RESPONSE OF ETHIOPIAN FIELD PEA (*PISUM SATIVUM* L.) CULTIVARS TO PHOSPHORUS FERTILIZATION OF NITOSOLS

by

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A thesis submitted in accordance with the requirements for the Philosophiae Doctor degree in the Department of Soil, Crop and Climate Sciences, Faculty of Natural and Agricultural Sciences at the University of the Free State, Bloemfontein, South Africa

MAY 2003

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DECLARATION

I declare that the thesis hereby submitted by me in accordance with the requirements for the Philosophiae Doctor degree in the Department of Soil, Crop and Climate Sciences, Faculty of Natural and Agricultural Sciences at the University of the Free the State is my own independent work and has not previously been submitted by me at another university. I further concede copyright of the thesis in favour of the University of the Free State.

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DEDICATION

To the memory of my mother, W/o Zewditu Alameneh, my father, Ato Ghizaw Amanu and my brother B.G. Yilma Ghizaw who are all deceased and are unfortunate to see the efforts they put in me to get me to this educational level.

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LIST OF ACRONYMS

m.a.s.l.	meter above sea level
AEZs	Agro-Ecological Zones
CSA	Central Statistical Authority
CIMMYT	The International Maize and Wheat Improvement Center
EARO	Ethiopian Agricultural research Organization
EPID	Extension Project Implementation Department
FAO	Food and Agricultural Organization of the United Nations
FSSA	Fertilizer Society of South Africa
GIS	Geographical Information System
HARC	Holetta Agricultural Research Centrer
ICRAF	International Council for Research in Agro Forestry
IITA	International Institute of Tropical Agriculture
KARC	Kulumsa Agricultural Research Center
MOA	Ministry of Agriculture
NFIA	National Fertilizer Industry Agency
NMSA	National Meterological services Agency
NSRC	National Soil Research Center
UFS	University of the Free State
WADU	Wolaita agricultural Development Unit

ABSTRACT

Field pea (*Pisum sativum* L.) is the third most important grain legume in Ethiopia where its productivity is constrained by several biotic, abiotic and socioeconomic factors. The crop is grown mainly on a wide range of soil types throughout the highlands (1800 to 3200 m.a.s.l.) in well drained soils like Nitosols that developed from volcanic rocks. Nowadays the blanket recommendation of diammonium phosphate (DAP) at 100 kg ha^{-1} to this low input crop is questioned by the farmers and development workers. Hence, experiments have been conducted with the major objective of quantifying the response of Ethiopian field pea cultivars to phosphorus fertilization of Nitosols under both glasshouse and field conditions.

Glasshouse experiments: Topsoil from Ilala and Cheffa were used. Experiments were laid out in a split plot design with three phosphorus fertility levels (Extractable phosphorus: low = 5, medium = 15 and high = 30 mg kg^{-1}) as the main plot treatments and factorial combinations of two pea cultivars (Ilala soils: Holetta and G22763-2C; and Cheffa soils: Tegegnech and Cheffa local) and six phosphorus application rates (0, 7.5, 15, 30, 60 and 120 mg P kg^{-1}) as the sub-plot treatments in a randomized complete block design with four replications. The phosphorus fertility levels together with the phosphorus application rates had positive influences on the growth and development of the pea crop as manifested in the biomass yield of the different cultivars. Critical phosphorus levels were estabilished by relating relative biomass yield to extractable soil phosphorus. In the case of the Bray 2 extractions, the critical phosphorus levels for Ilala soils were 14 and 15 mg P kg^{-1} for cvs. G22763-2C and Holetta respectively, for Cheffa soils 17 and 20 mg P kg^{-1} for cvs. Cheffa local and Tegegnech respectively. However, in the case of Olsen extractions the critical phosphorus levels for Ilala soils were 17 and 27 mg P kg^{-1} for cvs. Holetta and G22763-2C respectively, and for Cheffa soils 20 and 22 mg P kg^{-1} for cvs. Cheffa local and Tegegnech respectively

Field experiments: Two sets of experiments were conducted, viz. the first set at Holetta (1996 to 1999) and Bekoji (1996 to 1998) and the second set in 2001 at Ilala and Cheffa. For the first set of experiments a factorial combination of five phosphorus rates (0, 10, 20, 40 and 60 kg P ha^{-1}) and three pea cultivars (Holetta site: Tegegnech, G22763-2C, Holetta local ; and Bekoji site

Tegegnech, G22763-2C and Cheffa local) were laid out in a randomized complete block design with four replications. On the other hand, for the second set of trials a split plot design was used with three phosphorus fertility levels (Extractable phosphorus: low = 5, medium = 15 and high = 30 mg kg^{-1}) as the main plot treatments and the factorial combinations of five phosphorus application rates (0, 10, 20, 40 and 80 kg ha^{-1}) and two pea cultivars (Ilala site: G22763-2C and Holetta; and Cheffa site: Tegegnech and Cheffa local) as the sub-plot treatments which were replicated four times. At the Holetta and Ilala sites, grain yield response of the pea crop to phosphorus application was poor regardless of the phosphorus application rates or the cultivars. As a result, low marginal rate of returns (MRRs) were computed which implicated that phosphorus fertilization is not economically viable. On the contrary, at the Bekoji and Cheffa sites, the grain yield response of the pea crop to the application of phosphorus was good with significant differences between phosphorus fertility levels and cultivars. The interaction of phosphorus application rate and cultivars was significant ($p < 0.05$). A MRR of 100% was obtained at an application of 21 kg P ha^{-1} for cv. Tegegnech, 10 kg P ha^{-1} for cv. G22763-2C and 5 kg P ha^{-1} for cv. Cheffa local. The 100% MRR computed implicated that phosphorus fertilization to all cultivars at the low phosphorus fertility level was economically viable with the current prices of grain and fertilizer in the zone.

Unfortunately, no critical soil phosphorus levels could be estabilished under field conditions. The critical soil phosphorus levels that were established under glasshouse conditions should therefore still be validated in the field. However, the fact that the pea crop did respond to phosphorus application mainly at the low phosphorus fertility levels in the field confirms already to some extent their validity. In general, the improved pea cultivars responded better to phosphorus fertilization than the local cultivar. A thorough investigation on phosphorus use efficiency of pea genotypes to identify low phosphorus requiring ones should be considered to benefit resource poor farmers. The aspect of soil pH modifications through liming, and the use of non-nitrogenous phosphorus fertilizer sources for field peas are recommended.

CHAPTER 1

MOTIVATION, HYPOTHESIS AND OBJECTIVES

1.1 Motivation

Peas (*Pisum sativum* L.) were one of the first crops cultivated and have been a staple diet of mankind and livestock since the dawn of civilization (Evans & Slinkard, 1975; Davies, 1979; Gane, 1985; Davies *et al.*, 1985; Orman & Belaid, 1990). According to Davies *et al.* (1985), peas originated from four possible geographical regions, namely Abyssinian (Ethiopia), Mediterranean (Turkey, Greece, Yugoslavia and Lebanon), Near East (Iraq, Iran and Caucasia) and Central Asian (North-west India, Pakistan, USSR and Afghanistan) from where dispersion occurred to the temperate as well as the tropical regions of the world. Snoad (1985) recognizes four classes of pea production, viz. green (harvested at a tender green stage of the seeds when the sugar content is relatively high which are immediately canned or frozen), dry (harvested at the dry stage), forage (whole plant, if not used for grazing, is harvested at the flat pod stage) and green manure (incorporated to enrich the soil with organic matter and hence nitrogen) peas.

Green and dry peas are produced in different parts of the world (Davies, 1979; Davies *et al.*, 1985; FAO, 1999). The global area and production of dry peas are estimated at 6.5 million hectares and 12 million tonnes in more than 80 countries, which is about seven and half times greater than that for green peas (FAO, 1999). This renders the pea crop to be one of the world's four most important grain legumes (Davies, 1979; Davies *et al.*, 1985; Hulse, 1994; FAO, 1999). The leading green pea producing countries include the USA, UK, France, India, USSR and China, while Ethiopia records the largest area of dry pea production in Africa, amounting to 159200 ha with an average grain yield of only 0.81 t ha^{-1}. These respectively account for almost 32 and 41% of the area and production annually recorded in the continent followed by the Congo Democratic Republic and Burundi (FAO, 1999). Other countries with substantial areas under dry peas in descending order include Canada, India, China, France, Australia, Pakistan and USA. According to the same source, France registered the highest seed yield with 5.1 t ha^{-1} and Pakistan the lowest with 0.51 t ha^{-1}.

In Ethiopia, the national census (CSA, 2001) estimates that dry peas is the third important cultivated food legume after faba bean (*Vicia faba* L.) and chickpea (*Cicer arietinum* L.). It covers about 1.82 % of the cultivated land (8.7million ha) and almost 17 % of the area allotted to pulses (932530 ha). The crop is grown as a rainfed and is well adapted throughout the highlands (1800-3200 m.a.s.l.) with the most suitable being the temperate or 'Dega' (2200-3000 m.a. s. l.) zone (FAO, 1984a).

The majority of the Ethiopian population has always relied on dry peas and other pulses for protein to complement the cereals in their diets especially during the long fasting periods of the Ethiopian Orthodox Christians. Other benefits include its consumption of fresh and boiled dried seeds, and also the dried vines and stems are good livestock feed (Yetneberk & Wandimu, 1994; Telaye *et al.*, 1994). In addition to its value as a foodstuff, the crop is also important in cropping systems for ameliorating the soil because of its ability to fix atmospheric nitrogen and so reduce the use of expensive inorganic fertilizers (Ghizaw & Molla, 1994). It is also a low input break crop mainly for barley and wheat for reducing the incidences of pests on the cereals (Pala *et al.*, 1994).

Despite of the importance of pea production in Ethiopia, the yield has remained very low as a consequence of a number of limitations. Heath & Hebblethwaite (1985) had described details of agronomic problems associated with growing peas by focusssing on the relative importance which differs between geographical areas within regions and between regions within countries. Supplemental to their review, Telaye *et al.* (1994) and Beyene *et al.* (1994) discussed the agronomic constraints of cultivated grain legumes in Ethiopia. In the Ethiopian context the fungal diseases of powdery mildew caused by *Erysiphe polygoni* D.C. and *Ascochyta spp.* are of major economic importance (Gorfu & Besher, 1994). Of the latter, *A. pinodes (Mycosphaerella pinodes)* reduces field pea yields particularly when sown early in wetter years (EARO, 1999). Green pea aphid (*Acyrthosiphon pisum*) and pod borer (*Helicoverpa armigera*) are the two economically most important insect pests (Ali & Habtewold, 1994). The former causes more severe damage especially at lower altitude (< 2300 m.a.s.l.) when there is a break in rainfall while the latter is sporadic in nature. Since peas have inherently poor standing ability, crop lodging promotes diseases particularly under moist conditions. Hailstorms in some years, sensitivity to extreme soil water conditions and poor soil fertility status are considered as the major factors contributing for the low yields of peas in Ethiopia.

Yields could be improved by a number of options including increased pest resistance of varieties, improved stem strength that maintains erectness and judicial soil fertility management. Growing peas in association with other crops such as faba bean (*Vicia faba* L.), which is a common practice in Ethiopia provides physical support for field peas, which in turn improves its performance (Ghizaw, 1996; Ghizaw & Molla, 1994). However, peas are poor competitors with other crops and, thus, should be grown in pure stands for maximum yields (Evans & Slinkard, 1975).

Nitrogen (N) and phosphorus (P) in that order are the plant growth limiting factors in many soil types (Hernandez & Focht, 1985; Kaola *et al.*, 1988; Batten, 1992; NFIA, 1993; Mamo *et* *al.*, 1996; Ghizaw *et.al.*, 1999) as they are integral and essential parts of food production systems. In general, peas respond to fertilization much less than most other legume crops. Response to nitrogen is rare while the pea crop responds to phosphorus in soils deficient in phosphate. Several workers (Kay 1979; Ibrahim, 1982; Ratti *et al.*, 1995; Davies *et. al.*, 1985; Moharram *et. al.*, 1994, Agegnehu *et al.*, 2002) have shown the responses of peas to phosphorus. Application of phosphorus increased nodulation and thereby biological N_2 fixation (Moharram *et. al.*, 1994; Adu-Gyamfi *et al.*, 1989; Kaola *et al.*, 1988). Generally, response of peas to phosphate containing fertilizers depends on the residual concentration in the soil, which in turn is governed at least by the previous cropping history (Davies *et. al.*, 1985; Kaola *et al.*, 1988). In the tropics, the amount of plant available phosphorus in the soil is by and large insufficient to meet the demand of legumes (Kaola *et al.*, 1988; Girma *et al.*, 1997). Moreover, traditional cropping systems result in the mining of this plant nutrient from the soil as a consequence of removing crop residues, and enhancing soil erosion (Quinones *et. al.*, 1997).

In Ethiopia, no detailed work on the effect of phosphorus fertilization on peas was done for long and the available information is so meagre that it does not support any application of fertilizer N and P in Eutric Nitosols (WADU, 1977; Beyene, 1988). However, latter investigations showed that the application of diammonium phosphate (DAP) significantly ($P < 0.01$) increased field pea seed yields by about 25% on Holetta Nitosols (Ghizaw, 1997). Such positive responses to the application of DAP were also obtained from many other research sites (Haile & Belyaneh 1988; Tsigie & Woldeab, 1994). This could be attributed to the depletion of soil fertility over time, the differences in crop rotation systems and the differences among cultivars in their response to fertilizer application. On the other hand, due to the soaring price, chemical fertilizers are becoming unaffordable to resource poor farmers.

The farming community through extension workers has repeatedly questioned the blanket recommendation rate of 100 kg DAP ha^{-1} as it is not taking soil fertility differences into account (Ghizaw *et al.*, 1999). From a research point of view, this rate is of less practical relevance to make best use of scarce resources in the crop management practices.

The foregoing aspect was given due emphasis by Farmers Research Groups (FRGs) formed by the Holetta Agricultural Research Center, Ethiopia at the end of 1999 cropping season. Formation of the FRGs was part of the activities to implement the project 'Client Oriented Research to Strengthen Cool Season Food and Forage legumes' financed by the Royal Dutch Government through EARO. The FRGs have prioritized problems of the farming systems whereby soil fertility problems turned out to be the first, ranking among the factors identified to constrain field pea production. The problems were further grouped into those that need immediate research solutions and those that need a detailed participatory diagnostic analysis.

When farmers around the Holetta Agricultural Research Center were asked to categorize different levels of soil fertility, they classified their soils according to productivity based on colour, fertility status, degree of slope, type of crops grown, soil depth and the ability to retain water. Accordingly, they distinguished four different types of soils ranking in descending order of productivity and/or fertility: 'Kossi '> 'Dela' > 'Dimile' > and 'Cheffe' also known as 'Koticha'. The most fertile and hence productive soil, viz. 'Kossi' is found around homesteads, which from time to time receives organic wastes, and is insignificant in area coverage as compared to the other three soils. 'Dela' and 'Dimile' are drained Nitosols while 'Cheffe' is associated with Vertisols characterized by excess water. In the farmers' views the present blanket fertilizer rate recommendations of 100 kg DAP ha^{-1} does not take into account the soil fertility differences discussed above. Similar notions were conceived in the past on fertilizer recommendation for faba bean in different parts of the country as reported by Ghizaw *et al.* (1999). Generally, farmers don't apply fertilizer to the 'Kossi' type of soil. In this soil, faba bean is cultivated either without fertilizer at all or with sub-optimal application rates. Likewise, according to the experiences of farmers, the 'Dimile' type of soil is suited to field peas and is mainly cultivated without fertilizer.

Moreover, the State farms, which grow mainly wheat and barley, exclusively apply urea and DAP from year to year, resulting in residual build-up of P in soils from the latter fertilizer. Similarly, farmers who apply only DAP also experience a build-up of P in their soils. The prediction of the availability of residual P for plant usage on high P testing soils is not well understood (Yerokun & Christenson, 1990). Knowledge of this aspect is important to aid in formulating recommendations for growers that are economically viable as well as environmentally sound.

Presently, as many times in the past, there is food shortage in some parts of Ethiopia where the systems of crop production and/or distribution of food are by and large inadequate. It is crystal clear that with an increasing population there is a need for large and sustained increases of the basic food and fiber crops. The increase in population growth and subsequent fast human settlement and urbanization result in reduction of arable land for cultivation. Thus, in order to improve agricultural production to meet the demand of the increasingly high population more focus should be on increasing yield per unit area cultivated which will in turn increase the demand placed on soil to provide adequate nutrients (Sharpley & Menzel, 1987). Inadequate supply of nutrients is one of the major constraints to crop production faced by the smallholder subsistence farmers in those areas where arable land is scarce. This is not necessarily because farmers are abandoning the traditional practices of using natural fallow to restore soil fertility but because they are unable to leave land fallow for long enough for it to be effective. The use of mineral fertilizers is declining as they are increasingly beyond the economic reach of most small-scale farmers. Fertilizer use plays a vital role in considering the agronomic experiences of many countries, which are either self-sufficient or net exporters of basic food and fiber crops. The overall picture of fertilizer use in Ethiopia is very low, less than 10 kg ha^{-1} on arable land in comparison to the 83, 140, 324 and 750 kg ha^{-1} on arable land in the USA, Egypt, Germany and the Netherlands respectively (Reddy, 1996). Comparing the contribution of fertilizer to other management factors the author argues that in India for example, cereal production increased by 41% from fertilizers compared to 27% from irrigation, 13% from improved seeds, 10% from double cropping and 9% from other improved practices. Moreover, fertilizer use permits production on a reduced area thereby benefiting the environment. On the other hand, if production is confined to a smaller area, the need for such technologies as herbicides and insecticides will be substantially reduced.

In Ethiopia, Nitosols are one of the major arable soils which developed on a wide range of parent materials having a rather low CEC for their clay content and low plant available phosphorus (FAO, 1984b). Work of Sertu & Ali (1983) also reveals significant differences in the P fixing capacity of Nitosols collected from different environments in the country. These characteristics of the Nitosols can result in P deficiencies in peas which may limit nitrogen fixation by affecting survival of rhizobium, root hair infection, and nodule development and nodule function as well as by affecting host plant growth (Cadisch, 1990; Cadisch *et al.*, 1993). Nevertheless, grain legume responses to fertilizer P on slightly to strongly acidic soils have been less common suggesting that there are other factors responsible for such inconsistent responses to P fertilizer on acid soils, viz. climatic conditions and some other soil factors (Mahler *et al.*, 1988). For instance, a review by Papendick *et al.* (1988) showed that legume crops require only 5.5 to 6.5 kg P ha^{-1} for each 1000 kg seed ha^{-1} produced. Many soils can supply this amount of P for low producing varieties.

In summary, the use of inorganic fertilizers plays a vital role in the country's effort to become food self-sufficient and beyond. However, its effectiveness is negatively affected by the little documented information available on phosphorus requirements and use efficiencies of different genotypes of field peas in Ethiopia. Hence, there is a pressing need for investigating the response of Ethiopian field pea cultivars to phosphorus fertilization of Nitosols.

1.2 Hypothesis

There are varietal differences among Ethiopian field pea cultivars with regard to phosphorus application to Nitosols varying in phosphorus fertility levels, which should be taken into account when making fertilizer recommendations.

1.3 Objectives

The major aim of this study was to quantify the response of Ethiopian field pea cultivars to phosphorus fertilization of Nitosols under both glasshouse and field conditions. Specific objectives were the following, namely to:

- Measure the growth and development of different pea cultivars on Nitosols with varying phosphorus fertility levels and application rates.
- Establish threshold levels of phosphorus in either the soil or plant at which pea cultivars will not respond any more to fertilization.
- Determine the economic advantage of proper phosphorus fertilization to pea cultivars planted on Nitosols.

CHAPTER 2

REVIEW OF FIELD PEA PRODUCTION IN ETHIOPIA

2.1 Introduction

The centers of origin of peas (*Pisum sativum* L.) are believed to be Abyssinian (Ethiopia), Mediterranean, Near East and Central Asia from where it spreads to the temperate and tropical regions of the world (Davies *et al.*, 1985; Orman & Belaid, 1990; Hulse 1994). Although peas are grown as a cool-season crop in the subtropics, and higher altitudes in the tropics, it is more adapted to the temperate latitudes. Eighty percent of the world's pea production is located in the USSR, China, India, West Europe, and Australia with 60% coming from the USSR alone (Orman & Belaid, 1990).

Peas is the fourth most cultivated legume in the world, only soybeans, groundnuts and beans (*Phaseolus vulgaris*) are grown in larger quantities (Hulse, 1994). In Ethiopia, pea is the third important cultivated food legume after faba bean (*Vicia faba* L.) and chickpea (*Cicer arietinum* L.*)* (CSA, 2001). The crop covers about 1.82 % of the cultivated land (8. 7 million ha) and almost 17 % of the area allotted to pulses (0.9 million ha). According to FAO (1999), Ethiopia is the leading dry pea producer in Africa with an average grain yield of 0.81 t ha^{-1}, followed by the Democratic Republic of Congo and Burundi (FAO, 1999).

Field peas grown in Ethiopia are of two types, namely *Pisum sativum* ssp. *arvense* and *Pisum sativum* ssp *abyssinicum* (Westphal, 1974; EPID, 1975; Kay, 1979; Ghizaw & Molla, 1994). The *arvense* type has leaves with more than one pair of leaflets, usually purplish coloured, angular shaped flowers and seeds that are normally brownish gray or variegated in colour (EPID, 1975). The *abyssinicum* type has leaves with one pair of leaflets, very small reddish purple flowers and globose, glossy, sweet seeds with a black helium. Westphal (1974) indicated that *cv. Group abyssinicum* matures in 3 to 4 months while cv. *Group arvense* require 5 months. The former group fetched higher prices in the market than the latter group but reasons were not stated. However, the two types of peas have the same ecological requirements and are sown from the end of June to early July in the major rainy season. The geographic distribution of the *abyssinicum* type is limited to the highlands of Tigray and Wollo in north Ethiopia from where dispersion to the Eastern Highlands and other parts of the country took place (Westphal, 1974).

The popularity of peas in Ethiopia can be ascribed to the nutritional value thereof for humans and animals. Peas are regarded as a good source of dietary protein to complement the large intake of cereals by humans in this country. Green peas are eaten raw while dry peas are mainly consumed after they are ground into powder or split into larger pieces to make either sauce or a special stew for eating with 'injera' (a round flat and thin pancake like bread of about 50 cm diameter). Sometimes dry peas are also mixed with cereals in making 'injera'. (Yetneberk & Wandimu, 1994). The dried vines and stems of peas are also used as supplemental feeding for Ethiopian livestock.

Grain legumes have a high protein content but the range is considerable and is affected by genetic as well as environmental factors (FAO, 1984d). Telaye *et al.* (1994) reported that protein content of field peas ranges from 21.3 to 24.5% in the highlands and from 22.6 to 31.8% in the midlands of Ethiopia. On the other hand, the ripe dry seeds of cv. *abyssinicum* contain 20 to 30% protein (Westphal, 1974). Elsewhere in the world the protein content of peas varied from 18 to 28%, and the average is ca. 23% depending on the environment and varieties (Evans & Slinkard, 1975). A mean protein concentration of 23.8 % for peas was quoted by Huisman & van Derpoel (1994).

Duke (1983) discussed the chemical composition of peas in detail. According to him dried peas contain 10.9% water, 22.9% protein, 1.4% fat; 60.7% carbohydrate, 1.4% crude fiber, and 2.7% ash while raw edible-podded peas contain per 100 g: 53 calories, 83.3% moisture, 3.4 g protein, 0.2 g fat, 12.0 g total carbohydrate, 1.2 g fiber, and 1.1 g ash while raw dried mature seeds contain per 100 g: 340 calories, 11.7% moisture, 24.1 g protein, 1.3 g fat, 60.3 g total carbohydrate, 4.9 g fiber, and 2.6 g ash. The sulfur containing amino acids methionine and cystine are often the limiting amino acids in peas. Pea seeds also contain inhibitors like trypsin and chymotrypsin. Some Pakistan pea cultivars are said to be of contraceptive use.

2.2 Agroecological zones

In Ethiopia, based on seven moisture regimes that were superimposed on three temperature regimes 18 major agroecological zones were identified out of a potential of 21 (MOA, 2000). The zones are nomenclatured by terms commonly used to desccribe the broad temperature, moisture and elevation conditions of an area. All 18 zones are listed in Table 2.1 for the sake of convenience.

In this context the moisture regimes implicated areas that can be expected to have in 4 out of 5 years sufficient water sustaining optimum plant growth for a specified period, viz. arid < 45 days, semi-arid = 46-60 days, sub-moist = 61-120 days, moist = 120-180 days, subhumid = 181-240 days, humid = 241-300 days and per-humid = 300 days. Areas whereof the mean annual temperature and elevation range between certain threshold values are implicated by the temperature regimes, viz. hot to warm = > 21°C and < 1600 m.a.s.l., tepid to cool = 11-21°C and 1600-3200 m.a.s.l. and cold to very cold = < 11°C and > 3200 m.a.s.l.

Table 2.1 Major agroecological zones identified for Ethiopia based on moisture and temperature regimes (MOA, 2000).

Code *	Description
A1	Hot to warm arid lowland plains
A2	Tepid to cool arid mid highlands
SA1	Hot to warm semi-arid lowlands
SA2	Tepid to cool semi-arid mid highlands
SM1	Hot to warm sub-moist lowlands
SM2	Tepid to cool moist mid highlands
SM3	Cold to very cold moist sub-afroalpine to afroalpine
M1	Hot to warm moist lowlands
M2	Tepid to cool sub-moist mid highlands
M3	Cold to very cold sub-humid sub-afroalpine to afroalpine
SH1	Hot to warm sub-humid lowlands
SH2	Tepid to cool sub-humid mid highlands
SH3	Cold to very cold sub-humid sub-afroalpine to afroalpine
H1	Hot to warm humid lowlands
H2	Tepid to cool humid mid highlands
H3	Cold to very cold humid sub-afroalpine to afroalpine
PH1	Hot to warm per-humid lowlands
PH2	Tepid to cool per-hmid mid highlands

Moisture regimes: A = arid, SA=semi-arid, SM = sub-moist, M = moist, SH = sub-humid, H = humid, PH = per-humid and temperature regimes: 1 = hot to warm, 2 = tepid to cool, 3 = cold to very cold.

By superimposing the 7 identified physiographic regions, namely the lowland plains (1), lakes and rift valleys (2), valleys and escarpments (3), gorges (4), mountains and plateau (5), plateau (6) and mountain (7) on the mentioned 18 major agroecological zones 49 sub-agroecological zones evolved out of a potential 126 (MOA, 2000). Each subzone is relatively homogeneous in terms of climate, physiography, soils, vegetation, land use farming systems and animals. However, field peas are grown in 12 of these sub-agroecological zones (Figure 2.1).

The size of the individual sub-agroecological zones ranges from 0.6 million ha for H2-6 to 6.7 million ha for SH2-7 (Table 2.2). However, the size of all 12 sub-zones amounted to 30 million ha. Considering this large area of land when field peas are cultivated the variation in soil forming factors like parent material, topography, climate and vegetation are enormous. Therefore, various soils that differ in fertility are found in these sub-agroecological zones.

Each of these aspects will be discussed concisely to give a better perspective on field pea production in Ethiopia.

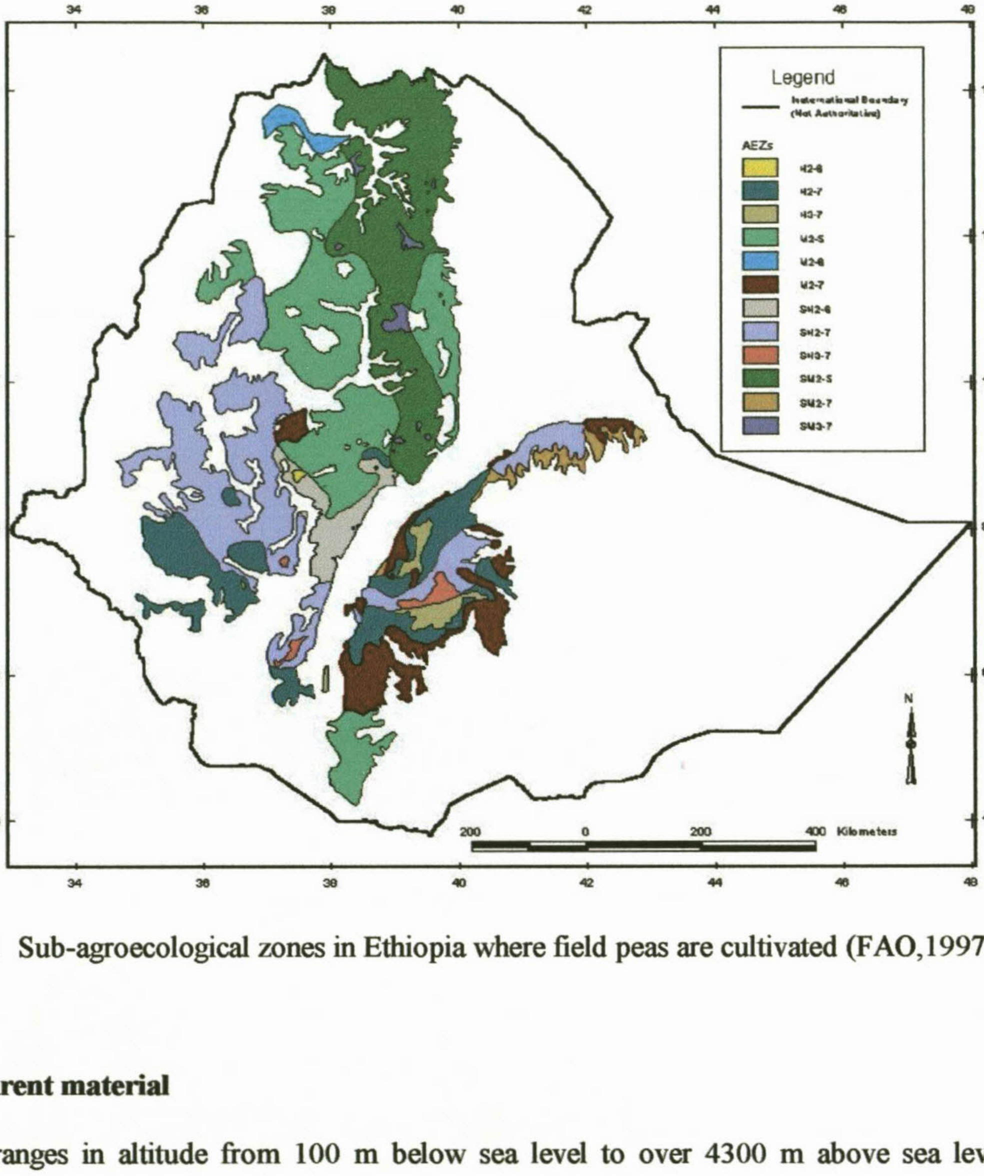

Figure 2.1 Sub-agroecological zones in Ethiopia where field peas are cultivated (FAO,1997)

2.2.1 Parent material

Ethiopia ranges in altitude from 100 m below sea level to over 4300 m above sea level (m.a.s.l.). However, the extensive highland plateaus, with an altitude of over 2500 m.a.s.l. covers 40% of the country. The Great African Rift Valley runs from north to south, bisecting the plateau and in conjunction with the surrounding lowlands, this feature isolates and separates the plateau from other parts of the continent (Woldu, 1999). Therefore, the country may be classified into the Western Plateau, Eastern Plateau, Ethiopian Rift Valley, Afar Depression, Somali (Ogaden) Lowlands and Western Lowlands (Mohr, 1983).

Table 2.2 Area of agroecological zones in Ethiopia where field peas are cultivated (MOA, 2000).

