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Challenges of Land Degradation to Agriculture in Ethiopia

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Ethiopian Society of Soil Science

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Challenges of Land Degradation to Agriculture in Ethiopia

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Ethiopian Society of Soil Science
Proceedings of the Sixth Conference

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PRESIDENT'S REPORT

EYLACHEW ZEWDIE
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Dear Dr. Abera Debelo: A/DG of EARO
Invited Guests
ESSS members
Ladies and Gentlemen

On behalf of the Executive Committee of the Ethiopian Society of Soil Science and myself, I welcome you to our Sixth Conference. Today, at this conference we will try to discuss our research achievements and performance. We must also be able to examine our contribution to the national development in general and to the agricultural sector in particular. Related to our discipline, members are analysing the constraints of the national development in their day-to-day activities and try to give possible solution.

During the last two years, the Executive Committee has conducted several meetings and tried to see the achievements of the last Executive Committee. The last Executive Committee has improved the capacity of ESSS in terms of office equipment and made contacts with several organisations, but due to various reasons we were not able to sustain most of them. The transfer of responsibility to the current EC has taken up a long time. Thus, our group was not able to plan and execute the activities outlined by the General Assembly and was not able to call this conference last year. Next year we will try to form ground so that the next EC can call the annual conference. At this point I would like to thank my colleagues who have worked hard to accomplish some of the important assignments given to us. The details of our activities will be reported in the last section of this conference before the election of new EC members.

The current EC would like to confirm that funding to organise this type of conference is getting tighter and tighter and some of the organizations do not even respond to requests. The contribution of members is too small and not paid on time. Thus, it cannot be used to organise such type of conference even once in two years. Our team has decided to sell the conference proceedings to members. This year, members are expected to pay only 50% of the publication cost since Global 2000 has covered the remaining 50%.

As decided in our last conference, the EC has prepared ID card for members. This ID card will be offered only to those who have settled their annual membership fee and will be renewed every year.

I would like to confirm to you that the publication of the *Ethiopian Journal of Natural Resources* is encouraging and coming out as planned. Latter in our Conference, the chief editor will report the details. But what worries the current EC is its circulation even among our members and national institutions. Thus, before the end of this Conference, members have to devise solution to this problem. A lot can be said about the status of EJNR from different aspects. I will request members to raise these issues and discuses them without reservation after the chief editor presents his report. I believe that an open discussion on our important activities will assist the process of improvement and give a new vision to the people involved in day-to-day activities of ESSS.

Ladies and Gentlemen

Our country is still food-insecure and has not come out from food aid. Yearly, the rural population, which is the backbone of the country's economy, is food-insecure at the household level. The natural resource degradation is still in an alarming state and most of our technologies are not helpful to avert or slow down the situation. The country has kept losing the bio-diversity and the environment becomes more fragile for crop and animal production. These conditions should, therefore, force us to ask ourselves "where have we really gone wrong? What are the weaknesses of the generated technologies and are we on the right track to address our national constrains in the agricultural sector?" Unless we answer these questions before planning any research or development project, I personally feel that we are robbing or misusing the scarce national wealth.

Currently, the Ethiopian Government has developed a strategy on poverty reduction, which is under discussion at different levels for adoption. But I personally feel that this group must be in the position to generate technologies that are able to abolish poverty and not only to reduce it. Thus, this conference is organised around the broad theme "Challenges of land degradation to agriculture in Ethiopia" and members will have the chance to discuses the problem from different angles. To facilitate the discussion, the EC has organised a panel discussion as part of this Conference on the 2nd day. Through the coming two days, 18 selected and one leading papers and a keynote address will be presented. The submitted papers were over 30, but due to time constraints we selected only 19 based on their relevance to the Conference theme. Those of you whose papers were not selected, please understand the position we were in and accept EC apologies. We hope that the panel discussion, which is a new feature of our Conference, will provide opportunity to our prominent scientists to pass their knowledge and feeling to the young generation. On behalf of the Society and myself, I sincerely thank the panelists for taking their time to be with us to share their experience.

Ladies and Gentlemen

We have a limited lifetime. It is a natural law. As much as possible, we have to try to produce some valuable knowledge for the next generation. Sometimes due to unexpected death we leave our materials without being published. This is true in the case of Dr. Asnakew, Dr. Tamire and others. Thus, I would like to reflect my worry that we are not losing only the being of our late friends, but also their materials. I, therefore, request this house to find means to collect, compile and publish the works of Tamire and Asnakew so that they can serve as reference material for the country. This may lead us also to a new thinking direction in remembering our loved late friends and give us a new vision for the near future.

Last but not least, I would like to inform members that without the assistance of EARO and STC, it would not have been possible to organise this Conference. EARO has allowed us also to use this conference hall with the available facilities free of charge. We are thankful. We thank also the National Soil Research Center for unlimited support that has given especial strength to ESSS.

I wish you a successful Conference.

Thank you!

Eylachew Zewdie (Dr.)
President of ESSS

OPENING ADDRESS

ABERA DEBELO
Ethiopian Agricultural Research Organization. P.O. Box 2003. Addis Ababa. Ethiopia

Mr. Chairman

Distinguished Guests

Conference Participants

On behalf of the Ethiopian Agricultural Research Organization and on my own behalf. it is a great pleasure and honour for me to address this opening session of the Sixth Conference of the Ethiopian Soil Science Society.

I understand that the Society has been conducting such conferences on a regular basis. As all of you know very well. the Ethiopia agricultural Research Organization (EARO) has been hosting many of these society conferences annually and is pleased to do it in the future too.

Though endowed with a great wealth of natural resources. Ethiopia is facing the challenge of this natural resource degradation at an alarming rate. The country, having a total area of 1.24 million sq.km with a population of 66 million. is an agrarian country. where agriculture is the backbone of the economy in which 86% of the population are engaged. The diversity of the soil and climate of the country on one hand is considered as a wealth endowed while on the other hand. it is a challenge to soil scientists in particular and to agricultural development in general.

In the past. the focus of research was mainly on crops with less emphasis given to livestock. soil and water. However. since the last few years. with the participation of all the concerned bodies in the country. EARO has developed research strategy for crops. livestock. forestry. soil and water. dryland agriculture. socio-economics and policy analysis. biotechnology. research extension. agro-meteorology. GIS and biometrics. food science, post-harvest and agricultural engineering. EARO also designed the research approach on agro-ecological basis.

At present. attempt is also being made by EARO to streamline both long and short-term training in accordance with the priorities set in the research strategy documents. Accordingly. to date 268 students are on long-term training for their MSc and PhD studies in local and external universities from both Federal and regional research centers.

With regard to the expansion of research work in the country. EARO in collaboration with cornered regional states is dedicated to give more emphasis to un-addressed and least research served agro-ecologies and regions on the basis of which establishment of six new research centre, vis-a-vis Sekota. Humerra. Dubti. Jijiga. Humera and Jinka, is in a process through loan money obtained from IFAD. This is to say that due attention is being given to pastoral and agro-pastoral areas where the situation of land degradation is also vulnerable.

Mr. Chariman,

I would like to take this opportunity to inform you that EARO has secured some money, i.e. "Agricultural Research Fund" from the same source and has established Agricultural Research Fund Management committee, where research, higher learning institutions, NGOs, exporters, and private sectors are represented. It will, thus, be announced very soon where the research award will be given on a competitive basis following the guideline developed. You are thus cordially advised in advance to make the necessary preparation to benefit from the ARF through developing and submitting project proposals particularly in the areas that have not been addressed in the past.

Mr. Chairman,

The theme of the conference: "Challenges of Land Degradation to Agriculture in Ethiopia" is a timely one from the point of view of the several degradation of our natural resources and unarrested food shortage for the last three and a half decades.

According to the Program, there are 18 papers to be presented and discussed. Then a " Paned Session" will follow on day two. Although the first part is traditionally done, the second one is a new introduction to the system. We hope all of us will enjoy it very much and look forward to its outcome earnestly assuming that it will shed some light on the current status and future direction which will have some value added to your professional endeavour in attaining the national goal.

Mr. Chairman,

I wish you and the conference participant's success in your deliberations and hope your discussions will be both worthwhile and enjoyable.

With these few remarks, I have the pleasure in declaring the conference officially open.

Thank you!

Abera Debelo (PhD)
A/Director General, EARO

KEYNOTE ADDRESS

MESFIN ABEBE
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"LAND DEGRADATION: A MERRY-GO-ROUND?"

Dear participants:

It appears that I am one of the privileged few to be honored with a repeated invitation to address members of this august Society. This, indeed, is a welcome opportunity which I always accepted with due humility. At the outset, I wish to emphasize that the theme of the Conference ***"Challenges of Land Degradation to Agriculture in Ethiopia"*** is apt for the occasion given the fact that renewable natural resources are the fountainheads from which society as a whole obtains the materials for survival.

I, accordingly, chose: ***"Land degradation: a merry-go-round?"*** as the title of this keynote address to stress the urgent need to acquire the knowledge behind the secrets of the ever-changing mysterious patterns of natural resources in Ethiopia. It is hoped that this would help us predict and control change in accordance with felt needs. Accordingly, the dangers from development would be avoided and the potentialities of finite resources realised. Then, for a win-win situation, there is the necessity to meet the challenges and threats to the endless array of services obtained from the use of these resources not only for comfort and convenience but also for survival. This, however, calls for knowledge of the resource potentials with genuine understanding of their capacities and limitations. This has to be based on sound scientific basis to establish a development agenda to set milestones across the diverse agro-ecology of the country.

Land degradation is also of concern since it has posed a threat to the remarkable diversity revealed in nature and the intimate relationships with the variable environment. Needless to say, their heterogeneity of these mosaic resources has always been the source of great excitement, wonder, and adulation to both lay and intellectuals. Their manifested grandeur and stark immutability would thus have continued to endow them with irrepressible scenic natural beauty if they are to be conserved.

In another note, farmers and pastoralists had appreciations of the inherent manifestations of natural resources and recognised their organic relationship that has remained almost filial. As a result, they acted upon the "secrets" behind complex and dynamic nature with the knowledge that there can be no divorce from this conjugal bond. This has been the fundamental force that underpinned their survival. However, plastic blinds have kept some in the dark about their dependence on them. As a consequence, land degradation stemmed from a host of factors, both human and natural.

The processes involved for the negative ecological changes that led to the multiple destructive natural resources and environmental deterioration practices are too many. For certain, the mounting destruction of life-support capacity is not the product of a preordained inescapable human predicament. Neither is the downward slide due to an impediment of professional nor does it emanate from disciplinary blinders or lack of "magical" scientific breakthroughs. They are reflections of poverty, underdevelopment and the absence of proper policy instruments to combat them.

In specific terms, some of the prominent negative impacts that under-grid their wise utilisation have been deforestation, erosion, siltation, salinity, overgrazing. This has led to the encroachment of desertification. The ultimate end of environmental degradation has become a major problem for some pristine landscapes and a malignancy in others. All told, the productivity of land was markedly, even permanently, undermined and sapped. In those regions with untapped natural resources, smoke screens were created for their misuse and abuse. These further remind us of the extent to which humans have undercut their own welfare. Consequently, land as the basis of livelihood has been compromised and/or destroyed. Then, land degradation has set in to become a plague to upset the traditional balance between people, their habitat and the socio-economic systems by which they lived.

The other side of the merry-go-round is that once established, environmental degradation and insecurity interact, swinging back and forth like a pendulum. Distinct from the normal turn of events, insecurity and conflict were treated as external. As a corollary, insecurity caused by environmental degradation and the reverse effect, environmental degradation caused by insecurity, have virtually been ignored. Often they tended to be sidestepped or treated as short-term phenomena. The fact, however, is that a shrinking resource base breeds insecurity, while insecurity spreads conflict, and conflict causes environmental destruction. This pattern has been clearly demonstrated in Ethiopia, though, with its rich and varied resource base, it has the potential of becoming one of the continent's major economic centers.

Another setting is that for some 30 years, the country has been in a state of turmoil and was torn apart by civil war including regional conflicts. It was also devastated by drought that led to major famines. The aftermath has been continued littered with ruins and barren landscapes where the routs suffered have often been squalor such as famine and starvation. There is a reason to believe that the tragic situation regarding the turmoil, bloodshed and war is now over. Events are currently tilted towards peace, sustainable development and prosperity. Hence, for the first time, the country is less likely to be at crossroads. Regrettably, natural resources degradation with ensuing land degradation is in evidence and is growing in magnitude. Among others, the "paradox" has led to accelerated deforestation, increased erosion and hence decline in soil-fertility. As development accelerates, the ills are bound to assume increased importance where the situation could border on tragedy and cataclysmic dimensions. The basic fact is that, when put under stress, both human and ecological systems exhibit much that is irrational. This has been largely ignored.

In contrast, millions of poor, often-malnourished subsistence farmers continue to live in quaint villages tucked away in the folds of mountains and the escarpments. Despite the diverse climate that imposes rigid schedule of operations, they have demonstrated their capacity for adjustments to remedy the vagaries of nature. They not only cultivate the more fertile and crowded areas, but also eke out sustenance from some of the marginal areas where there is maldistribution of population to resources. The consequences of their quest for food, pasture and fuel are such that, exacting demands are imposed upon these sustainers of life with disregard of their capacity and limitations.

Then, because of their growing depletion and even extensive abuse, the poor, in some important ways, have damaged the environment. To use a figure of speech, it often has meant cutting the ground from under their feet from the consequences of poverty, environmental degradation and development merry-go-round. The end result of this syndrome is that the poor continue to carry the brunt end of land degradation. Therefore, being forced by circumstances beyond their control, they now serve as agents of their own undoing and are the principal victims due to the vicious circle of underdevelopment.

Development efforts of past regimes had little relations to social realities and were imposed as blueprints for prosperity. As a consequence, suffering ensued. For instance, increased agricultural activity and unplanned human influx as settlement, has led to an incipient breakdown of a sustainable agricultural system with low and falling agricultural output. This has forced the extension of cropping to sub-marginal lands fit only for forestry or range management. The further human-caused environmental degradation leaves an aftertaste that is of near–misanthropy. What it all amounts to is that the cardinal issue of conservation-based sound management of core natural resources has not been kept to the fore. The lesson to be drawn is that political, economic, scientific, environmental and cultural factors need to be addressed to ensure equity. Then, their causes and consequences demand far more attention than they have received so far.

Given such poor natural resource endowment and man-made calamities, it has become difficult to meet the needs for mere survival. This view recognises the reality that it is poverty and not ignorance that is the root cause of environmental problems. The situation is accentuated by the vagaries of climate and aggravated by conditions of production that are not easily controlled. As a result, development has been difficult with manifested lags. In places, some of the visible results were the spread of drought and famine. This has often frustrated the best efforts of farmers and the government even where the term "household food security" has joined the lexicon of politics. Thus, there is a need to understand the inter-linked factors in the context of sustainable development to promote and/or ensure environmentally friendly resource utilisation.

Therefore, it is no longer possible to talk about sustainable development without meeting basic human needs. That is why there is the need to rise to the occasion with the necessary commitment to 'time-warp' the development agenda. The genuine appreciation and understanding of natural resources in terms of their importance, relevance and vital inter-relationships can then be fostered. Then, the centerpiece concern of soil scientists should be to keep this in perspective and relentlessly act upon the inter-dependence between agricultural development and the environment. This calls for the maintenance of a balanced self-maintaining and integrative character of soils with the interplay between physico-chemical and biological processes. In so doing, it is possible to clear the mist from the often-misunderstood world of soils. Rather, we could manifest their diverse inherent potentials, capabilities, limitations and interactions.

This is the key-link to save a habitable environment in Ethiopia. The ultimate aim of combating land degradation is to set the primal drive for survival. Accordingly, a conservation-based management of natural resources would herald sustainable socio-economic development that includes the attainment of social, cultural and environmental goals to usher improved quality of life. Otherwise, the battle to safeguard the environment could only be a skirmish in contrast to the war that has to be waged to fight poverty. This can only be attained through an enhanced conservation, sound management and utilisation of natural resources. In small measure, it would also help users and policy makers to either forecast or assess changes so as to reverse the precarious status through prioritised strategies.

The attempt to capture reality rather than improve on it is a major challenge to those concerned with science and technology (S&T). The revolution that can be wrought by S&T, given the correct political setting, cannot be stressed enough. It is also encouraging to note that professional associations and the organic fusion of agricultural R&D with S&T are now being given focused attention. An inventory on measured, indicated, and inferred natural resources reserves can help devise strategies for their expansion through sound production and management. Hence, the importance of intensified research to discover the secrets behind the obstacles to their transformation into sustainable economic resources can only be underscored. But, this calls for the creation of the capacity and capability to monitor, measure, analyze and forecast environmental trends. When all the complex phenomena are inter-woven, a fascinating variety of scenery could emerge

The institutionalised integration of environmental history with R&D and S&T can provide a solid basis for the introduction of appropriate packages and provide the impetus for accelerated development with improvement of quality and usefulness. Thus, emphasis is now placed on future resource management and the recognition of upgraded indigenous knowledge and practices (IKP). Despite the continuation of subsistence, the wealth of accumulated IKP have helped farmers and pastoralists avoided the dangers of being stream-rolled by the vagaries of nature. Undoubtedly, there is so much to be learnt from the people, plants and animals that have survived centuries of adverse environmental conditions. In concert with new formulae, the battle with nature can be fought with sound old concept.

To face the lure of the open future, there is now convergence of purpose between policy makers, planners and implementing agencies through efforts at participatory approach for fast but sustainable development. Such genuine grass-root participation is being integrated within the framework of a multidimensional definition and concept of development With emphasis on participatory arrangements, the aggregate outcome would be the provision of help to those who can use the knowledge at hand, and encouragement to those who are reluctant and fearful to abandon old ways.

For the harness of finite resources in concert with environmental issues, policies and strategies are now put in place and given full visibility. Their accelerated implementation as vehicles of change would assure the infusion of dynamism necessary to attain critical mass in the shortest possible time. Further, federal and regional institutions have been restructured and new ones have been created for a holistic coordinated approach. These would promote new initiatives for the changes to be amplified and not rendered obscure. This must be viewed in the context of the interaction of farmers and pastoralists to factors of production at their command in concert with nature as protagonists.

Such a review requires a re-assessment of old concepts from an ecological point of view instead of being circumscribed by the status quo. In the process, it must put into practice hitherto wisdom and acquire new knowledge that could sustain finite resources. This could enhance synergism in the execution of strategies and facilitate targeted interventions for maximum effectiveness. An appreciation of this would go a long way to usher sustainable socio-economic growth. The end purpose is the conservation and integrated use of natural resources to ensure optimum quality of life without compromising the future. This is a challenge of enormous importance and is a continuation of all that is forward-looking.

Thank you.

Session I. Soil Fertility / Microbiology

Sixth Conference Proceedings. 2002. 13–24

RESPONSE OF FABA BEAN AND FIELD PEA TO PHOSPHATE FERTILISER ON FARMERS' FIELDS ON NITOSOLS OF WOLMERA WOREDA, WEST SHOA

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ABSTRACT

Response of faba bean (*Vicia faba* L.) and field pea (*Pisum sativum* L.) to phosphate fertilizer on *dila* and *dimile* soils (Nitosols), respectively, was determined for three consecutive years (1999-2001) in Wolmera area. The experiment was carried out as on-farm soil fertility management with the participation of farmers. In 1999 three fertiliser rates (0/0, 9/23 and 18/46 kg N/P_2O_5 ha^{-1}) in the form of diammonium phosphate (DAP) were studied. In the following years, one additional level (27/69 kg N/P_2O_5 ha^{-1}) was added. The experiment was laid out in RCBD with two replications per site on five farmers' fields on a plot size of 10 x 10 m using cultivars CS 20DK for faba bean and Tegegnech for field pea. In faba bean, application of N/P_2O_5 fertiliser resulted in grain yield advantages of 24, 67 and 80% over the control for the respective application of 9/23, 18/46 and 27/69 kg N/P_2O_5 ha^{-1}. Similarly, the same fertiliser rates on field pea resulted in grain yield advantages of 55, 103 and 152% over the control. In addition, total biomass, plant height and number of pods per plant were positively influenced. The seed yields of faba bean and field pea were significantly correlated with plant height and number of pods per plant. The partial budget analysis also revealed that application of 18/46 and- 27/69 kg N/P_2O_5 ha^{-1} on faba and field pea, respectively, gave the highest net benefit. The marginal rate of return (MRR) was well above the minimum acceptable rate of return (MARR). Therefore, 18/46 kg N/P_2O_5 ha^{-1} for faba bean on *"dila"* soils and 27/69 kg N/P_2O_5 ha^{-1} for field pea on *"dimile"* soils could be recommended both from agronomic and economic points of view.

Key words: Dila and dimile soils, faba bean, field pea, Nitosols, phosphate fertiliser

INTRODUCTION

Faba bean and field pea are the most important grain legumes in Ethiopia in terms of area, production, protein source and as a rotation crop ameliorating soil fertility. About 4 and 2% of the total cultivated land and about 34 and 15% of the area allotted to pulses in Ethiopia is covered by faba bean and field pea, respectively (CSA, 2000). Despite the importance of the crop in the traditional farming systems, the yield is generally low due to several factors one of which is the critical phosphorus deficiency of soils of the growing areas. Phosphorus is the most important growth-limiting nutrient for pulses including faba bean (Angaw Tsige and Asnakew Woldeab, 1994; Amare Ghizaw et al., 1999). Although blanket applications of 100 kg diammonium phosphate (DAP) ha^{-1} have been recommended for faba bean production in the country, this was not substantiated by research results (Amare Ghizaw et al., 1999). Recent investigations using the cultivars CS 20DK for high altitudes (>2400 m) and NC58 for mid-altitude (1900 to 2300 m) at six and two locations, respectively, showed that faba bean seed yield was significantly affected by phosphorus applications (Amare Ghizaw et al., 1999). In all cases, a positive linear response of faba bean seed yield was obtained to P fertilisation. In most cases, improved varieties of faba bean responded better to applied fertiliser than the locals (Angaw Tsige and Asnakew Woldeab, 1994). It was also found that response of faba bean to phosphate application was dependent on the residual P fertility of the soil (Hebblethwaite et al., 1983). Faba bean seed yield response to N was noted on Holetta Nitosols. Likewise, investigations showed that the application of diammonium phosphate (DAP) significantly increased seed yield of field pea by about 25% (Amare Ghizaw, 1996). Such positive response was obtained from the application of DAP in many IAR/ADD sites. Seed yield of field pea significantly increased over the control due to application of phosphorus fertiliser.

The PRA study conducted in Wolmera Goro area revealed that deterioration of soil fertility is one of the major crop production constraints identified by farmers. Farmers classify soils of their farmland based on colour, fertility status, slope, soil depth and suitability to various crops. Farmers identified five types of soils, namely *kossi*, *dila*, *dimile*, *gombore* and *koticha* according to the degree of soil fertility. The first four are drained Nitosols but *koticha* is characterised as having excess soil moisture. *Kossi* soils which represent the smallest share of the cultivated land are the most fertile while *dimile* soils representing the largest share of the cultivated area are characterised by low soil fertility.

Farmers indicated that the blanket fertiliser recommendation for faba bean and field pea (100 kg DAP ha^{-1}) is not appropriate for the different types of soils, which have different levels of fertility. For instance, on *kossi* soils, which are rich in organic matter as a result of manure and waste application, chemical fertilisers are not required at all. Faba bean could be grown on *dila* and *kossi* soils with and without fertiliser, respectively, while field pea is grown mainly on *dimile* soils without fertiliser in the main season. On *dimile* soils, the recommended rate is low as the soil is exhausted because of continuous cropping and severe erosion. Participatory on-farm fertiliser experiments were, therefore, initiated to compare the recommended NP fertiliser rate with farmers selected NP rate for faba bean and field pea production on *dila* and *dimile* soils (Nitosols), respectively, as identified by farmers.

MATERIALS AND METHODS

The experiment was conducted on Nitosols of Wolmera area for three consecutive years (1999-2001). The PRA study showed that farmers wished to determine optimum NP fertiliser rates for faba bean and field pea grown on *dila* and *dimile* soils, respectively. Hence, five growers each for faba bean and field pea who had land of the specified soil type, members of the FRG and willing to host the trial were selected. The trial sites (farmers' fields) were visited by the FRG prior to planting to assert weather the selected fields meet the requirements of the experiments.

Farmers, extension agents and researchers together selected four fertiliser rates in the form of DAP 0/0, 9/23, 18/46 and 27/69 kg N/P_2O_5 ha^{-1}. The experiment was laid out in a randomised complete block design (RCBD) with two replications on five farmers' fields each for faba bean and field pea on a plot size of 10 x10 m. The fertiliser was applied during planting. The popular cultivars CS 20DK for faba bean and Tegegnech for field pea were broadcast at the rate of 200 and 150 kg ha^{-1}, respectively. Sowing was done from 25 June to 3 July 1999-2001 for both faba bean and field pea. Seeds were covered using animal drawn local plough.

Farmers were advised to prepare the land, plant and manage the trial according to their normal practice. They were also encouraged to assess and compare treatments based on their own criteria. Researchers monitored the trial and recorded farmer assessment throughout the year. Researchers also made their own records on plant stand count, plant height, number of pods per plant and seeds per pod, total biomass, seed yield, thousand seed weight and other important agronomic parameters. Besides, pre- and post harvest evaluation of the trials were made by the farmers research groups in field days organised by the highland pulses research programme.

Analytical results of soil pH, total organic carbon, available phosphorus and texture are also presented (Table 1). To estimate grain yield 25 m^2 was harvested from each plot. Data on input use (fertiliser and labour man-days) and prices were collected. The yield data were analysed taking mean grain yield of each site as a replication. Data were subjected to analysis of variance using MSTAT-C software. Results were presented as means, and the Least Significant Difference (LSD) test at 5% level of significance was used in order to establish the differences among the means. Correlation coefficients were also calculated for plant height, number of pods per plant and seeds per pod, seed yield and thousand seed weight.

Table 1. Soil pH, phosphorus concentration (ppm), percent organic carbon (OC) and soil texture of the trial sites

Field	pH 1:1	P*	OC	PSA%		
No.	H_2O	Ppm	%	Sand	Silt	Clay
Faba bean						
1	4.76	9.60	1.81	15.42	28.33	56.25
2	5.13	8.60	1.69	13.96	25.42	60.62
3	4.74	5.50	1.91	15.42	29.79	54.79
4	5.48	15.10	2.00	15.21	33.96	50.83
5	5.50	15.97	2.04	14.58	39.80	45.62
Mean	5.12	10.95	1.89	14.92	31.46	53.62
Field pea						
1	5.19	12.87	1.77	12.71	30.00	57.29
2	5.19	5.20	1.65	8.33	26.25	65.42
3	4.92	5.10	1.69	10.42	28.96	60.62
4	5.05	13.93	1.75	15.42	29.02	55.56
Mean	5.09	9.27	1.72	11.72	28.56	59.72

*=Bray II method

RESULTS AND DISCUSSION

The results of the study indicated that the application of phosphate fertiliser in the form of diammonium phosphate (DAP) significantly ($P< 0.01$) increased seed yields of faba bean over the control and the magnitude of response varied with the fertiliser rates (Table 2). The combined analysis of variance over years indicated that there was significant ($P<0.01$) interaction between fertiliser rate and years (F×Y) for mean grain yields of faba bean. In 1999 crop season, the application of 9/23 and 18/46 kg N/P_2O_5 ha^{-1} resulted in seed yield advantages of about 41 and 60%, respectively, over the control. In 2000 the application of DAP resulted significantly in linear response with seed yield advantages of about 19, 50 and 55% over the control for the respective application of 9/23, 18/46 and 27/69 kg N/P_2O_5 ha^{-1}. In 2001, the same rates resulted in seed yield advantages of about 11, 86 and 121%, respectively, over the control.

Likewise, the application of phosphate fertiliser at these rates resulted significantly in linear response with mean grain yield advantages of about 24, 66 and 80 % over the control (Table 2). The study of Amare Ghizaw et al. (1999) also showed a significant quadratic response of faba bean seed yield due to P fertilisation at Holetta. A review by Papendick et al. (1988) indicated that legume crops require 13-14 kg P_2O_5 ha^{-1} for each 1000 kg seed ha^{-1} produced. Faba bean seed yield response to N was also noted at Holetta Nitosols (Angaw Tsige and Asnakew Woldeab, 1994). Response of faba bean to phosphate application was found to be dependent on the residual P fertility level of the soil (Hebblethwaite et al., 1983). On IAR/ADD trial sites, positive responses were obtained from the application of

DAP to faba bean (Adugna Haile and Hiruy Belayneh, 1988). Similar results were obtained from on-farm trials carried out in the central highlands of Ethiopia (Alem Berhe et al., 1990). The optimum rate was 18/46 kg ha^{-1} N/P_2O_5 ha^{-1}, which produced an additional mean grain yield of 629 kg ha^{-1} (66%) over no fertiliser treatment (Table 2). Consequently, farmers and development workers during field evaluation of the trial indicated the existence of fertiliser response and selected the third NP rate (18/46) on the basis of visual observation while the trial was in the field.

Table 2. Effect of N/P_2O_5 fertiliser on total biomass, seed yield and thousand seed weight of faba bean in Wolmera

	Seed yield ($kg\ ha^{-1}$)				Total biomass ($kg\ ha^{-1}$)		Thousand seed weight (g)		
Factor	1999	2000	2001	Mean	2000	2001	1999	2000	2001
N/P_2O_5 rate ($kgha^{-1}$)									
0/0	1065c	783c	1000c	949c	2965b	2917b	495c	477b	376c
9/23	1505b	931b	1108c	1181b	3216ab	3250b	513b	482b	389c
18/46	1700a	1178a	1856b	1578a	3323ab	4302a	549a	515a	533b
27/69	-	1212a	2209a	1711a	3840a	3986a	-	486b	579a
F-test									
Rate	**	**	**	**	*	**	**	**	**
Linear		**	**	**	*	**		**	**
Quadratic		NS	*	NS	NS	NS		**	NS
Cubic		NS	**	NS	NS	*		NS	**
LSD (5%)	71.2	141.2	130.30	186.9	815.4	618.0	6.1	21.8	41.0
SE	15.9	44.1	42.3	64.4	254.9	200.6	1.9	6.8	13.3
CV (%)	3.5	10.5	7.8	16.0	18.7	15.7	1.2	3.4	8.0

*, ** = Significant at 0.05 and 0.01 probability level, respectively; NS = Not significant

Similar results were found for aboveground biomass, plant height, number of pods per plant and seeds per pod (Tables 2 and 3). Total biological yield was significantly ($P<0.05$ and $P<0.01$) affected both in 2000 and 2001 crop seasons, respectively, due to NP fertiliser application. The study of Cadish (1990) indicated that the supply of phosphorus increased dry matter production of tropical forage legumes by about 193% and N concentration in shoot tissue by 10% and percentage of N derived from the atmosphere by 15% fourteen weeks after planting on an Oxisol in Colombia. This increment resulted in 259% more N being fixed at 75 kg P ha^{-1} than at 5kg P ha^{-1}. Thousand seed weight was significantly ($P<0.01$) affected by fertiliser application in all years (Table 2). Plant height, number of pods per plant and seeds per pod also significantly ($P<0.01$) responded to fertiliser application in 1999 and 2001 crop seasons but not in 2000. Plant stand counts (m^{-2}) were significantly ($P<0.01$) affected only in 2001.The seed yield of faba bean was correlated with plant height and number of pods per plant ($r = 0.48^{**}$ and 0.63^{**}, respectively).

Table 3. Effect of N/P_2O_5 fertiliser on faba bean plant stand count, plant height, number of pods per plant and seeds per pod in Wolmera area

Factor	Stand count (m^{-2})			Plant height (cm)			Number of pods per plant			Number of seeds Per pod		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
N/P_2O_5 rate ($kg\ ha^{-1}$)												
0/0	36	30	22b	71c	83	104b	5.9c	6.2	6.9b	2.4a	1.92	2.9b
9/23	36	31	25b	82b	86	117a	7.7b	7.1	7.2b	2.5b	2.20	2.6b
18/46	38	36	46a	88a	91	123a	9.8a	8.0	10.2a	2.6c	2.35	3.6a
27/69	-	38	45a	-	97	125a	-	7.2	11.9a	-	2.32	3.7a
F-test												
Rate	NS	NS	**	**	NS	**	**	NS	**	**	NS	**
Linear		NS	**		NS	**		NS	**		NS	**
Quadratic		NS	NS		NS	NS		NS	NS		NS	NS
Cubic		NS	*		NS	NS		NS	NS		NS	*
LSD (5%)	NS	NS	9.4	3.0	NS	8.6	0.9	NS	1.9	0.1	NS	0.6
SE	1.9	3.1	3.0	0.9	3.7	2.8	0.3	1.0	0.6	0.02	0.2	0.2
CV (%)	16.8	22.6	24.8	3.8	10.2	6.7	11.5	24.2	19.5	2.4	17.2	17.8

*, ** = Significant at 0.05 and 0.01 probability level; NS = Not significant

Grain yields of field pea significantly responded to the application of phosphate fertiliser. In 1999 crop season, the application of 9/23 and 18/46 kg $N/P_2O_5\ ha^{-1}$ increased field pea seed yields by 26 and 59%, respectively, over the control. In the year 2000, the application of 9/23, 18/46 and 27/69 kg $N/P_2O_5\ ha^{-1}$ resulted significantly in linear response with seed yield advantages of 71, 143 and 95%, respectively, over the control which were higher compared to the increments in 1999 (Table 4). While in 2001 the same fertiliser rates resulted significantly in linear response with seed yield advantages of about 51, 81 and 115%, respectively, over the control. The application of phosphorus fertiliser at similar rates also resulted in grain yield advantages of about 55, 103 and 152% over the control (Table 4).

The highest grain yield of field pea was recorded from the application of 27/69 kg $N/P_2O_5\ ha^{-1}$. However, farmers and development workers selected the plots, which received 18/46 kg $N/P_2O_5\ ha^{-1}$ on the basis of visual assessment of the differential response of phosphate rates. A review by Angaw Tsige and Asnakew Woldeab (1994) showed similar results. The response of both local and improved cultivars of field pea was very high to fertilisers at many locations. Similarly, the application of 23, 46 and 92 kg $P_2O_5\ ha^{-1}$ increased field pea seed yield by about 21, 48 and 58%, respectively, compared with the unfertilised plots (IAR, 1995) which agrees with this finding.

The combined analysis of variance over years indicated that there was significant ($P<0.01$) interaction between fertiliser rate and years (F×Y) for mean grain yields of field pea. The application of phosphate fertiliser significantly ($P<0.05$) increased aboveground biomass in both seasons, but did not affect thousand seed weight in all years (Table 4).

Table 4. Effect of N/P_2O_5 fertiliser on total biomass, seed yield and thousand seed weight of field pea in Wolmera

	Seed yield ($kg\ ha^{-1}$)				Total biomass ($kg\ ha^{-1}$)		Thousand seed weight (g)		
Factor	1999	2000	2001	Mean	2000	2001	1999	2000	2001
N/P_2O_5 rate ($kgha^{-1}$)									
0/0	448c	1014c	999d	820d	5000b	2155c	183	208	412
9/23	565b	1738b	1506c	1270c	5080b	3215b	191	214	418
18/46	712a	2465a	1807b	1661b	7235a	4025a	198	216	424
27/69	-	1980ab	2147a	2064a	5825ab	4095a	-	205	402
F-test									
Rate	**	**	**	**	*	*	NS	NS	NS
Linear		**	**	**	NS	**		NS	NS
Quadratic		**	NS	NS	NS	NS		NS	NS
Cubic		NS	NS	NS	*	NS		NS	NS
LSD (5%)	34.6	565.4	235.6	201.1	1700.0	938.3	NS	NS	NS
SE	10.6	163.4	52.3	67.7	491.4	208.5	7.2	4.9	5.4
CV (%)	5.2	18.2	4.6	14.8	17.0	8.7	10.7	4.7	1.9

*, ** = Significant at 0.05 and 0.01 probability level; NS = Not significant

The highest total biological yield was obtained from the application of 18/46 kg N/P_2O_5 ha^{-1}. Plant height positively responded to fertiliser application while number of pods per plant was significantly ($P<0.01$) affected only in 1999. Similarly, data in Table 5 indicated that number of seeds per pod was statistically ($P<0.05$) affected by phosphate fertiliser application in 1999 and 2000. The grain yield of field pea was highly correlated with plant height, number of pods per plant and seeds per pod ($r = 0.82^{**}$, 0.60^{**} and 0.50^{**}, respectively).

Table 5. Effect of N/P_2O_5 fertiliser on field pea plant stand count, plant height, number of pods per plant and seeds per pod in Wolmera area

	Stand count (m^{-2})		Plant height (cm)			Number of pods per plant			Number of seeds per pod		
Factor	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
N/P_2O_5 rate ($kgha^{-1}$)											
0/0	45	52	74c	113	100b	3.6c	5.4	7.4	3.52b	3.7b	4.5
9/23	38	55	90b	116	129b	4.9b	5.5	7.5	3.67b	4.0b	4.7
18/46	39	58	98a	128	168a	6.5a	6.1	8.6	5.10a	4.3ab	5.2
27/69	47	63	-	126	180a	-	5.9	9.0	-	4.8a	6.1
F-test											
Rate	NS	NS	**	NS	*	**	NS	NS	*	*	NS
Linear	NS	NS		NS	**		NS	NS		**	NS
Quadratic	NS	NS		NS	NS		NS	NS		NS	NS
Cubic	NS	NS		NS	NS		NS	NS		NS	NS
LSD (5%)	NS	NS	4.3	NS	34.1	0.6	NS	NS	0.2	0.7	NS
SE	5.9	9.5	1.3	6.7	7.6	0.2	0.7	0.6	0.1	0.2	0.5
CV (%)	28.2	22.0	4.2	11.2	7.4	10.5	23.5	10.0	4.9	9.1	13.8

*, ** = Significant at 0.05 and 0.01 probability level; NS = Not significant

A partial budget analysis was conducted for both faba bean and field pea taking mean grain yields of the three years. Two partial budgets were done for both crops using the 1999/2000 (1992 EC) and the 2000/2001 (1993 EC) annual mean grain prices of Holetta market (Tables 6 and 7). Grain prices were higher in 1999/2000 compared to 2000/2001. At Holetta market where farmers of the study area sell their produce and purchase needed commodities, the 1999/2000 faba bean and field pea prices were higher by 59% and 50%, respectively, compared to 2000/2001. Grain yields of faba bean were adjusted downward by 20% while seed yields of field pea were adjusted downward by 30% to reflect what farmers could get under their own management on large plots of land. Marginal rates of return (MRR) were calculated and compared with the minimum acceptable rate of return (MARR) to identify and recommend to farmers the most profitable treatment. For treatment to be considered as a worthwhile option to farmers, the MARR needs to be at least between 50% and 100% (CIMMYT, 1988). A recent participatory rural appraisal in the study area revealed that interest rates in the informal credit market ranges from 100% to 120%. Researchers in other parts of the country suggested a MARR of 100% as realistic (Amanuel Gorfu et al., 1991).

Under lower price assumptions, the treatment 18/46 kg N/P_2O_5 ha^{-1} resulted in the highest net benefit for faba bean while the treatment 27/69 kg N/P_2O_5 ha^{-1} gave the highest net benefit under improved price for faba bean. For field pea, under both price assumptions, the treatment 27/69 kg N/P_2O_5 ha^{-1} gave the highest MRR 188 and 332% suggesting that it was the most profitable rate. In case of faba bean, when the output price of 1.25 ETB/kg was used, the treatment 9/23 kg N/P_2O_5 ha^{-1} gave MRR of 45%, very much lower than the MARR of 100%. The treatment 27/69 is dominated indicating high variable costs and lower net benefits. With improved price, however, all the three treatments become profitable. As has bean indicated earlier, field pea is grown on *dimile* soils considered as a very poor fertile soil whereas faba bean is grown on *dila* soils considered reasonably fertile. Hence, the economic analysis suggests that the marginal benefits would be higher if fertiliser is used at a rate of 27/69 kg N/P_2O_5 ha^{-1} on *dimile* soils for field pea and at a rate of 18/46 kg N/P_2O_5 ha^{-1} on *dila* soils for faba bean production.

Table 6. Partial budget analysis for on-farm participatory soil fertility management trail on faba bean in Wolmera area, 1999-2001

N/P_2O_5, kg ha^{-1}	Yield, kg ha^{-1}	Adjusted yield, 20%, kg ha^{-1}	Gross benefit, ETB ha^{-1}	Fertiliser cost, ETB ha^{-1}	Cost of application, ETB ha^{-1}	Cost of Harvesting, ETB ha^{-1}	Total variable cost, ETB ha^{-1}	Net benefit ETH ha^{-1}	Marginal cost, ETB ha^{-1}	Marginal net benefit, ETB ha^{-1}	Marginal rate of return (%)
Using the 2000/2001 (1993 EC) annual average faba bean price from the Holetta market, ETB 1.25/kg											
0/0	949	759.20	949	0	0	80	80	869	-	-	-
9/23	1181	944.80	1181	130	20	90	240	941	160	72	45
18/46	1578	1262.40	1578	260	20	110	390	1188	150	247	165
27/69	1711	1368.80	1711	390	20	130	540	1171D	150	X	X
Using the 1999/2000 (1992 EC) annual average faba bean price from the Holetta market, ETB 1.99/kg											
0/0	949	759.20	1510.81	0	0	80	80	1430.81	-	-	-
9/23	1181	944.80	1880.15	130	20	90	240	1640.15	160	209.34	131
18/46	1578	1262.40	2512.18	260	20	110	390	2122.18	150	482.02	321
27/69	1711	1368.80	2723.91	390	20	130	540	2183.91	150	61.74	41

Table 7. Partial budget analysis for on-farm participatory soil fertility management trail on field pea in Wolmera area, 1999-2001

N/P_2O_5, kg ha^{-1}	Yield, kg ha^{-1}	Adjusted yield, 20%, kg ha^{-1}	Gross benefit, ETB ha^{-1}	Fertiliser cost, ETB ha^{-1}	Cost of application, ETB ha^{-1}	Cost of Harvesting, ETB ha^{-1}	Total variable cost, ETB ha^{-1}	Net benefit, ETB ha^{-1}	Marginal cost, ETB ha^{-1}	Marginal net benefit, ETB ha^{-1}	Marginal rate of return (%)
Using the 2000/2001 (1993 EC) annual average field pea price from the Holetta market, ETB 1.48/kg											
0/0	820	574	849.52	0	0	60	60	789.52	-	-	-
9/23	1270	889	1315.72	130	20	75	225	1090.72	165	301.20	183
18/46	1661	1162.7	1720.80	260	20	90	370	1350.80	145	260.08	179
27/69	2064	1444.8	2138.30	390	20	105	515	1623.30	145	272.51	188
Using the 1999/2000 (1992 EC) annual average field pea price from the Holetta market, ETB 2.22/kg											
0/0	820	574	1274.28	0	0	60	60	1214.28	-	-	-
9/23	1270	889	1973.58	130	20	75	225	1748.58	165	534.30	324
18/46	1661	1162.7	2581.19	260	20	90	370	2211.19	145	462.61	319
27/69	2064	1444.8	3207.46	390	20	105	515	2692.46	145	481.26	332

Note: Price of DAP in the 2001 crop season in Wolmera area = ETB 2.60/kg

CONCLUSION AND RECOMMENDATIONS

The results of the study indicate that most of the soils of the experimental fields are low in pH and deficient in available phosphorus. Thus, the amount of available P in soils is insufficient to meet the requirements of faba bean and field pea. Though the application of mineral fertilisers has had an enormous impact on plant production, soil management practices, which increase nutrient-use efficiency, are equally of paramount significance for efficient use of applied fertilisers. Management practices that influence the availability and efficiency of nutrients such as P include liming, application of manure and crop residues, the rate, observance of the proper time and method of application, cropping systems and erosion control practices.

The applications of phosphate fertiliser in the form of DAP resulted in higher grain yields of both crops. Hence, given the agronomic responses and 2000/2001 grain prices, the application of 18/46 kg N/P_2O_5 ha^{-1} on faba bean and 27/69 kg N/P_2O_5 ha^{-1} on field pea as DAP could be recommended on *dila* and *dimile* soils, respectively. This requires further study involving other factors to determine the critical levels of NP for optimum faba bean and field pea yields.

