaena paniculata had higher height and more dry matter than *L*. *leucocephala*. Plants treated with P and rhizobium performed better than others. Uninoculated plants, especially *L. paniculata* had a few nodules suggesting the occurrence of native rhizobia on highland Vertisol. However, nodulation and growth were more in P plus rhizobium treatments than others. This shows the need for inoculation and P application for growing Leucaena on this soil (Luyindula and Haque, unpublished data).

Response of field crops to P fertiliser in Vertisols of Ethiopia are reported in Table 6. A notable case is the lack of response to P at Debre Zeit. Further studies carried out on durum wheat, teff, chickpea and lentils around Debre Zeit did not show any response to P on Vertisols, although empirical values show a low level of P in the soils. The response was not improved by improved drainage either as shown in Table 7 for chickpea. The possible reason for the lack of P response is given as increased root proliferation in the soil thereby enabling the plants to explore large volume of soil.

Mycorrhizae and phosphorus nutrition

Vesicular arbuscular mycorrhizal (VAM) fungal inoculation enhances plant growth and the uptake of mineral nutrients especially P (Tinker, 1978). VAM fungal inoculation also enhances the solubility of rock phosphate (CIAT, 1985; Islam et al, 1980; Tekalign Mamo and Haque, 1986).

In work conducted at ILCA headquarters the effects of inoculation with VAM fungus and fertilisation with either triple superphosphate (TSP) or Egyptian RP on the nodulation, growth and major the nutrient elements on nutrition of lucerne grown in a Vertisol was studied under greenhouse conditions. Results (Table 8) showed that mycorrhizal (M) plants flowered earlier and produced more nodule and shoot dry matter than control plants or those supplied with either form of P. Maximum weights occurred in plants that were both inoculated and fertilised. In all cases TSP was more effective than RP, but the effect of the latter was, nevertheless, impressive when combined with mycorrhiza.

Although there were some practical problems in the use of VAM technology, it is evident that in tropical soils, with their tendency to fix P. VAM fungal inoculation has considerable potential for legume enhancement and hence benefitting both livestock and overall food production.

Species and varietal variation in response to phosphorus

Problems of legume production caused by the mineral stresses can be alleviated by chemical amendments and fertilisers although both of these methods are costly and beyond the buying ability of the farmer (Bumb, 1991). Screening for tolerance to low soil fertility and use of cheaper sources of nutrients especially P may be similar and a less expensive method for overcoming the low P status. Large differences in the response of clover species and varieties to P on Shola Vertisol are shown in Figure 1. The use of varieties more tolerant to low levels of available P will result in more efficient use of fertiliser P. Clovers tolerant to low P are likely to have lower P concentration in their tissues. Their nutritive value may thus be lower than other cultivars/species. Direct P supplementation to livestock in the form of salts to offset deficiency may be needed.

Phosphorus sorption isotherms

Soil testing service in Ethiopia is minimal because of the cost of setting up such services and the time involved in making correlation studies of crop yields and various chemical extractants. The P sorption approach provides a basis for estimating P needs of crops for a given soil-crop combination (Fox and Kamprath, 1970; Memon and Pox, 1983) which is not the case for most conventional methods. Phosphorus sorption isotherms have found increasing use in evaluating the P status of forage legumes. Based on this, external P requirements (the P concentration in soil solution that will give near maximum yield, usually 95 to 90%) have been determined for some forage legumes (Nnadi and Haque, 1985). The very low P requirements of these legumes indicate that they can attain maximum yield with little P fertilisation and can compete effectively with grasses for P uptake.

Table 6. Response of field crops to phosphorus fertiliser in Vertisols of Ethiopia.

Location	Crop	Applied P (kg/ha)						
		0	13	20	26	40	53	Source
		Grain yield (kg/ha)						
Ginchi	Noug	670	-	900	-	920	-	2
Ginchi	Linseed	750	-	1010	-	960	-	2
Ginchi	Teff	380	-	970	-	1220	-	2
Ginchi	Bread wheat	1690	-	2590	-	2250	-	2
Holetta	Coloured Guinea	673	-	1434	-	2767	-	3
Holetta	Phalaris	3794	-	4610	-	4570	-	3
Holetta	Faba bean	2870	3420	-	3730	3960	-	3
Holetta	Bread wheat	1500	1690	-	1910	1890	-	4
Holetta	Barley	2560	2900	-	3590	3560	-	3
D/Z	Chickpea	1910	1470	-	2120	1930	-	5
D/Z	Lentils	513	515	-	472	576	-	5
Sheno	Barley	1743	2057	-	1856	1843	1678	6

a. Forage yield; D/Z = Debre Zeit; - = N not applied.

Sources: 1. Desta Beyene (1988).
2. IAR (1977).
3. IAR (1976).
4. Desta Beyene (1986).
5. AAU (1983).
6. IAR (1972).

Table 7. Effects of seedbed preparation and phosphorus application on chickpea grain yield (kg/ha) grown at three locations (1991).

Location	Seedbed	P rates (kg P/ha)					Mean
		0	10	20	30	40	
Debre Zeit	Flat	2927	2600	2508	2601	2630	2653a
	BBF	3239	3005	2939	3147	3168	3099b
	Mean	3083	2802	2723	2847	2895	
Akaki	Flat	3307	3215	3121	3084	2991	3144a
	BBF	3792	4044	3731	3874	3972	3883b
	Mean	3549	3629	3426	3479	3581	
Dembi	Flat	973	1043	1026	1144	989	1035a
	BBF	1799	1579	1551	1462	1285	153b
	Mean	1386a	1311a	1289a	1303a	1137a	

For each location, means followed by a common letter are not statistically different at P.
Source: Tekalign Mamo (Alemaya University of Agriculture, Debre Zeit, Ethiopia, unpublished data).

Phosphorus fertilisation on forage-based cropping systems

For efficient use of nutrients, fertiliser recommendations on Vertisols should take into account the cropping system as a whole rather than individual crops. This is particularly important in the case of P. where utilisation in the year of application is rather low (15-20%) and residual effects are considerable on Vertisols. The residual effect of P and the differential capacities of plants to utilise soil and fertiliser P should be taken into account in making P recommendations for forage-based cropping systems on highland Vertisols.

Nitrogen management

Nitrogen is one of the major plant nutrients and satisfactory levels of grain and forage crop production on Vertisols depends on its adequate supply. While the N status of soils can be improved by the addition of N fertiliser, it is an expensive input and this is reflected in its low consumption in the Ethiopian highlands (Mesfin Abebe, 1980).

Table 8. Effects of *G. macrocarpus* inoculation phosphorus fertilisation on root infection and nodule and shoot dry-matter yields of *M. sativa* grown on a sterile Vertisol.[1]

Treatment	Root infection (%)		Nodule DM (mg/pot)[2]		Shoot DM (g/pot)[2]	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
Control	0	0	1a	2a	0.02a	0.02a
RP	0	0	3b	5b	0.43b	0.48b
TSP	0	0	6c	21c	2.24c	2.01c
M	49a	71a	7c	67d	2.90c	1.71c
M + RP	60b	73a	146d	159e	6.11d	4.30d
M + TSP	69c	78a	177d	213e	7.89d	4.58d

1. Shoot dry-matter yields from the first nut are means of four replicates. All other values are means of two replicates, since plants from two replicates had to be uprooted in order to determine root infection at 90 days.
2. LSD calculated from log-transformed values since standard deviation increased with increase in nodule and shoot dry-matter yields. In each cut, values followed by the same letter are not significantly different at the 5% level.

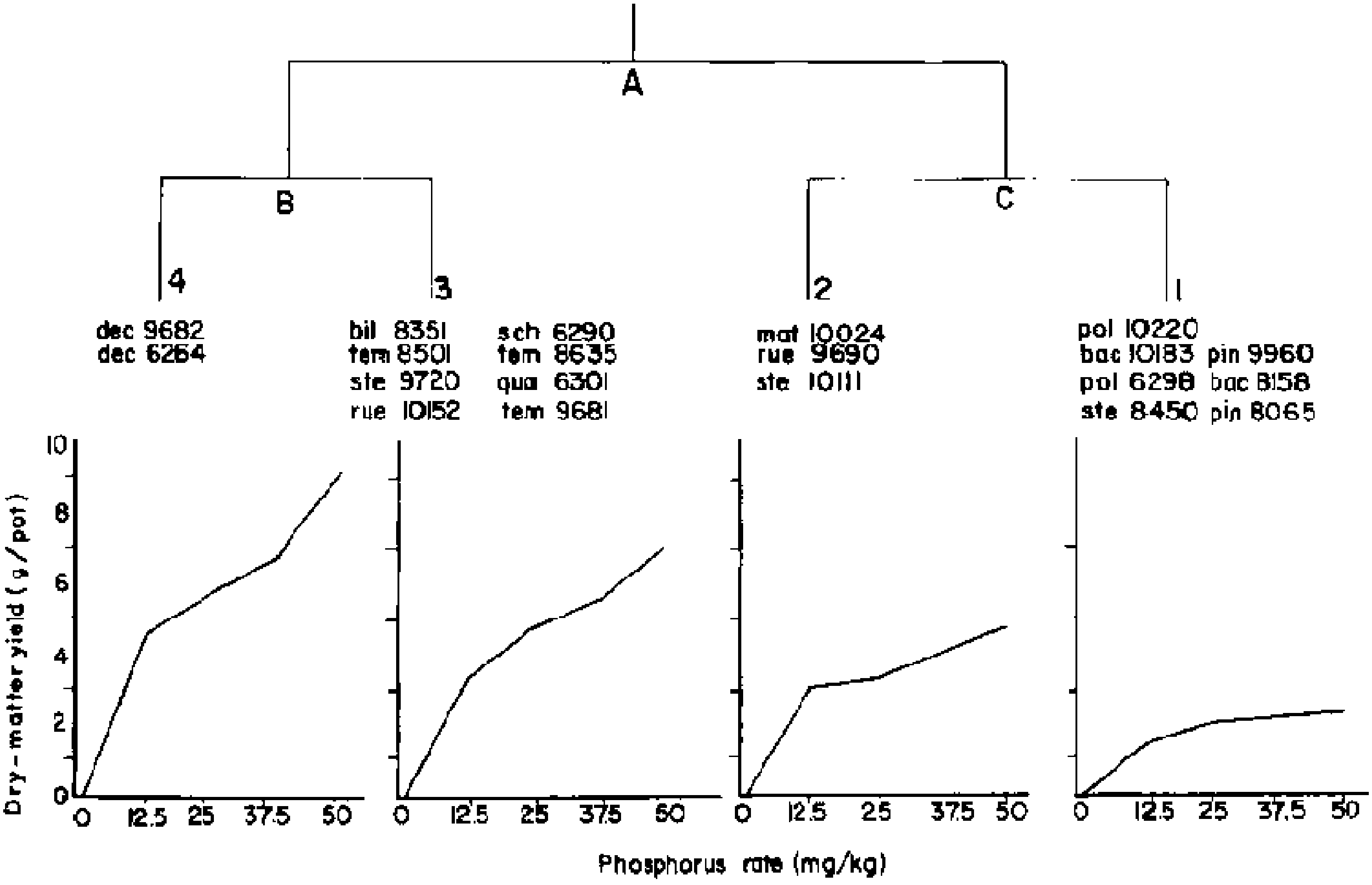
Note: M = mycorrhizae; RP = rock phosphate; TSP = triple superphosphate.
Source: Tekalign Mamo and Haque (1986).

A more effective and cheaper way of raising the N status of the soil is to exploit the ability of forage legumes to fix appreciable quantities of N. This N accumulates in the soil and is released over several seasons to non-legume crops if the soil is cultivated, or to companion grasses in pasture land. Thus forage legumes can indirectly boost crop yields and directly resolve feed quantity and quality problems in Ethiopian highlands (Haque and Jutzi, 1984).

Response to nitrogen by various crops

Crop response to N fertilisation at various locations is summarised in Table 9. There was a marked N response in most of the crops tested. Maximum barley yields at Sheno and maximum grain yields for noug, linseed, teff and bread wheat, barley and faba bean at Holetta, were all obtained with 90 kg N/ha. Similar results were found for teff grown at Debre Zeit, Akaki, Chefe Donsa and Dankaka (AAU, 1983). Trials carried out at Tafki, Inewari and Bichena also showed significant yield increases in bread wheat, durum wheat, teff and faba beans as a result of N fertiliser application (Adugna Haile and Hiruy Belayneh, 1986). For the forage grasses (Guinea and Phalaris) studied at Holetta maximum forage yield was found when 46 kg N/ha was applied. In a recent study conducted on Vertisols N use efficiency durum wheat was increased by improved drainage as shown in Table 10. This was further proved by the work of All Yimer (1992) who reported that durum wheat N use efficiency was high on broad beds as compared to plants grown on flat. In addition, total mineral soil N was low in the BBF plots due to enhanced uptake by plants (Table 11).

Figure 1. Hierarchy for the classification of dry-matter yield of clover tops on a Vertiso



Means of groups are plotted against the P rate.

Source: Mugwira and Haque (1991).

Table 9. Response of rainfed field crops to nitrogen fertiliser in Vertisols of Ethiopia[1].

Location	Crop	Applied N (kg/ha)					Sources
		0	30	46	60	90	
Grain Yield (kg/ha)							
Ginchi	Noug	750	-	860	-	880	2

Ginchi	Linseed	800	-	960	-	970	2
Ginchi	Teff	720	-	730	-	1120	2
Holetta	Coloured Guinea	673	-	1920	-	1827	3
Holetta	Phalaris	3794	-	4216	-	3630	3
Holetta	Bread wheat	2900	3410	-	3540	4110	3
Holetta	Barley	3001	2960	-	3200	3480	3
Holetta	Faba bean	1360	1830	-	1790	2020	4
Sheno	Barley	1448	1716	-	2018	2164	5

- = N not applied.
a. Forage yield.

Sources: 1. Desta Beyene (1988).
2. IAR (1977).
3. IAR (1976).
4. Desta Beyene (1986).
5. IAR (1972).

Table 10. Effects of seedbed preparation methods and nitrogen application rates on the grain yield (kg/ha) of durum wheat grown at Akaki (1990).

Seedbed	N rates (kg N/ha)			Mean
	0	60	120	
BBF	689	2591	2923	2068
Flat	496	1352	1667	1172
Mean	592	1972	2295	

LSD (0.05): N = 180.5; seedbed = 147.4.
Source: Tekalign Mamo (Alemaya University of Agriculture, Debre Zeit, Ethiopia unpublished data).

Table 11. The apparent recovery of nitrogen in the above-ground portions of the crop and soil and per cent of applied fertiliser recovered.

A	B	C	D	E	F	G	H
Flat	0	11.5	4.80	--	16.3	--	
	60	32.5	10.5	21.0	5.70	42.8	44.2
	120	47.5	15.6	36.0	10.8	63.1	39.0
BBF	0	15.4	4.40	--	--	19.8	--
	60	55.2	6.90	39.8	2.50	62.1	70.5
	120	74.8	9.92	59.4	5.52	84.7	54.1

A = Seedbed preparation.
B = N applied kg/ha.
C = Total N in grain and straw (kg/ha).
D = Total mineral N in soil.
E = Apparent N recovery in crop (%).
F = Apparent N soil in crop.
G = Total N in crop and soil (%).
H = Applied fertiliser recovered (%).

Source: Ali Yimer (1992).

The presence of appropriate rhizobium

The presence or absence of an appropriate rhizobium in the soil dictates whether inoculation of the legume seed is required. Those species or varieties which do not require inoculation have obvious advantages at the farm level. Obviously some tropical forage legumes exhibit rhizobium strain specificity comparable to that commonly associated with the temperate legumes.

Various strains of rhizobium (USDA 3786, 3110, 3781, 3782 and 3117) were compared on *Sesbania sesban* grown on highland Vertisol. Strain 3117 significantly increased the number of nodules and shoot dry weight relative other strains. On the other hand, no significant effect of various strains was noticed on shoot dry weight as compared with control (ILCA, 1989).

The effect of management on growth and N fixation by *Sesbania sesban* and Sesbania *goetzei* grown on a Vertisol was investigated in a greenhouse experiment using ^{15}N labelled urea. Plants were inoculated with rhizobium strain USDA 3117 at two N levels with or without P. Results showed a near-absence of *Sesbania* active native rhizobia in Shola Vertisol, suggesting that rhizobia strains effective on *Sesbania* spp. were absent or are insufficient in number in this soil. Inoculated plants with applied P had very high % Ndfa (Nitrogen derived from the atmosphere). Our results suggest that P was limiting for rhizobium infectivity and/or efficiency (Luyindula and Haque, 1992).

Rhizobium inoculation studies on faba bean, lentils and chickpeas were carried out at Denbi Holetta Sheno, Gohatsion, Bekoji and Ginchi. No significant responses to inoculation were noticed indicating the presence of active rhizobia in these Vertisols (Desta Beyene and Augaw Tsige, 1986; IAR, 1989 and 1990).

Microbial studies

Since the extent to which organic N is released to plants in available forms depends, in part, on the activity of soil micro-organisms, investigations on the microbial population of soils is important. In an attempt to address this problem, five highland Vertisol surface samples were studied for their microbial population. Results shown in Table 12 revealed that bacteria outnumbered both actinomycetes and fungi with the highest variation among sites, 303 x 10^6 at Debre Zeit to 36 x 10^6 at Alemaya. Actinomycetes were second in terms of abundance and variation was 660 x 10^5 at Alemaya to 105 x 10^3 at Wachu. Fungi were the least in terms of abundance with a three-fold variation among the five sites.

In a related study (All Yimer, 1992) the net increase or decrease in mineral N was studied in two Vertisols (Akaki and Debre Zeit). Samples were incubated for 28 days at 25 and 40°C and 60% field capacity. Results showed that apart from the Akaki soil incubated at 25°C, the increase was greatest in the 0-25 cm depth range. The Debre Zeit soil showed a larger amount of mineralisable total mineral N than the Akaki soil. In all cases except the Akaki soil at 40°C there was a decrease in NH_4 and an increase in NO_3 - N over the incubation period; thus net nitrification occurred at a faster rate than net mineralisation.

Table 12. Total count of bacteria, fungi and actinomycetes in five different highland Vertisols.

Locations	Bacteria (cells/g) (x10^6)	Fungi (cells/g) (x10^2)	Actinomycetes (Cells/g) (x10^5)
Debre Zeit	303	908	200
Wachu	109	305	105
Akaki	75	400	170
Shola	67	505	380
Alemaya	36	898	660

Source: Ali Yimer (1992).

Biological nitrogen fixation and its cycling in Vertisol cropping

Table 13 shows the effect of previous cropping on sorghum grain yields on a soil with vertic properties. The yield of sorghum after *Trifolium steudneri* was double that after oats (*Avena sativa*).

The residual effects of 15 vetch lines on the grain yield of oats on a Vertisol were investigated at Shola in the 1983/84 cropping season. The results showed that ILCA accession no. 5219 and 5219 benefit a subsequent oats crop: in both cases the cereal yielded grain at more than 2000 kg/ha, indicating the potential contribution of the legume to N fertility (Nnadi and Haque, 1988).

In another trial at Shola the grain yield of oats following *Medicago truncatula* cv Jamalong was higher than that of oats following pure wheat or wheat/medic mixture (Nnadi and Haque, 1988). In a study at Debre Zeit, the grain yield of wheat crop grown on Vertisol broadbeds increased when it followed forage legumes. However, the results were not significant compared with the control oats (Table 14) which might be due to a higher initial amount of available N.

The effect of P fertilisation on biological nitrogen fixation was studied on a Vertisol at Shola in 1983/84. Following 22 *Trifolium* accessions, oats were planted in plots that had received P at either 0 or 41 kg/ha as TSP. The increase in the grain yield of oats over the control (legume without P) varied from 28.2 to 100.2%. Different *Trifolium* accessions contributed different amounts of N to the following oats crop, but the effects of the legume and P were confounded. Nevertheless, the results showed the importance of P fertilisation for biological nitrogen fixation and, consequently, for increasing cereal grain yields on Vertisols (I Haque, unpublished data).

Table 13. Effect of preceding crops on grain yields of sorghum on a soil with vertic properties, Debre Zeit, Ethiopia.

1984 crops	Sorghum yield (kg/ha)
Trifolium steudneri	2632.0a
Vicia dasycarpa	2130.3a
Lablab purpureus	1549.7b
Trifolium tembense	842.0ab
Avena saliva	1571.3c

Within columns, values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).

Source: I Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

A field experiment was conducted on Vertisols at Shola to determine the amount of nitrogen fixed by eight accessions of five *Trifolium* species (*T. quartinianum*, *T. steudneri*, *T. decorum*, *T. rueppellianum* and *T. tembense*). The amount of nitrogen fixed was estimated using both the N difference method, with oats as the nitrophilous reference crop, and the ^{15}N method.

The two methods gave similar results and ranking, but the ^{15}N method indicated slightly larger amounts of nitrogen fixed. *Trifolium quartinianum* (ILCA 6301) and *T. decorum* (ILCA 6264) fixed more N (Table 15). Fixation contributed from 84 to 89% of the N needs of the various species and accessions.

Effect of drainage and P was investigated on clover grown on Ginchi Vertisol. No significant effect of drainage was noticed in various treatments and interaction between drainage and various treatments was also non-significant with respect to dry-matter yield, N derived from fertilisers and biological nitrogen fixation. Phosphorus application to clover significantly increased dry-matter yield. Phosphorus application also significantly increased N derived from fixation and biological nitrogen fixation relative to no P application (Table 16). Phosphorus deficiency seems to be the main constraint for dry-matter yield and N fixation by clover on this soil which will have implications for feed output and N contribution to the following wheat crop.

Green manuring consists of ploughing in whole green plant as fertiliser at flowering stages of plant growth. Results have shown that yields increased three-fold without fertiliser application when vetch was ploughed under at flowering stage. Response to N and P was higher on the vetch-wheat plots indicating increased efficiency as a result of green manuring.

Table 14. Effect of previous cropping on wheat grain yields on a Vertisol, Debre Zeit, Ethiopia, 1986.

1985 crops	Wheat yield (Kg/ha)
Medicago sativa	2034.3
Vicia dasycarpa	1689.3
Lablab purpureus	1685.3
Trifolium steudneri	1427.0
Arena sativa	1357.3

Note: Because of high coefficient of variation, the differences in wheat yields after the forage legumes and the control (*Avena sativa*) were not significant.

Source: I Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Secondary and micronutrients

Potassium

Laboratory studies were conducted to determine the status of K in 32 Ethiopian soils. Results showed that K values determined by all the methods (except water extraction) were within the adequate range (0.1 me/100 g) in all but soils from Afdeyu and Debre Sina.

All the soils could fix K but with variable capacity. Generally, the highest fixation was observed in Vertisols. Fixation was correlated with a percentage of clay of the soils. It is thought that in addition to montmorillonite, K fixation was promoted by the presence of amorphous materials in the soils (Tekalign Mamo and Haque, 1988).

Sulphur

Ten Ethiopian soils were studied with respect to their S status and highly significant correlations were observed among C, N and S in these soils indicating that most of the S was in the organic form. Sulphate sorption was significantly correlated with extractable Al and organic matter content of the soils, indicating that both are important factors controlling S sorption in these soils. The results also indicated that mineralizable S may serve as a potential source of S to plants and it should be considered in soil test studies for available sulphur (Tekalign Mamo and Haque, 1987).

Table 15. Bioloigical nitrogen fixation by various clover accessions grown on a Shola Vertisol, Ethiopia.

Treatments	^{15}N technique method	N difference N fixed (kg/ha)
T. quartinianum (ILCA 6301)	122a	100a
T. decorum (ILCA 6264)	112ab	104a
T. rueppellianum (ILCA 6260)	100bc	91ab
T. decorum (ILCA 9447)	89cd	80bc
T. tembense (ILCA 7102)	84d	77bcd
T. quartinianum (ILCA 9379)	81d	66cd
T. steudneri (ILCA 9720)	75d	63d
T. steudneri (ILCA 6253)	55e	45e

Within columns, values followed by the same letter do not differ significantly ($P < 0.05$) Duncan's Mutiple Range Test.

Source: ILCA (1988; 1989).

Micronutrients

Micronutrient status of some Ethiopian soils and plants have been reviewed by Desta Beyene (1983) while the micro and macronutrient distributions in Ethiopian Vertisol landscapes is presented by Fisseha Itanna (1992). However, the micronutrient status of Ethiopian soils seems to be cloudy and review in progress on micronutrient status in soils-crops-livestock continuum will clear the picture (Haque et al, in progress).

Crop management for sustained productivity

Residue management

Mulching is the covering of the soil with crop residues such as straw, cereal stalks and standing stubble etc. The cover protects the soil from rain-drop impact and reduces the velocity of runoff and wind. It contributes organic matter, which stabilises soil structure and thus increases infiltration. From a conservation view point, a mulch simulates the effect of a plant cover. It is most useful as an alternative to cover crops in dry areas where prolonged dry season prevents the establishment of ground cover before the onset of the main rains. A mulch should cover 70 to 75% of the soil surface. An application rate of 0.5 kg/m^2 is sufficient to achieve this (Morgan, 1980). A lesser covering does not adequately protect the soil whilst a greater covering suppresses plant growth.

Table 16. Effect of drainage and phosphorus on dry-matter yield and biological nitrogen fixation by clover on Ginchi Vertisol, Ethiopia.