Major AEZ	Sub AEZ	Area in Hectare	% of the country
SM2	SM2-5	63000000	5.59
	SM2-7	564000	0.50
SSM3	SM3-7	472000	0.42
M2	M2-5	6864000	6.09
	M2-6	376000	0.33
	M2-7	3780000	3.35
SH2	SH2-6	1248000	1.11
	SH2-7	6664000	5.91
SH3	SH3-7	532000	0.47
H2	H2-6	64000	0.06
	H2-7	2704000	2.40
H3	H3-7	604000	0.54

According to Merla *et al.* (1979), the main rock groups of Ethiopia are: (i) Volcanic rocks (Early Cenozoic age) covering 32% of the total surface area, (ii) Volcanic rocks (Late Cenozoic age) covering 12% of the total surface area, (iii) Metamorphic rocks with associated igneous intrusive bodies (Pre-Cambrian age) covering 23% of the total surface area, (iv) Marine sedimentary rocks (Paleozoic, Mesozoic and Early Cenozoic age) covering 25 % of the total surface area and (v) Sedimentary rocks of marine and continental origion (Cenozoic and younger age) covering 8% of the total surface area.

The predominant rocks in the field pea growing agroecological zones in descending order include igneous, methamorphic and sedementary rocks (Figure 2.2). Accordingly, basic and ultrabasic rocks (B), pyroclastic rocks (P), unknown rocks (X), undifferentiated igneous rocks (V), acid rocks/undifferentiated basement system gneisses/rocks (G/U), cover respectively estimated areas of about 59.3, 11, 9.1, 4.7% of the field pea growing agroecological zones. The average oxides composition of these rocks is shown in Table 2.3. Weathering of these rocks had resulted in the development of soils with varying fertility, depending on the amount of macro and micronutrients released.

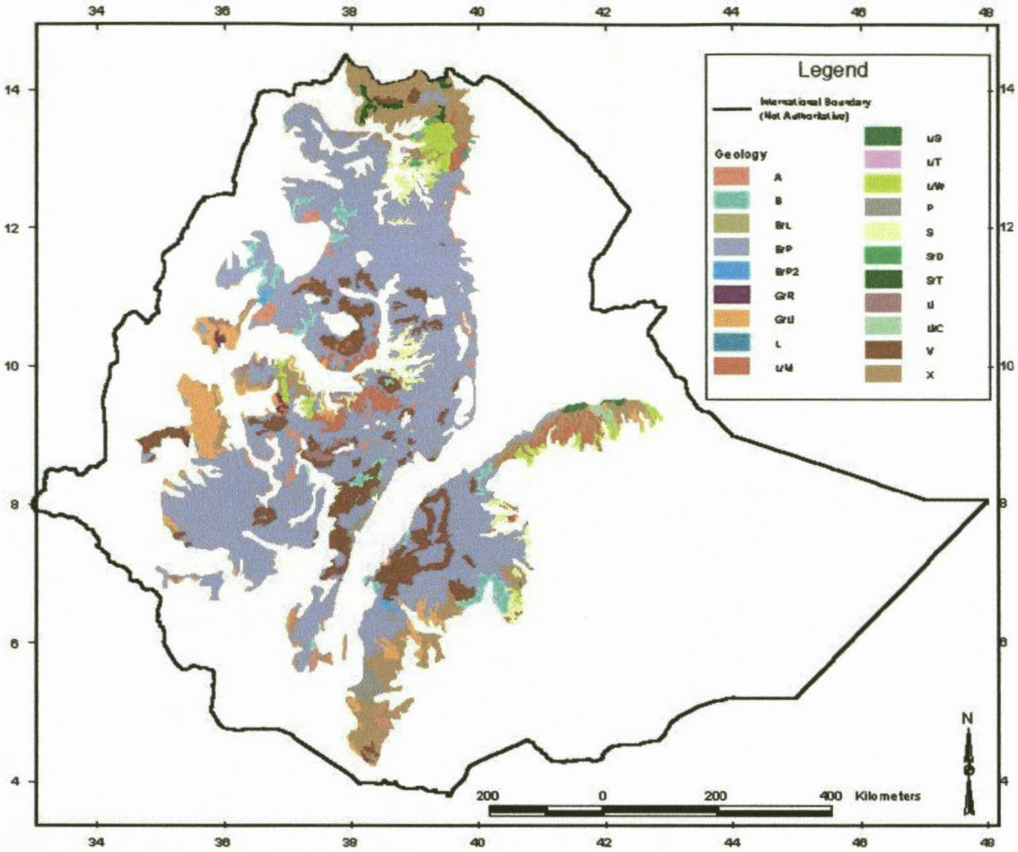

Figure 2.2 Major rock groups in Ethiopia where field peas are cultivated (FAO, 1997).

Table 2.3 Average oxide composition of rocks in Ethiopia where field peas are cultivated.

Oxides %	Volcanic rocks		Metamorphic rocks[3]			Sedimentary rocks [4]		
	Plateau Basalt[1]	Plateau Rhyolitic Ignimbrite[2]	Metabasites	Gneisses & Schists	Granitoids	Lime stone	Sandstone	Shales
Al_2O_3	14.43	12.89	15.90	14.12	14.46	0.8	5.0	15.1
Fe_2O_3	13.42	8.87	7.11	4.33	2.01	0.5^*	1.3^*	6.1^*
MnO	0.20	0.17	0.11	0.09	0.05	0.1	0.01	0.1
Mgo	5.99	3.87	13.2	1.91	0.47	7.7	1.1	2.5
CaO	9.30	5.03	11.8	2.98	1.45	42.3	5.5	3.1
Na_2O	3.11	3.6	0.89	2.32	3.63	0.1	0.4	1.3
K_2O	1	2.66	0.07	3.9	4.33	0.3	1.3	4.8
P_2O_5	0.5	0.24	0.02	0.1	0.07			

Source: (1) Pik *et.al* (1998), (2) Ayalew *et al.* (2002), (3) Peccerillo *et. al.* (1998) , and (4)Mason & Moore (1982).

However, the work of Abebe (1988) indicated that the soils of central Ethiopia where field peas are cultivated predominantly developed from volcanic parent materials that are relatively uniform in oxide composition. The P_2O_5 content of these igneous rocks is far higher than that of either the metamorphic or sedimentary rocks found in the pea growing agroecological zones. The phosphorus reserves of the soils that developed from the volcanic parent materials therefore should be relatively high. Unfortunately, these soils especially the Nitosols have a high capacity to fix phosphorus, resulting in low plant available phosphorus levels.

2.2.2 Topography

Inspection of Table 2.4 shows that the altitudes of the pea growing agroecological zones range from 1000 m.a.s.l for M2-7 to 4300 m.a.s.l for SH3-7. However, altitudes below 1800 and above 3200 m.a.s.l. are considered to be very marginal for pea production and is therefore very seldom practise at these altitudes. The most suitable altitudes for peas ranges from 2200 to 3000 m.a.s.l. Nevertheless, peas are still cultivated with moderate success in the altitude range of 1800 to 2200 and 3000 to 3200 m.a.s.l. (FAO, 1984a).

In the Ethiopian context, the highly suitable areas for peas with altitudes of 2200 to 3000 m.a.s.l. usually have slopes of less than 8%. The moderately suitable areas for peas with altitude ranges of 1800 to 2200 and 3000 to 3200 m.a.s.l. are typified by slopes of respectively 8 and 30% (FAO, 1984a). In the marginal suitable areas for peas with altitudes below 1800 m.a.s.l. slopes seldom exceed 8% but above 3200 m.a.s.l. slopes often exceed 30% (FAO, 1984a). From this it can be deduced that sheet erosion in the lower altitudes and gulley erosion in the higher altitudes are very severe problems in the pea growing agroecological zones. Hence, soil conservation practices are of paramount importance to lessen soil degradation.

2.2.3 Climate

Field peas are grown under rainfed conditions in Ethiopia. Rainfall is therefore an important environmental factor determining pea production. There is no systematic relationship between amount of rainfall and elevation, however, the rainfall in the lowlands is not only less but also more variable and less reliable than in the highlands (Gemechu, 1977). According to the author, the rainfall decreases in all directions from the southwestern highlands but the distribution is modified by elevation. The central and eastern highlands receive 950 mm or more annually due to double passage of the intertropical convergence zone aided by the orography (Westphal, 1975). The work of Tato (1964) emphasized that rainfall, except for the western areas, is so variable in the dry months that annual averages should be considered with great care. The rainfall pattern in Ethiopia is bimodal of nature. About 70 to 80 % of the rain falls in the major rainy season from June to August and the remaining in the minor rainy season from March to May (Westphal, 1974; Camberlin & Philipon, 2002). This bimodal pattern resulted that the pea crop is grown either in a single or double cropping system. The single cropping system entails fallow in the minor rainy season with peas cultivated in the major rainy season. In the double cropping system peas are also cultivated in the major rainy season after harvesting of short maturing barley or wheat that have been cultivated in the minor rainy season.

Peas require evenly distributed rainfall preferably 800 to 1000 mm although the crop is also grown where the rainfall is as low as 400 mm provided that the soils are deep and water retentive (Kay, 1979). According to this norm all the pea growing agroecological zones in Ethiopia receive sufficient precipitation with low drought probabilities (Table 2.4). The subagroecological zone SH2-7 has the smallest range of rainfall variability (10-25%) while the sub-agroecologial zones M2-6, SH2-7 and H2-7 have the largest range of rainfall variability (10-45%).

Table 2.4 Some topographical and climatic data on the agroecological zones in Ethiopia where field peas are cultivated (MOA, 2000).

Major AEZ	Sub AEZ	Altitude	Rainfall* (mm)	PET*	Temperature (°C)	Rainfall variability (%)	Drought Probability
SM2	SM2-5	1600-2200	700-1200	1800-1900	16-27.5	15-35	0.2-0.5
	SM2-7	1600-2000	300-1000	1200-2000	16-21	20-40	0.2-0.7
SM3	SM3-7	2800-4100	700-1600	1300-1800	7.5-16	15-40	0.2-0.6
M2	M2-5	1500-2700	500-1000	1550-1650	16-21	15-.25	0.4-0.5
	M2-6	1600-1800	1200-1500	1800-1950	11-21	25-30	0.2-0.3
	M2-7	1000-3000	600-2200	1300-2100	7.5-16	10-45	0.2-0.5
SH2	SH2-6	2000-2800	900-2000	1300-1600	11-21	15-35	0.1-0.4
	SH2-7	1600-3200	700-2200	1200-1700	11-21	10-45	0.1-0.5
SH3	SH3-7	2600-4300	700-1500	1200-1600	7.5-16	10-25	0.1-0.3
H2	H2-6	1400-3000	900-2000	1300-1500	11-21	15-30	0.3-0.5
	H2-7	2000-3200	700-2200	1200-1700	11-21	10-45	0.1-0.5
H3	H3-7	3000-4200	900-1800	800-1200	7.5-16	10-25	0.1-0.3

* Mean annual data.

Temperature is another important environmental factor, which determines the distribution, growth and development, and thereby seed yields of pulse crops (Saxena *et.al.*, 1988). In Ethiopia, there is generally a very good correlation between the altitude and the mean temperature during the growing period with the exception of the southwestern lowlands where the temperature drops more slowly with increasing altitude (FAO, 1984c). With a few exceptions, March to May is the warmest period due to rapid heating of the land surface, whereas June to August is relatively cool in most parts of Ethiopia during which minimum average temperature is experienced. The transitional period from September to November shows lower temperatures than spring. Relatively uniform temperatures are recorded throughout the year in the eastern highlands and the afroalpines of Ethiopia (Delliqadri, 1958 cited in Westphal, 1975).

Duke (1983) indicated that peas require a cool, relatively humid climate and are grown at higher altitudes in the tropics at temperatures of 7 to 24°C, with an optimum between 13 and 21°C. Hence, substantial areas of the field pea growing agroecological zones have the temperature requirements for optimum production (Table 2.4). Only the mean annual temperature range at sub-agroecosystems SM2-5, SM3-7, M2-7, SH3-7 and H3-7 exceed either the lower or upper optimum temperature of 13 and 21°C

Subsequent to the pattern of rainfall and temperature, field peas are sown at the end of June to early July in most parts of Ethiopia (Ghizaw & Molla, 1994) with the exception of the Bale highlands where it is sown in August. The growing period in the warmer agroecological zones is from June to October and in the cooler agroecological zones from June to November, which may even extend sometimes into December.

2.2.4 Vegetation

Over millennia erosion, volcanic eruption, tectonic movements and subsidence have occurred in Ethiopia (Teketay, 2000). This resulted in a great geographical diversity with high and rugged mountains, flat-topped plateaus, deep gorges of incised river valleys and rolling plains. The vegetation therefore is extremely complex as a result of the great variation in altitude, which causes large spatial differences in moisture and temperatures within very short horizontal distances (Teketay, 1999; Woldu, 1999).

Different workers have mapped the various vegetation types in Ethiopia (Woldu, 1999). The one done by FAO (1997) has been adopted to indicate the major vegetation types in the field pea growing agroecological zones as depicted in Figure 2.3. Accordingly, the vegetation types covering significance areas are savanna with 43%, dryland cropland and pasture with 14%, cropland/grassland mosaic with 13% and evergreen broadleaf forest with 11%.

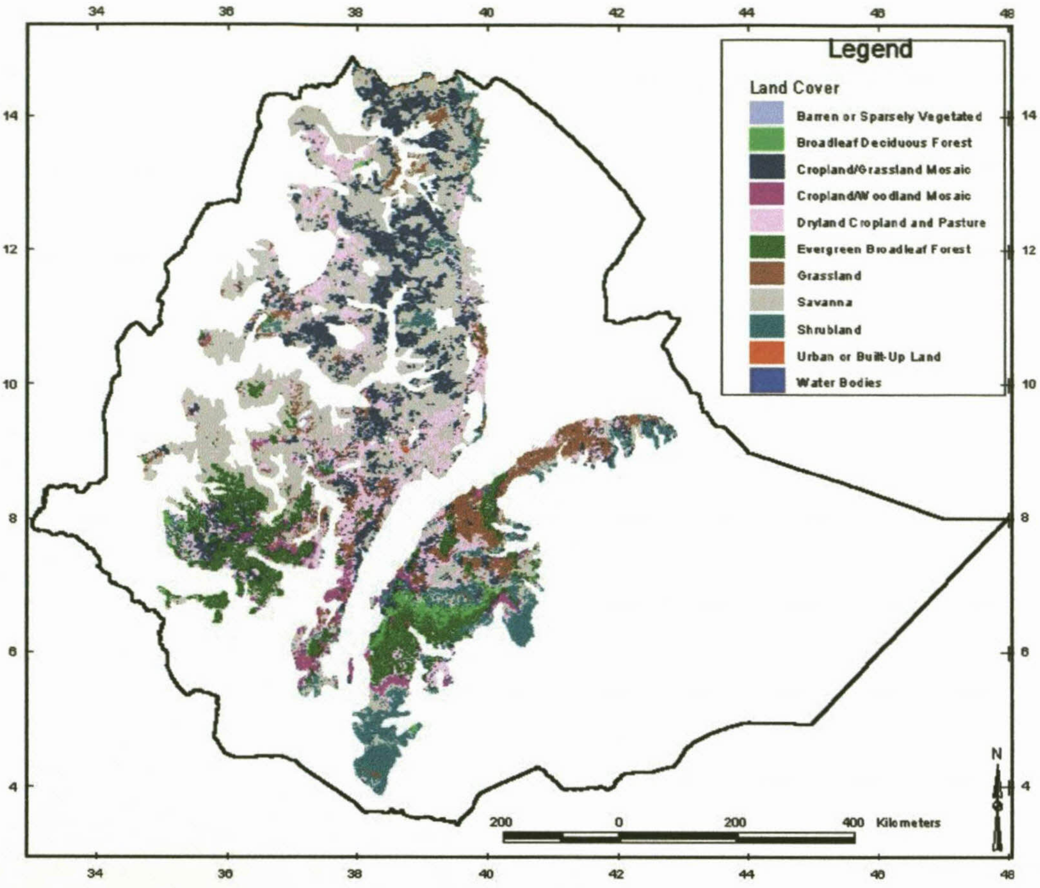

Figure 2.3 Major vegetation types in Ethiopia where field peas are cultivated (FAO, 1997).

According to Teketay (2000) several genera of trees (*Olea, Juniperus, Celtis, Euphorbia, Dracaena Carissa, Rosa, Mimusopa and, Ekebergia)*, grasses (*Hyparrhenia, Eragrostis, Panicum, Sporobolus, Eleusine, and Pennisetum,*) and legumes (*Trifolium, Eriosaema*, and *Crotalaria)* occur between 1500 and 3000 m.a.s.l. where pea production is common. The author emphasized that forests have virtually disappeared and that the legumes are endemic to the grassland.

As far as trees on farmlands are concerned, there is a clear boundary at around 2500 m.a.s.l. Below this altitude *Cordia abyssinica, Croton macrostachys, Acacia albida, Ziziphus spina-christ, and Baalanites aegyptiaca* are common and all have agroforestry potential. Above this altitude, there are fewer trees on farmlands. The most significant ones are *Acacia abyssinica, Juniperus procera and Podocarpus gracillor* whereof the latter two have low agroforestry potential (ICRAF, 1990).

In Ethiopia, information on the contribution of the different vegetation types to soil fertility is limited. However, the different vegetation types are diminishing at an alarming rate, which usually results in a decline of soil organic matter. This implicated lower reserves of organic nitrogen, phosphorus and sulphur for plant uptake.

2.2.5 Soils

In Ethiopia, there are 14 major soil types that had developed from a wide range of parent material as indicated earlier, namely volcanic, metamorphic, granitic and felsic materials as well as sandstone and limestone (Abebe, 1988). Nitosols cover 13% of the country followed by Cambisols with 12%, Regosols with 11%, Vertisols 10% and the others with smaller percentages. However, the major soil types regarded as arable include in descending order Nitosols, Cambisols, Vertisols, Xerosols, Solanchacks and Acrisols (Mitchelhill, 1988). Of these, the first three comprise 60% of the total arable land. The major soils that are found in the pea growing agroecological zones of Ethiopia are shown in Figure 2.4. Accordingly, the soils that covering significant areas in these zones are Leptosols with 33%, Nitosols with 20%, Luvisols with 17%, Vertisols with 15% and Cambisols with 8% (FAO, 1997).

Peas can be cultivated over a wide range of soil types, provided that the drainage is good as they cannot stand waterlogging. The crop does best on loams to clay loams, or sandy loams overlying clay. On light, sandy soils, which do not hold water, yields tend to be reduced. They are best adapted to a pH between 5.5 and 6.5 although some cultivars can tolerate a pH 6.9 to 7.5 (Kay, 1979). Such information showed that highly weathered soils which are predominant in high rainfall areas of Ethiopia (Abebe, 1988; FAO, 1984b) may limit the productivity of field pea due to acidity problems associated with these areas.

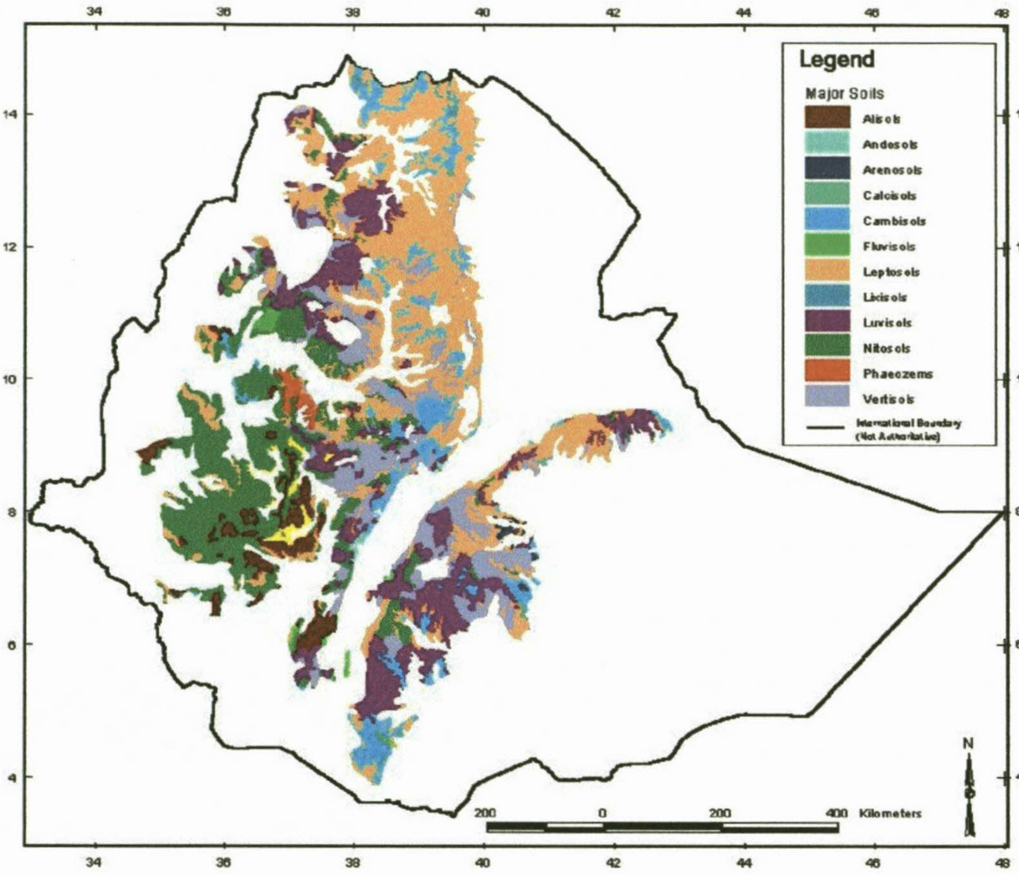

Figure 2.4 Major soil types in Ethiopia where field peas are cultivated (FAO, 1997).

Nitosols are estimated to comprise 23% of all available land in Ethiopia and hence cover a significant 20 % of the pea growing agroecological zones. These soils have a rather low cation exchange capacity for the clay content and available phosphorus is very low. In general, the pH of the Nitosols vary between 4 and 6 (FAO, 1984b).

2.3 Fertilization practices

2.3.1 Nutritional requirements

As already mentioned an ideal soil pH for peas ranges between 5.5 and 6.5 (Kay, 1979). A pH outside this range will reduce yields. Reduced yields, especially in acidic soils can be attributed to poor N fixation (Havlin *et al.*, 1999). The N fixing bacteria living in symbiosis with peas, viz. *Rhizobium leguminasorium* are best adapted in neutral to slightly alkaline soils (Paul & Black, 1989). In low pH soils the survival and growth of these symbiotic bacteria are restricted inter alia by high levels of Al, Mn and H as well as low levels of Ca and P (Havlin *et al.*, 1999). Except in acidic soils, where Ca and P deficiencies result in a smaller bacteria population with less nodulation, other macronutrient deficiencies seldom reduces N fixation. However, N fixation in the nodules requires more Mo than the host plant and therefore Mo deficiency is the most important micronutrient deficiency (Wild, 1988). Initiation and development of nodules can be affected by Co, B, Fe and Cu deficiencies to some extent.

Liming of soils with pH values below 5.5 is therefore highly recommended to ensure efficient N fixation by *Rhizobium leguminasorium* and hence optimum field pea yields. In addition sufficient supply of essential macronutrients like N, P and K as well as micronutrients like Mo, Zn and Mn is of utmost importance (Kay, 1979).

On average, every ton of field pea seed and straw remove respectively 40.5 and 23.8 kg of N (FSSA, 2002). Although peas belong to the legume family, it is found that additional N should be applied to supplement the symbiotic fixation by the *Rhizobium leguminasorium* because symbiotic fixed N only becomes available 4 to 6 weeks after emergence (Paul & Black, 1989). Besides for non-traditional areas with low population of N fixing bacteria, treatment of the seed with *Rhizobium leguminasorium* is always recommended to enhance the symbiotic fixation of N (Wild, 1988; Havlin *et al.*, 1999). The N content is always high in the roots during the vegetative phase but decreases at flowering stage due to the declining in nitrogenous activity and the translocation of N to the upper components (Bergmann, 1992). Therefore, soil applied N is beneficial to the plant at or prior to flowering to meet an increasing demand for N at this stage. The amount of N to be applied will vary according to the previous crop, cultivation practices and soil type, but it is estimated at around 60 kg N ha^{-1}on sandy soils to 30 kg N ha^{-1}on loamy soils (FSSA, 2002). However, a review by Askin *et al.* (1985) revealed that although some studies showed that small amounts of applied N is beneficial to legumes such as field peas, most studies indicated that N fixation was inhibited by high levels of available N in soils. High levels of especially nitrate reduced nitrogenase activity and thus fixation of N.

The most essential function of P in plants is in energy storage and transfer (Havlin *et al.*, 1999). Phosphorus is also an important structural component of nucleic acids, coenzymes, nuclecotides, phosphoproteins, phospholipids, and sugar phosphates. Thus an adequate supply of P early in the life of field peas is important in the development of its reproductive parts, especially the seeds. In addition a good supply of P is important for a healthy well developed root system, sufficient nodulation and hence efficient N fixation (Wild, 1988; Havlin *et al.*, 1999). The young pea plant with its restricted root development is particularly responsive to P fertilization. A deficiency of P is manifested in plants developing slowly with associated small dark coloured leaves (Bergmann, 1992) Under extensive deficiencies plants develop an upright stature with a reddish discoloring on the stems. Application of phosphorus will vary from 20 to 60 kg P ha^{-1}depending on the soil levels of phosphorus (FSSA, 2002). Field peas remove on average 4.0 and 2.5 kg P ha^{-1} per ton in seed and straw respectively.

Another nutrient, which is required in large amounts by field peas, is K (Kay, 1979). It has a marked influence on resistance of field peas to disease. Irregular yellow discoloring of the edges of the lower leaves is characteristics of K deficiency in young plants (Bergmann, 1992). This discoloured portion eventually dies and gives the leaves a marked scarred appearance. Soil analysis should be used to determine the K status of soils and application may vary from 0 to 80 kg K ha^{-1} (FSSA, 2002). On average 9 and 12.5 kg K per ton are removed by seed and straw of field peas respectively.

Peas are susceptible to deficiencies of one or more micronutrients as mentioned earlier, especially Mo, Zn and Mn (Wild, 1988; Havlin *et al.*, 1999) Molybdenum deficiencies is associated with acid soils and symptoms are very similar to that of N (Bergmann, 1992; FSSA, 2002). The leaves have a light green wilted appearance despite the lack of water stress. A definite indication of Mo deficiency is when no reaction takes place when N is applied. A deficiency of Zn is associated with alkaline soils (Havlin *et al.*, 1999). It will affect both the plant and the effectiveness of the root bacteria. A typical Zn deficient pea plant is dwarfed with irregular leaves and short internodes (Bergmann, 1992; FSSA, 2002). The characteristic Mn deficiency symptoms, also referred to as 'marsh spot' associated with various pea cultivars is identifiable by ripening seed becoming dark brown on the idented sections of the seeds (Bergmann, 1992; FSSA, 2002). Deficiency of Mn is more common on alkaline soils.

In Table 2.5 some adequate nutrient concentration ranges for peas are presented. These ranges are for just fully developed leaves at the top of the plant at onset of blossom. Careful usage of the range can be beneficial in identifying deficiencies of nutrients in peas. However, for most nutrients it will be to late for rectification at bloom or later.

Table 2.5 Adequate ranges of nutrient concentration in the dry matter of peas (Bergmann, 1992)

Macronutrients	Range (%)	Micronutrients	Range (ppm)
N	3.00-4.00	Cu	7-15
P	0.25-0.50	Mn	30-100
K	2.20-3.50	Zn	25-70
Ca	0.50-2.00	B	30-70
Mg	0.25-0.60	Mo	0.40-1.00

2.3.2 Fertilization guidelines

Fertilization guidelines are coordinated information arranged and presented in such a fashion to facilitate decisions concerning fertilizer inputs. Idealistic, fertilization guidelines are based on proper research where crop response is correlated with either soil or plant analysis for specific enviornmental conditions. However, guidelines can vary from very general and vague, to being specific and with foundation (FSSA, 2002).

In Ethiopia, the fertilization guidelines for grain legumes can best be described as very general and vague. Neither soil analyses nor plant analyses are used for fertilization recommendations on any legume crop. Even the yield potential of a crop is not taken into account. As mentioned earlier in the case of peas a blanket recommendation of 100 kg DAP ha^{-1} is valid (NFIA, 1993). This application therefore resulted in 18 kg N ha^{-1} and 20 kg P ha^{-1}.

The preference for DAP as a fertilizer evolved from literature evidence (Havlin *et al.*, 1999) that the uptake of $H_2PO_4^{2-}$ improves as a result of the NH_4^+. Both these ions are released when DAP is applied to moist soil: $(NH_4)_2HPO_4 \rightarrow 2NH_4^+ + H_2PO_4^{2-}$. However, the authors warned about injury of seedlings and inhibition of root growth when DAP is placed with the seeds. Depending on the soil pH, the released NH_4^+ can be converted to NH_3, which is toxic to seedlings and roots in high concentration. This conversion of NH_4^+ to NH_3 will be limited in the neutral to acid soils of Ethiopia.

The fact that phosphorus is applied to peas cultivated on Nitosols without considering the levels of phosphorus fertility is alarming. Nitosols, as indicated earlier, have a high capacity to fix phosphorus and therefore such an approach can easily result in either under or over fertilization. The poor resource farmers can thus experience yield losses due to under fertilization or unnecessarily costs due to over fertilization, which can be disasterous for them.

An understanding of the cycling of P in the soil-plant-atmosphere system as conceptualized in Figure 2.5 is essential in the developing of phosphorus guidelines for any crop. This P cycle can also be divided into P inputs or gains. P outputs or losses and P cycling within the soil where P is neither gained nor lost by the processes listed in Table 2.6. An understanding of these processes is essential to ensure a basis for some management of this element for optimum crop production without environmental damage.

Gains of P in soils are attributed to fertilizers and residues (Sharpley, 2000). Commercial fertilizers such as the super- and ammoniumphosphates contain mainly inorganic P compounds, which are water soluble. However, sometimes water insoluble inorganic P compounds are added to acid soils as rock phosphate. Mainly organic P compounds occur in either plant or animal residues, which have been identified primarily as inositol phosphate, phospholipids and nucleic acids.

Losses of P from soils are attributed to plant uptake, erosion and leaching (Sharpley, 2000). Plants obtain P from the soil solution actively in the form of $H_2PO_4^-$ and HPO_4^{2-} ions although plant uptake of HPO_4^{2-} appears to be slower than uptake of $H_2PO_4^-$ due to different carriers. Both ions move to the roots by diffusion. In soils with a pH below 7 the dominant ion is $H_2PO_4^-$ while in soils with a pH above 7 the dominant ion is HPO_4^{2-}. Leaching of both ions is limited due to their easy transformation into immobile forms. However, large losses of the various P fractions occur through sediments as a result of either water or wind erosion.

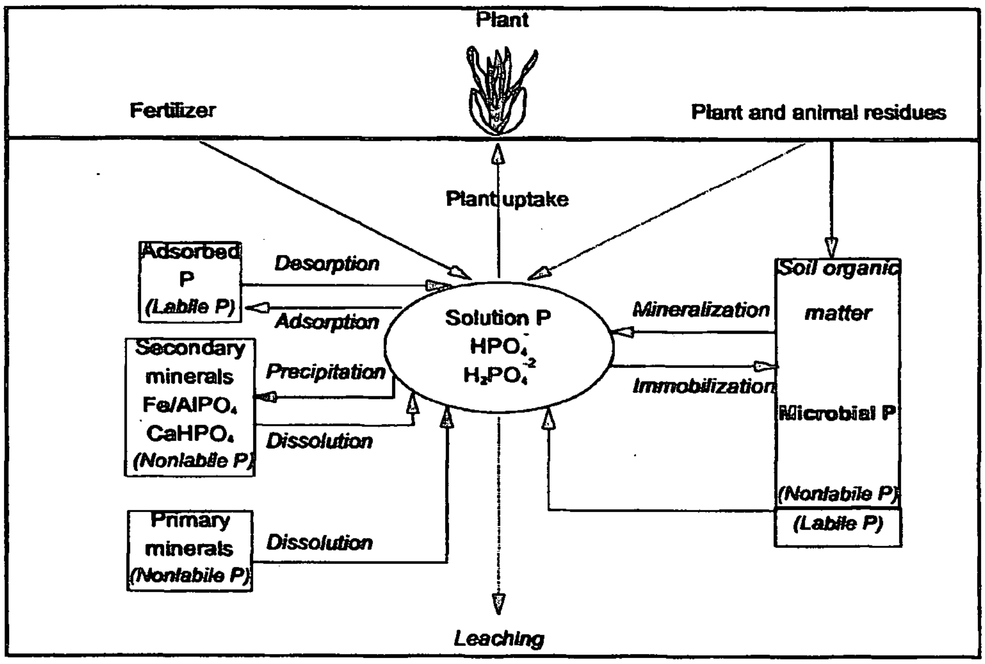

Figure 2.5 Phosphorus cycle in the soil-plant atmosphere system (Havlin *et al.*, 1999)

Cycling of P within the soil involves several biological and chemical processes which influence the soil solution P concentration (Sharpley, 2000). The biological and chemical processes will be discussed separately to indicate how the P concentration in the soil solution is buffered by the various organic and inorganic P fractions.