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CONTRIBUTION OF ORGANIC AMENDMENT TO PHYSICO-CHEMICAL CONDITIONS OF COFFEE NURSERY MEDIA

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ABSTRACT

In Ethiopia, the national average yield of coffee remained low, among others, due to the increasing decline in soil fertility status and limited use of improved cultural practices, including nursery media amendment for the heavy feeder arabica coffee which was facing escalating prices of chemical fertilisers. The study focused on locally available organic resources as alternative fertiliser inputs with the view of an optimised integrated use of available organic materials for good soil nutrient management towards simulating the "forest soil" which is widely in use at most nursery sites. To this end, undecomposed and decomposed coffee husk (UCH, DCH), farmyard manure (FYM) and their combinations were used to prepare five organic sources (UCH, DCH, FYM, UCH + FYM and DCH + FYM) which were incorporated with the topsoil (TS) in five ratios. Then, their effects were evaluated in a factorial experiment arranged in a split - plot design at Jimma Agricultural Research Centre under nursery conditions by taking into consideration soil physico-chemical conditions. The results show that coffee composts and FYM varied in their nutrient compositions and more optimised when combined. The incorporation of the organic sources in different combinations improved the: a) physical conditions, except for UCH, which impaired some media physical parameters. Otherwise, such combinations as 2M: 4TS to 4M:4TS led to reduced bulk and particle densities, high porosity, high water percolation rate and hydraulic conductivity due to the use of the decomposed organic sources, either singly or in combinations; and b) chemical conditions where both plant nutrients and soil organic matter were maintained notably, EC, nutrient status, total nitrogen, organic carbon and available phosphorus which were significantly enhanced by the incorporation of FYM singly or in combination with coffee composts with increased ratios and the lowest values were recorded from TS alone. UCH, however, resulted in the immobilisation of nitrogen and phosphorus in the media. Thus, those combinations of DCH with FYM are preferred, followed by UCH + FYM and least preferred being UCH. This suggests wider options in preparing potting media with ideal physical and chemical conditions using locally available organic resources.

Keywords: nursery media, organic resources/ratios, physico-chemical parameters

INTRODUCTION

With focus on the mineral nutrition of arabica coffee, it is recognised that the crop is a heavy feeder requiring high nutrient rates to give high yields (Michori, 1981; Coste, 1992; Paulos, 1994). In contrast, it is dominantly grown on the highly weathered Alfisols, Oxisols and Ultisols that have certain limitations and pose nutrient stress (Mesfin, 1996, 1997; Piccolo and Gobena, 1986). Hence, the intensification of coffee cultivation would call for the improvement of both chemical and physical constraints. However, only eight percent of coffee growers use some fertilizers in coffee cultivation largely because the high prices of the imported fertilizers beyond their purchasing power. As a result, the majority of smallholders have continued to produce the crop with minimum inputs to bolster the native soil fertility (Kassahun and Paulos, 1994). Hence, this calls for a search of locally available alternative plant nutrient sources with the recognition of the traditional knowledge that coffee farmers have long utilised organic materials to maintain soil fertility and to produce high quality coffee.

The potential roles of organic residue are clearly observable from the more vigorous and high performance coffee trees around homesteads. Paulos (1986) noted that forest coffee stands did not significantly respond to applied mineral fertilisers indicating the contributions of the dense litter to nutrient availability under forest conditions upon its decomposition. At present, however, the original ecology of the major coffee growing regions is being disturbed with the high intensity of deforestation. This and the prevailing high rainfall have resulted in severe erosion and exposure of the less fertile sub-soils. As a result, such degraded coffee soils require high doses of fertilizers for a reasonable crop production. This may not be economically feasible to farmers unless supplemented with locally available organic resources.

In Ethiopia, the sole and interactive effect of these plant nutrient sources in coffee production awaits through investigation. Mesfin (1982) and Yacob (1986) have reported on the use of forest soil as media components and it is widely in use at most nursery sites in Ethiopia. However, with the current scale of deforestation and thus diminishing accessibility to forest soils, recycling of organic by-products towards potting media amendments need closer attention. The main purpose of this study was to investigate the potential of using locally available organic materials as low-cost and complementary inputs to generate economically and environmentally friendly soil fertility amendments in a coffee-based production system. The specific objective of this study was, therefore, to assess the effects of coffee husk composts and animal manure, either singly or in combinations, on physico-chemical conditions of coffee nursery media, mimicking forest soils to produce high quality coffee seedlings with maximum field performances.

MATERIALS AND METHODS

The study was conducted at Jimma Agricultural Research Center. Centre is located at 7^0 46' N latitude and 36^0 0' E longitude. It is found within tepid to cool humid highland (H_2) agro-ecological zone of Ethiopia, at an altitude of 1750 meters above sea level with a long-term average rainfall of 1536 mm per annum. The mean maximum and minimum temperatures are 25.9 and 11.2 ^{0}C, respectively (IAR, 1997). The predominant soil of the Center is eutric Nitosols (IAR, 1978). A one-year undecomposed (UCH) and a two-year decomposed coffee husks (DCH) were collected from the dry coffee processing heaps, while the reddish-brown coffee soil was collected from open fields. The well-decomposed farmyard manure (FYM) was collected from the dairy development enterprise in Jimma. These materials were separately dried, manually crushed and passed through a 2 mm sized sieve to prepare five organic treatments including UCH, DCH, FYM and their combinations (UCH plus FYM, DCH plus FYM). Then, these treatments were thoroughly mixed with the topsoil (TS) at the ratios of 1M: 4TS, 2M: 4TS, 3M: 4TS and 4M: 4TS. A check plot without organic sources (0M: 4TS) was used for the study. A factorial experiment arranged in a split-plot design with three treatment replicates was used to assign organic sources and their proportions, respectively. Samples from each treatment were brought to the National Soil Laboratory Center to determine their initial nutrient status using the standard procedures (Sahlemedhin and Taye, 2000). After the completion of the study, their effects on some soil physico-chemical parameters such as water-holding capacity, particle and bulk densities, aeration, infiltration rates, nutrient status, pH, CEC, organic matter status and other aspects were also determined under the same laboratory settings. Finally, statistical analysis and simple linear regression and treatment mean separation were made according to Duncan's Multiple Range Test (DMRT) at 5% probability level using an MSTAT computer program.

RESULTS AND DISCUSSION

The results of some soil physico-chemical characteristics of the experimental soil are shown in Table 1. It is acidic in reaction with some chemical limitations and thus requires amendments for crop production. The results of the chemical composition of the organic sources (Table 2) depicted that coffee composts had high monovalent cations and total nitrogen. Whereas, FYM contained more divalent cations and available P, suggesting the integrated use of both organic sources to optimise potting media plant nutrients. As a whole, the plant and animal materials used in this study can be used as media ingredients as they have different nutritional status. This supports the findings of Asefa (1997) and Muller and Kotchi (1994). The low P content of coffee composts could be associated with the ecological adaptation of coffee trees to low P soils, as Paulos (1996, 1997) and Mesfin (1997) have documented it. The least and the highest C: N values were noticed from UCH and FYM, respectively. This indicates the importance of blending undecomposed and decomposed organic resources to formulate composts with partial decomposition stage.

Table 1. Some physico-chemical characteristics of the experimental soil

Character	Value
PH (1:2.5 H_2O)	5.08
EC (mmhos)	0.86
Sodium (me/100g)	0.47
Potassium (me/100g)	1.29
Calcium (me/100g)	6.49
Magnesium (me/100g)	2.75
CEC (me/100 g)	24.00
Base saturation (%)	46.00
Total nitrogen (%)	0.11
Organic carbon (%)	0.86
Organic matter (%)	1.48
Carbon: nitrogen ratio	8.00
Available P (ppm)	1.34
Sand (%)	21
Silt (%)	18
Clay (%)	61
Texture class	CL

Table 2. Chemical composition of the organic sources used for the study

Organic source	Exchangeable bases (%)				Available P (ppm)	TN	OC	C: N
	Na	K	Ca	Mg		%		
UCH	0.16	1.74	1.42	0.16	123.05	1.96	6.55	3
DCH	0.09	1.55	0.82	0.17	126.00	1.89	14.44	8
FYM	0.08	0.66	1.21	0.22	155.46	1.19	14.60	12
UCH+FYM	0.12	1.20	1.31	0.19	139.46	1.57	10.57	7
DCH+FYM	0.08	1.10	1.01	0.19	140.73	1.54	14.52	9

Effects on media physical parameters

Bulk density: Organic sources significantly influenced bulk density. It ranged from 0.86 g/cc to 0.93 g/cc for the media composed of DCH and UCH, respectively; while the others gave bulk densities between 0.88 g/cc and 0.92 g/cc (Table 3). Low bulk density values were obtained from decomposed than the undecomposed organic sources. For instance, DCH alone and UCH in combination with FYM at the highest ratio resulted in a bulk density reduction of 39.42% and 33.06%, respectively, over the topsoil alone (Table 3). The linear regression result also show negative and non-significant associations between organic source and bulk density and particle density (Table 4). Since both the volume of pore spaces and soil solids determine the bulk density of a given soil medium, then soil media with a high proportion of pore space to solids have lower bulk densities as compared to those with more compact and had less pore spaces (Kolay, 1991). On the other hand, those media with decomposed coffee husks and animal manure, singly or in combination, resulted in lower values due to high organic matter constituents which markedly improve soil structures with an ultimate reduction in media bulk density. Reduced bulk density of soils with the increased humus status has been long recognised as elaborated. Hence, those media containing undecomposed coffee husk had expected high bulk density values, which could be attributed to the low humification of the organic material.

Highly significant differences due to organic manure when mixed to surface soil were noted. Thus, the lowest (0.80 g/cc) and the highest (1.21 g/cc) results were recorded from the media with the ratios of 4M: 4TS and 0M:4TS, respectively. Even within the manure and topsoil (TS) mixture, 4M: 4TS, which gave the lowest, bulk density and the one composed of 2M: 4TS resulted in respective bulk density reductions of 33.06% and 33.88% over the control, the surface soil (Table 3). The relationship between organic levels and bulk density was negatively significant (r = 0.50*) and it could be attributed to the justification indicated earlier.

Particle density values had a narrow range and the variations among the different organic sources were no significant. Consequently, such values as 2.35 g/cc and 2.47 g/cc were noted for DCH and UCH blended media, respectively (Table 3). As in bulk density, the high values of 2.50 g/cc and 2.56 g/cc were observed from the media containing the lowest proportion of UCH, singly or in mixes with FYM, respectively (Table 3). The association between organic source and particle density was negative and non-significant (Table 4). Likewise, there was consistent reduction with increased proportion of organic sources except FYM. As a case in point, 2FYM: 4TS to 4 FYM: 4TS resulted in increase from 2.23 g/cc to 2.45 g/cc (Table 3). The use of DCH and FYM showed respective higher particle density reductions of 8.56% and 7.78% over that of the topsoil. This is unlike the UCH and UCH plus FYM that reduced particle density only by 3.89% and 5.06%, respectively. The reasons for this have been elaborated earlier.

Particle densities were decreased with the increased proportion of manures. In general, the values of particle density followed the order: 0M:4TS > 1M:4TS > 2M:4TS > 3M:4TS > 4M:4TS ratios of manures with a particle density reductions ranging between 5.45% and 9.34% (Table 3). Specifically, the highest (2.57 g/cc) and the lowest (2.33 g/cc) results were achieved at the lowest (0M:4TS) and the highest (4M:4TS) ratio. The correlation coefficient between organic proportion and particle density was negative and significant (PΩ0.05). The present findings are in line with that of Kolay (1991) and in agreement with basic principles that organic matter weighs less than an equivalent volume of mineral soil.

Porosity was higher for media, which consist of decomposed organic sources. This is unlike the values for bulk and particle densities. Consequently, the results were 62.71% and 63.65% for FYM and DCH where 18.50% and 20.27% increased porosity, respectively. In contrast, those media composed of undecomposed coffee husks as major constituents showed porosity values of 62.50% for UCH plus FYM and 62.43% for UCH alone with subsequent increased porosity of 17.97% and 18.10%, respectively (Table 3). Furthermore, porosity was positively associated with the proportion of organic manures added. It thus decreased with decreased organic material where the results were 65.79% and 52.92% for the ratios of 2M:4TS and 0M:4TS, respectively (Table 3). Porosity was positively correlated with organic source and ratio, though it was not significant (Table 4). Such variations could be explained in terms of the ultimate change in the bulk and particle densities, which in turn influence the proportion of micro-and macro pores in the medium (Brady, 1991).

Water-holding capacity was not significantly affected by organic sources within the soil media. However, the lowest (42.76%) and the highest (48.50%) field capacity moisture contents were recorded for those media composed of UCH and FYM, respectively. Nevertheless, their combined effect (UCH+FYM) had relatively high moisture content as compared to the decomposed coffee husks singly or in combinations (Table 3). On the other hand, the proportion of the organic sources incorporated highly significantly influenced the moisture contents at field capacity and permanent wilting points. Thus, higher values were noted for increased proportion of organic source treatments, except FYM.

Field capacity of 37.20% and 48.62% was recorded for top soil (OM:4TS) and 4M:4TS, respectively. Equally, the lowest (30.20%) and the highest (40.04%) permanent wilting points were recorded from these media compositions, respectively (Table 3). The result also indicates the direct, but non-significant effects of organic source ($r = 0.29$) and significant ($r = 0.50^{**}$) impacts of organic proportions on media moisture content. This is in contrast to their effects on bulk and particle densities and could be attributed to the improved media structure that comes with better porosity and increased organic matter contents.

Influence of organic sources on percolation rate was highly significant. Hence, the highest results were obtained from media of decomposed organic sources, singly or in combinations. The values ranging from the lowest of 17.83 to 35.80 ml/min for FYM and the highest of 25.86 to 48.17 ml/min for DCH+FYM, respectively. Conversely, the combinations with undecomposed coffee husks resulted in lower percolation rates. This ranged from 0.20 ml/min to 8.93 ml/min and 10.83ml/min to 18.67 ml/min for UCH and UCH+FYM, respectively. The results revealed that low (5.98 ml/min) and high (28.38ml/min) percolation rates were recorded from media composed of UCH and DCH+FYM, respectively (Table 3).

The proportion of organic manure in the media highly significantly affected the percolation rates. The rates were reduced with increasing the proportion of each organic source, except FYM plus DCH; thus, the highest values, in decreasing order, were obtained from the media compositions of: 3DCH+FYM, 1FYM, 2DCH, 2UCH + FYM and 1UCH. Relatively low values were recorded at the two extreme ratios of media compositions with respective values of 7.40 ml/min and 16.57 ml/min for topsoil and 4M: 4TS (Table 3).

Table 3. Physical conditions of the media as affected by sources and ratio of components

Treatment	Bulk density (g/cc)	Particle density (g/cc)	Porosity (% vol.)	Moisture content (%) FC (1/3 bars)	PWP (15 bars)	Percolation rate (ml/min)	Hydraulic conductivity (cm/min)
Organic source	*	NS	NS	NS	NS	**	**
UCH	0.93a	2.47	62.50	42.76	34.56	5.98c	0.13c
DCH	0.86b	2.35	63.65	44.52	38.12	22.73ab	0.58a
FYM	0.89ab	2.37	62.71	46.50	36.98	20.24ab	0.56a
UCH+FYM	0.92ab	2.44	62.43	44.74	36.16	14.45bc	0.37b
DCH+FYM	0.92ab	2.43	62.40	43.40	35.96	28.38a	0.63a
Manure: topsoil	**	*	*	**	**	**	**
0M:4TS	1.21a	2.57a	52.92b	37.20c	30.20b	7.40b	0.19b
1M:4TS	0.85b	2.43b	64.93a	43.90b	35.80a	24.05a	0.61a
2M:4TS	0.81b	2.36b	65.79a	45.60ab	37.54a	20.80a	0.53a
3M:4TS	0.84b	2.35b	64.33a	46.60a	38.20a	22.96a	0.49a
4M:4TS	0.80b	2.33b	65.71a	48.62a	40.04a	16.57ab	0.45a

Mean values followed by the same letter(s) within a column are not significantly different from each other at P≤ 5% probability level; NS = Non-significant, *, ** = Significant at P≤ 0.05 and P≤ 0.01, respectively

The results have revealed that percolation rate was highly dictated by the type and proportion of the organic sources used as media ingredients. On the whole, the regression analysis between organic amendments and media water contents revealed positive and significant associations (Table 4). Those treatments that ameliorated the adverse soil physical properties have promoted it. This is because of the beneficial direct or indirect effects of the organic matter to form a stable structure that can facilitate the movements of water. In contrast, the formation of closely packed particles of the wetted undecomposed materials and the reduced total pore spaces at the highest organic proportions retarded water flow and contributed to lower percolation rates. This could subsequently lead to water logged conditions as manifested in the nursery studies. Chane (1991) found such restricted water flows in nursery media composition containing undecomposed coffee husks. The current finding also supports the reports of Kolay (1991).

Hydraulic conductivity: The type of organic sources similar to percolation rates (Table 3) highly significantly affected hydraulic conductivity. Hence, relatively higher values were recorded from media composed of FYM either singly or in combination with DCH. The respective results of 0.56 cm/min and 0.63 cm/min were found unlike the lowest value (0.13) cm/min) obtained from UCH containing media.

Table 4. Correlation coefficient values between soil amendments and physical parameters

Character	Correlation coefficient (r)							
	1	2	3	4	5	6	7	8
1. Organic source	-							
2. Organic proportion	0	-						
3. Bulk density	-0.30	-0.50*						
4. Particle density	-0.17	-0.48*	0.73**	-				
5. Porosity	0.29	0.41	-0.95**	-0.47*	-			
6. Field capacity	0.26	0.57**	-0.74**	-0.80**	0.58**	-		
7. Permanent wilting point	0.23	0.56**	-0.78**	-0.87**	0.60**	0.91**	-	
8. Hydraulic conductivity	0.64**	-0.40	-0.37	-0.37	0.30	0.17	0.27	-

*, ** = Significant at 5 and 1% probability levels, respectively

Relatively higher hydraulic conductivity values were obtained at the low proportions, indicating its close relationships with percolation rates. It was positively and significantly (r = 0.64**) influenced by the organic source, but negatively and non-significantly associated (r = 0.40) with ratios of organic source (Table 4). From the foregoing, it can be seen that soil media composed of different organic treatments with high organic matter status were found to promote hydraulic conductivity. These can be categories in moderate to moderately rapid flow classes according to Brady (1991), unlike that of the topsoil treatment and UCH of slow water movement classes. The present findings are much closer with previous report (Taye et al., 1999) in that healthy and vigorous coffee seedlings were produced from nursery soil composed of the same organic inputs and had improved media physical conditions.

Effects on media chemical parameters

Reaction of the media (pH) due to the various organic sources and proportions on soil media was highly significant. Consequently, pH was raised with the increased ratio of organic sources. The values were 5.51 and 6.91 for those soil media composed of DCH and UCH plus FYM, respectively. Similarly, the highest (6.34) and the lowest (5.66) pH values were obtained for UCH plus FYM and DCH, respectively. On the whole, lower pH result from decomposed organic mixes while the reverse is true for undecomposed materials. This is possibly due to the concentrations of acid forming ions and production of weak acids during the course of decompositions in the former, and that of basic cations in the latter as it has been noted by Franco and Munns (1982). Similarly, pH increased from 5.08 to 6.55 for those media such as topsoil and 4M: 4TS, respectively (Table 5). This could be evident from the positive and significant (r = 0.63**) relationships discovered in the regression analysis between pH and proportion of organic materials in the potting media mix (Table 6). A positive effect on available P, while positive and significant influences on such chemical properties as ECE, OC, K, Na and TN, in that order was noted. This supports FAO report (FAO, 1984).

Organic sources significantly affected electrical conductivity which was also highly significantly affected by the proportion of components in the mix (Table 5). Those composed of FYM singly or in combination had higher EC values as compared with coffee composts with different stages of decomposition with values that ranged between 0.49 and 0.81 dS/cm. It also increased with higher ratio of organic components as in that of OM: 4TS (0.06) and 4M: 4TS (1.18 dS/cm) (Table 5). EC was positively and significantly associated with organic source (r =0.44**) and organic ratioon (r=0.84**) and its relationship with most other soil chemical parameters was positive, though their degree of association varied (Table 6).

Cation Exchange Capacity (CEC): The different organic sources and proportions significantly affected CEC. Hence, the highest and lowest CEC values of 36.00 and 27.88 me /100 g were obtained from DCH plus FYM and

UCH, respectively (Table 5). In general, CEC was much higher for the media composed of the decomposed materials than the undecomposed treatments singly or in combinations. This could be attributed to humification and the generation of pH dependent adsorptive sites on the organic exchange complex. Similar findings were also noted (Hsieh and Hsieh, 1990), in that the potential nutrient carrying capacity of the soil medium is determined on the nature and the amount of organic colloids. In addition, there was an increase in CEC from 24.00 to 39.04 me/100 g with the increased ratios from 0M: 4TS to 4M: 4TS (Table 5). From the multiple regression analysis it was noted that the relationship between CEC and organic ratio (r = 0.63**), EC, divalent cations and Na was observed to be direct and highly significant in that order (Table 6).

Exchangeable bases were significantly influenced by organic sources as revealed by the status of monovalent and divalent exchangeable cations (Table 5). Except for the UCH, the exchangeable cations uniformly increased with the increased proportions of the other organic sources. Relatively high Na (1.50 me/100g) and K (8.26 me/100g) were noted in DCH followed by that of UCH, which showed the respective Na and K values of 1.40 and 7.68 me/100 g. On the other hand, the divalent cations were much higher for the potting media composed of FYM (Ca = 15.87; Mg = 6.50 me/100g) and FYM plus DCH (Ca = 16.77, Mg = 6.30 me/100 g). Accordingly, Na and K; Ca and Mg increased from 0.47 to 1.88 and 0.62 to 10.45; 8.88 to 19.47 and 3.78 to 7.86 me/100 g, respectively (Table 5).

In addition, the incorporation of different ratios of organic mixes highly significantly affected the status of the exchangeable bases with increases in proportion to the organic manure.

Base saturation, similar to the exchangeable bases, was high for decomposed coffee husks and FYM singly or in combinations. The results followed the order: FYM > DCH > DCH+FYM > UCH+FYM > UCH, though not significant (Table 5). Similarly, base saturation shifted from 46.00% to 100.20% with increasing ratio from OM: 4TS to 4M: 4TS (Table 4), indicating its direct and highly significant relationships with most other chemical parameters such as cations, organic matter, available phosphorus and CEC (Table 6).

A highly significant regression value (r = 0.60**) was recorded between organic ratio and base saturation. Its associations with other chemical properties, except pH of the media likewise were also significant and positive, particularly for Mg, Ca and Na in such order (Table 6). Thus, any factor that influences these attributes may also affect the base saturation. The high base saturation status of decomposed materials, particularly with the increased proportions, could largely be due to the ultimate beneficial effects of the high organic matter contents of nursery media.

Total nitrogen (TN) was significant for the applied organic sources and highly significant for the different ratios of the organic mixtures (Tables 5 and 6). Hence, the highest (0.39%) and the lowest (0.27%) were from DCH plus

FYM and UCH, respectively. On the whole, the incorporation of high proportion of organic material appreciably increased the total nitrogen contents with a value of 0.11% for top soil alone and 0.46% for the highest ratio of organic source of 4M: 4TS, respectively (Table 5). Such relatively high total nitrogen contents of those media containing decomposed materials as a major component could be related to the release of mineralised nitrogen upon decompositions unlike the undecomposed organic sources, which binds nitrogen in the organic form. The findings also depict the positive relationship between organic source and TN (r = 0.48*) and organic ratio and TN content of the media (r = 0.77**) where EC, CEC, and organic carbon were also positively and significantly associated (Table 6). Jansse (1993) has documented similar results due to integrated use of plant nutrients.

Organic carbon was not significantly different among the organic sources. Thus, the results fell within the narrow range of 2.87% to 3.92% for UCH and DCH plus FYM, respectively (Table 5). In other words, the organic carbon content was relatively high for soil media composed of farmyard manure singly or in combinations as compared to those containing coffee husks alone. On the other hand, there were highly significant and positive associations between organic carbon and proportion of organic manure (Table 6) and hence, the results increased from 0.86% to 5.10% for media compositions of topsoil alone and 4M: 4TS, respectively (Table 5).

In general, an organic carbon content was positively and significantly correlated with organic source (r =0.48*) and with ratio (r = 0.78**) as well as with all the chemical parameters of the media. Particularly, it was more closely associated with EC, TN and divalent cations in that order (Table 6). Hence, the high organic carbon contents of the potting media mixture with FYM as a major constitute could be attributed to the high organic matter. This corroborates with the works of Mesfin (1982) and Yacob (19986).

Carbon to nitrogen (C/N) ratio had no significant variation due to the various organic sources and proportions of the media. However, the highest (13:1) and the lowest (9:1) were obtained from the media composed of FYM and DCH, respectively. The combined use of carbon and nitrogen-rich sources gave an intermediate C: N value of 10:1 (Table 5). Similarly, C: N ratio was relatively high for media composed of organic amendments at different ratio where the results increase by 37.5% over the sole soil treatment.

The narrow C: N ratios indicate that the organic sources and ratio contained high organic matter with ultimate increased total nitrogen. This could minimise the competitions for the inorganic nitrogen between the seedlings and the soil microorganisms, as opposed to the undecomposed materials. Similar findings were reported (Myers et al., 1994). These have indicated decreased decomposition of organic inputs with increased C: N ratio, which caused a shortage of nitrogen in the soil medium.

Table 5. Chemical status of nursery media as influenced by organic sources and their proportions

Treatment	pH (1:2.5 water)	EC (dS/cm)	Exchangeable bases (me/100g)				CEC (me/100g)	Total nitrogen	Organic carbon	C: N	AV.P (ppm)
			Na	K	Ca	Mg					
Organic source	**	*	*	*	*	*	*	*	NS	NS	**
UCH	6.28a	0.49c	1.40ab	7.68ab	6.09b	3.03b	27.88b	0.27b	2.87	11	7.07b
DCH	5.66b	0.55bc	1.50a	8.26a	10.78ab	5.612a	32.32ab	0.34ab	2.92	9	25.12b
FYM	5.92b	0.76ab	0.94c	3.69c	15.87a	6.50a	32.84ab	0.30ab	3.88	13	105.78a
UCH+FYM	6.34a	0.58abc	1.04bc	5.05bc	10.48ab	4.37ab	29.88ab	0.33ab	3.29	10	89.36a
DCH+FYM	5.94b	0.81a	1.37ab	6.07abc	16.77a	6.30a	36.00a	0.39a	3.92	10	92.89a
Manure :TS ratio	**	**	**	**	**	**	*	**	**	NS	**
0M:4TS	5.08d	0.06d	0.47d	1.29d	6.49c	2.75c	24.00c	0.11c	0.86d	8	1.34c
1M:4TS	6.00c	0.36c	1.03c	3.98cd	8.88bc	3.78c	28.00bc	0.25b	2.65c	11	51.21b
2M:4TS	6.13bc	0.72b	1.32bc	6.72bc	11.08bc	4.95bc	32.24ab	0.37a	3.82b	10	77.99ab
3M:4TS	6.36ab	0.88b	1.55ab	8.31ab	14.07ab	6.46ab	35.64a	0.44a	4.45ab	10	87.88ab
4M:4TS	6.55a	1.18a	1.88a	10.45a	19.47a	7.86a	39.04a	0.46a	5.10a	11	101.79a

Mean values followed by the same letter within a column are not different from each other at P□ 0.05;
NS = Non-significant; *, ** = Significant at P□ 0.05 and P □ 0.01, respectively.

Table 6. Correlation matrix values between organic amendments and media chemical parameters

Character	Correlation coefficient (r)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Organic source														
2.Organic ratio	0													
3.PH	0.23	0.63**												
4.EC	0.44*	0.84**	0.46*											
5.Na	0.01	0.72**	0.40	0.63**										
6.K	-0.12	0.70**	0.42	0.54*	0.97**									
7.Ca	0.53*	0.55*	0.09	0.80**	0.41	0.32								
8.Mg	0.41	0.61**	0.06	0.82**	0.53*	0.46*	0.96**							
9.CEC	0.42	0.63**	0.21	0.78**	0.63**	0.57**	0.70**	0.77**						
10.Base sat	0.23	0.60**	0.18	0.71**	0.61**	0.56**	0.84**	0.87**	0.46*					
11. Total Nitrogen	0.48*	0.77**	0.39	0.83**	0.67**	0.61**	0.56**	0.65**	0.81**	0.47*				
12.Organic carbon	0.48*	0.78**	0.44*	0.94**	0.52*	0.44*	0.75**	0.76**	0.70**	0.66**	0.84**			
13. C: N ratio	0.07	0.22	0.18	0.38	-0.01	-0.08	0.78**	0.40	0.01	0.52*	0.09	0.45*		
14. Available P	0.77**	0.40	0.28	0.68**	0.02	-0.06	0.72**	0.66**	0.59**	0.42	0.58**	0.74**	0.34	

*, ** = Significant at 5 and 1% probability levels, respectively.

Available phosphorus: Both organic sources and proportions in the media positively influenced the available phosphorus contents of the potting media. As a result, FYM dominated media mixes had significantly higher phosphorus in contrast to those of coffee compost alone (Table 5). This variation in the status of media phosphorus content could be related to the difference among the compositions of the organic sources used in this investigation. For instance, FYM contained the highest amounts and thus, contributed the highest proportions to the soil media (Table 5). In contrast, those media composed of coffee composts have low available P, indicating the low P requirement of the coffee plant. This supports the works done by Asefa (1997) and Paulo (1996, 1997). Further, a positively significant relationship was found between organic source and available P ($r = 0.77^{**}$) and its correlation with EC, divalent cations and an organic carbon content of the media was positively highly significant (Table 6). Thus, any factor that influences these characters might also determine the status of available phosphorus in the soil media and subsequently its plant uptakes. According to our earlier findings (Taye et al., 1999, Taye and Mesfin, 2000), high quality arabica coffee seedlings with desirable shoot and root growth were obtained from improved media chemical conditions due to the same organic amendments. This is in agreement with several reports (Bredero, 1977; Kolay, 1991 and Jama et al., 1997).

CONCLUSIONS

The results show that coffee composts and FYM varied in their nutrient compositions and more optimised when combined. Those media combinations of DCH and FYM, singly or in combinations, are preferred followed by UCH plus FYM and least preferred being UCH and topsoil alone in terms of preparing optimum media types with improved physico-chemical conditions. The different ratios of coffee composts and farmyard manure blended with topsoil had also significantly influenced potting media parameters. The results show improved media physical and chemical conditions with increasing levels of proportions. In essence, the study shows the possibility to simulate forest soils by recycling organic materials easily available in a coffee-based farming system of the country. However, determinations of the right methods of composting, rates, techniques and times of application of these organic materials calls further investigation under different agro-ecologies and farm conditions. Their utilisation would greatly promote future nursery management of coffee and reduce the 'dependence syndrome' on the mystical "ideal" forest soil. The finding also provides insights to focus on the use of organic resources to maintain soil fertility and promote organic coffee production in the country.

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EFFECT OF BIOMASS TRANSFER OF *CAJANUS CAJAN* WITH OR WITHOUT INORGANIC FERTILIZER ON BH-660 HYBRID MAIZE VARIETY AT BAKO, WESTERN OROMIA

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ABSTRACT

A biomass transfer study was conducted in 2000/01 cropping season at Bako Agricultural Research Center, western Oromia, Ethiopia. The study involved different rates of *Cajanus cajan* (L.) Millsp. biomass and different rates of inorganic fertilizer. The objective was to determine the optimum rate of *Cajanus* biomass that either substitutes or supplements inorganic fertilizer in maize production. The experiment was tested on the popularly used hybrid maize variety at Bako (BH-660), and it was also repeated during the 2001/02 cropping season to assess the possible residual effect of applying inorganic fertilizer and *Cajanus* biomass. Results indicated that maize grain yield was significantly affected by varying rates of *Cajanus* biomass (P = 0.0011) and inorganic fertilizer (P = 0.000) during the first cropping season, but not significantly affected during the second year. Maize grain index was only affected by *Cajanus* biomass (p=0.014), but not by inorganic fertilizer. Maize grain yield varied from 3093 kg/ha to 9057 kg/ha during the first year and from 1266 kg/ha to 2614 kg/ha during the second year. Maize yield with fully recommended rate of inorganic fertilizer rate alone (no biomass application) was 6913 kg/ha. Applying 4 t/ha *Cajanus* biomass gave a yield advantage of about 86.55% over the control, but less only by 16.55% from the plot that received recommended fertilizer rate (standard plot). From this preliminary finding, *Cajanus* biomass application seems promising alternative for maize production in the area, and can be mineralised and made available to crops during the year of application. However, the economic analysis to assess the profitability of using this organic fertilizer with or without inorganic fertilizer must be studied. Appropriate time of biomass application to synchronise the nutrient supply from biomass mineralisation and crop nutrient demand is also required to make the use of organic and/or inorganic fertilizers more efficient.

Key words: BH-660, *Cajanus*, inorganic fertilizer, organic fertilizer

INTRODUCTION

Declining soil fertility is one of the major constraints to agricultural production. It is especially serious in tropical and subtropical regions where many soils lack plant nutrients and organic matter and intense rainfall erodes vulnerable topsoil (Gutteridge and Shelton, 1994). This scenario is currently challenging Ethiopian agriculture in general and maize production in particular. Consequently, so many poor farmers are suffering from this problem - not because they are greedily exploiting the land but because they simply do not have the resources to make investments to protect and replenish the soils, their source of livelihood (Strvatava and Alderman, 1993; Abdissa, 1998). On the one hand, inorganic fertilizers are going beyond the reach of smallholder farmers because of the high cost and uncertain accessibility, and on the other hand, the organic inputs which are often proposed as alternatives to inorganic fertilizers cannot meet crop nutrient demands over large areas because of the limited availability, low nutrient contents and high labour requirements (Palm et al, 1997). Hence, the combined use of both inorganic and organic sources of nutrients is one alternative to compromise these issues for replenishing and maintaining soil fertility.

Biomass transfer, alone or integrated with the use of inorganic fertilizers, is one of the promising land management options for improving soil fertility and hence increasing crop yields (Rao et al., 1998; Shehu et al., 1997). It involves using the foliage of selected trees, shrubs and other plants as organic fertilizers - or green manure - on agricultural fields. Special features are required of plants to be used for biomass transfer, or green manuring - large biomass, capacity to assimilate nutrients and supply additional benefits (fodder, firewood, food, etc.) (Müller-Sāmann and Kotchi, 1997). *Cajanus cajan* is one such important leguminous shrub species commonly used as soil ameliorant.

Pigeon pea (*Cajanus cajan*) has a valuable fertilizer value and also provides a valuable dry season animal feed and seeds for human consumption (Shehu et al., 1997). Findings from India indicate that pigeon pea can contribute about 40 kg N ha^{-1} through N fixation, leaf fall and roots (Rao and Willey, 1981; Sheldrake and Narayanan, 1978). *C. cajan* is an adapted legume showing good performance in Bako area. But information on the effect of this tree species on maize yield and its comparative advantage with using inorganic fertilizer is lacking in the area. Therefore, the objective of this study was to determine the optimum amount of *C. cajan* biomass required to be added to maize fields in order to get a yield that is comparable to the inorganic fertilizer.

MATERIALS AND METHODS

Study site

The study was conducted in 2000/01 and 2001/02 cropping seasons at Bako Agricultural Research Center, Oromia Regional State, Ethiopia, which is located at 9°07' N latitude and 37°05' E longitude. The area is subhumid with unimodal rainfall pattern experiencing an average annual rainfall of 1270 mm and an average annual temperature of 20°C, with the maximum and minimum values of 27°C and 13°C, respectively. Bako Meteorological station is about 1650 m above sea level. The soil is dominantly reddish brown Nitosol, with a pH of 5–6 (Legesse et al, 1987; Abebe, 1998), and some properties of Bako soil is indicated in Table 1.

Table 1. Some chemical and physical properties of Bako soils

Soil property	† Agroforestry research site (n=*3)*	Farmers' field‡ (n=4)
Organic carbon, %	2.294	3.11
Total nitrogen, %	0.159	0.27
Available P, ppm	2.353	2.93
pH	5.36	5.66
CEC, meq/100 gm	18.4	36.35
Base saturation, meq/100 gm	47.33	56.75
Clay, %	47.33	25.25
Silt, %	18.67	27.50
Sand, %	34	47.25

CEC = Cation exchange capacity n= number of samples
Source: † Abebe et al (in press) and ‡ Abebe (1998).

Experimental details

In this study, two factors are involved as experimental treatments: rate of biomass application (organic fertilizer) and rate of fertilizer application (inorganic fertilizer). Four different rates of *Cajanus cajan* biomass (0, 2, 4, and 6 t/ha on dry weight basis), and three different rates of inorganic fertilizer (no fertilizer, half rate and recommended rate) were considered. The recommended inorganic fertilizer rate at Bako is 200 kg urea/ha and 100 kg DAP/ha. The treatments were handled as a 4x3 factorial experiment in randomised complete block design (RCBD) with two replications. The gross plot size was 6 m*6 m (36 m^2) and the harvestable size was 5m*5m (25 m^2). The test crop was BH-660, a popular hybrid maize variety in the area.

Application of treatments

Cajanus biomass was obtained from the stand that was established in June 1999 one year before biomass application. The stand was cut in April 2000 (nine months later) when it reached 50% flowering stage. The woody and foliar biomass was partitioned, and the fresh foliar biomass was air-dried and sub-samples were taken for oven-drying. Then the biomass was kept in sacks up to the day of application. *Cajanus* biomass was cut from *Cajanus* stand and carried to maize fields and hence the name biomass transfer. The biomass was applied and incorporated into the soil two weeks before maize planting. Maize was planted on 26 May 2000 during the first year and on 30 May 2001 during the second year. In the first year, DAP was applied at the time of maize planting. But split application was adopted for urea: the first application was made 30 days and the second 45 days after maize planting. But during the second year, neither *Cajanus* biomass nor inorganic fertilizer was applied. Maize was planted on the previous plots without any external input in order to assess the possible residual effects of these organic and inorganic fertilizers applied during the first year.

Data collection and analysis

Data on maize grain yield and grain index (1000 seed weight) were recorded. Border rows were harvested separately and excluded from the yield data. The data were subjected to the general linear model analysis of variance using SPSS computer software program. All comparisons of treatment means were made at $P<0.05$ level of significance using Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Table 2. Observed significance level of F (p value) for maize grain yield and size

Source of variation	Year 1 (with inputs)		Year 2 (without inputs)	
	Maize grain yield	1000 seed weight	Maize grain yield	1000 seed weight
Inorganic fertilizer	0.000	NS	NS	NS
Cajanus biomass	0.002	0.014	NS	NS
Fertilizer *biomass	NS	NS	NS	NS

During Year 2 only possible residual effects of inputs previously added during Year 1 assessed

Maize grain yield

The results showed that maize grain yield was significantly affected by *Cajanus* biomass ($P = 0.002$) and inorganic fertilizer ($P = 0.000$) during the first year (Figure 1), but the interaction effect of *Cajanus* biomass and inorganic fertilizer was not significant. This indicates that applying *Cajanus* biomass had no antagonistic effect on that of inorganic fertilizer and vice versa. Thus, both factors can be considered separately. Also no significant difference in maize yield was noticed for both factors during the second year when no external input was added (Figure 2 and Table 2), indicating that nutrients from *Cajanus* biomass were used and /or lost in the first year. Maize grain yield varied from 3093 kg/ha under the plot that received no *Cajanus* biomass and no fertilizer (control plot) to 9057 kg/ha under plot that received 6 t/ha biomass together with fully recommended fertilizer (the latter almost three times the former) during the first year and from 1266 kg/ha to 2614 kg/ha during the second year. Without any inorganic fertilizer, 5479, 5770, 5733 kg/ha maize grain yield was obtained by applying 2, 4, and 6 t/ha *Cajanus* biomass alone, respectively. With half rate application of inorganic fertilizer, 2, 4 and 6 t/ha biomass gave 5455, 6491 and 6787 kg/ha maize yield, respectively. Maize yield with fully recommended rate alone (no biomass application) was 6913 kg/ha. Applying 4 t/ha *Cajanus* biomass gave a yield advantage of about 86.55% over the check plot, but less by 16.55% from the plot that received recommended fertilizer rate (standard check). From this preliminary finding, the *Cajanus* biomass application seems promising alternative for maize production in the area.

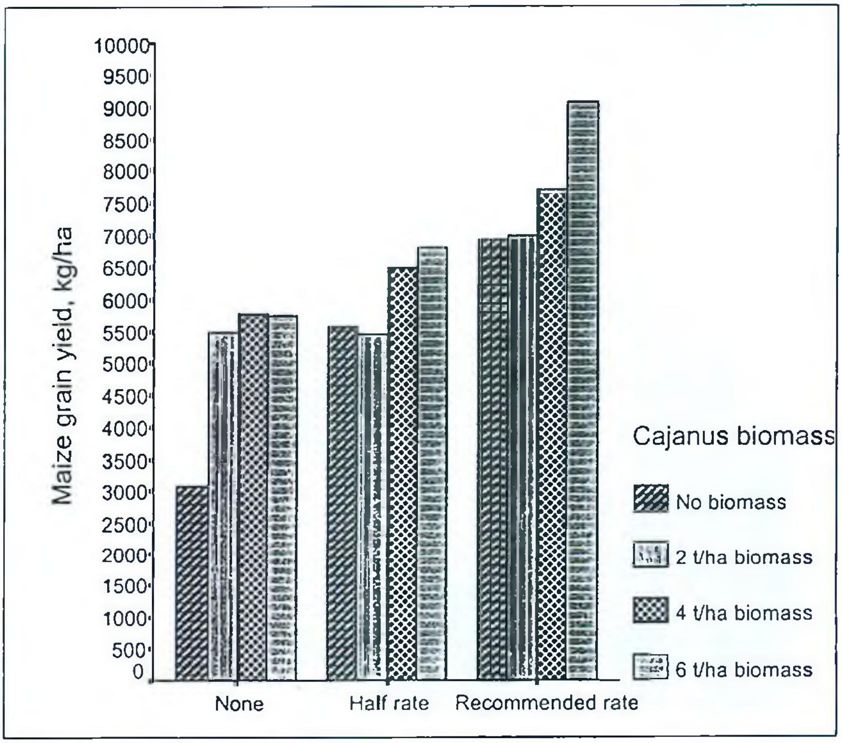

Figure 1. Maize grain yield as influenced by inorganic fertilizer and *Cajanus* biomass (Year 1)

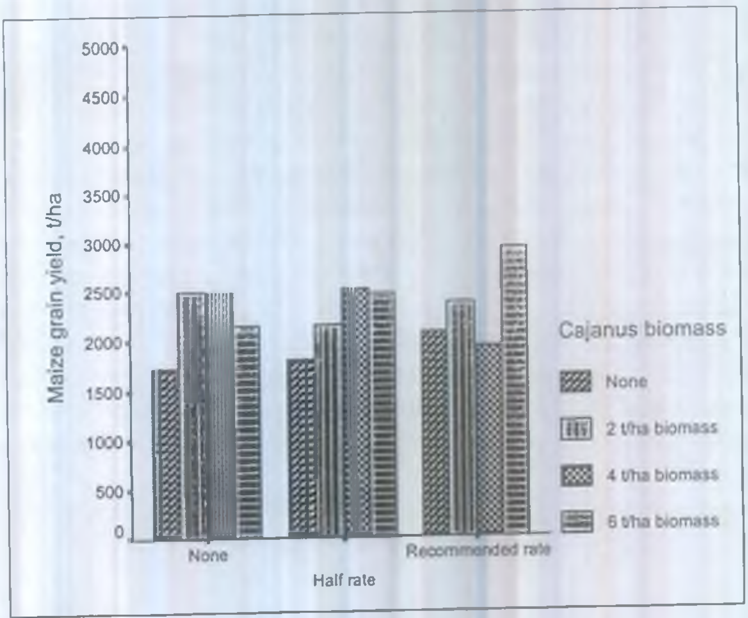

Figure 2. Maize grain yield as influenced by inorganic fertilizer and *Cajanus* biomass (Year 2)

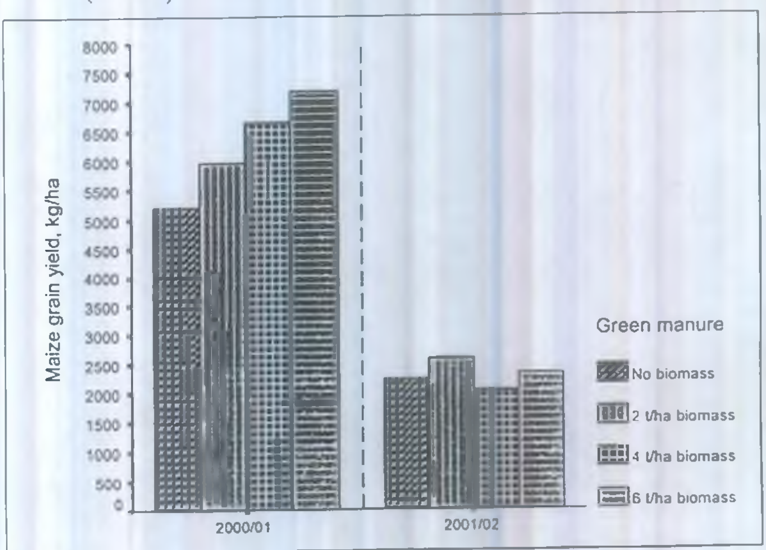

Figure 3. Maize grain yield as influenced by application of *Cajanus* biomass and its residual effect

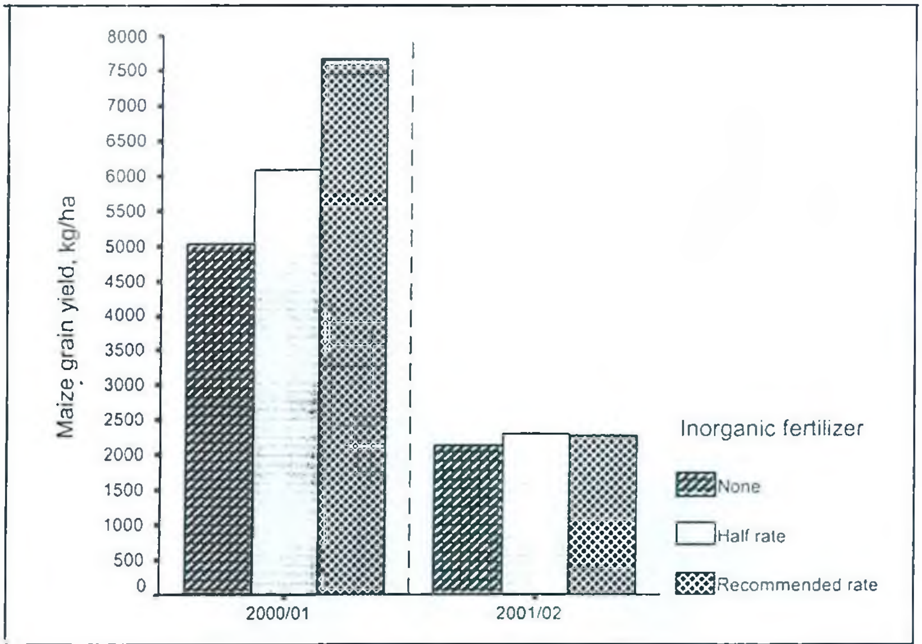

Figure 4. Maize grain yield as influenced by application of inorganic fertilizer and its residual effect.