Treatments	BBF	Flat	Mean

T. quartinianum	Dry matter (kg/ha)		
	455	418	436b
T. quartinianum + P	2508	2185	436b
Wheat	622	847	2347a
Wheat + P	1794	1657	735b
Mean	1345a	1277a	1725a
Fixed (kg N/ha)			
T. quartinianum	111.48	10.35	10.91b
T. quartinianum + P	71.57	64.46	68.01a
Mean	41.52a	37.40a	

Within columns or rows, values followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Source: I Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

A study of soil erosion on Vertisols of the Easter Darling Downs, Australia, by Freelain and Wockner (1986) showed that soil cover with crop residue reduced sediment concentrations while higher rainfall intensity increased concentrations, especially at low cover levels. When cover levels are high (50%), there is little variation in concentrations regardless of rainfall intensity. This probably demonstrates the combined effects of surface protection from rain drop impact (energy interception) maintained surface storage and greater flow. Rose (1960) showed the detachment of soil by rain drops to be proportional to rainfall intensity, and cover levels of 20-30% have brought significant reductions in suspended sediment concentrations. These levels may be obtained with 0.15-0.2 kg/m^2 of wheat stubble which is much less than Morgan (1980) recommended.

At Hermitage Research Station, Australia, soil chemical and physical properties of black cracking clay soils were measured after five years under stubble retention trial by Lock and Coughlan (1984). The results showed that increased organic carbon under stubble retention was the only measured changes that coda be considered in the long term but the increase of the organic carbon after five years was still small.

In Ethiopia almost all crop residue is used as animal feed. Even small amounts of different crop stubbles left on the fields are grazed and the fields left bare for most of the dry season which could go up to seven months. The Vertisols are no exception to this practice and the main incidences of erosion happens at the start of the main rains even at low rainfall intensities. Mulch maintains soil moisture to a certain extent: this might contribute to waterlogging.

Forage-based cropping systems

Highland Vertisols have high potential productivity because of their large water-holding capacity which allows crops to survive drought periods or to grow long after the rains have ended (Probert et al, 1987; Kamara and Haque, 1988). The length and reliability of the rainy season determine the cropping options. Cropping options for highland Vertisols are given by Westphal (1975). It is possible to grow two crops a year, one in the rainy season and a second on stored water after the rains (Nnadi and Haque, 1988; Abate Ted a and Mohamed-Saleem, 1992; Abate Ted a et al, 1992).

One of the main objectives of forage-based cropping systems should be the maintenance and improvement of soil fertility and protecting the soil surface from erosion to ensure sustained productivity of highland Vertisols. Forage-based cropping systems need to be given top priority in the Ethiopian highlands where soil degradation is a severe problem due to intense use of these soils. Studies at ILCA have shown that the use of high yielding legume-crop species and varieties in rotations, inter-relay cropping and undersowing allows a reduction of pronounced seasonality of animal feed of the traditional system protects the soil surface and increases water-use efficiency (Haque, unpublished data; Abate Ted a et al, 1992; Kamara and Haque, 1991). However, harvesting such legume-crop production options deplete the soil of nutrients which needs to be systematically replaced through crop residues, manure and fertiliser.

Integrated crop management systems including contour planting, early sowing, balanced fertiliser application and weed and pest control promote good crop growth and provide an early ground cover. The choice of an appropriate crop rotation and crop combination is equally important in soil conservation (Lal, 1984). Cropping systems with multicanopy structure and those that provide continuous vegetative cover throughout the year protect the soil against raindrop impact and reduce runoff and soil erosion.

Agroforestry

Growing *Acacia albida* as a permanent tree crop, on farmlands with cereals and legumes underneath or in between, is an indigenous agroforestry system in the central highlands of Ethiopia Recent reports reveal that the tree thrives well in highlands up to 2300 m asl (Mieche, 1986). The supply of fuelwood, provision of dry season fodder and soil condition improvement are the principal benefits derived from the presence of the *Acacia albida* tree. Improved growth and yield of crops under *Acacia albida* compared to areas outside these trees has been used to infer soil condition improvement including soil fertility and some physical conditions.

In the Hararghe highlands of Ethiopia, 40-year-old *Acacia albida* growing on Entisols and Inceptisols with low to medium N and P have been reported to improve the yields of maize and sorghum that grow under it above those outside the tree (Poschen, 1986). Though the superior growth and yield of maize and sorghum under the *Acacia albida* were attributed to improved soil fertility and soil physical condition status of the soil by the trees, there were no data on the improved properties.

The distribution of *Acacia albida* trees was measured on 14-ha plot at ILCA's Debre Zeit Station. The area had tree densities of 6.52 trees/ha, mean tree heights of 7.81 m and trunk diameter of 0.60 m. Organic matter was apparently higher on the West side of the tree than the East due to accumulated wind blown litter by the prevalent wind direction. Organic matter, N. P and K levels were higher under the tree than outside for all depths and directions. A significant increase relationship between organic matter, N. P. K levels and distance away from the tree was obtained for each soil depth samples. Soil pH, exchangeable Na, Ca and Mg under and outside the trees were similar (Kamara and Haque, 1992).

Data on improved physical, chemical and biological properties of soils under *Acacia albida* tree are required. Such data are needed under traditional management system to fully understand the soil improving potential of the tree. The data should provide guidelines for extending and intensifying the inclusion of *Acacia albida* and other trees in smallholder farmlands on highland Vertisols.

Summary

Vertisols and soils with vertic properties are an important soil group in the Ethiopian highlands. Poor drainage, soil, water and nutrient erosion are the most serious problems on highland Vertisols. Due to their high moisture-storage capacity, they have high production potential and this potential remains underutilised because of the difficulty of managing these soils.

This paper summarises available information on chemical properties, N. P and mineralogy. Literature on the P status of soils, P nutrition of forage legumes and crops, mycorrhizae and P nutrition, species and varietal variation in response to P. P sorption isotherms and P fertilisation based on forage-based cropping systems is reviewed.

The review also highlights the response of various crops to N in the presence of appropriate rhizobium, microbial studies and biological nitrogen fixation and its cycling in Vertisol cropping.

5 Land, soil and water management

K L Srivastava, Abiye Astatke, Tekalign Mamo, Hailu Regassa and Selamyihun Kidanu

Introduction

Several technical constraints relating to hydro-physical properties of Vertisols are of particular significance in small-holder, subsistence-oriented farming systems in Ethiopia where cash inputs and farm power sources are meagre. Firstly, accumulation of excess water in the soil profile and on the soil surface create serious problems for growth of most of the crop plants. Secondly, time periods available for carrying out tillage operations are usually very small as the soil becomes hard when dry and too plastic when wet. Thirdly, cultivated Vertisols are generally susceptible to excessive soil erosion if they are not protected from rain drop impact and gully-forming processes.

The technical constraints, coupled with socioeconomic factors, have led to severe underutilisation of Vertisols in spite of their positive attributes like relatively high moisture storage capacity, several favourable chemical properties, and capacity for structural restoration through swelling and shrinking. Only about 30% of the Vertisol area in the Ethiopian highlands is supporting annual crops; the remaining area is mostly under natural pasture. As described in other chapters, the current productivity levels are quite low and technological innovations are urgently needed. The main aim of land, soil and water-management techniques is to modify and manipulate the land features and soil properties in order to create a favourable environment for seedling establishment and crop growth while preserving the natural resource base. This chapter reviews relevant Vertisol properties, experimental results and the overall experience of the project on this subject.

Hydrophysical properties

The JVP has conducted investigations and compiled information on hydrophysical properties for a number of Vertisol sites (e.g. Kamara and Haque, 1988a; Kamara and Haque, 1988b; Selamyihun Kidanu, 1992). Some examples are presented below.

Kamara and Haque (1988c) found curvilinear relationships between soil moisture and bulk density at two locations (Debre Zeit and Shola). The following regression equation was developed for Debre Zeit:

$d = 2.068 - 0.02118\ w - 0.00004017\ w^2$
where:
d = bulk density (g per cubic cm)
w = gravimetric moisture content (%)

The available water capacity (AWC), which is the difference between moisture content at 333 mbar and 15 000 mbar suctions, was determined in laboratory for a wide range of locations. Table 1 shows AWC values for five locations which ranged from 14% at Akaki to 20% at Debre Zeit. The moisture content values in relation to nine levels of metric potential at Akaki are shown in Table 2.

Table 1. Soil moisture characteristics of the surface layer for five sites.

Location	Volumetric moisture content		
	Field capacity	Permanent wilting point	Available water
Debre Zeit	45	25	20
Akaki	55	41	14
Inewari	47	32	15
Dejen	584	40	18
Dogollo	51	32	19

Measured values of plant available water capacity (PAWC) for Ethiopian Vertisol locations are not yet available. Field determinations of PAWC (Gardner, 1988) at some representative locations need to be taken up for improved assessment of crop production potential.

Kamara and Haque (1988b) observed dramatic changes in initial and base infiltration rates in different periods of the rainy season (Fig. 1). Apparently, these changes could be attributed to swelling in soil mass and closure of macropores.

Kamara and Haque (1988b) and Selamyihun Kidanu (1992) reported consistency limits for different sites. The plastic limit ranged from 29 to 39% moisture content (volumetric) at different locations. Tillage implements can smear a soil readily if it is wetter than its plastic limit, but below the limit it will remain friable. Table 3 presents measured values of liquid limit, plastic limit and sticky point and plasticity index for Akaki.

Drainage improvement

Where external drainage is inadequate, the surface runoff may accumulate in Vertisol fields and cause waterlogging. The infiltrated water often forms an excess water zone in the profile because of extremely low hydraulic conductivity in the subsoil. This may lead to formation of a perched watertable in the root zone.

Thus there are several types of drainage problems in Vertisols whose magnitude may vary from site to site as follows:

- Low airfield porosity caused by inherent soil properties and prolonged wetting
- Ponding of runoff water on the soil surface (specially in depressions)
- Formation of watertable rising into the root zone.

The management practices should tee developed for minimising water accumulation on the soil surface and improving aeration within the top 30-40 cm of the profile. Conventional subsurface drainage techniques (e.g. tile drainage) are generally uneconomical because of the narrow drain spacing requirements as determined by the saturated hydraulic conductivity of the soil. Other options to improve drainage are: land-forming techniques, surface drainage structures such as diversion and relief drains, and management of soil structure through improved tillage and organic matter management.

Camber beds

Based on experiments at Sheno, Holetta and Ginchi stations, construction of camber beds, 7-11 m wide for improving drainage was recommended. Wheat and barley yields were two to three times higher by using these structures compared with traditional land preparation (Berhanu Debele, 1985). The domed shape of the beds encouraged water movement towards the drains provided they were properly aligned to evacuate excess runoff efficiently and safely. Although these were effective in improving drainage, Jutzi and Mesfin Abebe (1986) noted that the structures were inappropriate for the smallholders in the Ethiopian highlands. This led to a search for alternative technologies.

Broadbeds and furrows (BBF)

Encouraged by the traditional use of manually constructed broad- beds and furrows for drainage improvement in Inewari area of the Ethiopian highlands and also by ICRISAT's experience (Kanwar et al, 1982), the JVP decided to evaluate and adapt BBF technology at a number of locations. As discussed in other chapters, BBF and some other technology elements have been found effective and economically attractive at several locations.

Table 2. Moisture content (% volume) in relation to metric potential and soil depth at Akaki

Soil depth (cm)	Matric potential (mbar)									
	0	-10	50	-100	-150	-200	-333	-1020	-15000	AW%
0-10	67.64	65.21	63.92	63.71	60.48	58.81	55.05	49.02	41.21	13.84
10-20	68.88	65.25	63.48	61.11	60.81	58.56	55.86	49.51	42.61	13.26
20-50	68.48	66.33	65.86	63.48	60.45	59.85	55.86	48.16	42.48	13.38

Source: Selamyihun Kidanu (1992).

Figure 1. Infiltration rates in different periods of the rainy season at Debre Zeit, Ethiopia, 1987/88.

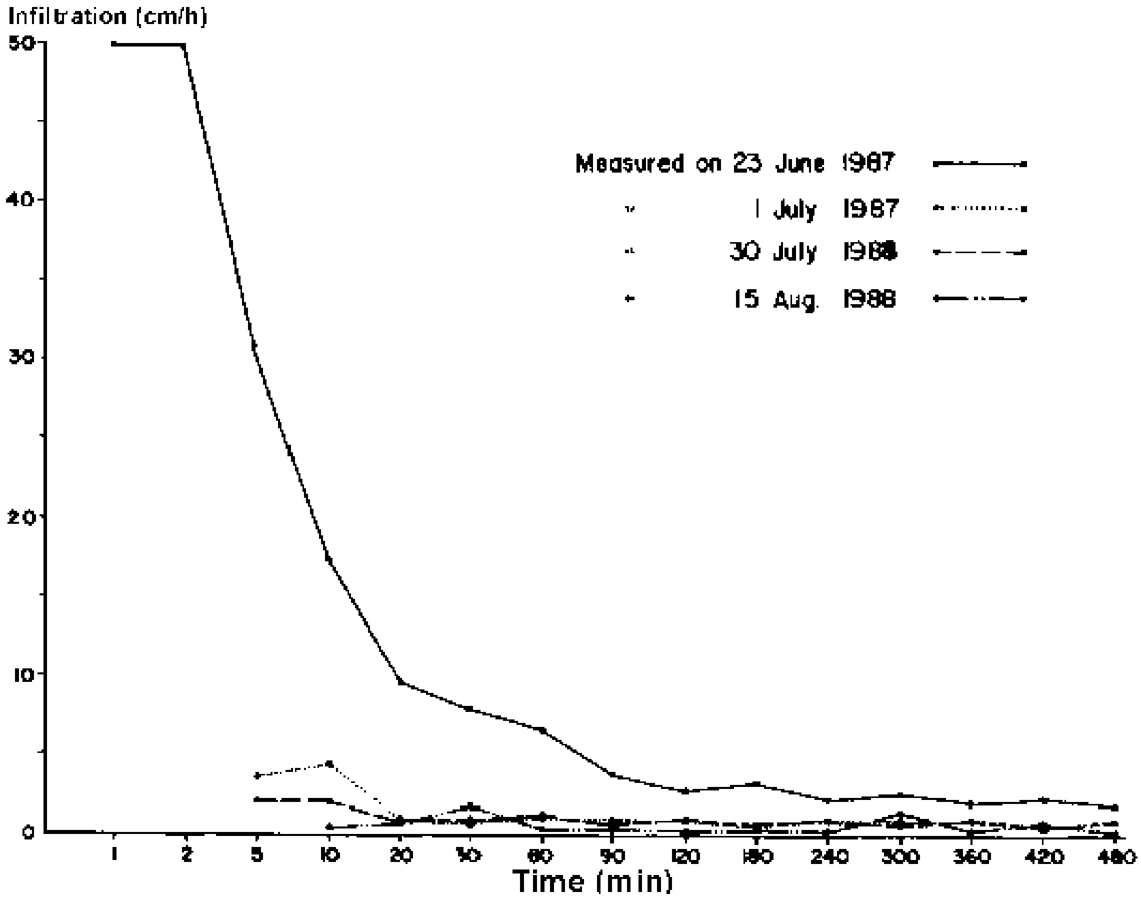


Table 3. Consistency limits (volumetric moisture contents) for the soil at Akaki.

Depth (cm)	Liquid limit	Sticky point	Plastic limit	Plasticity index
0-20	96.0	47.0	35.0	55.0
10-20	98.0	48.0	38.0	61.0
20-50	99.0	51.0	38.0	61.0

Source: Selamyihun Kidanu (1992).

Operational experience obtained through extensive use of BBF method on research stations and farmers' fields is summarised below:

- The BBF should be formed before the soil becomes wet, preferably when the soil moisture is below plastic limit. This helps in keeping draught requirement low and in preserving the soil structure.

- The length of furrow in any one direction of gradient should not exceed 60-70 m. This minimises overflows of runoff from furrows and consequent breakage of beds.

- Special care should be taken to divert external runoff away from BBF plots. It is also important that the discharge end of furrows should be cleared of any deposited sediments.

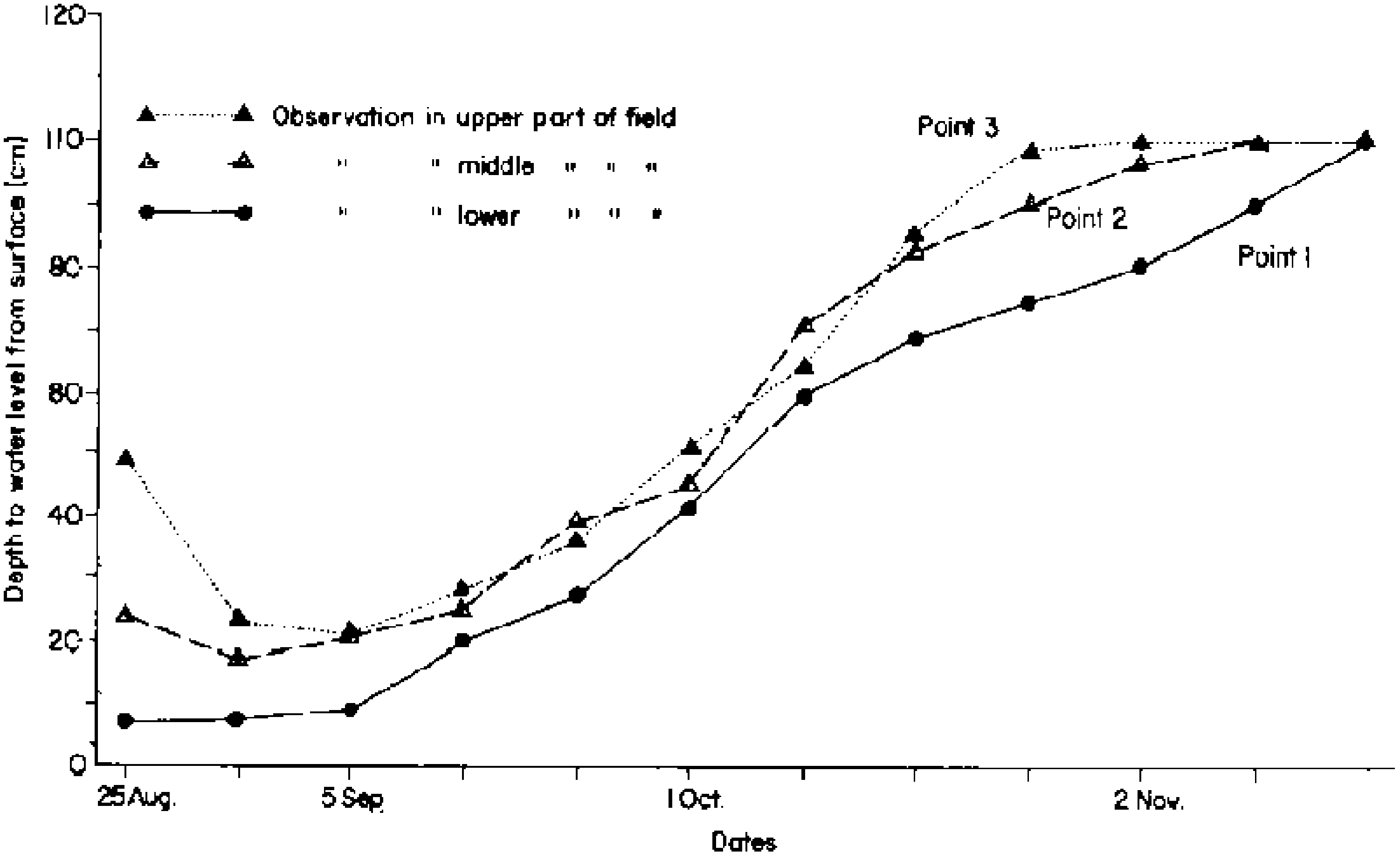
Field depressions

Vertisol fields in the Ethiopian highlands generally include several micro-depressions caused by gilgai 0microrelief. Observations at Debre Zeit and Ginchi have shown that wheat yields per unit area were 58% to 75% lower in depressed areas (maximum depth 15 cm) than in the smooth portions of the field. The positive effects of broadbed and furrow treatment (with 13- cm-high beds) was observed only in the smooth portions of the field and not in micro-depressions. Land-smoothing is, therefore, important for improving the surface drainage of these soils.

Perched watertable

Before 1991, there was no measured data of watertable in the root profile of rainfed Vertisols in Ethiopia. The piezometric measurements at Ginchi (Fig. 2) and Akaki in 1991 and 1992 have shown that perched watertable could rise upto 20 cm from the soil surface during certain periods. This may create anaerobic conditions in the root zone and damage upland crops like wheat, faba bean etc. In view of location specificity of drainage problems, the watertable data should prove useful for finding solutions.

Figure 2. Fluctuation of perched water-table at three observation points at Ginchi station, 1991.



Open ditches

Results of an experiment at Sheno research station in 1988 indicated that 30 cm wide and 40 cm deep parallel ditches (spaced 15 m apart) were quite effective in improving drainage and increasing barley yields (IAR, 1989). These ditches probably lowered the watertable and improved aeration in the root zone. There is need for a systematic and multidisciplinary evaluation of this practice as it appears promising for some situations.

Height of beds

The results from experiments at Ginchi and Akaki in 1991 have shown that broadbed and furrows with 26-cm-high beds produced significantly higher grain yield than the remaining two treatments: normal BBF with 13-cm-high beds and flat (Table 4).

The height of the bed is presently standardised on the basis of specifications of the available implement and draught power. It should be emphasised that the beds of inadequate height may be completely ineffective in some situations and may give suboptimal response in other situations. It, therefore, seems advisable to keep the technology specifications flexible so that, wherever possible, they could be adjusted to match with local requirements.

Soil erosion

There are two aspects of Vertisol management technology which can affect soil erosion. On the one hand, the graded drainage furrow, while draining out excess water, can exacerbate soil erosion. On the other hand, early establishment of crop canopy in the early part of the rainy season can reduce soil erosion. It was, therefore, decided to study the effect of traditional and new land management technologies on soil erosion. The measurement of soil loss from wheat - cropped plots with 0.65% slope at Debre Zeit, have shown that annual soil loss was less than 2.5 t/ha in traditional as well as in new land management plots. In another experiment at Hidi, it was observed that on 2.7% slope, the plot with BBF laid along the slope had annual soil loss of 7 t/ha as shown in Table 5. It is tentatively being recommended that the furrow gradient should not normally exceed 1%. In fields where furrows are vegetated (e.g. through linseed grown in furrows in Inewari area), higher furrow gradient can be used.

In future, more attention is needed for developing appropriate technologies for controlling gully erosion on Vertisols. Gully erosion is already a serious problem and uncoordinatd drainage-water disposal from individual fields may further aggravate this problem.

Table 4. Effect of height of bed on grain yield of wheat (cv ET-13) at two locations in 1991.

Location	Treatment	Bed height (cm)	Yield kg/ha	% yield increase over control
Ginchi	Flat (control)	0	835 (±75)*	-
	Normal BBF	13	979 (±45)	17
	Raised BBF	26	1221 (±45)	46
Akaki	Flat (control)	0	960 (± 62)	-
	Normal BBF	13	1286 (± 73)	34
	Raised BBF	26	1481 (± 73)	54

* Figures in parentheses are standard errors.

Table 5. Effect of two land management treatments on runoff and soil loss from wheat cropped plots at 2.7% slope at Hidi, 1987.

Treatment		Rainfall (mm) (Jun - Sep.)	Runoff (mm)	Soil loss (t/ha)
1	Flat	453	66	3.72
2	Broadbeds and furrows laid at 2.7% gradient	453	124	7.0

Supplemental irrigation

From purely technical standpoint, there are three factors which suggest good potential for runoff collection and supplemental irrigation on Ethiopian highland Vertisols:

- In the middle and later parts of the rainy season, the runoff rates are high.
- In postrainy season, crops suffer from drought and establishment of sequential crops is often difficult without irrigation.
- The saturated hydraulic conductivity of subsurface layers is low. Consequently, seepage loss from ponds is likely to be quite small.

In spite of these favourable factors, this subject of runoff management has not been researched adequately in Ethiopia. This is probably due to recognition of problems in pumping and distributing water and the need for capital investments.

A preliminary study on response to supplemental irrigation applied to chickpea (in wheat - chickpea sequential system) was made in 1987 and 1988. It was found that irrigating once only at the time of planting of chickpea was essential for crop establishment in 1987 but not in 1988 (Table 6). Irrigating more than once was unnecessary or even harmful for Deci-type chickpea (*Cicer arietinum*) (Abiye Astatke et al, 1991).

The problem of runoff collection and supplemental irrigation would require further research for determining their technical, economic and social feasibility in different regions.

Need for watershed development projects

Watersheds as hydrologic units provide appropriate units for conceptualising and planning area-wide drainage improvements, resource conservation and land-use management. They comprise combinations of arable and nonarable lands and drainage lines and are utilised by a community of land users. Considering the need for improving area-wide drainage and land management on Vertisols, there is need for initiating pilot watershed projects at some selected locations. The watershed development involves preparation of inventory of resource-base and available technologies, adaptive and participatory research, planning and monitoring, and evaluation (Doolette and Magrath, 1990). JVP's achievements can form important building blocks for watershed management in the Ethiopian highlands.

Table 6. Effect of supplemental irrigation on yield of sequentially cropped chickpea at Debre Zeit, 1987 and 1988.

Year		Yield (t/ha)				Standard error
		T1	T2	T3	T4	
1987	Grain yield	ny	1.39^{a}	1.38^{a}	1.09^{b}	0.07
	Straw yield	ny	2.16^{a}	2.00^{a}	1.92^{a}	0.16
1988	Grain yield	0.96^{ab}	1.29^{b}	1.21^{b}	0.72	0.15
	Straw yield	1.03^{a}	1.57^{b}	1.76^{b}	1.32^{ab}	0.20

T1 = No irrigation.
T2 = Irrigation at planting.
T3 = Irrigation at planting and vegetative stage (35-40 days).
T4 = Irrigation at planting vegetative stage and at 50% flowering (70-75 days).
a, b, ab = Means with different letters within a row differ significantly ($P < 0.05$).
ny = no yield.