The biological processes comprise mineralization of organic P to inorganic P and immobilization of inorganic P to organic P by heterotrofic soil organisms (Stevenson & Cole, 1999). In general these two processes are similar to those of N in that both occur simultaneously with one usually dominating the other depending on the C/N ratio in the soil. Several other factors also effect the direction, extent and rate of the two biological processes in soil.

Table 2.6 Phosphorus inputs, outputs and cycling in the soil-plant-atmosphere system (Havlin *et al.*, 1999)

Inputs	Outputs	Cycling
Fertilization	Plant uptake	Mineralization
Plant residues	Erosion	Immobilization
Animal manure	Leaching	Adsorption
		Desorption
		Precipitation
		Dissolution

The chemical processes include adsorption and desorption as well as precipitation and dissolution (Barrow, 1985; Syers & Curtin, 1989; Frossard *et al*, 1985). These two sets of processes differ from each other. In the case of adsorption and desorption the amount of P sorbed is controlled by the soil solution P concentration. However, for a given solution P concentration there is a large difference in the amount of P sorbed by different soils. In general, clay content approximates the reactive surface area of a soil responsible for P sorption. This surface reactivity is a function of the amount and type of hydrous oxides of Al and Fe and reactive Ca compounds present, other ions, pH of the system, and reaction kinetics. The release of sorbed P into solution, viz. desorption is usually not completely reversible.

In the case of precipitation and dissolution the solubility product of the least soluble P component in the solid phase controls dissolution and thus solution P concentration (Barrow, 1985; Syers & Curtin, 1989; Frossard *et al*, 1985). In general Ca controls these reactions in neutral or calcareous soils, while Al and Fe are the dominant controlling cations in acid soils.

As a result of this several secondary phosphate minerals are formed in soils and these minerals vary much in solubility, which resulted in different dissolution rates. Apatite is the most common primary P mineral and the dissolution thereof requires a source of H from soil or biological activity and a sink for Ca and P. The dissolution of apatite varies with rainfall and temperature and is therefore quite difficult to predict.

The P cycle can be simplified to soil solution P ↔ labile P ↔ non-labile P where labile and non-labile P represents both inorganic and organic fractions. Labile P is the readily available portion of both fractions that exhibits a high dissolution rate and rapidly replenishes soil solution P. Depletion of labile P causes some non-labile to become labile, but at a slow rate.

Knowledge on the ability of soils to supply P to plants is essential for sustainable crop production. Therefore, numerous methods have been developed for the estimation of plant available P. Most of these methods involve a chemical extraction procedure. Unfortunately, there is no chemical extraction procedures which is well correlated with plant uptake under all conditions (Prasad & Power, 1997). However, chemical extractions procedures commonly used for P are based on chemical principles that relate mainly to P minerals found in soils. These minerals can dissolve, or adsorbed P can be released, to resupply soil solution P when plants take up this P. Chemical extractants for P simulate this process, because they reduce the Al, Fe and Ca in the soil solution through either complexation or precipitation. As the Al, Fe and Ca in the soil solution decrease during extraction, the Al-P, Fe-P and Ca-P minerals dissolve to resupply Al, Fe and Ca to the soil solution. The P in the soil solution concurrently increases which provides a measure of the soil's ability to supply P to plants (Havlin *et al.*, 1999). Therefore, depending on the extraction solution used various forms and amounts of P in soil can be estimated (Sharpley, 2000).

The evaluation of soil P status and the calibration of soil test values with yield response data form an essential part of the prediction of optimum rates of P fertilization. In this study only two extractants viz. Olsen (0.50 mol dm^{-3} $NaHCO_3$ with pH adjusted to 8.5 with NaOH) and Bray 2 (0.10 mol dm^{-3} HCl + 0.03 mol dm^{-3} NH_4F) will be used in order to establish which one suited Nitosols the best (Olsen & Sommers 1982). Usually, the Bray 2 extractants is recommended for acid soils, while the Olsen extractants is recommended for slightly acidic to alkaline soils (Thomas & Peaslee, 1973).

2.3.3 Fertilizer usage

In Ethiopia, usage of chemical fertilizers started only in 1952. Nowadays, mainly two types of fertilizer are used, namely urea (46% N) and DAP (18 % N and 20% P) (NFIA, 1993). The bulk of these two fertilizers which are imported were consumed by the different types of cereal grown in the country (NFIA, 1993; CSA, 1998a, b; 1999).

The trend of fertilizer consumption in the country since 1990 to 2000 is shown in Figure 2.5. In general, the consumption of both urea and DAP steadily increased over this period. The recent estimates (CSA, 1998a, b; 1999) indicated that the consumption of DAP for field pea production in Ethiopia amounted 326, 4814 and 8694 MT in 1997, 1998, 1999 respectively. These amounts implicated that only 0.2, 3.0 and 5.5% of the area under peas during those three years were fertilized. The extension program in the country encourages the use of improved pea varieties with recommended packages, which includes the use of fertilizers. Although fertilizer importation increased over the years crop yields did not respond in accordance since farmers don't use appropriate agronomic practices and application rates. Some of the problems associated with the disappointing poor crop yield response to the use of fertilizers in the field pea growing agroecological zones include untimely application of fertilizer and shortage of water during planting. Nowadays, the farmers in Ethiopia have very limited access to credit facilities which severely incapacitate them to purchase expensive fertilizers. In most cases, due to a lack of subsidy, farmers have reached a stage where they cannot afford to buy any fertilizers. In addition, the prices of agricultural products declined which discourages the farmers to purchase the recommended inputs for optimum pea production.

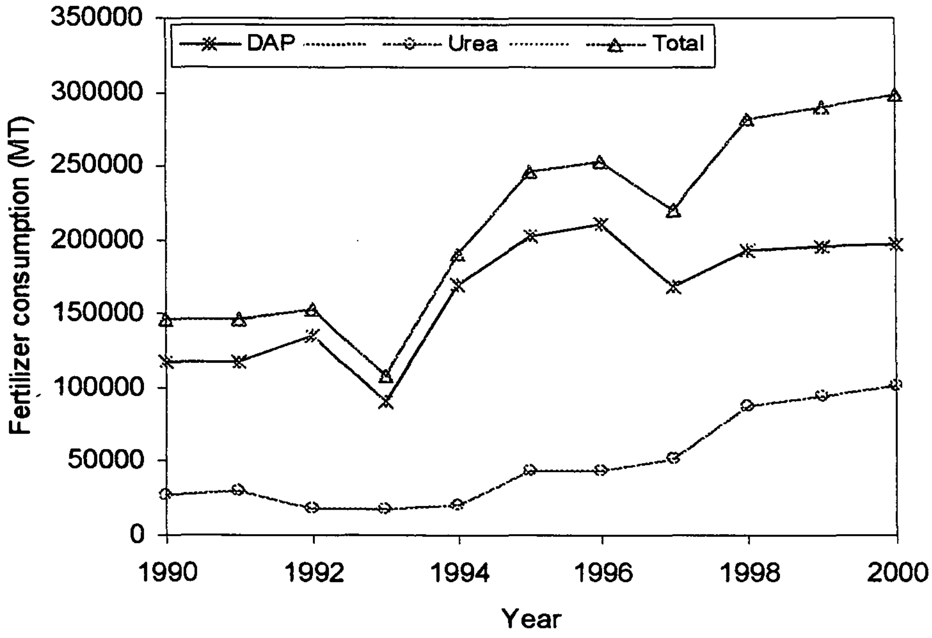

Figure 2.6 Trend of fertilizer consumption in Ethiopia (MT) in the past decades (Adugna, 2002).

2.4 Conclusion

Dry peas are the fourth most important grain legume in the world. In terms of area and production Ethiopia is the leading country in Africa where peas are ranking the third most important grain legume. In this country peas are an important protein source, soil ameliorater and break crop throughout the highlands. It is a low input crop cultivated on a wide range of soils mainly in altitudes ranging from 1800 to 3000 m.a.s.l. Deforestation and soil erosion are the major problems in the sub-aroecological zones.

However, Nitosols are the major soil group on which peas are cultivated. The Nitosols derived from basaltic volcanic parent material and have high phosphorus fixing capacities. The blanket recommendation of 100 kg DAP ha^{-1} for peas is not based on either soil or plant analyses and is therefore questioned by the farmers and development agents. Nowadays, less than 6% of the area alloted to field peas is fertilized.

CHAPTER 3

RESPONSE OF FIELD PEA (*PISUM SATIVUM* L.) CULTIVARS TO PHOSPHORUS FERTILIZATION OF NITOSOLS: GLASSHOUSE EXPERIMENTS

3.1 Introduction

In Ethiopia, field pea (*Pisum sativum* L.) is one of the grain legumes that together with cereals form an integral part of the traditional crop production system in the highlands (Telaye *et al.*, 1994; Beyene *et al.*, 1994). Here the crop plays a vital role as protein source for both humans and animals. Unfortunately, the resource-poor farmers often experience low yields with peas. In addition to socioeconomic constraints, technical factors are also responsible for the low productivity. Beyene (1988) indicated that the yields of the pulse crops grown under traditional cropping systems are generally low because of poor cultural practices, low soil pH and poor soil fertility status and recommended that intensive research should be carried out to boost production.

Nitosols are among the major arable soil groups in the Ethiopian highlands where pea production is common. These soils often have low pH values and hence are low in plant available phosphorus (Murphey, 1968; Sertu & Ali; 1983, FAO, 1984b). Sertu & Ali (1983) published an informative piece of work on P sorption and concluded that this phenomenon is one of the major constraints of crop production in the country.

Usually, the capacity of soils for P-sorption increases with increased weathering. The P sorption characteristics of soils can give reasonable estimates of their P requirements for crop production if the P solution concentration required by the crop and the buffering power of the soil are known (Kaola, *et. al.*, 1988). Unfortunately, high P fixation in soils necessitates application of large rates of P to get optimum crop yields. Such high rates seem in many cases not economically viable but it must be considered along with the fact that the additional P is satisfying the fixation needs of soils (Rao & Rao, 1991). One of the methods suggested to lessen this problem is the liming of acid soils which appears to be the most economical (Chen & Barber, 1990). Liming affects the response of grain legumes to P fertilization by precipitation of the oxides and hydroxides of either Al or Fe (Kaola, *et. al.*, 1988). According to Mappaone *et al.* (1995) liming is a common practice to improve the phosphorus fertility status of soils.

A review of literature by Föhse *et al.* (1988) reveals that plant species and even varieties of the same species differ in their ability to grow on soils low in P. They attributed this ability to several factors including the morphology of the root system (Randall, 1995; Hocking *et al.*, 1997). Hence, P uptake not only depends on the amount of available P in the soil but also on the root morphology of the plant species. Therefore, plant species and probably varieties of the same species may differ in their phosphorus use efficiency.

The existing blanket recommendations of 100 kg DAP ha^{-1} for field pea in Ethiopia is not based on extensive experimental evidence. Some research showed that peas sown on Nitosols and Vertisols did not respond significantly to different N and P application rates (Beyene, 1988; Tsigie & Woldeab, 1994). Similar results were reported from work done in the southern part of the country on soils having low levels of N and P (WADU, 1977). However, other investigations on various sites showed that peas responded positively to the 100 kg DAP ha^{-1} applications (Haile & Belayneh, 1988; Tsigie & Woldeab, 1994; Ghizaw, 1997).

Glasshouse experiments were therefore conducted with the aim to measure the effects of phosphorus application rates on the growth and development of pea cultivars that were sown on Nitosols with different phosphorus fertility levels. Additional aims were to establish critical soil phosphorus levels for optimum pea production.

3.2 Materials and methods

3.2.1 Soil collection and preparation

Topsoil (0-0.3m) of Nitosols was collected from farmland at Ilala (09°03' N, 38°30' E and 2390 m.a.s. l) and Cheffa (07°32' N, 39° 15' E and 2761 m.a.s.l.) in January 2001. The soil was transported in clean gunny yarn bags to Holetta Agricultural Research Center (HARC) where it was thoroughly mixed and air-dried on canvas sheet. Thereafter the soil was ground and sieved with a 2-mm sieve.

3.2.2 Pilot experiments

A subsample from each soil was analyzed for pH (1:1 H_2O) and extractable P (Bray 2) at HARC. The pH values were 4.60 for Ilala and 4.88 for Cheffa while the P values were 5.0 and 4.6 mg kg^{-1} for Cheffa and Ialla respectively. Therefore, prior to the main experiment two pilot experiments were conducted for establishing firstly, the amount of lime required to raise the pH of the soils to about 6.1 and secondly, the amount of phosphorus required to raise the extractable P of the soils to ca. 5, 15 and 30 mg kg^{-1}.

In the first pilot experiment 3 kg air-dried soil was thoroughly mixed with known amounts of $CaCO_3$ (0, 1.154, 2.308, 3.462, 4.615, 5.769, 6.923, 8.077, 9.231, 10.385 and 11.535 g) on clean plastic sheets. After mixing the soil was transferred to plastic pots (upper diameter 0.20 m, lower diameter 0.15 m and height 0.20 m), watered to field capacity and maintained within

20% of that level by frequent weighing during the 21 day incubation period in a lath house. After incubation the soil from each pot again was mixed thoroughly on clean plastic sheets before subsamples were taken for pH determination. From the relationships between pH values and applied $CaCO_3$ it was deducted that for every 3 kg soil respectively 6.9 and 10.4 g $CaCO_3$ were needed to raise the pH of the Ilala and Cheffa soils to 6.1.

In the second pilot experiment 3 kg air-dried soil was thoroughly mixed with $CaCO_3$ (6.9 g for Ilala and 10.4 g for Cheffa) on clean plastic sheets. Thereafter known amounts of P (0, 50, 100, 150, 150, 200, 250, 300, 350, 400, 450 and 500 mg) as dissolved $Ca(H_2PO_4).2H_2O$ were sprayed and mixed thoroughly with the soil. After mixing the soil was transferred to plastic pots (upper diameter 0.20 m, lower diameter 0.15 m and height 0.20 m), watered to field capacity and maintained within 20% of that level by frequent weighing during the 21 day incubation period in a lath house. After incubation the soil from each pot again was mixed thoroughly on clean plastic sheets and subsamples were taken for extractable P determinations. From the relationships between extractable P and applied P it was deducted that for every 3 kg soil from Ilala respectively 0, 265 and 330 mg P was needed to raise the extractable P to 5, 15 and 30 mg kg^{-1}. However, for every 3 kg soil from Cheffa respectively 0, 200 ad 400 mg P was needed to raise the extractable P to 5, 15 and 30 mg kg^{-1}.

3.2.3 Main experiments

3.2.3.1 Preparation of experimental soils

Soils for the main experiment were treated with appropriate amounts of $CaCO_3$ and $Ca(H_2PO_4).2H_2O$ to raise the pH and extractable P to the required levels mentioned earlier. The procedure was the same as in the second pilot experiment. For each of the Ilala and Cheffa soils, a total of 144 plastic bags were filled with 3 kg of treated soil resulting in three batches of 48 bags each. Thereafter the soil of all three batches should have the same pH (approximately 6.1) with each batch a different extractable P value (approximately 5, 15 and 30 mg kg^{-1}, respectively). The filled bags were watered to field capacity and maintained within 20% of that level by frequent weighing during the 67 day incubation period in a lath house. After incubation the filled bags were transferred from HARC to the National Soil Research Centre (NSRC) in Addis Abeba. There the soil from each bag was mixed thoroughly on clean plastic sheets and a sample was taken prior to the application of the phosphorus treatments. All 48 samples from a batch were mixed thoroughly to obtain a composite sample that was analyzed at HARC for pH (H_2O and KCl), organic carbon, total N, extractable P (Bray 2 and Olsen) and exchangeable cations (Ca, Mg, K and Na) with methods given in Section 3.2.3.

3.2.3.2 Execution of trials

In the glasshouse of the NSRC two phosphorus fertilization experiments were executed simultaneously, viz. with the Ilala and Cheffa pretreated soils respectively. In order to correspond with a field trial a split plot design was used with three phosphorus fertility levels (low = 5 mg kg^{-1}, medium = 15 mg kg^{-1}, and high = 30 mg P kg^{-1}) as the main plot treatment and the factorial combination of two pea cultivars (Holetta and G22763-2C on Ilala soil and Tegegnech and Cheffa local on Cheffa soil) and six phosphorus application rates (0, 7.5, 15, 30, 60 and 120 mg P kg^{-1}) as the sub-plot treatments which were replicated four times.

The appropriate amount of P was sprayed as dissolved $Ca(H_2PO_4).2H_2O$ on the pretreated soils that were evenly spread on plastic sheets. Through this solution, an equivalent amount of 15 mg N kg^{-1} as urea and 150 mg K kg^{-1} were also applied. In addition, to ensure that the essential micronutrients for plant growth were not limiting in these experiments, all pretreated soils were sprayed with a 20 ml solution whereof the composition is shown in Table 3.1.

Table 3.1 Composition of solution with micronutrients.

Chemical used			Solution concentration	
Composition	Nutrient	%	mg l^{-1}	%
$Na_2B_4O_7.5H_2O$	B	0.2	24	2.4
$CuSO_4.5H_2O$	Cu	0.3	47	4.7
$Fe_2\,(SO_4)_3.\,5H_2O$	Fe	0.3	59g	5.9
$ZnS\,O_4.\,H_2O$	Zn	0.3	70	7.0
$MnSO_4\,H_2O$	Mn	0.05	1.5	0.15
$Na_2MoO_4.2H_2O$	Mo	0.05	1.2	0.12

Every pretreated soil was thoroughly mixed after spraying and then transferred to a plastic pot (upper diameter 0.20 m, lower diameter 0.15 m and height 0.20 m) filled with 0.5 kg of washed sand. The pots were watered to field capacity and maintained within 20% of that level throughout the experimental period which lasted from mid July to mid September. Three pea seeds of the appropriate cultivars were planted per pot. Approximately three weeks after planting three 2.5-m long plastic conduits tied together with gunny yarn were inserted into the pots to support the three pea plants. From four weeks after planting the fungicide BRAVO-500 was sprayed at 10 day intervals to every pot at a rate of 2.5 kg ha^{-1} for preventing blight diseases caused by *Mycospaerella pinodes* (EARO, 1998). Throughout the growth period, temperature and relative humidity fluctuations were recorded from 05:30 until 17:30 at 4 h intervals. The average temperatures recorded at 05:30, 09:30, 13:30 and 17:30 were 9.8, 20.5, 22.1 and 20.8°C and the corresponding relative humidities were 79.3, 70.8, 67.7 and 72.5%, respectively.

3.2.3.3 Collection of data

Soil data: At 29 days after planting soil was sampled from every pot using a 0.20 m long rigid plastic conduit with an inner diameter of 13 mm. During sampling care was taken not to damage the roots. These samples were air dried in a lath house at HARC and then ground to pass a 2-mm sieve for analysis. The pH was measured in 1:1 soil to H_2O and 1:1 soil to KCl suspensions. Organic carbon was measured according to Walkley & Black (1934) method. A modified Kjeldhal method was used to determine total N (Cottenie, 1980; Bremner and Mulvaney, 1982). Extractable P was determined following the methods of Bray 2 and Olsen (Olsen & Sommers, 1982). The exchangeable cations were leached by NH_4OAc with pH adjusted to 7 (Thomas, 1982) and the concentration of Ca and Mg in the filtrate were determined using an Atomic Absorption Spectrometer and that of K and Na using a flame photometer (IITA, 1979).

Plant data: The plant height was measured just after all plants flowered hence at early podding stage. Thereafter, the plants were cut with scissors at the soil surface, rinsed in distilled water, ovendried at 65°C for 72 hrs and weighed to attain the shoot weight. The roots were separated from the soil by washing with tap water. Before oven drying at 65°C for 72 hrs to obtain the root weights, the nodulation characteristics namely number, position, colour and size were assessed on a four-point scale as suggested by Beyene & Tsigie (1986). The dried shoots and roots were ground for analysis using a Rotor-Speed-Mill"pulverisette 14", Fritsch GmbH, Germany. These pulverized samples were analysed for N, P, K, Ca and Mg. Steam distillation was used for the determination of N after digestion of the plant material in sulphuric acid (Hesse, 1971). Dry-ashing of the plant material with nitric was used to obtain P, K, Ca and Mg in solution (Hesse, 1971). The P was determined by colorimetery and K, Ca and Mg by atomic absorption.

3.2.3.4 Statistical analysis of data

The data collected were subjected to statistical analysis by using the MSTATC computer program, version 2.10. For all parameters, tests for homogeneity of variance were computed following the description of Gomez & Gomez (1984). None of the parameters required data transformation, as the computed X^2 values were smaller than that of the tabular X^2 values.

Based on the significance (either $p < 0.01$ or $p < 0.05$) of analysis of variance outputs for soil and plant parameters, the later mean data were fitted to a Mitscherlich equation: Y = A-B*EXP(-CX), where Y is the dependent variable, X is the amount of P applied, and A, B and C are coefficients. Details on these coefficients have been adopted from Bolland *et al.* (2000a; 2000b) and are as follows: Coefficient A provide an estimate of the asymptote or maximum value for a parameter, coefficient B estimates the difference between the asymptote and the intercept on Y axis at X = 0 and so estimates the response to added P and coefficient C describes the shape of the relationship and governs the rate at which Y increases as X increases. Initial estimates for the coefficients were made by using a Compressive Curve Fitting System for Windows of Association (3) in Curve Expert 1.37 (Hyams, 1995-2001). Then, the mean data were fitted to the equation by non-linear regression using a user model in Curve Expert 1.37.

3.3 Results and discussion

3.3.1 Soil environment

In Table 3.2, some properties of the Ilala and Cheffa soils after pretreatment with lime and phosphorus are presented. As mentioned in Section 3.2.2, the aim with the pretreatment was to modify both soils in such a manner that they have low, medium and high phosphorus fertility levels all with an optimum pH.

Table 3.2 Some properties of the Ilala and Cheffa soils after pretreatment with lime and phosphorus but before planting.

Property	Ilala	Cheffa
Particle size distribution (%)		
Sand (0.05-2.0 mm)	18	24
Silt (0.002-0.05 mm)	38	44
Clay (<0.002 mm)	44	36
PH values		
H_2O suspension	5.90	5.74
KCl suspension	4.99	4.94
Organic C (%)	3.40	1.59
Total N (%)	0.25	0.15
Extractable P (mg kg^{-1})		
Bray 2*		
Low	6.8	5.4
Medium	16.8	11.4
High	21.4	29.4
Olsen *		
Low	7.2	8.0
Medium	16.0	16.8
High	27.2	24.6
Extractable cations (mg kg^{-1})		
Ca	2295	2152
Mg	159	216
K	370	452
Na	35	28

* Phosphorus fertility level.

3.3.1.1 pH

Inspection of Table 3.2 showed that the pH (H_2O) of the Ilala soil was raised from 4.60 to 5.90 and that of the Cheffa soil from 4.88 to 5.74 and, therefore, not achieving the envisaged value of 6.1. However, the pH values of 5.90 for the Ilala soil and 5.74 for the Cheffa soil are still within the optimum range of 5.5 to 6.5 for field peas according to Kay (1979). Also within this range are the pH values measured after planting, viz. 5.84 for the Ilala and 5.62 for the Cheffa soils. It is worth mentioning that the latter pH values were not affected at all by any of the treatments, viz. the phosphorus fertility levels and application rates.

3.3.1.2 Extractable P

The Bray 2 extractable P values indicated three distinct levels of phosphorus fertility in both soils (Table 3.2). According to these values some of the envisaged levels were not achieved with the pretreatment, viz. the 30 mg kg $^{-1}$ level with the Ilala soil and the 15 mg kg $^{-1}$ level with the Cheffa soil. Usually, the Bray 2 extractable P values are consistently higher than the Olsen extractable P values which is not the case here. No obvious explanation can be given for this phenomenon, which warrants further investigation.

The effects of the phosphorus fertility level and application rate treatments for both soils are summerized in Table 3.3. Only the effects that were significant will be presented and discussed. After planting, the amount of P extracted by either the Bray 2 (Figure 3.1) or Olsen (Figure 3.2) procedures from the Ilala soil was significantly ($p<0.01$) affected by the interaction of phosphorus fertility levels and application rates. In both cases, the extractable P increased with increasing rates for each level. However, the Olsen procedure extracted more P than the Bray 2 procedure for comparative combinations of phosphorus fertility level x application rate. The interaction of phosphorus fertility level x application rate had no significant effect on the P extracted by either of the two extraction procedures from the Cheffa soil. However, the extracted P increased with increasing phosphorus fertility levels (Figure 3.3) and application rates (Figure 3.4).

Table 3.3 Summary on the analysis of variance computed with extractable phosphorus data indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala soil		Cheffa soil	
	Bray 2	Olsen	Bray 2	Olsen
A	**	**	**	**
B	**	**	**	**
C				
AB	**	**		
AC				
BC				
ABC				
Mean	15.97	22.90	20.82	22.51
CV%	15.15	18.60	20.57	13.57

[1] A= phosphorus fertility level, B = phosphorus application rate and C = cultivar.

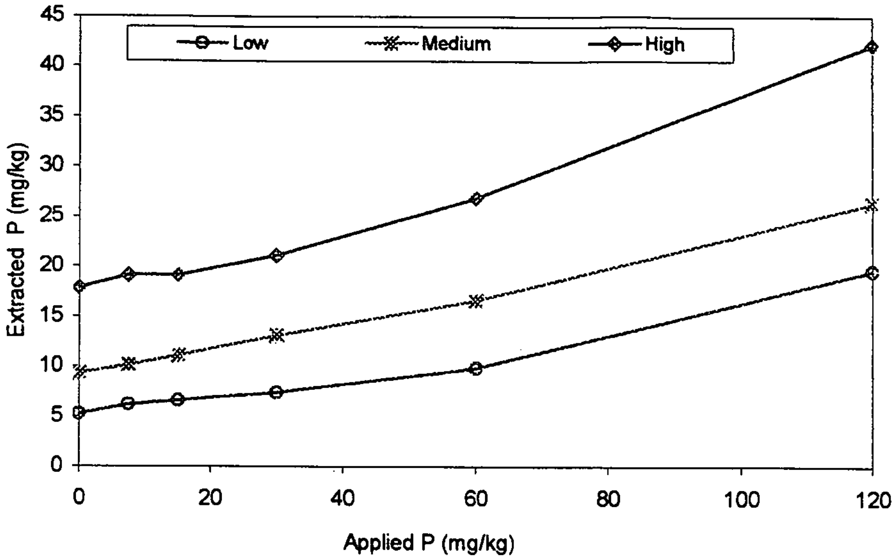

Figure 3.1 Effect of phosphorus fertility level x application rate on the P extracted from the Ilala soil with the Bray 2 procedure. Value of LSD by DMRT = 3.2 at p = 0.01.

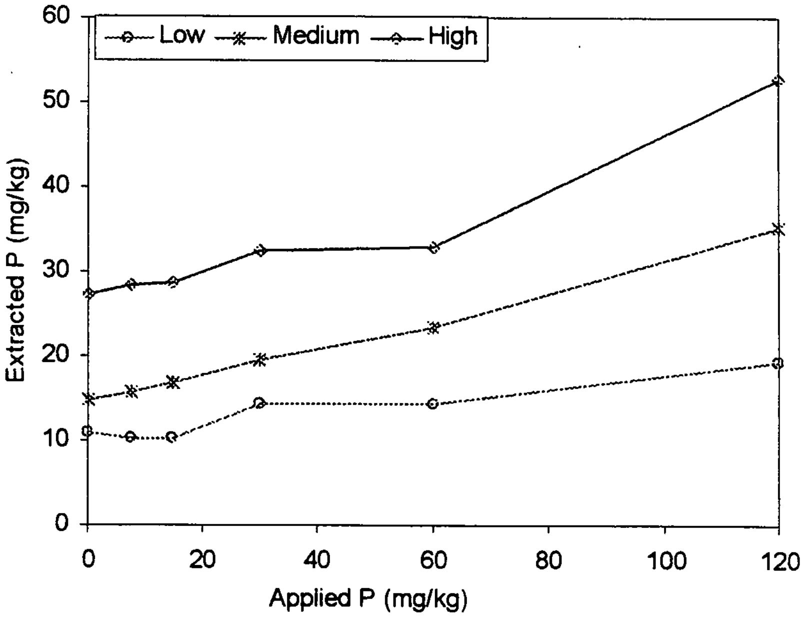

Figure 3.2 Effect of phosphorus fertility level x application rate on the P extracted from the Ilala soil with the Olsen procedure. Value of LSD by DMRT = 5.6 at p = 0.01.

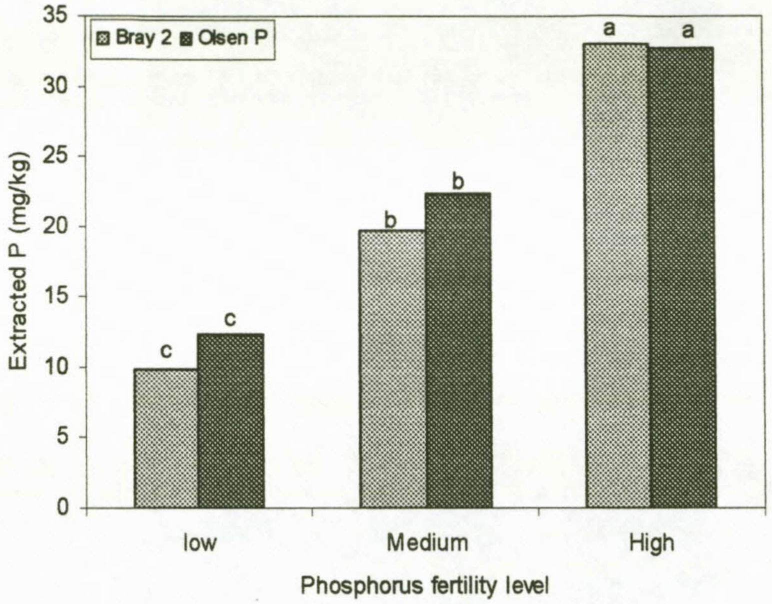

Figure 3.3 Effect of phosphorus fertility level on the P extracted from the Cheffa soil with the Bray 2 and Olsen procedures. Values of LSD by DMRT = 2.2 for Bray 2 and 6.1 for Olsen at p = 0.01. No significant difference between bars with the same letter.

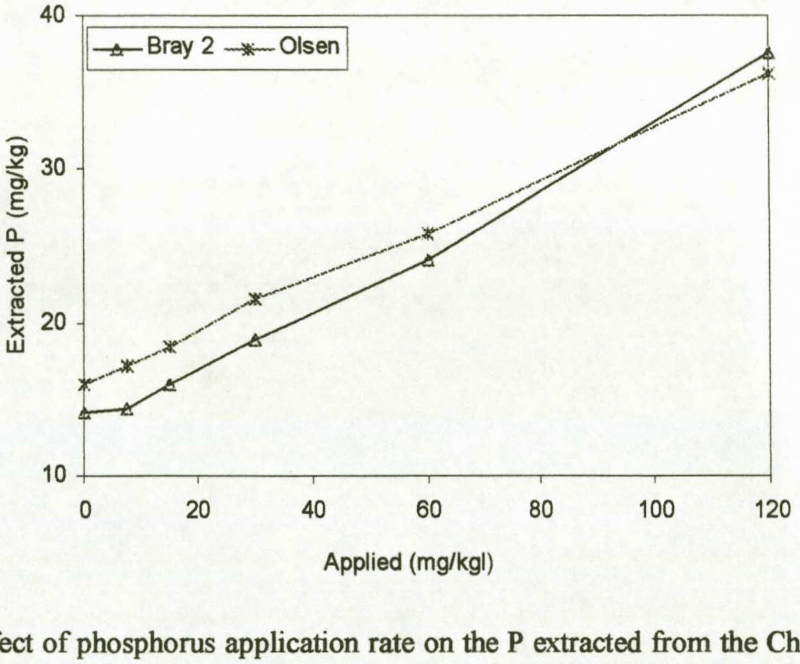

Figure 3.4 Effect of phosphorus application rate on the P extracted from the Cheffa soil with the Bray 2 and Olsen procedures, Values of LSD by DMRT = 0.9 for Bray 2 and 2.3 for Olsen at p = 0.01.