The significant difference in maize yield between the plots that received different treatments during the first year and the non-significant difference in yields obtained from the different plots during the second year suggest that the residual effects of applying *Cajanus* biomass and inorganic fertilizer was minimal (Figures 3 and 4). This might be because the climatic condition of Bako area (humid and hot) might have enhanced *Cajanus* biomass decomposition, mineralised nutrients and made available for the maize crop during the year of application.

Maize grain index

Maize grain index (1000 seed weight) was not affected by applying different rates of inorganic fertilizer, but it was significantly affected by the organic fertilizer (*Cajanus* biomass) as indicated in Table 2. Increasing the rate of *Cajanus* biomass resulted in an increase in grain size (Figure 5). The non-significant effect of inorganic fertilizer on grain size but the significant effect of organic fertilizer on grain size may due to partial fertilization (N and P) in the former case but complete fertilization in the latter. Hence, *Cajanus* biomass application is one means of producing organic maize.

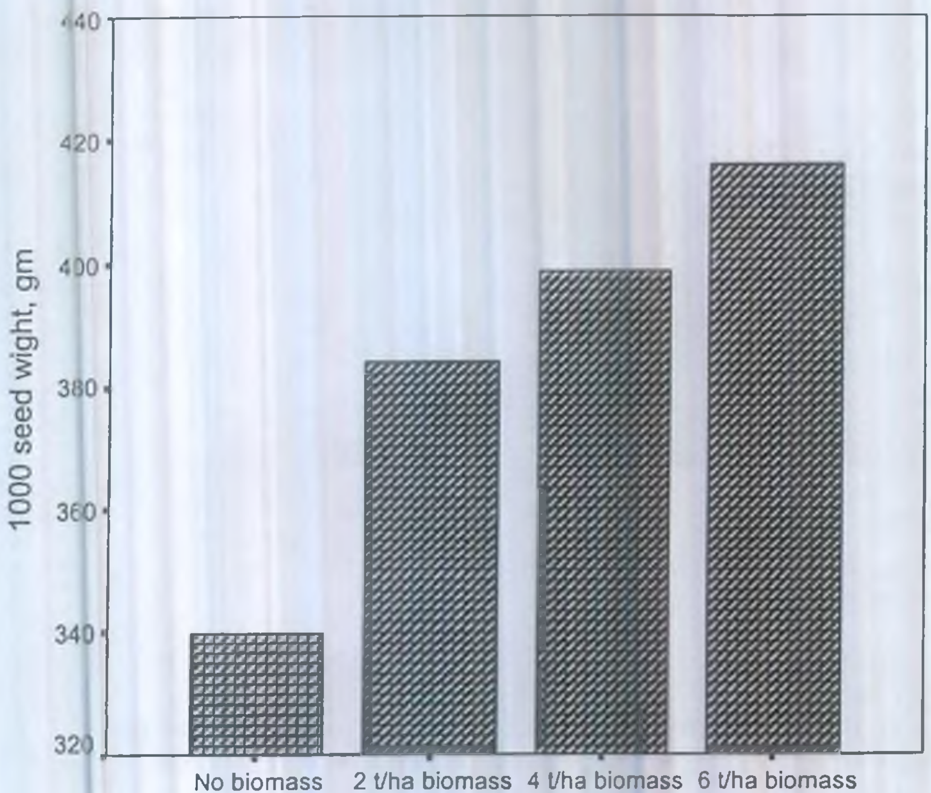

Figure 5. Maize seed size as influenced by rate of *Cajanus* biomass

CONCI USION

The present study suggests that *Cajanus* biomass application seems a promising alternative for maize production in the area. It can be mineralised and the nutrients contained therein made available to crops during the year of application. In fact, the availability of organic fertilizers in the future may be limiting, but which option is better for our prevailing situation?

- Sole dependency on imported inorganic fertilizers?, or
- Devising means of making organic fertilizers available for our purpose?

These issues deserve due attention.

Cost advantage: Currently, not one kilo of inorganic fertilizer is produced in the country. But farmers can produce tonnes of organic fertilizer, like plant biomass. This may be a good option for a land-locked poor country like Ethiopia with limited foreign currency to import inorganic sources. The scenario in Ethiopia can be expressed as follows:
"We are overlooking what we can have, but we are importing what we don't have."

Nutrition advantage: Apart from its cost, organic fertilizer is one means of getting organic maize. This is evident from the significantly higher maize grain index obtained in this study due to the application of *Cajanus* biomass as opposed to that of inorganic fertilizer where no considerable effect was noticed on grain quality. Unlike the inorganic fertilizers, another good opportunity with organic fertilizers (tree biomass) is that they also supply additional nutrients that may limit maize production such as potassium and micro-nutrients. Using tree biomass is thus complete fertilization as opposed to that of partial fertilization in the case of inorganic fertilizers (N and P in Ethiopia).

In light of the increasing cost of inorganic fertilizers but decreasing purchasing capacity of our farmers and decreasing price for maize grain, using organic fertilizers is inevitable for our condition in the near future.

Increasing organic fertilizer (foliar biomass) increased maize yield, but this could not be an end in itself. Further research work on the economics/ profitability of using organic fertilizers with or without inorganic fertilizer, time of biomass application to synchronise the nutrient supply from biomass mineralisation and crop nutrient demand for better efficiency, and nutrient concentrations in foliar biomass (organic fertilizers) to use as a base for using them as substitutes or supplements to inorganic fertilizers are suggested in the future.

ACKNOWLEDGEMENT

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BONEMEAL AND ROCK-PHOSPHATE AS ALTERNATIVE SOURCES OF P FERTILIZER FOR MAIZE PRODUCTION

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ABSTRACT

The experiment was executed in 1997 and 1998 cropping seasons in Bako area to evaluate bonemeal and rock-phosphate as alternative sources of P fertilizer. The treatments used were 200 kg bonemeal, 20 kg P from TSP, 20 kg P from DAP, 100 kg bonemeal plus 10 kg P from TSP, 100 kg bonemeal plus 10 kg P from DAP, 200 kg rock-phosphate, 100 kg rock-phosphate plus 10 kg P from TSP ha^{-1}and the check whereas 110 kg N ha^{-1} was used at basal in split form. The treatments were laid out in randomised complete block design with three replications using BH-660, which is hybrid maize variety. In 1997 cropping season, the experiment was conducted at Bako Research Center, Dongoro, Walda, Chari, and Shoboka whereas the residual of different P sources were evaluated in 1998 at Bako Research Center, Chari and Shoboka. The soil analysis indicated that the available P, total N and the organic matter were low in all sites whereas the soil reaction was strongly acidic in Chari and medium for Bako Research Center and Shoboka. The exchangeable bases were in optimum range for crop production in all sites. The bonemeal and rock-phosphate analysis showed that bonemeal was superior to rock-phosphate in supplying essential plant nutrients to the crop. The statistical analysis revealed significant ($P<0.05$) differences among the treatments on maize grain yield at Bako Research Center, Dongoro and Walda in 1997. The residual of different P sources on maize grain yield were significant ($P<0.05$) only at Bako Research Center. The highest maize grain yield was recorded at Dongoro (8.83 t ha^{-1}) followed by 8.23 t ha^{-1} at Walda with the integrated use of 100 kg ha^{-1} bonemeal and 10 kg ha^{-1} chemical P fertilizer as compared to 5.99 and 5.29 t ha^{-1} maize grain yield for their checks, respectively, in 1997. Therefore, using 100 kg ha^{-1} bonemeal along with 10 kg ha^{-1} chemical P fertilizer could be used for maize production on Alfisols of Bako area. Moreover, the sole use of either 200 kg bonemeal or rock-phosphate, as source of P fertilizer is encouraging for maize production in acid soil.

Keywords: Alfisols, bonemeal, chemical P fertilizer, maize grain yield, integrated

INTRODUCTION

Phosphorus is the limiting nutrient for maize *(Zea mays L.)* production on Alfisols of western Ethiopia. Different research findings indicated that high portion of the soils from tropical regions have a marked ability to fix applied inorganic phosphate (Fox and Kamprath, 1970; Sahlemedhin and Ahmed, 1983). The weathered soils of western Ethiopia have been reported to have high P requirement (Fikru, 1989; Asfaw, 1996). Wakene (2001) also reported that P was fixed in the form of Al-P, and Fe-P in Alfisols of Bako area. Therefore, the applications of P in the form of triple superphosphate (TSP) and diammonium phosphate (DAP) aggravates the acidity and P fixation capacity of the soil. The price of chemical fertilizer is increasing from year to year and becomes beyond the purchasing capacity of resource-poor farmers. Bonemeal, rock-phosphate and basic silage are the suitable sources of P fertilizer on acid soils, and were not exploited in the country for crop production so far.

Bonemeal acts more slowly than TSP and DAP and quite effective on acid soils particularly on crops with a long growing season (Asnakew, 1989). The study undertaken at Holetta on Alfisols indicated that bonemeal applied at the rate of 100 kg ha^{-1} was found to be as effective as 10 kg ha^{-1} chemical P fertilizers. According to Lupwayi and Haque (1996), application of rock-phosphate to crops grown on acid soils is cheaper than the refined phosphate fertilizers, especially if the rock is locally available. Considerable amounts of bonemeal and deposit of rock-phosphates are found in the country, but research information on the potential use of these resources as fertilizer was scarce. The objective of the study was, therefore, to evaluate the potential of bonemeal and rock-phosphate as sources of P fertilizer for maize production on Alfisols of Bako area.

MATERIALS AND METHODS

The experiment was conducted at Bako Research Center, Dongoro, Walda, Chari, and Shoboka in 1997. The residual of different P sources were investigated in 1998 growing season at Bako Research Center, Chari and Shoboka. The treatments used were 200 kg bonemeal, 20 kg P from TSP, 20 kg P from DAP, 100 kg bonemeal plus 10 kg P from TSP, 100 kg bonemeal plus 10 kg P from DAP, 200 kg rock phosphate, 100 kg rock-phosphate plus 10 kg P from TSP ha^{-1} and check (zero P) The treatments were laid out in randomised complete block design with three replications using BH-660, which is hybrid maize variety. The different sources of P were applied in spot at planting whereas 110 kg N ha^{-1} was used at basal in both seasons in split form. The processed bonemeal was obtained from the Addis Ababa Abbatoir while the fine ground rock-phosphate was imported from Tanzania. All recommended cultural practises for maize production were adopted for the management of the experiment. Analysis of variance for maize grain yield was undertaken using MSTATC computer software.

Soil Sampling and Analysis

Composite soil sample was collected from each experimental field before treatment application, and from the plots that received sole bonemeal and rock-phosphate after two years of application. The collected soil samples were air-dried and passed through <2 and 0.5-mm sieves for the following different analyses. The particle size distribution was determined by hydrometer method whereas the soil pH was measured in the supernatant suspension of 1:2.5 ratios of soil to H_2O and 1 M KCl solution. Exchangeable bases were extracted with 1 M ammonium acetates at pH 7 and Ca and Mg were measured with atomic adsorption spectrophotometery while K and Na were determined with flame photometry. Cation exchange capacity (CEC) of the soil was determined from ammonium-saturated samples that were subsequently replaced by Na from percolated sodium chloride solution. The ammonium that was displaced by sodium was measured using kjeldahl procedure (Chapman, 1965).

Exchangeable acidity was determined as described by Mclean (1965). Organic carbon was determined following the method of Walkley and Black (1934). Total nitrogen determination was carried out as described by Jackson (1958). Available soil phosphorus was determined by Olsen (Olsen et al., 1954) and Bray II (Bray and Kurtz, 1945) methods. Bray II method was used for determination of available P from the bonemeal and the rock-phosphate. Total phosphorus of bonemeal and rock-phosphate were extracted using aqua regia digestion technique. All different forms of phosphorus extracted by different methods were measured by spectrophotometer (Murphy and Riley, 1962) Available Fe, Mn, Zn and Cu were extracted from the bonemeal and the rock-phosphate with DTPA (Lindsay and Norvell, 1978) and were measured by atomic absorption spectrophotometery.

RESULTS AND DISCUSSION

Properties of Soil, Bonemeal and Rock-phosphate

The soil texture of Bako Research Center and Shoboka was clay whereas clay loam at Chari. The soil pH (H_2O) was strongly acidic at Chari whilst moderately acidic at Bako Research Center and Shoboka. However, the soil pH (KCl) was strongly acidic in all experimental fields (Table 1). According to Landon (1991), the exchangeable bases in all experimental fields were in the sufficient range for crop production. Moreover, soil fertility status based on CEC was high at Shoboka, and medium at Chari and Bako Research Center that was reflected on the recorded maize grain yield. For instance, 6.31 t ha^{-1} maize grain yield was obtained without P fertilizer application at Shoboka. The variation in soil fertility status attributed to the variation in cropping history and soil fertility management systems among the experimental fields.

The highest exchangeable acidity was observed at Chari, followed by Bako Research Center while the lowest was recorded at Shoboka. This was directly related to soil acidity status of the experimental fields. The exchangeable Al was trace at all sites indicating that Al toxicity was not problematic at surface soils which was in agreement with the findings of Wakene (2001). This could be due to the chelating effects of organic matter at the surface. The organic carbon, total N and the available P were low regardless of sites and different treatment applications (Table 2). There were no variations in soil properties among the plots that received different treatments because soil properties take time to be altered.

Table 1. Soil texture, soil pH, exchangeable bases and acids, and CEC before and after bonemeal and rock-phosphate application

		percent				pH 1:2.5		(cmol(+)kg^{-1}					
Location	Soil samples	Sand	Silt	Clay	Class	H_2O	KCl	Na	K	Ca	Mg	Acid	Al
	0 P (97)[a]	23	35	42	C	5.48	4.67	0.4	2.0	7.5	4.3	0.04	Trac
Shoboka	Rock P(97)[a]	21	37	42	C	5.65	4.83	0.6	1.8	8.5	3.3	0.06	Trac
	Bone (99)[a]	24	33	43	C	5.15	4.41	0.6	1.6	9.6	1.4	0.14	Trac
	0 P (97)[a]	29	43	28	CL	4.95	3.94	0.4	1.5	4.3	2.3	0.47	Trac
Chari	Rock P(99)[a]	28	44	28	CL	4.87	3.67	0.3	0.9	3.5	0.9	0.56	Trac
	Bone (99)[a]	29	42	29	CL	4.80	3.56	0.3	0.6	4.0	1.1	0.62	Trac
Bako	0 P (97)[a]	41	17	42	C	4.76	3.67	0.4	0.5	7.3	1.8	0.48	Trac
Research	Rock P(99)[a]	42	15	43	C	5.53	4.72	0.3	0.7	3.3	0.9	0.23	Trac
Center	Bone (99)[a]	40	18	42	C	5.32	4.01	0.6	1.8	8.8	2.3	0.34	Trac

[a] Soil samples taken for analysis from the plots that received sole bonemeal, rock-phosphate and the check whereas the numbers in parentheses refer to year of soil sampling. Rock P = Rock-phosphate, Bone = Bonemeal, C = Clay,
CL = Clay loam

The selected essential plant nutrients analysed from bonemeal and rock-phosphate revealed that bonemeal was superior to rock-phosphate (Table 3). Bonemeal provided the essential plant nutrients usually deficient in acid soils. As a result, the plots received bonemeal were deep green, vigorous and relatively resistant to pests and diseases. The total P analysed from bonemeal and rock-phosphate was 1.2 and 1.3%, respectively, which is very low as compared to the already established percentage of total P, which was 11-15.5 % for rock-phosphate and 7.5-13.5 % for bonemeals (Foth, 1984). The aqua regia extraction technique used for the determination of total P from bonemeal and rock-phosphate may not be efficient.

Table 2. Soil organic carbon, total N, and available P before and after bonemeal and rock-phosphate application

		percent			Available P ($mgkg^{-1}$)		($cmol(+)kg^{-1}$)
Location	Soil Samples	OC	TN	C:N	Olsen	Bray II	CEC
	0 P (97)[a]	2.42	0.21	12	4.8	6.5	33
Shoboka	Rock P (99)[a]	1.96	0.16	12	4.0	6.0	34
	Bone (99)[a]	1.81	0.10	12	7.2	8.1	30
	0 P (97)[a]	2.00	0.17	12	5.3	7.8	16
Chari	Rock P (99)[a]	1.48	0.11	13	6.3	7.5	19
	Bone (99)[a]	1.50	0.13	12	6.7	8.5	19
Bako RC[1]	0 P (97)[a]	1.88	0.16	12	4.2	5.6	17
	Rock P (99)[a]	1.68	0.13	13	6.2	7.0	21
	Bone (99)[a]	2.08	0.17	12	7.2	9.5	28

[a]Soil samples taken for analysis from the plots that received sole bonemeal, rock-phosphate and the check whereas the numbers in parentheses refer to year of soil sampling. Rock P = Rock-phosphate, Bone = Bonemeal, C = Clay, CL = Clay loam

[1]Bako RC = Bako Research Center

Table 3. The chemical properties of bonemeal and rock-phosphate used for the experiment

	($cmol(+)Kg^{-1}$)				Available nutrient ($mg\ kg^{-1}$)					percent	
P Source	Na	K	Ca	Mg	Fe	Mn	Zn	Cu	P (Bray II)	Total N	Total P
Bonemeal	0.9	17.1	15.3	15.7	31.0	145.0	29.4	3.5	410.0	3.67	1.2
Rock-phosphate	3.1	0.6	2.1	1.4	1.7	1.0	4.5	0.2	280.0	0.03	1.3

Maize Grain Yield

There was significant difference ($P<0.05$) among the treatments on maize grain yield in both seasons at Bako Research Center. The maize grain yield under the sole application of either bonemeal or rock-phosphate was slightly lower than the yield obtained using the recommended rate of chemical P fertilizer in 1997 but the opposite trend was observed for their residue (Tables 4 and 5). The maize grain yield under the residue of chemical P fertilizers (TSP and DAP) decreased compared to the freshly applied ones whereas the maize grain yield showed increment under the residual phosphate of bonemeal and rock-phosphate. This implies that phosphate in bonemeal and rock-phosphate becomes available more slowly compared to chemical P fertilizer.

There was no significant difference ($P>0.05$) among the treatments on maize grain yield in both seasons at Shoboka. Maize grain yield without applied P was 6.31 t ha^{-1} as compared to 6.74 and 8.53 t ha^{-1} with the application of 20 kg ha^{-1} P from TSP and DAP, respectively. A similar trend was observed in residual phosphate of different P sources on maize grain yield at Bako Research Center (Tables 4 and 5). The initial soil fertility status of the farmer's field at Shoboka was relatively better than the other sites (Table 1 and 2). The difference in soil fertility status was due to differences in socioeconomic factors.

Table 4. Effect of different P sources on maize grain yield in 1997 cropping season (t ha^{-1})

Treatment ($kgha^{-1}$)	BRC	Shoboka	Chari	Walda	Dongoro	Mean
0 P	4.18	6.31	5.02	5.29	5.99	5.54
200 bonemeal	4.70	6.38	6.20	6.55	6.72	6.34
20 P from TSP	5.92	6.74	5.04	8.02	7.86	7.14
20 P from DAP	6.89	8.53	5.28	8.23	8.59	7.91
100 bone +10 P (TSP)	6.27	7.62	5.80	7.11	7.12	6.86
100 bonemeal +10 P (DAP)	5.15	7.21	5.50	8.23	8.83	7.67
200 rock-phosphate	5.27	5.49	7.80	6.41	6.48	6.32
100 rock-phosphate +10 P (TSP)	5.08	6.78	5.78	8.15	9.15	7.80
LSD (5%)	1.32	NS	NS	1.96	1.40	NS
CV%	13.53	20.66	20.7	12.05	11.32	13.56

BRC = Bako Research Center

Table 5. Residual effect of different P sources on maize grain yield in 1998 cropping (t ha^{-1})

Treatment ($Kgha^{-1}$)	BRC	Shoboka	Chari	Mean
0 P	4.24	7.79	3.36	5.80
200 bonemeal	6.00	7.79	5.67	6.49
20 P fromTSP	5.12	7.79	6.13	6.35
20 P from DAP	5.52	7.11	6.44	6.36
100 bonemeal + 10 P (TSP)	6.80	8.55	6.21	7.19
100 bonemeal + 10 P (DAP)	6.16	9.08	6.89	7.38
200 rock-phosphate	5.60	8.17	7.81	7.19
100 rock-phosphate. + 10 P (TSP)	5.60	3.39	6.05	6.68
LSD (5%)	1.87	NS	NS	0.98
CV%	18.98	18.33	22.98	8.41

At Chari, no significant difference ($P>0.05$) was observed among the treatments on maize grain yield in 1997 cropping season. The highest maize grain yield was recorded from sole application of 200 kg ha^{-1} rock-phosphate followed by 200 kg ha^{-1} bonemeal, 7.80 and 6.20 t ha^{-1} maize grain yield, respectively. The residual phosphate from different P sources was also not significant ($P>0.05$) on maize grain yield. This could be due to the soil reaction that enhanced the fixation of available P since the soil is strongly acidic at Chari (Table 1).

At Walda and Dongoro, there was significant difference ($P<0.05$) among the freshly applied different sources of P on maize grain yield at both sites. Similar results were recorded at both sites with the recommended rate of chemical

P fertilizer, and integrated use of either 100 kg bonemeal or rock-phosphate with 10 kg chemical P fertilizer. Moreover, the sole application of either bonemeal or rock-phosphate at the rate of 200 $kgha^{-1}$ provided one ton maize grain yield over check. The freshly applied 100 kg bonemeal and 10 kg P from DAP provided the highest maize grain yield (8.83 t ha^{-1}) at Dongoro followed by 8.23 t ha^{-1} at Walda

CONCLUSIONS

According to the findings of this study, using 100 kg of bonemeal, or rock-phosphate with 10 kg chemical P fertilizer was found to be encouraging for maize production on Alfisols of Bako area and similar soil type in western Oromia. The use of either sole bonemeal or rock-phosphate at the rate of 200 kg ha^{-1} could also be used for maize production because they are appropriate P sources to be used on acid soils as they are less soluble and therefore do not precipitate so quickly. Likewise, their residual P provided comparable maize grain yield to the recommended rate of chemical P fertilizer. Currently, there is a bonemeal processing industry in the country for P fertilizer, hence, the concerned bodies should push the use of bonemeal on acid soils of the country. Additionally, research should be conducted on the potential of native rock-phosphate for use as alternative sources of P fertilizer.

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OPTIMUM NITROGEN AND PHOSPHORUS FERTILIZER REQUIREMENT FOR SWEET POTATO (*IPOMOEA BATATAS* L. LAM.) PRODUCTION IN SUB-HUMID ENVIRONMENTS OF WESTERN ETHIOPIA

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ABSTRACT

Field experiments were conducted at three locations; Bako and Loko during 1998-2001, and Nedjo during 1998-1999 cropping seasons to evaluate the influences of different levels of N and P on yield, yield components and root quality of the sweet potato variety, Cemsa. The experiments were laid out in randomised complete block design with three replications. The treatments consisted of five levels of N (0, 25, 50, 100 and 125 kg ha^{-1}) and four levels of P (0, 20, 40 and 60 kg ha^{-1}) used in a factorial arrangement. The combined analysis of variance over years showed that applied N significantly ($P<0.05$) influenced marketable and total root yield at Bako and Loko, but not at Nedjo. Due to the effects of applied N, root yield significantly increased up to 100 kg ha^{-1} N at Bako and 50 kg ha^{-1} N at Loko and Nedjo. Beyond that yield declined. Extreme yield differences observed the locations happened probably due to the differences in the inherent soil macro and micro nutrients, soil reaction and its uptake by the crop. In contrast to N, applied P did not bring about any significant increase of both marketable and total root yield at Bako and Loko. Although the overall yield was extremely low at Nedjo, however, highly significant ($P<0.01$) difference was recorded for both the parameters in response to applied P. At Bako and Nedjo, maximum marketable root yield was registered on plots applied with P of 20 kg ha^{-1}, while application at the rate of 40 kg ha^{-1} P at Loko produced higher. The interaction effects of N and P applied significantly influenced marketable and total root yield at Bako. The economic analysis of fertilizer use showed that the higher net benefit was obtained when 50/20 kg N/P ha^{-1} was applied for Bako. The marginal rate of return recorded was also higher when 50/20 kg N/P ha^{-1} was applied confirming that 50/20 kg N/P ha^{-1} could be recommended for sweet potato production. At Loko, the higher net benefit was obtained when 50/40 kg N/P ha^{-1} was applied. However, the marginal rate of return of the change from 0 to 40 kg ha^{-1} P was below the acceptable level.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) has been cultivated in Ethiopia for the last several years. Over 95% of the crop produce in the country grows in south-western, eastern and southern parts, where it has remained as one of the major subsistence crops, especially in periods of drought (Endale et.al., 1992). It is widely grown on about 50,000 ha with an average yield of only 7 t ha^{-1} (Geleta, 1996). Multitudes of problems could be cited for its low crop productivity and poor quality. Among these may be cited low soil fertility which is regarded as prominent in western Ethiopia.

It has been reported that most tropical soils are deficient in N and P (Chien and Menon, 1995). According to Murphy (1968) most of the Ethiopian soils are low in N and available P. The results of several studies conducted on the status of P in Ethiopian soils indicated that most of the soils require addition of P fertilizer for good crop growth (Eylachew, 1987 and Tekalign and Haque, 1987). In the western region of Ethiopia Nitisols, Acrisols and Alifsols are the dominant soil types with acidic properties. Under such conditions the availability of plant nutrients, specifically phosphorus, is expected to be low (Alemayehu, 1998). Soil fertility studies conducted over different locations for various crops in Ethiopia in general (Fisseha, 1982 and Yohannes, 1994) and in western parts in particular (Gemechu et.al., 1990 and Tadesse and Tolessa, 1996) have shown good yield response to applied N and P fertilizers indicating low N and P status of these soils.

In addition, crop requirement of N and P increases with the introduction of improved varieties, better cultivation, irrigation, use of other mineral fertilizers, and better control of pests and diseases (Raheja, 1966). This aspect may assume a serious dimension in sweet potato production as the crop is a heavy feeder of nutrients (Hill and Bacon, 1983 and Dayal and Sharma, 1999). This is because sweet potato produces high yield in a relatively short season. However, the available information pertaining to soil fertility studies with reference to sweet potato production in the country is scanty. Therefore, these studies were initiated to bridge the gaps.

MATERIALS AND METHODS

Field experiments were conducted at three locations; Bako and Loko during 1998-2001, and Nedjo during 1998-1999 cropping seasons to evaluate the influences of different levels of N and P on yield, yield, components and root quality of sweet potato variety, Cemsa. The experiments were laid out in randomised complete block design (RCBD) with three replications. The treatments consisted of five levels of N (0, 25, 50, 100, and 125 kg ha^{-1}) and four levels of P (0, 20, 40 and 60 kg ha^{-1}) were used in a factorial arrangement. The N source was urea whereas of P was triple superphosphate (TSP).

Bako is located at 1650 m asl at $9^0 6'$ N latitude and $37^0 09'$ E longitude. It receives annual rainfall of 1244 mm. Mean and maximum temperatures are 13.20 and 29.70^{0}C, respectively. Loko, a former state farm in the Anger-Didessa valley in western Ethiopia, has an altitude of 1280-1400 m asl. The farm receives an annual rainfall of 1350 mm. Mean minimum and maximum temperatures are 13.90 and 30.50^{0}C, respectively. Nedjo is located at 1900 m asl at 9^{0}30'N latitude and 35^{0}35' E longitude. It receives annual rainfall of 1200-2000 mm. The areas under study belong to the subhumid environment of western Ethiopia where Nitosols, Acrisols and Alifsols are the dominant soil types (Table 1).

Table 1. Physical and chemical properties of some western Ethiopian soils

Location	Texture			pH	OC	Total	Avail.	Total	Avail.	EC	BS%
	Clay	Silt	Sand			N %	P%	P%	K%		
Bako	34	26	40	4.6	1.7	0.15	$7.5x10^{-4}$	0.17	0.41	0.02	35
Loko	55.90	17	27	5.5	5.7	0.35	7	-	0.33	-	53.4
Nedjo	-	-	-	4.7	3.4	0.19	-	-	-	-	-

Adapted from: Anon (1977), Alemayehu (1998) and Girma (2001)

Cuttings of 30 cm length were planted on well prepared ridges at each location with a spacing of 30 cm on 3 m long row. Spacing was 1 m between rows and gross plot size was 15 m^2. Cultural practices were applied as needed. The data were recorded from three middle rows. Roots and parts above ground were harvested at about 150-165 days after planting. In the present study, poor root quality refers to unmarketable root yield which includes undersize, cracked and roots attacked by insects. Good root quality refers to marketable root yield.

The effects of N and P application on root yield, root quality and yield components were determined by analysis of variance using MSTAT-C computer program (M-Stat, 1990). The economics of fertilizer use was analysed following CIMMYT (1988) procedures.

RESULTS AND DISCUSSION

At Bako, the effect of applied N significantly influenced the average weight of roots but not the number of tuberous roots per plant. At Loko, however, the effect of applied N significantly influenced the number of tuberous roots per plant but not the average weight of roots. At Bako and Loko, the effect of applied P and its interaction effects with N did not significantly influence tuberous root number nor average weight of roots (Table 2). On the other hand, Ambecha (2001) reported that the combined effects of N and P applied significantly influenced both average tuberous root number and weight at Alemaya. It is important to note that tuberous root number and weight are the most important yield components in sweet potato.

Table 2. Analysis of variance of tuberous roots number per plant and average weight of tuberous root (kg), during 1998-2001 cropping seasons at Bako and Loko

Location	Source of variation	Degrees of freedom	Number of tuberous root	Average weight of tuberous root
Bako	N	4	NS	**
	P	3	NS	NS
	NxP	12	NS	NS
Loko	N	4	**	NS
	P	3	NS	NS
	NxP	12	NS	NS

** = indicate 1% probability level; NS = Not significant; N = nitrogen and P = phosphorus

The combined analysis of variance over years showed that applied N was significantly (P<0.05) influenced marketable and total root yield at Bako and Loko, but not at Nedjo (Table 3). This implied that the soils of the region are poor in the inherent N nutrient status and hence external supply of inorganic fertilizer is required to boost sweet potato production and soil fertility.

Table 3. Marketable and total root yield (t ha^{-1}) as influenced by N and application in sweet potato variety (Cemsa) combined over years (1998-2001)

Source of variation	Study area					
N kg ha^{-1}	Bako		Loko		Nedjo	
	Mark	Total	Mark	Total	Mark	Total
0	17045	22.11	7.72	9.51	2.55	3.04
25	20.77	24.86	9.85	11.63	3.57	4.23
50	21.72	26.81	10.66	13.29	3.72	4.40
100	25.66	30.94	10.07	12.91	3.34	4.16
125	23.41	28.86	9.07	11.15	3.60	3.96
	**	**	**	**	NS	*
LSD (0.05)	2.76	3.82	1.43	1.57	-	0.73
P kg ha^{-1}						
0	20.85	25.48	8.98	10.87	2.48	3.80
20	22.46	26.85	9.54	11.63	3.32	3.74
40	22.01	26.46	10.24	12.51	3.40	4.26
60	21.89	28.09	9.72	11.45	4.22	4.75
	NS	NS	NS	NS	**	**
LSD(0.05)	-	-	-	-	0.70	0.66

* = 5% probability level; ** = 1% probability level; Mark = marketable root yield;
N = Nitrogen; P = Phosphorus

This could be substantiated by soil analysis data (Table 1). Due to the effects of applied N, root yield significantly increased upto 100 kg N ha^{-1} at Bako and 50 kg N ha^{-1} at Loko and Nedjo. Beyond that yield declined (Table 3). This is because excess N delays tuberisation and promotes more vine growth at the expense of tuberous root growth (Lauer, 1985 and Ravindran et. al., 1987). Sweet potato yield increase following applied N was observed which might be due to the positive effects of N on its leaf area, duration and leaf size. These are the engine for photosynthesis, dry matter accumulation and translocation of leaves to the roots. Similar result was reported by Ambecha (2001).

In contrast to N, applied P did not bring about any significant ($P<0.05$) increase in marketable and total root yield both at Bako and Loko. However, a highly significant ($P<0.01$) increase was recorded with regard to both parameters at Nedjo (Table 3). The use of P, however, became imperative as its concentration in many soils appeared very low and possibilities of different chemical reactions rendering it unavailable to plants (Tisdale et. al., 1995). The non-significant response of Bako and Loko soils to P application would be probably explained by other micro-nutrient interactions and P fixation due to the acidic nature of the soils. It was observed that sweet potato is highly responsive to N both at Bako and Loko probably because of the fact that root and tuber crops, which bulk high yields in a relatively shorter period of time, need a high level of N compared to others. Similar response to N and P was observed with potato at Bako (Girma, 2001).

The combined analysis of variance showed that the interaction effects of N and P applied were high and significantly influenced marketable and total root yield at Bako (Tables 4 and 5) and non-significant both at Loko and Nedjo. Maximum biological total root yield of 125/60 kg N/P ha^{-1} was recorded at Bako. On the other hand, optimum root yield of 50/20 kg N/P ha^{-1} was recorded (Table 5). A similar study at Alemaya indicated that optimum sweet potato root yield when of 46/23 kg N/P ha^{-1} was recorded (Ambecha, 2001). Further, the study showed positive interaction between N and P on root yield and this indicates that these fertilizers increased yield when applied together than singly.

Table 4. Influence of N and P interaction on marketable root yield (t ha^{-1}) at Bako (1998 - 2001)

	P kg ha^{-1}				
N kg ha^{-1}	0	20	40	60	Mean
0	14.02	14.50	14.50	20.93	17.45
25	20.00	23.76	23.76	20.20	20.77
50	23.10	25.43	25.43	18.01	21.72
100	25.98	22.96	22.96	24.31	25.66
125	21.13	25.64	25.64	26.01	23.41
Mean	20.85	22.46	22.01	21.89	
LSD (0.05)			9.56		

Table 5. Influence of N and P interaction on total root yield (t ha^{-1}) at Bako (1998-2001)

N kg ha^{-1}	P kg ha^{-1}				
	0	20	40	60	Mean
0	19.79	18.25	23.27	27.10	22.11
25	23.40	27.45	25.37	23.28	24.86
50	27.63	30.89	24.76	23.96	26.81
100	30.19	27.66	33.76	32.16	30.94
125	26.97	29.92	25.16	33.89	28.86
Mean	25.48	26.85	26.46	28.09	
LSD (0.05)			12.80		

In a nutshell, the yield of sweet potato recorded was considerably lower at Nedjo, which was about 3 t ha^{-1} as compared to Bako (25 t ha^{-1}) and Loko (10 t ha^{-1}). This could be probably attributed to the acidity of Nedjo soils, which could reduce the availability of nutrients, particularly phosphorus thereby limiting plant growth and yield. Phosphorus is rendered unavailable in acidic soils as it precipitates in the form of insoluble iron and aluminium phosphates. On the other hand, interactions in terms of crop growth and yield may be seen when inadequate supply of one nutrient prevents the crop from making full use of others (FAO, 1979). In addition, soil acidity limits the availability of plant nutrients like K, Ca, Mg. In such soils, Al and Fe nutrient toxicity may arise, which also affects plant growth and yield. It was reported that the suitability of soils as a medium for plant growth and desirable microorganisms depends considerably on the soil reaction (FAO, 1979). This is because of the fact that the availability of plant nutrients is generally highest between pH 6.5 and 7.5. However, crops differ in adaptability to soil reaction (FAO, 1979).

The yield at Loko was also relatively lower as compared to Bako probably due to the repeated crop damage by hailstorm each year, and soil acidity coupled with other environmental factors.

Economic Analysis

The economic analysis of fertilizer use recorded a higher net benefit of 8172.50, 7824.50 and 7784.50 Birr, when 100/40, 125/60 and 50/20 kg N/P ha^{-1} were applied, respectively, at Bako (Tables 6 and 7). The marginal rate of return recorded was also higher for each combination of N/P kg ha^{-1} applied in the order of 125/60 (760.94%), 100/40 (501.09%) and 50/20 (201.89%). However, considering the high inorganic fertilizer effects on environmental pollution and their escalating costs at present, the lower but affordable and profitable rate 50/20 kg N/P ha^{-1} is optimum for sweet potato production for Bako area (Tables 6 and 7).

Table 6. Partial budget analysis, NP fertilizer study for sweet potato at Bako (1998-2001)

NP kg ha^{-1}	Avy t ha^{-1}	Ajy t ha^{-1}	GFB (Birr)	CV (Birr)	LC (Birr)	TC (Birr)	NB (Birr)	MRR (%)
0,0	19.79	17.81	5343	0	0	0	5343	
0,20	18.25	16.41	4923	274	42	316	4607D	
0,40	23.27	20.94	6282	548	42	590	5692	
0,60	27.15	24.44	7332	822	42	864	6468	283.21
25,0	23.40	21.06	6318	111	59.50	153	6165	
25,20	27.45	24.71	7413	385	59	444.50	6930.50D	275.64
25.40	25.37	22.83	6849	659	50	718.50	6130.50	
25.60	23.28	20.95	6285	933	59.50	992.50	5292.50	
50.0	27.63	24.87	7461	222	42	264	7179.00	201.89
50.20	30.89	27.80	8340	496	59.50	555.50	7784.50	
50.40	24.76	22.28	6684	770	59.50	829.50	5854.50	
50.60	23.69	21.56	6468	1044	42	1103.50	5364.50	
100,0	30.19	27.17	8151	333	59.50	375	7776.00	
100,20	27.66	24.89	7467	607	59.50	666.50	6800.50	501.09
100,40	33.76	30.38	9114	881	59.50	940.50	8173.50	
100,60	32.16	28.94	8682	1155	42	1214.50	7467.50	
125,0	26.40	23.76	7128	444	59.50	486	6642.00	
125,20	29.97	26.97	8091	718	59.50	777.50	7313.50	
125,40	25.16	22.64	6792	992	59.50	1051.50	5740.50	
125,60	33.89	30.50	9150	1266	59.50	1325.50	7824.50	760.94

Avy = Gross average yield; Ajy=Adjusted yield; GFB= Gross field benefit; CV= Variable cost; LC= Labour cost; TC= Total cost, and NB= Net benefit

Table 7. Partial budget analysis, NP fertilizer study for sweet potato at Loko (1998 - 2001)

Treatment	Avy t ha^{-1}	Ajy t ha^{-1}	GFB (Birr)	CV (Birr)	LC (Birr)	TC (Birr)	NB (Birr)	MRR (%)
N kg ha^{-1}								
0	7.72	6.96	2086.50	259.14	42	301.14	1785.36	
25	9.75	8.86	2658	434.44	59.50	493.94	2164.00	196.39
50	10.74	9.59	2877.75	577.02	59.50	636.52	2241.23	54.17
100	9.07	8.17	2451.00	716.62	59.50	776.12	1674.88	
125	10.66	9.67	2900.25	853.85	59.50	913.35	1986.90	
P kg ha^{-1}								
0	9.11	8.19	2458.20	369.58	42	411.58	2046.62	
20	9.37	8.44	2530.60	514.01	59.50	573.51	1957.09	8.86
40	10.24	9.22	2765.40	634.27	59.50	693.72	2071.63	
60	9.72	8.75	2624.40	759.59	59.50	819.49	1804.91	

Avy = Gross average yield; Ajy= Adjusted yield; GFB= Gross field benefit; CV= Cost that vary; LC= Labor cost; TC= Total cost, and NB= Net benefit. The cost observed on 0 levels of N are that of the average cost of 20, 40, and 60 P applications since NP levels was factorial arranged and the same holds true for P.

At Loko, the highest net benefit was obtained when 50 kg N ha^{-1} was applied. However, the trend was not clear for that of P. Nevertheless, with the same justification with that of Bako, the lower but affordable rate of 50/20 kg N/P ha^{-1} could be optimum for sweet potato production for Loko area (Tables 6 and 7). Based on the present result, the yield at Nedjo was considerably low. The Nedjo data were based on only two years; as a result economic analysis of fertilizer use was not made. Therefore, it is premature to make conclusive recommendation for Nedjo.

CONCLUSION AND RECOMMENDATIONS

Fertilizer use provides good ground cover of sweet potato, as a result of good vegetative growth, which in turn reduces the hazards of erosion. Sweet potato needs external supply of N fertilizer for high and good quality root. It is up to the farmer to decide the rate to apply from 25 to 125 kg N ha^{-1}. While 20-60 kg P ha^{-1} are lucrative, however, biologically the optimum rate was 100 kg N $ha^{-1}$for Bako area. Beyond that, the yield declined. Hence, based on the interaction effects, the lowest but affordable and profitable rate 50/20 kg N/P ha^{-1} is optimum for sweet potato production for Bako area. For Loko area, the optimum N rate applied was 50 kg N ha^{-1}; beyond that, yield declined. Sweet potato was non-responsive to P owing to the acidity of soils, which limited P availability and unbalanced macronutrient availability, both at Bako and Loko. Hence, future research direction should articulate towards systematic investigation of organic fertilizers to improve the efficiency of phosphate fertilizers. Investigation on Nedjo soils also needs due consideration.

In summary, the strategy for maximising crop yield by supplying fertilizers to soils requires knowledge of the inherent nutrient status and nature of nutrient release of the soils, and the nutrient uptake potential of the crop. As a result, the strategy needs due consideration in view of the present escalating fertilizers costs.