6 Modifying the traditional plough - Maresha - For better management of Vertisols

Abiye Astatke and Ferew Kelemu

Introduction

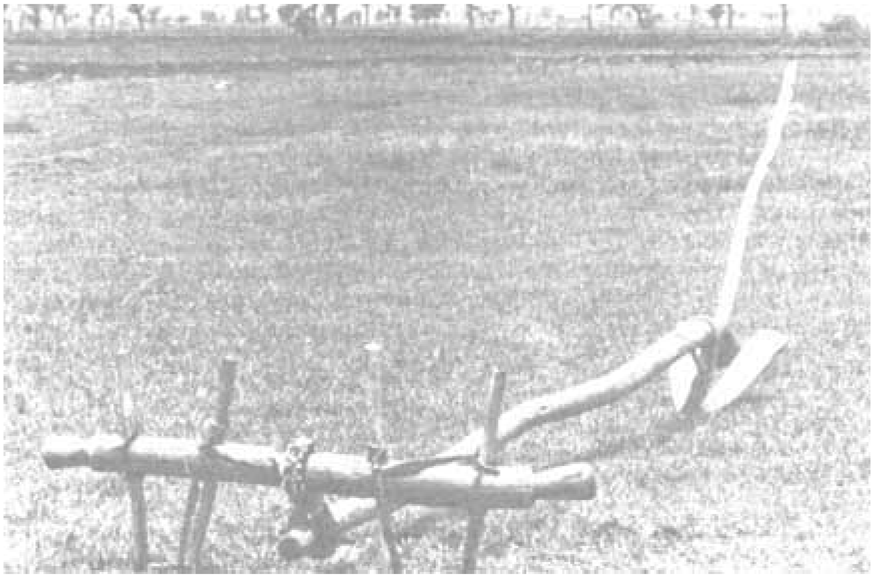
Crop production on Vertisols is often constrained by their physical and hydrologic properties. The main aim of land preparation is to modify and manipulate the land features and soil properties so as to create a favourable environment for seedling establishment and crop growth. The research and development in this field must take into account the practices used by the farming community and the experiences gained from previous research. This chapter provides a brief description of relevant farmers' practices, the traditional implements used and the experience of the Joint Vertisols Project (1986-91) in developing simple and low-cost implements for Vertisols in a highland agricultural system.

The traditional implement - "Maresha"

Historical background

Agriculture in Ethiopia is believed to have started 7000 or more years ago. It is not certain when, during this period, the use of animal-drawn tillage implements began. It has been conjectured that Ethiopians inhabiting the northern cereal growing highland areas of the country were introduced to the ard between 1000 to 400 BC by Semitic-speaking invaders from South Arabia (Goe, 1987). A more recent hypothesis, based on available archaelogical evidence, suggests that the use of the ard may have been developed previous to the Semitic invasion by Cushitic-speaking peoples from an ancient region called Nubia in north-eastern Sudan (Goe, 1987). The use of the *maresha* might not 'have' been associated with one specific group of people. It may have probably been dependent on the physical environment of a particular region that could support animals capable of pulling the implement. Regardless of who introduced the *maresha* or its prototype into Ethiopia, the acceptance and utilisation of an implement which was powered by animals has contributed towards developing crop-livestock integration currently existing in the country.

Figure 1. The traditional plough - *maresha*.



Description

There are certain areas in the highlands where hoe-cultivation is still practiced But by and large, cultivations are carried out by oxen, pulling the traditional plough the *maresha* Again in certain small pockets of the country, horses and mules are occasionally used to pull the *maresha*, but generally, oxen provide the main tractive force.

The traditional plough consists of a metal point or tine, fastened on a wooden arm, to the pole, which in turn is fastened to a 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 traditional plough is a light implement ranging from 17 to 26 kg with the yoke (Goe, 1987) and makes it possible to be transported together to and from the field over different terrain by one person. Except for the metal tine which the farmer has to buy from the blacksmith at about US$ 1.00, the rest is home-made. Depending on the crop types, three to five cultivations are required by the *maresha* before a field could be ready for planting (Table 1).

Each cultivation pass is made perpendicular to the previous one so as to disturb the whole soil. The depth of the first ploughing ranges from 5 to 8 cm while with the last pass up to 20 cm depth could be attained. The time required for land preparation also varies from 100 hrs/ha to 150 hrs/ha for Vertisols and light soils, respectively (Abiye Astatke and Matthews, 1982). The *maresha* has the advantage of being handled by a pair of indigenous oxen each weighing not more than 300 kg. The power developed by a pair of local zebu oxen pulling the *maresha* ranges between 050 to 0.90-kw (Abiye Astatke and Matthews, 1980).

Table 1. Average annual input of animal power (pair of oxen) for cultivation and seed covering for different crops at Ada and Baso and Worena *weredas* (hours/ha).

Crop type	Ada *Wereda*	Baso and Worena *Wereda*
Teff	165	n.a.p.
Wheat	144	148
Barley	n.a.p.	119
Horse beans	112	120
Chickpeas/field peas	103	79

n.a.p. = crops not grown in the area.
Source: Adapted from Gryseels and Anderson (1983).

The power developed is dependent on the soil type, soil moisture, soil compaction status, depth of ploughing and the pulling power of the animals.

A serious disadvantage of the *maresha* is that it is a cultivating implement rather than a plough. The soil is not inverted and there is no cutting action. It will be seen therefore, that whilst the *maresha* is an ideal cultivating implement, it is of very little use in burying stubble and weeds. It is significant to note that weeding out grass-type weeds from cereal crops is a major activity in the agricultural calendar making it probably the most serious bottleneck.

The other problem using the *maresha* occurs during seed covering. In the traditional cultivation method, all the cereal crops and pulses after being broadcast will be covered by a pass with the *maresha*. The exception is *Eragrostis tef* which is broadcast and left. Thus the depth of 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 double or sometimes triple the seed rates recommended by research institutes, as germination rates would be low otherwise.

Previous modifications

The development of a suitable mouldboard plough as a replacement for the *maresha* continued to prove difficult up through 1980, with major obstacles being cost, weight, durability and difficulties in getting repairs made at the artisanal level. Past attempts to modify the *maresha* have included the "Jimma plough" in which the wooden soles and share were substituted with flat iron strips and a vertical knife, the "Vita plough" in which the complete ard head of the *maresha* was replaced with a metal mouldboard assembly, and the "ARDU plough" which is a modified version of the "Vita" design (ARDU, 1980; Goe, 1987).

The Jimma plough was found to function poorly with respect to angle adjustment of the vertical wedge, and because the flat iron strips were stronger than the wooden soles there was a greater tendency for the beam to break at its base. Trials demonstrated that while the Jimma plough provided a better tillage than the *maresha* on loose soil, it had no advantages when used on fallow plots or clay soils (Goe, 1987). It was also more costly than the *maresha*.

Tests with the "Vita" prototype indicated that design changes in the moulboard assembly and angle of the handle were necessary to improve its tillage performance. These and other modifications were subsequently incorporated into what later became known as the 'ARDU plough'. However, this plough was rejected both by farmers and extension agents because it was too heavy to be easily transported to and from the field. The metal frame which was attached to the beam to support the mouldboard assembly did not provide adequate stability and the durability of the share and mouldboard were poor due to the high cost of the plough. It also had a higher draught requirement (10-40%) than the *maresha*, thereby causing the oxen to become more easily fatigued (ARDU, 1980). Overall, adoption of these three implements has not been successful.

Traditional practices followed for growing crops on Vertisols

During the main growing period, waterlogging is one of the major constraints for crop production in the Ethiopian highland Vertisol areas. The severity of the constraint varies from area to area depending on the clay content of the soil, rainfall (during that period) and the soil temperature which also depends on the moisture content of the soil. Farmers of the Vertisol areas realise the adverse effects of waterlogging on crop productivity and have developed traditional methods for overcoming it.

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, rough pea 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. Hence crop yields are low averaging 0.8 t/ha (Berhanu Debele, 1985).

In the high-altitude areas of Ethiopia, ie. above 2400 m asl, a unique practice called *'guie'* is adopted for growing barley on Vertisols after leaving the area fallow from 5-8 years (Tesfaye Tessema and Dagnatchew 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 (Berhanu 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 for fallow. The burning of the soil *'guie'* changes the top soil structure producing more coarse texture which facilitate better water movement and drainage.

Different cultivation techniques are also practiced using the *maresha* to minimise 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 horse bean, field peas, barley, linseed and sorghum are planted (Abate Tedla and Mohamed-Saleem, 1992).

In some parts of the central highlands of Ethiopia (Shewa and Gojam), drainage furrows are made with the *maresha* on the flat seedbed after planting These furrows are made across the contour at distances ranging from three to seven metres. These drainage furrows have an average of 15 cm and depths of 20 cm. The area taken by the drainage furrows from the crop areas can be 10-15% (Westphal, 1975). In areas with high rainfall, it is common practice in the traditional system to make ridges and furrows using the *maresha*. The ridges and furrows are made after broadcasting the seeds on the traditionally prepared seedbed. The ridges and furrows are again constructed by the *maresha* at an interval ranging from 40 to 60 cm. The height of ridges from the bottom of the furrows varies from 10 to 15 cm. The major problem with this traditional system has been that no outside drainage is constructed to take the field water. On very low slopes, this practice does not drain out the water from the field. The water thus forms ponds in the furrows (Fig. 2). On moderate and higher slopes, the flow of water from the fields accelerates erosion.

At Inewari which is found in the central highlands of Ethiopia, surface drainage of Vertisols is facilitated with the use of manually formed broadbeds and furrows (Fig. 3). The seedbed is prepared 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 not only form the broadbed and furrow but they also cover the seeds. In the traditional system, grass drainage channels are also constructed to carry the water coming from the crop fields. This practice of constructing broadbeds and furrows manually involves hard work for the farm family.

Figure 2. Ponding of water in the furrow tillage system.

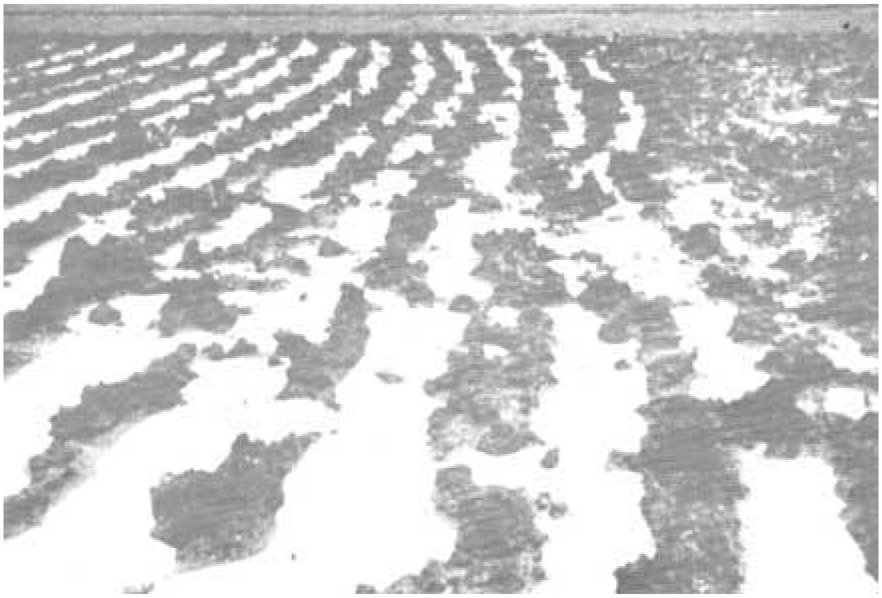


Figure 3. Broadbed and furrow construction using manual labour at Inewari.

General criteria considered in designing the BBM and attachments

General criteria considered in the design of the broadbed maker and attachments are soils, the resources available to the farmer, traditional farming systems and manufacturing and repair facilities locally.

Soils

Vertisols are comparatively fertile soils found mainly on land with a slope not exceeding 8%. These soils have clay contents between 35 and 80%, which largely determine their physical properties. Due to the high clay content, the water-holding capacity is high, the infiltration rate low, and the internal drainage slow. This often leads to waterlogging during the main rainy season. At low soil-moisture levels, Vertisols shrink forming cracks up to 10 cm wide and become hard whine wet; they also swell and become plastic and cohesive. This characteristic allows only partial exploitation of the potential of these soils by using traditional cropping practices, especially in high rainfall areas.

The changes required in the farming system need the tillage to be undertaken earlier when the soils are dry and hard. Shallow, rather than deep, tillage is desirable so as to allow for better weed control on Vertisols (Willcocks, 1984). This will minimise draught and reduce the amount of secondary tillage needed to break down large hard clods. The ability of Vertisols to loosen and regenerate their structure makes deep tillage unnecessary.

The Vertisols of the Ethiopian highlands are generally considered to have low available N and P (Asnakew Woldeab, 1988; Desta Beyene, 1988). Vertisols are not abrasive and for items of limited use mild steel should be adequate.

Farmers' resources

The limited cash income estimated at US$ 155 per annum (Gryseels and Anderson, 1983) for subsistence farmers of the Ethiopian high ends will be a major constraint to the dissemination of improved tools and farming methods. Implement designs should aim at low costs in order to be accepted by the majority of farmers. Farm sizes are about 2.5 ha but they split into smaller plots and are often at a great distance from the farmstead (Gryseels and Anderson, 1983). Therefore, implements will need to be light enough to transport and manoeuver easily

Traditional farming systems

The traditional systems use only the *maresha* and a pair of oxen for seedbed preparation and seed covering. The ground is left fallow throughout the dry season, providing little grazing for cattle. At the start of the small rains (February/March), the *maresha* is used to break the land for weed control. It is also used in incorporating trash with severe passes when soil moisture is suitable and until the crop is broadcast late in the main rains (August/September). Most crops are covered by using the *maresha* again.

The major crops grown on Vertisols are wheat, sorghum, teff, faba bean, chickpea, rough pea, lentils, noug, fenugreek and linseed. Weeding is done by hand.

Animal power seems to have a direct effect on production in the highlands with farmers who own a pair of oxen producing 62 - 82% more than farmers with no oxen (Gryseels, 1988). There also appears to be an effect on the cropping pattern as farmers with no oxen sow more pulses than ox-owning farmers. Pulses grow with lower labour inputs and rougher seedbeds than cereals. They also have lower gross margin and may, therefore, lead to lower income (Gryseels, 1988).

Manufacturing and repair facilities

Many materials are available but since most of the small rural cooperative workshops or blacksmiths find it more convenient to build the implements, it would be better to design the implements based on materials available there. Wood in the highlands is often scarce and of poor quality. The more sophisticated equipment might be built at a large centralised workshop which could possibly use other materials.

It would seem appropriate to use traditional blacksmithing techniques as far as possible in the design of the equipment. This would reduce the need for skilled training and the purchasing of special materials. It could also allow an informal dissemination of the equipment if they prove popular.

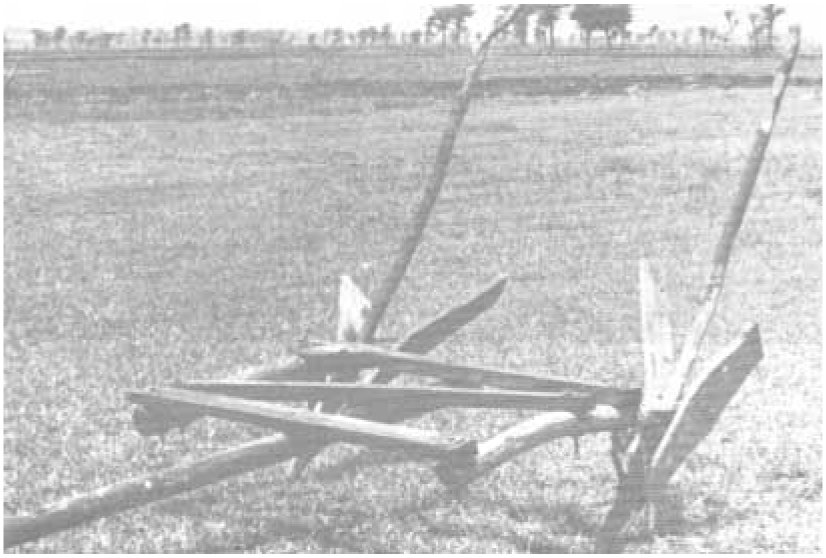
The broadbed maker and its evolution

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) developed an animal-drawn tool carrier in the mid-1970s for forming broadbeds and furrows to improve surface soil drainage of Vertisols (ICRISAT, 1985). The ICRISAT wheel-tool carrier is effective but there are several drawbacks that can hinder its easy acceptance by farmers. The power requirement of the wheel-tool carrier is higher than a pair of local zebu oxen could produce. It is also expensive as it is beyond what the subsistence farmers, who make up the majority of the farming population in Ethiopia, could afford. The International Livestock Centre for Africa (ILCA), with the collaboration of other national and international institutions started work on developing low-cost land-shaping implements based on local materials in 1986. From the beginning of the implement-development programme, farmers in the on-farm verification were invited to test the implement and their suggestions were incorporated in the design-refinement undertaking.

The first land-shaping implement had a wooden wing of mouldboard shape, replacing the traditional flat wings of the *maresha*. After loosening the soil (3-4 passes with the *maresha*), the implement was used to shift the soil. The time it took to form raised beds of one metre was equivalent to that of the *maresha* which took about 40 hrs/ha but the quality of the raised beds depended on the skill of the operators. Better quality bed formation was attained where the shift lines of the soil were close to each other. But where the shift lines of the soil were wide apart, they left depressions on the raised beds allowing water accumulation which reduced crop yields. With this modification it was found that making uniform beds was difficult to attain by farmers working on the on-farm verification. They also rejected the system on the basis that it was time-consuming.

The second version was a broadbed maker (REM) made from the *mareshas* (Fig. 4). The main beams of the *mareshas* were shortened to about 90 cm and were connected with a simple wooden frame. The two flat wings were replaced by mouldboard-shaped wings, two bigger ones throwing the soil to the centre and two smaller wings throwing it outside. Like its predecessor, this implement could only be used for land-shaping and therefore the field had to be ploughed with the *maresha* three to four times prior to its use. This implement weighed about 35 kg depending on the type of wood used. The average power consumption of 0.7 kw was about the same as the first ploughing required with the *maresha* (Jutzi et al, 1986). From on-farm verification trials, farmers found this BBM too heavy and bulky to transport to and from the field. They also expressed difficulty in finding the needed 12 bolts in the rural areas for making the frame of the BBM and the spanners required to tighten the bolts.

Figure 4. The broadbed maker was made from two shortened *mareshas* framed together.



This led to developing another version of the BBM which is in use today. It was made out of two *mareshas* connected in a triangular structure (Figure 5). The top ends of the *maresha* beams are tied together and connected to the yoke as the traditional method. For maintaining the distance of 1.2 m between the *maresha* tips, a crossbeam was tied between the two poles of the *mareshas* at around a metre from the lower edges of the poles. A steel wing of mouldboard shape is then attached on each of the inner flat wings of the *maresha* to push the soil inside and form the broadbed and furrow (BBF). The chain attached at the edge of the metal wings not only shapes the beds evenly but it also covers the seeds as the previous BBM. The power requirement for this new BBM is lower (0.62 kw) than the previous one and can be attributed to the metal wings which have lower frictional force through the soil than wood. The area constructed into BBF in six working hours by a pair of oxen ranges from 0.4 ha to 1.2 ha for this and the previous BBM. The rate of work depends on the number of passes applied to make each BBF, the filth status of the top soil and the condition of the working oxen. On-farm verification with the latest version of the BBM has continued until 1990 and the farmers seem to be satisfied with it. However, the farmers observed greater weed infestation on the BBF plots than on the traditional flat seedbed.

Figure 5. The last version of the broadbed maker: two *mareshas* connected in a triangular shape.

BBM attachments and their significance

The work described in this section, would be the attachments for the BBM designed for reduced tillage, weeding and seeding to allow permanent broadbed system to be developed. The potential benefit of post-harvest cultivation with the aim of reducing tillage requirements is obvious; the seedbed preparation time on broadbed can be reduced drastically. Better control of weeds and stubble incorporation could be possible and it can also partially fill the cracks thus reducing moisture loss which can help for the following crop.

The traditional method of planting most crops is broadcasting and covering by using the *maresha*. This method of covering has been shown to mix 15.3% of broadcast wheat seed to a depth of 10 to 20 cms yet leaving 25.3% within the top 2.5 cm (Tinker, 1989). Due to this variation of coverage depth emergence of crops is lower and might be the main reason why farmers use high seed rates. The Institute of Agricultural Research recommends most sorghum varieties to be planted at a rate of 7-10 kg/ha while farmers use up to 30 kg/ha.

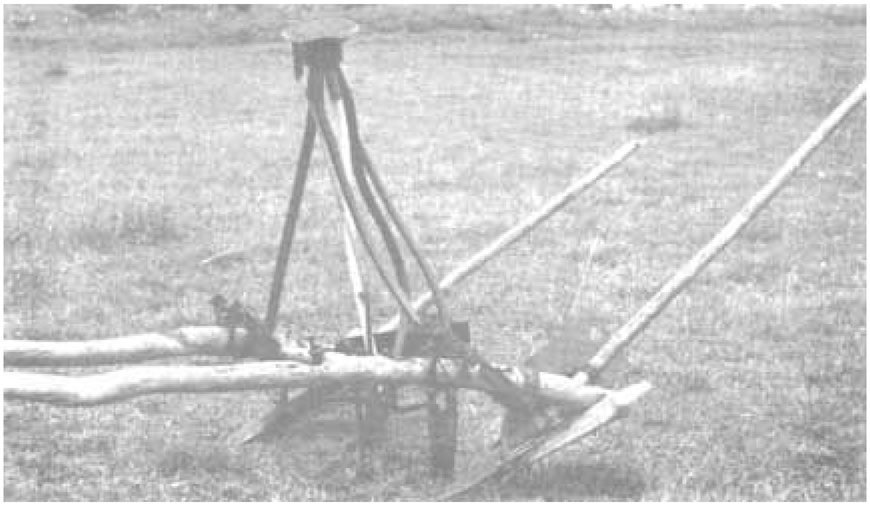
The broadcasting method of planting also makes it impossible for mechanical weeders to be used. Hand weeding is probably the most time-consuming operation in the traditional system. The labour requirement for weeding teff was 300 man-hours/ha while for wheat it was half of what was required for teff (Abiye Astatke and Matthews, 1980).

The planter attachment developed is similar to the traditional planters used in India and other countries in the region. The attachment is a simple hand-metered seeder that mounts on the

BBM (Figure 6).

The construction materials consist of sheet metal (1.3 mm thick) which are used for constructing the funnel and steel pipes. They are also used for connecting the funnel to the transparent polythene hose which carries the seeds to the steel pipe thus leading the seeds into the furrows opened by the metal tines.

Figure 6. Hand-metered planter mounted on the broadbed maker.



The planter was tested with wheat and maize on half a hectare each. It took 6.5 hrs/ha to plant wheat and 5.3 hrs/ha for maize. The seed rates for wheat and maize using the planter were 74 kg/ha and 31 kg/ha, respectively, while in the traditional system the seed rates being used for wheat range from 85 kg/ha to 110 kg/ha varying from area to area (Getachew Asamenew, 1991). The seed rate for maize in around 45 kg/ha. The tine attachment used for planting can also be used for weeding without causing major soil disturbance. Interrow cultivation of wheat was difficult by the tines because the row spacings were close to each other (10-cm space). For maize, which had row spacing of 50 cm, there was no difficulty in using tines for weeding.

A blade harrow consisting of a metal blade 4 mm thick fixed on both sides of the maresha tines (Fig. 7) was tried for post-harvest cultivation. 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. At this period, the implement drastically reduced power and time required for Vertisol cultivation, enabling long-term use of the BBF without having to do it again every year. However, most traditional crops have a long growing period stretching into December when the Vertisols have become very dry and hard and use of the blade harrow is difficult and not effective. Tests on the possibility of using tine attachments were carried out when soil moisture conditions were dry (Fig. 8). The purpose of the test was to reduce the number of tillage operations in order to enable the use of a broadbed over several seasons. A tine-bar attachment to the BBM enabled breaking up the surface crusts and remould the broadbeds.

Field preparations by using this method to uproot stubbles down to about 10 mm depth for half a hectare of broadbed and furrow plot without demolishing the beds took only 25 hrs/ha compared to 80 hrs/ha for the previous method of ploughing and making the BBF's.

Figure 7. Blade harrow attached to the broadbed maker.

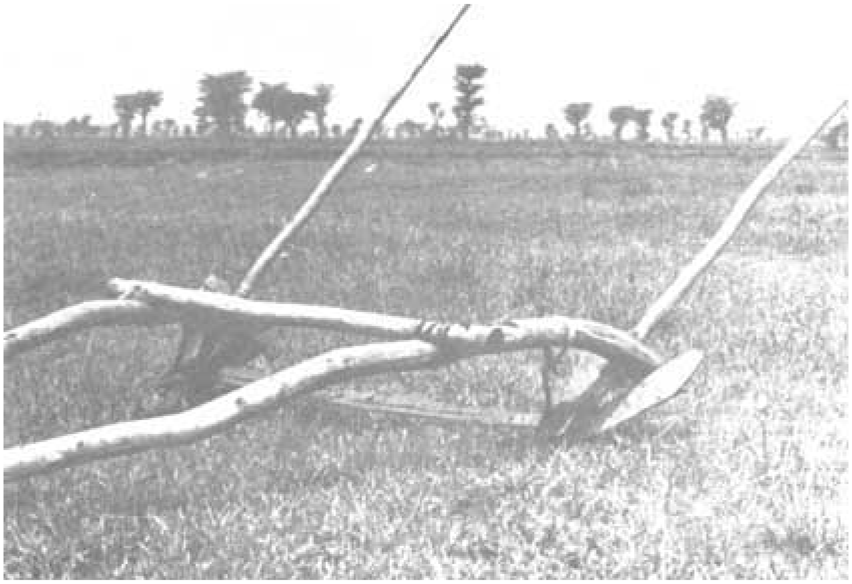
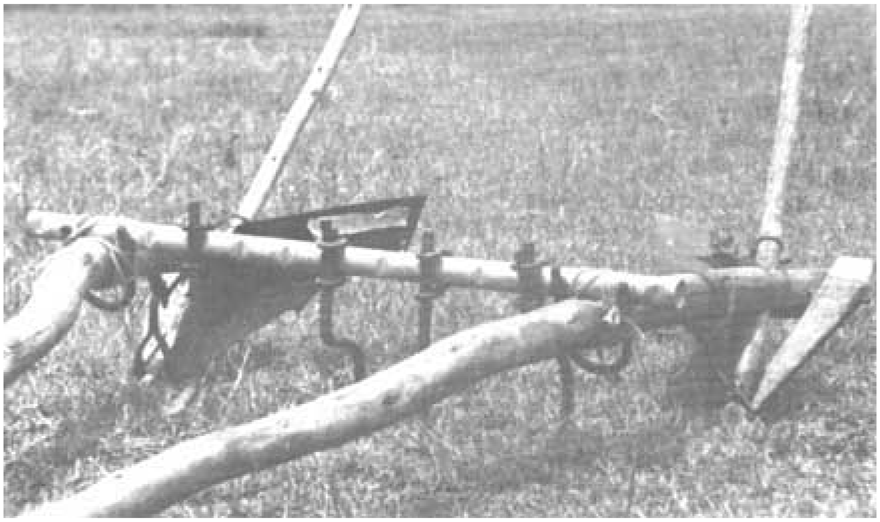


Figure 8. Tine harrow fixed on the cross-beam of the broadbed maker.