The correlation coefficients calculated for the relathionships between Bray 2 and Olsen extractable P values are highly significant ($p < 0.01$). For the Ilala and Cheffa soils the r values were respectively 0.93 and 0.94, indicating that any of the extraction procedures could possibly be used to determine the P status of soils. From these results, it can be concluded that the pH and extractable P of both the Ilala and Cheffa soils were modified successfully as was the aim for the glasshouse experiments.

The application of Ca to soils through liming materials often improve grain legume growth by increasing the base saturation of the soil and /or increasing nodulation on the roots (Mahler *et al.*, 1988). The authors further pointed out that soil pH values of less than 5.6 adversely affect *Rhizobium leguminosarum* populations. Such situations may lead to poor nodulation that in turn adversely affects the N nutrition of peas. Hence, in these experiments the problem associated with low pH has been largely removed by liming.

3.3.2 Crop growth

3.3.2.1 Plant height

Analysis of variance showed that plant height on the Ilala soil was affected significantly ($p < 0.01$) by phosphorus fertility level, phosphorus application rate, cultivar and the interaction of phosphorus fertility level x cultivar (Table 3.4.). Therefore, the effect of phosphorus application rates regardless of the phosphorus fertility levels is presented in Figure 3.5. The plant height increased sharply until a 15 mg P kg^{-1} application whereafter it stabilized. In Figure 3.6 the interaction effect of phosphorus fertility level x cultivar on plant height is illustrated. The plant height increased with increasing phosphorus fertility levels but at every level the Holetta plants were taller than the G22763-2C plants. Plants of the former cultivar were on average 23 cm taller than plants of the latter cultivar.

Table 3.4 Summary on the analysis of variance computed with plant height and total biomass data indicating significant treatment effects at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala soil		Cheffa soil	
	Plant height	Total biomass	Plant height	Total biomass
A	**	**	*	**
B	**	**	**	**
C	**		**	**
AB		**	*	**
AC	**			
BC				
ABC				
Mean	161.96	20.06	17.83	165.42
CV%	4.95	6.30	6.42	4.66

[1] A= phosphorus fertility level, B=phosphorus application rate and C=cultivar.

In the case of the Cheffa soil, all the main effects, viz. phosphorus fertility level ($p < 0.05$), phosphorus application rate ($p < 0.01$), and cultivar ($p < 0.01$) were significant (Table 3.3). The interaction of phosphorus fertility level x application rate was also significant ($p < 0.05$) and is therefore presented in Figure 3.7. At all three phosphorus fertility levels, plant height increased with increasing phosphorus application rates until a critical rate whereafter it stabilized. The critical rate for the low, medium, and high levels were 60, 30, and 7.5 mg P kg^{-1}, respectively. The Cheffa local plants were on average 13 cm taller than the Tegegnech plants.

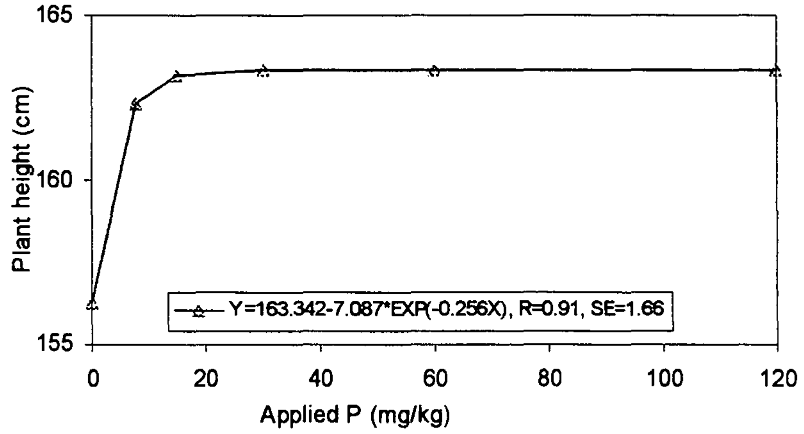

Figure 3.5 Effect of phosphorus application rate on the height of peas planted in Ilala soil.

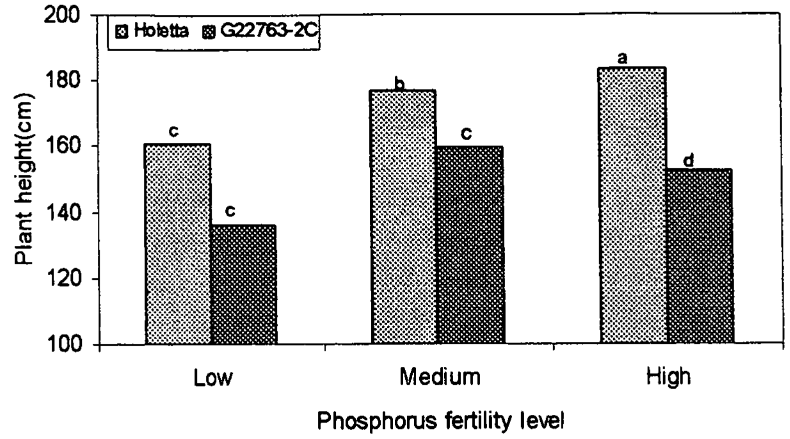

Figure 3.6 Effect of phosphorus fertility level x cultivar on the height of peas planted in the Ilala soil. Values of LSD by DMRT = 6.1 at p=0.01. No significant different between bars with the same letter.

Significantly ($p < 0.01$) correlation coefficients were calculated between plant height and extracted P. For the Ilala and Cheffa soils they were respectively 0.24 and 0.23 with Bray 2, and 0.34 and 0.26 with Olsen.

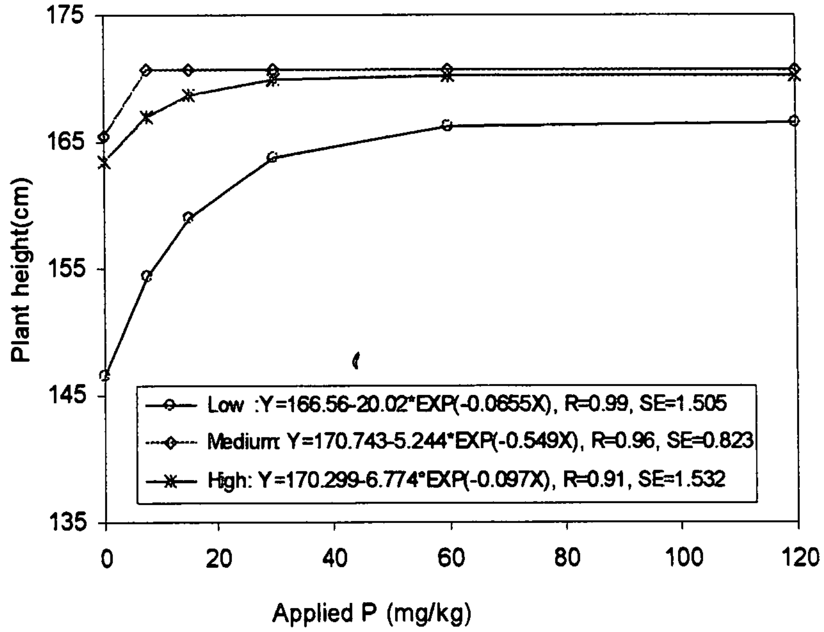

Figure 3.7 Effect of phosphorus fertility level x application rate on the height of peas planted in the Cheffa soil.

3.3.2.2 Total biomass

Only data on total biomass, viz. the shoot plus root mass are presented since the treatment effects on the three parameters were similar as confirmed also by correlation analyses. In the case of the Ilala soil, the correlation coefficients ($p < 0.01$) for biomass vs shoot mass, biomass vs root mass and shoot mass vs root mass were calculated as 0.79, 0.63 and 0.55 respectively. For the Cheffa soil, correlation coefficients ($p < 0.01$) of 0.79, 0.57 and 0.47 were calculated respectively for biomass vs shoot mass, biomass vs as root mass and shoot mass vs root mass.

Analysis of variance showed that total biomass on the Ilala soil was affected significantly ($p < 0.01$) by phosphorus fertility level, phosphorus application rate and the interaction between those treatments (Table 3.4). Therefore, only the interaction effects are shown in Figure 3.8. Inspection of this figure indicates that at all the three phosphorus fertility levels the total biomass increased with increasing phosphorus application rates. However, as expected this response declines sharply when the phosphorus fertility increases from a low to a high level. Therefore, at the low phosphorus fertility level more than 60 mg P kg^{-1} soil, and at the medium and high phosphorus fertility levels about 30 mg P kg^{-1} soil should be applied for optimum total biomass production of peas.

In the case of the Cheffa soil all the main effects, viz. phosphorus fertility level, phosphorus application rate and cultivar were significant (Table 3.3). However, the interaction of phosphorus fertility level x phosphorus application was also significant ($p < 0.01$) and is presented in Figure 3.9. At all three phosphorus fertility levels total biomass increased with increasing phosphorus application rates. This response as in the case of the Ilala soil decline when the phosphorus fertility increases. However, at the low and medium phosphorus fertility levels about 60 mg P kg^{-1} soil, and at the high phosphorus fertility level about 7.5 mg P kg^{-1}

soil is needed for optimum total biomass production. On average the total biomass of the cv.Cheffa local plants were 0.59 g more than that of the cv.Tegegnech plants.

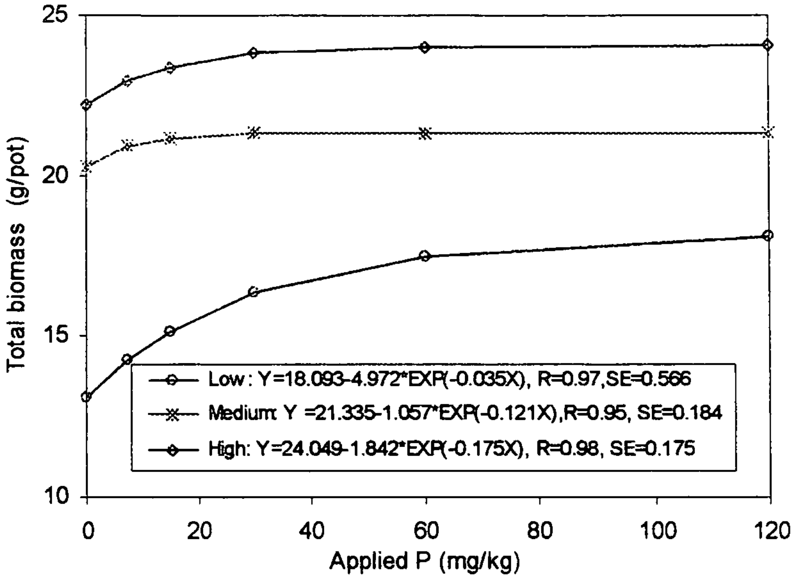

Figure 3.8 Effect of phosphorus fertility level x application rate on the total biomass of peas planted in the Ilala soil

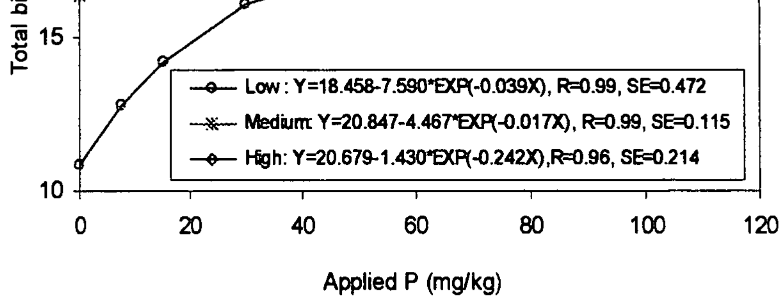

Figure 3.9 Effect of phosphorus fertility level x application rate on the total biomass of peas planted in the Cheffa soil.

Correlation coefficients between total biomass and extracted P were highly significant (p<0.01). For the Ilala and Cheffa soils respectively these values were 0.65 and 0.73 with Bray 2 and 0.70 and 0.73 with Olsen.

In general, the phosphorus fertility level of the soil together with the rate of phosphorus application had a positive influence on the growth and development of the pea crop as manifested in height and biomass. This is in accordance with the findings of several researchers (Ibrahim 1982; Srivastava & Ahlawat, 1995; Rathi *et al.*, 1995; Yamagishi *et al.*, 1995). This could be attributed to the association of P with several vital functions such as utilization of sugars and starch, nucleus formation, cell division, photosynthesis and root growth (Arnon, 1956; Dubey, 2001). In fact, P enhances cell division activities leading to increased plant height, number of branches and consequently increased biomass (Ibrahim, 1982; Yadav *et al.*, 1992; 1993). The lack of significant differences between the growth and development of the two field pea cultivars as a result of either phosphorus fertility level or application rate was somewhat surprising. However, this could be due to the development of the two cultivars under high input conditions and that they need more or less the same period for maturation.

3.3.2.3 Nodule characteristics

The significant effects of the phosphorus fertility level, phosphorus application rate and cultivar treatments on the position, size, colour and number of nodules were very limited (Table 3.5). Except for the mean score for position, the mean scores for size, colour and number were higher in the Cheffa than Ilala soil.

Table 3. 5 Summary on the analysis of variance computed with nodule characteristics data indicating significant treatment effects at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala soil				Cheffa soil			
	Position	Size	Colour	Number	Position	Size	Colour	Number
A	**	**	*			*		**
B						**	*	
C							**	
AB	*					*		
AC								
BC								
ABC								
Mean	3.56	2.27	2.84	3.25	3.86	1.85	2.52	2.70
CV%	8.86	11.96	13.36	14.47	6.84	16.35	16.72	18.76

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

Only the position, size and colour of the nodules were affected by the level of phosphorus fertility in the Ilala soil (Figure 3.10). The size and colour scores of the nodules increased with increasing levels of phosphorus fertility. However, this was not the case with the position of the nodules since the lowest score was recorded at the medium phosphorus level and no difference between the other two levels. The significant interaction between phosphorus fertility levels and application rates resulted that the position scores for every level increased with increasing rates (Data not shown).

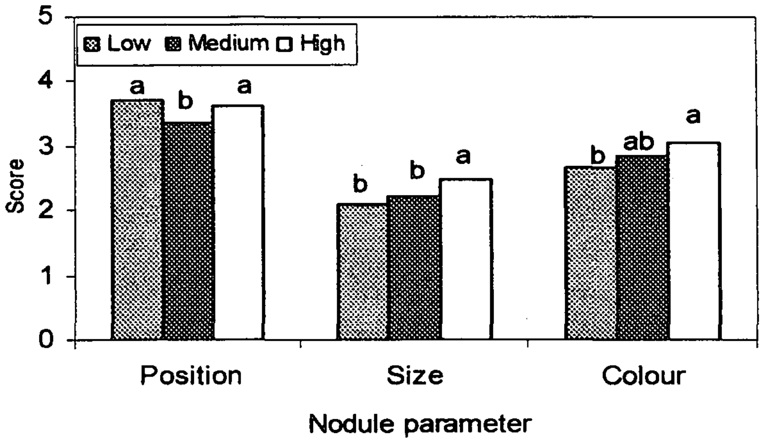

Figure 3.10 Effect of phosphorus fertility level on the position, size, and colour of pea root nodules in the Ilala soil. Values of LSD by DMRT = 0.22 for position, 0.27 for size and 0.37 for colour at $p = 0.01$. No significant difference between bars for a character with the same letter.

The effect of phosphorus fertility level on the size and number of nodules in the Cheffa soil is illustrated in Figure 3.11. Both parameters increased with increasing levels of phosphorus fertility. The significant interaction between phosphorus fertility levels and application rates accentuated this increase in nodule size (Data not shown). In addition the size and colour scores on the nodules increased with higher rates of phosphorus application until 15 mg kg^{-1} whereafter the scores stabilized (Figure 3.12). The only significant difference between the cultivars was that of the colour score of 2.67 for cv. Cheffa local which was higher than the 2.37 for cv.Tegegnech.

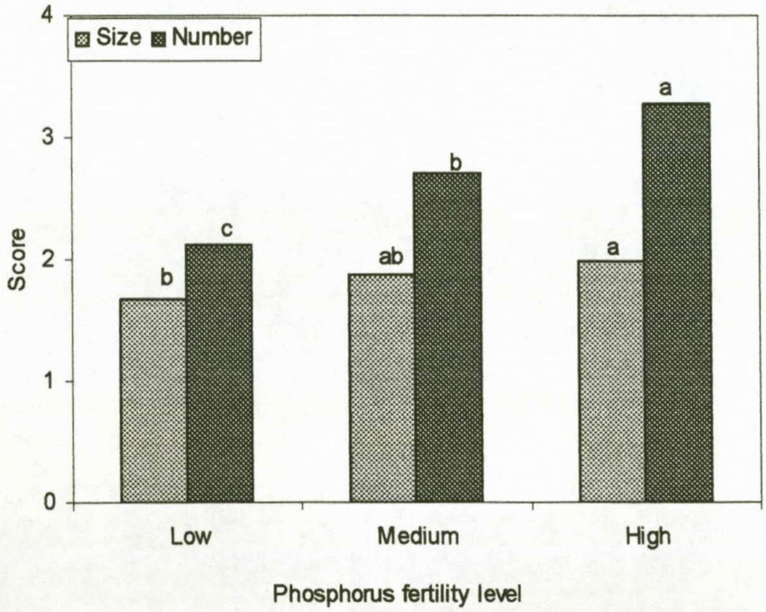

Figure 3.11 Effect of phosphorus fertility level on the size and number of pea root nodules in the Cheffa soil. Values of LSD by DMRT = 0.21 at p = 0.05 for size and 0.55 at p = 0.01 for number. No significant difference between bars for a nodule character with the same letter.

Normally, higher phosphorus fertility levels and/or application rates improve nodulation significantly as reported for various legume crops including peas (Tewari, 1965; Gates & Wilson, 1974; Bonetti *et al*, 1984; Mappaona *et al.*, 1995; Srivastava &Ahlawat, 1995; Nenadic, 1997). In addition to P which they reported as the most important nutrient to stimulate nodulation, sufficient water supply is also essential. The fact that the soil was maintained throughout the experimental period within 20% of field capacity may have contributed to the excellent nodulation observed regardless of the phosphorus fertility level and application rate treatments.

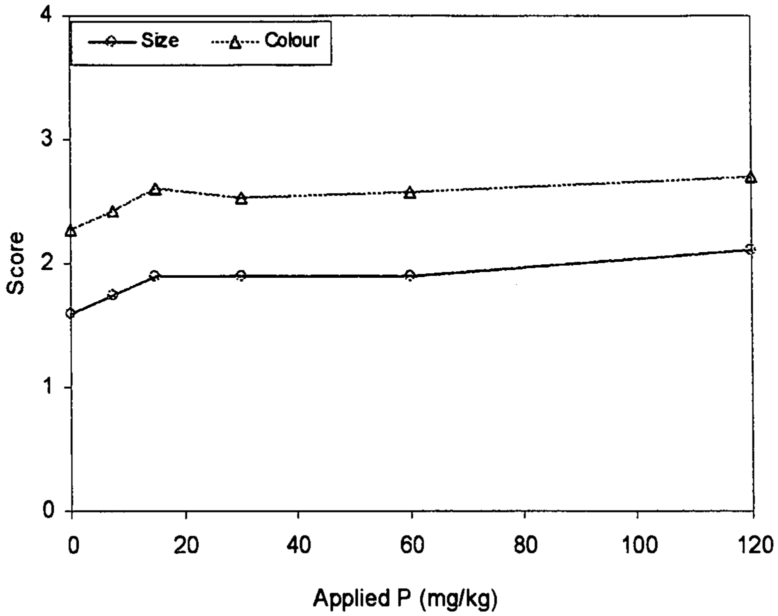

Figure 3.12 Effect of phosphorus application rate on the size and colour of pea root nodules in the Cheffa soil. Values of LSD by DMRT = 0.23 at $p = 0.01$ for size and 0.09 at $p = 0.05$ for colour.

3.3.3 Nutrient content

The effects of phosphorus fertility level, phosphorus application rate, cultivar and their interactions on the nutrient content of field peas planted in the Ilala soil are summerized in Table 3.6. At early podding stage just after flowering, the N, P, K, Ca and Mg contents of shoots were affected to some extent. The N content of the roots was not measured due to a lack of material. Otherwise, the Ca and Mg content of the roots were affected by the phosphorus fertility level and interaction thereof with cultivar, respectively.

Table 3.6 Summary on the analysis of variance computed with nutrient content data of field peas from the Ilala soil indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Shoots					Roots			
	N	P	K	Ca	Mg	P	K	Ca	Mg
A								**	
B	**	**							
C			**	**	*				
AB	*	**							
AC									*
BC									
ABC									
Mean	30.45	2.09	24.07	13.58	1.77	3.06	28.46	7.39	2.24
CV%	7.68	12.31	12.54	12.83	9.07	21.33	26.11	27.31	23.03

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

Nitrogen: The nitrogen content of the shoots from the low phosphorus fertility level increased almost linear with increasing phosphorus application rate (Figure 3.13). At the medium phosphorus fertility level, the N content of the shoots increased sharply until at an application

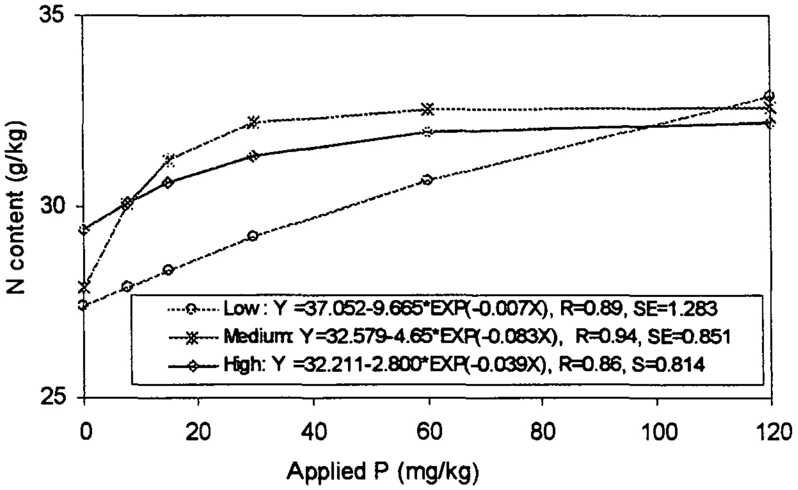

Figure 3.13 Effect of phosphorus fertility level x application rate on the N content in shoots of peas planted in the Ilala soil.

rate of 30 mg P kg^{-1} whereafter it stabilized. A similar trend though at a slower rate was observed at the high phosphorus fertility level. The response stabilized only after the 60 mg P kg^{-1} application rate.

Phosphorus: The phosphorus content of the shoots from the low phosphorus fertility level increased almost linearly with increasing phosphorus application rates (Figure 3.14). However, at the medium and high phosphorus fertility levels, the P content of the shoots increased until at an application rate of 60 mg P kg^{-1} whereafter it stabilized. The P content of the shoots from the medium phosphorus fertility level was, at every application rate, higher than that of the shoots from the high phosphorus fertility level.

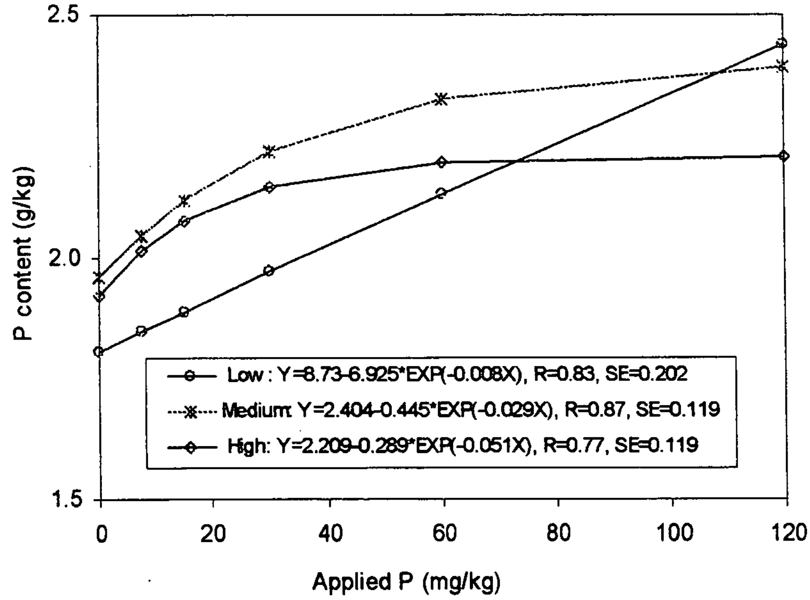

Figure 3.14 Effect of phosphorus fertility level x application rate on the P content in shoots of peas planted in the Ilala soils.

Potassium: The K content of the shoots from the Holetta cultivar was significantly higher than the K content of the shoots from the G22763-2C cultivar as illustrated in Figure 3.15.

Calcium: As shown in Figure 3.15 the Ca content of the shoots from the Holetta cultivar was significantly lower than the Ca content of the shoots from the G22763-2C cultivar. The Ca content of the roots increased slightly from the low to medium phosphorus fertility level but then decreased significantly to the high phosphorus fertility level (Figure 3.16).

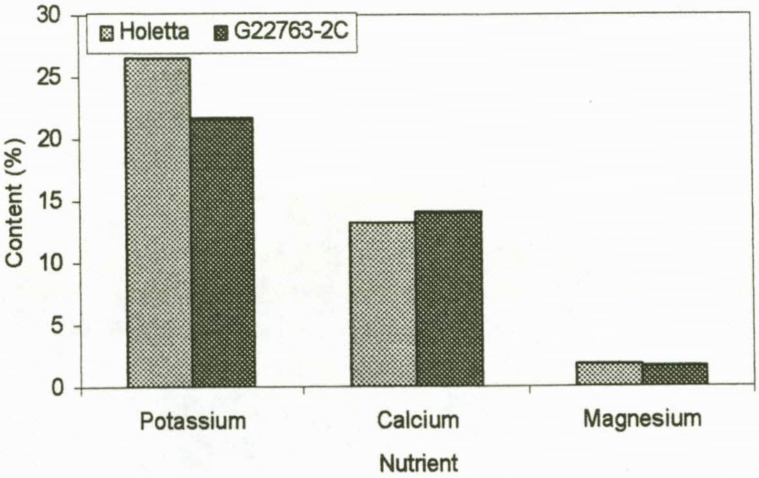

Figure 3.15 Effect of cultivar on the K, Ca and Mg content in shoots of peas planted in the Ilala soil. Values of SE for K = 0.21, Ca = 0.36 and Mg = 0.02 at $p < 0.05$.

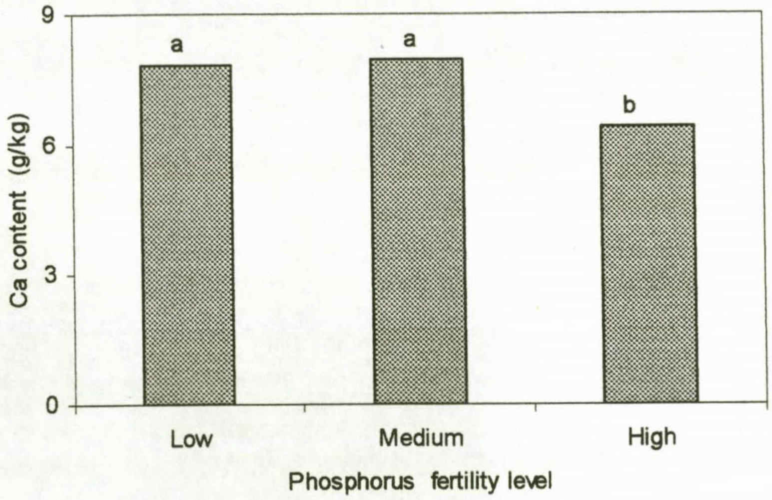

Figure 3.16 Effect of phosphorus fertility level on the Ca content in roots of peas planted in the Ilala soil. Values of LSD by DMRT = 0.82 at $p < 0.05$.

Magnesium: As in the case of Ca, the Mg content of the shoots from the Holetta cultivar was significantly lower than the Mg content of the shoots from the G22763-2C cultivar (Figure 3.15). The Mg content of the roots from the Holetta cultivar increased from the low to medium phosphorus fertility level, but not from the medium to high phosphorus fertility level (Figure 3.17). However, the Mg content of the roots from the G22763-2C cultivar decreased from the low to medium phosphorus fertility level and then increased from the medium to high phosphorus fertility level.

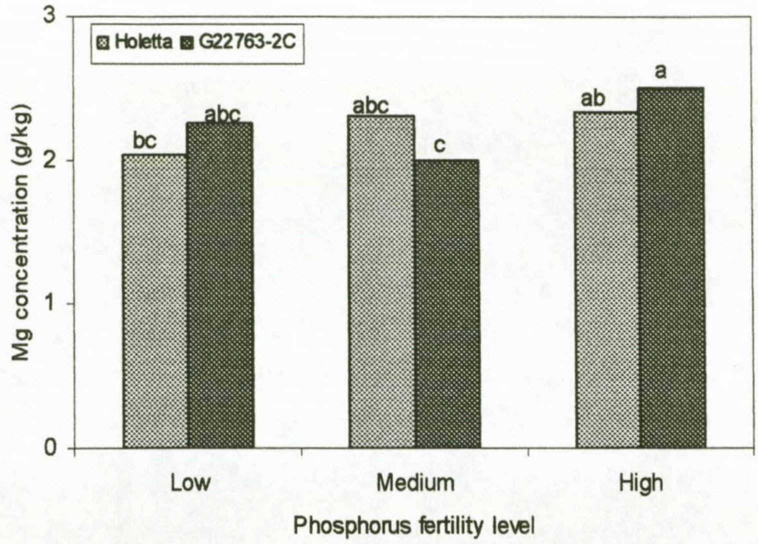

Figure 3.17 Effect of phosphorus fertility level x cultivar on the Mg content in roots of peas planted in Ilala soils. Values of LSD by DMRT = 0.30 at $p < 0.01$. No significant difference between bars with the same letter.

The nutrient contents of the field peas planted in the Cheffa soil were also affected by the different treatments as shown in Table 3.7. Just after flowering viz. at early podding stage, the N, P, K, Ca of the shoots differed significantly. For the same reason as above, the N contents of the roots were not measured. Otherwise, the P, K, and Ca contents of the roots were also affected to some extent.

Nitrogen: As shown in Table 3.7, the interaction of phosphorus fertility level x application rate was significant on N content. However, the Mitscherlich model used to calculate these relationships indicated that the data between the phosphorus fertility levels overflow too much. Therefore, only the mean effect of phosphorus application rate on the N content in the shoots is illustrated in Figure 3.18. The N content in the shoots increased sharply until an application rate of 30 mg P kg^{-1} whereafter the increase slowed down. Furthermore, the N content in the shoots of the Tegegnech cultivar was significantly higher than the N content in the shoots of the Cheffa local cultivar (Figure 3.19).