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EFFECT OF NITROGEN FERTILIZATION ON GRAIN PROTEIN CONTENT OF DURUM WHEAT CULTIVARS

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ABSTRACT

Five durum wheat (*Triticum turgidum* L var durum) varieties were evaluated for grain yield and grain protein content at two locations in the Central highlands of Ethiopia viz Akaki and Chefe Donsa under five nitrogen levels (0, 30, 60, 90,120 kg/ha) during the 2000/01 cropping season. The experiment was designed in Randomised complete block design (RCBD) with three replications. The objective was to study the effects of variety and nitrogen applications on grain protein content, an important durum wheat quality parameter for local pasta industries. Analysis of variance has shown that grain protein content showed significant differences ($P<0.05$) between locations, variety, and variety x location interactions. Fertizer level x location interaction was significant for grain protein content and was affected by fertilizer level at Debre Zeit but not at Akaki. The existence of significant nitrogen level x location interaction for grain protein content while varietal effects being significant in the combined analysis could suggest the importance of breeding works for better quality durum wheat variety production. Fertilizer levels 60, 90, 120 kg N/ha had significantly higher grain yield than the lower levels (0 and 30 kgN/ha. Besides, the highest fertilizer level N4 (120 kgN/ha) had significantly higher grain protein content (19.527%). All varieties except Foka had significantly higher protein content than variety Kilinto. From the study, it appears that selection of appropriate location, variety and management practices is necessary for the production of high quality durum wheat. Further studies on more locations and years are recommended for conclusive results.

Key words: durum wheat, *Triticum turgidum* L var durum, grain protein content, grain yield

INTRODUCTION

Durum wheat (*Triticum turgidum* L var durum) is an indigenous predominant tetraploid wheat species in Ethiopia. It is exclusively grown on Vertisols by small-scale farmers under rain-fed conditions. The major production zone lies in altitudes ranging from 1800 to 2800 metres above sea level (m asl). The country is also a recognised centre of genetic diversity for tetraploid wheat (Harlan, 1971); of which, durum wheat is the most dominant.

Currently, with the emergence of new food processing industries, durum wheat products such as macaroni and spaghetti are becoming important part of daily diet in the urban areas of Ethiopia. During five years period, 1994-1998, on average, the country imported 720,725 quintals of durum wheat per year (Ethiopian Customs Authority, 1999). Currently, however, local pasta industries largely depend on imported durum wheat. Therefore, there is a large gap between demand for and supply of durum wheat in the country. Unlike, these days, Ethiopia used to export durum wheat grain and flour until late fifties (Pinto, 1971). Due to the high local demand for durum wheat for use in pasta industries in the country, it is becoming imperative to include industrial quality as selection criteria for the development of improved durum wheat varieties. The major objectives have been to increase grain protein concentration and other industrial quality parameters in most varietal development process (Metho, Hammes and Beer, 1997).

For durum wheat, quality is as important as its production. Durum wheat is utilised for pasta production because of its hard grain texture and amber colour. A high proportion of vitreous kernels is required for quality pasta products. The non-vitreous kernels have different physical texture which makes them more easily broken than vitreous kernels (ICARDA, 1986). Hardness and vitreousity are frequently considered synonymous, hard wheats are vitreous and translucent in appearance. For durum wheat milling quality relates to kernel hardness and is measured as the percentage of flour and the rate it can be extracted from the whole grain during milling

Vitreosity is maintained by selection of appropriate variety, environment and good management practices. Hard grained wheats, if grown under conditions of high fertility favouring high protein levels in the mature grain, will yield hard vitreous kernels. Under high rainfall and lower soil fertility conditions, favouring starch production rather than protein, kernels tend to be soft (Simmonds, 1989). The effect of environment and management methods, especially availability of nitrogen in the soil during ripening on vitreousness of durum wheat, has been reported (Mosconi and Bozzini, 1973). Hadjichristodoulou (1979) also reported significant effects of nitrogen fertilization, genotype and location on vitreousness of durum wheat. Dexter et al (1982) investigated significant difference between varieties for several quality traits at different nitrogen fertilizer levels.

The objective of this experiment was to evaluate various factors affecting the quality of durum wheat viz-a-viz variety, nitrogen fertilization levels and location so as to improve breeding methodologies in durum wheat.

MATERIALS AND METHODS

During the main cropping season of 2000/01, five durum wheat varieties: Kilinto, Tob66, Foka, Assasa and Boohai) were studied at two representative midhighland durum wheat producing areas in the central highlands of Ethiopia viz Debre Zeit and Akaki. Debre Zeit is situated at 8°. 44' N, 39° 02' E at an altitude of 1980 m asl. It has 851mm average annual rainfall (moderate), 17.9°C average mean temperature and Pellic Vertisol. Akaki is situated at 8°.52' N, 38° .47' E at an altitude of 2100 m asl. It has an average annual rainfall of 1086 mm and 15.6°C average temperature. The local pasta industries selected the five varieties for their industrial quality, hence the reason for the study.

The experiment was conducted under rain-fed conditions. The cultivars were planted at five different nitrogen levels (0, 30, 60, 90 and 120 kg N/ha) with uniform basal application of 10 kg P/ha in the form of TSP). The plot size was 3 x 4 m and the experiment was laid out in randomised complete block (RCB) with three replications in factorial arrangement. Nitrogen was split-applied half at planting and the remaining half at full tillering. After cleaning of threshed wheat kernels, grain yield was weighed and expressed in kilogram per hectolitre. Grain protein content was determined according to the standard Kjeldhal procedure (FAO, 1980). Data were analysed by ANOVA using SAS/STAT (SAS Institute, 1999).

RESULTS AND DISCUSSION

Grain yield

Analysis of variance for gain yield at Akaki showed that, significant differences between varieties, nitrogen fertilizer levels ($P<0.05$) and variety X location interactions were observed (Table 1). Nitrogen levels (60, 90 and 120) gave significantly higher grain yield level than the rest but no significant difference among them. At Akaki, the check (1685 kg/ha) was significantly lower than 30 kg N/ha (2188 kg/ha) and similar results were observed in the combined analysis. At Debre Zeit, the highest grain yield (4072 kg/ha) was obtained from 120 kg N/ha while the check and 30 kg N/ha treatments were significantly lower than the rest. In the combined analysis of variance, significant differences between locations, varieties, fertilizer levels and variety x location interactions were evident. This result is similar to the previous nitrogen recommendation (60-90 kg/ha) for durum wheat varieties for Vertisols under different cropping systems in the central highlands of Ethiopia (Mesfin and Tekalign, 1997). Location mean grain yield at Debre Zeit (3294 kg/ha) significantly out-yielded that of Akaki (2554 kg/ha). The higher grain yield at Debre Zeit could be due to proper distribution of rainfall during the season.

With respect to varieties, Assassa (3688 kg/ha) was the top yielder in overall mean at Debre Zeit (Table 1); however, at Debre Zeit it significantly out-yielded only Foka and significantly out-yielded Boohai and Tob 66 at Akaki Kilinto (2812.9 kg/ha). Boohai was among the top yielders at Debre Zeit but performed least at Akaki suggesting differential responses of varieties at the two locations. As shown in Figs. 1 and 2, with increasing amounts of nitrogen supply, the yield rises rapidly but flattens out to reach a wide plateau and then declines at both locations. Benzian and Land, (1979) have reported similar findings. However, the nitrogen level at which varieties reach maximum yield varies. The grain yield reduction for most varieties at both locations beyond 90 kg N/ha could be due to lodging. In the combined analysis across the two locations, Kilinto (3202 kg/ha) was the top yielder while Foka (2703 kg/ha) was the least. In overall mean, Kilinto and Assassa were superior to others and this strengthens their recommendations for large-scale production in these areas.

Grain protein content (%)

ANOVA revealed that at Debre Zeit, fertilizer had significant (P<0.05) on grain protein content (%) of durum wheat varieties but no significant difference between varieties and variety-fertilizer rate interaction. The highest fertilizer rate 120 kg N/ha resulted in significantly higher grain protein percent (19.527) at Debre Zeit but no significant difference among 0, 30, 60 or 90 kgN/ha. At Akaki, on the other hand, no statistically significant difference between varieties, fertilizer levels or fertilizer X variety interactions, was observed.

As in most grain quality traits in wheat, protein content is known to be affected by genetic and environment mainly location (season including temperature during maturation, fertilizer application and management practices). The effect of nitrogen levels on grain quality (Kramar, 1979), gluten and protein content (Prima et al, 1982) was reported. Dexter et al (1982) and Kramar (1979) also investigated the contribution of both varietal differences as well as nitrogen levels on grain quality of wheat. Metho et al (1997) also reported increased grain nitrogen content of wheat with increased soil fertility. In the combined analysis, significant differences between varieties, locations and fertilizer levels by location interactions were recorded. The occurrence of genetic variability for grain protein content of wheat has been reported elsewhere (Desai and Bathia, 1978; Cox et al., 1985). As shown in Figs. 3 and 4., all varieties tended to increase grain protein content with increasing nitrogen levels at Debre Zeit while at Akaki beyond application of 90 kg N/ha, there is a descending trend in the response curve. This could be due to the difference in the two locations in terms of air temperature and degree of waterlogging which fever protein synthesis in the case of Debre Zeit and starch production at Akaki. In this study, varieties Boohai, Assassa and Tob 66 had significantly higher grain protein content than Kilinto. This was no significant difference between Foka and Kilinto (Table 2).

Table 1. Effect of variety and N fertilization on grain yield (kg/ha)

	Location		
Treatment	Debre Zeit	Akaki	Mean
Nitrogen levels			
0	2296b	1685c	1990c
30	2712b	2188b	2449b
60	3613a	2807a	3210a
90	4072a	3027a	3549a
120	3777a	3063a	3420a
LSD (0.05)	637.5	316.2	238.3
Variety			
Kilinto	3591a	2813a	3202a
Tob66	3076ab	2345bc	2710b
Foka	2722b	2683a	2703b
Boohai	3393a	2274c	2834ab
Assassa	3688a	2656ab	3172a
CV (%)	26.35	16.85	25.144

Values in a column followed by different letters are significantly different at P<0.05 by DMRT

Table 2. Effect of variety and N levels on grain protein content (%)

	Location		
Treatment	Debre Zeit	Akaki	Mean
Nitrogen level			
0	15.07b	13.02	14.04
30	15.4 b	13.66	14.54
60	15.62b	14.89	15.25
90.	16.17b	15.09	15.63
120	19.53a	12.69	16.11
LSD (0.05)	2.2708	ns	ns
Variety			
Kilinto	14.77	12.4	13.58b
Tob66	15.71	15.17	15.43a
Foka	16.26	13.63	14.94ab
Boohai	17.37	14.93	16.15a
Assassa	17.69	13.23	15.46a
CV (%)	18.9	21.13	21.03

ns = non-significant

Values in a column followed by different letters are significantly different at P<0.05 by DMRT

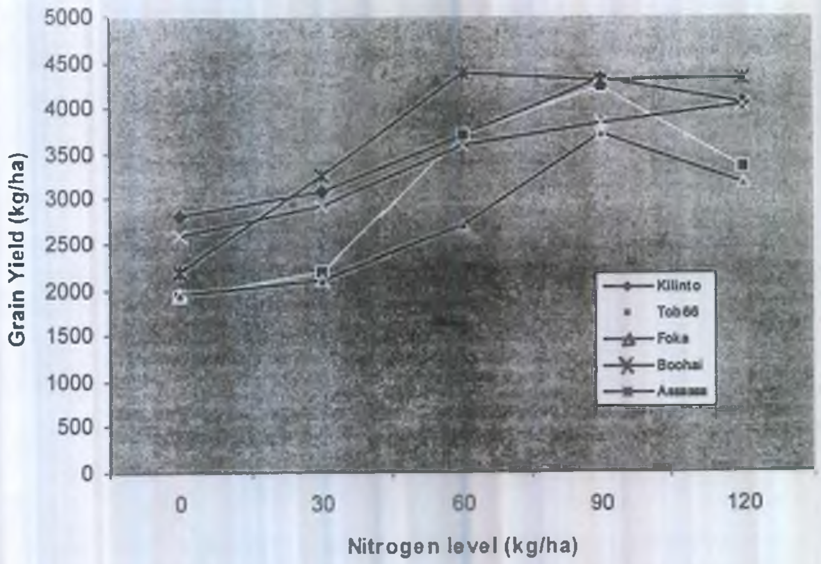

Figure 1. Effect of nitrogen levels on grain yield of durum wheat varieties at Debre Zeit

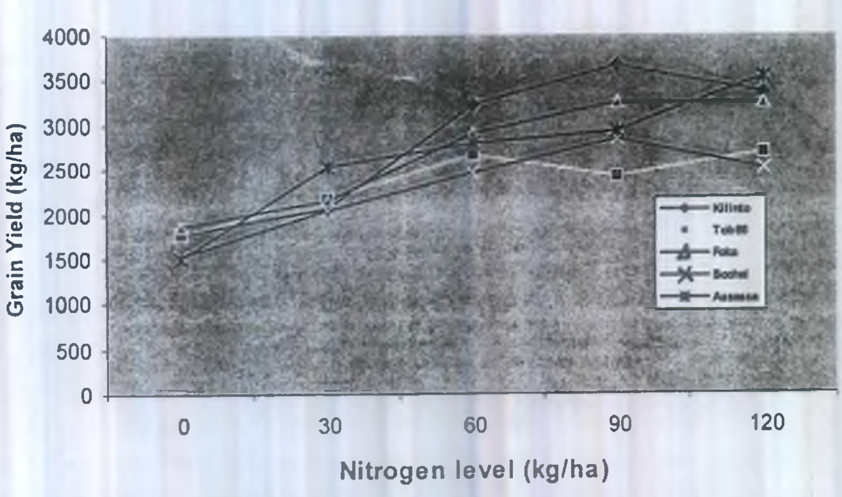

Figure 2. Effect of nitrogen levels on grain yield of durum wheat varieties at Akaki

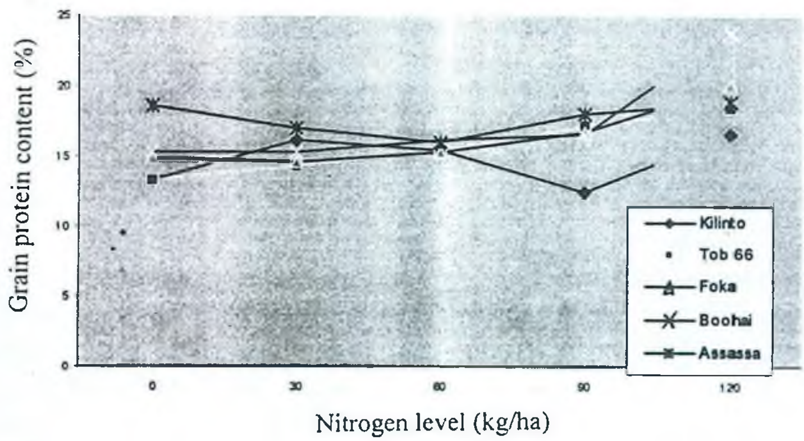

Figure 3. Effect of nitrogen levels on grain protein content (%) of drurn wheat at Debre Zeit

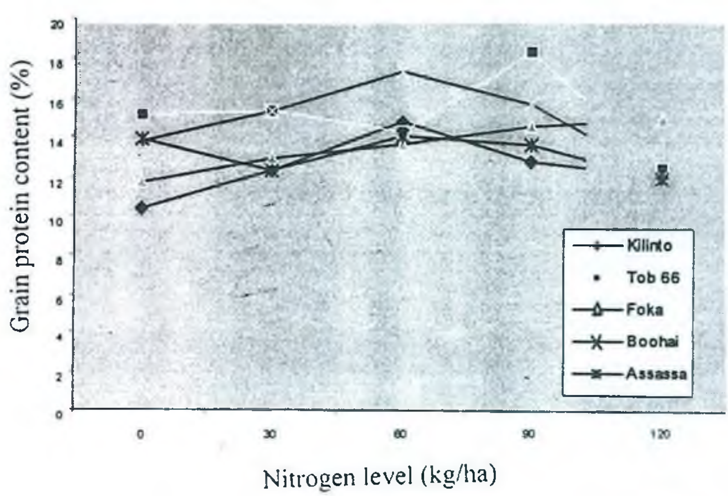

Figure 4. Effect of nitrogen levels on grain protein content of durum wheat at Akaki

CONCLUSION

Grain protein content affects industrial quality of durum wheat and should meet standards of pasta industries. Vitreosness of durum wheat is usually associated with grain hardness and high protein content which are high quality traits in durum wheat. The effect of nitrogen on grain protein content of durum wheat varieties was location-specific. Environmental factors, which affect nitrogen availability as well as protein synthesis, could generally affect grain protein content. This study showed the effects of variety on grain protein content to be significant in the combined analysis suggesting the importance of breeding for better quality durum wheat production. With the use of high nitrogen levels which resulted in the highest grain protein content, durum wheat varieties like Tob 66 and Boohai under Debre Zeit or similar environments could result in maintaining superiority of durum wheat quality and significantly contribute to ultimate import substitution of durum wheat in the country. With selection of appropriate environment, unless the negative effect of lodging is confounded, certain increments in nitrogen fertilizer level for medium to tall durum wheat cultivars could significantly contribute to grain quality of durum wheat varieties. Currently, local pasta industries are willing to buy local durum wheat grain, which fulfill their quality standards, with premium price. Therefore, selection of appropriate variety, location and management practices are necessary to produce high quality durum wheat. Further studies on more locations and years should be done for conclusive results.

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COMPARISON OF CARRIER AND ALTERNATE PROPAGATION MATERIAL FOR RHIZOBIAL INOCULA PRODUCTION

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ABSTRACT

Research on *Rhizobium* in Ethiopia started in the early 1980s. However, there is no rhizobial inoculum production in the country. One of the reasons is the lack of reports on research work done on inoculant carrier material available in the country. The inoculant carrier is material supporting the living rhizobia from the point of manufacture to the user. The availability of an inexpensive and suitable carrier and production material for rhizobia is essential for economic production of legume inoculants. The suitability of any material used as carrier is determined by its capacity to maintain the viability of high numbers of the added rhizobia over long periods without loss of infectiveness and effectiveness. Most important, the material must be able to maintain a high number of rhizobial, implying that it should provide proper nutrition and moisture for rhizobial growth. Ideally, the carrier will be highly absorptive, easy to process, available in adequate amount, stick easily to seeds and provide good pH-buffering capacity. In this regard, molasses-D was tested to replace manitol sugar in yeast Extract manitol media to propagate *Rhizobium* on a large scale. Five possible carrier materials (filter mud, bagasse, charcoal, lignite and peat) were also compared for the usefulness in keeping quality of *Rhizobium* and on their organic matter content, percent carbon, water-holding capacity, hygroscopic coefficient and particle density. Of these compared carriers, lignite was found to be a superior carrier in all aspects followed by filter press-mud.

Key words: Carrier, propagating material, Rhizobia, Growth curve

INTRODUCTION

Interest in the technologies appropriate for study of the legume-*Rhizobium* symbiosis has changed considerably over the last 20 years. World-wide development projects such as NifTAL have done much to transfer the fundamental methodologies for applied biological nitrogen fixation (BNF) research to scientists in the developing world (BNF, 1995). While research in industrialised countries moved increasingly towards basic involvement with biochemical and molecular techniques. There clearly remains considerable scope to improve N_2 fixation in legumes, particularly in the developing world, through application of appropriate BNF techniques. Whether or not research objectives are increased, yields through inoculation, improved inoculants or enhanced legume N input into cropping systems, the key to success is a step-wise strategy using a set of proven methodologies in establishing the main actors: the N-fixing prokaryotic cells in the soil. This requires a good understanding of the organism involved, *Rhizobium* or *Bradyrhizobium* in this case, what requirement it has and know how to maintain that need.

Research in the area of BNF in Ethiopia started in the early 1980s (Amare Abebe, 1982). However, for many reasons it did not continue and was done with meager resources. Until the mid-1990s, there was no one responsible organisation to handle this research in a proper and sustainable manner. It was at its infant stage at the then National Soil Service Laboratory (Asfaw Hailemariam, 1993). But there was a tremendous interest among researchers to carry out research in this area. This interest gave birth to Biofertilizer Pilot Scale Production Sub-Project of National Sector Project.

The projects first step was to identify proper long lasting indigenously available carrier material to obtain an alternate propagating and carrier material available within the country. The need for studying alternate propagating and carrier materials arose from the restrictive quarantine policy and financial regulation that the country follows in not allowing *Rhizobium* inocula producers to import already established propagating material and carrier such as peat.

The inoculant carrier is the material supporting the living rhizobia from the point of manufacture to the user. The availability of an inexpensive and suitable carrier for rhizobia is essential for economic production of legume inoculants. Normally, at least $5 * 10^8$ or 500 million living rhizobia should be contained in each gram of carrier. This means that by using normal application methods, each seed will have 10^4 -10^5 rhizobia if there is good attachment. The lower level (10^4 rhizobia / seed) is the minimum if good nodulation is expected in soils where the necessary rhizobia are not present (Beck et al, 1993). The suitability of a material to be used as carrier is determined by its capacity to maintain the viability of high numbers of the added rhizobia over long periods without loss of infectiveness and effectiveness.

There are several qualities to look for in acceptable carriers. Most important, the material must be able to maintain high numbers of viable rhizobia, implying that it should provide proper nutrition and moisture for rhizobial growth. In this regard, many researchers have tried different carrier materials at different times. To mention some of them, Chao and Alexander (1984) studied mineral soils as carrier. Deschodt and Strijidom (1976) tried coal-bentonite base as carrier. Lignite impregnated with broth was studied by Dube et al (1973). Later nutrient-supplemented vermiculite as rhizobium carrier was tested by Graham-Weiss et al (1987). Coal was used by Paczkowski and Brryhil (1979). Coir dust and soybean meal compost have been tested by Iswaran (1972). Lignite alone was examined carrier by Kandasamy and Prasad (1971) and fiter mud by Philpotts (1976).

Ideally, the carrier should be highly absorptive, easy to process, available in adequate amounts, stick easily to seeds, and provide good pH-buffering capacity. The carrier material also must be inexpensive because farmers can not afford to spend more money on inoculant. It must be lightweight for transporting and must be stable if exposed to adverse conditions during transport and storage. It should be relatively easy to sterilize (autoclaving or gamma-irradiation). Finally, the carrier must be low in content of soluble salts and phenolic products of organic matter breakdown, and therefore nontoxic both to rhizobia and seed (Beck et al, 1993).

The carrier most commonly used in the inoculant industry is peat. Since peat is not available in Ethiopia, one is prompted to investigate uses of other alternate materials. Some of these are filter mud, bagasse, charcoal and lignite. Though chemical and physical analyses do not confirm the quality of a carrier, they are helpful in differentiating their qualities. Hence physico-chemical analyses of these materials available in abundance in the country was compared with imported peat. Regardless of the type chosen for inoculum production, it is important to keep in mind that carrier-rhizobia interactions cannot be avoided. These interactions must be known for all strains in production. For this study, tests were carried out with one strain each of a fast-growing *Rhizobium leguminosarum*, var. *Vicia fabae* and a slow-growing *Bradyrhizobium japonicum*. In order to produce rhizobia culture on a large scale, one needs to identify a cheaper source of producing medium, where the bulk of component is the carbon source. The usual accepted suitable medium for growing rhizobia is "yeast-extract mannitol broth (YEMB)", where d-mannitol is the source of carbon needed in bulk (Vincent, 1970). As an alternate source of carbon for large production of rhizobia, some researchers and companies have identified sources of growing materials. Perhaps for patenting reseason they are not disclosing them. However, among the studies found in literature include Graham (1964) who studied some carbohydrates, and Gulati (1979) who studied Kreb's cycle intermediates, non-synthetic medium from waste and Somasegaran (1985) who studied diluted liquid culture method. In our study, we have tested Mollasses-D as an alternate to d-mannitol in the usual YEMB medium.

MATERIALS AND METHODS

Carrier materials preparation

The carrier materials in this study were collected from their respective places, filter press mud and bagasse from Wonji Sugar Industry, lignite from Coal and Phosphate Project, and peat was imported from South Africa. Each material was ground to pass through 150 μm and neutralised as per the need to bring the pH to 7. The 125 g. of each neutralised material is then autoclaved at 121 °C for 1 h., in half closed polycarbonyl coloured plastic bugs. Immediately after the autoclaving process was complete, bags were sealed with plastic bag sealer under aseptic condition in the Laminar Flow Hood. Each material was initially subjected to physico-chemical analyses.

Test of rhizobia keeping quality

One strain each of *Rhizobium leguminosarum* and *Bradyrhizobium japonicum,* authenticated to faba bean and soybean, respectively, were allowed to grow in yeast extract broth (YEB) until each attained 10^9/ml growth. Placing equal amounts of viable rhizobia cells (10 ml. of 10^9 colony forming units (cfu) / ml.) in the material, the growth and survival of the *Rhizobium* strains were monitored for over a period of six months. The actual keeping qualities of each material was tested using Miles and Misera serial diluting technique mentioned in Vincent (1970).

Test of an alternate propagating material

In the study, the usual YEMB's d-mannitol is replaced by molasses-D of the sugar industry by-product. Molasses- D is the last molasses coming out after all possible profitable sucrose had been extracted and was brought fresh from Wonji Sugar Industry, Wonji. Yest extract molasses broth (YEMoB) and yeast extract mannitol broth (YEMB) were prepared in the following composition:

YEMB composition(g/lt)
(Suba Rao, 1988)

$K_2 HPO_4$---------------0.5 g
Mg SO_4. $7H_2O$--------0.2g
Na Cl-------------------0.1g
Yeast extract----------1.0g
d-Mannitol-----------10.0g
Distilled water---------1.0lt
pH----------------------7+/- 0.1

YEMoB composition(g/lt)

$K_2 HPO_4$---------------0.5g
Mg SO_4. 7H2O--------0.2g
Na Cl--------------------0.1g
Yeast extract-----------1.0g
Molasses-D-----------10.0g
Distilled water---------1.0lt
pH----------------------7+/- 0.1

These media were autoclaved at 121°C for 20 minutes and were used for growing each strain in triplicates of each medium. The population count of each strain was measured using Miles and Misera serial dilution method mentioned at Vincent 1970. The-growth curve was plotted with the logarithm number of the population count.

RESULTS AND DISCUSSION

Physico-chemical analyses of carrier materials

Each carrier, filter press mud and bagasse from Wonji Sugar Industry, lignite from Coal and Phosphate Project, peat from South Africa and charcoal from local market were collected and ground to fine powder possible. These materials were allowed to pass through two sieves (150 μm and 212 μm). The proportion passed through each sieve was measured and their percentage was recorded. Each of these carrier materials was subjected to the following physico-chemical analyses; hygroscopic moisture %, ash %, CO_2 %, organic matter (%), and carbon (%). The result is indicated in Table 1. On the bases of the physico–chemical analyses done lignite was found to have the highest water-holding capacity, high organic matter and the 2nd highest carbon %(Fig. 1). It was also equally good in keeping rhizobia for longer than 180 days (Figures 2 and 3).

Table 1. Showing Physico-chemical analyses of carrier materials

Item	pH	% Ash	% C_{O_2}	%O.M	% pass through 112umsieve	Hygroscopic H2O	W.H.C.	Particle density	Carbon %
Filter press mud	7.46	62.6	37.4	17.58	96.78	7.26	81.21	1.76	10.2
Bagass	5.03	39.7	60.3	28.34	83.47	5.71	78.79	0	16.45
Charcoal	9.22	19.9	80.1	37.67	76.87	5.93	58.18	1.48	21.85
Lignite	4.48	24.5	75.5	35.5	61.88	30.8	58.11	1.45	20.59
Peat	7.21	65.2	34.8	30.65	82.89	18.13	44.94	1.75	17.78

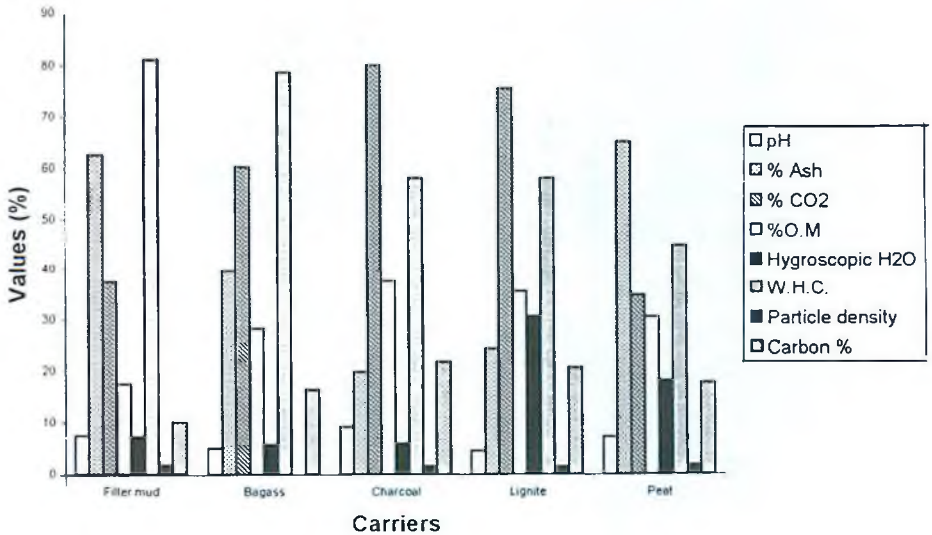

Figure 1. Physico-chemical anlyses of carriers

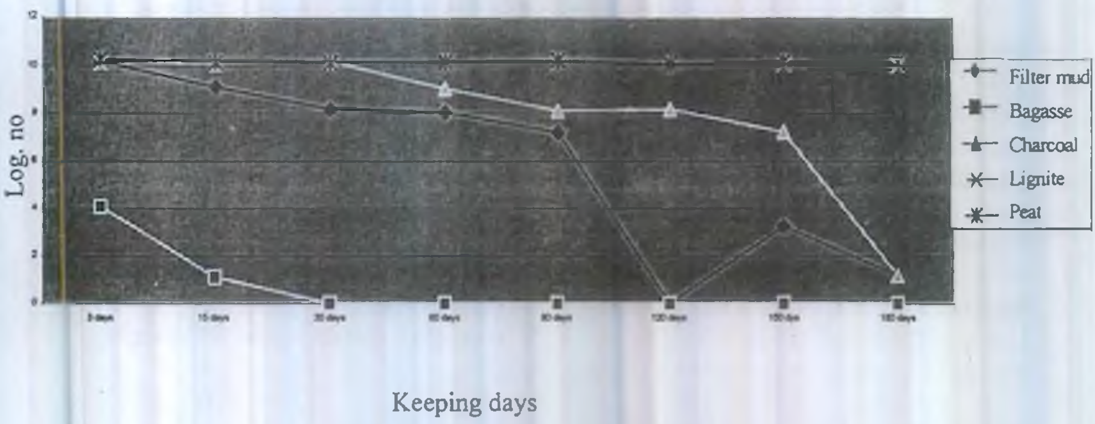

Figure 2. Population of not legible (log. no./g of material) at respective keeping days

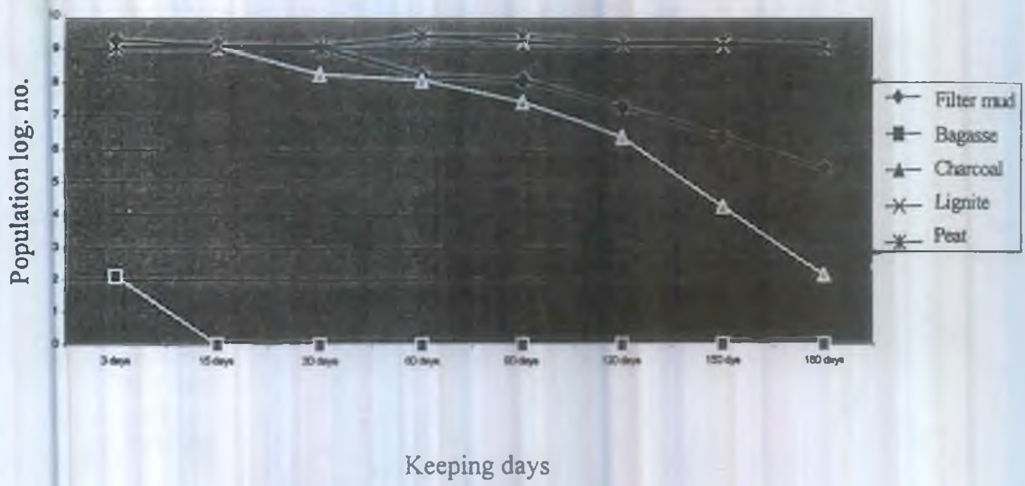

Figure 3. Population of Bradyrhizobiumjaponicum (log no/g of carrier material) at respective keeping days

Estimation of lime requirement for neutralising a carrier material to pH (6.5-7.0)

- 20 gm of the carrier material weighed, dissolved in 100 ml distilled water, then filtered in a filter paper (what man no.1)
- 1 gm of calcium carbonate $CaCO_3$ (lime) weighed and dissolved in 100 ml distilled water, then diluted to 100 ml (05 gm /100 ml)
- 40 ml filtrate of the carrier taken and dilute to 100 ml distilled water, pH in the ratio 1:2.5 lime to carrier material was measured, the required amount of carrier material and lime to make pH 6.5-7.0 calculated for the amount that will be prepared for inoculation purpose.
  e.g. (lime required to bring lignite 20 gm of the carrier)

Calculation = 0.5/100* 22* 100/40* 100/20 =

Where, 22 ml = the required amount of filtrate to make pH 6.5-7.0
0.5 gm /100 ml = lime diluted in 100 ml distilled water
100 ml / 40 ml = filtrate of carrier diluted to 100 ml distilled water
100 ml / 20 gm = carrier material diluted in 100 ml distilled water

Each carrier material, neutralized to pH (6.5-7.0) is weighed to 125gm each in heat resistant coloured polycarbonyl plastic bags. These bags were partially sealed, leaving small holes for air to come out and for later inoculation purposes. The bags containing 125 gm in each carrier material were subjected to autoclaving at 121°C for 1 hr. After complete cooling of the autoclave, taking out of autoclave inoculation of the strains known number of population for each stain were made. These inoculated bags were kept at room temperature for six months measuring the population of each strain at intervals of 3 days, 15 days and at 1month for 6 months. Each measurement was made making appropriate dilutions so as to count the population on YEMA plates (Tables 2, 3 and 4). In their *Rhizobium* and *Bradyrhizobium* keeping quality each carrier differed significantly except peat and lignite (Figures 2 and 3). In this study lignite of Bedele's Coal and Phosphate Project site was found to be comparable to the peat of South Africa.

Table 2. Population of Rhizobium leguminosarum / g of carrier material at respective keeping time Population Rhizobium leguminosarum/ g of carrier material at respective keeping days
Medium Population *Rhizobium leguminosarum*/ g of carrier material at respective keeping days

Materials	3 days	15 days	30 days	60 days	90 days	120 days	150 dys	180 days
Filter mud	$1.42 X10^{10}$	$1.3 X10^{9}$	$1.5 X10^{8}$	$1.1 X10^{8}$	$1.6 X10^{7}$	1.2 X10[illegible]	$1.8 X10^{3}$	1.5 X10
Bagasse	$1.2 X10^{4}$	1.3 x10	Nill	Nill	Nill	Nill	Nill	Nill
Charcoal	$1.5 X10^{10}$	$1.2 X10^{10}$	$1.4 X 10^{10}$	$1.1 X10^{9}$	$1.3 X 10^{8}$	$1.5 X 10^{8}$	$1.8 X 10^{7}$	$1.3 X 10^{6}$
Lignite	$1.4 X10^{10}$	$1.6 X10^{10}$	$1.1 X10^{10}$	$1.3 X10^{10}$	$1.4 X10^{10}$	$1.2 X10^{10}$	$1.2 X10^{10}$	$1.1 X10^{10}$
Peat	$1.8 X10^{10}$	$1.4 X10^{10}$	$1.3 X10^{10}$	$1.4 X10^{10}$	$1.6 X10^{10}$	$1.2 X10^{10}$	$1.5 X10^{10}$	$1.4 X10^{10}$

Table 3. Population *Rhizobium leguminosarum*/ g of carrier material at respective keeping days Population of *Rhizobium leguminosarum* in Log. No. / g of carrier material at respective keeping days

Materials	3 days	15 days	30 days	60 days	90 days	120 days	150 dys	180 days
Filter mud	10.1523	9.1139	8.1761	8.0414	7.2041	5.0.792	3.2553	1.1761
Bagasse	4.0792	1.1139	0	0	0	0	0	0
Charcoal	10.1761	10.0792	10.1461	9.0414	8.1139	8.1761	7.2304	1.1761
Lignite	10.1461	10.2041	10.1461	10.1139	10.1461	10.0792	10.0792	10.0414
Peat	10.2553	10.1461	10.1139	10.1461	10.2041	10.0792	10.1761	10.1461

Table 4. Population of *Bradyrhizobium* in Log. No. / g of carrier material at respective keeping days

Materials	3 days	15 days	30 days	60 days	90 days	120 days	150 dys	180 days
Filter mud	9.2553	9.1139	9.0414	8.2042	8.0792	7.2553	6.3802	5.415
Bagasse	2.1139	0	0	0	0	0	0	0
Charcoal	9.0792	9.0414	8.2553	8.0792	7.415	6.3802	4.2553	2.1461
Lignite	9.0141	9.0414	9.0792	9.3802	9.2041	9.1461	9.1139	9.0414
Peat	9.0792	9.0792	9.0414	9.415	9.3802	9.2041	9.2041	9.0792

Alternate propagation material

The results of the experiment should that molasses-D, a by –product of the sugar industry can easily replace d-Mannitol. Both genera representative taken in this experiment, *Rhizobium leguminosarum* and *Bradyrhizobium japonicum* were found to multiply properly in yeast Extract molasses –D broth (YEMoB). However, both showed a lag phase in which *Bradyrhizobium*, being slow growing, has taken more lag period than *Rhizobium* (Table 5).

Table 5. Comparison of population Log. No./ml of YEMB and YEMoB at different interval of growth periods

Medium	ohr	2 hrs	6 hrs	12 hrs	24hr	36hrs	48 hrs	60hrs
YEMB	1.3222	2.2833	3.3424	4.5441	5.6232	7.716	9.6812	10.5798
YEMoB	1.0414	1.1523	2.2095	3.1644	4.4472	6.5563	8.5441	10.6232

RECOMMENDATIONS

The production of solid carrier-based inoculants, which contain only one strain of rhizobia, requires a completely sterile carrier in a sterile package. Generally, peat is used as carrier in many inoculant industries. However, peat is not available and very strict quarantine law is followed in the country. The commercial inoculant carrier must be inexpensive, available in bulk within the country, has to be light weight and easy to sterilize. It should also have good quality to withstand various changes during storage and transportation. It has to have high water-holding capacity, high organic mater, high utilisable carbon, and must have low content of soluble salts and phenolic product of organic matter breakdown, therefore, nontoxic both to rhizobia and to seeds. Hence, not to import peat and to make the inoculant production more cheaply and easily we need to utilise the available and equally good carrier material i.e. lignite of Bedelle. For large- scale production of rhizobia inoculant, if one has to be more profitable and to sustain the production, it is advisable to use an alternate means of propagation such as mollasse-D. However, this requires further studies.

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INVESTIGATION ON PHOSPHATE SOLUBILISING ABILITY OF BACTERIA ISOLATED FROM SOME ETHIOPIAN SOILS

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ABSTRACT

Phosphorus (P) is one of the most important nutrients required by plants or crops for their growth and development. However, it is deficient in most Ethiopian soils limiting crop production. The deficiency may arise due to the fact that the amount of P in most soils is very low or it may exist in unavailable form. Moreover, there is marked fixation of applied soluble P in acidic or alkaline soils. There are some soil bacteria endowed with ability to solubilise insoluble P compounds and make it available to crops. Thus, such bacteria can be utilised in using cheap sources of P like rock-phosphate and old bone meal as P fertilizers. In recognition of this fact, three phosphate souliblising bacteria (PSB) coded as Jim41, Gim10, Hag12 were isolated from Jimma, Gimbi and Hageremariam soils, respectively. These were characterised to generic level and all belong to *pseudomonas* spp. Tricalcium phosphate (TCP), rock-phosphte (PR) and old bone meal (OB) solublisation efficiency of isolates and a reference strain *Psedomonas straita* was studied in the laboratory. The result revealed that all the test organisms solublized significantly p (0.01) greater amount of TCP and PR over the uninoculated control. Isolate Jim41,Gim10, Hag12and *Pseudomonas striata* solubilised 37.2, 31.5, 25.9 and 21.9% of TCP, respectively. Whereas the same isolates solublised 12, 10.8, 9.7 and 8.8% of PR, respectively. In the case of OB isolate Gim10, Hag12 and *Pseudomonas.striata* solublised significantly (P<- 0.01) greater amount of OB over the uninoculated and Jim41. The result would mean that Jim41 could not be used as PSB inoculant where OB is required as P fertilizer. The implications of results are discussed and future research directions are indicated.

INTRODUCTION

Phosphorus is one of the most important nutrients required by plants for their growth and development. However, it is deficient in most Ethiopian soils thus limiting crop production. According to Desta (1982) 70–75% of Ethiopian soils are deficient in P. The deficiency may arias due to the fact that a particular soil may be poor in its native P or it may exist in unavailable form to be taken up by crops or plants (Brady, 1990). Moreover, in acidic soil dominated by Al^{3+} and Fe^{3+} such as those occurring in the south, south-western and western regions of the country, P is fixed and rendered unavailable to crops (Sahlemedhin and Ali, 1983).

In an effort to improve the P nutrition of crops and thereby increase yield, applications of industrially manufactured P have been in use fertilizers around the world for a long period. Indeed, much has been achieved through this technology. And currently, in Ethiopia applications of P fertilizers along with other inputs is taken as major route to boost crop yield. But the cost of fertilizers is ever increasing becoming unaffordable to subsistent farmers. Even if they could afford it, the fertilizer-use efficiency of crops is very low as most of the applied soluble P is turned into unavailable form in the soil. According to Biswas et al. (1994), only 15 – 25% of the applied P is utilised by crops in one season. Thus, to alleviate these problems, there is a need to develop an alternative or supplementary means of improving P nutrition of crops.

One such method is the use of cheap sources of phosphorus such as rock-phosphate and bonemeal by the action of P solubilising bacteria (Gaur, 1972). Phosphate solubilising bacteria have the ability to solubilise insoluble P compounds and release soluble form in excess of their requirement, which could be taken up by plants or crops (Alexander, 1977). The mechanism of solubilisation is generally due to the production of organic acids. These acids chealate with Al^{3+}, Fe^{3+}, Mg^{2+} and Ca^{2+} resulting in effective solubilisation (Rao, 1982). PSB, in addition to phosphate solubilisation they produce hormones, and antagonising plant pathogens in the rhizosphare (Kundu and Gaur, 1988).

Consequently, the use of PSB as inoculant of seed or soil started and has long been in use in the former USSR and in East European countries (Tisdale et al.; 1985). This practice is becoming popular in many countries especially in India and appreciable increase in the yield and P uptake of crops like wheat, rice, maize beans etc. was reported by SubaRao (1993).

To this end, natural rock-phosphate deposit and a huge accumulation of bones are available in this country. The exploitation of such cheap source of P by the action of PSB may reduce our dependence on imported fertilizers to appreciable extent. Furthermore, effective PSB could be inoculated alone to seed or soil during planting as they have the ability to prevent P fixation and increase P availability from the existing source in the soil. However, only limited research has been conducted so far in Ethiopia. The objectives of this study were therefore to isolate PSB from some soils of Ethiopia and compare their solubilisation efficiency of tricalcium phosphate, rock-phospate and bone meal.

MATERIALS AND METHODS

Isolation and characterisation of phosphate solubilising bacteria (PSB)

Soil samples were collected from locations in Jimma, Gimbi and Hageremariam. These soils were selected to represent tropical acidic soil of south-western, western and southern regions of the country and have high P- fixation problem. From each of these areas, 50 soil samples were collected in a plastic bag at an interval of 5 km and the bags were kept in an ice box until they were brought to the laboratory to arrest the growth of bacteria.

PSB were isolated following a method developed by Pikovskaya, cited in Asfaw (1988), in which 10 g of soil from each sub sample was added to 90 ml of distilled and sterilised water to make 1:10 dilution. Then a series of tenfold dilution viz. 10^{-2}, 10^{-3}, 10^{-4} 10^{-5}, and 10^{-6} were made. From delutions of 10^{-5} and 10^{-6}, .1 ml of suspensions were added on a petridishes containing Pikovskaya's agar medium (its ingredients and preparations are shown below). The suspensions were spread uniformly on the petridish using glass road spreader aseptically. Then inoculated petridishes were incubated in an inverted position for 4–5 days at 28 + 2 ^{0}C. Colonies showing clear zones around them were picked and replated in order to purify them. The purified cultures were mainlined in Pikovskaya,s agar slants for subsequent work.

Pure cultures of PSB isolates were characterised to their respective general following standard microbiological procedures (Aneja, 1993).