The evaluation of the broadbed maker

Background

Agricultural production could be increased either by direct physical inputs like fertiliser and improved seeds or by increasing the area of land which could be cultivated at any one time. The latter requires improved agricultural implements which enhance labour productivity by reducing drudgery. Improvement on agricultural equipment should be undertaken by taking the target group into account. The majority of the Ethiopian farming sector being the small farmer with small fragments of land, the situation limits us to give priority to hand-tool technology and animal-drawn equipment. In the case of hand tools, the power that could be generated by human labour is low and is limited to light work. The case of land preparation specially on Vertisols requires high draft power and the alternative for smallholders is to use animal power. It was with this understanding that ILCA and institutions that collaborate with it developed the animal- drawn broadbed and furrow maker for Vertisol areas. They have been conducting trial on farmers' fields and modifications have been made based on feedback obtained from farmers.

The equipment is now very close to being distributed to the end-user in large numbers. If the implement is to reach the end-user on a wider scale, it has to satisfy two clients simultaneously. One is the direct user, the farmer, and the other is the manufacturer. The manufacturer requires the availability of raw material and the ease of manufacturing to be incorporated in the design process of the equipment. The farmer requires the equipment to meet the purpose it is designed for and that its price is within the range of his economic ability. To confirm this, tests should conducted at representative agroecological sites.

To test an equipment, a standard test procedure which is interpretable (no matter where it is conducted) is required. At the moment in Ethiopia there is no standard test procedure.

The agricultural implements specification and performance standard which is a cutoff line for certification is not set yet. In the absence of all these, the Agricultural Implements Research and Improvement Center (AIRIC), based on the mandate given to it to test all kinds of agricultural equipment and based on its testing experience, has done a preliminary observation on the ILCA broadbed-and-furrow maker. The objective of the observation was to see its technical feasibility in terms of the construction material and skill requirement as well as the ease in operating it. Another purpose was to examine the agricultural feasibility in terms of meeting the purpose it has been designed for. The test was conducted at Debre Zeit on June 6, 1990 in a 12 x 50 m^2 plot size in four replications with wheat as a test crop. Data on the construction features, draft requirement, bed stability and yields were collected. Table 2 shows the construction features of the BBM while Table 3 shows the soil property and performance of the BBM. Measurements of furrow configuration after 50 and 71 days are shown in Tables 4 and 5, respectively, while the crop performance is given in Table 6.

Test results

Looking at the specification and construction material of the BBM, the construction material and the skill requirement are within the technical capability of the rural blacksmith who manufactures *maresha*. It is also within the economic reach of the user.

The BBM is very easy to adjust and assemble and it requires almost the same skill as that of the traditional plough. But it takes more time to set up and is less manoeuvrable in the field. Between the flat wooden wings and the metal wing soil flows down to the furrow and this limits the height of the bed. Before working with the BBM the field has to be well prepared. The clod size has to be reduced considerably since bigger clods tend to flow back to the furrow and result in uneven bed configuration.

The draught requirement of BBM will be high as shown in Table 2 if the BBM is not used at the proper moisture content. The draught increased with an increase in moisture content. The proper time for using the BBM must be specified.

A decrease in the cross-sectional area of the furrow and furrow depth as shown in Tables 3, 4 and S shows that the bed-configuration changes with time during the growth period of the crop. This could be attributed to a build-up of the soil in the furrows caused by erosion of the bed surface.

The draught requirement of the BBM was recorded as high as 140 kgf. which is higher than the capability of a pair of local oxen for sustained operation. This could be minimised by using the broadbed maker in a well-pulverised soil at moisture regime.

Since a performance level standard for the broadbed maker is not set, it is advisable to make a comparative test against the traditional practice of broadbed-making.

Table 2. Construction features of the broadbed maker.

1. Specifications: Overall dimension (measured)	
Length	384 cm

Width	154 cm		
Height (in working position)	77.5 cm		
Overall weight	42 kg		
2. Construction materials and dimension of components (measured):			
Component	**Construction material**	**Dimension**	**(cm)**
Handles (2 pieces)	Wood	Length	165
Chain	Mild steel	Length	111
		Round bar diam	12
Metal wings (2 pieces)	Mild steel	Thickness	3.25
		Width	20
		Length	51.5
Crossbar	Wood	Length	131
		Diameter	4.5
Wooden wings (4 pieces, tapered)	Wood	Length	54
		Max. width	9
		Min. width	0
Metal tips (2 pieces)	Mild steel	Length	40
Beam	Wood	Length	300
Metal hook	Mild steel	Length	20

Table 3. Soil property and performance of the broadbed maker.

Plot no.	Soil moisture content (%)	Furrow x-sectional area (cm^2)	Maximum furrow depth (cm)	Average furrow depth (cm)	Maximum furrow width (cm)	Bed width (cm)	Average speed (m/s)	Draught (k.gf)
1	20.90	340.80	12.55	6.55	48.00	70.50	0.67	120.69
2	26.53	331.78	11.53	5.95	48.50	73.17	0.68	136.75
3	23.99	283.34	11.42	5.69	47.08	71.00	0.67	123.70
4	26.10	357.29	11.92	6.38	48.89	69.84	0.79	140.13
x	24.38	328.30	11.86	6.14	48.20	71.13	0.69	130.00
se	2.23	27.52	0.44	0.34	0.73	1.25	0.06	8.30
cv (%)	9.14	8.38	3.73	5.55	1.52	1.76	8.70	6.37

Table 4. Measurement of furrow configuration after 50 days of formation (July 27, 1990).

Plot no.	Furrow x-sectional area (cm^2)	Maximum furrow depth (cm)	Maximum furrow width (cm)	Average furrow depth (cm)
1	235.00	7.70	46.60	4.28
2	222.55	7.60	44.00	4.20
3	267.50	8.00	50.60	4.72
4	285.00	8.20	54.00	4.85
x	252.51	7.88	48.89	4.51
se	24.92	0.24	3.81	0.28
cv (%)	9.87	3.03	7.81	6.16

Table 5. Measurement of furrow configuration after 71 days of formation (1990).

Plot no.	Furrow x-sectional area (cm^2)	Maximum furrow depth (cm)	Maximum furrow width (cm)	Average furrow depth (cm)
1	183.33	6.67	43.67	3.57
2	162.42	6.17	41.67	3.03
3	215.55	7.00	45.00	4.13
4	183.33	6.33	44.00	3.69
x	186.16	6.54	43.59	3.61
se	19.00	0.32	1.21	0.39
cv (%)	10.20	4.89	2.77	10.86

Table 6. Test results indicating crop performance at Debre Zeit in 1990.

Plot no.	Moisture content		Grain & straw weight ratio (%)	Grain yield (kg/ha)
	of grain (%)	of straw (%)		
1	11.39	20.04	1:1.74	2478.58
2	11.56	9.37	1:2.28	2686.75
3	11.58	9.49	1:2.19	2560.80
4	11.30	10.64	1:2.08	2455.14
x	11.46	12.39	1:2.07	2545.32
se	0.12	4.45	0.2	90.59
cv (%)	1.02	35.89	9.88	3.56

7 Grain, fodder and residue management

Abate Tedla, MA Mohamed-Saleem, Tekalign Mamo, Alemu Tadesse and Miressa Duffera

Introduction

Subsistence-oriented smallholder is the main mode of production in the highlands and, therefore, no special effort is made to grow feed for farm animals. Cattle are mainly kept for draught purposes but they also contribute meat and manure like the small ruminants in the system. Milk from dairy cows seems specialised in peri-urban areas or where there is quick access to milk collection outlets. All ruminants as well as the equines depend on two major feed resources, namely natural pasture and crop residues. Concentrates are well known but are seldom fed to livestock on a regular basis although there is severe feed shortage during the year. Examples can be cited of cultivated forages where there has been some extension effort. Growing oats and vetch by cooperative farmers in part of the crop land and Tagasasste (*Chamaecytisus palmensis*) fencing in the Selale Peasant Dairy Project are some of them.

Although this document is intended to report research on Vertisols, livestock do not respect this boundary as they graze communal land. Hence a general situation of the available feed resources in the highlands is also highlighted which is followed by specific efforts of collaborative partners of the Joint Vertisol Project.

Native pastures

Natural grasslands in the Ethiopian highlands are generally confined to degraded, shallow upland soils, fallowed crop land and to soils which cannot be successfully cropped because of physical constraints such as flooding and waterlogging. Thus natural grasslands occur in conditions presently considered adverse for cropping. However, in the future increased human population pressure will force farmers to push cropping onto these traditional grasslands.

Previous surveys in Ethiopia claim that in areas classified as intensively cropped, up to 40% of the surface is still under volunteer or permanent grassland vegetation, including roadsides and pathways, spaces between plots etc. This suggests that a considerable number of animals can be fed on this resource even in highly populated areas.

It has been estimated (Lulseged Gebre-Hiwot, 1985) that there are 73 million ha of native pasture land in the Ethiopian highlands receiving more than 700 mm annual rainfall, with 24 million livestock units (LU) in the same area. These figures indicate that native pastures are an important feed source. However, even when a high average dry matter production of three t/ha/year is assumed for this grassland, these areas could only contribute a maximum of 50% of the total feed required. The remainder, only partly met by crop residues, explains the need for improvement and management of feed resources for high livestock production.

Improvement of native pasture

ILCA's Highlands Programme devoted considerable effort to carry out research on native pasture improvement mainly on flat deep clay soils which exert less stringent constraints on plant growth than the shallow degraded upland soils.

Three interventions which seemed to be promising for increasing native pasture yield and quality were tested at three different altitudes (1900 m, 2400 m, 2800 m asl). These included plant nutrient supplies, forage legume oversowing and soil ripping to improve aeration and accelerate nutrient mineralisation. These treatments were partially successful in terms of increasing pasture yields or legume proportion of the swards.

Table 1 shows two-year results on an *Andropogon longipes* pasture in Debre Berhan (2800 m asl). No effect on yield or quality was recorded which is evidence of the ecological stability of these native pasture communities. Similar trends were recorded in Debre Zeit (1900 m asl) on *Hyparrhenia* pasture. Dry-matter yields in the warm ecosystem of Debre Zeit were about one and a half times higher than in Debre Berhan. The *Hyparrhenia* pasture in Addis Ababa (2400 m asl) reacted slightly differently in that the legume percentage in the dry matter was strongly increased by oversowing (Table 2). As Table 3 shows, however, this qualitative improvement is rather insignificant since it can not be acquired if the pasture is not properly managed, such as if it is cut too late.

All these yield figures have been recorded on plots which have been protected from animal access during the experiment. They are, therefore, only relevant for the assessment of the production of those few pocket areas in the highlands where hay is traditionally made.

Table 1. Effects of legume oversowing[1] soil ripping[2] on the dry-matter production of a native *Andropogon longipes* pasture at Debre Berhan (2800 m asl), 1983 and 1984.

Treatment[3]	Total DM (t/ha)		Legume DM (%)	
	1983	1984	1983	1984
No ripping; no oversowing	4.17a	3.62	0.51	1.12
No ripping; oversowing	4.23a	3.62	0.50	0.82
Ripping; oversowing	3.52b	3.85	0.59	0.91
se of treatment means	0.32	0.19	0.23	0.56
Significance of treatment effects[4]	s	ns	ns	ns

1. Five kg/ha each of *Trifolium tembense* and *Trifolium rueppellianum*.
2. 15-cm-deep ripping of soil with animal-drawn metal tine attached to the ox-plough (30-cm distance between lines).
3. Means of 0 and 30 kg/ha P.
4. s = significant; ns = not significant; means followed by the same letter are not significantly different at the 5% probability level.

Table 2. Influence of soil ripping[1] and oversowing[2] of legumes on dry-matter (DM) yield, crude protein, plant phosphorus, dry-matter digestibility and botanical composition of a native *Hyparrhenia* pasture at Addis Ababa (2400 m asl), 1984.

Treatment				

Parameter	Control	No ripping; oversowing	Ripping; oversowing	LSD (0.05)
Dry matter (t/ha)	2.5	2.2	2.9	ns
Crude protein (%)	8.0	9.2	10.2	ns
Plant - P (%)	0.19	0.18	0.20	ns
Dry-matter digest. (%)	51.0	53.2	55.3	ns
Legume in DM (%)	13.0	27.0	32.2	11.4

1. Soil ripping to 15-cm depth at 30-cm distance between ripping lines with metal tine attached to animal-drawn plough.
2. Five kg/ha each of *Trifolium pratense*, *Trifolium tembense* and *Trifolium rueppellianum*.

Table3. Influence of harvest date on dry-matter (DM) production, crude protein, plant phosphorus, dry-matter digestibility and botanical composition of a native Hyparrhenia pasture at Addis Ababa (2400 m asl) with partial soil ripping[1], legume oversowing[2] and P fertilisation[3], 1984.

Parameter	Harvest date			
	End Sept.	End Oct.	End Nov.	LSD (0.05)
DM yield (t/ha)	1.7	3.3	2.6	0.5
Crude protein (%)	11.9	11.0	5.2	1.5
Plant - P (%)	0.23	0.19	0.16	0.03
DM - digestibility (%)	58.7	53.6	47.3	2.2
Legume in DM (%)	25.8	38.3	8.0	9.4

1. Soil ripping with metal tine attached to ox-plough, 30-cm distance between rows, 15-cm deep.
2. Five kg/ha each of *Trifolium pratense*, *Trifolium tembense* and *Trifolium rueppellianum*.
3. No P: Control; plus P: 30 kg/ha.

Reference is often made to the heavy overstocking of many highland areas. The consequent overgrazing has negative effects on the overall pasture yield although the extent is difficult to assess under field conditions. A pot experiment was, therefore, carried out where overgrazing was simulated (frequent compared with less frequent offtake). *Andropogon longipes* is the dominant grass species in the central Ethiopian highlands above 2600 m asl on deep black soils which are generally communal grazing areas with heavy overstocking. This grass was compared in the experiment with an exotic grass (*Festuca rubra* cv Cascade) which is similar in its growth habit to *Andropogon*.

Table 4 summarises the results of the pot trial and shows at least two striking results:

> • An offtake which is too frequent (a two-week interval is to simulate the overgrazing situation) drastically reduces total dry-matter production to about half of that observed at a harvest interval of four weeks.
>
> • Input of fertiliser N cannot be transformed into higher biomass production by the grasses once they are too heavily exploited. Thus even if the soil N level were sufficiently high e.g. supposing adequate legume share in the botanical composition, this N could not be effectively used.

Table 4 also suggests better persistence of *Andropogon* under heavy offtake pressure as compared with *Festuca* which is considered to be tolerant to grazing. There is also no evidence for a weaker response of the native grass to N fertilisation.

Table 4. Effects of defoliation frequency on dry-matter yield of *Andropogon longipes* and *Festuca rubra* as influenced by N supply, 1984.

Species	Month of evaluation after beginning of differential treatment	Yield (g) at different defoliation frequencies and N levels				LSD (0.05)
		4 weeks		2 weeks		
		No N	Plus N	No N	Plus N	
Andropogon longipes	First	0.93	1.83	0.48	0.50	0.20
	Second	0.98	1.72	0.59	0.50	0.37
Festuca rubra	First	0.88	1.72	0.42	0.66	0.10
	Second	0.84	1.60	0.17	0.26	0.15

1. N fertiliser was applied at a rate of 100 mg/pot of 2-litre at the beginning and one month after the beginning of the evaluation.

The results indicated that the dry-matter yields of heavily grazed grassland probably do not exceed 1500 kg/ha (half of that recorded under protected conditions) in the highland areas above 2600 m asl and will not exceed 2500 kg/ha below this altitude.

Assuming the highland natural grasslands (7.3 m ha with more than 700 mm annual rainfall) have an average production of two tonnes per ha per year and support some 24 million LU (Livestock Units), then they provide at the maximum one half of the animal feed even if allowance is made for some rangeland resources within the highlands. The remaining livestock feed is in the form of crop residues.

With approximately a million ha crop land in the highlands, this ratio between native pasture and crop residues is very likely to shift in favour of crop residues in the future as the human population continues to increase.

Native pasture is generally confined to soils with rather severe constraints for plant growth. The grassland vegetation that has been produced by ILCA and other research institutes indicates that exotic germplasm performs better than these highly specialised pasture communities unless major changes in the physical or chemical conditions of these soils are undertaken (such as drainage or heavy fertiliser inputs) and unless grassland management practices are changed.

Soil improvements imply capital investments which are more likely to be profitable if the improved soils are afterwards used for food crop production rather than for exclusive animal feed production (unless dairy or beef/smallstock fattening enterprises are considered).

Crop residues as main animal feed and possibilities for increased production

As outlined above, about half or more of all animal feed in the Ethiopian highlands is in the form of crop residues (straws, stubble, chaff or weeds from crop plots). The dependence on this feed source is likely to strengthen along with increasing human population densities and corresponding extension of crop land into traditional grassland.

Twenty out of 28 sub-Saharan countries recorded falling agricultural productivity (per caput) between 1970 and 1981. Among the many factors which contributed to this most worrying development, two are of relevance in this context:

- Increasing population pressure increases the pressure on the available crop land and leads to the disturbance of traditional farming practices geared to preserving soil fertility and stability. In many highly populated areas, ancient soil fallowing practices have been replaced by continuous cropping. Since no or insufficient soil fertility inputs are made on these soils, average yields are tending to stagnate or even decline. This same pressure on land is leading to the dominance of cereals in the crop rotations to the detriment of grain legume crops which previously helped restore soil N levels.

- Increasing population pressure is also forcing farmers to extend cropping onto marginal soils previously not cropped. This development not only contributes to low average yields but also to lower production stability and higher environmental risks (especially soil loss).

Nitrogen deficiency is the major soil-related constraint to increased food crop production in subsistence- oriented smallholder farming systems. Fertiliser N is expensive and often only erratically available. Thus the leguminous plant with its ability to fix atmospheric N through its symbiosis with bacteria is the only soil-N source of significance for these farming conditions. Nitrogen fixation figures between 62 and 290 kg N/ha per year have been recorded in sub-Saharan Africa for a wide range of temperate and tropical forage legumes (Haque and Jutzi, 1984). The legume as a N source in general cropping practices offers a unique possibility for increasing and sustaining food crop and fodder yields.

ILCA has initiated a two-stage research programme on legume germplasm. During the first phase, environmental, nutritional and biological factors limiting legume growth and N fixation were investigated and legumes which perform best in both biomass production and N-fixation under low levels of plant nutrient availability were selected (low input approach). The single most important plant nutrient limiting legume growth in Ethiopia appears to be phosphorus. Some results on the effect of improved P nutrition on growth and nodulation of African clovers have also been reported (Jutzi and Haque, 1985).

In the second phase strategies and technologies are developed for the integration of the 'best-bet' legumes into cropping systems. This requires studies on the agronomic behaviour and the physiological structure of the legume plant itself and on the possibilities for fitting it into the cropping cycles in a most appropriate way.

There are several different approaches for the integration of legumes in strategic uses depending upon local circumstances. The profiles of legumes and cereal crops will determine which of these techniques is most appropriate. These techniques include:

- legumes in rotation with cereals

- legumes as intercrops

- relay cropping whereby normally a cereal crop is relieved by an undersown legume

- so-called sequential cropping whereby a crop follows another crop immediately in the same season

- alley-cropping

and these were adopted.

Fodder improvement in the Ethiopian highland Vertisols

It is estimated that only 25% of the 7.6 million hectares of Vertisols are cultivated at present in the Ethiopian highlands. Despite their potential to support higher productivity, Vertisols are waterlogged, especially in higher rainfall and cooler temperature regimes where evaporative demands are low. As the water recedes native pasture grows luxuriously using the residue moisture in the bottom and Vertisols and provide valuable grazing when herbage growth in the uplands suffer from moisture stress.

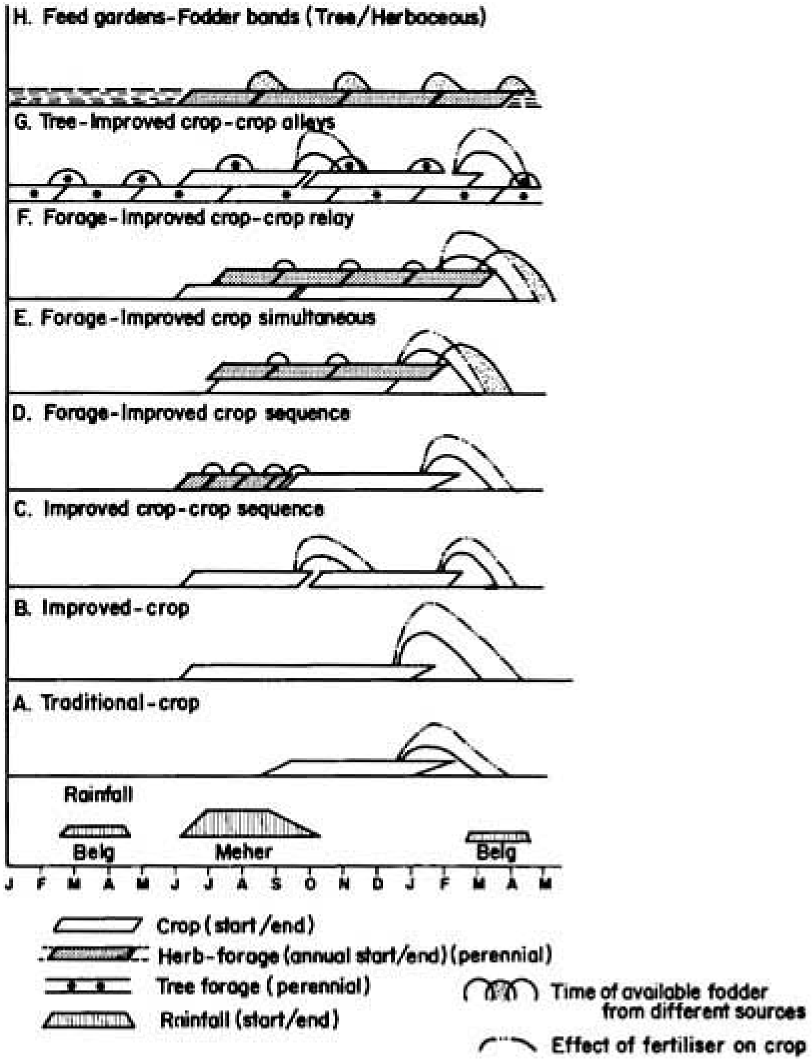
In the food-deficient and land-constrained Ethiopian highlands, the Vertisols could contribute much more if only the seasonal waterlogging constraint is alleviated Land prepared into broadbeds and furrows (using animal-drawn broadbed makers) seems to provide satisfactory drainage and rooting medium. Crops can, therefore, be sown much earlier in the rainy season compared to the traditional practice of sowing late in the season after standing water in the field has drained naturally.

By improving drainage, the entire growing period is potentially available for growing food crops. Farmers would prefer this a so because there is an additional investment for land-shaping to improve drainage. There is a possibility of further increasing the length of the growing period in Vertisol areas by providing a small amount of irrigation to wet the surface as a supplement to the large amount of moisture held in reserve a few centimetres below the soil surface. This will be relevant in Vertisol areas closer to a ready source of water or where ponds have been dug to capture excess water during the early part of the rainy season in order to increase one's crop harvesting ability late in the season.

In most of the Vertisol areas crops are sown during late August early September and harvested during December/January. Harvested crop residues are stored and fed to livestock, most importantly to work-oxen which need to be in good condition before the onset of the next growing season. Yields of the crops that are traditionally grown on Vertisols are very low. The crop residue available at the end of the growing season will depend on many factors most importantly the crop variety, rainfall, soil fertility and the land are cultivated. But since fodder from the cropped area which is low quality is delivered at the end of the growing season, livestock in the Vertisol areas suffer from energy and protein shortages during most of the year. The problem becomes acute for dairy and fattening animals.

An extended growing period provides opportunities for different cropping alternatives. It allows growing two short duration crops or mixtures sequentially or as relay crops, compatible forages as companion crops in mixtures or in alleys and concentrated feed gardens. These options can be manipulated to deliver good-quality fodder in addition to grain but delivery of fodder can also be targeted to desired time and needs. Some of the options are summarised in Fig. 1 and discussed below.

Figure 1. Potential crop-forage production options for drainage-improved Vertisols in the Ethiopian highlands.