Table 3.7 Summary on the analysis of variance computed with nutrient content data of field peas from the Cheffa soil indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Shoots					Roots			
	N	P	K	Ca	Mg	P	K	Ca	Mg
A	*							*	
B									
C	**	**	**			*	**	**	
AB	*					**			
AC				**	*	**			
BC									
ABC									
Mean	25.93	2.52	24.74	8.26	1.49	4.27	31.40	11.83	2.54
CV%	13.05	14.12	17.63	19.94	12.42	24.17	36.75	22.80	34.81

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

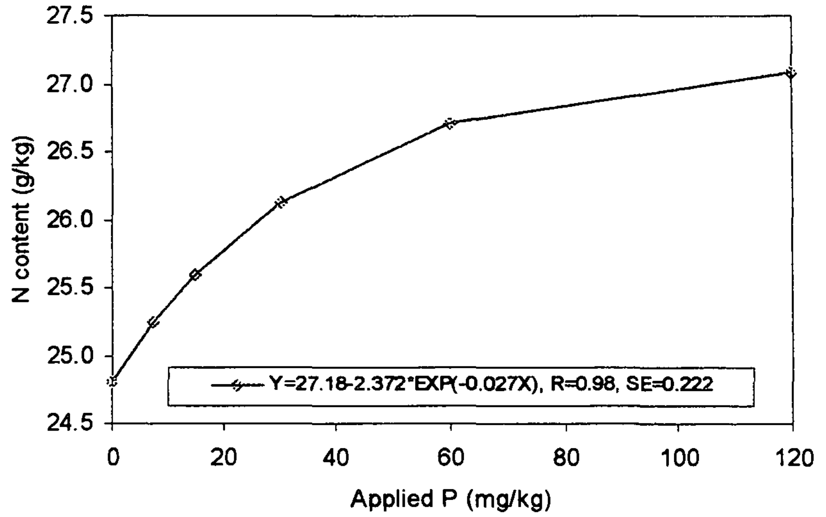

Figure 3.18 Effect of phosphorus application level on the N content in shoots of peas planted in the Cheffa soil.

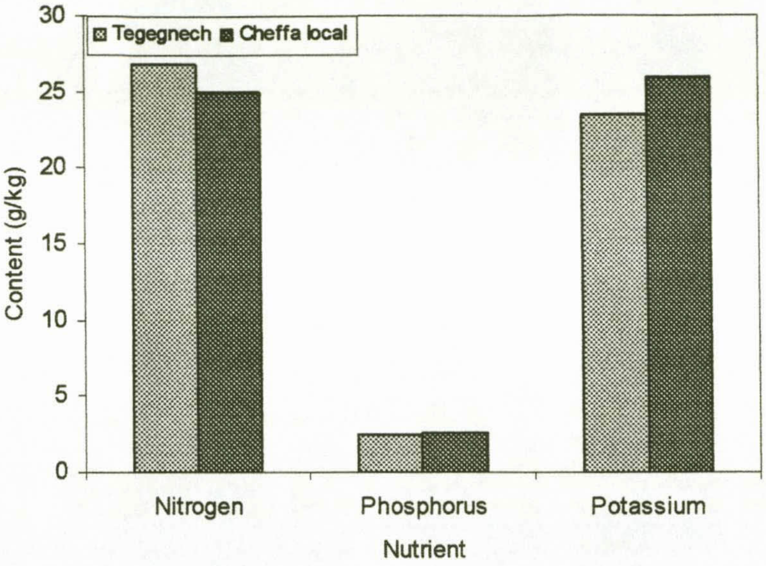

Figure 3.19 Effect of cultivar on the N, P and K content in shoots of peas planted in the Cheffa soil. Values of S E = 0.51, 0.04 and 0.40 for K, P and N repectively, $p < 0.01$.

Phosphorus: The only significant difference of P content in the shoots resulted between the two cultivars as illustrated in Figure 3.19. However, the P content in the roots was significantly affected by cultivar, the interactions of phosphorus fertility level and application rate, and phosphorus fertility level and cultivar (Figures 3.20, 3.21 and 3.22). The P content of the roots at the low phosphorus fertility level increased with application rate until 30 mg P kg^{-1} and then stabilized (Figure 3.20). At the medium and high phosphorus fertility levels, the P content of the roots was not affected at all by the phosphorus application rates. Similarly only at the low phosphorus fertility level did the P content of the roots from the Tegegnech and Cheffa local cultivars differ (Figure 3.21). The same was true even in response to the cultivar alone (Figure 3.22).

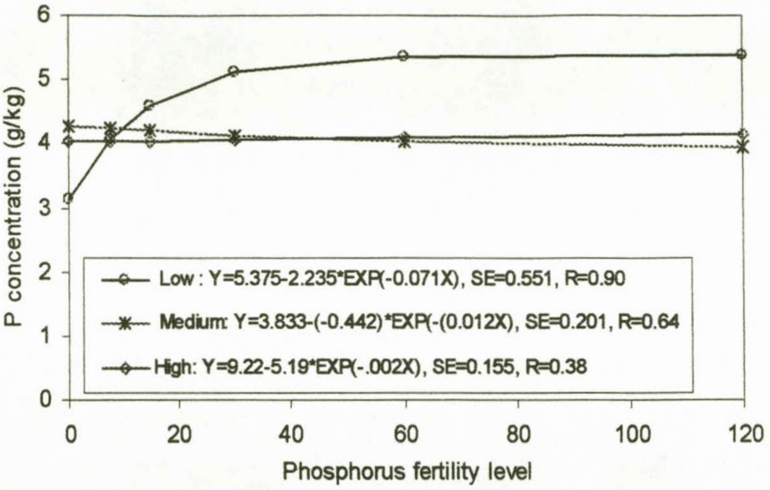

Figure 3.20 Effect of phosphorus fertility level x application rate on the P content in roots of peas planted in the Cheffa soil.

Potassium: The only significant difference of K content in the shoots (Figure 3.19) and roots (Figure 3.22) resulted between the cultivars. Cheffa local shoots had a higher K content than the Tegegnech shoots while the Tegegnech roots had a higher K content than the Cheffa local roots.

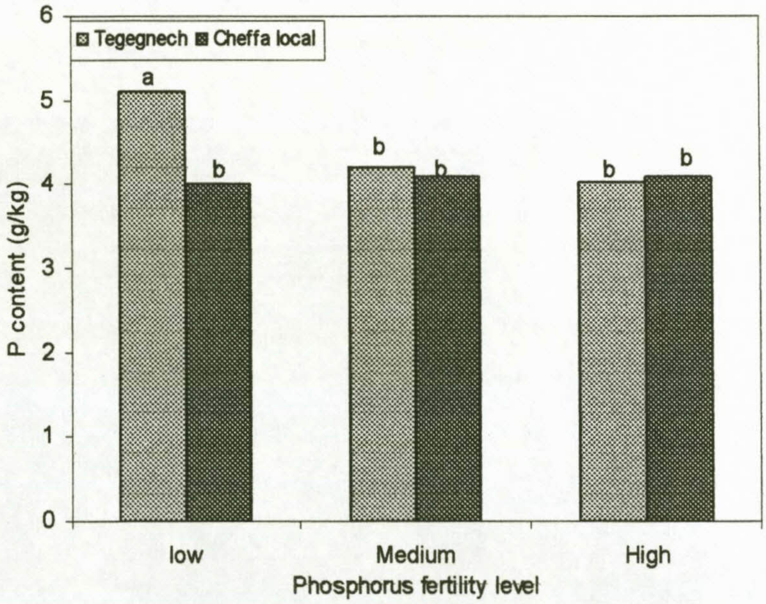

Figure 3.21 Effect of phosphorus fertility level x cultivar on the P content in roots of peas planted in the Cheffa soil. Values of LSD by DMRT = 0.59 at $p < 0.05$. No significant difference between bars with the same letter.

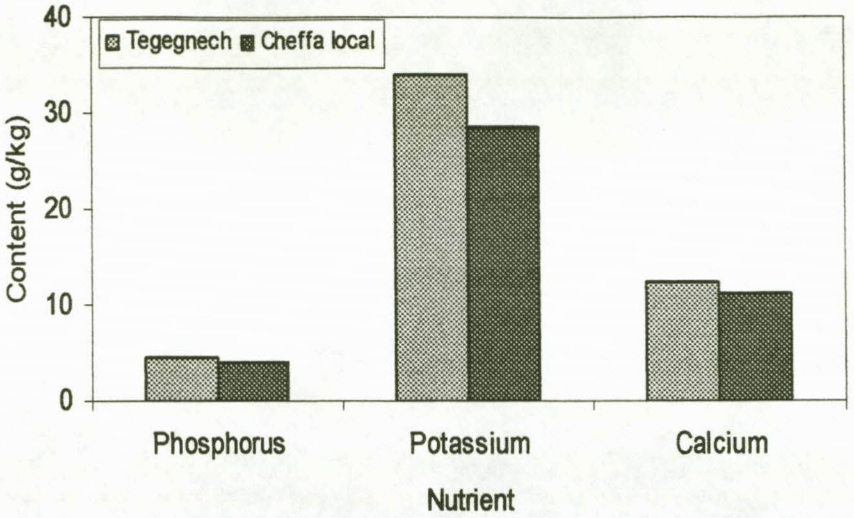

Figure 3.22 Effect of cultivar on the P, K and Ca content in roots of peas planted in the Cheffa soil. Values of SE = 0.12, 1.36 and 0.32 for P, K and Ca respectively at $p < 0.05$.

Calcium: The Ca content in the shoots differed significantly as a result of the interaction between phosphorus fertility level and cultivar but the differences were not consistent (Figure 3.23). However, cv. Tegegnech roots had a significant higher Ca content than cv.Cheffa local roots as illustrated in Figure 3.22.

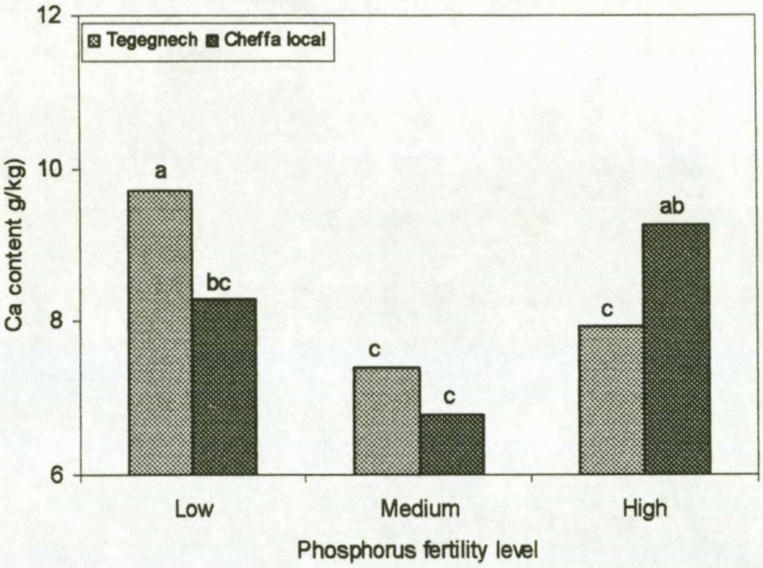

Figure 3.23 Effect of phosphorus fertility level x cultivar on the Ca content in shoot of pea planted in the Cheffa soil. Values of LSD by DMRT = 1.25 at $p < 0.01$. No significance difference between bars of the same letter.

Magnesium: Only the Mg content of the shoots was affected, viz. by the interaction between phosphorus fertility level and cultivar (Figure 3.24). The Mg content in cv.Tegegnech shoots declined as the phosphorus fertility level increased from low to high. However, the Mg content in cv. Cheffa local shoots was the highest at the medium phosphorus fertility level, followed by that at the low and then the high phosphorus fertility levels. Differences between the two cultivars at every phosphorus fertility level were not consistent.

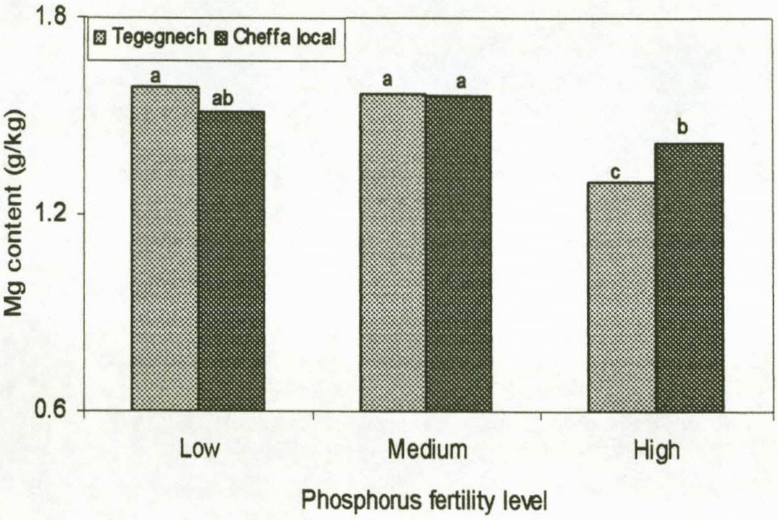

Figure 3.24 Effect of phosphorus fertility level x cultivar on the Mg content in shoots of peas planted in the Cheffa soil. Values of LSD by DMRT = 0.11 at $p < 0.05$. No significance difference between bars with the same letter.

Figure 3.23 and 3.24 reveal an interesting phenomenon with regard to Ca and Mg in the shoots. At the low phosphorus fertility level the content of both nutrients were higher in cv. Tegegnech than cv. Cheffa local, while at the high phosphorus fertility the content of both nutrients were higher in cv. Cheffa local than cv.Tegegnech. No difference in both Ca and Mg contents were recorded between the two cultivars at the medium phosphorus fertility level. However, it also seems that the uptake of Ca and Mg were inhibited when the phosphorus fertility increases probabily as a result of the precipitation of Ca and/or Mg phosphates. This aspect is discussed in more detail in Section 2.3.2.

From results on nutrient content, it can be concluded that effects of the various treatments were to a large extent not very consistent. The reasons for this inconsistency are unknown and therefore hampered any further interpretation.

3.3.4 Critical phosphorus levels

For proper fertilization recommendations to crops, it is essential to establish the critical phosphorus fertility levels in soils (Lewis & Hawthorne, 1996). Usually, crop response to phosphorus fertilization is very likely below and unlikely above these levels (Bekele & Höfner , 1990). The experience worldwide is that such critical phosphorus levels vary considerably and should therefore be determined for specific soil and crop combinations (Tchuenteu, 1997). This is possible with data gathered from the glasshouse experiments. The method of Cate & Nelson (1971) was used to determine critical phosphorus levels for every combination of soil and cultivar tested. For this purpose, relative yield of the total biomass (percentage of the maximum yield) was calculated and plotted as a function of extracted P determined by the Bray 2 and Olsen procedures. The graphs for the Ilala soil is presented in Figure 3.25 and for the Cheffa soil in Figure 3.26.

The critical phosphorus levels deducted from these graphs are summerized in Table 3.8. These levels can be used with great benefit as guidelines for fertilizer recommendations especially when such pea cultivars are planted on soils of similar nature. However, validation of these critical phosphorus levels under field conditions is recommended.

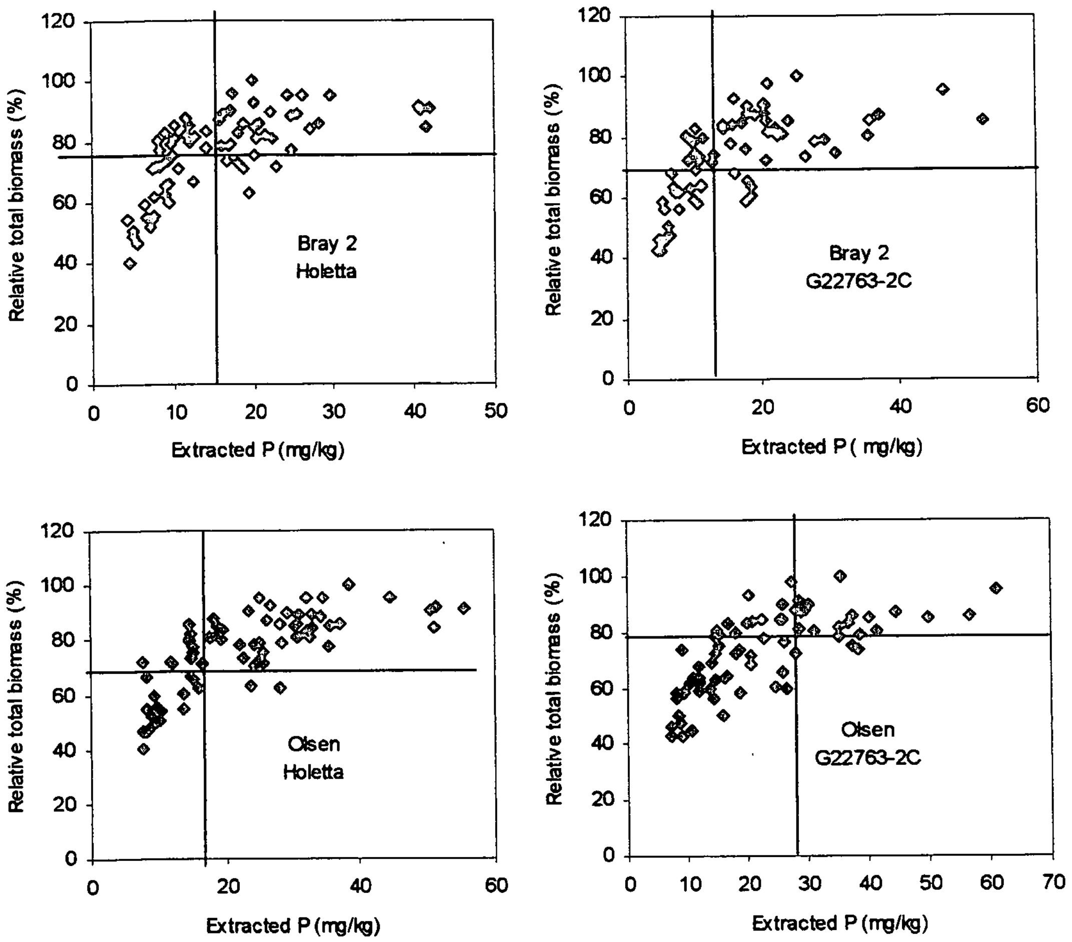

Figure 3.25 Relationship between relative total biomass yield and extracted phosphorus for the Ilala soil showing the critical phosphorus levels.

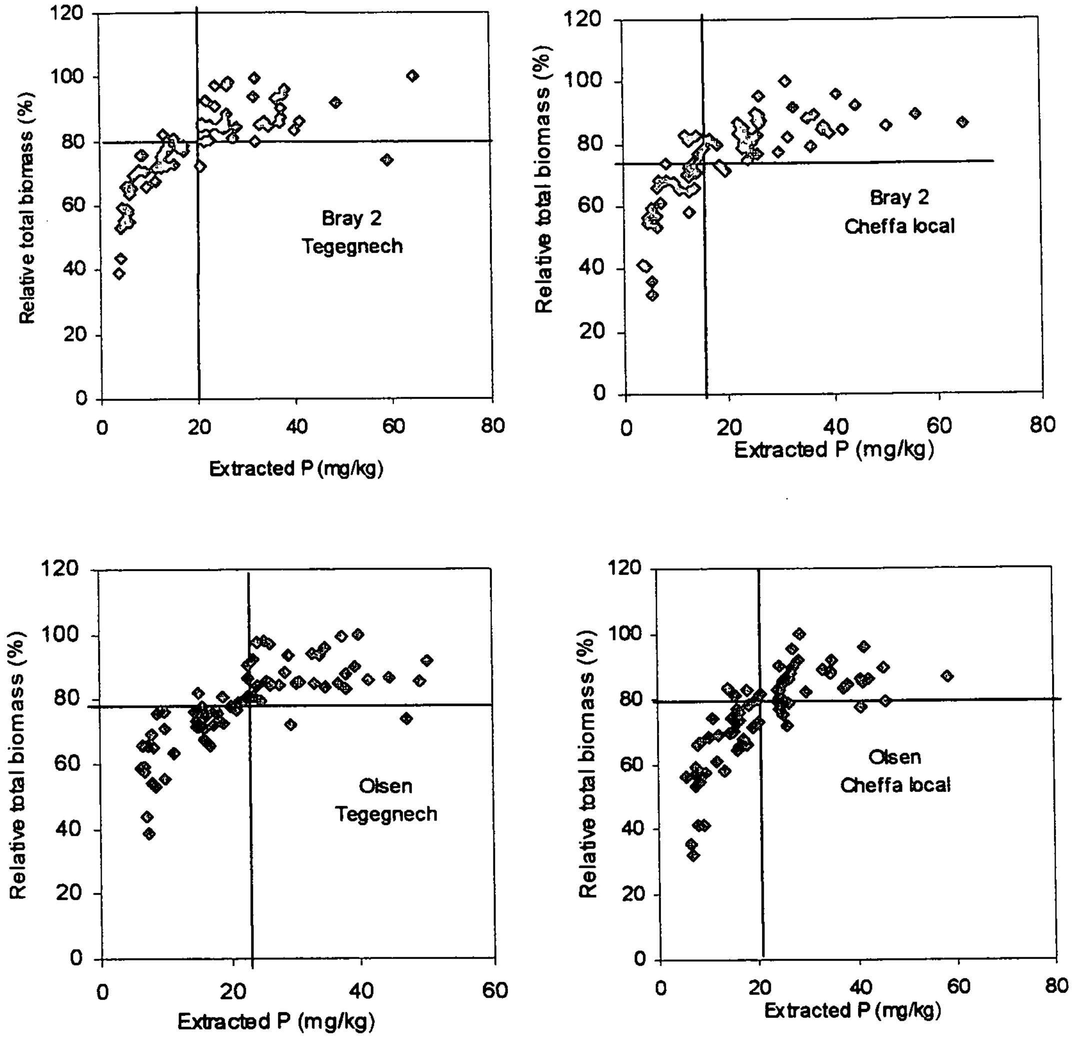

Figure 3.26 Relationship between relative total biomass yield and extracted phosphorus for the Cheffa soil showing the critical phosphorus levels.

Table 3.8 Critical phosphorus levels (mg P kg^{-1}) in Nitosols for fertilization recommendation to field peas.

	Ilala soil		Cheffa soil	
Extraction procedure	Holetta	G22763-2C	Cheffa local	Tegegnech
Bray 2	15	14	17	20
Olsen	17	27	20	22

3.4 Conclusion

The purpose of these glasshouse experiments was to quantify the effects of phosphorus application rates on the growth and development of pea cultivars that were sown on Nitosols with different phosphorus fertility levels was largely met. As expected the phosphorus fertility levels together with the phosphorus application rates had a positive influence on the growth and development of the pea crop as manifested in the height and biomass of the cultivars. The position, size and colour of the nodules were affected by the phosphorus fertility levels of both soils, viz. Ilala and Cheffa. However, phosphorus application rates had significant effects only on the size and colour of the nodules recovered from the Cheffa soil. All cultivars showed excellent nodulation characteristics regardless of phosphorus fertility levels and application rates. The N and P content of the shoots increased with increasing phosphorus application rates, but stabilized sooner at the high than the low phosphorus fertility level. The medium phosphorus fertility level was intermediate in stabilizing. There were some differences in the shoot nutrient contents of the cultivars but these differences were not consistent. Critical soil phosphorus levels were established with the glasshouse data. However, validation of these levels under field conditions is recommended.

CHAPTER 4

RESPONSE OF FIELD PEA (*PISUM SATIVUM* L.) CULTIVARS TO PHOSPHORUS FERTILIZATION OF NITOSOLS: FIELD EXPERIMENTS

4.1 Introduction

Field peas (*Pisum sativum* L.) are ranked as one of the most important pulse crops in the highlands of Ethiopia (Ghizaw & Molla; 1994; Telaye *et al.*, 1994). Peas are not only a large source of protein for humans and animals but also an important break crop in the cereal cropping systems practised by Ethiopian farmers. Despite the importance of the crop in Ethiopian agriculture, the yield has remained low. Poor soil fertility is considered as one of the major factors contributing to low pea yields (Beyene *et al.* 1994; Telaye *et al.*, 1994; Tsigie & Woldeab, 1994).

Several studies indicated that the tropical soils of Ethiopia are often nutrient deficient (Mamo & Haque, 1991; Mamo *et al.*, 1996; Ghizaw *et al.*, 1999). For example, Mamo & Haque (1991) reported that P is deficient in about 70% of the soils in the country and often cultivated soils are fertilised with lower rates of P as compared to N. The use of fertilizer is not a common practice for field pea production, and yields are low with an average of 0.73 t ha^{-1} (CSA, 2001). Recently, various pea improved cultivars were developed under high input conditions which included inter alia the current blanket recommendation of 100 kg DAP ha^{-1}. However, this recommendation was questioned in many instances since it did not consider soil fertility differences among fields. Ghizaw *et al.* (1999) reported that the farming community considered the recommendation as too high and researchers pointed out that it is not based on extensive experimental research work in the country.

Actually, in any cropping sequence, the fertilizer needs of a crop will vary depending upon the characteristics of the preceding crop and fertiliser applied to that particular crop, which may result in a residual effect on the succeeding crop (Srivastava *et al.*, 1999). The fate of applied P is strictly dependent on environmental conditions, soil properties and crop characteristics (Lambert & Toussaint, 1977). However, regular use of phosphate containing fertilizers in most cases result in accumulation of some insoluble compounds in soils, which are partially available to crops. Many studies (Yerokun & Christenson, 1990; Srivastava *et. al.*, 1999; Katayama *et.al.*, 1999) have shown that soils with high levels of residual P are able to sustain crop production without P application. The effectiveness of residual P depends, except for the level thereof in a soil, also on other soil properties, the time since application and cropping intensity. This suggests that soil testing for residual P could prove to be an effective aid in making decisions about rates of fertilizer to apply. However, in a huge country like Ethiopia with inaccessible, fragmented cultivated fields in most cases and inadequate laboratory facilities, it will not be possible to carry out soil testing for each field even in the distant future. Nevertheless, agronomic research should focus on preceding crops and residual P for a given soil in order to refine recommendations on fertilizer.

A literature review by Mahler *et al.* (1988) indicated that grain legume responses to fertiliser P on slightly and strongly acidic soils have been less common and suggested that climatic conditions and other soil factors are responsible for the inconsistent yield responses to P fertilization. A rview by Davies *et al.* (1985) showed that the response of field pea was influenced by the initial soil P as manifested in dry matter and grain yields, but they have failed to indicate background contents. Hence, for efficient fertilizer management, it is obligatory to evaluate precisely the role of the preceding crop coupled with the residual effect of the applied fertilizer for sustaining the productivity of soils.

In the Ethiopian context, pea production will play an important role in food self sufficiency and beyond. Thus, there is an urgent need to determine the nutrient requirement of various pea cultivars on soils with varying phosphorus fertility levels. Two sets of field trials were, therefore, conducted with the previous statement in mind to establish optimum phosphorus applications rates for peas. Data on these two sets of trials are reported here.

4.2 Material and methods

4.2.1 Characterization of the study area

4.2.1.1 Sites

Two sets of experiments were conducted. The first set of two experiments was conducted on fields of the Holetta Agricultural Research Centre (HARC) for four years from 1996 to 1999 and on farm fields near Bekoji sub-center for three years from 1996 to 1998. The second set of two experiments was conducted in 2001 on farm fields at Ilala (about 3 km north of HARC) and Cheffa (about 2 km west of Bekoji sub-center). These sites (Holetta/Ilala: 09°03'N, 38°30' E and 2390 m.a.s.l; Bekoji/Cheffa: 07°32'N39°15'E and 2761 m.a.s.l.) are representative of Nitosols in Ethiopia.

Over the years, all fields at HARC were properly prepared for crop production using farm machineries. The fields were also fertilized with urea and DAP as per approved recommendations for every crop in rotation. Major crops that are grown on these fields include barley, wheat, tef and potato. Break crops are faba bean, field pea and oil seeds such as brassica, niger seed and linseed. The current crop rotation is either cereals→pulses→ oilseeds→pulses or cereals→oilseeds→pulses→potato→pulses.

At Ilala, Bekoji and Cheffa the fields were prepared over the years using oxen-drawn local plough called 'maresha. These fields were seldom fertilized except when used either for technology generation or demonstration by researchers. If at all farmers apply fertilizer to these fields at sub-optimal levels of DAP for cereals and none for legumes. The major cereals grown at Ilala are tef, wheat and barely. Legumes included in the cropping system are faba bean and field pea, which is often, cultivated as mixed crops. At Bekoji and Cheffa the major cereals are still wheat and barley, which are cultivated in rotation with break crops like faba bean, field pea and linseed.

4.2.1.2 Soils

Detail profile descriptions for the soils on which the two sets of experiments were planted are given in Appendix 1. Based on the World Reference Base for Soil Resources (FAO-UNESCO, 1989), the soils were classified as Haplic Nitosols which is equivalent to Typic Rhodostaf based on the Keys to Soil Taxonomy (Soil Survey Staff, 1999). In addition to the profile descriptions, some physical and chemical properties of the different hoizons are also presented in Appendices 2 and 3. In all the three profiles, there were sharp increases in clay contents with depth. The topsoil at Ilala had the highest extractable phosphorus followed by the one at HARC and then the one at Bekoji and Cheffa . In general, the other soil chemical properties were fine for field production.

4.2.1.3 Climate

Some rainfall and temperature data from the weather stations at Holetta and Bekoji are presented in Figures 4.1 and 4.2, respectively. Inspection of the two figures showed that the longterm monthly rainfall and temperature data for the growing season at Holetta (June to

November) and Bekoji (June to December) fulfill the climatic requirements of field peas as described by Kay (1979).

The longterm annual rainfall for Holetta is 1049 mm of which 73.6% falls during the cropping season. During the experimental years, viz. 1996, 1997, 1998, 1999 and 2001, the annual rainfall amounted respectively to 1071, 825, 1227, 1015 and 1065 mm of which 74, 82, 78, 82 and 74 % fall from June to November. At Bekoji, the recorded longterm annual rainfall is 1075 mm of which 65% falls during the cropping season. The total rainfall in the 1996 1997, 1998 and 2001 experimental years amounted respectively to 1064, 1906, 1192 and 870 mm of which 60, 64, 63 and 54% fall from June to December.

Inspection of Figure 4.1 showed that the mean monthly maximum and minimum temperatures recorded at Holetta (June to November) in the 1996, 1997, 1998, 1999 and 2001 experimental years deviated not very much from the longterm values. The mean monthly maximum and minimum temperatures at Bekoji (June to December) in the experimental years 1996, 1997, 1998 and 2001 were also very similar to the longterm values.

In general, the rainfall and temperature at Holetta and Bekoji were excellent during the experimental years for growing field peas to test their response to phosphorus fertilization. However, at Holetta in 1996 an overall yield reduction of 5% was estimated as a result of hail damage at flowering stage. Also at Cheffa in 2001 hail caused slight damage to the peas 10 days after planting which was not reflected in the yields due to compensatory branchings. Fortunately, no frost damage was recorded at all since in some years it may occur in the later growth stages.