Ingredients of Pikovskaya's medium: glucose, 5g; $Ca_3(PO_4)_2$, 5g; $(NH_4)_2SO_4$, 0.5g; yeast extract 0.5g; $MgSO_4$. $7H_2O$, 0.2g NaCl 0.1g $MnSO_4$, trace; $FeSO_4$ trace; agar, 15g; distilled water, 1000 ml; and pH7.

The components of the medium were carefully weighed and mixed in 500 ml capacity ernmerye flask and sterilised in autoclave at 121^{0}C for 15 minutes. Following that 15 to 20 ml of medium were poured in petridishes and allowed to solidify.

Tricalcium phosphate (TCP), Rockp-hostate (PR) and old bone (OB) meal solubilisation efficiency test

Three PSB isolates coded as Jim41 Gim10 and Hag12 isolated from Ethiopian soils and reference commercial strain *Pseudomonas* introduced from India were used in this test. Insoluble sources of phosphorus tricacium phosphate (TCP), rock-phosphates (PR) and old bond meal (OB) were obtained from national soil research laboratory, Holleta research Center and Addis Ababa Abattoirs Corporation, respectively.

Fifty ml of Pikovskaya's broth (with out phosphorus source) was dispensed in 250 ml capacity of Erlenmeyer flasks and to these 250 mg of TCP.

333.3 mg of PR and 200 mg of OB were added separately to each flask. The above equivalent amount of phosphorus (50 mg each). Then, flasks were sterilised at 121^0C for 15 minutes. After cooling they were inoculated with 24hrs active culture (Containing 10^8 cells/ ml) suspensions of each PSB isolate and the remaining time in an incubator for 20 days. Four replicated flasks were used for each isolate and four uninoculated flasks were included as a control as a control.

At the end of 20^{th} day, the pH of broths were measured and were filtered through whatman filter No.1. The filtrate centrifuged at 13000 rpm for 10 minutes. Soluble phosphorus in the neat filtrate was analysed quantitatively following a method described in SubaRao (1993).

The resulting data were subjected to Analysis of Variance (ANOVA) using MSTAT4C computer software. Means were separated using least significance difference (LSD).

RESULTS AND DISCUSSION

Characterisation of phosphate soulubilisation bacterial isolates (PSB)

Preliminary, a total of 100 bacteria were isolated as phosphate solubilzating bacteria. However, most them were forming clear zones (indications of P solubilizing ability) measuring a diameter less than 2 mm after 96hrs of growth (Katenelson and Bose, 1959). Thus, only three isolates coded as Jim 41, Gim10 and hag12 isolated from Jimma, Gimbi and Hageremariam soils, respectively, were retained. IsolateJim14 formed a clear zone measuring a diameter of 3 and the other two measured a diameter 2.5 mm.

Some of the cultural, morphological and biochemical characteristics the three PSB isolates are shown in Table1. By comparing these characteristics to those described in Bergey's manual of systematic bacteriology (Krieng and Holt, 1984), attempt was made to classify them in to their respective genera. Accordingly they were all belong to *Pseudomonas* spp. Most efficient and frequently encountered PSB occur in the genera of *Bacillus* or *Pseudomonas* (SubaRao, 1993).

However, the PSB isolates were distinct species of the genus *Pseudomonas* because the PSB isolates have shown marked differences in some of the important characteristics tested. For instance, isolate Jim41 produced fluorescent pigment whereas the other two did not produce. Nitrate reduction was observed in only isolate Hag12. The test organisms have shown discrepancies in the utilisation of meso-inositol, trehalos and lactose as a sole carbon source.

Tricalcium phosphate (TCP), Rock-phosphate (PR), and old bone meal (OB) solubilisation efficiency of PSB isolates

The result of tricalcium phosphate solubilised by different bacterial isolates including the reference strain (*Pseudomonas striata*) and associated pH changes in the medium are shown in Table 2. All the test organisms solubilised significantly (P <0.01) greater amount of TCP over the inoculated control. The highest amount of solubilisation TCP was brought about by isolate Jim41 (20.88mg) of P/50ml), followed by Gim10 (18.05mg/50ml), Hag12 (15.25mg/50ml of P and *P. striata* (13.25mg of P/50ml). The result has also shown that as the solubilisation of TCP increased there was a corresponding decrease in the pH of inoculated medium.

Table 1. Some morphological and biochemical characteristics of PSB isolates

	Isolates		
Characteristics	Jim41	Gim10	Hag12
Gram reaction	-	-	-
Shape of cells	rod	rod	rod
Colour	greenish yellow	yellow	white
Spore	-	-	-
Mobility	mo	mo	mo
Flagella	po	po	po
Fluorescent pigment	+	-	-
Catalase	+	+	+
Oxidase	+	+	+
OF-test	o	o	o
MR	-	-	-
VP	-	-	-
Indole	-	-	-
Nitrate reduction	-	-	+
Growth at 4^0C	-	+	+
Utilization of			
Inositol	-	+	-
Trehalose	-	+	+
Lactose	-	-	+

Table 2. Tricalcium phsphate solubilising efficiency of PSB isolates

PSB Isolate	pH	mg of soluble P/50ml	Increase over the control*	% Solubilisation
Jim41	4.0	20.88	18.58	37.2
Gim10	4.3	18.05	15.75	31.5
Haag12	4.8	15.25	12.95	25.9
P. striata	5.0	13.25	10.95	21.9
Control	6.8	2.30	-	-
LSD (0.05)	-	4.07	-	-
CV (%)		12		

* Total soluble P release by each PSB isolate minus soluble P in the uninoculated control flask

The pattern of solubilisation of PR by the same test organisms was similar to that of TCP. All the test organisms solubilised significantly p (0.01) greater amount of PR over the uninoculated control medium (Table 3). However, the amount of soluble P released from PR was much smaller than that released from TCP. Moreover, the decrease in the PH of inoculated medium containing PR was more drastic than that containing TCP. Like in the result of TCP solubilisation efficiency test, Isolate Jim41 solubilised the highest PR followed by Gi41, Hag12 and *P. striata*. The presence of a small amount of phosphorus in the uninoculated control flask was due to the release of PO4 -3 ions during autoclaving. This is in agreement with that reported by Agnihotri (1970). As the solubilisation of tricalcium and rock-phosphate increase, there is a corresponding decrease in the pH of inoculated medium (Agnihothri, 1970; Gaur, 1987).

Table 3. Rock-phosphate solubilisation efficiency of PSB isolates

PSB Isolates	pH	mg of soluble P/50ml	Increase over the control	% Solubilisation
Jim41	3.2	6.66	6.04	12.00
Gim10	3.5	6.04	5.42	10.80
Hag12	3.5	5.48	4.84	9.6
P. striata	4.6	5.06	4.44	8.8
Control	7.2	0.62	-	-
LSD (0.05)	-	0.4	-	-
CV (%)		8.5		

In their studies Paul and SundraRao (1971) found a perfect inverse correlation with the amount of phosphate solubilised and pH of the medium inoculated with PSB cultures. The decrease in the pH of inoculated media is due to the release of organic acids (Paul, 1987). Such acids include formic acetic, propionic, lactic and succinic acids (Rao, 1982; SubaRao, 1993). In the present study, it has also been observed that the drop in the pH of inoculated media containing PR was more drastic than those containing TCP. This is due to the high insolubility of PR compared to TCP. Thus is the same PSB isolate when inoculated in a medium with PR should release more acid than when it is with TCP (Gaur, 1972).

In the case of OB, isolate Gim10, Hag12 and *P. striata* solubilised significantly P (0.01) greater amount of OB over the uninoculated control (Table 4). IsolateJim41, the most efficient in solubilising TCP and PR failed to solubilise OB. This suggest that the mechanism employed by PSB isolate in solubilising OB was different from that employed in TCP and PR. The solubilization of OB was probably due to the production of enzymes such as acid phosphates (Gaur, 1972).

Table 4. Old bonemeal solubilisation efficiency of PSB isolates

PSB isolate	pH	Mg of soluble P/50ml	Increase over the control	% Solubilisation
Jim41	7.4	3.30	0.35	0.7
Gim10	2.3	32.5	29.55	59
Hag12	3.1	29.95	27.00	54
P. striata	3.3	29.6	26.65	53
Control	6.9	2.95	-	-
LSD (0.05)	-	5.17	-	-
CV (%)		11		

In general, the percent solubilisastion by the test organisms ranged from 21.9 to 37.2 for TCP, 8.8 to 12 PR and 0.7 to 59.1 for OB. It means that the maximum amount of soluble P was brought about from OB followed by TCP and the least from PR.

CONCLUSIONS AND RECOMMENDATION

Using method developed elsewhere in the world three phosphate solubilising bacteria coded as Jim41, Gim10 and Hag12 were isolated from some Ethiopian soils. They were characterised under the genus *Pseudomonas.* It was found that all the teast organisms solubilised significantly greater amount of tricalcium and rock-phosphate. However, with old bonemeal, two isolates (Gim10 and Hag12) and *P. striata* solubilised appreciable amount with equal efficiency. On the other hand, isolate Jim41, the most efficient strain in solubilising TCP and PR, was found to be poor in solubilising OB. This implies that this isolate cannot be used as inoculant where old bone is going to be used as insoluble P fertilizer.

Based on these conclusions, it can be recommended that field inculation experiment should be conducted in different crops to see whether the PSB inoculants persist in benefiting.

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Session II. Soil Chemistry / Mineralogy / Classification

KINETICS OF PHOSPHORUS FOR SELECTED SOILS OF THE NORTH-WESTERN HIGHLANDS OF ETHIOPIA

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ABSTRACT

The kinetics of phosphorus was studied with the objective to estimate the rate of sorption along with the concentrations of applied P and incubation periods of the P in the soil. In order to determine the rate of P fixation, two soils each from low- and high-sorbing category were treated with different rates of P (50, 100, 200, 400, and 800 mg P kg^{-1} soil). The mixtures were sampled after 5, 15 and 30 days of incubation. Rate describing models and the component parts of the models (parameters) were used in estimating the kinetics of P in the soil. As a result, magnitudes of desorbed P (ln Co, intercept of the first order kinetics equation, FOKE) increased linearly with the rate of applied P and vice-versa held true for the reaction rate parameter (K_{ad} slope of the FOKE). The Freundlich affinity parameter (Log K, intercept of the model), on the other hand, increased linearly with the duration of incubation. Furthermore, losses of the original equilibrium solution P (24 hrs incubation and equilibration) was to the extreme i.e., 80-85.7% for soil 48 and soil 44, and 43-60% for soil 71 and soil 125 when the incubation period extended to 30 days. Thus, the fate of applied P on such soils will need a maximum care so as to maintain the crops' requirements for P and the economic return for the smallholders. Remedial actions in prolonging the life of available P in the soil such as time and methods of placement, selecting the fertilizer type, etc. are the most important ones. Otherwise, under the present situation, crops requiring soil-P for about a month or two in the course of their growth will suffer much from the deficiency.

Key words: kinetics, kinetic-model, incubation, phosphorus, sorption

INTRODUCTION

The concentration of P in soil solution provides useful information about P nutrition since concentration gradients are the driving force for flow of P to the roots and its uptake by roots also is concentration-dependent. As crops depend upon phosphates desorbed from the soil solid phase, knowledge of the characteristics of adsorption/desorption is of paramount importance for investigating the factors controlling utilisation of fertilizer phosphate. The most labile soil P that is the immediate source of P for crop uptake is largely influenced by the initial P-concentration, sorbing capacity of the soils and exposure time of the applied P to the adsorbing minerals (Fitter, 1974 and Barrow, 1978).

Phosphate retention by soils probably involves a complex combination of sorption and precipitation reactions. The ion is initially adsorbed physically into organic or inorganic surfaces and then slowly precipitated into less plant available forms (Ravikovitch, 1986). The situation is serious in tropical soils where soils are highly weathered and poor agricultural land management is practiced. Soils of north-western Ethiopia are tropical soils with undulating topography with problems. Soil fertility is a crop production problem and phosphorus requirement is crucial.

This work was initiated with the objective of studying the kinetics of P in the soil in relation to the P concentration gradients, sorbing capacity of the soils and effect of applied P on soil solution P levels through time.

MATERIALS AND METHODS

Study Area

The study encompassed the mid- to high altitudes (1500-3000 m asl) areas of the north-western Ethiopia. The areas have a mean annual rainfall ranging from 1200 to 1500 mm and the daily temperature from 10 to 20 ^{0}C. The soils are predominantly brown Cambisols and/or Nitosols followed by the red Nitosols and Vertisols in some valley bottoms and flat uplands. These soils are largely developed on parent materials of volcanic origin, predominantly basalt, and a few from alluvial, limestone and sandstone. Characteristic features of the soils used in the study are indicated in Table 1.

Table 1. Description of the sampling sites and the associated properties of the soils used in the study

Ref. No.	Location	Soil/land -use[1]	Altitude (m asl)	Slope (%)	pH (1:1, H_2O)	Adsorption Parameters[2] Xm	ln K	OM (%)
44	Dembecha	NS/G	2510	8.0	4.36	58.83	8.05	3.00
48	Dega-Damot	CS/C	2540	6.4	3.21	107.90	8.50	2.57
71	H.E. Enese	CS/C	1870	11.0	6.87	5.24	4.53	3.49
125	Tseda	CS/C	1990	15	5.72	5.72	5.11	3.70

Ref. No.	ex.Al (cmol/kg)	CEC (cmol/kg)	Total P (g/kg)	Av.P (mg/kg)	Texture (%) Clay	Silt	Sand
44	2.55	18.2	10.36	5.51	57.5	25.0	17.5
48	9.96	25.3	14.42	38.74	27.5	27.5	45.0
71	0.21	22.2	9.98	92.66	30.0	27.5	42.5
125	0.08	23.6	11.29	64.35	38.7	33.7	27.5

[1]NS= Nitosols, CS= Cambisols, C= Cultivated and G= Grazing

[2]Xm = adsorption maximum of the Langmuir isotherm, and ln K = adsorption energy of the Freundlich isotherm

ex Al = exchangeable aluminium, av.P = available phosphorus (Bray-II P)

Phosphorus sorption study

Four soil samples, two from the different P sorbing categories (soils adsorb >150 mg P kg^{-1} soils as high sorbing group and <150 mg P kg^{-1} soils as low sorbing group) were selected from soils indexed for their P sorption characteristics. Before conducting the incubation study, the air-dried soil samples were ground and sieved with a 2-mm mesh size. Different rates of P (50, 100, 200, 400, and 800 mg P kg^{-1} soils) in the form of KH_2PO_4 were applied to 20g of soils in petridish and incubated under field capacity moisture condition for 5, 15 and 30 days.

At the end of each incubation period, 3g soils were drawn to determine the rates of P adsorption by the soil. Following the procedures in Murphy and Riley (1962), 30 ml of 0.01 M $CaCl_2$ solution was added on the soil in a 250 ml erlymer flask, and the mixture was agitated for 24 hours on an orbital shaker and the suspensions were filtered so as to obtain a clear solution for the subsequent determination of P adsorption. The supernatant solution was measured for P concentration left unadsorbed using the Spectrophotometer apparatus. P sorbed by the soils was calculated from the difference between initially added P and that remaining in the soil.

Fitting the Kinetic Models

In order to describe the rates and trends of P adsorption along with the durations of incubation, the first order kinetic equation and the Freundlich equation were fitted on the extended data (Gracia-Rodeja, 1995; Papadopoulos et al., 1998).

The first order kinetic equation is given by:

$$C = C_o e^{-kad\,t} \quad \text{or} \quad \ln C = \ln C_o - k_{ad}\, t \qquad [1]$$

where: C (mmol P L^{-1}) is the P concentration in solution at reaction time t (days); C_o (mmol P L^{-1}) is the initial P concentration, and k_{ad} is the reaction rate coefficient per day. By plotting ln C versus t, a straight line with slope equal to k_{ad} and intercept equal to ln C_o were obtained.

The Modified Freundlich Equation, which also is proposed by Kuo and Lotse (1974) to describe P-sorption is given by:

$$X = KC_o t 1/m \quad \text{or} \quad \text{Log } X = [\text{Log } K + \text{Log } C_o] + 1/m \text{ Log } t. \qquad [2]$$

where: X (mg P kg^{-1}) is total P adsorbed by the sample at time t, K is a kinetic factor and m is a constant. Plotting the amount of P adsorbed against the reaction time on a logarithmic scale revealed a straight line. The value of 1/m was calculated from the slope of the straight line and the value of K from the intercept with y-axis.

The Freundlich isotherm, on the other hand, as used by Bhuiyan and Sedberry (1995b) in describing the rate of P adsorption along with the incubation period is given by:

$$\text{Log Ps} = \text{Log K} + \text{nLog C} \qquad [3]$$

where: Ps is sorbed P (mg P kg^{-1} soil), C is P in the soil solution (mg Pl^{-1} solution), n and K are constants. Plotting Log C against Log X, straight line is obtained with intercept, Log K and slope, n.

RESULT AND DISCUSSION

The magnitude of P remaining in the soil solution diminished a linearly as the duration of the incubation period increased. The reverse was true in the case of the increased application of P in the soil (Table 2). Unlike the soils with high sorbing capacity (soils 44 and 48), the concentration of soil solution P in soils with low sorbing capacity (71 and 125) was less affected as the duration of incubation increased.

Table 2. Mean values of phosphate concentration in soil solution (mg/l*) obtained after equilibrating the P-treated and incubated soil

Soil No.	Incubation Period (days)	P rates added (mg/kg soil) 50	100	200	400	800
		---- mg P/l solution ----				
44	5	0.018	0.027	0.069	0.105	0.166
	15	0.007	0.010	0.021	0.034	0.065
	30	0.005	0.009	0.019	0.030	0.046
48	5	0.029	0.040	0.060	0.067	0.138
	15	0.019	0.025	0.039	0.042	0.117
	30	0.012	0.015	0.023	0.033	0.064
71	5	0.116	0.315	1.460	2.879	6.318
	15	0.053	0.149	0.633	2.240	5.129
	30	0.043	0.113	0.429	2.164	5.050
125	5	0.129	0.221	0.624	2.666	4.607
	15	0.100	0.116	0.259	0.943	3.038
	30	0.070	0.102	0.197	0.813	2.853

*SE (±) = 0.0521 and CV (%) = 11.20

Parameters of the Kinetic Models

The parameters of the linear regression model (slope = k_{ad} and intercept = ln Co) and the coefficient of determination (r^2) of the first order kinetic equation (FOKE) at the various rates of applied P are presented in Table 3. To illustrate the linear relationship between soil solution P and the incubation period (days), the natural Log of P in the soil solution (ln C) was plotted against the incubation period. In most cases, the relationship between soil solution P concentration and the duration of incubation along with the rate of applied P was significant ($r^2 \geq 0.8$; $P \leq 0.01$).

Table 3. Intercept, slope and r^2 of the linear regression equations in the First Order Kinetic Equation (FOKE) between solution P and incubation periods (days) along the different rates of applied P

Applied P	Soil reference no. and their isotherm parameters											
	44			48			71			125		
mg/kg	lnC_0	k_{ad}	r^2	lnC_0	k_{ad}	r^2	lnC_0	k_{ad}	r^2	lnC_0	k_{ad}	r^2
50	-3.48	0.640	0.929	-3.09	0.441	1.000	-1.98	0.393	0.561	-1.73	0.305	0.990
100	-3.2 0	0.549	0.821	-2.72	0.490	1.000	-0.72	0.513	0.933	-1.21	0.387	0.870
200	-3.08	0.320	0.865	-2.31	0.481	0.996	0.92	0.612	0.958	0.00	0.576	0.916
400	-2.35	0.416	0.861	-2.39	0.354	0.966	1.16	0.143	0.837	1.43	0.594	0.843
800	-1.25	0.641	0.966	-1.11	0.539	0.996	1.92	0.112	0.941	1.71	0.240	0.846

Trends of the slopes (values of the reaction parameter) along with the rates of applied P were in decreasing order and this is consistent with the findings by Papadopoulos et al. (1998). Since k_{ad} is obtained from the slope of the regression model, values near to zero are towards lower reaction rates, therefore; the k_{ad} values (Table 3) show declining reaction rates with the subsequent increment of applied P in the soil.

In addition, the first order kinetics equation (FOKE) was effective enough in differentiating the adsorption parameters along with the soil's sorption capacity as well as the rates of applied P. The rate determining parameter, K_{ad} (reaction rate per day), showed little or no changes with the rates of applied P in soils 44 and 48. On the contrary, this situation showed a general declining trend in soils with low P-sorption capacity (71 and 125). The initial P-desorption (ln Co) values, as intercept of the model, remained low for the two high sorbing soils, but got larger with increasing rates of applied P in soils with low sorption capacity (when the estimates of lnCo in Table 3 understood from its anti-log). The difference between the two categories of soils might be because soils with high P-sorption capacity were less satisfied for their adsorbing sites than soils with low P-sorption capacity that were releasing P into the soil solution. The present results are consistent with earlier reports of Bhuiyan and Sedberry (1995b) and Papadopoulos et al. (1998).

In accordance with the underlined assumption of the FOKE which states that "rate of change in concentration is proportional either to the concentration of the solution or to the number of empty sites" (Griffin and Jurinsk, 1974). Thus, the K_{ad} values in the present study were changed with the changes of P-concentration and adsorption capacity of the soils. Consequently, soils with low P-sorption capacity (71 and 125) showed a subsequent decline on its reaction rate parameter (k_{ad}) along with P-concentration than soils of high sorption capacity (44 and 48) that remain unaffected with the ranges of applied P, rather.

Parameters of the modified Freundlich equation (MFE) were estimated by plotting the sorbed P against incubation periods in a logarithmic scale (Table 4). The kinetic parameter, K (days$^{-1/m}$), showed a linear increment with P-concentration in the soils. However, this increment was in contradiction with the assumption of the model that "rate of reaction should be lower with the subsequent increment of P-concentration in the soils" (Papadopoulos et al., 1998).

Table 4. Estimates of the slope, intercepts and the coefficient of determination (r^2) in the Modified Freundlich Equation (MFE) for soils studied in different rates of applied P and incubation times

Applied P	Soil reference No. and the isotherm parameters											
	44			48			71			125		
(mg/kg)	1/m	K	r^2	1/m	K	r^2	1/m	K	r^2	1/m	K	r^2
50	0.003	1.70	0.984	0.003	1.69	0.984	0.007	1.68	0.728	0.006	1.68	0.941
100	0.001	2.00	0.986	0.001	2.00	0.852	0.012	2.00	0.968	0.008	1.98	0.945
200	0.001	2.30	0.852	0.001	2.30	0.630	0.032	2.25	0.962	0.013	2.28	0.958
400	0.001	2.60	0.852	0.001	2.60	0.852	0.011	2.58	0.924	0.028	2.55	0.882
800	0.001	2.90	0.852	0.001	2.90	0.630	0.011	2.86	0.924	0.013	2.87	0.912

It is obvious that fitting equations requires a series of testing data on various related models and choosing the "best" equation that can provide "best" values for the parameters under consideration (Barrow, 1978). The equation parameters in the Freundlich isotherm, as indicated in Table 5, were better in describing the relationship between sorbed P and soil solution P at the different incubation periods and sorption capacity of the soils.

Table 5. Intercept, coefficient and r^2 estimates of the linear regression equations for the Freundlich isotherm ($\log S = \text{Log } K + n \text{ Log } C$) between sorbed P and solution P at different incubation time

Soil	Incubation period and equation parameters								
	5 days			15 days			30 days		
No.	Log K	n	r^2	Log K	n	r^2	Log K	n	r^2
44	3.972	1.244	0.960	4.295	1.180	0.990	4.457	1.211	0.990
48	4.529	1.803	0.958	4.436	1.516	0.912	4.808	1.562	0.970
71	2.280	0.655	0.980	2.432	0.548	0.994	2.449	0.549	0.986
125	2.371	0.681	0.976	2.570	0.695	0.941	2.630	0.682	0.955

The values of the coefficient of determination for all soils were higher ($r^2 > 0.90$) which indicate the existence of linear relationships between sorbed P and soil solution P levels (quantity/intensity factors). With a subsequent increment of incubation periods, the rate of changes in the affinity of the adsorbates (Log K) was larger. The model, can thus be used to quantify the amount of P sorbed by a soil in order to maintain a desired level of P in the soil solution and also in predicting the soil solution P at different soil-P contact time and rates of P application. According to Kuo and Lotse (1974) and Barrow (1978 and 1979), the Freundlich isotherm is known to describe P-sorption characteristics of soils over a limited range of P concentrations and phosphorus-deficient soils. At the same time, the Freundlich isotherm is capable enough in describing the relationship between the quantity and intensity factors at a given duration of incubation.

Trends of sorption curves

The changes of the sorption curves for soils with high P-sorption capacity in relation to the duration of incubation are indicated on Figure 1. The standard P requirement (SPR) of soils 44 and 48, to meet a 0.2 mg Pl^{-1} of solution were increasing with increasing duration of incubation from 5 to 30 days. The slope differences between the sorption curves, which are indications for deviation of the sorption curves through time (an hysteresis effect), were almost parallel to the x-axis for the initial incubation periods (within five days), whereas these were changes subsequently as the duration of incubation advanced to 15 days and onward. In soils with low sorption capacity (soils 71 and 125), the equilibrium state between sorption and desorption were reached when the soils incubated to about 15 days (Fig. 2).

The changes of sorption curves for incubated soils are in agreement with results of earlier reports (Rajan and Fox, 1972; Barrow and Shaw, 1975a; Barrow, 1983a; Dimirkou et al., 1993). Reaction between P and adsorption sites is quick at first, and becomes slower and continues for a long period without reaching true equilibrium.

Relying on sorption curves drawn from data obtained after a short period of equilibration as an indication of effective P management is a controversial issue while the longevity of the isotherm is inconsistent. This is because the SPC levels that were obtained in the one-day equilibration time do not necessarily remain constant during the whole contact time and the soil solution P (intensity factor) depend on the adsorbed P (capacity factor) or the P buffering capacity of the soils (Fox, 1981). On the other hand, high-adsorption capacity soils have been reported by Dear et al. (1992) and Gracia-Rodeja (1995) as failing to sustain the adsorption/desorption equilibrium obtained from the initial equilibration if the applied P was maintained for a longer period of time.

The changes of phosphates in soil solution, in relation to the incubation time, are given on Figure 3. The change of the applied P concentration was to the extreme in soils with high P-sorption capacity (Fig. 3a). These soils could not reach a state of equilibrium within the incubation period (5-30 days). Fast initial sorption (within five days) followed by a steady state (5-15 days) and a near stable equilibrium (after 15 days) were observed in soils with low P-sorption capacity (Fig. 3b). The results are consistent with the findings reported by Barrow and Shaw (1975 a and b).

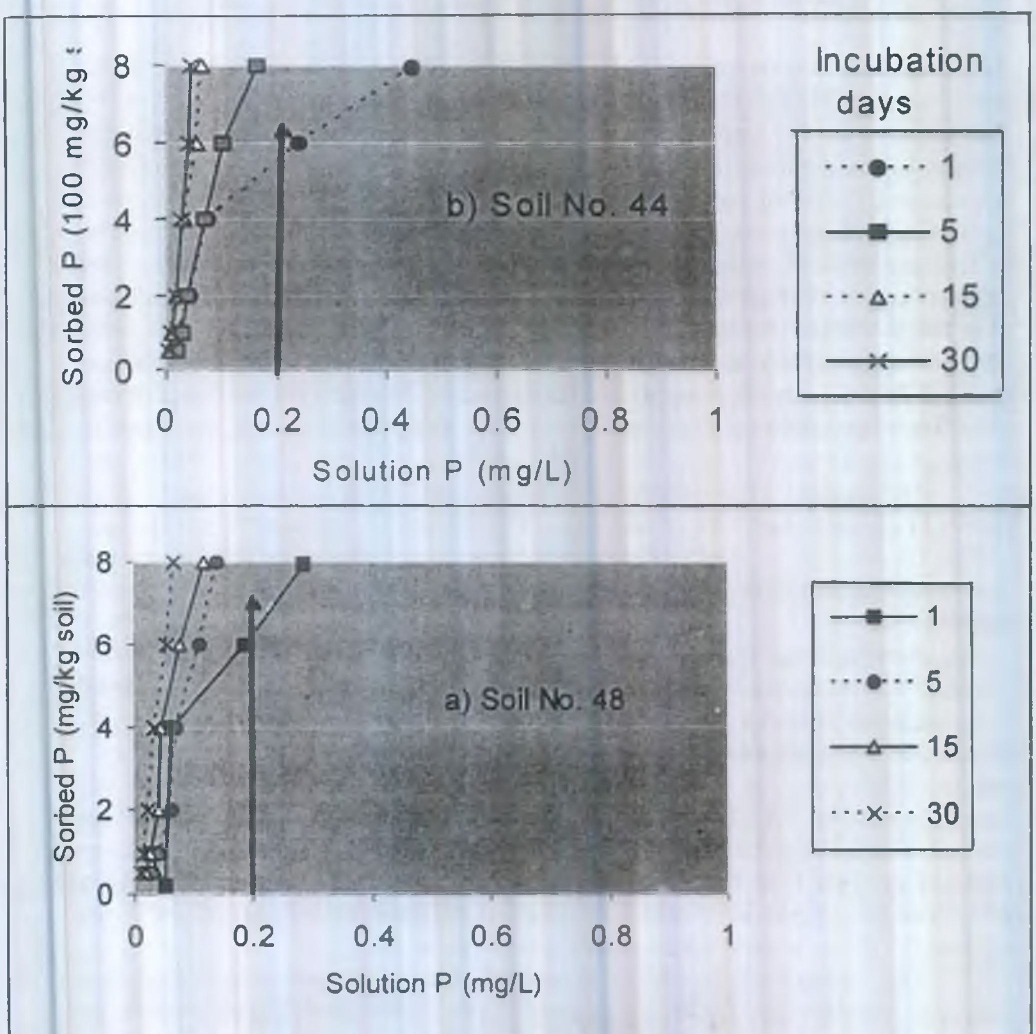

Figure 1. Isotherm curves of the high sorbing soils under different incubation periods; vertical arrows are indicating the increment of P requirement of the soils along the incubation periods

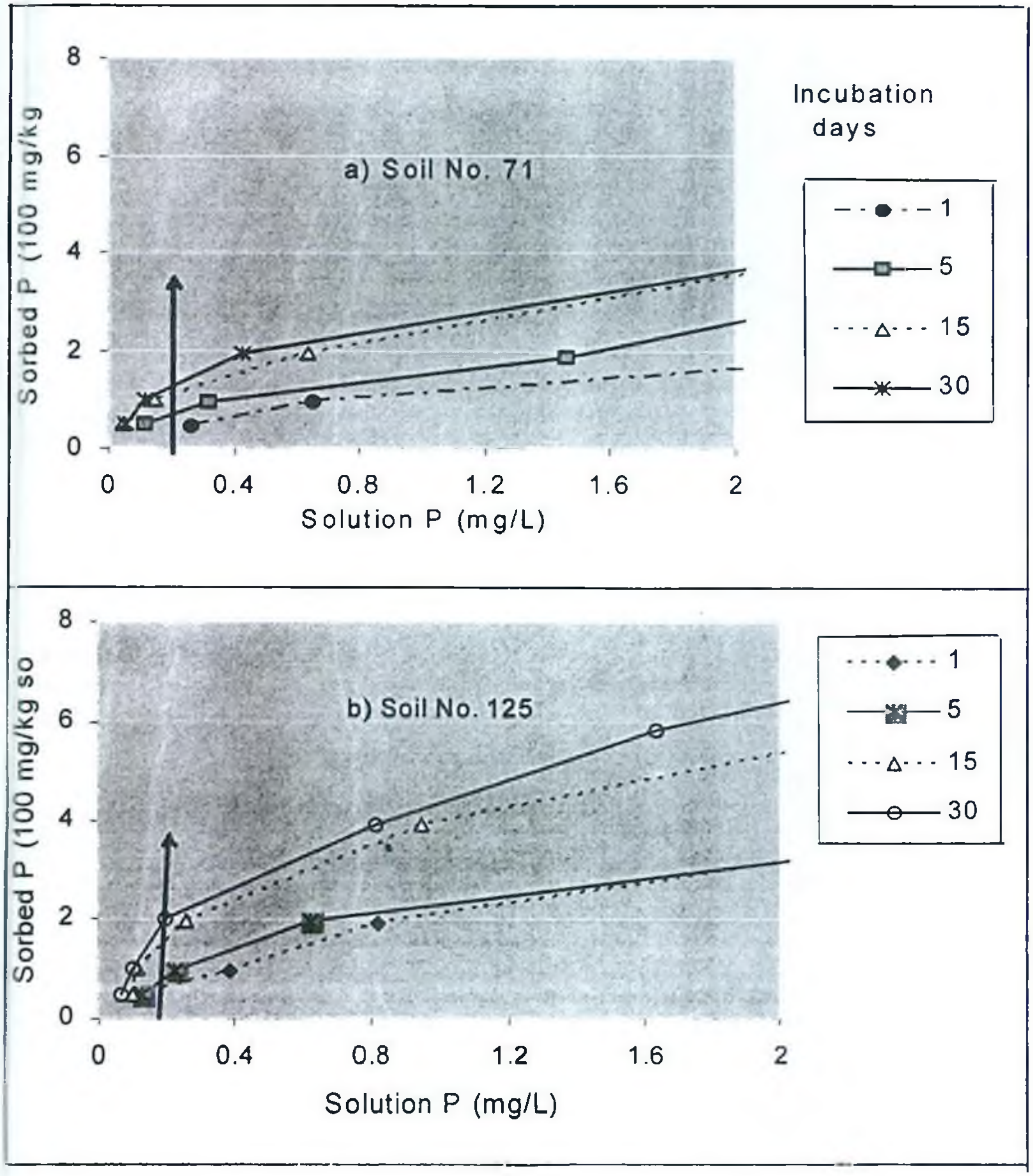

Figure 2. Isotherm curves of the low sorbing soils under different incubation periods; vertical arrows are indicating the increment of P requirement of the soils along the incubation periods

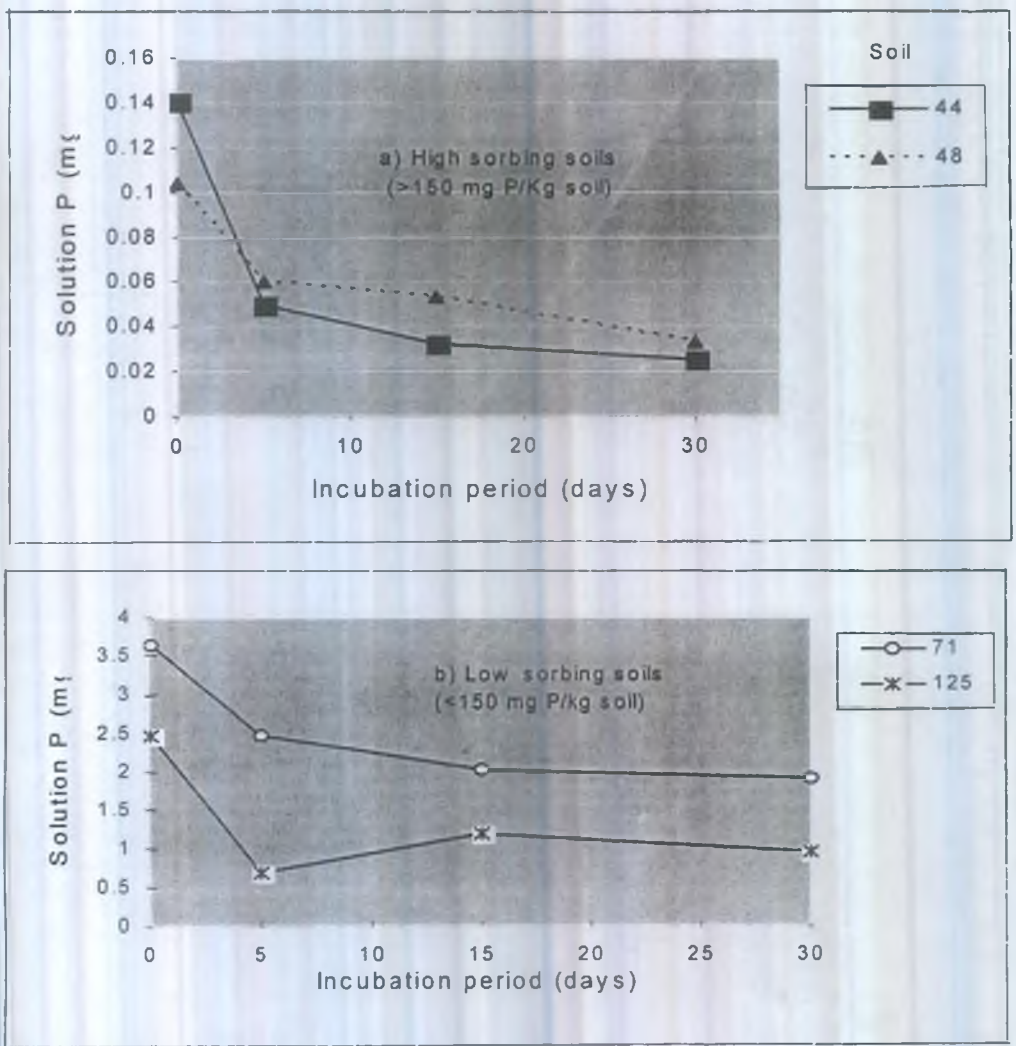

Figure 3. Change of phosphate in soil solution along incubation period for soils with high and low P-sorption capacity

The losses of soil solution P concentration due to fixation within the incubation period (5-30 days), therefore, were about 85.7, 80.0, 42.9 and 60.0% of the equilibrium P concentration that were obtained after a 24 hours equilibration for soils 44, 48, 71 and 125, respectively. The wide variations of P adsorption among the soils is in agreement with the assumption of the first order kinetic equation (Griffin and Jurinsak, 1974) in which "the change in soil solution P due to adsorption is proportional to the number of empty sites" or it depends on the adsorbing capacity of the soils.

Generally, irrespective of sorption capacity the soils, the longer the time that the soil and the fertilizer P remained in contact under moist condition, the larger quantity of P migrated from the solution to the adsorbing sites. If the process of chemisorption is dominant under this situation, the availability of applied P to growing crops may be much more diminished.

CONCLUSIONS

In general, the sorption/desorption reactions of P in the soil decreased as the applied P increased and increased with the duration of incubation. The kinetics of P also was influenced by the adsortion capacity of the soils. Similarly, deviations of the isotherm curves from the x-axis along with duration of incubation were larger for soils with higher sorption capacity than soils with low sorption capacity. In addition, the trends of fast initial immobilisation of P (within five days) followed by a steady state was exhibited in soils with high sorption capacity, whereas it was in a steady state for about 15 days and then followed by a nearly equilibrium state for soils with low sorption capacity. As a result of prolonging contact time between applied P and the soils there was deviation of the obtained equilibrium due to P-fixation. Phosphorus fixation was extreme for soils 44 (85.7%) and 48 (80.0%) than for soils 71 (42.9%) and 125 (60.0%). Obviously, unless the soil P buffering capacity outweighs the process of chemisorption and precipitation reactions, the fast initial immobilisation of soil solution P will seriously unbalance the standard P concentrations (SPC) required in the soil for various crops; thereby crops will suffer much from P deficiency.

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BEDROCK MINERALOGY VERSUS SOIL TOTAL ARSENIC, SPECIATION AND PLANT AVAILABILITY

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ABSTRACT

The total arsenic content of a soil collected from Gasen (a village in SE Austria) was determined by using a Graphite Furnace Atomic Absorption Spectrometer (GF-AAS). The level determined was about 3000 mg kg^{-1} which was extremely high. Scanning-Electron-Microprobe (SEM) analyses on underlying bedrocks confirmed that arsenic in the soil is of geogenic origin and arsenopyrite is the main mineral from which it is derived. Various other sulfide minerals were also observed to exist in contact with arsenopyrite among which pyrite and chalcopyrite are the predominant. Cyclic voltametric investigations of the Modified Carbon Paste Electrodes of pyrite and chalcopyrite indicated that, the co-existence of these minerals with arsenopyrite enhances the extent of its chemical weathering. Although such a high level of arsenic was known to exist in the soil, its phyto-availablity remained comparably low. The mean value of arsenic concentration in the above-ground organs of the mixture of grasses grown on the soil was 1.7 mg kg^{-1}, which is very low relative to the high arsenic level. Results obtained from a sequential leach study revealed that the fraction of arsenic bound to the water-soluble and exchangeable phases, account for only about 0.5% of the total and the low level of arsenic in the grass mixture is partly attributed to the low level of arsenic in these phases.

INTRODUCTION

Arsenic, although known to be essential for life in small amounts (NAS, 1977), becomes toxic for plants, animals and humans when ingested in large amounts (NAS, 1977; Scott et al., 1995; Tang and Miller, 1991; Galbraith, 1995; Carbonell-Barrachina et al., 1998). Arsenic has been recognised through the years for the toxic properties of some of its compounds. The word 'arsenic' has become synonymous with 'poison'. It affects the skin, and in its most severe form causes skin cancer (Polmear, 1998). During its circulation in the environment, arsenic can reach into the human body via plant uptake from soils, by drinking arsenic contaminated surface or ground water, by dermal contact and by inhalation (Ng et al., 1998).

Arsenic in soils originates either from the weathering of underlying parent material or from anthropogenic sources such as mining activities, use of arsenical pesticides, application of fertilizers, irrigation, dust from the burning of fossil fuels, and disposal of industrial and animal waste. A wide range of arsenic content, with an average of 5-6 mg kg^{-1}, has been reported for soils that contain arsenic at concentrations that are reflective of the parent rock material from which they were formed. In the native state arsenic exists as the sulfide ores: orpiment (As_2S_3) and realgar (AsS), or the arsenides or sulfarsenides of heavy metals, especially arsenopyrite (FeAsS). The arsenic levels in soil enriched in these ores are often higher than in normal soil (Yan-Chu, 1994).

Arsenic is a characteristic element in Austrian soils (Tahlmann et al., 1989). Even though typical amounts of arsenic in natural uncontaminated soils varied from 5 to 6 mg kg^{-1} (Bhumbla and Keefer, 1994), certain soils of the low-lying parts of the country contain higher concentrations. At Gasen (a rural area located in SE Austria) the level of arsenic in the soil is found to be exceptionally high, about 3000 mg kg^{-1}. In spite of such a high level, no toxic symptom due to arsenic is observed on plants, animals or people living in the surrounding. This paper reports results of studies carried out to understand the origin of such a high level of arsenic in the soil, its phyto-availability and form of binding in the soil.

MATERIALS AND METHODS

Sampling

The random and grid sampling techniques were respectively used for the collection of soil and plant samples.

SEM analysis

Minerals in underlying bedrocks were identified using a combination of reflected light microscopy and SEM analysis. The analysis was carried out on a JEOL-6310 SEM with an attached link energy dispersive system (EDX) and a microspec wavelength dispersive system (WDS) using 20 kV accelerating voltage and counting time of 100 sec calibrated on cobalt.

Mineralisation and arsenic determination

Soil samples were air-dried and allowed to pass through a 2-mm sieve. Arsenopyrite, pyrite and chalcopyrite minerals were pulverised in a ball-mill. Accurately weighed 0.5 g aliquot of the soil or mineral sample was transferred to a high-pressure Tetrafluormethaxil (TFM) microwave digestion vessel and mineralised by using a mixture of, 4.0 ml of sub-boiling distilled HNO_3, 1.0 ml

30% (w/w) H_2O_2, and 2.0 ml 40% (w/w) HF in a microwave-heated closed-vessel digestion apparatus. The time-power heating programme applied is given in Table 1.

Table 1. Microwave-heated closed-vessel heating program used for the mineralization of soil and mineral samples

Step	1	2	3	4	5	6	7	8	9
Power (Watt)	250	0	250	0	450	0	600	500	vent
Time (min)	2	0.5	10	0.5	5	0.5	7	7	2

Plant samples were rinsed with Milli Q+ water, freeze dried and milled in an Ultra-Centrifugal mill. Accurately weighed 0.2 g portions of the processed plant samples were mineralised in a microwave-heated closed-vessel digestion apparatus by using 3.0 ml sub-boiling distilled HNO_3 and 0.5 ml, 9.8 *M* H_2O_2. The time-power heating programme applied is given in Table 2.

Table 2. Microwave-heated closed-vessel heating program used for plant mineralization

Step	1	2	3	4	5	6	7	8	9
Power (Watt)	250	0	300	0	400	0	500	600	vent
Time (min)	2	0.5	5	0.5	10	0.5	5	4	2

Total arsenic in all samples was determined from appropriately diluted solutions of their respective digests by using a GF-AAS.