Traditional management, cropping patterns and calendar of highland Vertisols

The traditional management of Vertisols in the Ethiopian highlands varies from one place to another depending on the amount and duration of rainfall, extent of drainage problems, soil fertility and slope and farm size. Land preparation techniques include:

- Flat-bed planting
- Drainage furrows
- Ridges and furrows
- Hand-made broadbeds and furrows
- Post-rainy season planting
- Soil burning (*guie*).

These techniques and their applications for cropping have been discussed by various researchers (Mesfin Abebe, 1981; Tesfaye Tessema end Dagnatchew Yirgou, 1973; Berhanu Debele, 1985; Abate Tedla and Mohamed-Saleem, 1991).

The major cropping calendar is presented in Figure 2. Crops like barley, noug, field pea and horse bean are sown at the start of the rains on higher slopes. The crops are also common in areas with low rainfall or well-drained fields. Crops such as teff, durum wheat and lentils are sown during the second half of the rainy season while other crops, namely chickpea and rough pea are sown at the end of the rains.

Most crops are low-yielding under traditional management in the central highlands of Ethiopia (Table 5).

The general rotation practice on Vertisols involves planting a pulse crop after each cereal. However, this varies across the highlands. In some areas, 3-4 consecutive cereal crops, such as teff or durum wheat, follow every pulse crop. Monocropping is common on Vertisols. Broadcasting is the most widely used practice for establishing crops (Figure 3). There are instances of mixed cropping with two or more crops, without distinct rows. The most common mixtures are:

- horse bean and field peas
- teff and safflower
- sorghum and chickpeas wheat and barley
- sorghum and finger millet
- wheat and rape-seed
- horse bean and rape-seed.

Figure 2. Cropping calendar of highland Vertisols.

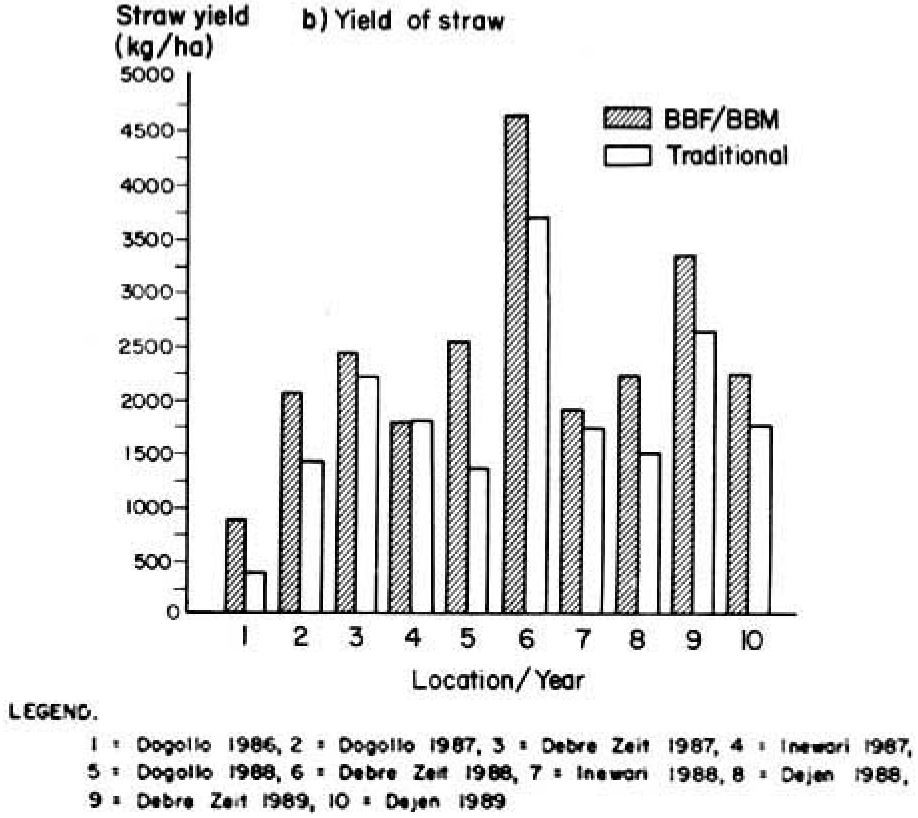


Table 5. Grain yields of food crops on Vertisols under traditional management in the central highlands of Ethiopia.

Crop	Grain yield (kg/ha)
Teff *(Eragrostis tef*)	530
Barley (*Hordeum vulgare*)	860
Emmer wheat (*Triticum dicoccum*)	680
Durum wheat (*Triticum durum*)	610
Horse bean (*Vicia faba*)	750
Linseed (*Linum usitatissimum*)	300
Lentils (*Lens culinaris*)	500

Chickpeas (*Cicer arietinum*)	600
Field peas (*Pisum sativum*)	730
Noug (*Guizotia abyssinica*)	290
Grass peas (*Lathyrus sativus*)	690

Source: Berhanu Debele (1985).

In the Fogera plains, farmers grow two crops sequentially each year. Common crops include teff followed by rough peas and teff followed by chickpeas. Where supplementary irrigation is available durum wheat and maize follow teff as late season crops.

Farmers in highland Ethiopia have traditionally been practicing soil burning (guie) to improve crop productivity in highland Vertisol areas of northern Shewa. In order to create wider management options for use by farmers, assessment of the soil management practices in comparison with the recommended packages have been performed. In a recent study conducted on a Vertisol in order to investigate the chemical changes taking place due to soil burning, it was found that it takes more years before the pH and organic matter of the soil come to equilibrium with the initial levels (Table 6). On the other hand, available P was at its lowest even after 25 years of soil burning. In general the results prove that the practice of soil burning leaves the soil in a less productive state and should be avoided. The productivity of the land may be revived by introducing improved drainage practices.

Figure 3. Altitudinal range (m) of commonly grown crops on highland Vertisols.

Source: Westphal (1975).

Evaluation of improved wheat varieties for drained Vertisols

In collaboration with the Institute of Agricultural Research (IAR) and Alemaya University of Agriculture (AUA), improved bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) varieties for the high and medium altitudes were tested. The objectives of the study were:

- To examine the possibility of early planting of improved wheat varieties on drained Vertisols as opposed to the traditional late planting, towards the end of the rainy season, and

- To evaluate wheat varieties in terms of grain and straw yields and quality across highland drained Vertisol sites.

Table 6. Chemical properties of guied surface soil samples from Sheno as influenced by length of years after burning (*guie*).

Years after guie	p^H (1:1)	% organic matter	Available P (ppm)	NH_4-N (ppm)	Total releasable N
0.5	5.5	3.32	14.00	83.9	155.7
2	5.4	6.50	2.33	9.9	4.8
3	5.3	6.95	3.79	8.5	12.7
5	5.5	3.70	3.21	9.3	14.4
8	6.1	5.93	8.71	9.8	16.9
10	5.8	4.22	1.75	9.3	12.7
15	5.8	7.71	2.33	15.3	20.9
20	6.2	7.64	1.47	12.1	14.7
25	6.2	5.13	1.17	20.8	22.5

Source: Ali Yimer (1992).

Separate field studies have been conducted on several highland Vertisol sites since the 1988-90 cropping seasons.

The first study with improved bread wheat varieties took place in the high altitude (2400 m asl) at Bichena, Inewari and Were Ilu and the second study in the medium altitude (1500-2400 m asl) were at Akaki, Debre Zeit and Ginchi. For both studies local durum wheat varieties were included as check. Details of the treatments/varieties, their year of release and origin are given in Table 7.

Table 7. Name of treatments/varieties and their year of release and origin used in the study.

Treatment/variety	Year of release	Origin
Study 1 for high-altitude sites		
Local durum wheat (check)		Ethiopia
Bread wheat var HAR 407	1987	
Bread var Enkoy	1974	Kenya/Ethiopia
Bread var ET 13	-1980	Ethiopia
Study 2 for medium-altitude sites		
Local durum wheat (check)		Ethiopia
Durum wheat var Boohai	1982	CIMMYT/Ethiopia
Durum var Cocorit 71	1976	CIMMYT/Ethiopia
Durum CIT 71/Candeal II	in the process of release	

Study 1 at high-altitude sites

Low temperature coupled with poor drainage set a limit to crop productivity at Bichena, Inewari and Were Ilu than the mid- altitude highland sites.

Crops also matured late in the high altitudes in comparison to the mid-altitudes.

Grain and straw yields for the four wheat varieties meaned over sites for each year are given in Table 8. The mean grain yield ranged from 805 kg/ha to 1641 kg/ha in 1989 cropping season. However, the mean grain yield in 1990 cropping season were found to be lower than that of the 1988 and 1989 for the same varieties due to hail-storm damage.

In all cropping seasons, there were statistically significant differences among varieties in grain yield. Bread wheat var ET 13 was found to be the highest yielder. Similarly, the strew yield ranged from 1951 kg/ha to 4391 kg/ha in 1989 season and 1806 kg/ha to 3279 kg/ha in 1990 cropping period. For all three years, variety differences in straw yield were significant (Table 8).

The chemical composition and straw quality harvested from the high and medium altitude Vertisol sites are presented in Tables 10 and 11, respectively.

Table 8. The mean grain and straw yields (kg/ha) of bread wheat varieties grown on drained Vertisols at Bichena, Inewari and Were Ilu* high altitude highland sites, Ethiopia.

Variety	Year					
	1988		1989		1990	
	Grain	Straw	Grain	Straw	Grain	Straw
Local check	956	2629	831	3456	710	2622
Bread wheat var HAR 407	1177	2167	805	1951	637	1806
Bread wheat var Enkoy	1268	2906	1203	3751	857	3279
Bread wheat var ET 13	1728	3256	1641	4391	975	2775
LSD (5%)	195	576	122	332	229	521

* Were Ilu site was used only in 1988 crop season.

Study 2 at medium-altitude sites

Mean wheat yields across the three medium-altitude sites for 1988-90 is given in Table 9.

It is evident from the grain and straw figures that durum wheat var CIT 71/Candeal II yielded significantly higher than the other varieties.

With the exception of straw in 1990, significant differences were observed among varieties for grain and straw yields.

Table 9. The mean grain and straw yields (kg/ha) of durum wheat varieties grown on drained Vertisol at Akaki,[1] Debre Zeit, and Ginchi mid-altitude highland sites, Ethiopia.

Year Variety	1988		1989		1990	
	Grain	Straw	Grain	Straw	Grain	Straw
Local check	672	2962	1358	3245	1224	3307
Durum wheat var Boohai	1076	3103	1446	3781	1232	3039
Durum Cocorit 71	1433	3613	1227	3391	1120	2526
Durum var CIT 71/Candeal II	1422	3578	1571	4096	1430	3430
LSD (5%)	651	1096	245	318	122	756

1. Akaki site was used only in 1988 and 1989 crop seasons.

Table 10. Wheat straw chemical composition and quality of four varieties grown on drained Vertisols of high-altitude sites (Bichena and Inewari).

Site	Wheat variety	Ash %	CP %	NDF %	ADF %	IVDMD %
Bichena	Local check	12.84	2.50	69.87	45.40	48.42
	ET 13	12.87	1.81	69.12	47.72	44.98
	HAR, 407	13.63	1.50	69.96	45.23	47.44
	Enkoy	12.02	1.60	70.14	46.74	47.61
Inewan	Local check	15.70	2.44	65.83	38.29	54.75
	ET 13	14.74	2.00	68.43	40.21	49.78
	HAR 407	13.18	2.25	65.35	37.60	54.16
	Enkoy	8.75	2.00	77.60	49.36	45.53
	Mean	12.97	2.01	69.54	43.82	49.08
	SD	2.06	0.37	3.75	4.49	3.65

Table 11. Wheat straw chemical composition and quality of four varieties grown on drained Vertisol of mid-altitude highland sites (Akaki, Debre Zeit and Ginchi).

Site	Wheat variety	Ash %	CP %	NDF %	ADF %	IVDMD %
Akaki	Local check	6.90	2.69	75.80	50.89	57.09
	Boohai	7.42	3.31	68.44	44.65	60.02
	Garardo	6.70	1.62	78.06	51.87	56.35
	CIT 71/Candeal	6.30	1.75	74.71	50.51	58.40
Debre Zeit	Local check	13.03	2.63	71.34	51.26	42.72
	Boohai	12.34	2.44	75.62	51.23	43.34
	Garardo	13.66	2.88	72.24	49.79	42.17
	CIT 71/Candeal	14.62	3.31	70.85	44.85	46.72
Ginchi	Local check	11.52	2.31	73.20	47.11	49.71
	Boohai	11.49	2.38	74.93	49.96	43.17
	Garardo	11.14	1.81	75.95	48.64	42.35
	Mean	10.55	2.48	73.91	49.43	48.71
	SD	2.93	0.58	2.73	2.60	7.22

Comparative yield advantages of improved drainage

Several studies have shown that productivity of Vertisols improve through surface drainage. Of the various methods of surface drainage, the broadbed and furrows (BBF) are effective to improve drainage from plants to durum wheat, chickpea and lentils, which are traditional Vertisol crops. In all the trials BBF-planted crops gave superior yield compared to ridge and furrow or flat planting (Tables 12,13 and 14).

Table 12. Mean grain and straw yield (kg/ha) of durum wheat as influenced by three seedbed preparation method.[1]

Seedbed	Grain^2 yield	% increase over flat	Straw^2 yield	% increase over flat
BBF	1632^a	58	3597^a	36
Ridge/furrow	1325^b	28	3042^b	15

Flat	l034^{c}		2652^{c}	

1. Pooled from yield data for three seasons and three locations.
2. Means in a column followed by the same letter are not statistically different at $P<0.05$.

Drainage influence on fertiliser-use efficiency

In a separate study, the effect of improved drainage on fertiliser-N-use efficiency of two wheat varieties was investigated. From the data given in Table 15 it was found that improved drainage enhanced better utilisation of N by wheat. The response ratios of the two durum wheat varieties were also comparatively better on broadbeds; maximum mean grain yield was also obtained from improved variety Boohai on broad beds.

From the foregoing results, it may be generalised that high returns from improved drainage of Vertisols are evident if the practice is accompanied with additional improved practices such as variety, fertilisation etc.

Table 13. Mean gain and straw yield (kg/ha) of chickpea as influenced by three seedbed preparation methods.[1]

Seedbed	Grain[2] yield	% increase over flat	Straw[2] yield	% increase over flat
BBF	2101^{a}	106	3104^{a}	78
Hat	1021^{b}	28	1743^{b}	
LSD	255		353	
CV (%)	17.3		15.5	

1. Pooled from yield data for two seasons and two locations.
2. Means in a column followed by the same letter are not statistically different at $P<0.05$.

Table 14. Mean grain and straw yield (kg/ha) of lentils as influenced by two seedbed preparation methods.[1]

Seedbed	Grain[2] yield	% increase over flat	Straw[2] yield	% increase over flat
BBF	1944^{a}	106	4685^{a}	78
Flat	1065^{b}	28	2284^{b}	
LSD	96.2		445.2	
CV (%)	8.8		15.2	

1. Data are pooled from yield data for two seasons and two locations.
2. Means in a column followed by the same letter are not statistically different at $P < 0.05$.

Table 15. Effects of N fertilisation and method of seedbed preparation of the grain yield (kg/ha) of two durums grown on Akaki Vertisol.

N (kg/ha)	Local variety (DZ-04-118)				Improved variety (Boohai)			
	Flat	RR[1]	BBF	RR[1]	Flat	RR[1]	BBF	RR[1]
0	1659		2326		2284		2564	

30	2037	13.8	2826	16.7	2311	0.9	3084	17.3
60	2183	8.7	3156	13.8	2934	10.8	3450	14.8
90	2320	7.3	2442	1.3	2516	2.6	3206	7.1
Mean[2]	2059		2688		2511		3076	

1. RR = Response ratio (kg grain/kg N).
2. Yield difference between the two seedbed preparation methods weighted for both varieties is significant at the 5% probability level.

Moisture conservation

It is not always true that all Vertisol locations receive adequate rainfall. Some receive less or rainfall is erratic with uneven distribution during the year. Appropriate management practices are therefore required to conserve moisture. Yearly average rainfall data at Alemaya University campus, eastern Ethiopia, indicate occurrence of rainfall quantity fluctuation from year to year. Table 16 shows that maize yield was significantly increased when planted in furrows of tied ridges as compared to planting on top of open ridges or flat.

Table 16. Grain yield of maize (variety EAH-75) grown on a Vertisol under different soil and water conservation (tied-ridging) practices (Alemaya, Ethiopia).

Treatment	**Yield (kg/ha)**	
	Unfertilised	**N/P fertilised**
Flat planting	4623**ab**	7083**ab**
Open end, planting on ridges	4325**ab**	6624**a**
Open end, planting in furrows	5101**b**	7851**c**
Closed end, planting on ridges	4722**ab**	7176**abc**
Closed end, planting in furrows	4937**b**	7515**bc**

Means followed by the same letter within a column are not statistically different at P<0.05.

Sequential cropping

Sequential cropping is defined as growing more than one crop on the same piece of land with each crop during a different time of the year.

In an experiment which has been in progress fast growing oats and oats/vetch mixture were established in June as first crop, which was harvested as forage for livestock. Chickpea and rough pea were established late as second crop for grain and straw. The first crop was sown in June and harvested at the end of August. Chickpea and rough pea were sown on the same plots beginning August and harvested in January-February (Figure 4) and the results are shown in Table 17.

Introducing a rainy season oats and oats/vetch mixture in areas where feed is an acute shortage during the rainy season due to shortage of communal grazing appears to be a viable alternative, but further large plot studies are needed to determine farmer adoption. Furthermore, utilisation of forages from the sequential cropping needs investigation as hay making is impractical in the wet season. In years with short rainy season or early cessation of rains, the second crops may go into dry periods. Hence crops that can grow on residual moisture and tolerate some moisture stress are required. However, if supplementary irrigation is available most of the highland crops can be grown (Abiye et al, 1989).

In the very high altitudes, low temperature and low solar radiation may limit rate of growth and thus sequential cropping may not be practicable.

Figure 4. Cropping options on highland Vertisols of Ethiopia.

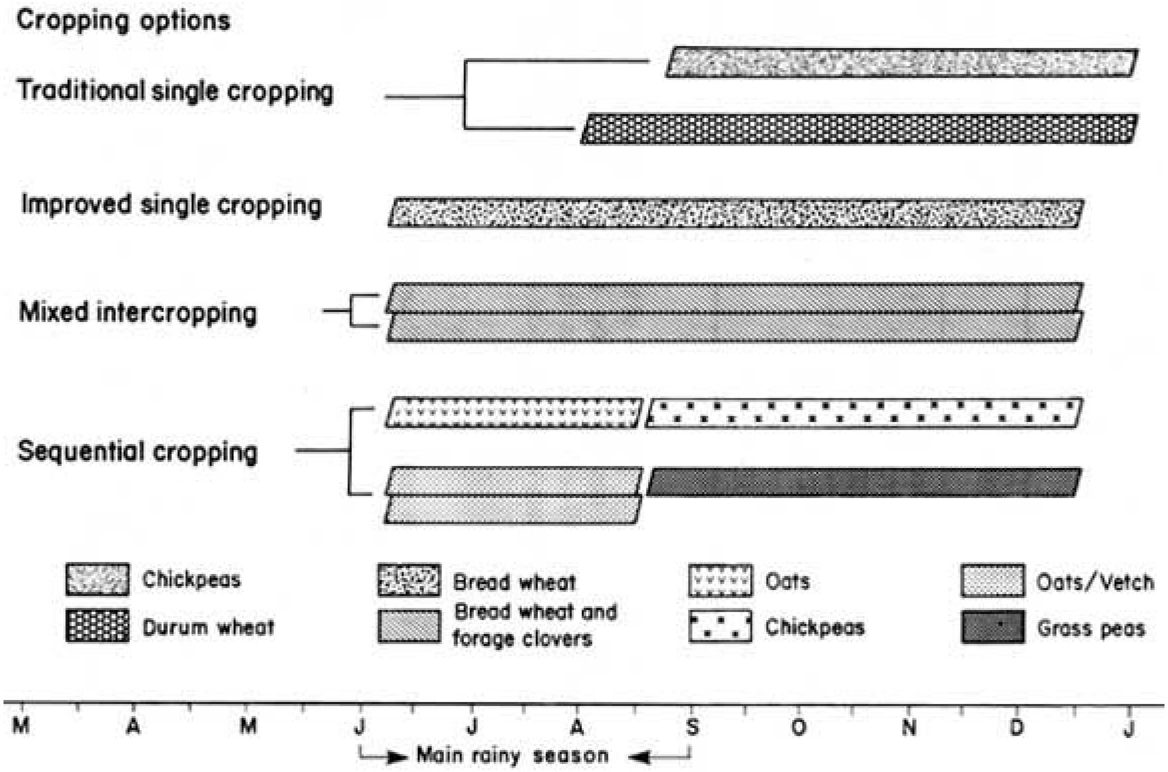


Table 17. The mean yield (kg/ha) of sequential cropping experiment on Vertisols in the medium-altitude highland of Ethiopia.

Year	Location	First crop	DM kg/ha	Second crop	Grain yield
1988	Debre Zeit	Oats in pure	4820	Chickpea	966
		Oats/vetch (mixture)	4716	Rough pea	1588
		LSD (0.05%)	NS		324
1989	Debre Zeit Ginchi	Oats in pure	4305	Chickpea	516
		Oats/vetch (mixture)	4445	Rough pea	1057
		LSD (0.05%)	NS		179

As large quantities of forage in excess of the household livestock requirement become available, there is need to develop storage capability at the farm level. However, in an intense small-scale dairy or fattening-oriented livestock enterprise herbage from early sown oats/vetch can be cut and carried periodically.

Mixed cropping

Mixed cropping is defined as growing more than one species on the same piece of land at the same time or with a short interval (Beets, 1982). The different species are either mixed in an organised manner with a fixed pattern of spacings (row intercropping) or are planted in an unorganized manner, where species are unevenly distributed.

A combination of wheat/clovers mixture was established by broadcasting them together at the beginning of the rains in 1988 and 1989 cropping seasons. The sites were selected in the medium (1500-2400 m asl) and high (> 2400 m asl) altitudes of central Ethiopian highlands on

Vertisols. The medium-altitude sites were Debre Zeit, Ginchi and Akaki and the high-altitude sites included Inewari, Bichena and Were Ilu.

For the medium altitudes *Trifolium steudneri*, and *T. rueppellianum* were used in a 1:1 mixture. For the high altitudes, a mixture of *T. decorum, T. tembense, T. quartinianum* and *T. steudneri* were in equal proportions. The wheat varieties were Enkoy (*Triticum aestivum*), Boohai and Gerardo (*T. durum*) for medium altitudes and for the high altitudes bread wheat varieties ET-13, Dashen and HAR 407 were used. Clovers and wheat where sown at the rate of 10 kg/ha and 150 kg/ha, respectively. Diammonium phosphate (DAP) was applied at the rate of 100 kg/ha at planting. Seeds were manually broadcast in late June of each year after land was prepared as broadbeds and furrows using the broadbed maker. Wheat was sown first and covered with soil, followed by broadcasting clovers mixture on the same day. The plots were selectively handweeded, leaving the clovers under the wheat. Harvesting was done starting at the end of October and continued till November. Wheat was first cut to 0.4 m to separate the grains and then to ground level and separated into clovers stubble end wheat straw. Wheat strew from belong end above the 0.4 m height together determined wheat straw yield.

Tables 18 and 19 show the results of mixed cropping experiments in 1988 for the medium- and high-altitude sites. In the medium altitudes wheat varieties differed significantly in both grain and straw yield, but the association of clover mixture caused no reduction in wheat grain and straw.

The 1989 results from the same experiment in the medium- altitude sites are also shown in Table 20.

In general, wheat varieties grown alone produced less straw compared with those grown in association with annual clovers. It proved that mixture of clovers can grow together with improved wheat varieties on drained Vertisols, without adversely affecting wheat grain yield. This seems, therefore, a good way of enhancing the quality of crop residue in smallholder situations.

Row intercropping

Sorghum and maize are important crops in the mid-altitudes. They are planted in rows. As a way of improving the fodder quality for legume types, namely cowpea (*Vigna unguiculata*), clover (*Trifolium steudneri*) and Lablab (*Lablab purpureus*), they were sown under between the crop rows during 1990 and 1991 season.

Grain and fodder yields and fodder quality of the crop/forage mixture were compared for a similar land unit with sole crop stands. Harvest for grain from sole maize, sorghum and wheat and of the mixture was carried out on the same day.

The fodder from the sole crop was the total of the dry matter from two weedings and the crop residue. The fodder from the mixture was composed of crop residue, weeds from the two weeding operations and herbage cut from the different forages sown in the mixture three times (August/October/January), twice (September/December)/or once. Table 21a and 21b presents a situation where forage was cut twice.

Results suggest that different legumes can be manipulated to take advantage of their growing habits and livestock feed requirements without substantially reducing the anticipated food grain yields. In situations where food crops are grown with forages of indeterminate habits or perennial tree alleys (such as Sesbania), growth of these forages can continue after harvest of the food crop using the residual moisture stored in the Vertisols.

Table 18. The overall mean wheat grain, straw and total crop residue yield (kg/ha) for mixed intercropping experiments at Akaki and Ginchi (medium altitude), 1988.

Cropping	Wheat yield		Total crop residue yield
	Grain	Straw	
Variety Enkoy	1350	2988	3853
Gerardo	1057	2490	3485
Boohai	970	2518	3690
LSD (0.05)	167	414	486
No clovers	1176	2799	2799
With clovers[1]	1066	2532	4553
LSD (0.05)	136	338	396
F-test probabilities			
Variety	$P < 0.05$	$P < 0.01$	ns
Clovers	ns	ns	$P < 0.01$

1. Referred to an equal mixture of *Trifolium steudneri* and *Trifolium rueppellianum*.
Source: Abate Tedla et al (1992).