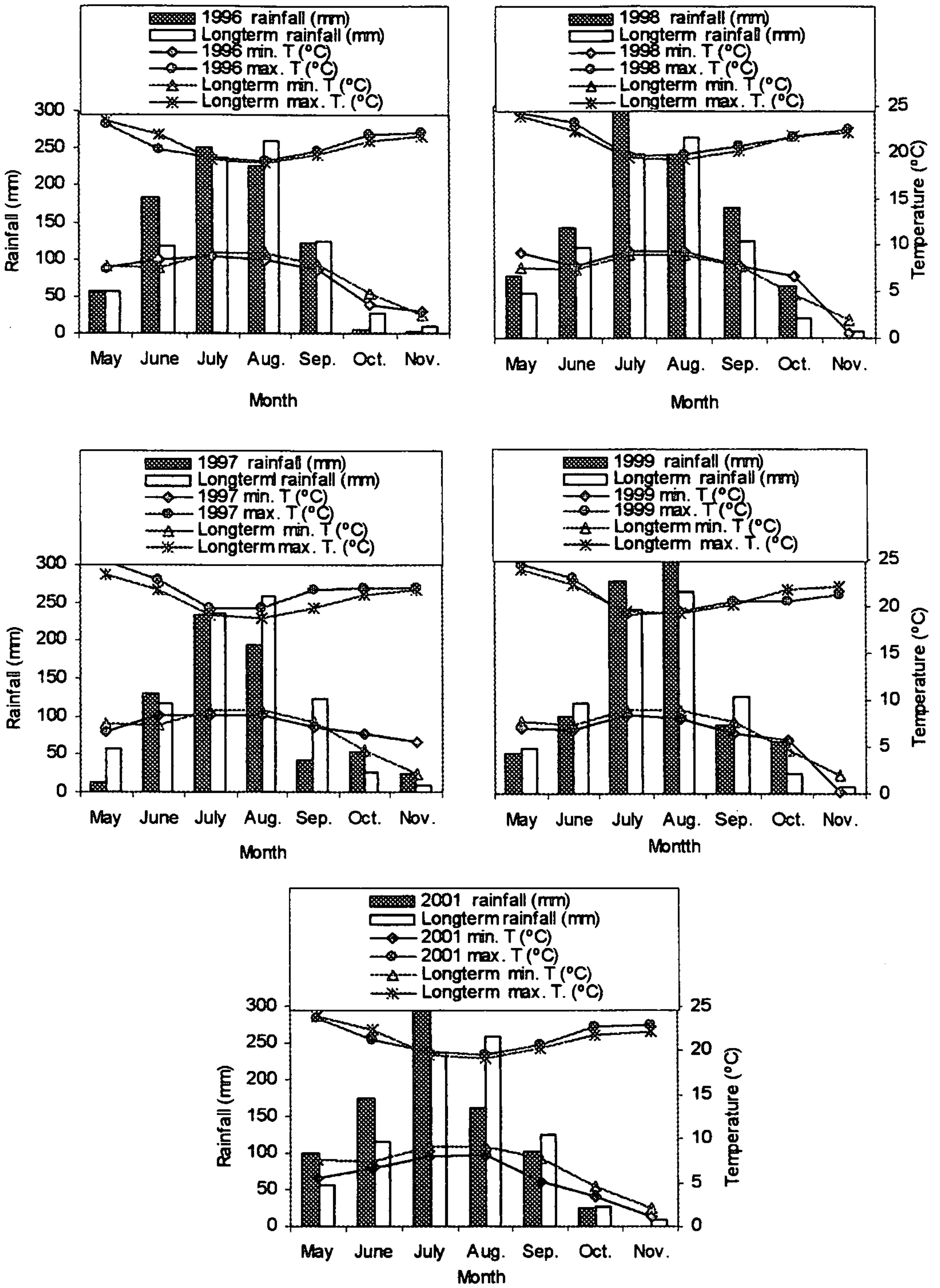

Figure 4.1 Annual mean monthly rainfall and temperature data (for 1996, 1997, 1998 and 2001) together with the longterm mean monthly rainfall and temperature data measured at Holetta Agricultural Research Center(NMSA, 1969-2001).

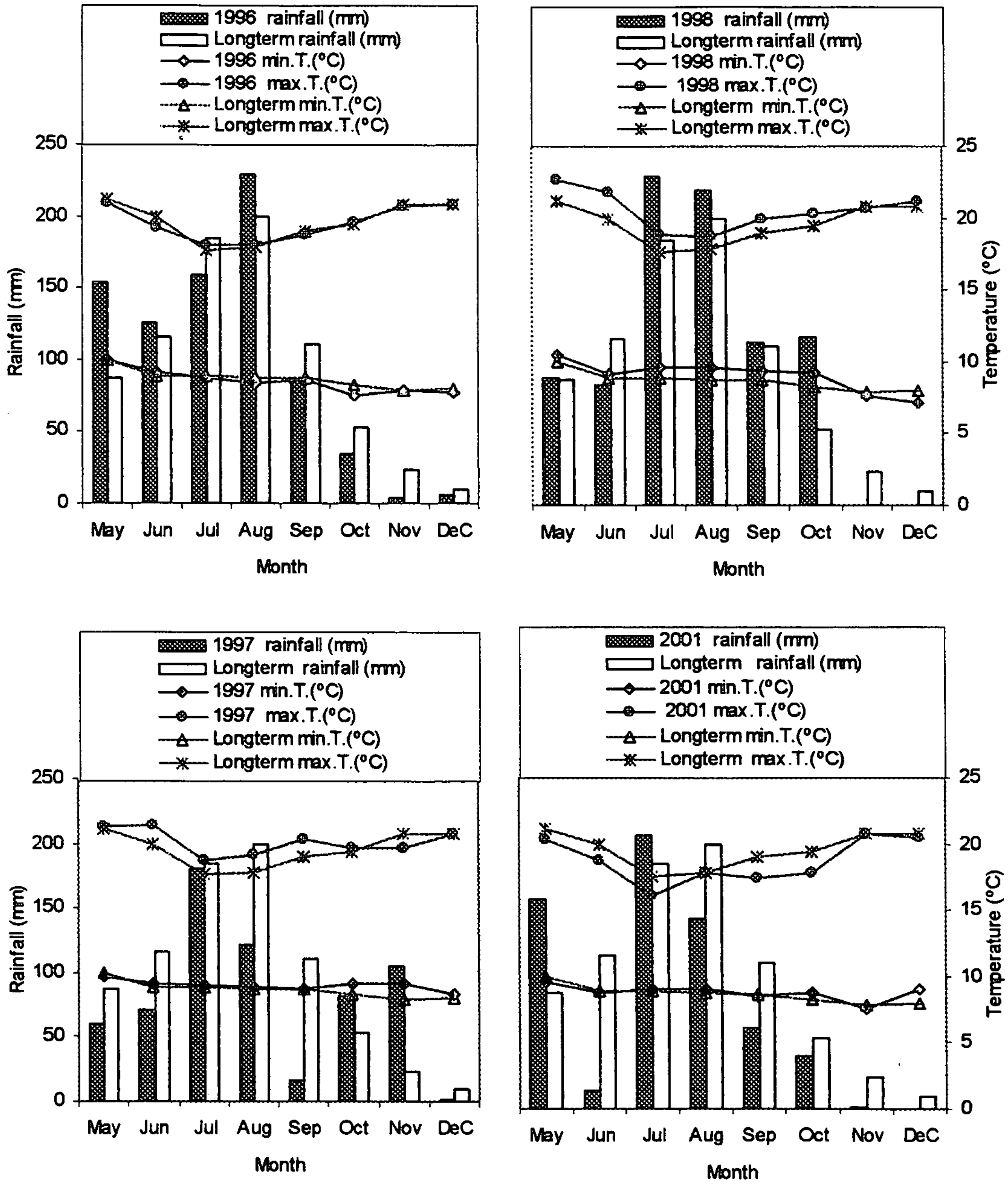

Figure 4.2 Annual mean monthly rainfall and temperature (for 1996, 1997, 1998 and 2001) together with the longterm mean annual monthly rainfall and temperature total data (1990 to 2001) at Bekoji, a sub-center of Kulumsa Agricultural Research Center (NMSA, 1990-2001).

4.2.2 Execution of experiments

4.2.2.1 First set of experiments

In this set of experiments that was conducted at Holetta and Bekoji, the response of field pea cultivars to phosphorus fertilization was tested on Nitosols whereof the pH and extractable P were not adjusted at all before planting. Some relevant properties of the soils at this stage are presented in Table 4.1.

Table 4.1 Some relevant properties of the soils at Holetta and Bekoji before planting.

Propertity	Holetta	Bekoji
pH (1:1 H_2O)	5.02	5.80
Organic C (%)	1.78	1.95
Total N (%)	0.15	0.29
Exchangeable cations (mg kg^{-1})		
Ca	1564	2051
Mg	308	257
K	601	441
Na	25	81
Extractable P (mg kg^{-1})*	5.48	6.02

* Bray 2 extraction procedure.

The response of three cultivars at Holetta (Tegegnech, G22763-2C and Holetta) for four years (1996 to 1999) and at Bekoji (Tegegnech, G22763-2C and Cheffa local) for three years (1996 to 1998) were tested in factorial combinations with five phosphorus application rates (0, 10, 20, 40 and 80 kg P ha^{-1}) in a randomized complete block design with four replications. Randomization of the treatments was done every year since the fields were assigned for these experiments according to the crop rotation at each site. The relevant pea seeds were drilled in plots, each having a size of 5.0 m length and 2.4 m width at a rate of 150 kg ha^{-1}. This resulted in 0.5 m rows with a distance of 50 mm between the plants. However, just before planting urea (at a rate of 20 kg N ha^{-1}) and $Ca(H_2PO_4)_2.2H_2O$ (at the mentioned P rates) were applied in the rows and incorporated into the soil using wooden pegs. Sowing of the pea cultivars were done during the recommended periods, viz. in the third week of June at Holetta and from end of June to early July at Bekoji.

Every year, the following plant data were determined at both sites, namely plant height (average of 10 plants), pods per plant (average of 10 plants), 1000 seed weight, and grain yield (whole plot). In addition, above-ground biomass of whole plots was measured only at Holetta.

4.2.2.2 Second set of experiments

This set of experiments was conducted at Ilala and Chefa on farms in 2001 to test the response of field pea cultivars to phosphorus fertilization on Nitosols that were pretreated with lime to increase the pH to a more suitable level, and with phosphate to create three different levels of phosphorus fertility. The two sites were selected on the basis of the current land use, size of the fields and willingness of the farmers to cooperate.

4.2.2.2.1 Preparation of the soils

Inspection of the Ilala site showed that the straw stand of the previously cultivated tef gradually declined in one direction, indicating probably a decline in fertility levels. The field was therefore divided into three equal strips perpendicular to the declines in straw stands. However, at Cheffa no differences in the straw stands of the previously cultivated wheat were observed but the field was regardless of the straw stands also divided into three equal strips. Composite soil samples were collected at 45 spots to a depth of 0.3 m from each strip at both sites. The samples were thoroughly mixed, air-dried, sieved and analyzed for pH (1:1 H_2O) and extractable P (Bray 2) as shown in Table 4.2.

Table 4.2 Some properties of the soils at Ilala and Cheffa before pretreatment.

Site	Strip	pH (H_2O)	Extractable P (mg kg^{-1})
Ilala	1	4.75	8.0
	2	4.81	13.6
	3	4.80	24.6
Cheffa	1	4.60	5.0
	2	4.77	6.3
	3	4.70	4.8

In March 2001, both fields were ploughed by oxen using the local plough called 'maresha'. Then at Ilala $Ca(H_2PO_4)\ 2H_2O$ was broadcasted at respective rates of 0, 3 and 6 kg P ha^{-1} on the three strips. At Cheffa the $Ca(H_2PO_4)\ 2H_2O$ was broadcasted to the respective strips at rates of 0, 10 and 25 kg P ha^{-1}. Immediately after broadcasting of the fertilizer, the fields were ploughed as described above. In May 2001, both fields were limed. Based on earlier research (Tsigie & Beyene, 1988; EARO, 1999) 3 ton $Ca(OH)_2$ ha^{-1} was broadcasted to all three strips at each site . The lime was incorporated into the soil by ploughing with oxen using the 'maresha.'.

During the third week of June 2001 just before planting, composite soil samples were collected from 40 spots to a depth of 0.3 m from each strip at both sites. The samples were throughly mixed, air-dried, sieved and analyzed for pH (H_2O and KCl), organic C, total N, extractable P (Bray 2 and Olsen) and exchangeable cations (Ca, Mg, and K) with methods given in Section 4.2.2.2.4. The results of these analyses are presented in Table 4.3 indicating three distinct phosphorus fertility levels in the soils of both sites.

4.2.2.2.2 Experimental layout and treatments

On both sites a split plot design was used with the three phosphorus fertility levels (low, medium and high as shown in Table 4.3) as the main plot treatments and the factorial combination of two pea cultivars (G22763-2C and Holetta at Ilala and Tegegnech and Cheffa local at Cheffa) and five phosphorus application rates (0, 10, 20, 40 and 80 kg P ha^{-1}) as the sub-plot treatments replicated four times. The source of fertilizer was $Ca(H_2PO_4).2H_2O$. During the last week of June 2001, the appropriate amount of fertilizer was broadcasted on the plots (5.0 m long and 2.4 m wide). Immediately thereafter the relevant pea seeds were also broadcasted on the plots at a rate of 150 kg ha$^{-1.}$ Both the fertilizer and seeds were then incorporated into the soil. The fields were kept free of weeds by weeding once at Ilala and twice at Cheffa before flowering. During early flowering a protective fungicide known as BRAVO-500 was sprayed at a rate of 2.5 kg ha^{-1} against blight diseases caused by *Mycosphaerella pinodes* (EARO, 1998).

Table 4.3 Some properties of the Ilala and Cheffa soils after pretreatment with lime and phosphorus but before planting.

Property	Ilala	Cheffa
PH values		
H_2O suspension	5.50	5.12
KCl suspension	4.52	4.10
Organic C(%)	1.51	3.64
Total N (%)	0.16	0.28
Extractable P (mg kg^{-1})*		
Bray 2		
Low	6.60	4.80
Medium	11.20	14.40
High	22.80	34.60
Olsen		
Low	10.20	5.40
Medium	16.00	18.80
High	27.20	24.00
Exchangeable cations (mg kg^{-1})		
Ca	1397	1315
Mg	220	137
K	390	408
Na	32	33

*Phosphorus fertility level.

4.2.2.2.3 Collection of data

Twenty nine days after planting, composite soil samples were collected from 40 spots to a depth of 0.2 m from each plot. These samples were air-dried, sieved and analyzed for pH

(H_2O and KCl) and extractable P (Bray 2 and Olsen) with the methods mentioned in Section 4.2.2.2.4.

At flowering, five plants were sampled from each plot after leaving borders of about 0.5 m. The plants were cut with scissors at the soil surface, rinsed in distilled water, oven-dried at 65 °C for 72 hrs, weighted to obtain the dry shoot weight and then ground to be analyzed. Plant height was determined on another 10 plants from every plot after leaving 0.5 m alley sides during the physiological maturity stage before they were cut with scissors at the soil surface to determine the number of pods and dry shoot weight. All these data were converted to a per plant basis. All the remaining plants in a plot were used to establish total above-ground biomass, and seed yields. The seeds were also ground for analysis.

4.2.2.2.4 Soil and plant analyses

Soil analysis: Particle size distribution was determined using the Bouyoucous hydrometer method (Day, 1965). The pH was measured in 1:1 soil to H_2O and 1:1 soil to KCl suspensions. Organic carbon was measured according to Walkley & Black (1934) method. A modified Kjeldahl procedure (Cottenie, 1980; Bremer and Mulvaney, 1982) was used to determine total N. Extractable P was determined following the methods of Bray 2 and Olsen (Olsen & Sommers, 1982). The exchangeable cations were leached by NH4OAc with pH adjusted to 7 (Thomas, 1982) and the concentration of Ca and Mg in the filtrate were determined using an Atomic Absorption Spectrometer and that of K and Na using a Flame Photometer (IITA, 1979).

Plant samples: Steam distillation was used for the determination of N after digestion of the plant material in sulphuric acid (Hesse, 1971). Dry ashing of the plant material with nitric acid was used to obtain P, K, Ca and Mg in solution (Hesse, 1971). The P was determined by colorimetery and K, Ca and Mg determined by atomic absorption.

4.2.2.2.5 Statistical analysis of data

The data from the two sets of experiments were subjected to analysis of variance using General Linear Models Procedure of SAS. Based on significance of the F test (either $p < 0.01$ or $p < 0.05$) outputs for plant parameters mean data were fitted to a Mitscherlich equation: $Y = A-B*EXP(-CX)$ where Y is the dependent variable, X is the amount of P applied, and A, B and C are coefficients. Details on these coefficients have been adopted from Bolland *et al.*(2000 a; 2000 b). Coefficient A provides an estimate of the asymptote or maximum value for a parameter, coefficient B estimates the difference between the asymptote and the intercept on the Y axis at $X = 0$ and so estimates the response to added P, and coefficient C describes the shape of the relationship and governs the rate at which Y increases as X increases. Initial estimates for the coefficients were made by using a Compressive Curve Fitting System for Windows of Association (3) for Growth Model in Curve Expert 1.37 (Hyams, 1995-2001). Then the mean data were fitted to the equation by non-linear regression using a user model in Curve Expert 1.37.

4.3 Results and discussion

4.3.1 First set of experiments

A summary on the analyses of variance computed with data of some plant parameters from Holetta and Bekoji are given in Table 4.4. From this table, it is clear that at Holetta (1996 to 1999) and Bekoji (1996 to 1998) the grain yield, plant height, and pods per plant were significantly affected by either phosphorus application rates or cultivars over the years.

Table 4.4 Summary on the analyses of variance computed with data of plant parameters from Holetta and Bekoji indicating significant treatment effects at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Holetta				Bekoji		
	Grain yield	Plant height	Above-ground biomass	Pods per plant	Grain yield	Plant height	Pods per plant
A	**	**	*	**	**	**	**
B	**	**	**	**	**	**	**
C		**	**		**	**	**
AB		**				**	**
AC	**		**		**	**	**
BC					*		
ABC							
Mean	1272.53	134.51	4590.88	6.68	2403.78	128.91	10.74
CV%	32.27	11.50	25.33	24.91	18.31	9.54	27.38

[1] A = year, B = phosphorus application rate and C = cultivar.

4.3.1.1 Grain yield

At Holetta the grain yield increased significantly from less than 1 ton ha^{-1} with a 0 kg P ha^{-1} application to more than 1.2 ton ha^{-1} with a 60 kg P ha^{-1} application (Figure 4.3). However, significant interactions were recorded over the years with cultivars as shown in Figure 4.4. From this figure it is clear that in 1997 very low yields were recorded which was not the case in 1996 and 1998. The year 1999 was intermediate with regard to grain yield. These differences in yield between years can be attributed to climatic conditions as illustrated in Figure 4.1. In 1996, cvs. Tegegnech and Holetta respectively gave the lowest and highest grain yield while cv. G22763-2C gave intermediate grain yield. However, in the following three years cv. Tegegnech gave the highest grain yield. The grain yields of cvs. G22763-2C and Holetta were very similar in these years but lower than that of cv. Tegegnech, especially in 1998 and 1999.

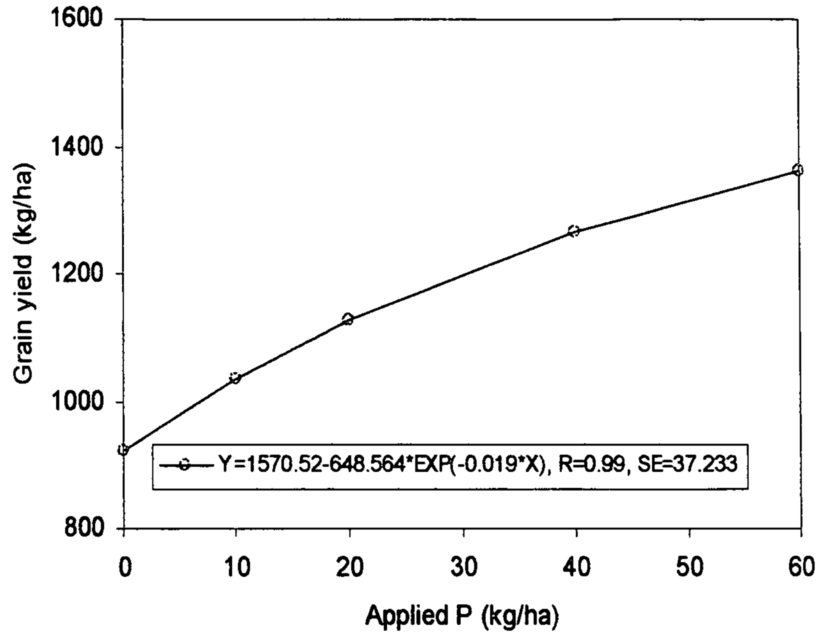

Figure 4.3 Effect of phosphorus application rate on the grain yield of peas planted at the Holetta site.

At Bekoji, the grain yield of all the three cultivars increased with increasing rates of phosphorus application (Figure 4.5). The response of cv. Cheffa local to phosphorus application was relatively poor in comparison to that of cvs. Tegegnech, i.e. high, and G22763-2C, i.e. intermediate. Significant interactions of year by cultivar were also recorded as illustrated in Figure 4.6. In 1997, the grain yields were far lower than in either 1996 or 1998 which can be attributed to climatic conditions, viz. lower rainfall (Figure 4.2). The only significant differences between cultivars regarding grain yield were in 1998 when the cultivars Tegegnech, G22763-2C and Cheffa local gave the highest, intermediate and lowest grain yields, respectively.

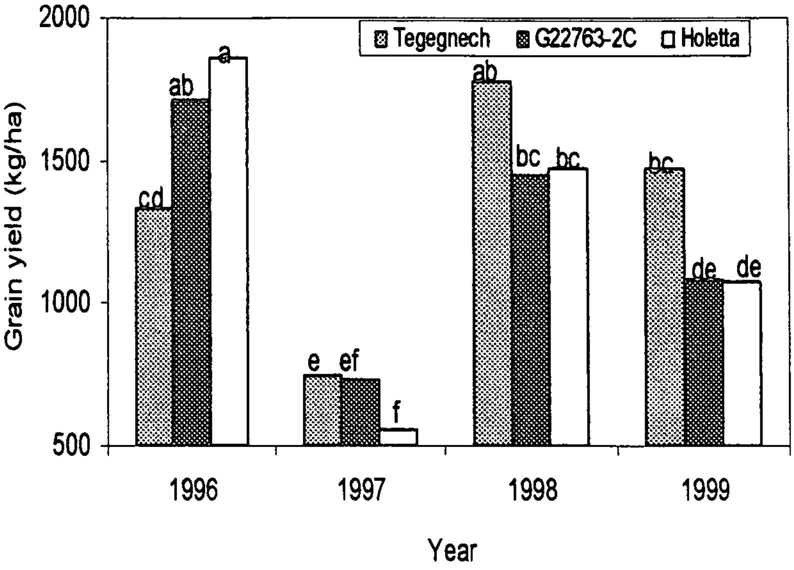

Figure 4.4 Effect of year x cultivar on the grain yield of peas planted at the Holetta site. Values of LSD by DMRT = 338.4 at p = 0.01. No significant difference between bars with the same letter.

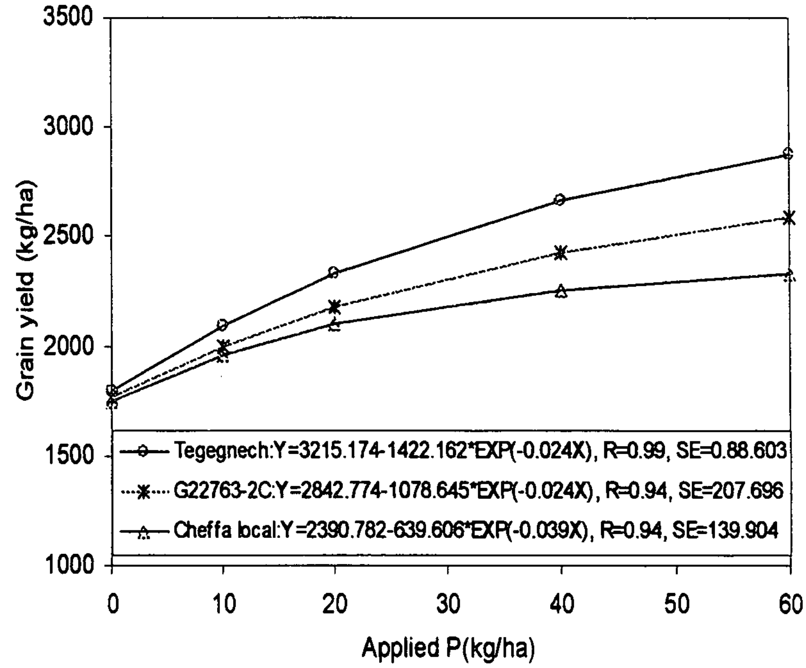

Figure 4.5 Effect of phosphorus application rate x cultivar on the grain yield of peas planted at the Bekoji site.

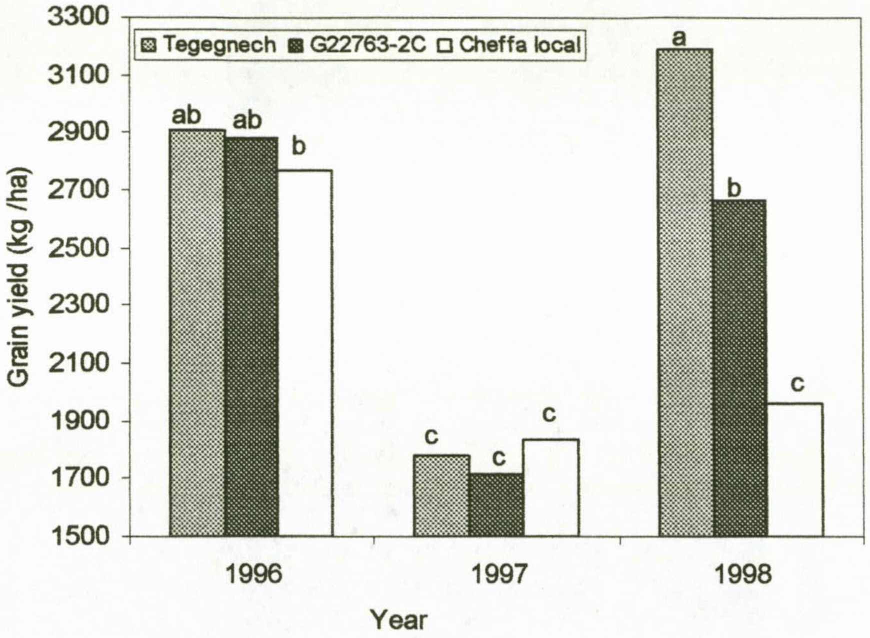

Figure 4.6 Effect of year x cultivar on the grain yield of peas planted at the Bekoji site. Values of LSD by DMRT = 363.8 at p = 0.01. No significant difference between bars with the same letter.

As already mentioned the variation in grain yield between years at both sites can be attributed to climatic conditions. In general, the grain yield of the improved cultivars tended to be higher than that of the local cultivars. At Bekoji, the improved cultivars responded better to phosphorus application than the local cultivar. This is consistent with previous findings of other researchers (Haile & Belayneh, 1988; Tsigie & Woldeab, 1994, Agegnehu *et al.*, 2002). However, at Holetta there was no difference in response to phosphorus application between the two improved cultivars and the local cultivar. This was in accordance with the work of Agegnehu *et al.* (2002).

An attempt was made to establish with either the absolute or relative grain yields critical soil phosphorus levels. Unfortunately, the outcomes were not at all conclusive to apply in practice and are therefore neither presented nor discussed.

4.3.1.2 Plant height

In two of the four years at Holetta, viz. 1997 and 1998 plant height increased significantly as a result of increasing rates of phosphorus application (Figure 4.7). During 1996, the plant height increased until an application of 20 kg P ha^{-1} and stabilized thereafter. However, in 1997 and 1998 the increase in plant height due to increasing phosphorus application rates was more remarkable and stabilized only after the 40 kg P ha^{-1} application. However, in 1999 phosphorus application had no effect on plant height. As illustrated in Figure 4.8, cvs. Tegegnech and Holetta plants were respectively the shortest and longest with cv. G22763-2C intermediate regardless of the year or phosphorus application rate.

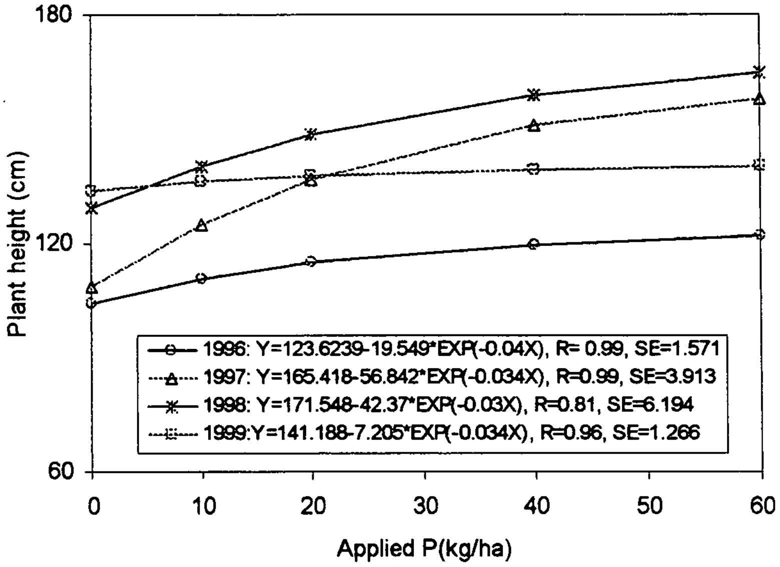

Figure 4.7 Effect of year x phosphorus application rate on the plant height of peas planted at the Holetta site.

Only in 1996 at Bekoji the plant height increased significantly with increasing phosphorus application rates (Figure 4.9). In the other two years, viz.1997 and 1998 the response of plant height to increasing rates of phosphorus application was very poor. As illustrated in Figure 4.10, the plant heights of the cultivars were more or less similar in 1997 and 1998, which was

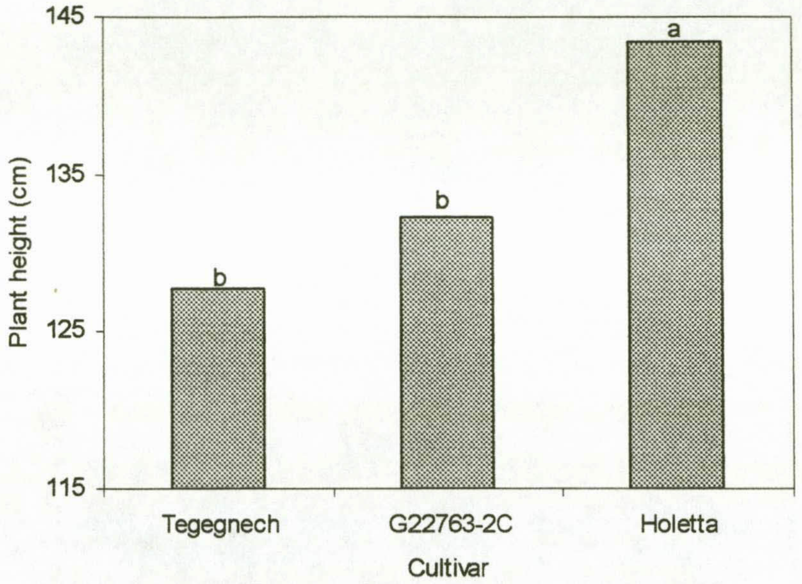

Figure 4.8 Effect of cultivar on the plant height of peas planted at the Holetta site. Values of LSD by DMRT = 6.32 at p = 0.01. No significant different between bars with the same letter.

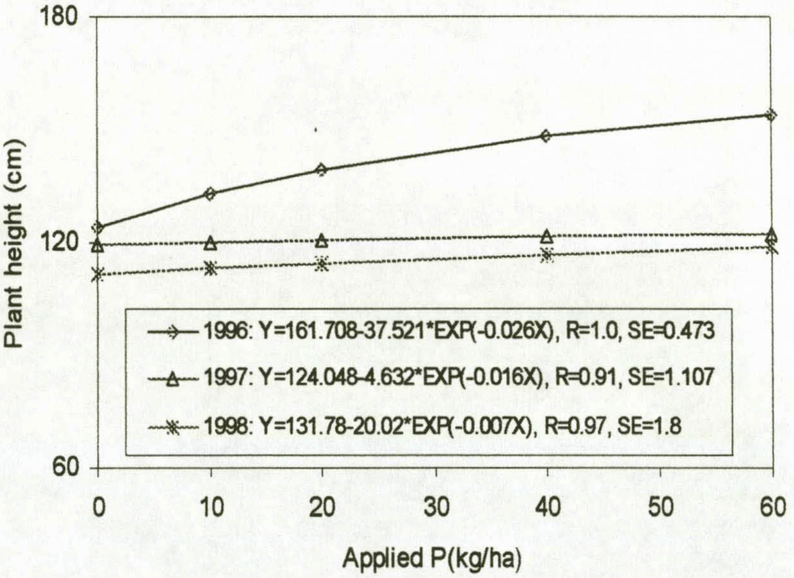

Figure 4.9 Effect of year x phosphorus application rate on the plant height of peas planted at the Bekoji site.