Weathering

Informations on the electrochemical weathering behaviors of arsenopyrite (FeAsS), pyrite (FeS_2) and chalcopyrite ($CuFeS_2$), and the influence of the co-existence of pyrite and chalcopyrite on the release of arsenic from arsenopyrite were acquired from cyclic-voltametric investigations carried out in ranges of potentials commonly encountered in soils on a Modified-Carbon-Paste-Electrode of each mineral and by determining the arsenic levels in the leachates of various combinations of pyrite and chalcopyrite with arsenopyrite.

Sequential leach speciation

The concentration of arsenic in the various fractions of the soil: water soluble, exchangeable, bound to carbonates, amorphous and crystalline Fe-oxide, organics and sulfides, silicates and residual oxides was determined by using the schemes developed by Tessier et al. (1979) and Hall et al. (1996).

RESULTS AND DISCUSSION

Scanning Electron Microprobe (SEM) studies revealed that Arsenopyrite (FeAsS) is the most common mineral in the study area and is the main source for the soil arsenic. It occurs as a few centimeter long prismatic crystals often in paragenesis with pyrite. The arsenopyrite and pyrite structures are fractured and breciated due to tectonic movements. The fractures are filled by other sulfide minerals among which chalcopyrite ($CuFeS_2$) is dominant. A representative image of the SEM analyses showing the association of arsenopyrite with pyrite and chalcopyrite is given in Figure 1.

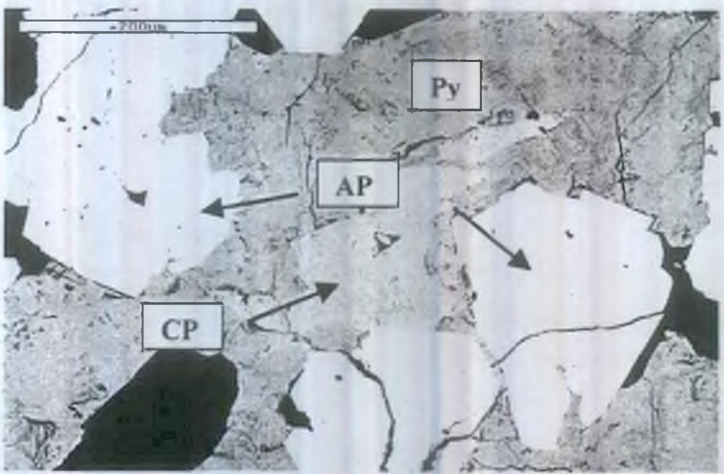

Figure 1. SEM image of arsenopyrite showing its association with pyrite and chalcopyrite. Pyrite (Py), Chalcopyrite (Cp), Arsenopyrite (Ap).

From the electrochemical and leach experiments, it seems that the release of arsenic from arsenopyrite seems to be highly influenced by the co-existence of other sulfide minerals in contact with arsenopyrite. Cyclic voltametric investigations of the minerals in the moderately acidic to moderately alkaline pH range and in the range of potentials usually encountered in soils revealed that chalcopyrite undergoes oxidation at a lower potential than arsenopyrite and pyrite to produces Cu^{2-}, Fe^{2-}, Fe^{3-}, S, SO_4^{2-} and various other oxidised forms.

Arsenopyrite on the other hand undergoes oxidation at a lower potential than pyrite to form Fe^{2+}, Fe^{3+} (or their hydroxides), $H_2AsO_4^-$, $HAsO_4^{2-}$, and SO_4^{2-}. Pyrite gets oxidised at a higher potential than chalcopyrite and arsenopyrite to form Fe^{2+} Fe^{3+}, S, and SO_4^{2-}. Pyrite, being the most noble sulfide mineral, can influence the oxidation of arsenopyrite and chalcopyrite through galvanic coupling. Pyrite may act as the cathode and enhance the oxidation of arsenopyrite and chalcopyrite. Chalcopyrite on the other hand influences the weathering of arsenopyrite through its oxidation products. After the initial oxidation of chalcopyrite the earliest-formed free sulfuric acid and sulfates such as $FeSO_4$, $Fe_2(SO_4)_3$ and $CuSO_4$ exert more strong oxidising effects on arsenopyrite, thus accelerating its oxidation.

Table 3 shows the level of arsenic released from one-week incubated pure arsenopyrite and arsenopyrite-pyrite or arsenopyrite-chalcopyrite mixtures. The level of arsenic in 0.5 g, 1.0 g and 1.5 g pure arsenopyrite leachates was nearly the same (about 7 mg kg^{-1}). This level was observed to increase in the leachates of the arsenopyrite-pyrite and arsenopyrite-chalcopyrite mixtures even when the quantity of arsenopyrite in the mixture is less than the pure one. The negligible amount of arsenic, existing as an impurity, in pyrite (270±5 mg kg^{-1}) and chalcopyrite (265±3 mg kg^{-1}) as compared to the concentration in arsenopyrite (370900±265 mg kg^{-1}) indicates that the quantity of arsenic contributed from the dissolution of pyrite in the arsenopyrite-pyrite or from the dissolution of chalcopyrite in the arsenopyrite-chalcopyrite mixture leachate is also negligible and nearly all the arsenic is derived from arsenopyrite dissolution.

Table 3. Concentration of arsenic in the leachates of arsenopyrite (AP) mixed with various levels of pyrite (PR) and chalcopyrite (CP)

Quantity of PR and CP mixed with AP	Conc. of As in the leachates of arsenopyrite (mg/kg)		
	0.5 g AP	1.0 g AP	1.5 g AP
Pure AP	6.75±0.02	6.73±0.03	6.74±0.06
0.5 g PR	10.12±0.03	9.95±0.07	9.22±0.01
1.0 g PR	14.43±0.01	10.23±0.03	10.03±0.01
1.5 g PR	16.73±0.02	15.86±0.04	11.30±0.05
0.5 g CP	7.37±0.05	7.02±0.03	6.89±0.02
1.0 g CP	8.75±0.03	8.14±0.03	7.67±0.05
1.5 g CP	11.31±0.01	10.05±0.01	8.23±0.02

This indicates that chalcopyrite and pyrite, when exist in contact with arsenopyrite, are able to enhance its dissolution and thus the release of arsenic into the soil. The higher dissolution of arsenopyrite in presence of pyrite and chalcopyrite could be an electrochemical corrosion process in which dissolved species such as Fe^{3+} and Cu^{2+} get reduced at the arsenopyrite surface behaving as an anode and arsenopyrite as the cathode. In spite of the considerably high arsenic level in the soil, its phyto-availablity remained comparably low. The mean value of arsenic concentration in the above-ground organs of the grass mixtures was 1.7 mg kg^{-1}. The highest concentrations measured were in the 3 mg kg^{-1} range (terrestrial plants growing at uncontaminated sites usually contain < 0.2 mg kg^{-1} arsenic, Cullen and Reimer, 1989); where this accounted for 9% of the overall determinations. Although some plants are tolerant to higher concentrations of arsenic in the soil, normally many plants show growth disturbances if the arsenic concentration in the soil exceeds 2 mg kg^{-1}.

Total arsenic concentration in samples of four predominantly abundant plant species in the pasture was determined to see if there is species-specific accumulation or not. However, observed differences were not dramatic; *Anthoxantum odoratum*, 4 mg kg^{-1}; *Dactylis glomerata*, 1.6 mg kg^{-1}; *Plantago lanceolata*, 5.9 mg kg^{-1}; *Taraxacum officinale*, 0.5 mg kg^{-1}.

Results of the sequential leach speciation experiment indicated that the concentration of arsenic in the water soluble and exchangeable fractions of the soil (which are generally considered to be the most mobile and immediately bioavailable forms) account for only about 0.5% of the total arsenic. The rest of the arsenic exists in the recalcitrant fractions. This could be a reason for the less phyto-availability of arsenic in the Gasen soil. Since arsenic phyto-availability is a result of a number of soil properties and plant species, it cannot be attributed to a single factor. The low level or arsenic in the labile fractions can not be taken as the sole factor for the less phyto-availability of arsenic in the area.

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EFFECTS OF STRAW MANAGEMENT, TILLAGE AND CROPPING SEQUENCE ON SOIL CHEMICAL PROPERTIES IN THE SOUTH-EASTERN HIGHLANDS OF ETHIOPIA

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ABSTRACT

Four multi-factor crop management trials were initiated during 1992 in the south-eastern highlands of Ethiopia. Two of the trials were based on mechanised tillage, while two trials were based on the traditional ox-plow of Ethiopia. The long-term trials examined the effects of alternative practices for crop residue management, tillage and cropping sequence on soil chemical properties. Retention of straw on the soil surface increased the important plant nutrients in the upper layer (i.e., 0-15 cm) of the soil as compared to burning and partial removal of straw. Zero or minimum tillage practices also increased the concentration of some important plant nutrients like phosphorus and potassium in the upper layer of the soil in both system trials. Cropping sequence had little effect on soil chemical properties. Soil organic matter levels were, markedly decreased by stubble burning and by conventional tillage.

INTRODUCTION

Soil chemical properties can have a critical impact on crop production. In order to attain crop production goals, it is important to maintain an optimal soil environment. Integrated crop management practices may be the most effective means of achieving this goal. Crop residue maintenance, reduced or conservation tillage, and crop rotation are among the crop management practices that can play a significant role in optimising soil chemical properties (Aulakh and Gill, 1988; Stobbe, 1990; Sweeney and Moyer, 1995). Conservation tillage practices generally retain most of the residue from previous crops on the soil surface by minimising mechanical manipulation and mixing of the soil. Reduced soil mixing combined with the retention of crop residues on the surface can markedly change soil chemical properties in the soil profile over time (Blevins et al., 1983b; Griffith et al., 1988).

Retention of crop residues on the soil surface may help to conserve soil organic matter and moisture, especially when coupled with conservation tillage (Griffith et al., 1986). In addition, retention of crop residue on the soil surface has been shown to increase total nitrogen (N) in the top 15 cm of soil (Rasmussen and Collins, 1991): these authors attributed the higher level of N in the surface soil layer to a slower rate of residue decomposition. Straw orientation may be an important factor as decomposition is hastened when the straw is flattened and placed in contact with the soil (Bulman and Stobbe, 1994). Maintenance of a crop residue cover can also reduce soil erosion due to rain-drop impact (Aulakh and Gill, 1988). Raindrops can be trapped more effectively with a cover of retained stubble as opposed to a bare soil surface.

Stubble burning is controversial, and its demerits are considered to outweigh its merits due to undesirable changes in soil chemical properties over the long-term (Rasmussen and Rohde, 1988). However, stubble burning can result in a short-term yield advantage by reducing the incidence of root diseases and the density of weed seeds in the soil (Rasmussen et al., 1986).

Tillage practices can affect various soil chemical properties, including organic matter (OM), nitrate (NO^-_3), and ammonium (NH^+_4) content. As the degree of tillage disturbance increases, deterioration of soil structure and increased erosion become more pronounced. Conservation tillage practices can reduce such deleterious soil effects (Stobbe, 1990). Reduced tillage can increase soil moisture and OM in the surface layer of the soil, and enhance water infiltration (Kamwaga, 1990): this author indicated that 50% straw retention increased soil moisture content. However, others have reported that conventional tillage increased rainfall infiltration, soil aeration and soil temperature under specific environmental and edaphic conditions (Throckmorton, 1986).

Soil chemical properties can be modified by specific cropping systems. Several long-term studies have demonstrated the beneficial effects of crop rotation, especially with the inclusion of legumes (Odell et al., 1984; Johnston, 1986). These studies generally revealed that crop rotations including legumes increased soil organic C and N after several years of cropping even without manure or fertiliser N input, and contrasted markedly with continuous cereal sequences. The contribution of legumes to soil OM, NO^-_3 and NH^+_4 content has considerable practical significance for small-scale agriculture in Africa.

In Ethiopia, soil properties have not been studied in relation to the long-term effects of stubble management, tillage practice and cropping sequence. Thus, this study was initiated to examine the effects of integrated crop management systems on soil chemical properties in the south-eastern highlands of Ethiopia.

MATERIALS AND METHODS

Experimental sites

Four crop management trials were initiated during 1992 at the Kulumsa (8°02'N and 39°10'E) and Asasa (7°08'N and 39°13'E) research stations located in the south-eastern highlands of Ethiopia at altitudes of 2200 and 2360 m a.s.l., respectively. During the main crop growing season (i.e., June to November), long-term mean monthly minimum and maximum temperatures are 10.6 and 22.1 °C at Kulumsa and 6.7 and 22.7 °C at Asasa; mean precipitation during the main cropping season is 504 mm at Kulumsa and 472 mm at Asasa. Kulumsa is located on a clay soil (an intergrade between a eutric

Nitisol and a luvic Phaoezem). The Asasa soil is a clay loam (calcic Chernozem).

Trial design

Two trials were located at each site: one mechanised and one ox-plow trial were located at each of Kulumsa and Asasa.

The mechanised trial consisted of 12 treatments comprising the complete factorial combination of: (a) three levels of post-harvest straw management (SM) i.e. straw burning, partial straw removal (50%), and complete retention of straw; (b) two levels of tillage i.e. zero tillage (ZT) and conventional tillage (CT) at Kulumsa, and minimum tillage (MT) and CT at Asasa, and; (c) two levels of cropping sequence (CS) i.e. continuous wheat and one year of faba bean (*Vicia faba*) followed by two years of wheat.

The ox-plow trial consisted of eight treatments comprising the complete factorial combination of: (a) two levels of post-harvest SM i.e. straw burning and partial removal (50%); (b) two levels of tillage i.e. MT and CT, and; (c) two levels of CS i.e. continuous wheat and one year of faba bean followed by two years of wheat.

For each trial, all treatments were laid out in a split-split-plot arrangement in a randomised completed block design with three replications. SM treatments were initiated in main plots of 20 x 20 m, tillage in sub-plots of 10 x 20 m, and CS in sub-sub-plots of 5 x 20 m in 1992. All treatments were applied to permanent plots maintained over the trial duration.

Crop management practices

In the mechanised trials, conventional tillage consisted of one pass with a tractor-drawn disc plow followed by two passes with a disc harrow during the "short rains" fallow period in order to maximise weed control. At Kulumsa, a tractor-drawn "Aitchison Seedmatic 3000" zero-till drill was used to sow seed plus basal fertiliser for the conventional tillage and ZT treatments. However, in the mechanised trial at Asasa, one pass with a disk harrow was used to incorporate broadcast seed and fertiliser for the MT and conventional tillage treatments.

In the ox-plow trials, conventional tillage consisted of four plowings prior to sowing (i.e., similar to farmers' practice) while, for MT, one pass was done to incorporate the broadcast seed and fertiliser.

For the MT and ZT treatments, chemical fallow was substituted for tillage during the "short rains" period each year: glyphosate was applied at 720 g active ingredient (a.i.) ha^{-1} as required during the "short rains" season to prevent weeds from attaining a height of 20 cm with a maximum of two applications per season.

Partial straw removal simulated grazing by removing 50% of post-harvest crop stubble. Thus, approximately 500 kg ha^{-1} of stubble remained on the soil surface at sowing time. Straw burning was carried out during late January each year before the "short rains" began. Plots with complete straw retention were left undisturbed until spraying or tillage operations began; more than 2 t ha^{-1} of stubble remained on the soil surface at sowing time.

Zone-specific recommended levels for the non-experimental crop management factors were adopted for bread wheat and faba bean during the trial period. Over the trial period (1992 to 2000), sowing dates ranged from June 11 to 19 at Asasa and from June 26 to July 7 at Kulumsa. As per the initial trial plan, the best recommended crop cultivars were utilised each season. This was particularly important for bread wheat since some cultivars succumbed to new races of foliar rust (*Puccinia* spp.) pathogens during the course of the trial. Thus, over the trial duration, the bread wheat cultivars Enkoy (1992-93), Mitike (1994), and Qubsa (1995-2000) were sown using a seed rate of 150 kg ha^{-1}. From 1992 to 94, bread wheat received a basal N application of 41 kg ha^{-1} at Kulumsa and 18 kg ha^{-1} at Asasa. From 1995 to 2000, newly-recommended fertiliser rates were implemented, and bread wheat received a basal N application of 82 kg ha^{-1} at Kulumsa and 41 kg ha^{-1} at Asasa. During 1992, 1995 and 1998, faba bean cultivar CS20DK was sown using a seed rate of 200 kg ha^{-1}; for faba bean, basal N was applied at the rate of 18 kg ha^{-1} at both Kulumsa and Asasa. Both crops received a basal application of 20 kg P ha^{-1} each year. Due to the risk of damage by spray drift, hand weeding was used to control weeds during 1992, 1995 and 1998 when both wheat and faba bean were sown. During 1993, 1994, 1996, 1997, 1999 and 2000, when all plots were sown to wheat, weed control entailed a post-emergence spray application of a tank mix of fenoxaprop-P-ethyl + fluroxypyr + MCPA at 0.069 + 0.175 + 1.0 kg a.i. ha^{-1}, respectively.

Agronomic data

Data on crop parameters were collected from sub-sub-plots throughout the cropping season, including seedling density, seedling biomass, crop heading, flowering dates and maturity dates, plant height, and spikes m^{-2}. At crop maturity, a 9 m^2 area was harvested by sickle from each sub-sub-plot for the determination of crop grain and biomass yield, harvest index, thousand grain weight and percent grain moisture.

Soil chemical properties

To determine the effects of treatments on soil chemical properties, soil samples were taken prior to planting and post harvest of wheat in 1996, 1997, 1998 and 1999 from Kulumsa and Asasa for organic matter content (0-5 cm) and pre-planting for NO_3^-, NH_4^+, pH and P at three depths (0-15, 15-30 and 30-60 cm). Samples were analysed for soil OM (Walkley and Black, 1947), NO_3^- (2M KCl), NH_4^+ (2M KCl) (Bremner, 1965) and pH (water). P content was determined by the method of Mehlich et al (1962) for 1996-97 samples and by the Olsen (1953) method for 1998-99 samples. Starting from 1998, determinations of K (Morgan, 1952) and Zn (Emmel and Stotera, 1977) content were carried out for the 0-15, 15-30 and 30-60 cm soil depths for all locations. K was measured using a flame photometer and Zn was measured by spectrophotometer.

Statistical analysis

The soil chemical properties were subjected to statistical analysis using analysis of variance (ANOVA) separately for each trial, and combining data across years. For the significant factor interactions, interaction means were separated by LSD test at the P=0.05 level.

RESULTS AND DISCUSSION

Soil Reaction

Analysis of the effect of straw management on soil pH revealed a significant effect in the Kulumsa mechanised trial during 1999 (Table 1), in the Asasa mechanised trial during 1998 (Table 2), and in the Kulumsa ox-plow trial during 1996 (Table 3). In the Kulumsa mechanised trial, BURN significantly increased soil pH cf. RET, while PARM was intermediate and equal to the other two treatments (Table 1). In the Asasa mechanised trial, RET markedly increased soil pH cf. BURN, while PARM was again intermediate and equal to the other two SM treatments (Table 2). In the Kulumsa ox-plow trial, PARM exhibited an increased soil pH cf. BURN (Table 3). In general, the effect of SM on soil pH was non-significant for the majority of the site-season combinations. It was apparent that pH consistently increased with soil depth.

Tillage showed a significant effect on soil pH only in the Asasa mechanised trial during 1999, in which case MT exhibited an increased soil pH relative to CT (Table 2). CS significantly affected soil pH in the Kulumsa ox-plow trial during 1996 and 1999 (Table 3). In each case, CW exhibited a higher soil pH cf. the faba bean rotation (Table 3). This might be the consequence of a higher soil N content due to N fixation by the faba bean precursor, resulting in a lower soil pH. In this trial, CS showed a consistent effect on soil pH. No interaction effects were observed for soil pH across the individual trials and seasons.

In the combined analysis across years tillage significantly affected soil pH in the Asasa ox-plow trial (Tables 4 and 5): the soil pH was higher under conventional tillage cf. MT. (Blevins et al., 1977) reported that soil pH was significantly lower under no-tillage as compared to conventional tillage in the upper 5 cm soil layer.

The interaction of SM by tillage exhibited a significant effect on soil pH in the Kulumsa ox-plow trial (Table 6): CT with BURN and MT with PARM increased the soil pH cf. the other two SM by tillage combinations. It has been reported that soil OM accumulation under no-tillage management alleviates problems associated with low soil pH (Hargrove and Thomas, 1981).

Table 1. Effect of crop management practices on soil chemical properties pre-planting in the mechanised system trial at Kulumsa: treatment means for 1996-99

	PH	pH	pH	pH	NO_3	NO_3	NH_4	NH_4	P	P	P	K	K	Zn	Zn
Treatment	96	97	98	99	96	98	96	98	96	98	99	98	99	98	99
SM (S)															
Burn	6.13	5.68	6.29	6.22A	18.1	15.9	16.3	10.1	27.7	6.28	3.99	720B	352AB	0.24	0.56B
Removal	6.28	5.45	6.04	6.03AB	18.6	11.9	17.9	12.5	24.6	8.74	3.12	704C	327B	0.25	0.57B
Retention	6.10	5.37	6.32	5.98B	19.5	10.9	18.1	11.6	25.0	6.77	3.31	772A	373A	0.24	0.70A
LSD(5%)				0.21								2.7	41.1		0.12
Tillage															
Conventional	6.15	5.52	6.20	6.06	17.6	13.8	17.6A	11.6	23.9	6.33	3.28	719	358	0.25	0.62
Zero	6.19	5.48	6.24	6.09	19.8	12.2	17.2B	11.2	24.2	8.19	3.78	746	343	0.24	0.60
CS (C)															
Faba bean	6.14	5.48	6.22	6.03	19.5A	14.5	17.3	11.7	24.2	6.93	3.23	720	345	0.25	0.62
Wheat	6.19	5.52	6.22	6.12	17.9B	11.5	17.6	11.1	23.9	7.60	3.71	744	356	0.24	0.60
Depth (cm)															
0-15	6.12B	5.44B	5.84C	5.82C	17.6B	21.7A	16.2B	12.4A	25.6A	13.3A	6.81A	813A	400A	0.34A	0.91A
15-30	6.16AB	5.45B	6.21B	6.07B	18.8A	11.2B	18.4A	11.9A	23.2B	6.4B	2.56B	699B	338B	0.22B	0.63B
30-60	6.23A	5.61A	6.60A	6.34A	19.7A	6.1C	17.8A	9.9B	23.5B	2.0C	1.04C	684B	314C	0.16C	0.29C
LSD(5%)	0.07	0.11	0.08	0.17	1.18	2.53	1.43	1.21	1.07	2.30	0.28	28.3	13.9	0.03	0.10

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H_2O); NO_3 and NH_4 (mg kg^{-1}); P, K and Zn (ppm).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 2. Effect of crop management practices on soil chemical properties pre-planting in the mechanised system trial at Asasa: treatment means for 1996-99

Treatment	PH 96	pH 97	pH 98	pH 99	NO_3 96	NO_3 97	NO_3 98	NH_4 96	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																
Burn	5.78	5.54	5.82B	6.04	20.5	24.0	22.1	9.59	28.6	28.9	11.8	10.5	737	427	0.92	0.86
Removal	5.70	5.77	5.87AB	6.01	20.5	24.6	21.2	9.45	39.9	31.3	12.3	9.48	738	381	0.99	0.94
Retention	5.89	5.56	6.18A	6.28	23.9	27.8	17.5	9.78	36.1	31.1	9.5	9.05	753	422	0.79	0.71
LSD (5%)			0.36													
Tillage																
Conventional	5.82	5.67	5.88	6.06B	22.3	25.1	23.9A	9.67	38.2	30.6	11.9	10.2	746	410	0.93	0.86
Minimum	5.76	5.65	6.03	6.16A	20.9	25.8	16.6B	9.60	38.2	30.3	10.5	9.18	739	410	0.87	0.79
CS (C)																
Faba bean	5.77	5.64	5.91	6.01	21.9	24.7	20.8	9.50	38.6	29.7	10.8	8.80B	733	392B	0.93	0.80
Wheat	5.81	5.61	5.99	6.21	21.3	26.2	19.7	9.78	37.9	31.1	11.6	10.5A	752	428A	0.86	0.87
Depth (cm)																
0-15	5.64C	5.50C	5.58C	5.76C	23.4A	28.9A	32.8A	10.2A	41.5A	36.9A	21.6A	17.8A	853A	495A	1.28A	1.26A
15-30	5.77B	5.60B	5.80B	6.08B	23.1A	27.0A	19.9B	9.46B	36.3B	28.3B	9.4B	8.01B	643C	358B	1.01B	0.94B
30-60	5.96A	5.78A	6.48A	6.49A	18.5B	20.5B	8.0C	9.28B	36.9B	26.0C	2.6C	3.13C	731B	377B	0.40C	0.31C
LSD (5%)	0.94	0.05	0.08	0.24	2.09	4.05	4.03	0.70	3.08	1.74	1.85	1.48	54.2	46.1	0.12	0.09

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H_2O); NO_3 and NH_4 (mg kg^{-1}); P, K and Zn (ppm).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 3. Effect of crop management practices on soil chemical properties pre-planting in the ox-plow system trial at Kulumsa: treatment means for 1996-99

Treatment	pH 96	pH 97	pH 98	NO_3 96	NO_3 98	NH_4 96	NH_4 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)															
Burn	6.11B	5.51	6.23	19.9	14.5	9.99	14.4	23.5	14.2	5.84	4.75	657	377	0.43	0.84
Removal	6.23A	5.42	6.40	19.2	11.3	10.3	13.2	23.7	11.2	6.06	4.31	679	352	0.49	0.78
Tillage															
Conventional	6.19	5.41	6.34	17.9	12.6	10.0	14.9	23.8	13.9	5.40	4.48	664	370	0.46	0.81
Minimum	6.15	5.53	6.28	21.2	13.3	10.3	12.6	23.5	11.5	6.50	4.58	673	359	0.46	0.81
CS (C)															
Faba bean	6.15B	5.47	6.32	20.4	14.1	9.8B	14.4	23.8	12.2	5.65	4.23	651B	357	0.43	0.80
Wheat	6.20A	5.46	6.31	18.7	11.8	10.5A	13.2	23.4	13.2	6.25	4.84	685A	372	0.48	0.81
Depth (cm)															
0-15	6.13B	5.37B	5.81C	18.7B	23.4A	9.3B	15.8A	24.6A	14.6A	11.8A	9.11A	740A	411A	0.61A	1.20A
15-30	6.14B	5.46AB	6.27B	20.1A	9.6B	10.9A	14.2A	23.9A	12.3AB	4.1B	3.13B	645B	335B	0.45B	0.85B
30-60	6.24A	5.58A	6.86A	19.8AB	5.8C	10.2AB	11.4B	22.4B	11.2B	1.9C	1.35C	619B	317B	0.30C	0.38C
LSD(5%)	0.08	0.12	0.23	1.35	3.41	0.99	1.76	0.97	2.62	1.31	0.87	38.2	34.0	0.07	0.09

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.
SM = Straw management; CS = Cropping sequence.
pH (1:1 H_2O); NO_3 and NH_4 (mg kg^{-1}); P, K and Zn (ppm).
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Table 4. Effect of crop management practices on soil chemical properties pre-planting in the ox-plow system trial at Asasa: treatment means for 1996-99

Treatment	pH 96	pH 97	pH 98	pH 99	NO_3 96	NO_3 97	NO_3 98	NH_4 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																
Burn	6.11	5.72	6.04	6.04	22.8	23.9	21.4	10.8	32.6	29.5	11.2	8.12	598	390	0.58	0.89
Removal	6.07	6.61	5.98	6.10	20.5	25.9	18.2	11.9	31.0	27.3	9.8	7.60	551	375	0.58	0.52
Tillage																
Conventional	6.14	5.73	6.07	6.11	21.9	25.4	19.2	11.7	31.3	27.9	8.7B	7.99	558	379	0.58	0.89
Minimum	6.05	5.60	5.96	6.03	21.4	24.5	20.4	11.1	32.3	28.8	12.3A	7.73	591	385	0.57	0.85
CS (C)																
Faba bean	6.04	5.71	5.98	5.98	22.1	23.9	19.3	11.9	32.5	28.4	10.1	8.12	574	372	0.59	0.88
Wheat	6.15	5.62	6.04	6.16	21.1	25.9	20.4	10.8	31.2	28.3	10.8	7.60	564	393	0.59	0.86
Depth (cm)																
0-15	5.97 B	5.46C	5.54C	5.84B	23.4A	30.2A	31.8A	12.6A	35.2A	31.9A	20.1A	15.7A	627A	373AB	0.91A	1.47A
15-30	6.02 B	5.62B	5.85B	6.13A	21.9A	23.6B	20.1B	12.4A	31.7B	26.8B	8.4B	5.41B	483B	353B	0.60B	0.82B
30-60	6.29 A	5.93A	6.65A	6.24A	19.7B	21.2B	7.6C	8.9B	28.6C	26.6B	3.0C	2.45C	614A	421A	0.22C	0.32C
LSD (5%)	0.13	0.12	0.13	0.27	1.92	2.22	3.65	1.99	2.67	1.91	2.28	1.85	39.3	49.0	0.09	0.16

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.
SM = Straw management; CS = Cropping sequence.
pH (1:1 H_2O); NO_3 and NH_4 (mg kg^{-1}); P, K and Zn (ppm).
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Table 5. Effect of tillage practices on soil pH pre-planting in the ox-plow system trial at Asasa: treatment means

Tillage	pH (1:1 H_2O)
Conventional	6.10A
Minimum	5.91B

Values followed by the same letter within a column are not significantly different at the 5% level of the LSD test

Table 6. Effect of interaction of straw management by tillage on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

	Kulumsa mechanised				Asasa mechanised		Kulumsa ox-plow	
Straw management	NH_4 (mg kg^{-1})		K (ppm)		NH_4 (mg kg^{-1})		pH (1:1 H_2O)	
	CT	ZT	CT	ZT	CT	MT	CT	MT
Burn	12.9B	11.4C	558AB	514B	11.9A	10.8AB	6.0A	5.9B
Remove	13.6AB	14.0A	514B	517B	11.2AB	12.1A	5.9B	6.0A
Retention	13.3AB	13.3AB	543B	602A	10.5B	10.5B	-	-
LSD (5%)	0.95		54.5		1.37		0.099	

Values followed by the same letters for each parameter are not significantly different at the 5% level of the LSD test.
CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage

The interaction between year and CS revealed a significant effect on soil pH in the Asasa mechanised trial during 1999 and in the Asasa ox-plow trial during 1996 and 1998 (Table 7). In two instances, CW significantly increased soil pH cf. the faba bean rotation, while in the Asasa ox-plow trial during 1998, the faba bean rotation increased soil pH. A significant interaction of SM by CS was observed in the Asasa ox-plow trial (Table 8): the faba bean rotation combined with partial removal of stubble resulted in a lower pH cf. the other three SM by CS combinations. The interaction of tillage by depth exhibited a significant effect on pH in the Asasa ox-plow trial (Table 9): CT exhibited a higher soil pH than MT at the 15-30 and 30-60 cm depths. A significant interaction between CS and depth was observed in the Kulumsa mechanised trial (Table 10): the faba bean rotation resulted in a lower soil pH at the 0-15 and 15-30 cm depths cf. the CW treatment.

Soil nitrate

Soil NO_3 decreased with soil depth for all site-season combinations except the mechanised and ox-plow trials at Kulumsa during 1996 (Tables 1 and 3). This discrepancy was probably due to the occurrence of heavy rainfall at Kulumsa during the early part of the cropping cycle in 1996. Tillage significantly affected soil NO_3^- in the Asasa mechanised trial during 1998 (Table 2): CT significantly increased soil NO_3^- cf. MT (Table 2). Dowdall et al. (1983) also reported higher nitrate concentrations in plowed fields than in direct drilled plots. It is perhaps not surprising that soil disturbance by plowing increases nitrate concentration in the soil, presumably due to an increased rate of organic matter mineralisation.

CS showed a significant effect on soil NO_3^- in the Kulumsa mechanised trial during 1996: the faba bean rotation increased soil NO_3^- cf. CW (Table 1). The inclusion of a grain legume in the cropping sequence generally increases soil nitrate as compared to continuous wheat (Wacquant et al., 1989). The interaction between tillage and depth was significant in the Asasa mechanised trial during 1998: conventional tillage exhibited a higher level of soil NO_3^- than MT, but only in the 0-15 cm soil depth (data not shown). Under conventional tillage, the soil in the plow layer is inverted each year, resulting in a fairly uniform distribution of organic matter in the top 0.2 m of soil (Haynes and Knight, 1989). From the combined ANOVA, a significant interaction between year and tillage was observed for the mechanised trial at Asasa: MT exhibited a lower soil nitrate level cf. CT, but only during the 1998 season (Table 11).

The interaction between tillage and depth significantly affected soil NO_3^- in the Asasa mechanised trial: CT increased soil NO_3^- cf. MT, but only in the 0-15 cm soil depth (Table 9). Kitur et al. (1984) evaluated the influence of no-tillage and mouldboard plowing on crop recovery and transformation of fertiliser N; with mouldboard tillage, fertiliser N was more uniformly distributed throughout the surface 15 cm soil layer – equivalent to the depth of plowing.

Table 7. Effect of interaction of year by cropping sequence on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

Cropping sequence	Asasa mechanised						Kulumsa ox-plow			Asasa ox-plow			
	pH (1:1 H_2O)				Zn (ppm)		NH_4 (mg kg^{-1})			pH (1:1 H_2O)			
	1996	1997	1998	1999	1998	1999	1996	1997	1998	1996	1997	1998	1999
Faba bean	5.77	5.64	5.91	6.00B	0.93A	0.80	9.78	11.9	14.4A	6.04B	5.71	5.98A	5.98
Wheat	5.81	5.61	6.00	6.21A	0.80B	0.87	10.5	11.8	13.1B	6.15A	5.67	5.62B	6.04
LSD (5%)		0.13			0.12			1.04			0.08		

Values followed by the same or no letter within each column are not significantly different at the 5% level of the LSD test

Table 8. Effect of interaction of straw management by cropping sequence on soil chemical properties pre-planting in the ox-plow system trials at Kulumsa and Asasa

Straw management	Kulumsa ox-plow		Asasa Ox-plow	
	K (ppm)		pH (1:1 H_2O)	
	FB	CW	FB	CW
Burn	514AB	520AB	5.98A	5.98A
Remove	494B	537A	5.88B	6.01A
LSD (5%)	27.3		0.095	

Values followed by the same letter for each parameter are not significantly different at the 5% level of the LSD test.

FB = Faba bean rotation with wheat (1 year in 3); CW = Continuous wheat.

Table 9. Effect of interaction of tillage by depth on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

Depth (cm)	Kulumsa mechanised				Asasa mechanised				Kulumsa ox-plow						Asasa ox-plow			
	P (ppm)		K (pmm)		NO_3 (mg kg^{-1})		P (ppm)		NH_4 (mg kg^{-1})		K (ppm)		Zn (ppm)		pH (1:1 H_2O)		K (ppm)	
	CT	ZT	CT	ZT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT
0-15	14.5B	12.1C	615A	599A	31.5A	25.2B	28.8A	21.6B	13.1A	11.6B	616A	564B	0.95A	0.86B	5.70D	5.71D	474B	525A
15-30	10.6D	16.6A	516B	520B	23.9B	22.7B	17.7D	30.1A	12.6A	12.2AB	486C	494C	0.60D	0.70C	5.99C	5.82D	405C	430C
30-60	12.2C	10.8D	484C	514B	15.8C	15.4C	19.4C	16.6D	11.0C	11.4BC	447D	488C	0.35E	0.33E	6.35A	6.20B	526A	509AB
LSD (5%)	1.24		22.0		2.82		1.48		0.98		35.5		0.077		0.12		43.1	

Values followed by the same letters within a parameter are not significantly different at the 5% level of the LSD test.

CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Table 10. Effect of interaction of cropping sequence by depth on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

Depth (cm)	Kulumsa mechanised						Asasa mechanised		Kulumsa ox-plow			
	NH_4 (mg kg^{-1})		pH (1:1 H_2O)		Zn (ppm)		K (ppm)		P (ppm)		K (ppm)	
	FB	CW	FB	CW	FB	CW	FB	CW	FB	CW	FB	CW
0-15	13.3AB	13.9A	5.76D	5.85C	0.60B	0.65A	641B	707A	14.5B	15.7A	563B	617A
15-30	12.1C	12.9BC	5.92C	6.02B	0.45C	0.40D	482D	518CD	10.9C	11.4C	479CD	502C
30-60	13.1AB	13.1AB	6.21A	6.17A	0.25E	0.20F	564C	544C	9.7D	9.4D	470CD	466D
LSD(5%)	0.94		0.078		0.044		49.3		0.85		35.4	

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.

FB = Faba bean rotation with wheat (1 year in 3); CW = continuous wheat.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 11. Effect of interaction of year by tillage on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

Year	Asasa mechanised		Kulumsa ox-plow			
	NO_3 (mg kg^{-1})		NH_4 (mg kg^{-1})		P (ppm)	
	CT	MT	CT	MT	CT	MT
1996	22.3	21.0	10.0	10.3	23.8	23.5
1997	25.1	25.8	11.7	12.2	14.2A	13.1B
1998	23.9A	16.6B	15.0A	12.6B	5.4B	6.5A
1999	---	---	---	---	4.5	4.6
LSD (5%)	4.21		1.69		0.84	

Values followed by the same or no letter within a row are not significantly different at the 5% level of the LSD test.
CT = Conventional tillage; MT = Minimum tillage.
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

The interaction between year and depth revealed significant differences in soil NO^-_3 in the soil profile in the Kulumsa mechanised trial during 1997 and 1998, in the Asasa mechanised trial during 1996, 1997 and 1998, in the Kulumsa ox-plow system trial during 1997 and 1998, and in the Asasa ox-plow trial during 1996, 1997 and 1998 (Tables 12 to 15). For most site-season combinations, the NO^-_3 content of the soil decreased with depth.

Soil ammonium

Soil NH^+_4 tended to decrease with soil depth for all site-season combinations except the Kulumsa mechanised and ox-plow trials during 1996 (Tables 1 to 4). Tillage significantly affected soil NH^+_4 in the Kulumsa mechanised and Asasa ox-plow trials during 1996 (Tables 1 and 4). In the Kulumsa trial, CT markedly increased soil NH^+_4 cf. MT (Table 1). With CT, the soil in the plowed layer is inverted annually so that there is a fairly uniform distribution of available organic N within the top 20 cm (Khakural et al., 1992). In contrast, MT significantly increased the NH^+_4 concentration of the soil in the Asasa ox-plow trial as compared to CT (Table 4). Conservation tillage retains most of the crop residue on the soil surface by minimising mechanical manipulation, resulting in changes to soil chemical properties over time (Blevins et al., 1983a). CS significantly affected soil NH^+_4 only in the Kulumsa ox-plow trial during 1996: CW exhibited increased soil NH^+_4 cf. the faba bean rotation (Table 3). In the combined analysis, SM significantly affected soil NH^+_4 in the Kulumsa mechanised trial: RET and PARM resulted in higher levels of soil NH^+_4 in contrast with BURN (Table 16). Rasmussen and Collins (1991) stated that retaining crop residues on the soil surface rather than burning or incorporating them by tillage increased organic C and total N in the top 15 cm of the soil.

Table 12. Effect of interaction of year by depth on soil chemical properties pre-planting in the mechanised system trial at Kulumsa

Depth	NO_3 (mg kg^{-1})			NH_4 (mg kg^{-1})			PH (1:1 H_2O)				P (ppm)				K (ppm)		Zn (ppm)	
(cm)	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999	1998	1999
0-15	17.8	29.5A	21.7A	16.2B	10.8	12.4A	6.13	5.44B	5.84C	5.82C	25.6A	16.6	13.3A	6.8A	813A	400A	0.34A	0.91A
15-30	18.8	28.9B	11.2B	18.4A	10.2	11.9A	6.13	5.45B	6.21B	6.07B	23.2B	16.2	6.4B	2.6B	699B	328B	0.22B	0.63B
30-60	19.7	26.9B	6.1C	17.8A	10.2	9.9B	6.23	5.61A	6.60A	6.34A	23.5B	16.3	2.0C	1.0B	684B	314B	0.16C	0.29C
LSD(5%)	2.17			1.15			0.11				1.75				22.0		0.030	

Values followed by the same or no letter within a column for each parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 13. Effect of interaction of year by depth on soil chemical properties pre-planting in the mechanised system trial at Asasa

Depth	NO_3 (mg kg^{-1})			PH (1:1 H_2O)				P (ppm)				K (ppm)	
(cm)	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999
0-15	23.4A	28.9A	32.8A	5.64C	5.50B	5.58C	5.76C	41.5A	37.0A	21.6A	17.8A	853A	495A
15-30	23.1A	27.0A	19.9B	5.77B	5.60B	5.80B	6.08B	36.3B	28.3B	9.4B	8.1B	643C	358B
30-60	18.5B	20.5B	7.9C	5.96A	5.78A	6.48A	6.49A	36.9B	26.0C	2.6C	3.1C	731B	377B
LSD (5%)		3.50			0.12					2.09		49.3	

Values followed by the same letter within a column for each parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 14. Effect of interaction of year by depth on soil chemical properties pre-planting in the ox-plow system trial at Kulumsa

Depth	NO_3 (mg kg^{-1})			NH_4 (mg kg^{-1})			pH (1:1 H_2O)				P (ppm)				Zn (ppm)	
(cm)	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999
0-15	18.7	35.2A	23.4A	9.26B	11.9	15.8A	6.13	5.37	5.81B	5.82	24.6A	14.6	11.8A	9.1A	0.61A	1.20A
15-30	20.1	32.3B	9.6B	11.0A	11.9	14.2B	6.14	5.46	6.27AB	5.91	23.6AB	13.4	4.1B	3.1B	0.45B	0.85B
30-60	19.8	32.5B	5.8C	10.2AB	12.0	11.4C	6.24	5.58	6.86A	5.98	22.4B	12.6	1.9C	1.4B	0.30C	0.38C
LSD(5%)		2.71			1.20				0.60			2.15			0.077	

Values followed by the same or no letter within a column for each parameter are not significantly different at 5% level of the LSD test.
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 15. Effect of interaction of year by depth on soil chemical properties pre-planting in the ox-plow system trial at Asasa

Depth	NO_3 (mg kg^{-1})			NH_4 (mg kg^{-1})			PH (1:1 H_2O)				P (ppm)				K (ppm)		Zn (ppm)	
(cm)	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999	1998	1999
0-15	23.4A	30.2A	31.8A	9.38	9.87	12.7A	5.97B	5.46B	5.54C	5.84B	35.2A	31.6A	20.1A	15.7A	527A	473A	0.91A	1.47A
15-30	21.9AB	23.3B	20.1B	9.25	9.68	12.4A	6.02B	5.62B	5.85B	6.13A	31.7B	26.8B	8.4B	5.4B	418B	418B	0.60B	0.82B
30-60	19.7B	21.2B	7.6C	9.29	9.48	9.0B	6.29A	5.93A	6.65A	6.24A	28.6C	26.6B	3.0C	2.5C	538A	498A	0.22C	0.32C
LSD(5%)		2.63			1.51			0.17				2.15			43.6		0.13	

Values followed by the same or no letters within a column for each parameter are not significantly different at the 5% level of the LSD test.
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 16. Effect of straw management practice on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means

	Kulumsa mechanised		Asasa mechanised	Asasa ox-plow
Straw management	NH_4	K	Zn	P
	(mg kg^{-1})	(ppm)	(ppm)	(ppm)
Burn	12.2B	536B	0.89A	20.3A
Removal	13.8A	516C	0.97A	18.9B
Retention	13.3A	573A	0.75B	-
LSD (5%)	0.97	17.9	0.14	-

Values followed by the same letter within a column are not significantly different at the 5% level of the LSD test.
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

The interaction between tillage and year was significant for soil NH^+_4 in the ox-plow trial at Kulumsa: only during 1998, CT increased soil NH^+_4 in contrast to MT (Table 11). Under CT, soil fertiliser N was more uniformly distributed throughout the plow surface layer and mineralisation and transformation of fertiliser N was increased (Kitur et al., 1984).

A significant interaction between SM and tillage was observed for soil NH^+_4 in the Kulumsa mechanised trial: BURN in combination with ZT markedly decreased soil NH^+_4 relative to the other treatment combinations; in general, RET and PARM, with either tillage treatment, exhibited equal NH^+_4 levels (Table 6). The interaction between year and CS was significant for soil NH^+_4 in the Kulumsa ox-plow trial. Only during the 1998 season, the faba bean rotation exhibited an increased level of NH^+_4 as compared to the CW treatment. Many studies have indicated that cultivation of N_2 fixing legumes increases soil N content (Senaratne and Hardorson, 1988). The interaction between year and depth revealed significant differences in soil NH^+_4 in the soil profile in the Kulumsa mechanised trial during 1996 and 1998, in the Asasa mechanised trial during 1996, 1997 and 1998, in the Kulumsa ox-plow trial during 1996 and 1998, and in the Asasa ox-plow trial during 1998 (Tables 12 to 15). With the exception of the Kulumsa mechanised and ox-plow trials during 1996, soil NH^+_4 decreased with soil depth in all other site-season combinations.