Table 19. The overall mean wheat grain, straw and total crop residue yield (kg/ha) for mixed cropping experiments at Bichena, Inewari and Were Ilu (high altitude), 1988.

Cropping	Wheat yield		Total crop residue yield
	Grain	Straw	
Variety ET	742	2029	3279
Dashen	592	1464	2790
HAR 407	489	1319	2822
LSD (0.05)	408	313	422
No clovers	696	1892	1892
With clovers[1]	522	1316	2753
LSD (0.05)	279	915	601
F-test probabilities			
Variety	ns	$P<0.01$	$P<0.01$
Clovers	ns	$P<0.01$	$P<0.01$

1. Clover is referred to an equal mixture of *Trifolium decorum*, *Trifolium quartinianum*, *Trifolium steudneri* and *Trifolium tembense*.
Source: Abate Tedla et al (1992).

Table 20. The overall mean wheat grain, straw and total crop residue yield (kg/ha) for mixed cropping experiments at Debre Zeit, Ginchi and Akaki (medium altitude), 1989.

Cropping	Wheat yield		Total crop residue yield
	Grain	Straw	
Variety			
Enkoy	1007	2839	5335
Gerardo	919	2539	5783
Boohai	818	2580	5312
LSD (0.05)	108	181	543

No clovers	916	2744	2744
With clovers[1]	913	2562	8208
LSD (0.05)	88	147	444
F-test probabilities			
Variety	P<0.01	P<0.05	ns
Clovers	ns	P<0.05	P<0.01

[1]. Clover is referred to an equal mixture of *Trifolium steudneri* and *Trifolium rueppellianum*.
Source: Abate Tedla et al (1992).

Table 21a. Grain yield (kg/ha) of sorghum and maize as affected by forages intersown cut twice during the year.

Cereal	Fertiliser level (kg/ha)	Sole cereal	Legume			
			Vetch	Clover	Cowpea	Lablab
Sorghum	0	2021	2330	1420	2920	1830
	100	2406	3080	1750	3170	2580
Maize	0	4073	1870	2580	2500	3420
	100	4417	3170	3580	3508	3920

Table 21b. Straw yield (t/ha) of sorghum and maize as affected by intersown forages cut twice during the year.

Cereal	Fertiliser level (kg/ha)	Sole cereal	Legume			
			Vetch	Clover	Cowpea	Lablab
Sorghum	0	8.70	8.50	6.94	8.59	9.15
	100	0.29	8.85	16.65	13.59	12.17
Maize	0	8.00	3.69	7.75	736	4.94
	100	9.19	4.67	18.34	14.53	13.39

Evaluation of forage crops on Vertisols

Avena Sativa Vigna unguiculata, *Lablab purpureus*, *Vicia dasycarpa*, *Trifolium steudneri* and *Sesbania sesban* have shown good potential for the medium-altitude highlands of Ethiopia (Lulseged Gebrehiwot and Alemu Taddesse, 1985; Jutzi et al, 1987d). These forage crops can provide a high-quality feed either as cut and carry during the rainy season or as hay for the dry season feed when seasonal shortage becomes a serious problem to meet livestock requirements. Moreover, these forage crops are high-yielding (Abate Tedla, 1984) compared with native pastures which are low yielding up to 3-4 t/ha of dry matter annually (Jutzi et al, 1987d). Native pastures are poor in quality resulting in low livestock performance in the dry season. One approach to improve the situation is the use of forage legumes to enhance animal performance (Straw, 1961 and 1978; Tothill, 1974). However, the yield and quality of these forage legumes are influenced by many factors in a given climatic and soil conditions.

Research emphasis at Debre Zeit was, therefore, to assess the yield and nutritive value of potential forage crops when planted early under traditional and improved drainage systems on Vertisol and under different times of harvest over the growing season.

The dry-matter yield in the 1989 crop season of three forage crops with different times of harvest over the growing season on Vertisol is shown in Table 22.

There was no significant dry-matter yield difference between flat and BBF seedbed methods at a 6-week period of harvest. However, when harvested at 12 and 18 weeks time, there were significant dry-matter yield differences ($P < 0.05$) between the two seedbed methods. Among the forage crops, there were statistically significant dry-matter yield differences at 6-week ($P<0.05$), 12-week ($P<0.05$) and 18-week ($P < 0.01$) times of harvest.

Lablab purpureus was the most productive species. It was followed by *Vigna unguiculata*. Seedbed method by forage crop interaction on dry-matter yield was significant at harvest week 6 ($P < 0.05$) and 12 ($P < 0.05$) whereas harvest at 18 weeks was insignificant. Table 23 shows the quality of the forages at different times of harvest.

Table 22. The mean dry-matter yields (kg/ha) of three forage crops planted on Vertisol and harvested at different times of the growing season at Debre Zeit, 1989.

Seedbeds	Forage crop	Time of harvest (week after plant emergence)		
		6	12	18
Flat	*Sesbania sesban*	250	1980	2500
	Lablab purpureus	650	4450	6410
	Vigna unguiculata	830	4780	6010
BBF	*Sesbania sesban*	540	2490	3650
	Lablab purpureus	470	3360	7140
	Vigna unguiculata	1040	4000	5930
	LSD (5%)	150	1230	1320
	F-test probability			
	Seedbed method	ns	P<0.05	P<0.05
	Forage crops	P<0.001	P<0.05	P<0.01
	Interaction (SM x FC)	P<0.05	P<0.05	ns

Review of Vertisol work at IAR Sites (Ginchi and Sheno)

Numerous experiments have been carried out at Ginchi and Sheno. It is evident that crop yields can be increased if excessive surface soil water is drained off and if appropriate cropping and soil fertility practices are used.

This paper reports on crop improvement, crop/forage agronomy trials in two highland Vertisol sites of IAR. The major objective was to replace the traditional practices of crop production with improved drainage, fertiliser and crop management techniques.

Ginchi

The sub-centre was established for research on drainage and fertiliser management and on the selection of high yielding crops and cultivars for early sowing on vertisols. Improved drainage had a significant effect on grain yields of crops, especially of wheat, whose yields increased by more than 100% compared to the yields from undrained plots. Fertiliser efficiency was also highest with wheat with improved drainage (Hiruy Belayneh, 1986). The major direction in cereal breeding is to select high yielding varieties for the area. For bread wheat, advanced observation nursery, pre-national variety trials and national variety trials are carried out. On the basis of yield, disease resistance and agronomic characters from nurseries promising lines are advanced to pre-national and national variety trials. These programmes are continuously undertaken until varieties that are tolerant to waterlogging are developed. For the Ethiopian subsistence wheat farmer, cultivars are the easiest technology to adapt. However, it seems that cultivars alone can do little to increase the yields on farmers' fields. Therefore, the complementary contribution for improved agronomic and tillage practice is highly essential, particularly if the genetic potential for high yield in improved exotic varieties is to be exploited.

Table 23. The mean[1] of the chemical composition of forage crops harvested at different times on Vertisol at Debre Zeit, 1989.

Harvest time (week)	Forage crop	Ash %	CP %	NDF %	ADF %	Lignin %	ADF-Ash %
6	*Sesbania sesban*	11.2	20.3	37.9	28.0	4.8	0.4
	Lablab purpureus	14.7	18.2	36.4	29.6	4.7	2.2
	Vigna unguiculata	22.1	19.2	40.5	29.1	5.1	4.4
12	*Sesbania sesban*	8.9	12.6	45.6	34.6	6.1	0.4
	Lablab purpureus	13.3	20.7	42.5	35.8	7.0	1.9
	Vigna unguiculata	10.4	11.8	48.1	40.3	6.7	0.7
18	*Sesbania sesban*	7.8	11.0	48.5	37.2	5.9	
	Lablab purpureus	9.0	12.3	48.0	39.4	6.9	0.3
	Vigna unguiculata	9.9	14.7	45.9	37.0	6.7	0.7

1. The mean value was taken from flat and BBF seedbed methods.

Sheno

Sheno agricultural research sub-center is found in the central highland Vertisol areas of Ethiopia. Thus Sheno farmers have been practicing double-cropping by using belg and *meher* seasons rainfall. Moreover, farmers plant lentils, chickpea, rough pea and different local cultivars of wheat by using the residual moisture of the black soil. Poor soil fertility and drainage problems have been identified to be the prominent yield factors for *meher* season production of major crops such as barley and faba bean.

The major objective for agronomy research was to replace the inefficient traditional practice of "*guie*" crop culture with improved drainage, fertiliser and crop management techniques for continuous crop production. In the early years, research on soil and fertiliser management was directed towards comparing the crop yields obtained from plots prepared by tractor-drawn ploughs (such as disc, mouldboard, and chisel) with those from narrow and wide cambered beds (prepared with mechanised operation), using different rates of application of N and P fertilisers.

The research activities are grouped into three broad categories, namely

(a) Integrated cultural practice study,
(b) fertiliser studies, and
(c) cropping systems studies.

Highlights of completed work

Monthly clipping of natural pasture was done for three years to identify the optimum harvesting time of pasture for hay. Harvesting in October consistently gave higher dry-matter forage yield as shown in Table 24. However, samples of the pasture have not been analysed for quality due to lack of facilities.

Table 24. Dry-matter yield of natural pasture harvested at different months of 1989/90, Sheno.

Month	t/ha
October	2.19
November	1.47
December	1.67
January	1.11
February	1.69
March	1.89
April	1.73
May	2.09
June	1.72
July	2.05
August	1.20
September	1.44
Mean	1.71
se	10.18
cv (%)	21
LSD (0.05)	0.51

In another trial involving fodder oats, a total of 15 oat varieties were evaluated for four years and among them Jassari from the late sets and 805A95, 80 Ab 2764 and 805A94 from the early-set varieties were selected based on grain and anthesis cut dry-matter production (Tables 25 and 26). These varieties significantly outyielded both the local and standard checks.

Table 25. Grain and forage yields of late-set oat varieties at Sheno (1986-1989).

Varieties	Grain yield (q/ha)	DM forage yield (t/ha)
Jassari	31.3	6.6
80 Ab 2291	26.7	5.7
80 Ab 2252	25.4	5.7
60 MN 16016	22.8	5.0
CI-8237	22.8	6.7
CI-8237	24.3	6.2
Sheno local +	20.3	5.7

+ Average of two years, hence not included in the analysis.

Table 26. Grain and forage production of early-set oat varieties at Sheno (1987-89).

Varieties	Grain yield (q/ha)	DM forage yield (t/ha)
80 Ab 2764	30.3*	7.6
80 SA 94	30.2*	7.1
80 SA 95	27.9	9.2*
Kyto-w78394 Landa	27.9	7.6
80 Ab 2806	26.9	7.5

80 Ab 2267	25.3	7.6
808A 130	24.5	8.0
Lampton	21.4	6.6
Sheno Local +	21.3	4.9

* Significantly ($P < 0.05$) different from the check.
\+ Mean of two years, so not included in the analysis.

In an attempt to investigate forage production potential of annual forage legumes during the short rains, 15 varieties of herbage legumes were tested for two years (1989 and 1990). The additional purpose of the test was to screen suitable species for sequential cropping with cereals and at the same time to find out which could alleviate the existing feed shortage. Based on the performance of the species during the short rains, the following annual legumes have been selected for further evaluation: *Medicago alba*, Barrel medics, *M. polymorpha* and *V. saliva* (Table 27).

Table 27. Yields of forage legumes sown during the short rains (1990) at Sheno.

Species/varieties	DM (t/ha)
1. *Trifolium ruppellianum*	4.66 +
2. *T. tembense*	1.39 +
3. *T. subterraneum*	0.24
4. *T. quartinianum*	2.90 +
5. *Medicago polymorph*	0.17 +
6. *M. scutellata*	0.21 +
7. *Barrel medics*	1.77 +
8. *M. altismus*	3.70
9. *M. alba*	5.25 +
10. *Vicia dasycarpa*	0.73 +
11. *V. sativa*	-
12. *V. villosa*	2.33 +

\+ 2 cuts.

Yields of items no. 3,5, 6, 10 and 11 are either low or nil due to heavy grazing of the plants by rabbit.

In the cool and seasonally waterlogged region of the highland a study was conducted from 1988 to 1990 to assess the carrying capacity of unimproved natural pasture. Results obtained in 1989/90 are presented in Table 28.

In the heavier stocking rates, considerable weight losses were observed (Table 28) during the 9-month grazing period of which most months were dry. This was so probably because the treatments were too far from the optimum for year round grazing. However, during the last three months of the pasture growing season, results indicated that the highest rate (15 sheep/ha) gave the largest gain per ha though no significant differences were detected among the stocking rates (Table 28).

Table 28. Carrying capacity of unimproved natural pasture.

Sheep/ha	Gain/sheep	Gain/ha
6	2.93 a*	17.55 a

9	0.72 b	6.45 a
12	-2.27 c	-27.24 b
15	-4.15 d	-62.22 c

* Means followed by different letters in the same column are different significantly ($P < 0.05$).

From the results obtained so far, the optimum stocking rate appeared to lie between six and nine sheep/ha for year-round grazing of unimproved native pasture.

It might be suggested that in future studies, it would be essential to develop an economical and acceptable package which could arrest the weight losses during the dry season.

Implications

The Ethiopian farmer adopts an escape strategy to utilise Vertisols by planting late in the season. Even where manually made BBF is common to alleviate waterlogging problems, only a single crop is harvested. In the majority of cases in the highlands where rainfall is high and evaporative demands are low Vertisols are sparingly utilised or left idle. In years of exceedingly high rainfall, waterlogging problem is acute and crop damages are commonplace.

Improvement of drainage can potentially open up vast land areas for cropping and the alternatives that have been described offer ample flexibility to meet the demands of the resource-poor farmer. As livestock are intimately associated with smallholder-farming systems, the cropping provides an opportunity to increase feed output from a unit area of land.

Inputs such as fertilisers can be strategically used to improve productivity of grain and fodder yields. Significant yield improvements could be obtained during a given year due to multiple cropping or improved management compared to yields from traditional cropping practices. This is important to a food-deficient country like Ethiopia.

The potential of improved Vertisol management on food and feed production is substantially high. The popularisation of this intervention could support the rising population in the Ethiopian highlands.

8 Technology validation and transfer

Getachew Asamenew, Hailu Beyene, Adugna Haile and Workeneh Negatu

Introduction

Vertisols are agriculturally important in Ethiopia. However, waterlogging is a predominant problem to increased production on these soils. Hence, actual Vertisol productivity is far below potential. Various studies have indicated surface drainage to be a key factor to the release of the agricultural potential of Vertisols (Jutzi et al, 1987; Getachew Asamenew et al, 1988b). Though this fact has also been acknowledged by farmers in the Ethiopian highlands, an efficient traditional technique that can utilise animal traction to harness Vertisols is not commonly known.

As farming in Ethiopia is heavily dependent on animal traction, technologies that are based on this power source were envisaged to be appropriate for better management of Vertisols. Hence, the Joint Vertisol Project (JVP) began research on improved Vertisol technology that included (1) the use of an animal-drawn broadbed maker (REM) to facilitate surface drainage and (2) the use of appropriate seeds, fertiliser and early planting.

As cash income is generally low and credit institutions are not within easy reach of farmers on most highland smallholdings investments are meager. Hence in the development of the BBM, least costliness and simplicity were important considerations.

Technology verification and transfer framework

The objectives of the technology verification and transfer were to:

- verify the economic viability and acceptability of the BBM/Vertisol technology package
- popularise the technology so as to encourage large-scale adoption.

The target areas and farmers

Five principal Vertisol areas with diverse farming systems in the Ethiopian highlands were purposefully selected to verify the BBM/Vertisol technology package and study the transfer of the technology. Altitude, abundance Vertisols and traditional land-shaping methods to control waterlogging were important criteria in the selection of the target area.

Debre Zeit, Ginchi, Inewari, Dogollo and Dejen were the study sites which represented various traditional Vertisol farming systems. Description of the farming systems of these sites has been given in an earlier Chapter in this report.

The technology validation included individually operating farmers and producer cooperatives (PCs). In 1986, on-farm monitoring began with 56 individual farmers (IFs) and three producers' cooperatives at Debre Zeit, Dogollo and Inewari. The addition of Dejen in 1987 increased the technology testing sites to four making a total of 67 IFs and 20 PCs. In 1988 an on-farm verification at Ginchi was conducted jointly by ILCA and IAR. In 1990, a policy declaration by the government gave farmers the right to dismember producers' cooperatives. As a result, most producers' cooperatives were dissolved. Hence, in the fifth year the number of participating individual farmers in the on-farm verification increased to 158 while PC's were reduced to 10 (Table 1). As of 1991 the focus of the technology verification and transfer was on individual farmers.

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

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

Source: Getachew Asamenew and Mohamed-Saleem (1992).

In 1989 Oxfam-America, a non-governmental organization, started to transfer the technology to farmers at Dogollo based on its on-farm research results. The Dogollo site was closed down in the same year because of security reasons. At the time, farmers' participation was excellent. After more than five years of operating a well-focused research and outreach programme in Vertisol areas of the Ethiopian highlands, emphasis was shifted in 1991 towards technology popularisation and transfer at Debre Zeit, Inewari and Ginchi.

Technology verification approach

Research on a farming systems perspective was adopted. It was linked to a two-way information flow between on-station and on-farm research. Technology designed on-station was first verified on-farm while farmers' unsettled queries, obtained through feedback, were redirected to the station to improve the technology for better adaptation. Investigation on appropriate cropping systems, soil fertility and erosion, animal-drawn implements for soil, water and crop management and animal draught power output on-station back-stopped on-farm technology validation. Component research was conducted at ILCA, IAR, AUA and MOA stations. Work on draught power was carried out mainly at the ILCA station in Debre Zeit. Work on crops was carried out mainly at IAR and AUA stations. Trials to develop new cropping systems were undertaken on MOA's Agricultural Development Department (ADD) sites which were also part of JVP's on-farm technology verification sites. There was close collaboration among ILCA, AUA, IAR and MOA on all aspects of Vertisols research. The inter-institutional links were aimed at achieving: (1) mutual information exchange and (2) avoiding duplication and (3) obtaining a critical mass of information in several areas thus generating maximum returns from scarce available resources.

Vertisol technology was first popularised in a community followed by on-farm verification. It was finally transferred to the farming community. Adoption was monitored and further socio-economic constraints were identified.

Monitoring and evaluation of an innovation and its adoption by farmers is the central focus of an on-farm technology verification and transfer. Trials carried out by farmers included cultivation, construction of BBF, planting, weeding, harvesting and threshing. For on-farm technology verification, monitoring was designed on the basis of dialogue with farmers. The farmers were frequently and regularly visited and invited to suggest improvements to the new innovation. Feedback from farmers were important in refining the technology on-farm, where possible, and on experimental stations where not possible otherwise. A teacher-pupil relationship was avoided and an equal partnership was established as the on-farm verification research progressed.

All inputs used and outputs obtained from the verification plots were monitored frequently and carefully by highly experienced resident field staff in the respective research sites. A structured diary was used to record data in the first instance from farmers. The computed data were then transferred to a properly structured format.

To compare the technology in a whole-farm context, the entire cropping pattern was determined and all inputs for the various crops grown on-farm and yields are also accounted for.

Bio-technical feasibility, economic viability and social acceptability are critically important criteria in an evaluation of a technology on-farm. Hence the parameters used in assessing the performance of the Vertisol technology were yield response, economic benefits, risk, and acceptability.

Performance of the BBM

Compared to the traditional land-shaping methods, there was a consistent increase in crop yields and economic returns by using the BBM on Vertisols across the highland sites (Figure 1). Effects of the BBM on Vertisol productivity appear to vary slightly between locations and years. The differences resulted mainly from variation in the traditional Vertisols management practices. This was particularly true of the land-shaping and agroclimatic conditions. Regardless of the land-shaping methods, differences in productivity on Vertisols were, in general, significant across sites and years. Yields of crops in the lower and medium altitude highland Vertisols (Debre Zeit and Ginchi) were higher than in higher altitude highlands at Dogollo, Inewari and Dejen. This was mainly because of differences in rainfall intensity and evapotranspiration which increased the waterlogging intensity in Vertisols. With the use of improved wheat cultivar during the second and third year, the effects of BBM on physical yields, net gain, return to human and oxen labours from crops on Vertisols at Dogollo significantly increased. In the second year, net gain and labour returns from use of the BBM for wheat production was 75% and 43%, respectively, higher than from that produced on ridges and furrows. In the third year, because of BBM use the difference increased to 131% in net gains and to 114% in return to labour.

At Inewari the BBM efficiently replaced the drudgery of manual broadbed and furrow construction thus increasing human welfare. Use of the BBM increased the economic value of draught animals as they were not utilised for seed covering tasks as in other Vertisol areas. Use of the BBM reduced the 55 hr/ha average labour requirement for the manual BBF construction by about 67%. As the manual BBF construction is labour-intensive, farmers indicated labour to be a constraint for this farm activity, thus acknowledging the benefits from use of the BBM. As manually made BBF's can facilitate drainage of excess surface water, crop yields are not significantly different from yields on the broadbed furrows formed with the broadbed maker. BBFs are manually made when Vertisols are moist and pliable. But in years when the rainfall is late, farmers hurry to complete their activity on time and the quality of broadbed furrows constructed suffers resulting in reduced yields. During such periods, use of the BBM helped in increasing crop yields and economic benefits.

Use of the BBM also resulted in increased Vertisol productivity in the medium-altitude highlands of Debre Zeit and Ginchi where crops are traditionally grown on flat plots but no significant variation was observed between years on effects of the BBM on productivity. At Debre Zeit, over a period of five years there was a 32% average net return from wheat production as a result of using the BBM. In the high-altitude highlands of Dejen the effects of BBM on productivity were also positive.

There were variations in total labour input in plots prepared with the BBM across sites and years. Average total labour for wheat production ranged between 466 hr/ha and 681 hr/ha at Debre Zeit and Dogollo, respectively. With the exception of Ginchi, it appeared that total labour use increased with a rise in altitude since higher weed infestation and higher clay content in Vertisols require more weeding and plowing time. However, total labour demand was found to be relatively lower at Ginchi where some farmers use herbicide and hence little weeding was required on wheat fields sown on Vertisols. The net effect of BBM-use was that it generally increased labour productivity across sites and years. For example, at Dogollo in 1986 and 1988 returns to labour from use of the BBM for wheat production increased by 50% and 114%, respectively, compared to the traditional land-shaping method.

The animal traction time required to make one hectare of BBF was on average 50% less than that required for the traditional method of seed covering. The traction time varied between the study locations but very slightly between years because of mainly traction inputs to land preparation. On well-ploughed Vertisols, BBF formation is easier to make and quicker. Although two farmers are needed to handle the BBM, making a broadbed furrow with the broadbed maker took less animal traction time (15.4 hr/ha) than by the traditional method which took 25 hr/ha.

Performance of the Vertisol Technology Package

The previous section has assessed the effect of BBM on Vertisol productivity. But comparison of the two methods is necessary since farmers usually compare the results of the technology with their entire traditional practice. The Vertisol package involves use of the BBM, use of appropriate seed cultivar, application of a given amount of fertiliser and early planting (dry-season sowing). By contrast, traditional practice requires planting of crops late in the season (wet-season sowing), use of usually local seed cultivar (except at Inewari) and application of some fertilisers. Planting on Vertisols is done using traditional land-shaping methods that vary from location to location as explained earlier. Fertiliser is preferably applied to cereal crops such as wheat and teff although pulses are also grown. While it is necessary to assess the opportunity cost of Vertisols under crops grown using the improved technology package, it is clear to see the benefits of using the improved technology compared with traditional cropping practices of Vertisols.

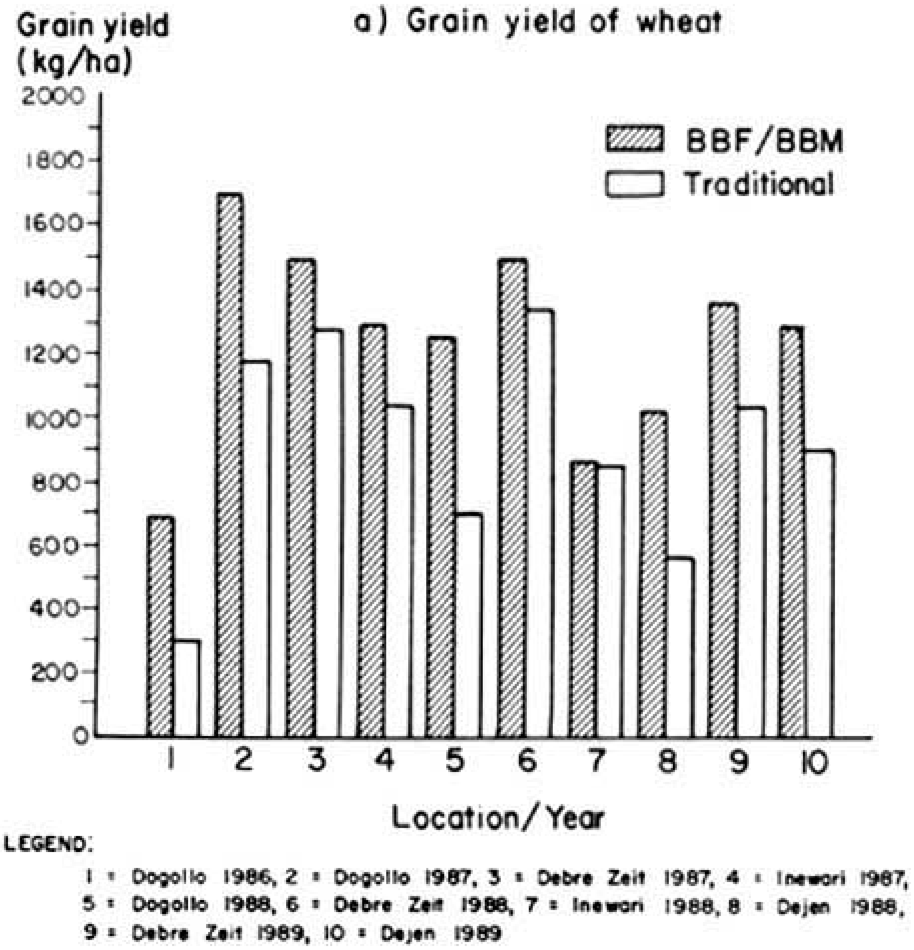
Greater yields of grain and crop residue from using the technology package has made the economic benefits very attractive. Compared to crop yields obtained through traditional methods, yields of wheat (for example) grown with the improved technology were on average more than double (Table 2). Hence the net gain and marginal rate of return (MRR) from wheat were more than double. At Dogollo, with the improved technology wheat yielded even more than four times than wheat grown on Vertisols traditionally. Crop residue harvest was even greater than this.