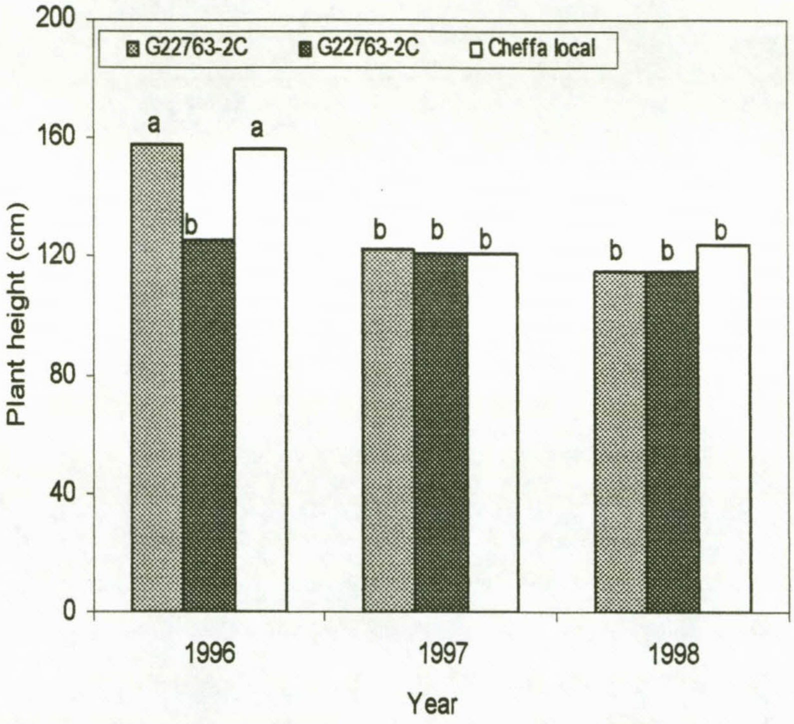

Figure 4.10 Effect of year x cultivar on the plant height of peas planted at the Bekoji site. Values of LSD by DMRT = 2.43. No significant difference between bars with the same letter.

not the case in 1996. In this year, cvs. Tegegnech and Cheffa local plants were significantly higher than cv. G22763-2C plants.

However, the mean plant height of the cultivars over the experimental period increased at both sites with increasing phosphorus application rates (Figure 4.11). The plant height increased from about 120 cm with a 0 kg P ha^{-1} application to about 135 cm for Holetta and 145 cm for Bekoji with a 60 kg P ha^{-1} application.

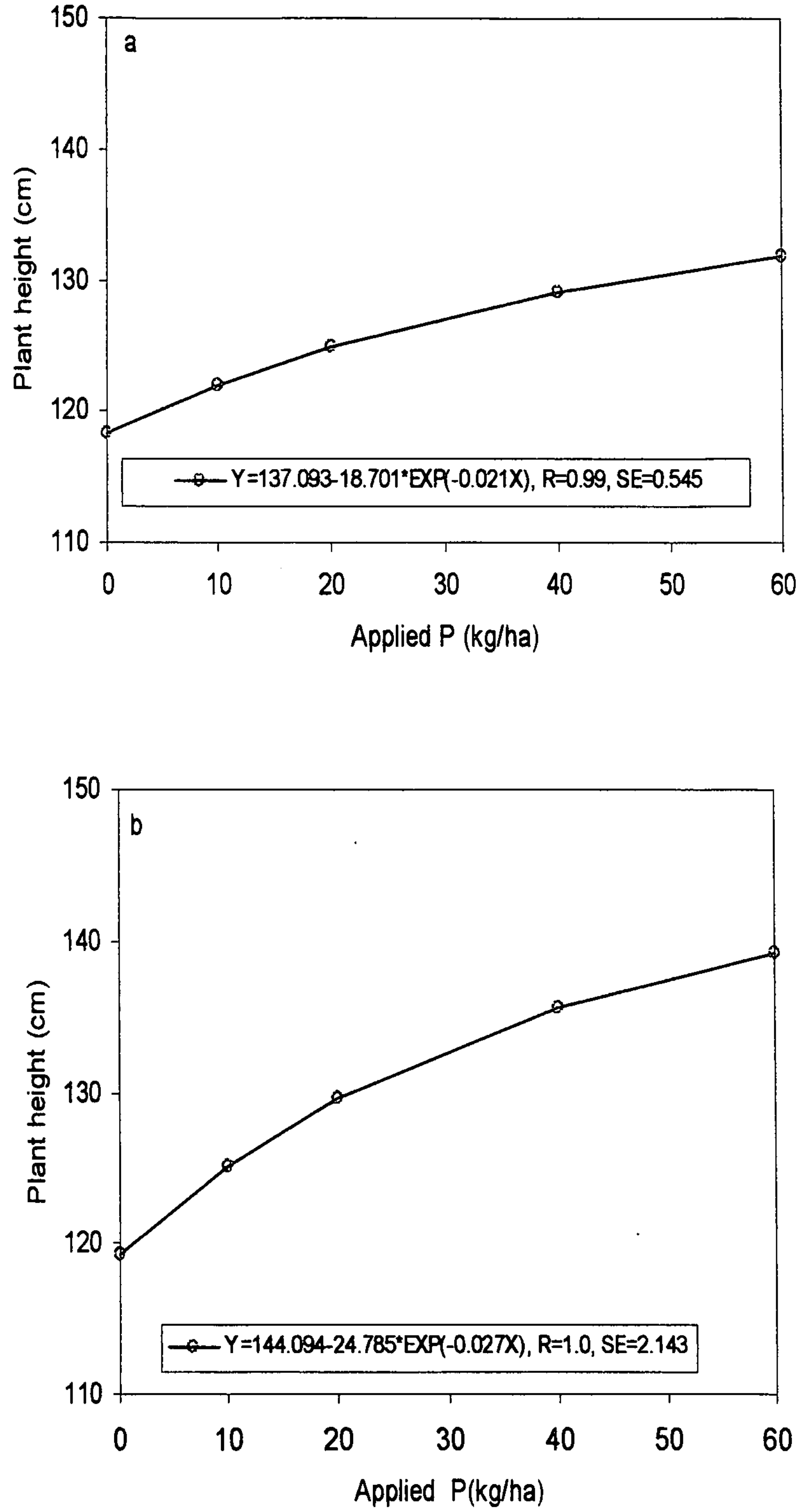

Figure 4.11 Effect of phosphorus application rate on the plant height of peas planted at the Holetta (a) and Bekoji (b) sites.

4.3.1.3 Above-ground biomass

The above-ground biomass was recorded only at Holetta and not at Bekoji as mentioned in Section 4.2.2.2.3. At Holetta there was a significant interaction between years and cultivars as illustrated in Figure 4.12. As a result of less rain in 1997 than in other years (Figure 4.1) the lowest above-ground biomass was recorded in this year with no differences between the cultivars. However, in 1996 cvs. Tegegnech and Holetta local had respectively highest and lowest biomass with cv. G22763-2C intermediate. In that ranking order, the biomass from cv. Holetta was significantly ($p < 0.01$) higher than that from cv. Tegegnech. This pattern did not repeat itself in 1998, however. In 1999, the above-ground biomass of cv. Holetta local was significantly higher ($p < 0.01$) than cv. G22763-2, but not significantly different from that of cv. Tegegnech. However, irrespective of year and cultivar the above-ground biomass increased with increasing phosphorus application rates (Figure 4.13). The above-ground biomass increased from about 3200 kg ha^{-1} with a 0 kg P ha^{-1} application to about 5000 kg ha^{-1} with 60 kg ha^{-1} application.

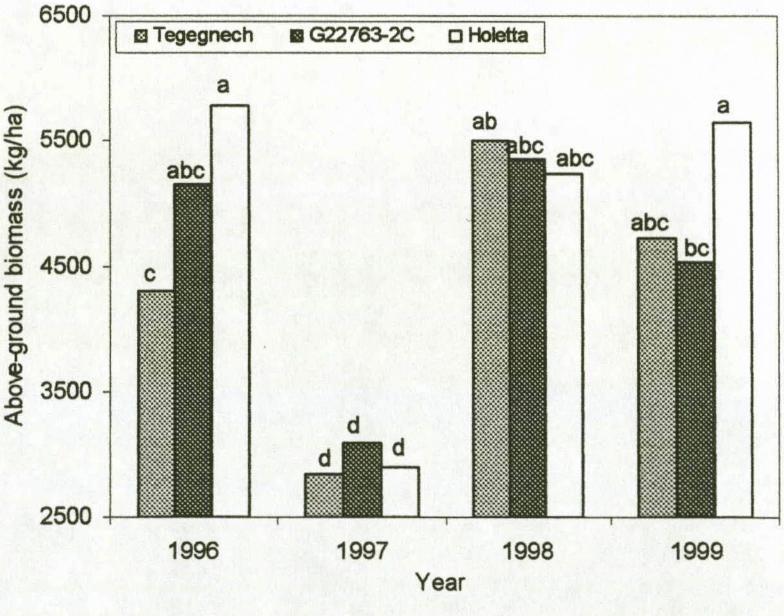

Figure 4.12 Effect of year x cultivar on the above-ground biomass of peas planted at the Holetta site. Values of LSD by DMRT = 957.6 at p = 0.01. No significant difference between bars with the same letter.

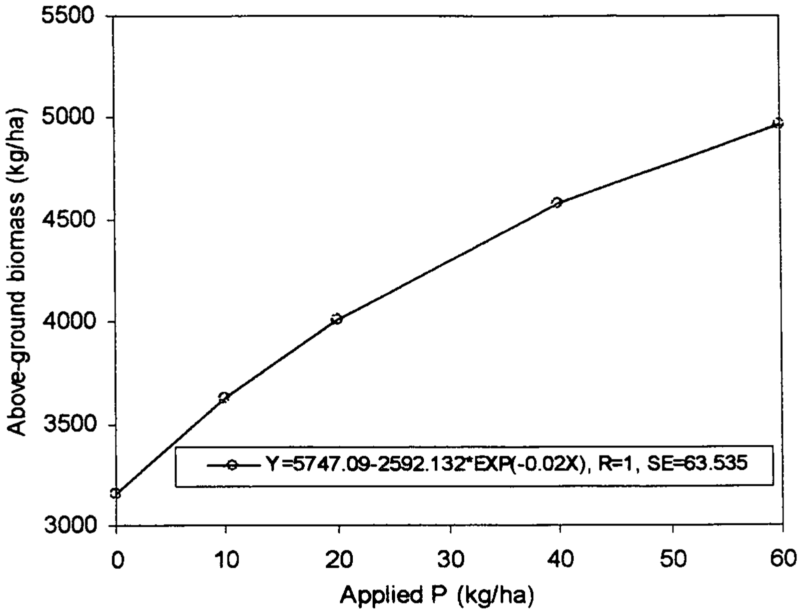

Figure 4.13 Effect of phosphorus application rate on the above-ground biomass of peas planted at the Holetta site.

4.3.1.4 Pods per plant

At Holetta, significant ($p < 0.01$) differences between years for the number of pods per plant were obtained. Significantly ($p < 0.01$) lower number of pods were obtained in 1997 than in 1999 and intermedite in 1996 and 1998 (Figure 4.14). As illustrated in Figure 4.15, the number of pods per plant increased almost linearly until an application of 20 kg ha^{-1} whereafter the rate of increase declined.

At Bekoji, the number of pods per plant increased only in 1996 noticeable with increasing rates of phosphorus application (Figure 4.16). Cultivars Tegegnech and Cheffa local had significantly ($p < 0.01$) more pods per plant than G22763-2C (Figure 4.17). In 1997 and 1998, the number of pods per plant of the cultivars were similar to those of G22763-2C in 1996. However, the mean number of pods of the cultivars over the experimental period increased with increasing phosphorus application rates (Figure 4.18). The number of pods per plant increased from about 9 with a 0 kg P ha^{-1} application to about 11 with a 40 kg P ha^{-1} application whereafter it stabilized.

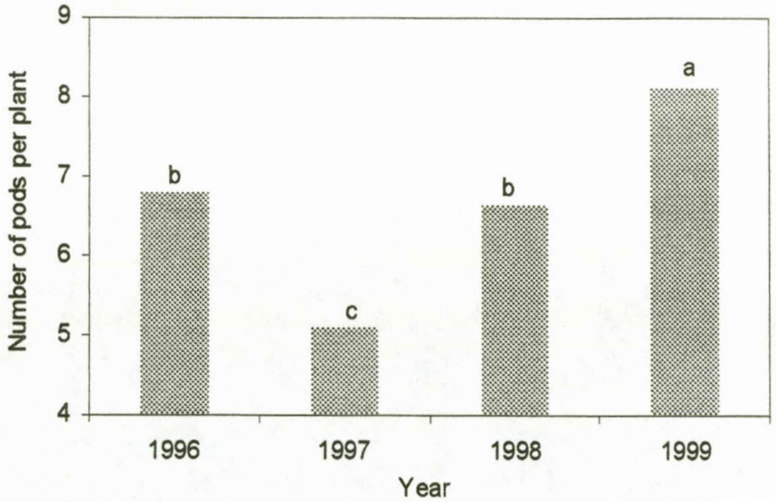

Figure 4.14 Effect of year on the number of pods per plant for peas planted at the Holetta site. Values of LSD by DMRT = 0.79 at p = 0.01. No significant difference between bars of the same letter.

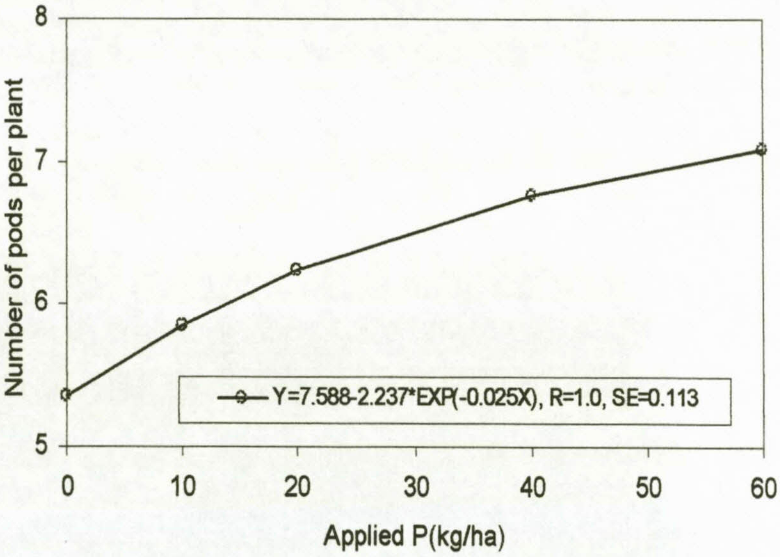

Figure 4.15 Effect of phosphorus application on the number of pods per plant for peas planted at the Holetta site.

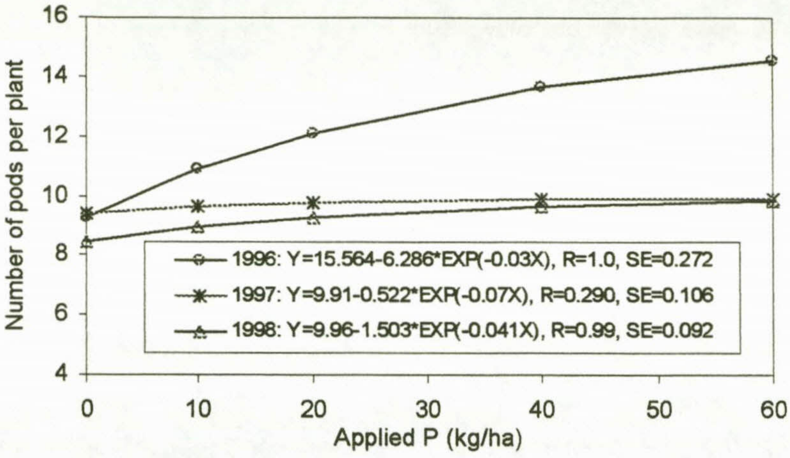

Figure 4.16 Effect of year x phosphorus application rate on the number of pods per plant for peas planted at the Bekoji site.

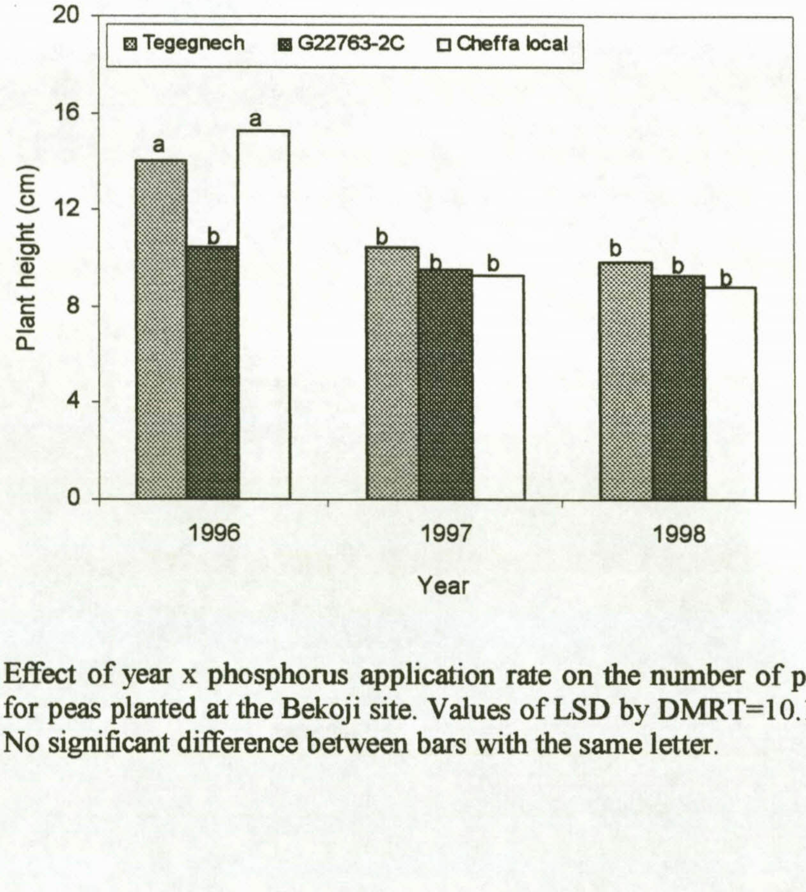

Figure 4.17 Effect of year x phosphorus application rate on the number of pods per plant for peas planted at the Bekoji site. Values of LSD by DMRT=10.16 at p=0.01. No significant difference between bars with the same letter.

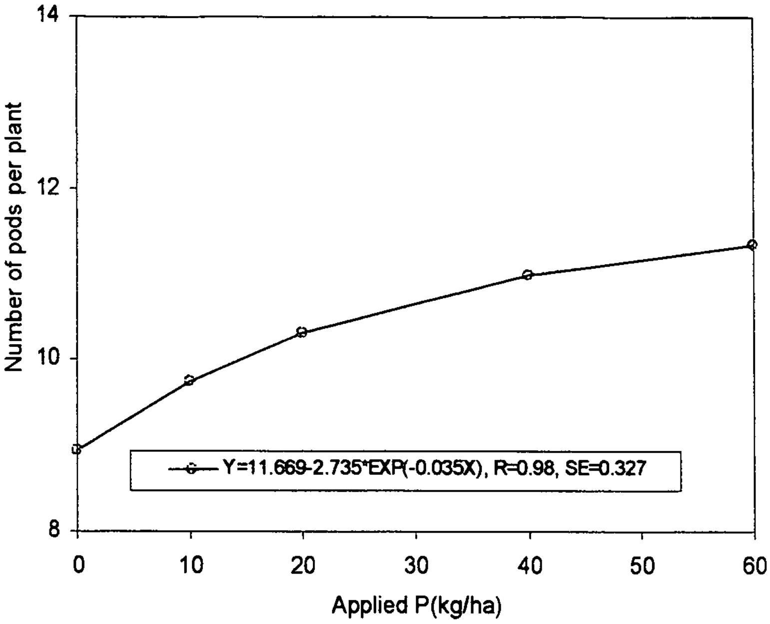

Figure 4.18 Effect of phosphorus application rate on the number of pods per plant for peas planted at the Bekoji site.

Usually, on phosphorus deficient soils field peas respond positively to phosphorus fertilization as was the case in this study (Ibrahim, 1982; Bakry *et al.* 1986; Srivastava & Verma, 1986; Singh et al., 1992; Paradkar & Sharma, 1994). The positive response of peas to phosphorus fertilization is attributed to an increase in photosynthesis on account of a larger leaf area caused by better cell division (Jakobsen, 1985; Adu-Gyamfi *et al.*, 1989; Rathi *et al.*, 1995). Enhanced cell division in turn resulted also in better root elongation and hence to more efficient use of water and nutrients in the soil can be utilized more efficiently by peas (Havangi, 1965 cited in Singh *et al.* (1983).

4.3.1.5 Marginal rate of return

Partial budget analyses (CIMMYT, 1988) were then computed in order to quantify the marginal rate of return (MRR)= marginal net benefit/marginal cost expressed as a percentage as a result of phosphorus application. In order to perform these analyses, grain and phosphorus prices were required. Based on the price of pea grain over the past seven years, a field price of 1.63 Ethiopian Birr kg^{-1} grain at Holetta and 1.46 Ethiopian Birr kg^{-1} grain at Bekoji were used. As mentioned earlier, only DAP is available as a phosphorus source in Ethiopia and with this in mind a price of 15 Ethiopian Birr kg^{-1} P which included transport and application costs was adopted.

The Mitscherlich equations estabilished for the relathionships between grain yield and phosphorus application rates (See Figure 4.3 for Holetta and Figure 4.5 for Bekoji) were used to generate grain yield data for 1 kg P ha^{-1} application intervals starting at 0, and ending at 100 kg ha^{-1}. On these data sets, partial budget analyses were computed using the adopted prices of grain and phosphorus mentioned earlier to obtain a MRR. A MRR above 100% indicates that the income from increased grain yield is more than the associated fertilizer cost, whereas a MRR below 100% indicates that the income from increased yield is less than the associated fertilizer cost. Thus, the most economical application rate of phosphorus will be at MRR of 100%. According to CIMMYT (1988), the acceptable minimum MRR needs to be at least between 50 % and 100%.

At Holetta, the response of grain yield to the application of phosphorus was poor with no differences between the three cultivars (Figure 4.3). As a result of this, low MRR were calculated which implicated that phosphorus fertilization is not economically viable. For example, the highest MRR, viz. 33% was obtained with an application of only 1 kg P ha^{-1}.

However, at Bekoji the response of grain yield to the application of phosphorus was good with differences between the three cultivars (Figure 4.5). This resulted in high MRR, which implicated that phosphorus fertilization to all the three cultivars is economically viable. A

100% MRR was obtained at an application of 21 kg P ha^{-1} for cv. Tegegnech, 10 kg P ha^{-1} for cv. G22763-2C and 5 kg P ha^{-1} for cv. Cheffa local, indicating the most economical phosphorus application rates for the three cultivars. For the above-mentioned farming systems, the economically viable phosphorus application rates should be adopted.

4.3.2 Second set of experiments

4.3.2.1 Soil environment

Analysis of variance showed those 29 days after planting the pH values of the Ilala and Cheffa soils were not affected by the treatments applied at planting, as described in Section 4.2.2.2. On average the pH (H_2O) of the Ilala soil was then 5.57 and that of the Cheffa soil 5.19. According to Kay (1979), the optimum pH range for field peas is 5.5 to 6.5. At this pH range, soil phosphorus is most available for plant uptake (Chen & Barber, 1990; Hillard, *et al.*, 1992; Maier *et al.*, 2002).

In addition, at a pH of 5.5 to 6.5 a deficiency in Ca or toxicity in Al or Mn are very limited (Jones *et al.*, 1982; Tsigie & Beyene, 1988; Mappaona *et.al.*, 1995; EARO, 1999). However, analysis of variance showed significant differences of extractable P in both the Ilala and Cheffa soils (Table 4.5). The amount of P extracted by either the Bray 2 or Olsen procedure differed significantly between the strips at Ilala and Cheffa where low, medium and high phosphorus fertility levels were induced before planting (Figure 4.19). As a result of the phosphorus applied during planting at different rates to these strips, the extractable P also differed significantly (Figure 4.20). The interaction between phosphorus fertility level and application rate was non-significant and no obvious reason can be given for this phenomenon.

Table 4.5 Summary on the analysis of variance computed with extractable phosphorus data indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala soil		Cheffa soil	
	Bray 2	Olsen	Bray 2	Olsen
A	**	**	**	**
B	**	**	**	**
C				
AB				
AC				
BC				
ABC				
Mean	22.74	25.52	45.59	32.73
CV%	22.60	19.71	31.19	18.39

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

It is interesting to note that in the case of the Ilala soil more phosphorus was extracted with the Olsen than the Bray 2 procedure (Figures 4.19 and 4.20). However, in the case of the Cheffa soil more phosphorus was extracted with the Bray 2 than the Olsen procedure even though the differences were not statistically significant. No explanation can be given for this contradiction. From these results, it can be concluded that the pH and extractable P of both the Ilala and Cheffa soils were modified successfully as was the aim for this field experiments for testing the response of fields peas for phosphorus fertilization.

4.3.2.2 Crop growth

A summary on the analysis of variance with data of some plant parameters from Ilala and Cheffa are given in Table 4.6. From this table, it is clear that grain yield, plant height and above-ground biomass at Ilala, and grain yield, plant height and pods per plant at Cheffa were significantly affected by some of the treatments applied.

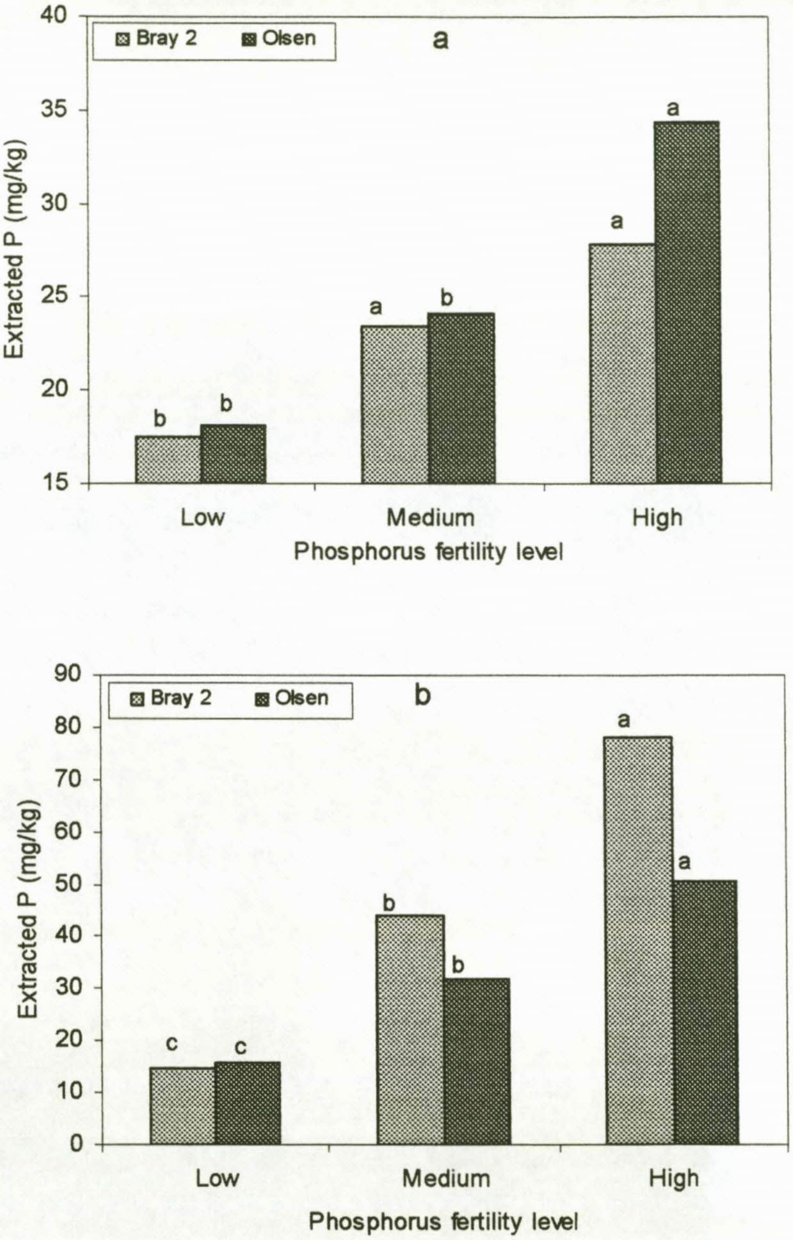

Figure 4.19 Effect of phosphorus fertility level on the P extracted from the Ilala (a) and Cheffa (b) soils with the Bray 2 and Olsen procedures. Values of LSD by DMRT for Ilala soil are 5.01 for Bray 2 and 7.03 for Olsen at $p < 0.01$, and for the Cheffa soil are 21.12 for Bray 2 and 12.15 for Olsen at $p < 0.01$.

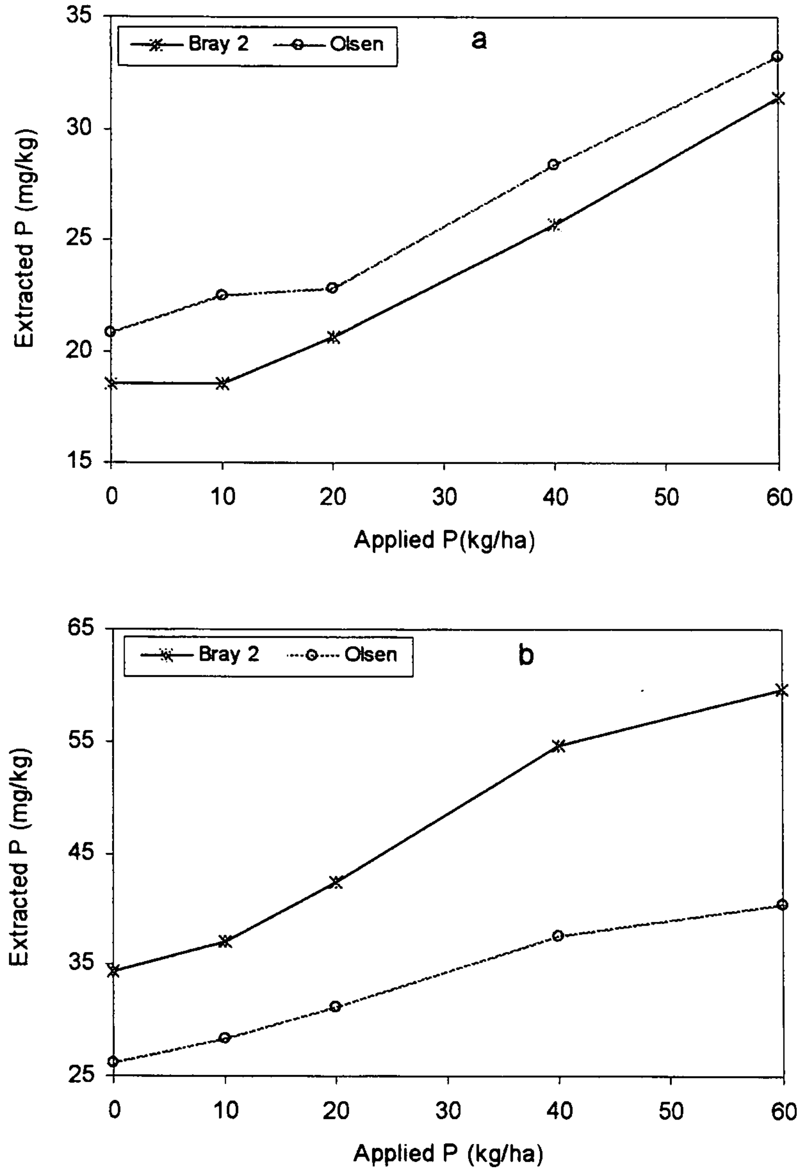

Figure 4.20 Effect of phosphorus application rate on the P extracted from the Ilala (a) and Cheffa (b) soils with the Bray 2 and Olsen procedures. Values of LSD by DMRT for the Ilala soil are 3.96 for Bray 2 and 3.83 for Olsen at $p < 0.01$, and for the Cheffa soil are 10.83 for Bray 2 and 4.58 for Olsen at $p < 0.01$.