Soil phosphorus

In general, soil phosphorus decreased with soil depth because P is a less mobile plant nutrient in the soil profile (Tables 1 to 4). Tillage significantly affected soil P in the Asasa ox-plow trial during 1998. For this site-season combination, MT exhibited a higher level of soil P cf. conventional tillage (Table 4). CS significantly affected soil P in the Asasa mechanised trial during 1999: CW exhibited a significantly higher level of soil P (Table 2). The interaction between SM and depth exhibited a significant effect on soil P in the Kulumsa mechanised trial during 1999 and in the Asasa mechanised trial during 1997. In the Kulumsa mechanised trial, BURN resulted in a higher soil P level than the other SM treatments, but only in the surface layer. In the Asasa trial, PARM increased soil P in the 0-15 cm layer. Several studies have attributed such a stratification of P to its slow movement into the soil profile (Eckert and Johnson, 1985).

The interaction between tillage and depth was significant for soil P in the Asasa mechanised trial during 1997 and 1999. In both seasons, soil P content tended to be higher under MT in the 0-15 cm soil layer, while P levels were lower under MT in the two deeper soil layers. Many studies have shown that no-tillage systems tend to accumulate P near the soil surface and to exhibit decreasing P levels deeper in the soil profile; this often results in higher soil test P levels at the soil surface than when the soil is periodically inverted by tillage (Fink and Wesley; 1974; Cruse et al., 1983; Triplett and van Doren, 1969).

In the combined analysis over years, SM significantly affected soil P content in the Asasa ox-plow trial: the BURN treatment significantly increased soil P cf. PARM (Table 16). The interaction between year and tillage revealed significant differences in soil P content in the Kulumsa ox-plow trial during 1997 and 1998 (Table 11). In 1997, CT increased soil P content, while, in 1998, MT significantly increased soil P content. The interaction between SM and depth significantly affected soil P content in the mechanised trials at Kulumsa and Asasa (Table 17). In the Kulumsa mechanised trial, PARM > BURN = RET in the 0-15 cm layer, while PARM > BURN and RET was equal to the other two treatments in the 15-30 cm layer. In the Asasa mechanised trial, the same trend was observed as for the Kulumsa mechanised trial in the 0-15 cm layer, but, for the 15-30 cm layer, BURN > RET while PARM was intermediate and equal to the other two SM treatments (Table 17).

The interaction between tillage and depth was significant for soil P in the mechanised trials at Kulumsa and Asasa (Table 9). At each site, the interaction effect followed the same pattern: CT markedly increased soil P cf. ZT/MT in the 0-15 and 30-60 cm depths, while, in the 15-30 cm layer, CT < ZT/MT (Table 9).

The interaction between CS and depth was significant for soil P in the Kulumsa ox-plow trial (Table 10). CW increased the soil P level relative to the faba bean rotation, but only in the upper layer of the soil (0-15 cm). This might be due to the high demand for P by faba bean for growth and development during the break crop year or the high demand of wheat following the faba bean precursor due to enhanced vegetative growth. The interaction between year and depth revealed significant differences for P levels in the soil profile in the Kulumsa mechanised trial during 1996, 1998 and 1999, in the Asasa mechanised trial during 1996, 1997, 1998 and 1999, in the Kulumsa ox-plow trial during 1996, 1997 and 1999, and in the Asasa ox-plow trial during 1996, 1997, 1998 and 1999 (Tables 12 to 15). In each site-season combination, the P content of the soil decreased with soil depth.

Table 17. Effect of interaction of straw management by depth on soil chemical properties pre-planting in the mechanised system trial at Kulumsa and Asasa

Depth (cm)	Kulumsa mechanised									Asasa mechanised					
	P (ppm)			K (ppm)			Zn (ppm)			P (ppm)			Zn (ppm)		
	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain
0-15	15.2B	17.5A	14.0BC	598B	566C	657A	0.59B	0.62AB	0.67A	28.0B	31.9A	28.6B	1.25B	1.38A	1.18BC
15-30	11.0EF	13.1CD	12.3DE	519D	486E	550C	0.36D	0.41D	0.51C	21.4C	20.9CD	19.3DE	0.99D	1.14C	0.78E
30-60	10.4F	11.6DEF	10.1F	491E	495DE	511DE	0.24E	0.21E	0.23E	18.0EF	17.0F	16.4F	0.43F	0.37F	0.28G
LSD (5%)	1.52			27.0			0.054			1.81			0.087		

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.
P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Soil potassium

In general, soil K decreased with soil depth, with the exception of the Asasa ox-plow trial during 1999 (Tables 1 to 4). SM significantly affected soil K content in the Kulumsa mechanised trial during 1998 and 1999 (Table 1). In 1998, RET > BURN > PARM, while, in 1999, RET > PARM and BURN was intermediate and equal to the other two treatments (Table 1).

CS affected soil K content significantly in the Asasa mechanised trial during 1999 and in the Kulumsa ox-plow trial during 1998 (Tables 2 and 3). In both cases, the CW treatment exhibited a significant increase in soil K content (Tables 2 and 3). Thus, CS showed a consistent effect on soil K content in both trials. In the combined analysis across years, SM significantly affected soil K in the Kulumsa mechanised trial (Table 16): RET increased soil K cf. BURN, while PARM exhibited the lowest K content of the three treatments (Table 16). Blevins et al. (1977) noted that under stubble retention, potassium tended to be more concentrated in the upper layer of the soil profile.

The interaction between SM and tillage significantly affected soil K in the Kulumsa mechanised trial (Table 6). RET with ZT increased soil K relative to the other treatment combinations. For the BURN and PARM SM treatments, there was no effect of tillage treatment. Triplett and van Doren (1969) found that soil K levels in the surface 5 cm were greater under no-tillage. The interaction between SM and CS significantly affected soil K in the ox-plow trial at Kulumsa (Table 8). Partial removal of crop stubble in combination with continuous wheat significantly increased soil K content relative to the combination of PARM with the faba bean rotation. The interaction between tillage and CS significantly affected soil K content (Table 18): ZT in combination with CW increased soil K content relative to the other three treatment combinations.

Table 18. Effect of interaction of tillage by cropping sequence on soil chemical properties pre-planting in the mechanised and ox-plow system trials at Kulumsa and Asasa

Cropping sequence	Kulumsa mechanised K (ppm)		Asasa ox-plow Zn (ppm)	
	CT	ZT	CT	MT
FB	541B	523B	0.77A	0.69C
CW	535B	565A	0.70BC	0.74AB
LSD (5%)	23.4		0.047	

Values followed by the same letter for each parameter are not significantly different at the 5% level of the LSD test.
CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage;
FB = Faba bean rotation with wheat (1 year in 3); CW = continuous wheat.

The interaction between SM and depth was significant for soil K in the Kulumsa mechanised trial (Table 17). RET resulted in the highest soil K level in the two uppermost soil layers. In both layers, BURN was lower than RET, and PARM was lower than BURN. Various studies have shown that the reduction in soil cultivation associated with minimum or zero tillage can significantly change the distribution of plant available nutrients in the soil profile (Blevins et al., 1977; Drew and Saker, 1980). Such changes are characterised by concentration gradients in the soil profile for the less mobile plant nutrients (e.g., phosphorus and potassium) under reduced tillage.

The interaction between tillage and depth revealed significant differences in soil K content in the soil profile in the Kulumsa mechanised and ox-plow trials and in the Asasa ox-plow trial (Table 9). In the Asasa ox-plow trial, MT significantly increased soil K at the 0-15 cm depth. In the Kulumsa ox-plow trial, CT increased soil K at 0-15 cm and decreased soil K content at 15-30 cm. In the Kulumsa mechanised trial, only the 30-60 cm soil layer exhibited a difference in soil K content: in this instance, ZT exhibited a higher level of soil K cf. CT. Thus, the effects of the tillage by depth interaction were highly variable across the trial sites. The interaction between CS and depth revealed significant differences in soil K in the soil profile in the Asasa mechanised trial and in the Kulumsa ox-plow trial (Table 10). For both trials, CW significantly increased soil K cf. the faba bean rotation, but only for the 0-15 cm soil depth. The interaction between year and depth revealed significant differences in soil K content in the soil profile in the mechanised trials at Kulumsa and Asasa and the ox-plow trial at Asasa during 1998 and 1999 (Tables 12, 13 and 15). Soil K tended to decrease with soil depth, with the exception of the Asasa trials which showed an increase for the bottom layer relative to the middle soil layer (Table 15).

Zinc: For each sampled trial and season combination, Zn content decreased with soil depth (Tables 1 to 4). SM significantly affected soil Zn in the Kulumsa mechanised trial: RET of crop stubble increased soil Zn cf. PARM and BURN.

The interaction between SM and depth was significant for soil Zn in the Kulumsa mechanised trial during 1998 and 1999, and in the Asasa mechanised trial during 1999. In the Kulumsa mechanised trial during 1998, RET and PARM were equal and higher than BURN at the 15-30 cm depth. In contrast, at the 30-60 cm depth, the BURN treatment resulted in the highest Zn content of the soil. In the Kulumsa mechanised trial during 1999, RET significantly increased soil Zn, while PARM = BURN, in the two uppermost soil layers. In the mechanised trial at Asasa, PARM increased soil Zn cf. the other two treatments in the 0-15 cm layer, RET < BURN = PARM in the 15-30 cm depth, and at 30-60 cm BURN significantly increased soil Zn cf. RET, while PARM was intermediate and equal to the other two treatments.

In the combined analysis across years, SM significantly affected soil Zn in the Asasa mechanised trial: RET of crop stubble significantly reduced the Zn content of the soil cf. BURN and PARM (Table 16). The interaction between year and SM revealed a significant effect on soil Zn in the Kulumsa mechanised trial during 1999 (Table 19): RET markedly increased soil Zn cf. the other two SM treatments.

Table 19. Effect of interaction of year by straw management on soil Zn (ppm) pre-planting in the mechanised trial at Kulumsa

	Year	
Straw management	1998	1999
Burn	0.24	0.56B
Remove	0.25	0.57B
Retain	0.24	0.70A
LSD (5%)	0.030	

Values followed by the same or no letters within a column are not significantly different at the 5% level of the LSD test

The interaction between year and CS revealed a significant effect on soil Zn in the Asasa mechanised trial during 1998: the faba bean rotation significantly increased soil Zn cf. CW (Table 7). The interaction between tillage and CS significantly affected soil Zn in the Asasa ox-plow trial (Table 18): CT combined with faba bean rotation exhibited the highest soil Zn, while MT with CW reduced soil Zn.

The interaction between SM and depth revealed significant differences in soil Zn in the soil profile in the mechanised trials at Kulumsa and Asasa (Table 17). In the Kulumsa mechanised trial, RET of crop stubble significantly increased soil Zn in the top two soil layers. In the Asasa mechanised trial, PARM markedly increased soil Zn relative to the other two treatments, with the exception of the 30-60 cm depth in which PARM = BURN (Table 17).

The interaction between tillage and depth revealed significant differences in soil Zn in the soil profile in the Kulumsa ox-plow trial (Table 9). CT significantly increased soil Zn cf. MT in the 0-15 cm layer, while MT increased soil Zn in the 15-30 cm layer. Zn accumulation in the surface soil layer under no-tillage probably relates to the surface accumulation of plant residues containing significant quantities of the element (Hargrove et al., 1982).

The interaction of CS by depth was significant for soil Zn in the Kulumsa mechanised trial (Table 10). The faba bean rotation significantly increased soil Zn in the middle and lower layers of the soil (i.e., 15-30 and 30-60 cm), while, in the 0-15 cm layer, CW increased soil Zn (Table 10).

The interaction of year by depth revealed significant differences in soil Zn in the soil profile in the Kulumsa mechanised trial during 1998 and 1999, in the Kulumsa ox-plow trial during 1998 and 1999, and in the Asasa ox-plow trial during 1998 and 1999 (Tables 12, 14 and 15). In each case, soil Zn decreased with soil depth, reflecting a consistent pattern.

Soil organic matter: The results of the combined ANOVA for soil OM for the mechanised and ox-plow trials at Kulumsa and Asasa revealed that year, SM, SM by year, tillage, CS, and CS by year comprised a high proportion of the total variability, reflecting a pronounced environmental effect on soil organic matter content. In general, the Kulumsa soil had a higher level of SOM than the Asasa soil.

SM practices in the mechanised trials at Kulumsa and Asasa exhibited significant effects on soil organic matter. In the Kulumsa mechanised trial, RET of crop stubble resulted in the highest SOM content cf. PARM and BURN (Table 20); PARM was significantly higher than BURN (i.e., RET > PARM > BURN). At Asasa, RET and PARM were equal, but BURN exhibited the lowest soil organic matter content (Table 20). The ox-plow system trials at both sites did not exhibit any significant difference between the PARM and BURN treatments (Tables 20). Rasmussen and Collins (1991) stated that retaining crop residues on the soil surface rather than burning or incorporating them by tillage increases soil organic C and N, due to a higher level of C and N in the surface soil layer and slower oxidation.

Table 20. Effect of crop management practices on soil organic matter content in the mechanised and ox-plow trials at Kulumsa and Asasa: treatment means over nine samples taken across five years (1996-2000)

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	3.46C	3.12B	3.54	3.18
Removal	3.63B	3.29A	3.59	3.18
Retention	3.92A	3.32A	---	---
LSD(5%)	0.076	0.14	NS	NS
Tillage				
Conventional	3.50B	3.22	3.53	3.18
Zero/Minimum	3.84A	3.26	3.60	3.18
Cropping sequence				
Faba bean	3.62B	3.19B	3.50	3.16
Wheat	3.72A	3.29A	3.63	3.20
Year				
1996				
Pre-planting	3.95B	3.66B	3.62D	3.56C
Post harvest	3.76B	4.21A	3.95BC	3.85B
1997				
Pre-planting	3.99B	3.41BC	4.08B	4.25A
Post harvest	3.77B	3.53B	3.93BC	3.69BC
1998				
Pre-planting	3.61B	3.06C	3.77CD	2.86D
Post harvest	4.49A	4.11A	4.52A	3.68BC
1999				
Pre-planting	3.08C	2.36D	2.86F	2.20E
Post harvest	3.26C	2.52D	3.08E	2.33E
2000				
Pre-planting	3.10C	2.34D	3.20E	2.23E
LSD (5%)	0.48	0.35	0.21	0.21

Values within a factor level within a column and followed by the same letter(s) are not significantly different at the 5% level of the LSD test

Tillage treatment significantly affected soil organic matter only in the mechanised trial at Kulumsa. In this trial, ZT significantly increased soil organic matter cf. CT (Table 20). Organic C concentration is often reduced by cultivation; this effect can be ascribed to physical disruption of protected organic matter, resulting in a higher rate of microbial breakdown (Roberts and Chan, 1990). In contrast, the mechanised trial at Asasa and both of the ox-plow trials showed no significant effect of tillage (Table 20). CS significantly affected soil organic matter content in both of the mechanised trials. At both locations, CW increased soil organic matter cf. the faba bean-based rotation (Table 20). In contrast, both of the ox-plow system trials showed no significant effect of the CS treatments. Year significantly affected soil organic matter in all trials. In general, the highest soil organic matter levels were observed in the 1998 post-harvest samples - except for the Asasa ox-plow trial. The lowest results were generally observed in the 1999 pre and post harvest and 2000 pre harvest samples (Table 20).

The interaction effect of year by SM was significant for the mechanised trial at Kulumsa: with the exception of the 1999 pre harvest sample (in which RET = PARM < BURN) all of the other sample dates showed that RET of crop stubble significantly increased soil organic matter cf. BURN (Table 21). For some sample dates, PARM was intermediate to and different from the BURN and RET treatments; in others, PARM was not different from RET. Thus, crop management systems that maintain surface residues may result in higher levels of soil organic C and N, and improve soil productivity (Havlin et al., 1990).

Table 21. Effect of interaction of straw management by year on soil organic matter in the mechanised trial at Kulumsa

	1996		1997		1998		1999		2000
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Straw management									
Burn	3.65C	3.40B	3.72C	3.47B	3.51B	4.33B	3.99A	3.04B	3.00B
Removal	3.91B	3.91A	3.99B	3.64B	3.58AB	4.24B	3.13B	3.28A	3.00B
Retention	4.29A	3.96A	4.29A	4.20A	3.78A	4.92A	3.11B	3.42A	3.29A
LSD (5%)					0.23				

Values within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test; Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest)

The interaction effect of CS by tillage was significant for the mechanised trial at Kulumsa. In this trial, ZT in combination with CW resulted in the highest soil organic matter cf. the combination of CT with continuous wheat or faba bean (Table 22). Lamb et al. (1985) observed that reduced tillage intensity increased surface residues and reduced the loss of SOM.

The interaction effect of CS by year was significant for the mechanised trial at Kulumsa. For the first three sample dates, CW significantly increased soil organic matter cf. the faba bean-based rotation (Table 23); for the other six sample dates, there was no effect of CS on soil OM.

Table 22. Effect of interaction of cropping sequence by tillage on soil organic matter in the mechanised trial at Kulumsa: means combining nine samples taken across five years (1996-2000)

	Cropping sequence	
	Faba bean	Continuous wheat
Tillage		
Conventional	3.47B	3.52B
Zero	3.75AB	3.93A
LSD (5%)	0.30	

Values followed by the same letter(s) are not significantly different at the 5% level of the LSD test

Table 23. Effect of interaction of cropping sequence by year on soil organic matter in the ox-plow trial at Kulumsa

	1996		1997		1998		1999		2000
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Cropping sequence									
Faba bean	3.42B	3.79B	3.93B	4.03	3.77	4.46	2.91	3.06	3.20
Continuous wheat	3.81A	4.11A	4.22A	3.84	3.78	4.59	2.80	3.10	3.19
LSD (5%)					0.25				

Values within a column followed by no letters are not significantly different at the 5% level of the LSD test; Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest).

CONCLUSIONS

Crop management practices such as stubble management, tillage and cropping sequence play an important role in maintaining an optimal soil environment. The retention of straw on the soil surface can be important for nutrient recycling. Thus, in the current study, the retention of straw on the soil surface increased the concentration of most important plant nutrients in the upper layer of the soil (i.e., 0-15 cm) cf. burning and partial removal of the straw. Furthermore, the presence of straw on or near the soil surface can reduce rain run-off and erosion, and can increase soil moisture levels. Increased soil moisture can enhance the activity of micro-organisms involved in decomposing residues and changing unavailable forms of nutrients to available forms. Conservation tillage practices also increased the concentration of some important plant nutrients such as phosphorus and potassium in the upper layer of the soil as compared to conventional tillage in both the mechanised and ox-plow trials. An increased concentration of these elements in the root zone of the plant can facilitate nutrient uptake for growth and development. Cropping sequence had little effect on soil chemical properties in the current study.

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DROUGHT IN ETHIOPIA

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ABSTRACT

In Ethiopia, a wide range of climatic, ecological and socio-economic diversities influence agriculture. Most of the population depend on rain-fed crop production. This has made the country's economy extremely vulnerable to the effects of weather and climate, which are highly variable both temporally and spatially. Most of the rural population depends on subsistence agriculture for its livelihood. Hence, if the fails rain in one season, the farmer is unable to satisfy his needs and pay his obligation. This indicates that the rural population in Ethiopia, which feeds the whole population, is exposed to extreme poverty and is leading a risky life. Moreover, due to climate change and other human induced factors, areas affected by drought and desertification increasing in Ethiopia. Drought is threatening the lives of millions of people that occupy about one-third of the land surface. Deforestation is one of the major causes that aggravated drought and desertification especially over the semi-arid and arid areas. Drought being one of man's worst natural enemies has a history, which dates back to 253 BC in Ethiopia. Analyses of the chronological events of Ethiopian droughts/ famines have been divided into four parts and the analysis suggested some interesting features. During the period from 253 BC to the commencement of AD, one drought/famine was reported in seven years period. From the beginning of AD to 1500 AD, there were some cruel famines which killed millions. In this period, there were 177 droughts/famines, about one in nine years, were reported in the country. From 1500 to 1950, the information is relatively based on recorded data and is more reliable. From the 16th to the first half of the 20th century, 69 droughts/famines were reported in a period of 450 years. This signifies that on an average drought occurs every seven years. The two notorious famines locally known as *quachine* and *kifuken* (bad days) which devastated major areas of the country were reported during this period. The reports from 1950 onwards are well documented with scientific data. The analysis of rainfall data for this period indicated 18 droughts/famines in 38 years, suggesting the occurrence of drought every two years. The main objectives of this paper are to discuss drought chronology in Ethiopia, to identify its causes and delineate drought-prone areas. Further more drought monitoring and mitigation systems in the country and future research needs will be focused.

INTRODUCTION

Agriculture supplies 51.8% of the gross product and 90% of the export earnings of Ethiopia as well as supplying significant proportion of the raw materials for the agro-industries and 86% of the population is engaged in agriculture (CSA, 1999). Improvements in the agriculture sector meant the generation of higher incomes, reduction of poverty, and promotion of higher standards of nutrition and health of the rural people. It would also mean increasing and diversifying the production of raw materials for industries and exports as well as making agriculture the driving force for economic development.

In Ethiopia, a wide range of climatic, ecological and socio-economic diversities influence agriculture. The dependency of most of the population on rainfed crop production has made the country's economy extremely vulnerable to the effects of weather and climate, which are highly variable both temporally and spatially. Most of the rural population depends on subsistence agriculture for its livelihood. Hence, if the fails rain in one season, the farmer is unable to satisfy his needs and pay his obligations. This indicates that the rural population in Ethiopia, which feeds the whole population, is exposed to extreme poverty and is leading a risky life. Moreover, due to climate change and other human-induced factors, areas affected by drought and desertification is increasing in Ethiopia (NMSA, 1996b; WMO, 1986). Drought is threatening the lives of millions of people that occupy about one-third of the land surface. Deforestation is one of the major causes that aggravated drought and desertification especially over semi-arid and arid areas.

The main objectives of this paper are to discuss drought chronology in Ethiopia, to identify its causes and delineate drought-prone areas. Furthermore, drought-monitoring and mitigation systems in the country and future research need will be focused.

In this presentation, the seasons are termed as the first or the second instead of ***belg*** (small rainy season that extends from about February to May over central parts of northern, southern and eastern parts of the country,) and ***kiremt*** (main rainfall season for most parts of the country with the exception of southern and south-eastern parts of the country. It extends from June to September) (NMSA, 1996a). This is because the latter terms are confined to limited locations. Therefore, in order to avoid misinterpretations, the former terms are introduced. The first season means the first rainy season in any calendar year (January being the first month) and similarly the second season means the second rainy season in any calendar year and refers only the bimodal rainfall regimes.

DEFINITIONS AND TYPES OF DROUGHT

Numerous definitions of drought have been proposed but none has received a widespread acceptance. A few examples of the many that may be found in the literature, Palmer (1965), WMO (1975a), Ogallo and Gbeckor (1989) and NMSA (1996b) serve to illustrate the lack of agreement in the definition. It is nevertheless an inescapable fact that drought is one of man's worst natural enemies. Its beginning is subtle, its progress is insidious and its effects can be devastating. Drought may start any time, last indefinitely and attain many degrees of severity. It can also occur in any part of the world, with an impact ranging from slight personal inconvenience to endangered nationhood (WMO, 1975a).

Though the definitions of drought are many, they all can be divided into two groups: Drought as meteorological phenomena and drought as agroclimatological phenomena. (Drozdov, 1980). As meteorological phenomena, drought is prolonged absence or marked deficiency of rainfall (WMO 1990) when it is by far less than evaporation and accompanied by high temperatures so that the soil loses its potential to retain soil moisture (Loginov et al, 1972; WMO, 1986). Drought may also be termed as a period of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious hydrologic imbalance i.e. water supply damage in the affected area as AMS explains. Hence, meteorological drought is described as a significant decrease from normal rainfall distribution over a wide area and for an extended period of time (Carr, 1966). Hydrological drought is characterised by the drying up of springs and small streams, falling water level in wells, the shrinking of rivers and the depletion of stored water in lakes (Dickerson and Dethier, 1970). Agricultural drought is experienced when rainfall is inadequate to maintain soil moisture at optimum levels in terms of normal or generally experienced moisture supply (Kulik, 1958; WMO, 1975a; WMO, 1990). The meaning of adequate soil moisture is relative. However, crop production is related to plant species, soil fertility and other environmental factors in addition to soil moisture. Lack of available soil moisture for crop production is generally the first manifestation of a rainfall deficit (Dickerson and Dethier, 1970).

MAJOR CAUSES OF DROUGHT IN ETHIOPIA

Climate change and climate variability

It seems that virtually everywhere drought is within the normal range of climatic conditions and is recurrent phenomenon. But drought can be a manifestation of climate change as well. Climate changes are induced by a number of natural phenomena over which man has no control; but major interventions are beginning to play a significant role in inducing change. The major impact of climate change in Ethiopia is manifested through rainfall variability. Seasonal and annual rainfall variations in Ethiopia are associated with the macro-scale pressure systems and monsoon flows related to the changes in the pressure systems (NMSA, 1996a). The interactions between the pressure systems are extremely complicated and to date are poorly understood (WMO, 1975a; 1975b; 1983a; 1993). However, if any rain-producing system in any season is lacking, there will be abnormal rainfall behaviour during that season. The result of a recent study made by Engida (1999) indicates that the area coverage under stable rainfall activity has decreased and areas, which are covered by highly variable rainfall, have substantially increased in the latter study. Hence, areas that used to receive abundant rainfall are now receiving low rainfall in sufficient for crop production. This creates the condition for the occurrence of drought.

Method of cultivation

Method of cultivation, selection of cropping pattern, inappropriate land use and deforestation are very important point to be raised when Ethiopian drought is an issue. Ethiopian farmers are still continuing implementing unscientific way of cultivation, wind and rain are eroding the topsoil. As a result of erosion, water could not percolate into the soil and instead it is wasted as run-off. Therefore, the soil cannot maintain the required amount of soil moisture. As a result of depletion of soil moisture and soil nutrients, the soil cannot sustain plant growth. The Ethiopian Highland reclamation study (Constable and Belshaw, 1989) had estimated that over half of the highlands (270,000 km^2) are already significantly eroded, of which about 100 tons per hectare of soil is eroded every year primarily because of the erosive cropping practices followed while the annual soil loss due to erosion is estimated at 1.9 to 3.5 billion tons, when the medium to lowland regions are included the cost of land degradation on the nation is astronomic (EARO, 1999a). It is widely believed that land degradation is mainly caused by cultivation. According to the Hans Hurni (1986) study, soil loss on cultivated land is estimated to be 4-10 times higher than on grazing land, and 80% of the recorded annual soil loss occurs in the month of ploughing and in the first month after planting. The Ethiopian Highland Reclamation Study (Constable and Belshaw, 1989) stressed that the condition of land prior to sowing during the short rainy season (*belg*) or during the first month of growth is important in averting soil erosion.

Deforestation

Deforestation is another very important factor that contributes to drought in Ethiopia. Historical sources indicate that high forests that might have covered about 35-40% of the total area of Ethiopia have now been reduced to 2.7%. It is estimated that these resources are vanishing at an alarming rate, estimated at 150,000 to 200,000 hectares per year (EARO, 1999b; IUCN, 1990; EFAP, 1994). Therefore, deforestation had caused and continues to cause environmental degradation in the form of land degradation, water resource deterioration and lose of bio-diversity.

Livestock density and grazing patterns

Livestock density and grazing patterns lead to overgrazing, which is a major cause of drought and desertification. Rangelands account for almost 90% of desertified lands (Mabbutt, 1984). Overgrazing results when livestock density becomes excessive and too many animals are grazed at the same area of rangeland, leading to degradation of vegetation and the compaction and erosion of the soil. The uncontrolled browsing of trees and shrubs is another aspect of overgrazing and a patent cause of deforestation, leading to flooding and siltation in adjacent areas because rains are no longer held back by the sponge effect of the trees and carry with them large loads of eroded soil. Overgrazing also leads to soil erosion. The degradation of sparse rangeland vegetation by overgrazing exposes the soil to erosion by wind and water. Ethiopia has one of the largest livestock populations in Africa with 30 million head of cattle, 22 million sheep, 17 million goats, 7 million equines and 1 million camels (CSA. 1999). From 70 to 80% of these livestock are found in the highlands (Alemneh Dejene, 1990).

Population pressure

Though there are many arguments about the population growth being the cause of degradation in Ethiopia it has undoubtedly direct consequences for the environment: growing demand for more land for crop production; for fuelwood; shortening of fallow cycles and contribution to over cultivation. Ethiopia has a total area of 1.24 million km^2 with a population of about 60 million and is estimated at 3-4% growth rate and agriculture has always been the backbone of the economy (CSA, 1998). Without a major fertility decline, Ethiopia will have to feed a population nearly double in the year 2030. These are frightening figures to consider since the land cannot support even the present population. Moreover, an important feature of Ethiopia's population is that about 45% is under the age of 15 years (CSA, 1999). These figures signify a high dependency burden on the working population. Moreover, because of high population growth, the size of individually owned plots is shrinking in the relatively fertile highland and medium altitudes. This diminution will lead to intensive cultivation, which will inevitably result in a loss of soil fertility. In the absence of modern techniques for enriching the soil, and with dung being increasingly converted into a source of fuel, the reduction in soil fertility is imminent. Thus diminishing land size will lead to reduced soil fertility and subsequently to a decline both the capacity of the soil to produce food and to its incapacity to resist drought. This condition in its turn leads the society to poverty. When people lack access to alternative sources of livelihood, there is a tendency to exert more pressure on the few resources that are available to them. Bekele Shifereaw and Holden (1997) showed the intensified pressure on natural resources as a vicious cycle in which resource degradation and drought lead to reduced household assets, and reduced household assets in turn affect degradation in the Ethiopian highlands. Deforestation, and burning of dung and crop resides are increased by people's inability to afford, or lack of alternative fuel sources.

Land ownership

The other very important factor that contributes to the recurrent drought in Ethiopia is the problem of land ownership. Investment decisions on land are affected by tenure security (Place and Hazel 1993; Gavain and Fafchamps 1996). Communal ownership is believed to lead to mismanagement, particularly, over-grazing and inefficient removal of wood for fuel (Hudson 1981). The ability to transfer land sales and leasing also allow land to be used by farmers who are able to earn the highest return from it, through mobility of scarce factors to production such as draft animals, farm implements, labour and management ability (Pender 1998). The systems of land tenure that have developed in Ethiopia have had varying and significant impacts on land management. From a historical perspective, it is believed that the Ethiopian smallholder is uncertain about his or her security of rights to the land. This has led to cultivation for short-term needs rather than long-term yield. Accordingly, no long-term investments are made that would maintain or boost yields, and this has resulted in ecological damage, which has become almost impossible to reverse (Lakew et al. 2000). Other soil and water conservation measures on croplands are lagging behind due to the problem of land insecurity for long-term utilisation of the land.

HISTORY OF DROUGHT IN ETHIOPIA

Information sources on African droughts are mainly from local chronicles, archived data, historical texts, traveller's dairies, European settlers' notes, folk songs and so on. The historical reports of these events are mostly qualitative in nature. The National Meteorological Services Agency (NMSA, 1996b), Workineh Degefu (1987), Mesfin Welde Mariam (1984) and Pankhurst (1984) attempted to collect and document the history of drought and famine and their impact on various administrative regions of Ethiopia from different national and international documents. The chronology of drought and famine in Ethiopia is shown in Table 1.

Drought being one of man's worst natural enemies has a history, which dates back to 253 BC in Ethiopia. Analyses of the chronological events of Ethiopian droughts/ famines have been divided into four parts and the analysis suggested some interesting features. During the period from 253 BC to AD, one drought famine was reported in seven years period. From the beginning of AD to 1500 AD, there were some cruel famines, which killed millions. In this period, there were 177 droughts/famines, about one in nine years, were reported in the country. From 1500 to 1950, the information is relatively based on recorded data and is more reliable. From the 16th to the first half of 20th century 69 droughts/famines were reported, in a period of 450 years. This signifies that on an average the occurrence one drought in seven years. The two notorious famines locally known as *quachine* and *kifiuken* (bad days) which devastated major areas of the country were reported in this period. The reports from 1950 onwards are well documented with scientific data. The analysis of the rainfall data for this period indicated 18 droughts/famines in 38 years, suggesting the occurrence of drought every two years.

Table 1. Chronology of drought in Ethiopia (adapted from Mesfin Welde Mariam, 1984; Workineh Degefu, 1987; Pankhurst, 1984; NMSA, 1996b)

Years	Areas affected	Reported severity level
253-242BC	Ethiopia	Mainly deduced from the chronology* of low Nile river levels
192-187BC 139-130BC 50-42 BC	Ethiopia, Sudan, Egypt and the rest of Africa is also suspected	Low Nile levels
12-19 AD 53-63 AD 111-124 AD 151-170 AD	Egypt and suspected also the rest of Africa and the Sahelian region	Low Nile levels
254-265 AD	Ethiopia	Low Nile levels
758-787 AD	Ethiopia	Low Nile levels
832-849 AD	Ethiopia	The earliest known Ethiopian drought.
1006-1013 AD	Ethiopia	Low Nile levels
1066-72 AD	Ethiopia	Low Nile level
1131-1145 AD	Ethiopia	Low Nile levels
1252	Ethiopia as a whole	Mentioned as a famine year called '*Axaha*'
1258-59	Ethiopia.	Mentioned as a famine called "*Fassas*'
1272-75	Ethiopia	Mentioned as a famine called "*Hglah*"
1295-1340	Ethiopia	Low Nile level
1400-05	Ethiopia	Low Nile levels
1435-36	Ethiopia	Severity unrecorded
1445-1452	Ethiopia	Noted as famine years
1540	Ethiopia	A great. People were obliged to live on the roots of trees
1543-44	Ethiopia	There was a great famine as described by the chronicler
1559-61	Ethiopia	For three years following the killing of Emperor Gelawdewos, there was no rainfall, especially in Harar (Eastern Ethiopia)
1611	Parts of Ethiopia	Mentioned as both a times of famine and epidemic. The plague was *called "Manin Tita"*(Whom did it leave)
1618-19	Parts of Ethiopia	Mentioned as both a time of famine and epidemic
1623	Ethiopia	Mentioned as a time of famine
1625-27	Especially in Hararghie and as well as northern Ethiopia	The plague was so oppressive that there remained no food, grass or leaves of trees
1633-35	Especially in Harar and as well as northern Ethiopia	A horrible locust plague invaded nearly the whole region and the Emperor was obliged to change the seat of his palace to another place
1650	Parts of Ethiopia	Mentioned as a famine year
1653	Parts of Ethiopia	Mentioned as a famine year

Years	Areas affected	Reported severity level
1668	Ethiopia	A great famine, so intense that the price of grain rose five times and many horses and donkeys perished
1678	Parts of Ethiopia	Mentioned as a famine year
1700	Parts of Ethiopia	Mentioned as a famine year
1706	Ethiopia	Mentioned as famine years
1721-25	Ethiopia	There was famine; a very weak Nile flood
1747-48	Ethiopia	Mentioned as famine years as the result of two successive plagues of locust
1752	Ethiopia	Mentioned as a famine year
1772-74	Ethiopia	Mentioned as a famine year, which was called *Quachine*, "My thinness"
1782-83	Ethiopia	One of the worst famines of the century
1788-89	Ethiopia	All the provinces were reported to have suffered great distress
1796	Northern Ethiopia	Famine triggered by locust invasion
1800	Ethiopia	Both people and horses died of famine
1812-16	Tigrai	Severity unrecorded
1826-27	Ethiopia	There was great failure of both cotton and grain crops and many cattle died
1828-29	Shoa	Crop failure occurred and cattle epidemic followed in which much livestock perished
1831	Tigrai	Severity unrecorded
1835-38	Shoa and Tigrai	Many people died following failure of rain.
1864-66	Tigrai and Gonder	Severe famine that resulted in the death of 220 persons out of 280 over a specific village
1867-68	Ethiopia	The weakest Nile floods and reported as one of the worst outbreak of locusts
1876-78	Tigrai and Awash valley	Heavy livestock death tools
1980	Tigrai and Gonder	Much loss of livestock
1888-92	The whole of Ethiopian	It was one of the most serious drought experienced in Ethiopia and was known in Ethiopian history as the "Kifuken" (the Harsh days). Both the *belg* and *kiremt* rain failed.
1895-96	Ethiopia	A minor drought occurred that year, due to the failure of the *Kiremt* and *Belg* rains and resulted in the death of many people and cattle.
1899-1900	Ethiopia	Low levels of Lake Rudolf and the Nile
1913-14	Northern Ethiopia.	Very low Nile flood the price of grain increased 30 fold and there was great starvation in Tigrai
1920-22	Ethiopia	Similar drought to that of 1895-96.
1932-34	Ethiopia	Deduced from low level of Lake Rudolf.
1953	Wello and Tigrai	Severity unrecorded
1957-58	Wello and Tigrai	Failure of rain during 1957-58, outbreak of locusts and epidemics famine of which the worst year was said to be 1957. According to the information given by the Ministry of Interior to the Red Cross, the famine-affected population in Tigrai alone was estimated to be 1 million.
1962-63	Western Ethiopia	Very severe

Years	Areas affected	Reported severity level
1964-65	Ethiopia	About 25% of the country were under famine
1965-66	Wello, Tigrai, South-central and western parts of the country.	The failure of the *Belg* and *Kiremt* rains and the high temperature that accompanied the drought affected 60% of Tigrai, and 67% in Wello and about 59% of the country were under famine
1971-75	Northern, Southern and Eastern parts of Ethiopia, particularly Tigrai and Wello region	Sequences of much below normal rainfall and the number of dead to be about 200,000 for Tigrai, Wello and Northern Shoa. Other estimates give for the number of affected people as 400,000 to 1 million for Tigrai and more than 100,000 for Wello. 80% of the cattle, 50% of the sheep and 30% of the goats perished.
1975-76	Wello and Tigrai	Wello and Tigrai had below normal *Kiremt* rainfall. In Wello alone about 1.2 million people were affected. For both Wello and Tigrai estimate figures of affected people go up to 2-3 million people. In 1975 about 52% of the country were under famine.
1978-79	Southern Ethiopia and *Belg* areas	Failure of *Belg* rain and kiremt rain was deficient About 4.3 million people were affected in 1978 and 4.5 million people were affected in 1979.
1982	Northern Ethiopia	Late onset and low in amount of *kiremt*
1984-85	Ethiopia	Failure of *Belg* rains and deficiencies in kiremt resulted in a drought, which had developed into a famine said to be of biblical proportions, where 7.9 million people were severely affected.
1987-88	Northern Ethiopia most of Shoa, most of Hararghie and the Rift Valley	Late onset of *kiremt* rains
1990-92	Northern, eastern and south-western Ethiopia	Failure of rainfall and regional conflicts affected 4 million people

The decadal analysis shows that 1970-79 was the worst decade having seven disaster years. It can be noted that the highest frequency of droughts/famines occurred in the second century AD followed by the first part of the 20th century and an increasing trend from sixteenth century onwards. The broad features of low rainfall and the associated drought over northern parts of Ethiopia are reflected in the level of Lake Tana, which feeds the Blue Nile. The level of water in Lake Tana at Bahir Dar and the rainfall deficiency at Gonder reflected some of the major drought years like 1982. The worst period appears to be the 1980's and the worst drought year happens to be 1984. The areas that were affected severely by droughts/famines are mainly the northern parts of the country.

DROUGHT-PRONE AREAS

Drought probability map of Ethiopia

Decile method as indicator of drought was proposed by Gibbs and Maher (WMO, 1975b) and Rao (1986). Therefore, a drought probability map of Ethiopia is produced using the decile methodologies mentioned above as it applies to the Ethiopian condition (Danilov, 1987). Figure 1 shows the drought probability map of Ethiopia. The country is divided into high, moderate and low drought-prone areas. As observed from the figure, the drought probability values in Ethiopia range from completely drought-free zone (some highland areas in southern and south-western Ethiopia) to high drought- prone areas in north-eastern and south-eastern Ethiopia.

Areas with low drought risk are located in south-western parts of Ethiopia, parts of north-western and north-eastern and the highland belts stretching from Sidamo to Hararghie. The marginal areas of the above, parts of eastern and southern Ethiopia and northern lowlands encounter medium drought risk. The high drought prone areas are located in the lowlands of north-western, north-eastern, south-eastern and parts of central Ethiopia.

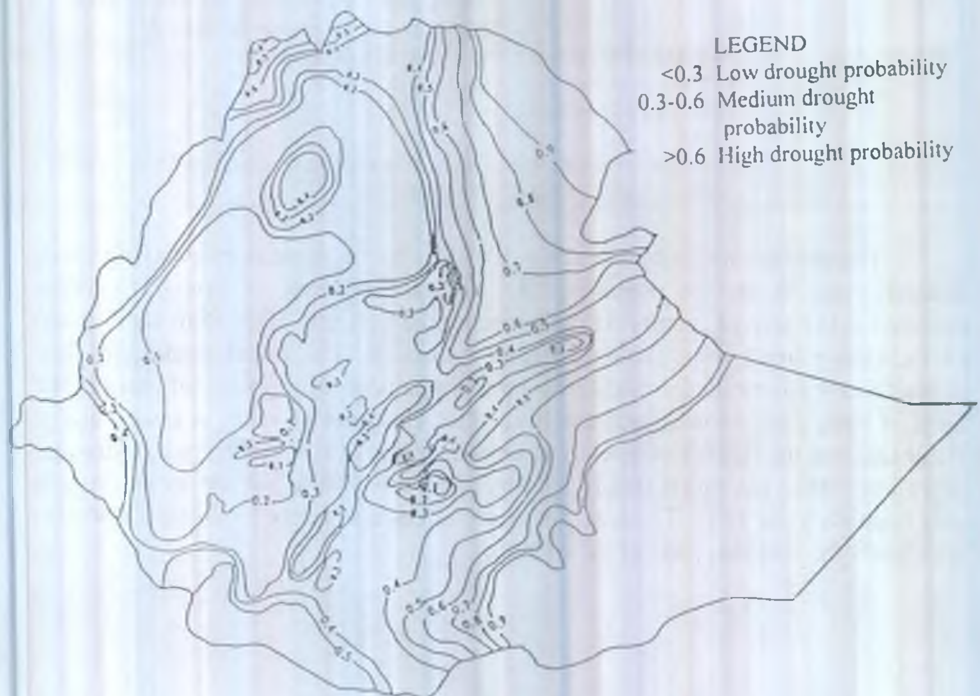

Figure 1. Drought probability map of Ethiopia (Danilov, 1987)

Agricultural drought

To enable quantitative assessment of the growing period, the following working definition is used (FAO, 1978). The growing period is defined as the period (in days) during a year when rainfall exceeds half the PET, plus a period required to evapotranspire water from excess rainfall (or less if not available) stored in the soil profile. The length of a growing period (LGP) is calculated through a simple water balance model that relates rainfall and moisture stored in the soil to the PET of the crop. Crop production can then be estimated at least qualitatively in terms of the time during which plant growth can proceed without serious restriction due to moisture stress (Henricksen and Durkin, 1985).

The choice of half PET as the threshold value for moisture availability is based on considerable experimental evidence, which showed that important physiological changes are induced in many crops below half PET (FAO, 1978; Doorenbos and Kassam, 1979). Half PET has been considered as being sufficient to meet the water requirement of establishing crops. Moreover, germination also proceeds in most crops when rainfall exceeds half PET.

To determine the drought condition, a year with LGP of below 90 days is considered to be a drought year. Because most crops grown in Ethiopia with the exception of some pulses and very low yielding varieties of teff and wheat, require a growing of at least 90 days (Henricksen and Durkin, 1985). The frequency of this below 90 days LGP divided by the total number of observation gives the occurrence of drought over that area. Based on this ratio Reddy (1990) had classified drought from low to very high scale.