Field days, feedback and technology popularisation

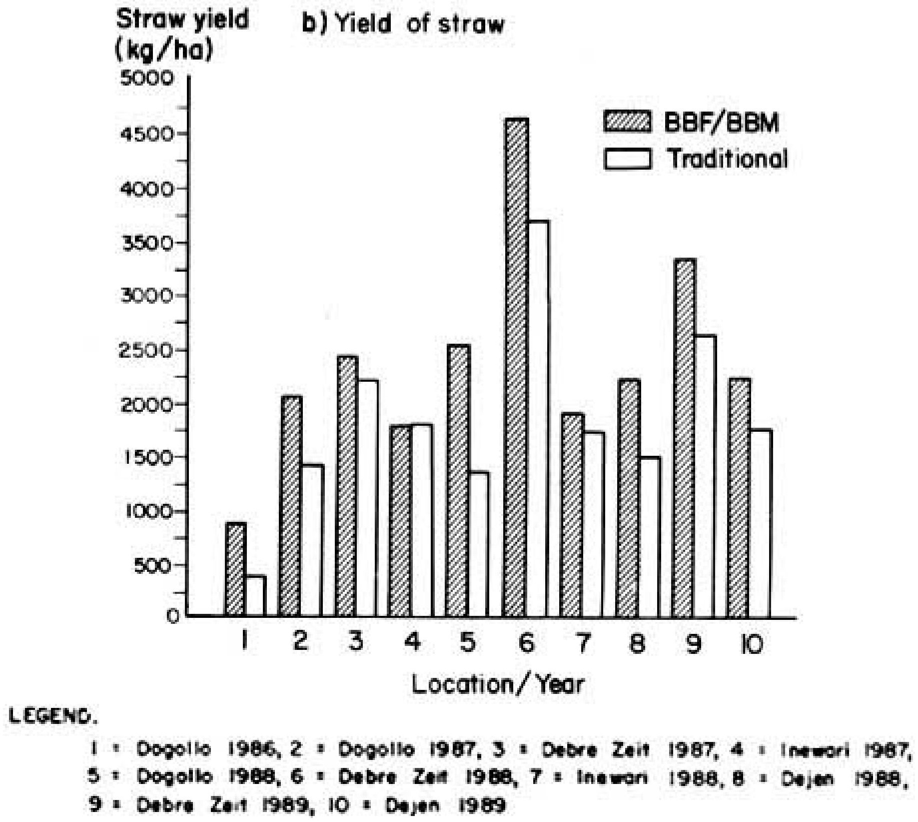
A field day is an important activity of on-farm research because it creates an occasion for farmers to get together and express their opinion about the technology being tested. The Joint Vertisol Project held such field days annually just before harvest. Key/progressive farmers move within the research sites to exchange experiences with farmers from different locations and backgrounds. Invited policy-makers are briefed on the achievements as well as constraints encountered. Participating farmers are given the opportunity to show their verification plots and share their experiences. The research team usually explains about the objectives of the on-farm trials. As much as possible, a teacher-pupil relationship is avoided and all the field-day participants are encouraged to contribute additional knowledge to the innovation. The field days have served as useful fore to collect very constructive feedback and to popularise the technology.

Figure 1. Effect of BBM-formed surface drainage on wheat grain in the Ethiopian highlands.

a) Groin yield of wheat



b) Yield of strong



LEGEND:

1 = Dogollo 1986, 2 = Dogollo 1987, 3 = Debre Zeit 1987, 4 = Inewari 1987,
5 = Dogollo 1988, 6 = Debre Zeit 1988, 7 = Inewari 1988, 8 = Dejen 1988,
9 = Debre Zeit 1989, 10 = Dejen 1989

Table 2. A comparison of economic returns from crops grown with Vertisol technology package and traditional methods in selected Ethiopian highlands.

	Gross margin (EB/ha)	Net gain (EB/ha)	MRR (%) traditional management
Inewari (1988 and 1989):			
Improved management:			
Wheat	789	468	
Traditional management:			
Wheat	537	288	134
Teff	565	241	162
Chickpea	432	239	92
Rough pea	230	16	171
Ginchi (1988 and 1989):			
Improved management:			
Wheat	1214	976	
Traditional management:			
Wheat	536	337	313
Teff	986	725	127
Rough pea	493	333	196
Chickpea	532	355	218

EB = Ethiopian birr. US$1 = EB 2.07 during the study period.
MRR = Marginal rate of return.

Factors that influenced technology adoption

In general participating farmers of the on-farm verification research were impressed in the results obtained from the new technology. Feedback during the initial on-farm verification years, however, indicated that there were some constraints to its wider adoption by the farming community. At the beginning farmers were concerned about the weight of the prototype BBM which they thought was heavy for draught oxen. It was heavy for farmers as well who had to transport it to the fields. As a result, a lighter modified BBM based on the local plough was constructed during the second year. Since two light local ploughs were brought together to form the modified BBM, some farmers felt that the weight would hurt their oxen. They went ahead and tried the new BBM and in time the complaint stopped.

Farmers' most-cited constraint concerned the short supply of technology inputs: BBM parts, fertiliser and appropriate seed. Although MOA had a fertiliser credit scheme for farmers, they felt that the supply was not adequate and that it was usually issued too late to be of any use for early planting. This was because creditworthy farmers were being penalised by being refused receipt of fertiliser on credit if other farmers within their Peasant Association failed to settle their debts.

Since BBM benefits are enhanced when in combination with other technological components, the attitude of farmers towards each component had a great bearing on the adoption of the BBM. For example, as early planting (dry planting) of cereals was a new agronomic practice, farmers initially felt that it could be a loss of investment in seed and fertiliser if the main rain delayed. Eventually, however, after most farmers adopted the technology, and used fertiliser and improved seed, the emphasis shifted to technology transfer of the modified BBM.

If a short dry spell occurred during the main rains, there was pest attack on early planted crops, particularly at lower altitudes. This was another concern expressed. The problem needed chemical control measures.

A major drawback to the spread of improved Vertisol technology was the shortage of extension staff to give advise. Consequently the improved use of animal traction was not given the emphasis it deserved.

To popularise the technology during 1991 and 1992 three modules were used at Ginchi, Debre Zeit and Inewari:

1. Farmer-to-farmer contact: Enthusiastic farmers who participated in the previous on-farm verification research were encouraged to teach and assist other new farmers to use the technology.

2. Encouraging interested individuals among the farming community to promote the technology.

3. Technology inputs were made available to farmers. Observation was made on whether those who had previously used the technology would continue using it.

4. In addition, development agents (DAB) of the MOA were involved and encouraged to train farmers and popularise the technology for wider dissemination.

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9 The joint project on Vertisols management: Retrospect and prospects

Mesfin Abebe and S Jutzi

Introduction

To make agriculture and its growth sustainable to fuel economic growth in an essentially agriculture-based society like Ethiopia, is a formidable and multidimensional challenge. Faced with this urgent need to increase agricultural output there is the risk that this will be done at the expense of the productivity and sustainability of the resource base and environment where there is a hierarchy of interlocked subsystems of Vertisol-related resource utilisation This encompasses diverse components: (1) as the intimate relationship between plants and the soil, or between crops and domestic animals, including energy and nutrient flows among them; (2) relationships between land facets within ecological zones; (3) economic interactions at the farm, and no less important (4) the policy environment within a given political framework. Sustainability at any one level may depend on events occurring at other levels.

Hence, the Joint Vertisol Project which, by its nature and intention has dealt with natural resource research and development; has inherently addressed the complexity of factors and interactions among them. This has led to the two-dimension strategy of choice or prioritisation: 1) issues related to research of the high-rainfall, low temperature and thus highly waterlogged Vertisols of the Ethiopian highlands, thereby providing a common denominator to collaborators for subsequent stages of research and development activities; and 2) high disciplinary priority to soil management related research; waterlogging and soil fertility being the most important constraints for Vertisols use high rainfall areas. Interinstitutional effort was therefore designed involving those in charge of training, research, development and extension. This would ensure more or less simultaneous design of both Vertisol-related management technologies and effective validation and transfer mechanisms commensurate with the constraints and opportunities of target farming systems. Seven years after its initiation, the Joint Vertisol Project had acquired a wealth of experiences which provide important lessons for future direction of its own programme and for similar activities elsewhere.

The scenario

It can safely be generalised that the cereal-based segment of Ethiopian subsistence agriculture where cereals occupy about 80% of the total cultivated area each year is concentrated in the highlands above 1500 m asl. The highlands constitute about 44% of the country but the concentration of both population and cereal production is found here. Not surprisingly, severe ecological destruction resulted in consequence of the high misuse of resources. It has even been argued that any deviation from the normal farming condition, could easily disable about 60% of the rural population from meeting its basic food requirements. Yet, it is here that more than 13 million hectares of the dark clay, the Vertisols, are found. These soils with their characteristic shrink-swell properties pose soil-management-related production constraints of waterlogging and fertility. It then follows that potentials have not been fully exploited to maximise productivity leading to a generally stagnant cereal production hence low productivity of land and labour in Ethiopia.

No less important is the fact that contrary to popular belief, fertile land not put under productive use within the means available to the rural farming community is not that much. Equally, the available base-line information on the soils of Ethiopia as well as the concomitant fertiliser use must dispel the myth and illusion that Ethiopia is a very fertile country. The highlands might have offered a habitable environment but not the required land productivity. In contrast, surrounding the highlands are large semi-arid valleys with considerable Vertisols and soils with vertic properties which enjoy the luxury of major rivers that are virtually untapped and/or underutilised. These offer ample potentials for highly productive and sustainable agricultural development.

Pertaining to the need for increased agricultural productivity, a major production breakthrough in cereal self-sufficiency is possible through increased production per unit area followed by increased land under cultivation. Among other things, intensification of production through double cropping, supplementary irrigation from divertable streams could lead to considerable achievement. This would have enormous cumulative effects through the effective utilisation of such resources as land, water, fertiliser, fodder etc which, by necessity, must be augmented by improved varieties, agronomic and/or cultural practices etc with provision to avoid postharvest losses.

On the other end of the spectrum is the stark prospect of the country becoming ever more import-dependent and the inability of increasing food availability to the level of 2000 calories per day. This stark prospect could be a reality if the current rate of population increase is not balanced by major breakthroughs which permit intensification and diversification through the use of appropriate R & D technologies. This could be the overriding concern of the peoples and Government of Ethiopia. Thus, unless massive investments are made that call for further research and development the productivity of the underutilised Vertisols will not be raised.

The joint Vertisol project

The main features of Vertisols are highly characteristic. Emanating from the mineralogy of montmorillonite, Vertisols have shrink-swell properties depending on the soil moisture status. Hence, they form hard clods when dry but become sticky and form into puddles when moist. Workability is a major physical problem associated with the agricultural use of Vertisols in high-rainfall as well as in irrigated areas. Low crop yields on these soils are directly or indirectly related to their poor internal drainage, with effects on root penetration, root deformity, aeration, nutrient uptake etc. These are important for both crop and livestock management because they provide opportunities to increase production if properly managed.

About 7.6 million ha of Vertisols are in the highlands above the 1500 m contour in areas of traditional mixed smallholder farming. They are extensively cropped in cereal-based production systems. It is estimated that some two million ha of Vertisols representing as much as one-third of the total national cropland are under arable crop cultivation. In the management of dark clays, both crop and animal production systems should, however, take account of other vertic soils with which they are associated and behave similarly to Vertisols in their management. The total hectarage of vertic soils in Ethiopia is thus increased to 12.2% or 14.4 million ha (Berhanu Debele, 1985).

Despite the fact that the fertility of Ethiopian Vertisols is comparatively above average, with deficiencies of nitrogen and, to a lesser extent, of phosphorus (Berhanu Debele, 1985; Mesfin

Abebe, 1979, 1980, 1981, 1982; Kamara and Haque, 1987), Vertisols are generally regarded as marginal soils for crop and livestock production, mainly due to their physical properties. However, the high waterholding capacity of Vertisols makes them comparatively low-risk soils, in the sense that once recharged they will bridge even prolonged dry spells in the growing season and sustain crop growth and yield. In this context, it has long been realised that waterlogging is severe in the highland Vertisols where high-rainfall and low evaporative demands prevail (Tesfaye Tessema and Dagnachew Yirgou, 1967; Mesfin Abebe, 1981, 1982; Jutzi and Mesfin Abebe, 1987).

Traditional farming, nevertheless, has developed a wide range of practices. One of these concerns Vertisols where the use animal-draught power and low-yielding crop germplasm adapted to poor internal soil drainage or germplasm, perform reasonably well on residual moisture after the main rains. The most widely practiced system since antiquity is using the local plough to construct narrow ridges and furrows at sowing. The crops grow on the ridges and the excess water drains out from the root zone to flow out of the field through the furrows, or to pond in the furrow.

Another system, which is the historic precursor of the new broadbed-and-furrow (BBF) technology (Jutzi and Mesfin Abebe, 1987), consists of drawing shallow drainage furrows with the local plough at varying distances across the contour and thus forming a raised seedbed. In very limited areas, more sophisticated surface drainage structures are utilised. These are broad beds and furrows of about 120 cm wide, and made entirely by hand. The operation entails the participation of the whole family, including women and children.

Soil burning is practiced at high elevations exceeding 2400 m asl, where considerable organic matter (soil) accumulates subsequent to extended fallow period, ranging from 10 to 20 years (Tesfaye Tessema and Dagnachew Yirgou, 1967; Mesfin Abebe, 1981; 1982). Soil burning not only enchances *in situ* drainage through the transformation of micropores into macropores as a consequence of the cementing and aggregation of clay into sand- and gravel-sized particles, but it also contributes to the mineralisation of nutrient elements from organic matter, thereby promoting improved plant nutrition. Soil burning, however, is not only a tedious practice involving women and children, but introduces inefficient land use when considering the extended fallow period before land can be brought into repeated production.

Researchers, however have long recognised (Tesfaye Tessema and Dagnachew Yirgou, 1967; Mesfin Abebe, 1981;1982; Jutzi et al, 1987a; Getachew Asamenew et al, 1989) that with the exception of the hand-made broadbeds and furrows, the traditionally applied surface drainage techniques are inadequate to allow the full realisation of the potential of Vertisols. These considerations were the basis for the establishment of the Joint Vertisol Project on Improved Management and utilisation of Dark Clay Soils in Ethiopia.

While research at each level of resource utilisation is necessary, integrative research that links all levels is required for long-term sustainable agricultural resource use. Thus, at the outset research requirements on Vertisol utilisation were recognised to be potentially comprehensive and overwhelming, and a strategy of intelligent choice was considered to be of paramount importance for its successful progress. Conceptually, the integration of development institutions in the Joint Vertisol Project was to safeguard effective research development linkages for technology transfer and feedback generation from the field to research. Nevertheless, there were many instances in important Vertisol areas where local institutional complexity of a multi-institutional research and development project has had both positive and negative aspects. On the one hand, it may provide unique permanent fore for information exchange and decision generation across often tight institutional borders; on the other hand, it may contribute to rather heavy decision processes and little transparent overall project representation. Hence, there was a deliberate attempt to reduce the inherent complexity of resource management research while maintaining a systems approach to problem solving.

The strategy recognised the inter-relationship between economic ecological, social and political parameters in the analysis of land-use issues and in the design of options. Collaboration was thus to be encouraged among the following institutions:

International research institutions such as -

- ILCA (International Livestock Centre for Africa)
- ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)
- IBSRAM (International Board for Soil Research and Management), an international research network sponsoring institution; the national agricultural research systems in Ethiopia, namely
- IAR (Institute of Agricultural Research)
- AUA (Alemaya University of Agriculture)
- AAU (Addis Ababa University);

and the formal agricultural development institutions, namely:

- the Ministry of Agriculture, and
- the Relief and Rehabilitation Commission.

In addition to the above, attempts were made to involve non-governmental development organisations in technology field testing and pilot extension activities.

The Joint Vertisol Project also recognised, where possible, indigenous knowledge as the starting point. To this end, the JVP worked in association with people who had traditional knowledge or with those who regulate the use of resources. Experience so gathered constituted a "store-house" of knowledge. Therefore attempts has been made to replenish the store house or at least keep under control the loss of information and lack of coordination.

The Joint Vertisol Project would, thus, represent an exemplary model of interinstitutional and inter-disciplinary collaboration towards the support and sustenance of agricultural and natural resource development. Here, the classical trinity functions of instruction, research and extension were integrated to play a vital role in the conservation, development, utilisation and monitoring functions of our fragile environment.

The identification of a problem and the search for the solution thereof is a great task, an almost impossible task at times. In this context, the Joint Vertisol Project has made impressive progress and a qualitative leap. JVP's bold initiative in its short life of seven years resulted in creation of critical mass going hand in hand in the inter-play of comparative advantages and complimentarities. Some of the advances constitute giant steps while others are a modest contribution but nevertheless encouraging considering the difficulties and obstacle, which constituted pitfalls in the search for direction. Notwithstanding, these same difficulties and obstacles indeed were valuable sources of strength and inspirations in the formulation of the new Joint Vertisol Programme. In retrospect, this becomes more true and can be best appreciated because the Joint Vertisol Project was initiated at a time when the military government intensified its attempts to collectivise agricultural production; where the risk-taking attitudes even among progressive farmers was dampened in a scenario of a *Dergue* policy that was inversely related to participatory developments; and in a setting where a reliable, sufficiently stable agricultural environment which respects established cultural structures as a precondition for vigorous, and sustainable technology adoption did not prevail.

Achievements lessons learnt

Achievements

A number of national institutions have been involved in the identification and mitigation of Vertisol-related problems, but in a rather loose collaborative setup. But, emanating from the rational that the general availability and economic viability of animal power for Vertisol cultivation in the Ethiopian highlands should allow the addition of animal-powered surface drainage construction with concomitant increased productivity of both grain and straw, towards food self-sufficiency in Ethiopia the Joint Vertisol Project was initiated as a research, training, and outreach project aimed at improved management of Vertisols in the Ethiopian highlands. From the outset, national and international institutions joined in the operation, along with their respective interests, mandates, and comparative advantages relevant to the undertaking (Jutzi and Mesfin Abebe, 1987; Jutzi et al, 1988a).

The constitution of the advisory and technical committees, and the general agreement on institutional coordination, constituted the basis for a considerable degree of research and development integration. While the extent to which this can be implemented Is a function of time, project success, and the commitment of each participating institution, it was planned to address the development of the Joint Vertisol Project in three stages:

> a) consolidation of Vertisol-related activity planning and implementation in participating institutions with necessary support organization across institutional borders;
>
> b) organisation of comprehensive programmes for research and development with the aim of implementing the projects' internal procedures for the formulation of priorities, strategies, and the execution and reporting routines for collaborative projects across institutional borders; and
>
> c) acquisition of funds and major strategic inputs, including those necessary for the training of qualified manpower for national institutions in order to remove operational constraints (Jutzi et al, 1988).

Consolidation and activity planning

The initial phase focussed on the coordination of research activities and establishing the basic research groupings and information-exchange mechanisms required for inter-institutional agreements on this coordination. Within the framework of the project, considerable research protocols were established which included soil-water management, tillage, cropping systems and nutrient management. When designing options there was no attempt to assemble a comprehensive technological package, but rather stand-alone technological elements which could be introduced and combined as per the opportunities of a target-farming community. This project strategy to ease the process of management-technology adoption was the result of an early involvement of framers in technology development.

Programme development and implementation

The animal-powered conventional tine-plough broadbed maker (BBM) as developed by ILCA which is an implement within the technical and economic reach of small farmers thus offer an option for reducing drastically the drudgery of seedbed preparation as in the soil-burning practice or in hand-made broadbeds and furrows. Through the use of the BBM for implementing effective surface drainage, participating institutions designed and executed a number of trials on the effects of improved drainage on crop germplasm and cropping systems, and on soil fertility management in improved cropping systems.

In this process, ILCA provided to all national partner institutions extensive training opportunities in the manufacture of the animal-drawn surface drainage implement, and in handler and oxen-training. Through its core funds, a number of short-term training opportunities were offered to Ethiopians at both ILCA and ICRISAT. Logistical support was provided to the Ethiopian NARS during the initial phase of the Project.

In the second year of the Joint Project (1987), ILCA in collaboration with the NARS, organised an international conference on the management of Vertisols in sub-Saharan Africa, in Addis Ababa, Ethiopia. The proceedings of the conference have since been published (Jutzi et al, 1988).

ICRISAT not only provided specific training in economics, agro-ecology, and soil and water management to Ethiopian scientists, but was also consistently represented at the regular meetings of the Technical Committee. In addition, ICRISAT seconded a senior ICRISAT scientist to the Ethiopian Vertisol Project particularly for research work on watershed management.

The concerted efforts made in the Joint Vertisol Project were further enhanced by the creation of Vertisol research teams at IAR and AUA with a mandate to carry out research on tasks agreed upon within the Joint Vertisol Project. Therefore, a growing appreciation emerged to define more sharply the responsibility domain of partner institutions within the overall programme. With the regular exchange of experiences, the buildup of mutual trust, the confidence in the Joint Vertisol Project and hence greater commitment by participating institutions, more understanding on research task-sharing within the Joint Vertisol Project was achieved in 1988. This implies the delegation of "intellectual leadership" for comprehensive coverage of the research areas assigned to each institution. Even with the institutionalisation of the "intellectual-leadership" approach, it is recognised that substantial flexibility is indicated to safeguard institutional autonomy.

Acquisition of funds

Research on natural resource management in the comprehensive sense requires, as stated above, the concerted action of several institutions for the research agenda to be adequately treated.

The Joint Vertisol Project successfully integrated international and national research institutions around a broad agenda of interest such as agricultural research and manpower development where the AUA and the IAR jointly represent the major elements of the Ethiopian NARS while the MOA represents the extension arm.

Funding was sought in order to strengthen and enlarge the national network of research, training and extension activities of the NARS, the MOA and others with a supplementary budget from the Ethiopian Government The objective was the establishment of an inter-institutional understanding of the problems and their possible solutions set on priority basis. While research tasks were shared among participating agencies along institutional mandates and individual scientists' priorities, commitment of the institutions during the project life was naturally variable.

Experience has shown that formal support of the shared research agenda by the chief executive of an institution is required for that institution's contribution to be commensurate with expectations.

Effort was made to acquire hard currency funding for all active partners; and detailed research portfolios were elaborated for activity-based budget submissions to the donors.

In view of the rather precarious recurrent funding situation of the national research system, incremental, particularly hard currency capital and supply funding is required at this level for safeguarding working conditions at least technically comparable with international project partners. The Joint Vertisol Project has, in cooperation with the main project donor, the Swiss Development Cooperation Agency (SDC) and through mediation by ILCA, elaborated a mode of fund acquisition and handling which is one viable example of complex resource management research activities likely to become more frequent in the future, particularly in the context of the ecoregional research approach within the CGIAR (Consultative Group on international Agricultural Research).

Features of this funding operation are (1) an agreed research agenda based on comparative institutional advantages, (2) activity-based budgets, (3) equal material cost standards for all partners and (4) presence of an honest broker or mediator institution for fund handling. In the experience of the Joint Vertisol Project the latter role may preferably be with an international agricultural research centre which by mandate and strategy is required to look for effective research alliances with national agricultural research systems. Such research alliances are indeed likely to be very effective tools for the generation of technologies. Their balanced and equitable funding, however, requires adequate attention for them to be sustainable.

Lessons learnt and the prospects

Convincing evidence for the strong impact of Vertisol surface drainage on crop production has motivated a number of international and national agencies to direct increased attention to the agricultural utilisation of these soils. A formal agreement on the coordination of these efforts has been adopted and quite detailed procedures for the implementation of inter-institutional research and development initiatives have emerged from this agreement. It has now been confirmed that improved Vertisol management technologies are the result of muti-disciplinary efforts. These efforts have dealt with agroecological and socio-economic resource assessment of Vertisol areas. Improved soil and water management, new cropping systems for drained Vertisols, improved land management techniques, and on-farm technology verification were also included.

The initial phase has focused on the coordinating research activities and establishing the basic information exchange mechanisms required for inter institutional agreements on this coordination. The research emphasis has been on the use of am animal-drawn implement, the broadbed-and-furrow maker, that enhances surface drainage, thus reducing waterlogging.

During the intermediate term, the emphasis was on crop germplasm, cropping systems, and soil fertility research on Vertisols with improved drainage. The aim was to offer improved agricultural Vertisol utilisation technologies to generate maximum returns from scarce available resources. To achieve these aims, there was a need to further integrate the research and development of participating institutions so as to generate and transfer technology more rapidly primarily in smallholder mixed crop-livestock farming systems for very substantial returns in terms of grain and crop residue production. Given the large acreage of Vertisols in high-rainfall, high-potential highland areas of Ethiopia, and given the large gap between actual and potential production from these soils, these returns may have a significant bearing on the national thrust towards food self-sufficiency.

Despite the conceptual clarity and the symphonic working relations of partner institutions in the JVP, funding for development, and especially for research activities, tended to be chronically deficient. The coordination of effort is therefore crucial for the judicious use of scarce available resources in order to maximise the returns from the respective investments.