This methodology is applied to the Ethiopian condition. The results are indicated in Figure 2 for the first and second seasons, respectively. During the first season most parts of the Amhara regional state with the exception of eastern and southern parts, western parts of Oromiya, Benshangul Gumuz, SNNPR with the exception of parts of South Omo, Gambella Regional State, the highlands of Sidamo, Arsi, Bale and Hararghie the frequency of occurrences of agricultural drought is below 15% which is considered to be low. The frequency of drought is between 15 and 40% (moderate) over northern parts of North Gonder, south-western parts of south Tigrai, western parts of eastern Amhara, most parts of North Shoa, parts of east Shoa, parts of East and West Hararghie, northern parts of Bale, northern and western parts of Borena and parts of South Omo. On the other hand, over most parts of Tigrai, Afar, eastern Oromiya, Somali and southern Borena the frequency of drought is very high. However, the area covered by high drought frequency has decreased and limited itself to the eastern parts of Tigrai, most parts of Afar, most parts of Somali, southern Borena and parts of South Omo during the second season. Most parts of Amhara, western parts of Tigrai, most parts of Oromiya and SNNP are under low drought frequency during the second season as indicated in Figure 2b. The other parts of the country that experience two rainy seasons are under 15 - 40% of drought risk during the second season.

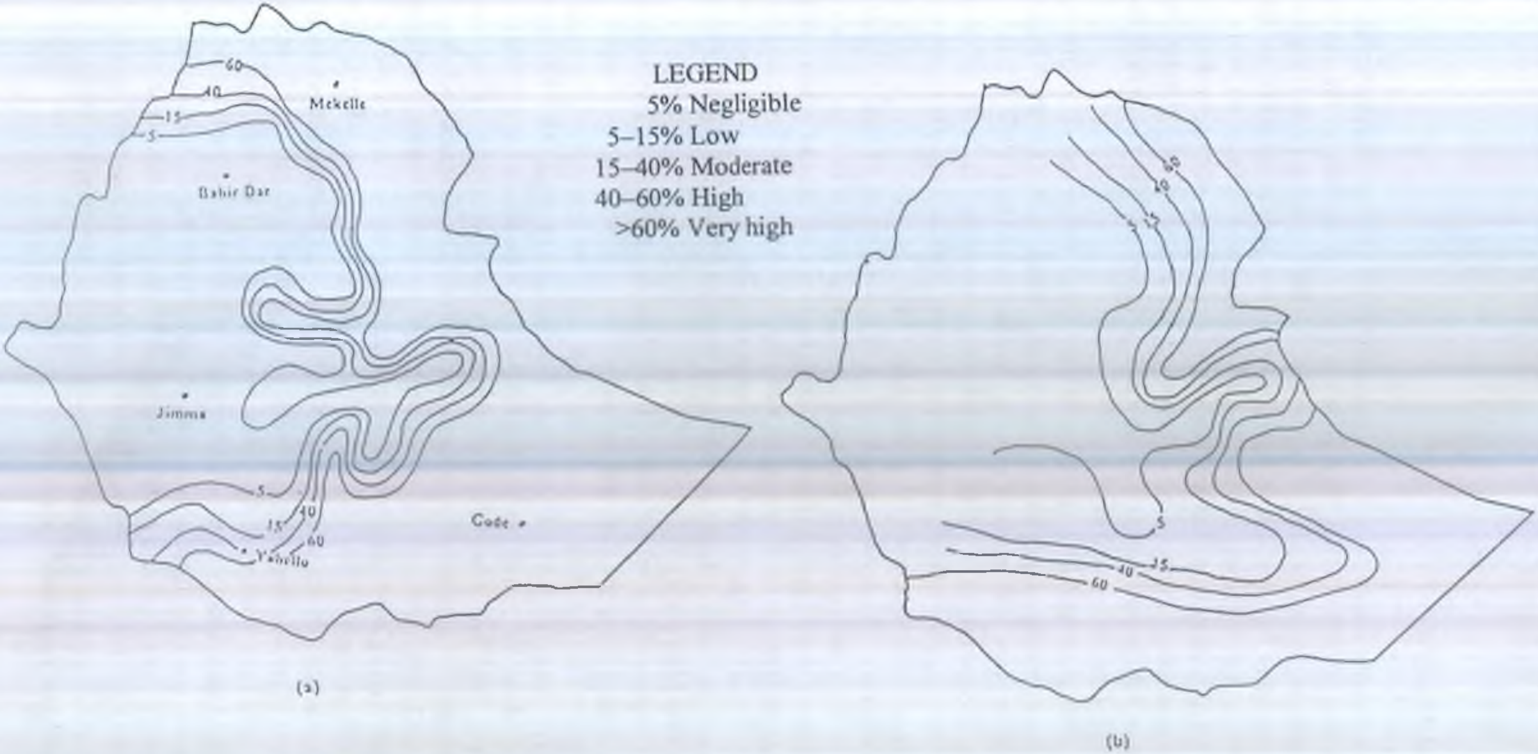

Figure 2. Frequency of drought during the first and the second season over Ethiopia

CONCLUSIONS AND RECOMMENDATIONS

The historical documentation of drought shows recurrent drought in Ethiopia for many years. Compared to the previous centuries (starting from 253 BC), drought appears to show an increasing trend since 1950. The frequency of occurrences of drought over most parts of Tigrai, Afar, parts of eastern and southern Oromiya and the Somali regional state is high. It accounts for above 60%. This indicates that over these parts of the country drought occurs every three years out of five during the first season. During the second season, most parts of eastern parts of Tigrai, most parts of Afar, most parts of Somali and the Borena lowlands of Oromiya encounter 40 - 60 % of drought risk. Over these parts of the country drought occurs every 2 - 3 years out of 5 years during their secondary season. In the areas indicated above, it is very difficult to carry out rain-fed agriculture. Hence, it would be very appropriate to introduce irrigated agriculture to reduce crop failure risk. It is possible to conclude from the results of this study that the frequency of drought occurrence has substantially increased in recent years. Hence, some appropriate controlling measures against the anthropogenic causes of drought should be taken to minimise the impact of drought.

Therefore, future drought assessment should focus on the inclusion of this information on drought assessment. Ethiopia suffers from droughts very often. During some years, almost the whole territory is subjected to drought (NMSA, 1996b). The seriousness of the climate-related food problem in Ethiopia requires further development of early warning activity in this direction. One of the most important aspects of the problem is to define the frequency at which drought may occur during the crop growing season in different parts of the country. Preparation of a drought probability map based on this information can help to develop an early warning system for monitoring drought.

The complex nature of the causes of drought, coupled with its adverse consequences, still provides a challenge to many scientists to investigate the problems of drought in Africa. In Ethiopia, the need to predict drought is very high because severe and prolonged droughts have multidimensional impacts on the progress and development of the country's economy, including suffering and death for thousands of human beings and animals.

Drought prediction is still a fascinating activity. The existing knowledge about drought needs to be improved, and all drought detection and monitoring methods have to be upgraded. New findings are emerging for monitoring and forecasting the global climate system in near real time. Fast communication technology is also being developed to allow distribution and archiving of climate information. Investigations have to use this information for a better prediction of drought. There are different indices for drought monitoring. However, these indices are general. Hence, location and crop specific drought indices should be developed for Ethiopia.

Satellite data on rainfall and vegetation are serving as a good supplement to the conventional data sources for early warning for system for food security for Ethiopia. These data are the only available source of information some remote and inaccessible areas. The fact that these data are continuous in space could be processed for remote areas in near-real time basis has made them indispensable for drought monitoring. Yet, both data sources have got some shortcomings. They are still far away from being the best data. Further effort is required to improve the accuracy of the rainfall estimate and make the best use of the vegetation index data.

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WETLAND SOILS, LAND-USE/LAND COVER CHANGES AND MANAGEMENT PRACTICES IN TULUBE CATCHMENT, ILLUBABOR HIGHLANDS

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ABSTRACT

Natural and human factors have been responsible for the utilisation of inaccessible and marginal lands for agricultural production. Forest and wetland soils are among those widely used in south-west highlands of Ethiopia. This study aimed at characterisation and classification of wetland soils in Tulube catchment, in the vicinity of Mettu area, Illubabor highlands. Field surveys (using FAO/UNESCO guidelines) were collected and analysed on standard laboratory methods and procedures. Field observations, mapping and stereoscopic examinations were applied in the interpretation of the years 1982 and 1998 aerial photographs. The PRA/RRA tools and procedures were used in the identification of traditional/ local soil management practices in the study. Wetland soils showed gleyic properties in effecting prolonged waterlogging. Farmers, being aware of the soil degradation and low agricultural yield, use wetlands for domestic purposes except crop cultivation. However, in the upslope of the undulating plateau both local and modern soil management practices are being applied in order to raise crop yield.

Key words: crop cultivation, gleying, prolonged waterlogging, wetlands

INTRODUCTION

The wetlands of south-west Ethiopia account for approximately 4% of the area. They spread in patches of sizes varying from 10 to several hundred hectares (Wood,nd). They are typical of East African valley bottoms (EWRP, 1997). Wetlands are valuable for determining ground water release, control of flood and erosion, exporting biomass and stabilisation of microclimate (Denny, 1991; Groombridge, 1992; Howard, 1997; Ogawo, 1997). In Illubabor, they are also important bird areas, functioning of sediments and nutrients, and important carbon holders (Wood, 1996).

Despite their drainage problem, wetlands are used for grazing and for production of "spring crop or belg" (Mesfin, 1972). These include sorghum and maize in order to minimise food shortage in the rainy seasons (Hailu, 1963a; 1963b; Westphal, 1974). There have been socio-economic and political pressures that made further invasion of wetland soils for various purposes in the south-west Ethiopia. These include explicit policy of governors after the Italian occupation that encouraged wetland cultivation (Wood, nd), and the construction of artificial dam (namely Fincha in Wellega area) to generate hydroelectric power and to initiate plantation agriculture (Tesfa. 1964). The wetlands cultivation was also aggravated by the Derg regime's campaign towards expansion of food crop production even through the inclusion of wetlands since the drought of 1984/85 (BOA,1997; Wood, nd). Since 1990s, the Menschen Fur Menshen(MFM) continued to implement different development programmes including wetland drainage systems to improve crop yield and food security (Butches and Wood,nd). Moreover, demographic factors enforced farmers to devise mechanisms to the gap of food shortage, after every May to the next season (Wood, 1996; Tsehai, 1994).

The unsustainable system of drainage in the wetlands not only degraded soils but also forced farmers to abandon crop cultivation except controlled grazing during the driest months (Butcher and Wood, nd). Researches undertaken in Illubabor highlands suggested the full utilisation of the wetlands in order to ameliorate the continuous and intensive cultivation of the uplands (Getachew, 1991). Likewise, Hagmann (1991) accepted the land-use system in the Fluvisols of the wetlands.

However, the wetland soils (namely Histosols, Gleysols and even Vertisols) were identified among the problem soils in Ethiopia, whose management and use require special attention (Fikru, 1986). Existing knowledge about organic (and/or wetland) soils is not plentiful (Bridges, 1995). The impact of drainage on wetland soils in Illubabor still awaits further research (Wood, nd). The study at hand, hence, comes up with facts regarding the wetland soils, land/use cover changes management practices in the Tulube catchment.

MATERIALS AND METHODS

The study area

Tulube wetland is found in the south-west region of Ethiopia, 6 km west of Mettu town (600 km south-west of Addis Ababa). It is located between 08° 19' 40" –08° 20' 11" N latitude and 35° 33' 00" –35° 33' 21" E longitude and at an altitude of about 1680 m asl. An undulating dissected plateau marked by valley bottom and interfluves characterises the topography.

Geologically, the area is made up of heavy basalt of the Ashanghe group of Trap series which consists of olivine, basalt, and tuff and rarely of the rhyolites of the Paleocene-Oligocene-Miocene period (Kazmin, 1972). Even though the soils are developed on these Trap series volcanic materials, the effects of parent material are not directly reflected in the soil development (FAO, 1984; Hagmann, 1991) which is apparent from the low pH values.

The area is classified as Wet Woynadega agroclimate (Hurni,1986) having 1847 mm of annual rainfall and about 19°C of mean annual temperature (Table 1). The length of the growing period ranges from 300 to 330 days (FAO, 1984).

Table 1. The Mean Monthly Distribution of Temperature and rainfall (averages from 1967 to 1997)

Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual average
MeanTemp. (°C)	19	21	22	21	21	19	19	19	19	20	20	19	19
Rainfall (mm)	27	28	74	108	228	273	297	281	304	143	60	26	1847

Source: Mettu Hospital station of NMSA, 1998

The climatic condition and its soil resources favour the natural vegetation in the study area. The dominant vegetation comprises broadleaf evergreen forests including the major tree species namely *Albizia gummifera, Croton macrostachyus, Sapium ellipticum, Ficus vasta, Cordia africana, Accacia gerrard, Coffee arabica* as well as *Cyprus* spp. (Kumlachew etal, 1997). Because of continued and intensive human interference, the natural forests have been, and are, being modified in to secondary types that fulfill the immediate economic and domestic advantages to the farmers. The forest stretches have been rendered into discontinuous layer of forest and bush strata.

The valley bottom, with its flat surface slop position, gains water from the undulated plateau and its interfluves. The water-table level depends on the seasonal pattern of rainfall, which follows the rainfall pattern but with a slight time lag (Table 2).

Table 2. The Distribution of Rainfall and Depth of Ground water-table [for some months, 1997]

	Months in 1997								
Records	A	M	J	J	A	S	O	N	D
Rainfall (mm*)	213.4	206.8	282.8	204.1	273.3	240.7	266.0	9.3	4.2
Depth (cm)**	0.09	-1.47	7.11	8.39	5.29	3.35	-0.68	0.00	-4.25

Source: * Mettu Hospital station of NMSA, 1998
** Depth of water-table, EWRP, Mettu Office, 1998

NB: Depth of water-table was recorded from deep wells that were put in the Tulube wetland. The data for the year 1997 were incomplete due to inaccessibility of the data on time.

Thus, farmers make use of these wetland soils for crop cultivation by digging drainage ditches. The continued process of such management practices brought the replacement of wetland papyrus by running grass and thereby facilitated cattle grazing.

Soil sampling

The topographic map of scale 1:50,000 was enlarged four times to give the base map a scale of 1:6250. Measurement and recording of geographic information was undertaken using GPS 40. Physiographic units and sub-units were selected to determine the transect lines and soil pits. The morphological characteristics of soils were described following FAO/UNESCO guidelines (FAO/UNESCO, 1990). The Addis Ababa University Department of Geology carried out analysis of the rock speciemens.

Soil analysis and classification

Samples were brought to the National Soils Testing Laboratory in Addis Ababa for analyses of physico-chemical properties of soils. BD was determined by the weight of oven-dried core sampled soil (105°C) divided by the volume of the soil (core volume 100 cm^3). Particle size analysis was determined using the hydrometer method (Black et al, 1965). The USDA particle size classification (Soil Survey Staff, 1969) was adopted to determine the percentage of sand (2.00 - 0.05 mm), of silt (0.05 - 0.002 mm) and of clay (< 0.002 mm). Soil pH value was measured in 1: 2.5 soil-water mixtures. Electrical conductivity (Ek_{es}) measured in 1:2.5 soil-water suspension at 25°c (Landon, 1984). Organic carbon was determined following Walkley-Black method. The content of total nitrogen was estimated by employing the Kjeldahl procedure whereas the Olsen method was used to determine the available phosphorus (Olsen et al, 1954; Landon, 1984: 110). CEC and the exchangeable basic cations were measured separately by the ammonium acetate method.

After the release of laboratory results, the morphological, physical, and chemical properties of the soils were identified, grouped and tabulated. Under this final phase, the diagnostic horizons and diagnostic properties in the soils were identified and then checked with respect to the requirements.

Classifications of the soils were carried out based on the FAO/UNESCO soil classification system (1990). In order to identify the sub-units of these soils, further consideration of colour based on FAO/UNESCO soil classification (1990) was necessary.

Aerial photo interpretation and analysis

A systematic method was used to collect the desired information pertaining to la.'c use/land cover. It involved aerial photograph interpretation for the year 1982, field observation and mapping of the land-use/land cover in 1998. The stereo pairs of aerial photographs for 1982 (with a scale of 1:20,000) were obtained from the Ethiopian Mapping Agency. Under stereoscope examination and field verification of photo interpretation, aerial photographs were annotated to describe the land-use/land cover units. Further stereoscopic assessment for the second time was employed so as to finalise the details to be mapped in light of the field observation. After the photo interpretation and field observation, the size of land-use/ land cover was transferred/ documented on map with the scale of 1: 6,250 using the enlarged aerial photograph of the study area. The recent (1998) land-use/land cover was obtained and treated by field observation and mapping. Digital planimeter is used to calculate the area of land use/ land cover for the two comparative periods (namely 1982 and 1998). Interpretations of aerial photographs went through the technical process reducing any distortion as much as possible.

Data on soil management practices

During field survey, different PRA/RRA tools and techniques were used, whereby almost al! the inhabitants of the study area and/or their representatives and community leaders were gathered. Then, checklists on topics in relation to history of land tenure, patterns of land-use/ land cover, agricultural land-use system, traditional soil classification, soil management practices, soil erosion and soil degradation were organised. Groups of farmers were organised according to their interest and expertise to provide us with valuable information rearranged, grouped and organised to make the data more suitable for qualitative and/or quantitative analysis. Formal and informal discussions with inhabitants and/or land users were used.

RESULTS AND DISCUSSIONS

Wetland Soils: Morphological and Physical Characteristics

The soils are developed on mafic material (basalt) in undulating plateau with altitudes of about 1680 m asl. They have flat valley floors (0% gradient) on the slope and on valley bottom physiographic position. However, all of these profiles had been saturated for a long period resulting in very poor drainage conditions. The ground water-table was 25 cm in T_{u} - T_3 P_3 and 30 cms in -T_6 P_3 while it was on the surface in the rest of the profiles. These profiles were also sharing similar micro-topography, i.e. drainage furrows/ditches that were dug to drain the excess water from the wetland soils (Solomon et al, 1997).

These wetland soils were marked by very dark gray (N3/), (10YR 3/1), very heavy gray (2.5Y 3/1) and dark gray (10YR 4/1) on the surface horizon. Whereas dark gray (10YR 4/1, 2.5Y 4/1, gray (N 5/, 2.5Y 5/1, 10YR 5/1) and greenish gray (N4/10y) in the subsoil horizon under wet moisture condition (Table, 3).

Table 3. Abbreviated[1] descriptions of different wetland soils

Depth (cm)	Horizon	Colour (wet)	Tex. class	Structure	Consistence (wet)	Roots[2]
Profile: T_u - T_3P_3); Gleyic Alisols; Flat (0%); wetland						
0-15	Ah	10YR 3/1	l	1 to 2-f to m gr	wvs,wvp	m, f
15-35	A_2	10YR 4/1	scl	1 to 2-f to m gr	wvs,wvp	cm, f
35-60	Btg	10YR 5/1	sc	2-f to m sbk	wvs,wvp	cm,f
>60	R	Bed rock				
Profile: T_u - T_7P_1; Gleyic Alisols; Flat (0%); wetland						
0-30	Ah	10YR 4/1	scl	1 to 2-f to m gr	wvs,wvp	m, f
30-60	Btg	10YR 4/1	scl	1 to 2-f to msbk	wvs,wvp	cm, f
60-95	B_g	10YR 4/1	scl	2-m, sbk	wvs,wvp	cm, f
95-155	C	10 YR3/1	s	1-c	wso,wpo	fw,f
>155	R	Bed rock				
Profile: T_u - T_7P_3) Gleyic Alisols; Flat (0%); wetland						
0-20	Ah	2.5Y 3/1	scl	1 to 2-f to m gr	wvs,wvp	cm, f, vfw, md
20-40	Btg1	2.5Y 4/1	cl	2-f to m gr	wvs,wvp	cm, f
40-80	Btg2	2.5Y 5/1	cl	2-m abk	wvs,wvp	cm,f
>80	R	Bed rock				
Profile: Tu - T_6T_3: Gleyic Luvisols; nearly level (1%); Valley bottom						
0-30	Ah	N 3/	scl	1 to 2-f to m, gr to sbk	wvs, wvp	m, f
30-65	Btg1	N 5/(10Y)	cl	2-m, gr to sbk	wvs, wvp	Cm, f
65-100	Btg2	N 5/1	c	2-m, abk	wvs, wvp	Cm, f
100-135	BC*	2.5Y4/3	sc	1 to 2-m to c	wso, wpo	
>125	Soil continues below this layer (alluvial sediments)					
Profile: T_u - T_4P_3; Gently sloping (4%); wetland						
0-30	Ah	7.5YR 3/2	scl	1 to 2-to m, gr	wvs, wvp	cm, f; vfw, m
30-60	A_2	10YR 4/1	scl	1 to 2- m gr to sbk	wvs, wvp	cm, f
60-115	Bw	N 3/	scl	2- m, sbk	wvs, wvp	cm, f
> 115	R	Bed rock				

NB: [1]. Abbreviations used for the descriptions of soil profiles are adopted from Soil Survey Staff (1969) and FAO (1990). * Augers were used for Horizon BC

The chrome of 2 or less generally indicates grayer soils (Mitsch and Gosselink, 1993). The soil turned more gray with depth due to the effect of poor drainage. The prevalence of gray on the soil minerals is attributed to the removal of free-iron under reducing conditions (Buol et al., 1975).

The soils in the subsurface horizons consist of ferric-iron mottles (having red to reddish brown colour) on the soil matrix that suggests the effect of poor drainage due to high level of ground water-table and/or weathering (Young, 1976) under the process of gleization. The pale colours together with mottling were evidences of the comparatively low level and/or uneven distribution of sesquioxides in the Alisols (Driessen and Dudal, 1991) which may suggest the relatively low effects of sesquioxides, i.e. low stabilisation of the soil structure. The subsoil horizons have higher clay content than the overlying surface horizon that implies the accumulation of clay. The mean silt content and the silt-to-clay ratio are relatively higher in the surface horizons. This may suggest the existence of weatherable minerals and also of the effect of basic parent materials. The silt content and S/C ratio were almost uniform and medium throughout the T_u-T_4P_3 profile. This may suggest relatively moderate weatherable minerals. However, the comparative rise of the ratio in the surface horizon may reflect considerable leaching process. These soils exhibited weak to moderate, fine to medium granular in the Ah horizons, and moderate, fine to medium subangular to angular blocky in the subsoil (B) horizons. Whereas the C-horizon was characterised by weak, fine rock structure and the profile has a C-horizon as well that is marked by very dark gray (10YR 3/1) matrix with yellowish red (5YR 5/8) mottles.

The Ah horizons have heavy/darker colour that may be caused by humus (Young, 1976: 86). The average clay content of the Ah (A_2) horizons were 27.5% but ranged from 25 to 31% whereas those of the Btg (Bg) horizons were 33.8 and ranged from 25 to 39%. The effect of gleyic together with the accumulation of clay in the B-horizons was apparent. This material might be derived through "translocation from the topsoil, but is deposited when the soil is submerged (Young, 1976).

The fine roots in the soils showed from many to common fine and very few medium roots. However, in Tu - T_7 P_1 the last two horizons have very few coarse roots. Development of the soil profile was from moderately deep (60 cm in T_u - T_3 P_3 and 80 cm in T_u - T_3 P_3) to very deep (> 155 cm in T_u - T_3 P_3). There were earthworms that were more apparent in the top horizon but the soils in T_u - T_3 P_3 have earthworms throughout the profile.

The roots in the topsoil horizon and immediately underlying it were ranged from undecomposed to partially decomposed fibres, which suggest relatively low decomposition (Fitzpatrick, 1983). These soils exhibited weak to moderate, fine to medium granular in the Ah horizons, and moderate, fine to medium subangular to angular blocky in the subsoil (B) horizons. Whereas the C-horizon was characterised by weak, fine rock structure and the profile has a C-horizon as well that is marked by very dark gray (10YR 3/1) matrix with yellowish red (5YR 5/8) mottles. The weak, poorly developed structure of the soil is attributed to poor drainage and humid climatic conditions (Landon, 1984).

Chemical characteristic

The soil reaction ranged from extremely acidic to strongly acidic (pH value 4.16 - 5.11). The electrical conductivity was around 0.05 ds/m that clearly suggests non-salinity of the soils (Landon, 1984). The organic carbon in the Ah (A_2) horizon ranged from 3.66% to 5.47% while it ranged from 0.66 to 1.96% in the subsoil horizons. The relatively higher content was in the Ah (A_2) than those in the subsoil [Btg (Bg)] horizons. This shows the concentration of OM at the surface horizon. However, the soil in the profile Tu-T_4 P_3 has a relatively higher deposition of OM in the Bw horizon. The total N ranges from 0.29 to 0.50% (very high) at the top [Ah (A_2)] horizons whereas it was from 0.30 to 0.66% in the Btg (Bg) horizons. The value of total N corresponds to that of organic carbon.

Table 4. Some Selected Physico-Chemical Properties of the Pedons

Depth (cm)	Hori-zon	BD (gm/cm^3)	Texture S	Si	C	class	S/C ratio	pH 1:2.5 H_2O	EC (ds/m)	Org. C (%)	Total N (%)	C/N
Profile: T_u - T_3P_3; Gleyi-Alisols, very shallow GWT* (at 20cm)												
0-15	Ah	0.66	45	30	25	L	1.20	4.52	0.07	5.47	0.50	11
15-35	A_2	1.59	47	24	29	SCL	0.83	4.58	0.04	2.83	0.30	9
35-60	Bt_g	1.79	47	16	37	SC	0.43	4.85	0.03	1.96	0.30	10
Profile: T_u - T_7P_1; Gleyi-Alisols; Very Shallow GWT* (at surface)												
0-30	Ah	0.80	55	20	25	SCL	0.80	4.16	0.04	6.86	0.53	13
30-60	Btg	1.21	47	20	33	SCL	0.61	4.37	0.06	4.67	0.34	14
60-95	B_{g2}	1.55	55	20	25	SCL	0.80	4.53	0.03	3.91	0.23	17
95-155	C**		89	4	7	S	0.57	4.79	0.02	1.26	0.07	18
Profile: T_u - T_7P_3; Gleyi-Alisols, very shallow GWT* (at 20cm)												
0-20	Ah	0.82	47	22	31	SCL	0.71	4.42	0.06	5.71	0.43	13
20-40	Btg_1	1.10	43	18	39	CL	0.46	4.45	0.04	3.13	0.34	9
40-80	Btg_2	1.82	45	20	35	CL	0.57	4.86	0.02	1.60	0.13	12.
Profile: T_u - T_6P_3; Gleyic Luvisols; Shallow GWT* (at 30cm)												
0-30	Ah	1.28	45	26	26	scl	1.00	5.11	0.06	3.65	0.29	12.
30-65	Btg_1		45	20	35	cl	0.57	5.27	0.02	0.66	0.08	8
65-100	Btg_2		43	10	47	c	0.21	5.08	0.02	0.40	0.04	10
>100	BC**		65	18	17	sc	1.06	4.92	0.02	0.30	0.03	11

NB: *-GWT - Ground water-table

**-The horizon is sampled using an auger due to the high amount of ground water.

However, this value in the surface and subsoil does not indicate the available N since organic N must be mineralised into ammonia and nitrate. This process of mineralisation may be inhibited/or considerably reduced by the low pH that is reflected in low microbiological activity. Furthermore, it may lead to a reduction in the availability of N since about 95 to 98% are fixed in an organic or unavailable form (Hagmann, 1991).

The C/N ratio 12 implies the medium degree of humification of the organic matter (ILACO, 1981 cited in Hagmann, 1991). The C/N ratio in the surface soil of profile Tu-T_4 P_3 was 10 which indicates satisfactory mineralisation of N (Young, 1976). These generally low contents of available P in the surface and subsurface horizons are markedly affected by the soil reactions and corresponding fixation. Furthermore, it implies the presence of considerable decrease in the availability of primary and secondary minerals (Young, 1976). However, profile T_u - T_3 P_3 has values of about 16.9 mg/kg that rated high ((ILACO, 1981 cited in Hagmann, 1991). This increment may be related to apatite (Thompson and Troen, 1978) since appatite was one of the accessories in the parent materials.

The CEC value of the top horizons ranged from 27.2 to 32.4 cmol (+)kg^{-1} soil whereas in the subhorizons were 17.8 to 32 cmol (+)kg^{-1} soil (Table 5 &7). The mean values of profile Tu-T_4 P_3 are 33.2 cmol (+) kg^{-1} soil in the A1& A2 horizons while it was 32 cmol (+) kg^{-1}soil in the Bt horizons, both of which indicate higher value (Landon, 1984). The CEC computed against clay fraction suggests that the clay mineral may consist of Illite, Chlorite having reserves of potassium (Landon, 1984; Young, 1976).

The BS of these soils showed relative rise in the subsoil than those of the surface horizons (Table 5). This may be in response to the relative rise in their pH value. Because of the low BS and pH values, aluminium may be released from decaying minerals whose adequate discharge was hampered by low permeability and poor drainage (Driessen and Dudal, 1991). The Ca/Mg ratio of the surface soils of these horizons imply approximately optimum range for most crops (Landon, 1984).

Soil classification

The Ah(A_2) horizons of these soils fulfill the requirements for the Umbric A horizons because they have high organic matter content. Mostly the colour value and chroma are less than 3.5 and the BS is <50% (Table 5). The topsoil with unconsolidated materials can not fulfill the requirements of H horizons since the organic carbon was less than 8%. However, the Umbric A horizons were saturated with water for prolonged periods. The Ah(A_2) horizons are darker than the adjacent underlying horizons, as the case indicated in FAO/UNESCO(1990).

Table 5. Some Selected Physico-Chemical Properties of the Pedons

Depth (cm)	Horizon	Exchang. basic cations cmol (+) kg^{-1} soil Na	K	Ca	Mg	TEB	CEC cmol (+) kg^{-1} Soil	Clay	BS (%)	Av.P mg/kg	EPP (%)	ESP (%)	Ca/Mg ratio
Profile: T_u - T_3P_3; Gleyic Alisols													
0-15	Ah	0.39	0.27	5.39	1.58	7.63	27.20	33.44	28	8.96	0.99	1.43	3.41
15-35	A_2	0.35	0.17	4.04	1.42	5.98	28.20	63.58	21	7.60	0.60	1.24	2.85
35-60	Btg	0.31	0.16	5.04	1.75	7.26	21.00	38.54	35	4.80	0.76	1.48	2.88
Profile: T_u - T_7P_1; Gleyic Alisols													
0-30	Ah	0.55	0.35	3.74	1.33	5.97	27.40	19.12	22	7.56	1.28	2.01	2.81
30-60	Btg1	0.47	0.20	3.84	1.33	5.84	26.80	32.42	22	5.16	0.75	1.75	2.89
60-95	Bg2	0.39	0.13	4.99	1.50	7.01	21.20	30.48	33	3.86	0.61	1.84	3.33
95-155	C	0.39	0.08	1.10	0.33	1.90	6.60	32.29	29	10.44	1.21	5.91	3.33
Profile: T_u - T_7P_3; Gleyic Alisols													
0-20	Ah	0.55	0.28	6.29	1.58	8.70	29.60	32.02	29	13.28	0.95	1.86	3.98
20-40	Btg	0.39	0.18	5.09	1.50	7.16	28.80	46.16	25	6.40	0.63	1.35	3.39
40-80	Bg2	0.39	0.15	6.59	2.00	9.13	21.40	45.42	43	3.96	0.70	1.82	3.29
Profile: T_u - T_6P_3; Gleyic Luvisols; Shallow GWT (at 30cm)*													
0-30	Ah	0.54	0.73	9.03	2.67	12.97	28.80	62.38	45	3.38	2.53	1.88	3.38
30-65	Btg_1	0.38	0.18	6.39	2.33	9.28	17.80	44.34	52	2.56	1.01	2.13	2.74
65-100	Btg_2	0.47	0.30	8.98	3.08	12.83	25.20	50.68	51	1.02	1.19	1.87	2.92
100-125	BC**	0.47	0.25	13.52	4.41	18.65	35.60	203.29	52	16.90	0.70	1.32	3.07

NB: Most of the data are rounded two decimal fraction; ** for abbreviation, refer Table 4

Table 6. Physico-Chemical properties of the soils in Profile T_u - T_4P_3

Depth (cm)	Horizon	BD (gm/ cm^3)	Texture S	Si	C	clas	Sa: Silt ratio	Silt: clay ratio	pH 1:2. $5H_2O$	EC (ds/m)	Org. C. (%)	OM (%)	Total N (%)	C/N
Profile: T_u - T_4P_3; very shallow GWT (at 20 cm)														
0-30	A_1	0.74	55	18	27	SCL	3.05	0.67	4.25	0.05	3.99	6.88	0.42	10
30-60	A_2	0.82	55	18	27	SCL	3.05	0.67	4.27	0.06	4.99	8.60	0.46	11
60-115	Bw	0.95	51	18	31	SCL	2.83	0.58	4.31	0.04	5.07	8.74	0.40	13

Depth (cm)	Horizon	Exchangeable basic cations [cmol (+) kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol (+) $kg)^{-1}$] Soil	Clay	BS (%)	Avail. P (mg/kg)	EPP (%)	ESP (%)	Ca/Mg ratio
Profile: T_u - T_4P_3;													
0-30	A_1	0.47	0.28	2.74	0.83	4.32	32.4	69.04	13	10.08	0.86	1.45	3.30
30-60	A_2	0.47	0.23	3.54	1.25	5.49	34.0	62.22	16	5.84	0.68	1.38	2.83
60-115	Bw	0.39	0.18	3.54	1.17	5.28	32.0	46.84	17	3.34	0.56	1.22	3.03

The B-horizons in these profiles were argic B-horizons (Tables 4 and 5) and also show gleyic properties due to the shallow ground water-table. Thus, the morphological, physical, bio-chemical and chemical characteristics of the soils in profiles T_u - T_3P_3, T_u - T_7P_1, and T_u - T_7P_3 qualify for Gleyic Alisols of the FAO/UNESCO soil classification system. In addition to the argic B-horizons, the soils in profile Tu-T_6 P_3 have PBS of >50% throughout the subsoil horizon, but lacking mollic A horizon and the E horizon. They show gleyic properties within 100 cms of the surface. Thus, they fall in Gleyic Luvisols (FAO/UNESCO, 1990). The soils in profile Tu-T_4 P_3 fulfill the requirements of diagnostic Cambic B-horizons. These soils showed gleyic properties within 50 cm of the surface. The visible evidences were the dark gray colour (10YR4/1) in the A_2 horizon within 30 cm of the surface and very dark gray (N3/) in Bw horizon within 60 cm of the surface(Table 6). The absence of argic properties and permafrost in the profile were the other requirements that enabled to classify the soils in profile T_u - T_4 P_3 under Umbric Gleyisols of the FAO/UNESCO (1990) soil classification system.

Pattern of land-use and land cover changes

In the study area, five major land-use/land cover categories were identified (Table 7). The data indicated changes in these categories between 1982 and 1998. Cultivated land showed an increase by 62%while forestland declined by 43%. Both of them changed at an average of 1% per year. In Tulube wetland, hydromorphic grasslands are used for livestock grazing and browsing during the short dry months. Such grasslands consist of grass species that are adapted to clayey soils and poor drainage condition (Young, 1976).

Table 7. Patterns of distribution of landuse/ land cover and their changes in Tulube Catchment

Land-use/ Land cover type	Areas in Hectare				Changes in (ha)	Changes in (%)	Average Rate[1]
	1982		1998				
	Ha.	%	Ha.	%	1998-1982	1998-1982	(%/ Yr.)
Forestland[2]	24.41	33.59	13.86	19.06	-10.55	-14.53	-0.91
Bushland[3]	6.95	9.57	7.05	9.70	+0.10	+0.13	+0.01
Cultivated	19.50	26.83	31.64	43.52	+12.14	+16.69	+1.04
Grassland[4]	17.36	23.89	14.53	19.99	-2.83	-3.90	-0.24
Wetland	4.44	6.12	5.62	7.73	+1.18	+1.61	+0.10
Total	72.70	100	72.70	100			

Source: Aerial photograph interpretation (1982)

NB: [1]the spatial and temporal variations throughout the time perspectives are assumed to have taken place at regular/uniform trends..

[2]Forestland includes dense woodland and modified coffee forests.

[3]Bushland also includes complex land cover of bush & grass where bush found in relatively larger portion.

[4]Grassland also consists of fallow lands and those with few shrubs.

Grasslands in the interfluve's slopes in the upslope (through fallowing) are used for crop cultivation. Thus, absence of remarkable changes in the grass and bush lands may relate to the soil management of the inhabitants.

Even though there are no quantitative data for the periods prior to 1982, it can be deduced that land under crop cultivation had increased prior to 1982. Land under forest cover showed a relative change in Mettu area. The change in the forest land coverage in the period prior to 1982 was due to 1) coffee development programmes that increased the areal coverage of forest land between 1960 and 1975 and/or 2) land proclamation of 1975 that led to an expansion of cultivated land and hence reduction of forest land cover from 1975 to 1982 (Solomon, 1994).

Therefore, socio-economic phenomena together with land/soil management practices are important for the apparent changes of the land use/land cover in Tulube wetland and its catchment.

Soil management practices

The decisions made by farmers regarding soil management and conservation practices are dependent upon the level of perception on soil hazards and upon opinions and feelings of the beneficiaries as well as the accessibility efficiency and utility of range of measures (Belay, 1992). Both of these interplay by the farmers to undertake soil management practices in the study area. Thus, both local and improved methods of soil management practices were used by the farmers.

Only two to three generations ago shifting cultivation system was clearly visible. However, with population pressure and soil depletion, it was replaced by short/bush fallow periods. The decline in fallow periods together with the fragile nature of the soils made them vulnerable to accelerated erosion.

Therefore, farmers make use of a combination of measures because of the absence of a self-sufficient measure to maintain soil fertility in Tulube wetland (Solomon, 1994). The most important components of these management measures are summarised in Table 8.

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Table 8. Soil Management Practices by Slope and Land-Use/ Land Cover Types in Tulube Catchment

Slope type	Soils in the Uplands: Cultivated	Soils in the Uplands: Uncultivated	Wetlands Soils
Steep	- Crop rotation with fallowing - Drainage ditches and furrows - Inorganic fertilizers application (rarely under planted coffee)	Traditional Agroforestry	—
Moderate	- Crop rotation with fallowing - Drainage ditches and furrows - Inorganic Fertilization	Traditional Agroforestry, Fallowing with crop rotation	—
Flat/Level	- Pen-manuring - Inorganic Fertilization - Traditional Agroforestry, mainly on crest position	- Fallowing	- Drainage ditches/ furrows

Source: Solomon et al. (1997)

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Dear Conference Participants

I adies and Gentlemen

It is a great honour and privilege to get this opportunity to be at this conference with you and make a closing remark for the sixth Conference of the Ethiopian Society of Soil Science.

The major theme of the Conference is "Challenges of Land Degradation to Agriculture in Ethiopia". This issue is timely and very urgent. Consequently, there is a pressing need to assess, analyse discuss and seek solution for this important problem. The urgent need to combat rural poverty, to conserve and regenerate the deteriorating resource base of small farmers particularly requires active new agricultural research and resource management strategies. These were highlighted by the different papers presented and the discussion by the panelists during this conference.

It has long been argued that a sustainable agricultural development strategy that is environmentally enhancing must be based on agroecological principles and on a participatory approach for technology development and dissemination. Focused attention to the linkage between agriculture and resource management will help greatly in solving the problem of poverty, food security and environmental degradation.

The presentations made in the past two days indicate a shift from the classical field and laboratory experimental results to practical, multi-disciplinary, agroecological perspective, participatory and highly sensitive issues.

This shift of emphasis has a basic reason. The base for food production, which is land, is highly threatened and is becoming less productive. Research cannot alleviate this alone. That is why a participatory approach has become necessary. The other is the multidisciplinary aspect. We have to see situations from many angles, i.e. the impact of a field experiment and measuring a few parameters, since the conclusions reached based on these alone could have been influenced by other factors. Therefore, in order to go out of the vicious circle, it is important that we go for broader perspectives, without de-emphasising the need for specific and basic research issues.

In this aspect, some of the presentations made yesterday and today, particularly the lead papers and the panel discussion are steps in the right direction, and should be pushed further. Focusing on the Research Directions and Approaches, I would like to stress that these have to be dynamic and accommodative of new ideas. In addition, we should shape our approach based upon the practical experience and field back what we get through the course of our undertakings. This calls for open discussion and dialogue, and should be viewed constructively. EARO has developed research strategies in order to guide the research undertakings. These need to be enriched with them. Their implementation also needs to take into consideration the wide range of stakeholder – farmers, development personnel, policy makers, researchers at both federal and regional levels. We have to modify our approach in accordance with the changing situations. Unless we do that, it would be difficult to register results easily. I do not mean to imply that we have to come up with new directions every time, but to build upon and strengthen the existing ones, thus allowing dynamism.

Research is an expensive venture. Accordingly, we should try to be cost-effective by not repeating activities here and there. If possible, it would be wise to plan ahead of time to include relevant agroecologies so that the result obtained does address such conditions. In other cases, we can check the applicability of research finding to similar agroecologies. This requires crossing over of boundaries (if at all they exist). Wherever possible, complimentarily of efforts should be maximised. In research planning and evaluation, we should be able to invite experts from all sectors for enriching our efforts.

What is expected from the ESSS?

So far, the ESSS has been hosting a conference biennially; it has regularly been publishing a Journal of Natural Resource in collaboration with the forestry society. Although these are commendable activities, I feel there is more to be done. It has also been publishing newsletters occasionally.

Professional societies such as the ESSS do assemble experts from various organizations with different purposes and mandates. Therefore, they should make sure that issues of concern are beyond research and academic, as it has been the case traditionally in the past. ESSS should have an influence on the research, academic, policy and other interventions.

Through various means (such as discussion groups, newsletters, brochures and the media) it should make sure that pertinent issues are addressed and disseminated to the public. The ESSS newsletter should be able to relay information in the aspects of land degradation, natural resource, and environment from many angles. For example, new information, abstracts of publications, database etc. need to be part of the contents of the newsletters to disseminate the information to the end users. Similarly, the discussion groups should involve all sectors of the community.

If there should be a professional society that should have made rigorous awareness campaign. then it should be the ESSS, for the reasons mentioned. I therefore expect that the ESSS would make significant strides towards realising these issues.

Several conclusions can be drawn from the rich discussions held during the workshop:

- Improving the management of natural resources is not only linked to the alleviation of poverty, but it is also essential to achieving sustainable productivity increases in traditional and ecologically vulnerable areas. For this to happen, the proposed NRM strategy, however, has to deliberately target the poor, and not only aim at increasing production and conserving natural resources, but to crate employment, provide access to local inputs and output markets.
- Researchers and rural development practitioners will need to translate general ecological principles and natural resource management concepts into practical advice directly relevant to the needs and circumstances of smallholders.
- Any serious attempt at developing sustainable agricultural technologies must bring to bear local knowledge and skills on the research process. Particular emphasis must be given to involving farmers directly in the formulation of the research agenda and on their active participation in the process of technological innovation and dissemination. The focus should be in strengthening local research and problem-solving capacities. Organising local people around NRM projects that make effective use of traditional skills and knowledge provides a launching pad for additional learning and organising, thus improving prospects for community empowerment and self-reliant development.
- A pro-poor NRM strategy should include delineating an agenda for policy formulation that facilitates participatory natural resource management practice based on both farmer-based traditional innovations and selected external inputs when appropriate. The strengthening of local institutional capacity and widening access of farmers to support services that facilitate use of technologies will be critical. There is also need to increase rural incomes through interventions other than enhancing yields, such as complementary marketing and processing activities. To design and implement such an agenda, cooperation among governments, international agencies, NGOs, committed members of the private sector, and the technical and scientific communities will be required.

Having said this, I declare the sixth Conference of the Ethiopian Society of Soil Science officially closed.

I thank you.

Ethiopian Society of Soil Science
Members list attained on 6th Biennial Conference
(Feb. 28 - March 1, 2002)

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1	Abay Ayalew
2	Abebe Fanta (Dr.)
3	Abebe Yadessa
4	Abiy Fantaye
5	Ademe Adenew (Dr.)
6	Adugna Berhanu
7	Alemayehu Mamo
8	Alemayehu Tafesse
9	Alemu Mekonnen
10	Amanuel Tamiru
11	Ameha Yaekob
12	Aregu Amsalu
13	Asfaw Hailemariam (Dr.)
14	Asgelil Dibabe (Dr.)
15	Askal Alamirew
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17	Assefa Taa (Dr.)
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20	B.B. Mishra (Prof.)
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22	Bamlaku Balkew
23	Belay Demissie (Dr.)
24	Belay Tseganeh
25	Berhane Kidane
26	Bitew Genet
27	Brhane Tadesse
28	Brook Tekele
29	Chali Hundessa
30	Daniel Alemayehu
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32	Dawit Deguefu (Dr.)
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60	Girma Abera
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