It is generally understood that each participating agency will, in principle, independently fund its own Vertisol-related activities. The CGIAR centres involved also pledged to provide strategic inputs into national research and development institutions and to be instrumental in catalysing incremental funding for national partner institutes to implement agreed activities. Such executive commitments to the Joint Project were made by AUA, IAR, IBSRAM, ICRISAT and ILCA. In the experience of the Project, the formal inclusion of institutions without such high-level commitment was probably somewhat inconsiderate in that it tended to create am erroneous impression of programme strength and did lead to a dangerous gap between expectations and performance.

Institutional complexity of a multi-institutional research and development project has both positive and negative aspects. On the one hand, it may provide unique permanent fora for information exchange and decision generation across often rather tight institutional borders; on the other hand, it may contribute to rather heavy decision processes and little transparent overall project representation. This latter aspect is a particular problem in programme funding There is therefore, much justification for careful preparation, discussion and application of exigent criteria by which formal membership in the multi-institutional project may be awarded or withdrawn. Formal executive commitment to the joint programme is also prerequisite since internal and external fund allocation to the activities agreed are within the programme.

We now note that agricultural research centres such as those within the CGIAR system have an important innovative potential given the considerable human and material resources allocated to them. However, these centers can only fully exploit this potential for the benefit of their mandate areas if they are all properly linked with national research and extension systems where such a diversity of activities requires a large degree of intra- and inter-institutional coordination The work of individual institutes therefore, can be substantially upgraded if directly of indirectly assisted by collaborators of partner institutes working along similar lines. The assembling of a critical mass of information is thus more likely to be achieved from more areas of work and in less time. This becomes more obvious during the implementation stage thus further underlining the fad that many institutions have conducted research on soils which are essentially similar, but which require somewhat different management according to rainfall amount, and distribution differences.

Conceptually, the integration of development institutions in the Joint Vertisol Project was to safeguard effective research-development linkages for technology transfer and feedback generation from the field to research. Therefore, improved surface drainage technologies, once validated on-farm, should be brought into the extension phase as soon as possible. This will involve the extension services of the Ministry of Agriculture, as well as institutes mandated with research. In the experience of the JVP there were many instances in important Vertisol areas where local and regional Ministry of Agriculture officials agreed to embark on Vertisol management technology extension at the pilot or even on a larger scale. There was, however, no decision at the executive Ministry level for such activity to be within its central mandate. The institutional integration of research and development was therefore not as successful as anticipated.

JVP must conclude from this experience that it should abstain from formally integrating the research and development sectors and rather address research and extension agendas in separate, though interlinked institutional set-ups. The aims of the collaborative research were to study Vertisols management in a range of wet to semi-arid environments, and, by exchanging experience between similar areas, to evolve locally adapted management techniques and cropping systems.

Agreed priorities for Vertisol management research include soil water management and tillage problems. The aim has been to develop techniques for using as much as possible of the water received while also providing surface drainage to avoid waterlogging. Man-made microrelief patterns to improve surface drainage include cambered beds, ridges, narrow beds and furrows, and broadbeds and furrows. In very dry areas, water harvesting techniques involve planting crops in the furrows rather than on the beds and ridges. These aspects have also been tried. Some M.Sc. and Ph.D thesis have also been undertaken (Ali Yimer, 1992; Selamyihun Kidanu, 1992; Tamrat Tsegaye, 1992).

All told, research must be linked with development. Hence there is a need for pilot extension projects to be an integral part of the Joint Vertisol Project with the Ministry of Agriculture to prepare the implementation of a general Vertisol management line and its increased responsibility in setting a logical framework for activity planning and programme direction in the Joint Vertisol Project.

In some quarters it has become fashionable to refer to "women's role" and 'participatory development'. Such euphemism does not apply to the Ethiopian woman because the role of women in improving the Ethiopian subsistence agriculture is high. This is important in Vertisols where it is estimated that, depending on localities, women contribute from 50 and 911 per cent of the labour input. Corrective measures that remove the household chores and the back-breaking drudgery of making hand-made BBF would unleash a formidable working force. Thus, appropriate projects need to be designed to gain the meaningful participation of women in future development programmes.

With the advent of appropriate research and development and the ushering of decentralisation, the prospect of making traditional agriculture responsive to the changed situation, and hence increased productivity, looms large. This is because of the prospects of favourable government policy and its implementation being streamlined. Hence, the motivation and popular participation of the rural communities needs to go hand in hand with agricultural extension programme. Thus, the cooperative initiation and implementation of the activities will seek a high degree of coordination between NARS, international communities and finally the government. Unlike the top-down approach of the past, the current democratic situation allows provision for a genuine participation with the community. Hence, there is a need to guarantee the formulation and adoption of participatory extension service" for promoting sustained agricultural development. As a consequence, cognisance must be taken of social dynamics in the conceptualisation, designing, and implementation of projects that would involve popular participation on Vertisols towards their sustainable utilisation.

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Annex 1: Training, workshops/conferences and publications

Abate Tedla, KL Srivastava and Tekalign Mamo

The Joint Vertisol Project (JVP) has been involved in organising a range of training, public awareness and scientific exchange activities since its inception. These are summarised below:

Training

Individual training of scientific personnel

The Project has offered training opportunities to visiting scientists, post-doctoral fellows, graduate and undergraduate associates, particularly in the areas of soil management and feed legume research. These individuals were drawn from national research and development institutions seeking to strengthen their work on Vertisols. They have benefitted from direct participation in on-going research and evaluation programmes under close supervision by their advisors.

Croup training of scientific personnel

About 10 personnel from the institute of Agricultural Research (IAR), the Alemaya University of Agriculture (AUA), the Ministry of Agriculture (MOA), the Addis Ababa University (AAU) and the International, Livestock Centre for Africa (ILCA) underwent training in production agronomy, cropping systems, soil fertility and land and water management at ICRISAT Centre, Hyderabad, India After their return to Ethiopia, these staff have contributed to Vertisol research and technology verification.

Field days and training to farmers and development agents

JVP has annually organised farmer-training sessions and field days. Farmers, extension workers, researchers and policy makers actively participated in these sessions and field days (Fig. 1).

The aim of the Project with regard to training of farmers and development agents was geared primarily to "training the trainers". Therefore, the participation of some previously trained farmers participating in the training sessions as trainers was encouraged. The training sessions for farmers and development agents were of two types:

- General information about the Project and its achievements. In this session, key farmers and development agents were invited to various research sites where they interacted with research staff and amongst themselves. This proved a highly useful as farmers were exposed to innovative practices in different Vertisol areas and there was cross-fertilisation of ideas.

- Training in preparation and use of the broadbed maker (BBM). These sessions were conducted at different on-farm verification sites. The previously trained farmers acted as resource persons. Some basic tools were provided to selected farmers. This has enabled them to use their newly acquired skills beyond the training sessions.

Practical training for university students

JVP provided training opportunities to some 10 Alemaya University of Agriculture students each year during their summer vacations. These were students who had completed their third year majoring in agricultural engineering, plant and animal sciences and in agricultural economics.

They carried out trials on specific projects: cropping systems, better feed utilisation trials, implement designing, soil management (e.g. erosion) trials and on-farm economic evaluations etc which they carried out on all JVP sites.

Training in JVP enabled the students to translate theory into practice and gain a hands-on experience in Vertisols management. Many of them used the opportunity to prepare their fourth year research paper. They popularised Ethiopian Vertisols in AUA and today serve as link people.

Public awareness

The JVP has achieved a remarkable degree of public recognition both in and outside Ethiopia

There have been in-depth coverage of Project field days by all Ethiopian media. The Projects's activities have also been covered among others by the BBC World Service (Farming World), Radio France International, *New Scientist* and *Neue Zuercher Zeiting.* The Vertisol conference held in 1987 contributed decisively to public awareness. The Ethiopian Ministry of Education included a report on the Project in its bulletins for adult literacy training in six languages. The Project featured in the CGIAR Annual Report 1986/87 under the heading "Impact: From farmers' fields to national policies".

Scientific exchange

Workshops/Conferences

A Vertisol conference was organised at ILCA, Addis Ababa from 31 August to 4 September 1987 in collaboration with national and international organisations. The purpose of this conference was to acquaint African researchers and development personnel with work being undertaken in different countries and to determine the Vertisol research agenda for the African Continent.

Project staff participated in and contributed to the following Vertisol management workshops and conferences:

1986. Workshop on Management of Vertisols under Semi-arid Conditions
Organised by IBSRAM in Nairobi Kenya.
1987. Conference on Management of Vertisols in sub-Saharan Africa
Organised by ILCA in Addis Ababa, Ethiopia.
1988. Workshop on Vertisol Management in Africa.
Organised by IBSRAM in Harare, Zimbabwe.
1989. Workshop on Vertisol Management.
Organised by Texas A & M University, College Station, Texas, USA.

1990. Networkshop on Vertisol Management in Africa.
Organised by IBSRAM in Nairobi Kenya.
1992. Annual Networkshop on Management of Vertisols in Africa.
Organised by IBSRAM in Accra, Ghana

JVP learned several things from these conferences:

- that there were several studies underway in the rest of the world as well on Vertisols where water was scarce

- that research in the developing world was focussing on characterisation and coming out with specifications

- that a multidisciplinary approach would be better for creating an impact on the target audience - the farmer

- that Ethiopian Vertisols had great potential: with simple modification of implements, impact in terms of higher yields of food and feeds was possible.

Figure 1. Visit to farmers' field on a field day

Publications/Reports

The Joint Vertisols Project has produced a range of publications and internal reports which are listed below:

1) Abate Tedla, 1989. Improved technology for draining Vertisols in the Ethiopian highlands. ILCA's contribution. In: *MOVUSAC/IBSRAM Workshop on Vertisol Management in Africa, Harare, Zimbabwe, January 16-21.* IBSRAM Proceedings 9. pp. 173-179.

2) Abate Tedla, and Abiye Astatke. 1989. Vertisol management project highlights. Paper presented at the Agronomy and Soil Training Workshop, Holleta, Ethiopia.

3) Abate Tedla and Abiye Astatke. 1992. *Some methods for introducing forage legumes into the smallholder mixed farms in the Ethiopian highlands.* Paper presented at the Symposium on Environmental Degradation, Mekele, Ethiopia.

4) Abate Tedla, and Getachew Asamenew. 1992. *Food and feed production*

strategies for Vertisols in the Ethiopian highlands. Paper presented at the IBSRAM Annual Workshop on Management of Vertisols in Africa, 11-14 June 1992, Accra, Ghana.

5) Abate Tedla, and Mohamed-Saleem M A. 1992. Cropping systems for Vertisols of the Ethiopian highlands. ID: *Reports and papers on the management of Vertisols (IBSRAM/AFRICALAND).* Network Document 1. IBSRAM (International Board for Soil Research and Management), Nairobi Kenya. pp. 55-66.

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12) Abiye Astatke and Abate Tedla. 1992. *Small-scale water reservoirs for erosion control and for sustainable agricultural J production.* Paper presented at the Symposium on Environmental Degradation, Mekele, Ethiopia

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14) Abiye Astatke, Airaksinen H and Mohamed-Saleem M A. 1990. Supplementary irrigation for sequential cropping in the Ethiopian highland Vertisols using broadbed and furrow land management system. *Agricultural Water Management* (in press).

15) Abiye Astatke, Jutzi S C and Abate Tedla, 1988. *Sequential cropping on Vertisols of the Ethiopian highlands using broadbed and furrow system.* 4 pp. (ILCA internal report).

16) Abiye Astatke, Jutzi S C and Grunder M. 1988. *Vertisol surface drainage and effects on soil nutrient conservation, excess water disposal and wheat growth at Debre Zeit.* Paper presented at the National Crop improvement Conference (NCIC), Addis Ababa Ethiopia 28-30 March 1988. IAR (Institute of Agricultural

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Annex 2a: Authors and co-authors of JVP'S synthesis report

Abate Tedla
Forage Agronomist
International Livestock Centre for Africa
P.O. Box 5689
Addis Ababa, Ethiopia

Abiye Astatke
Agricultural Engineer
International Livestock Centre for Africa
P.O. Box 5689
Addis Ababa, Ethiopia

Adugna Haile
Agronomist
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa, Ethiopia

Alemu Taddesse
Forage Agronomist
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa, Ethiopia

Ferew Kelemu
Agricultural Engineer
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa, Ethiopia

Getachew Asamenew
Agricultural Economist
International Livestock Centre for Africa
P.O. Box 5689
Addis Ababa, Ethiopia

Gezahegn Ayele
Agricultural Economist
Alemaya University of Agriculture
Agricultural Research Centre
P.O. Box 32
Debre Zeit, Ethiopia

Hailu Beyene
Agricultural Economist
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa, Ethiopia

Hailu Regassa
Soil Scientist
Institute of Agricultural Research
P.O Box 2003
Addis Ababa, Ethiopia

I Haque
Soil Scientist
International Livestock Centre for Africa
P.O. Box 5689
Addis Ababa, Ethiopia

S Jutzi
Forage Agronomist
Head, Department of Tropical and
Subtropical Field Crops
University of Kassel
STEINSTRASSE 19
D-3430 Witzenhausen
Germany

Mesfin Abebe
Soil Scientist
Minister of Natural Resources
and Environmental Protection
Addis Ababa, Ethiopia

Miressa Duffera
Soil Scientist
Alemaya University of Agriculture
Agricultural Research Centre
P.O. Box 32
Debre Zeit, Ethiopia

Mitiku Haile
Soil Scientist
Alemaya University of Agriculture
P.O. Box 138
Dire Dawa, Ethiopia

M A Mohamed-Saleem
Forage Agronomist
International Livestock Centre for Africa
P.O. Box 5689
Addis Ababa, Ethiopia

Selamyihun Kidanu
Soil Scientist
Alemaya University of Agriculture
P.O. Box 32
Debre Zeit, Ethiopia

K L Srivastava
Soil and Water Engineer
ICRISAT

ICRISAT/ILCA
P.O. Box 5689
Addis Ababa, Ethiopia

Tekalign Mamo
Soil Scientist
Alemaya University of Agriculture
Agricultural Research Centre
P.O. Box 32
Debre Zeit, Ethiopia

Workeneh Negatu
Agricultural Economist
Alemaya University of Agriculture
Agricultural Research Centre
P.O. Box 32
Debre Zeit, Ethiopia

Annex 2b: Technical committee members of the joint Vertisol project

Name	Institution	Duration
Abate Tedla	ILCA	1986-1991
Abiye Astatke	ILCA	1992-cont
Alemu Tadesse	IAR	1990-1991
Asgelil Dibabe (Dr.)	IAR	1988-1990; 1992-cont.
Asnakew Woldeab (Dr.)	IAR	1986-1987
Aweke Aynalem	MOA	1986-1988
Betru Haile	MOA	1989-1991
Desta Beyene (Dr.)	IAR	1987-1990
Ermias Bekele (Dr.)	MOA	1986-1989
Fikru Abebe	MOA	1989-1991
Getachew Alem	IAR	1986-1987
Goshu Makonnen (Dr.)	AUA	1988-1990
Hailu Gebre (Dr.)	IAR	1986-1987; 1988-1991
Hailu Regasa	IAR	1990-1992
S Jutzi (Dr.)	ILCA	1986-1989
Kebede Tatu	MOA	1992-cont.
Mesfin Abebe (Dr.)	AUA	1986-1987
M A Mohamed-Saleem (Dr.)	ILCA	1989-1991
Rezene Fessehaie	IAR	1987-1989
K L Srivastava	ICRISAT	1990-1992
Takele Gebre	MOA	1989-1991
Tekaling Mamo (Dr.)	AUA	1987-cont.
Teshome Negash	RRC	1987-1989

Acronyms:

AAU	Addis Ababa University
AUA	Alemaya University of Agriculture
IAR	Institute of Agricultural Research
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
ILCA	International Livestock Centre for Africa
MOA	Ministry of Agriculture
RRC	Relief and Rehabilitation Commission

Annex 2c: Advisory committee members of the joint Vertisol project

Name	Institution	Duration
Aregay Waktola (Dr.)	AAU	1986-1991
Berhanu Debele	MOA	1988-1991
P S Brumby (Dr.)	ILCA	1986
Dejene Mekonnen (Dr.)	AUA	1986-1991
P Egger (Dr.)	SDC	1991-cont.
Gizaw Negussie	MOA	1986-1988
Goshu Makonnen (Dr.)	AUA	1990-cont.
M Latham (Dr.)	IBSRAM	1988-1991
Mesfin Abebe (Dr.)	MNRDEP	1991-cont.
J Ryan (Dr.)	ICRISAT	1991-cont.
Seme Debela (Dr.)	IAR	1986-1992
L Swindale (Dr.)	ICRISAT	1986-1991
J Walsh (Dr.)	ILCA	1986-cont.

Acronyms:

IBSRAM	International Board for Soil Research and Management
MNRDEP	Ministry of Natural Resources Development and Environmental Protection
SDC	Swiss Development Cooperation

Annex 3: Future prospects: Resource management for the improvement and sustainability of crop and livestock productivity on highland Vertisols in Ethiopia

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Background

In smallholder farming systems of sub-Saharan Africa livestock provide milk, meat, manure, wool, hide and skin for on-farm use and marketing and draught power for cropping. Integrated crop-livestock systems can substantially meet the increasing food and other demands of people if some of the major production constraints are removed.

The Ethiopian highlands, where millions of people scratch out a living from lighter soils on steep slopes, is fast degrading under the combined effects of continuous cropping and overgrazing. Meanwhile, the potentially productive Vertisols located on mild slopes continue to be underutilised because of socio-technical problems associated with their management. As a result, the majority of the rural people in Ethiopia are becoming dependent on food aid. Sustainable technologies that could further reinforce crop-livestock interactions in the farming systems are urgently needed.

Of the estimated 12.6 million ha of Vertisols in Ethiopia, 7.6 million ha are in the highland zone and five million ha in the lowland zone. Only about 28% of the highland Vertisols are cultivated giving generally low-yielding food crops during the latter part of the growing season. Waterlogging, drought and poor workability are the major problems of Vertisols.

During the past six years, a consortium of five active collaborating institutions, namely the International Livestock Centre for Africa (ILCA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Institute for Agricultural Research (IAR), the Alemaya University of Agriculture (AUA) and the Ministry of Agriculture (MOA) were formed as the Joint Vertisol Project (JVP) to coordinate research, training and outreach activities. The JVP-developed package of technologies for raising the productivity of Vertisols included broadbed maker (BBM), better cropping options and the concept of dry planting.

The traditional animal-drawn implement, the *maresha* is inadequate for land-shaping, but it can be modified (using attachments) to give it a land-shaping character. This new implement (the BBM) makes broadbeds and furrows (BBF) allowing drainage of excess water during the growing season. The drainage furrows, in some instances, serve as irrigation furrows also; this makes the BBF technology more versatile. The JVP has recommended crop varieties that are suitable for extended cropping periods on drained Vertisols. On-farm research results confirm that crop yields can be increased by 60% through drainage improvement by the BBF method. By combining several elements of technology, crop yields can be raised twofold or even more. These results have attracted the attention of development and extension agencies. According to one estimate these technologies could potentially benefit four million farm-families living in highland Vertisol areas of Ethiopia alone.

In order to make the drainage improvement practices widely applicable and environmentally safe, further research is needed for translating the plot-based research into watershed management technologies. In the absence of coordinated watershed planning, water drained from individual field plots can cause widespread land degradation. Watershed research will involve systematic study for soil conservation and water control techniques that may suit the farmer endowments. This should also include techniques to make broadbeds and furrows and other structures long-lasting. Selected soil-binding crops (including tree species and other perennials) should form part of the production system for ensuring soil and water conservation and sustained production on the Vertisols. Also, efficient modes of technology transfer will have to be formulated.

In addition to research and development activities on already cultivated Vertisols, future work should also develop criteria and technologies for optimising land use in other areas - e.g., shift from less productive pastoral systems towards crop-livestock systems including elements of higher productivity as well as sustainability in potentially suitable areas.

The first two phases of the project have been funded mainly by the Swiss Development Cooperation (SDC). The second phase of the JVP ended in December 1992. This proposal seeks funds to continue the Project and is therefore jointly submitted for donor support. The proposal covers activities envisaged for the third phase of the JVP to be executed by ILCA, ICRISAT, IAR and AUA.

Goals and objectives

Goals

1. To investigate and recommend appropriate soil, water and crop management practices for increased and sustainable food production on Vertisols in Ethiopia

2. To simultaneously enhance research capacity in Ethiopia in land and water management

3. To devise and implement the rapid transfer mechanism of the technological packages developed during the past years.

Ojectives

1. To identify, develop and adapt a range of cropping options for Ethiopian Vertisols

2. To conduct research, training and outreach activities on porous barriers (e.g. Vetiver hedges), and other grasses for stabilisation of soil and water conservation structures taking into account the unique physical properties of Vertisols

3. To develop and adapt better resource management practices in a watershed context incorporating agro-forestry practices in the agricultural production system

4. To promote optimisation of labour with simple technological inputs, human as well as animal power

5. To promote the already available technological packages to the farmers

6. To verify new cropping technologies on farmers' fields

7. To develop training and extension information manuals for Vertisol management

8. To contribute to the development of trained manpower needs of the country in the various

disciplines of Vertisol management.

Project duration and expected outputs

The Project duration is five years during which time the following activities will be undertaken and outputs are expected:

1. Better resource conservation and management of Vertisols

2. Increased human food, animal feed and fuel production as a result of better floral mix and management of Vertisols

3. Optimal use of human and animal power

4. Introduction of new methods and fools that will increase productivity of farm labour (including women) and reduce drudgery on farm work

5. Experience and technologies developed in the Project may have spillover effect in Vertisols in other countries of Africa.

Implementation

Operational arrangement

The partner institutions will be IAR, AUA, ILCA and ICRISAT and they will bear the primary responsibility for the conduct of the Project. The Project will also seek the active collaboration of the Ethiopian Ministry of Agriculture and International Board for Soil Research and Management (IBSRAM). Task-sharing among the partner institutions would depend on the institutional mandate and is given in Table 1.

Table 1. Framework for institutional cooperation and task-sharing among the partner institutions.

Task	Institutions				
	ILCA	ICRISAT	IAR	AUA	MOA
1. Field and watershed scale surveys and assessment of constraints:					
- Agroclimatic and hydrologic	*	***	*	**	**
- Agronomic (food + forage)	***	*	***	***	*
- Trees and shrubs	***	**	**	*	***
- Socio-economic	***	**	***	*	*
- Crop-livestock integration	***	**	**	**	*
2. On-station research:					
- Land and water management	***	***	*	*	***
- Soil fertility	*	*	***	***	*
- Crops and varieties	*	*	***	***	*
- Design and evaluation of cropping and alternative land-use systems	***	***	***	***	**
- Farm implements	***	*	***	*	**
3. On-farm research	***	***	***	***	***
4. Preparation of reports and manuals	***	***	***	***	**
5. Training of Ethiopian scientists and technicians	***	***	***	***	***
6. Technology diffusion to user organisations and farmers	*	*	**	**	***

* Less input; ** Medium input; *** More input.

Acronyms:

ILCA	International Livestock Centre for Africa
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IAR	Institute of Agricultural Research
AUA	Alemaya University of Agriculture
MOA	Ministry of Agriculture

Strategic considerations

Based on the experience of several projects in Africa and in recognition of environmental diversity and socio-economic factors affecting the use of Vertisols in Ethiopia, the Project will include the following strategies:

Coordination: In order to organise and coordinate the efforts of collaborating institutions an Advisory Committee (AC) composed of the heads of the collaborating institutions and a Technical Committee (TC) composed of leaders of the respective Vertisol project teams of the active institutions have been formed. To ensure more collaboration and follow-up, a coordination office is being opened soon.

Multidisciplinary approach: The Project will have input from technical as well as social scientists. It will adopt a systems-approach perspective in investigations and formulating recommendations based on on-station and on-farm studies.

Low-cost inputs: In providing technical solution, the Project will emphasise the use of locally available and low-cost inputs.

Flexibility of technology options and land-spatial scale: It is envisaged that extension workers and farmers will take into account local factors (landscape position, source of excess water, rainfall pattern etc) while choosing a particular option for water control and crop management. Some options will be appropriate for individual field plots while others will require planning on small watershed basis.

Main areas of investigations

1. Field and watershed scale surveys; analysis of hydrologic, socio-economic and agronomic constraints

2. Evaluation of runoff diversion channels and network of surface drains for efficient and safe disposal of drained water on watershed (community) basis; methods for managing field depression; linking of practices for individualplots with community drains

3. Adjustment of specification of broadbed and furrows in relation to topography, climate and soil factors; management of surface cracks for reducing evaporation in post-rainy season. Further improvement of -the BBM in terms of draught and efficiency

4. Development of attachments for the broadbed maker to perform minimum tillage, row planting and weeding practices

5. Investigating options for minimising soil erosion in a watershed context: planting of trees and shrubs on marginal and high slopy grounds, reclaiming gullies, covering of channels with

vegetation etc. Evaluation of options for double cropping on Vertisols (e.g. different crop combinations; planting on raised beds during the rainy season and in furrows during the post-rainy season)

6. Crop response to nitrogen application on Vertisols in relation to toposequence and water regime.

Target areas

The project will develop recommendations primarily for smallholder farming systems of rainfed Vertisol areas in the highlands and semi-arid tropical zones of Ethiopia.

Project coordination

The Project technical activities will be coordinated by the existing Technical Committee (TC) of the Joint Vertisol Project in accordance with the terms of reference given to it by the Advisory Committee (AC) of the JVP. The overall management will be followed up by the coordination office.

Project evaluation and reporting

Annual reports will be submitted to donor agencies and heads of partner institutions through the coordination office. Biennial review shall be encouraged to evaluate the progress of the Project.