Table 4.6 Summary on the analysis of variance computed with data of plant parameters from Ilala and Cheffa indicating significanct treatment effects at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala				Cheffa			
	Grain yield	Plant height	Above-ground biomass	Pods per plant	Grain yield	Plant height	Above-ground biomass	Pods per plant
A						*		*
B						*		**
C		**	**		**	**		**
AB					**			
AC		*			**			**
BC	*							
ABC								
Mean	2228.92	155.5	6328.23	10.38	3036.6	153.72	5665.51	11.81
CV%	10.37	8.21	9.41	13.28	16.55	8.29	20.43	12.04

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

4.3.2.2.1 Grain yield

The grain yield at Ilala was only significantly affected by the interaction between phosphorus application rate and cultivar (Figure 4.21). The grain yield of cv. G22763-2C decreased with increased phosphorus application rates while that of cv. Holetta was positively increased.

At Cheffa, the interaction between phosphorus fertility level and application rate affected the grain yield significantly (Figure 4.22). The grain yield increased at the low and medium phosphorus fertility levels with increasing rates of phosphorus application. However, at the high phosphorus fertility level the grain yield decreased with increasing rate of phosphorus application. This phenomenon can be explained by the interaction between phosphorus fertility level and cultivar (Figure 4.23). From this figure, it is clear that the grain yield of cv. Cheffa local was very low in comparision to that of cv. Tegegnech at the high phosphorus fertility level. Even at the medium and low phosphorus fertility levels, the grain yield of cv.Cheffa local was lower than that of cv. Tegegnech, although not significant. Therefore, it seems that the grain yield of cv.Cheffa local was suppressed by either high phosphorus fertility levels or application rates. This was not the case with the improved cultivar cv. Tegegnech.

As was the case in the first set of experiments an attempt was made to establish with either the absolute or relative grain yields critical soil phosphorus levels. This could unfortunately not achieved as a result of the inconclusiveness of the outcomes and are neither presented nor discussed here.

The lack of response of the field pea crop at Ilala and to a lesser extent at Cheffa to either increasing phosphorus fertility levels and/or phosphorus application rates may be partially attributed to the pre-plant liming of the soil at both sites. As a result of the pre-plant liming and hence increase in pH enhanced mineralization of organic labile P and desorption of inorganic labile P could raise the soil solution P to sufficient levels. This aspect is discussed in more detail in Section 2.3.2.

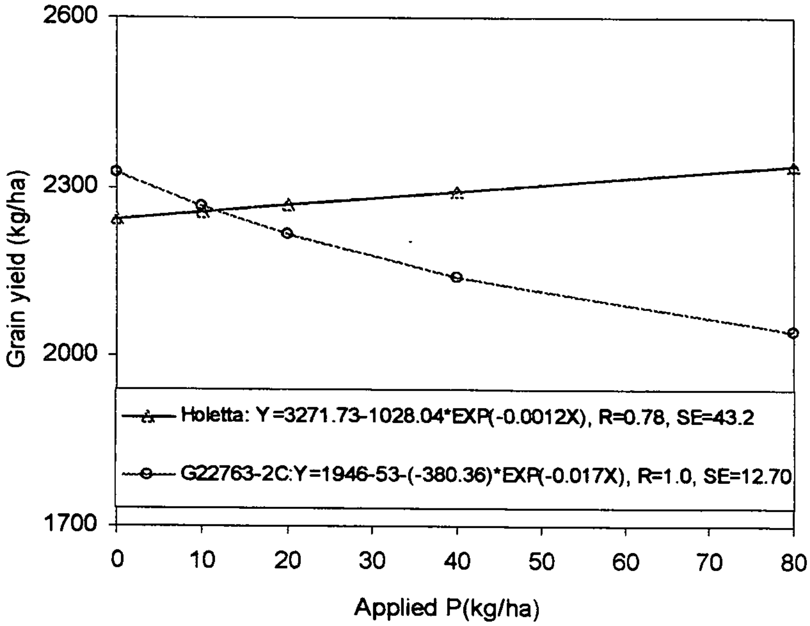

Figure 4.21 Effect of phosphorus application rate x cultivar on the grain yield of peas planted at the Ilala site.

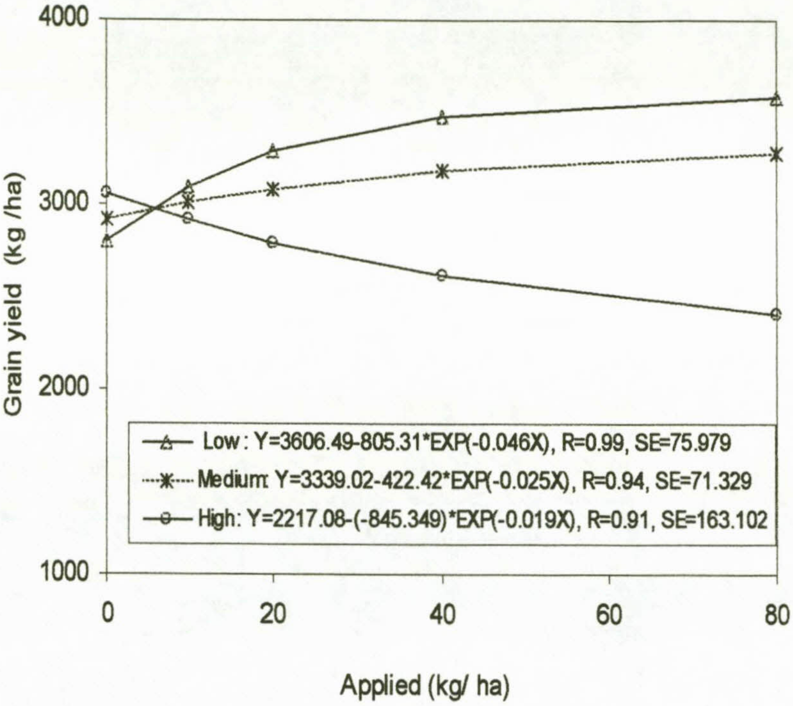

Figure 4.22 Effect of phosphorus fertility level x application rate on the grain yield of peas planted at the Cheffa site.

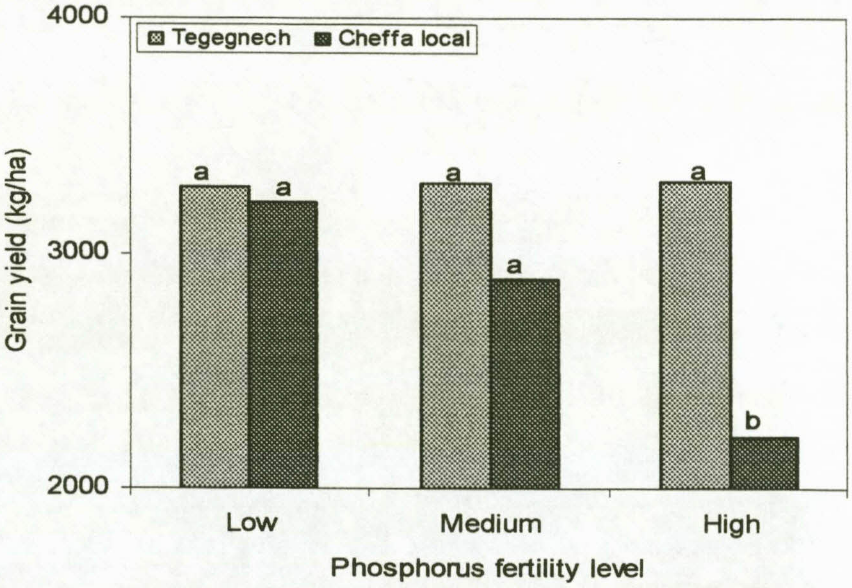

Figure 4.23 Effect of phosphorus fertility level x cultivar on the grain yield of peas planted at the Cheffa site. Values of LSD by DMRT = 419 at p=0.01. No significant difference between bars with the same letter.

4.3.2.2.2. Plant height

At the Ilala site, the height of the cv. Holetta plants increased slightly from the low to either the medium or high phosphorus fertility levels where the height of cultivars were very similar (Figure 4.24). The height of cv.G22763-2C plants increased slightly from the low to medium phosphorus fertility level and then decreased sharply to the high phosphorus fertility level. Plants of cv. G22763-2C were significantly ($p < 0.05$) higher than plants of cv. Holetta, especially at the low and medium phosphorus fertility levels.

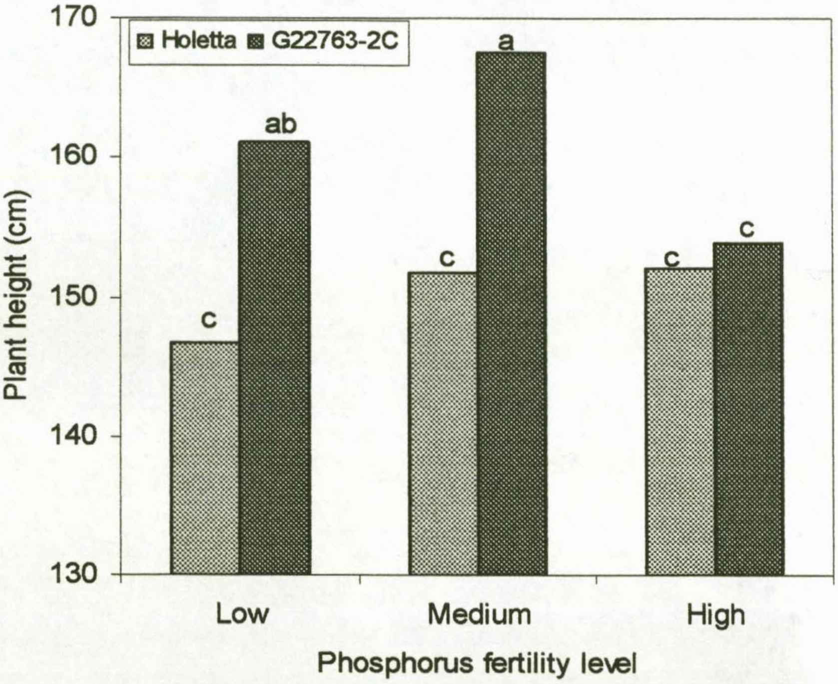

Figure 4.24 Effect of phosphorus fertility level x cultivar on the plant height of peas planted at Ilala site. Values of LSD by DMRT=8.03 at p=0.05. No significant difference between bars with the same letter.

At Cheffa, the height of the pea plants increased from the low to medium phosphorus fertility level but then decreased to the high phosphorus fertility level (Figure 4.25). The plant height increased sharply until an application rate of 40 kg P ha^{-1} whereafter it stabilized (Figure 4.26). Plants of medium and low fertility levels were significantly ($p < 0.05$) higher than those of high fertility level. On average, the plants from the low and medium fertility levels were respectively about 18 and 25 cm taller than plants from the high phosphorus fertility level.

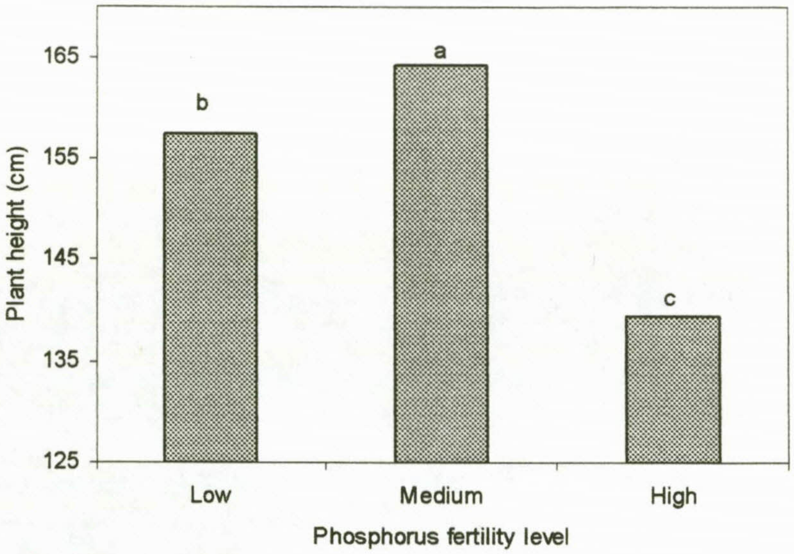

Figure 4.25 Effect of phosphorus fertility level on the plant height of peas planted at the Cheffa site. Values of LSD by DMRT = 16.16 at p = 0.05. No significant difference between bars with the same letter.

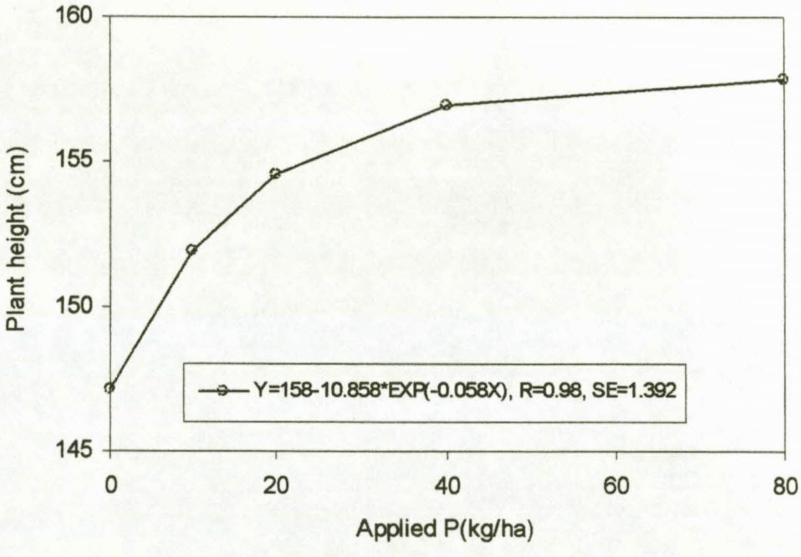

Figure 4.26 Effect of phosphorus application rate on the plant height of peas planted at the Cheffa site.

4.3.2.2.3 Above-ground biomass

The only significant difference in above-ground biomass was measured at Ilala as a result of cultivars. On average, the above-ground biomass of cv. G22763-2C was 6620 kg ha^{-1} and that of cv.Holetta 6037 kg ha^{-1}.

4.3.2.2.4 Pods per plant

None of the treatments had a significant effect on the pods per plant at Ilala. However, at Cheffa the pods per plant were significantly affected by all the treatments and the interaction of phosphorus fertility with cultivar. The pods per plant of both cultivars declined with increasing levels of phosphorus fertility (Figure 4.27). At all the phosphorus fertility levels, cv. Cheffa local had more pods per plant than cv. Tegegnech but the difference was only significant at the low phosphorus fertility level. As illustrated in Figure 4.28, the pods per plant also increased with increasing rates of phosphorus application up to 40 kg P ha^{-1} and then stabilized.

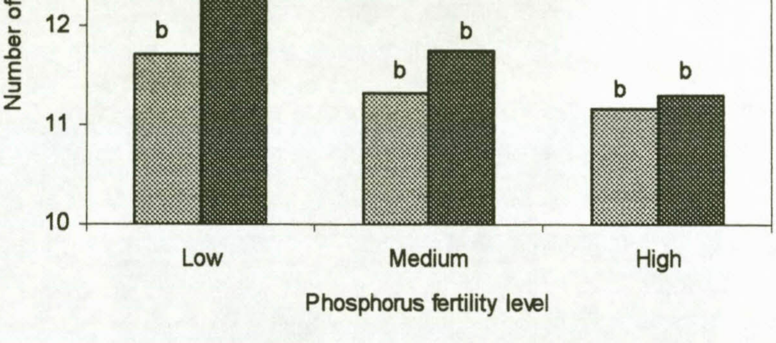

Figure 4.27 Effect of phosphorus fertility level x cultivar on the number of pods per plant for peas planted at the Cheffa site.

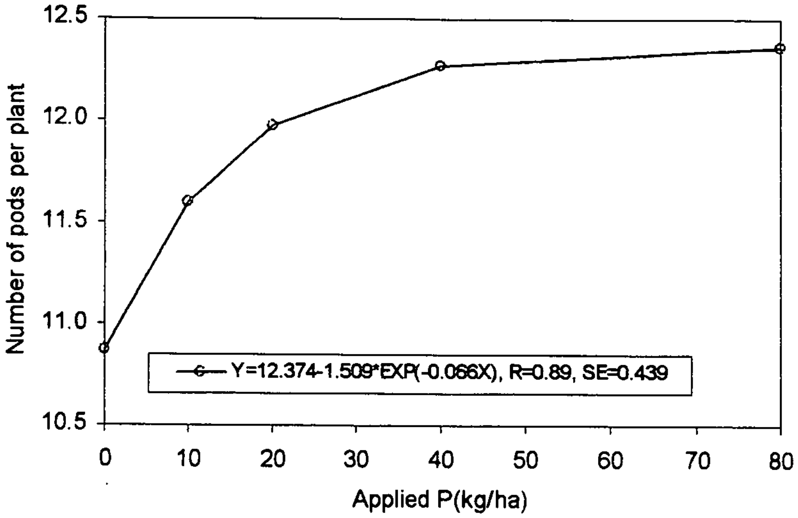

Figure 4.28 Effect of phosphorus application rate on the number of pods per plant for peas planted at the Cheffa site.

4.3.2.3 Nutrient content

As described in Section 4.2.2.2 the nutrient content of the vegetative growth, viz. above-ground biomass was determined at flowering and physiological maturity. In addition, the nutrient content of the grain at physiological maturity was determined.

4.3.2.3.1 Above-ground biomass at flowering

The effects of the various treatments on the nutrient contents of the above-ground biomass at flowering are summarised in Table 4.7. From this table, it is evident that far less significant differences were recorded at Ilala than at Cheffa. At Ilala , only the N and K contents differed significantly as a result of the cultivars that were planted (Figure 4.29). The N contents of the G22763-2C and Holetta cultivars were respectively 2.91 and 3.12% and the K content 2.36 and 2.07%.

Table 4.7 Summary on the analyses of variance computed with nutrient data of above-ground biomass at flowering of field peas from the Ilala and Cheffa soils indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala					Cheffa				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
A						*		**		
B										
C	**		**			*		**	*	**
AB										
AC							**			
BC										
ABC										
Mean	3.01	0.30	2.22	0.62	0.14	3.02	0.25	2.11	0.70	0.14
CV%	9.10	10.25	14.56	9.50	10.81	17.28	14.85	14.29	11.57	12.35

A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

On the other hand, at Cheffa the contents of N, P, K, Ca and Mg were affected to some or other extent by the various treatments and their interactions. As illustrated in Figure 4.30, both the N and K contents declined with increasing levels of phosphorus fertility. The cv.Tegegnech plants had significantly higher N and Ca contents than the cv Cheffa local plants, while the cv. Cheffa local plants had significantly higher K and Mg contents than the cv. Tegegnech plants (Figure 4.31). Figure 4.32 shows the interaction effect of phosphorus fertility level and cultivar on P content. The P content of the cv. Tegegnech plants was not affected by the phosphorus fertility levels. However, the P content of the cv. Cheffa local plants tended to decline with increasing levels of phosphorus fertility. At the low and medium phosphorus fertility levels, the P contents of the cv. Cheffa local plants were higher than that of the cv. Tegegnech plants which was not the case at the high phosphorus fertility level even though the differences were not statistically significant.

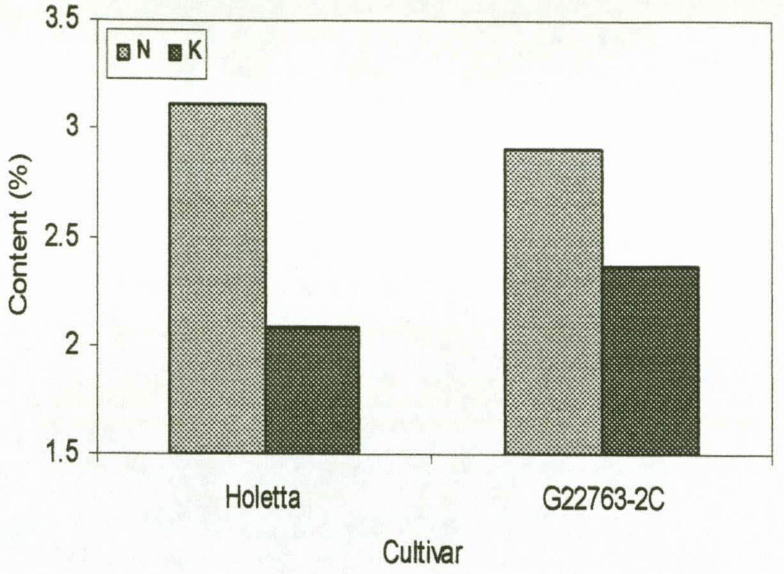

Figure 4.29 Effect of cultivars on the N and K contents of above-ground biomass during flowering of peas planted at the Ilala site. Values of SE = 0.035 for N and 0.041 for K at p = 0.01.

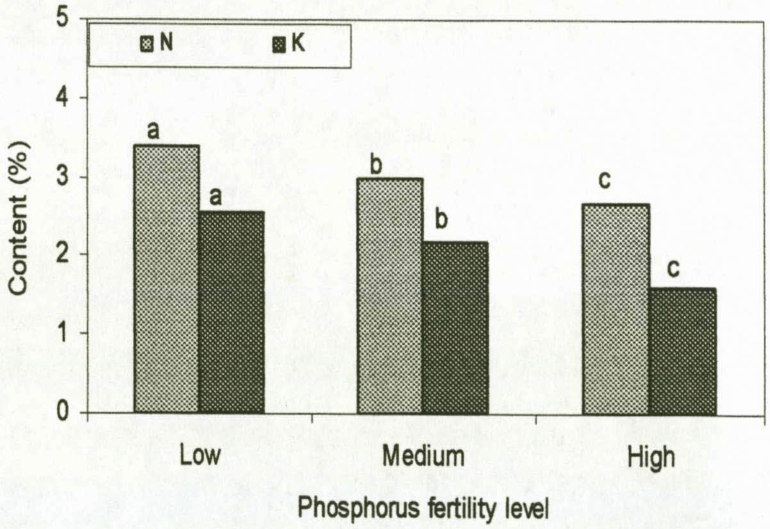

Figure 4.30 Effect of phosphorus fertility level on the N and K contents of above-ground biomass during flowering of peas planted at the Cheffa site. Values of LSD by DMRT for N = 0.31 at p = 0.05 and for K = 0.18 at p = 0.01.

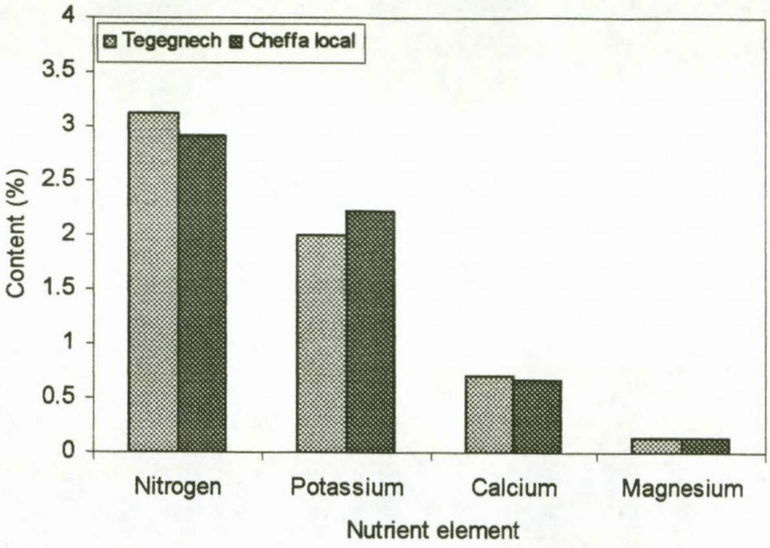

Figure 4.31 Effect of cultivars on the N, K, Ca and Mg contents of above-ground biomass during flowering of peas planted at the Cheffa site. Values of SE for N = 0.07 at p = 0.05, K = 0.01 at p = 0.01, Ca = 0.01 at p = 0.05 and Mg = 0.002 at p = 0.01.

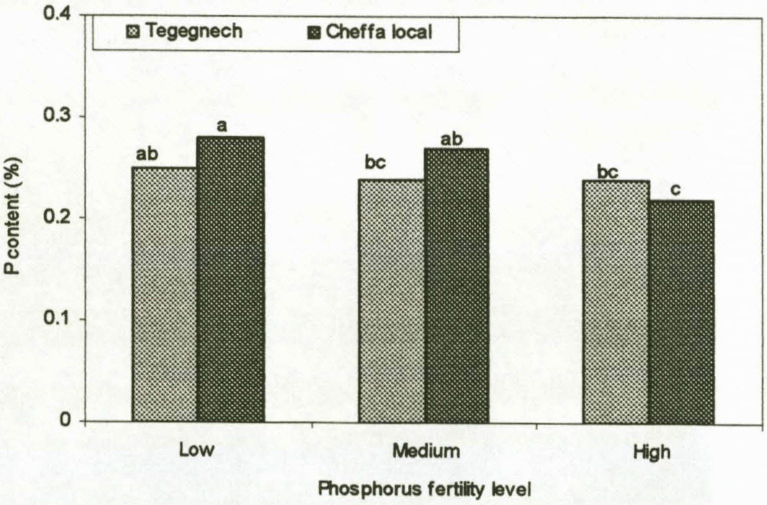

Figure 4.32 Effect of phosphorus fertility level x cultivar on the P content of above-ground biomass during flowering of peas planted at the Cheffa site. Values of LSD by DMRT = 0.026 at p = 0.01. No significant difference between bars with the same letter.

4.3.2.3.2 Above-ground biomass at physiological maturity

The effects of the various treatments at the nutrient contents of the above-ground biomass at physiological maturity are summerized in Table 4.8. As was the case at flowering stage far more significant differences were measured at Cheffa than at Ilala site. However, the pattern at physiological maturity is not exactly similar to that at flowering stage.

Table 4.8 Summary on the analyses of variance computed with nutrient data of above-ground biomass at physiological maturity of field peas from the Ilala and Cheffa soils indicating significant effects of treatments at confidence levels of $p < 0.05$* or $p < 0.01$**.

Factor[1]	Ilala					Cheffa				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
A								*	*	
B										
C			**	*		**			*	
AB										
AC								*		
BC										
ABC										
Mean	1.24	0.09	1.51	1.05	0.16	0.97	0.13	1.39	1.15	0.17
CV%	14.55	25.25	14.42	9.75	9.19	17.45	12.70	19.10	14.68	22.12

[1] A = phosphorus fertility level, B = phosphorus application rate and C = cultivar.

At Ilala, the K and Ca contents of the two cultivars differed significantly as illustrated in Figure 4.33. The K contents of cvs.G22763-2C and Holetta were respectively 1.59 and 1.44 % and the Ca contents 1.03 and 1.07% At Cheffa, the contents of N, K and Ca were affected by either the phosphorus fertility levels and/or cultivars. The K content increased slightly from the low to medium phosphorus fertility level and then decreased markedly to the high phosphorus fertility level (Figure 4.34). However, the Ca content decreased with increasing levels of phosphorus fertility. As illustrated in Figure 4.35, cv. Tegegnech plants had lower N content and higher Ca content than the cv. Cheffa local plants. The K contents of both the cv. Tegegnech and cv. Cheffa local increased slightly from the low to medium phosphorus fertility level and then decreased markedly to the high phosphorus fertility level (Figure 4.36).

At the low phosphorus fertility level, the K content of the cv. Cheffa local plants was higher than that of cv. Tegegnech plants which was not the case at the medium and high phosphorus fertility levels.

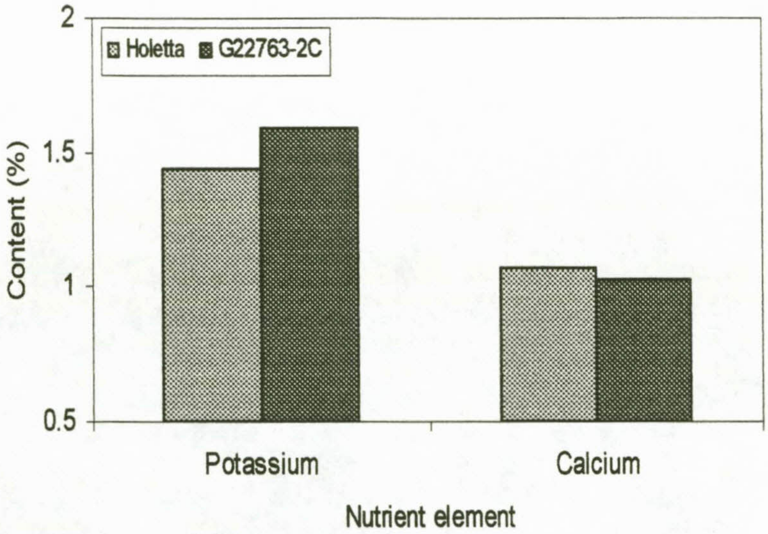

Figure 4.33 Effect of cultivars on the K and Ca contents of above-ground biomass during physiological maturity of peas planted at the Ilala site. Values of SE for K = 0.028 at p = 0.01 and for Ca = 0.021 at p = 0.05.

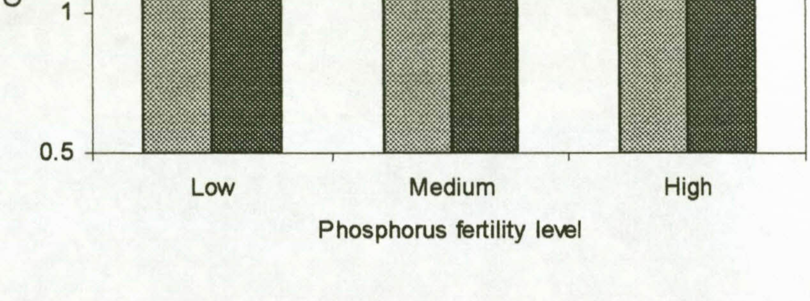

Figure 4.34 Effect of phosphorus fertility level on the K and Ca contents of above-ground biomass during physiological maturity of peas planted at the Cheffa site. Values of LSD by DMRT for K = 0.12 and Ca = 0.074 at p = 0.05. No significant difference between bars with the same letter

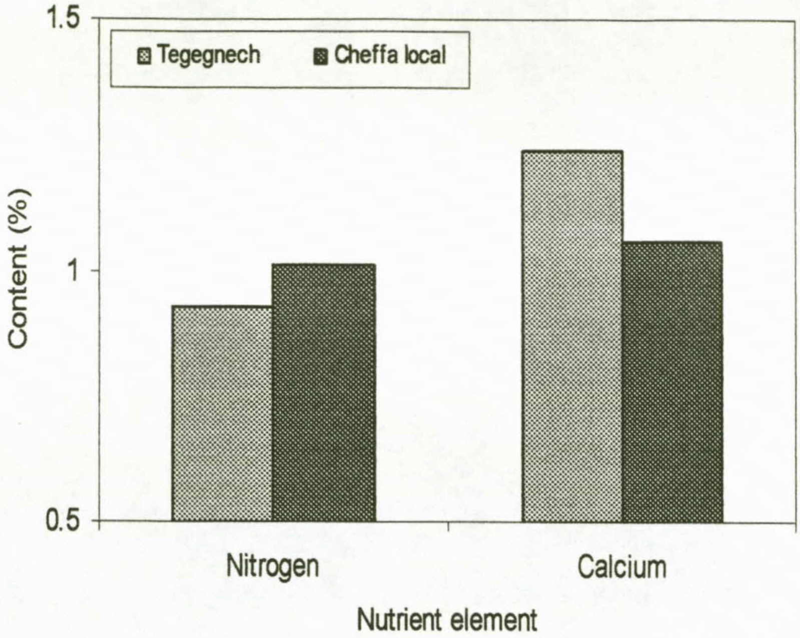

Figure 4.35 Effect of cultivars on the N and Ca contents of above-ground biomass during physiological maturity of peas planted at the Cheffa site. Values of SE for N = 0.025 at p = 0.01 and Ca = 0.022 at p = 0.05.

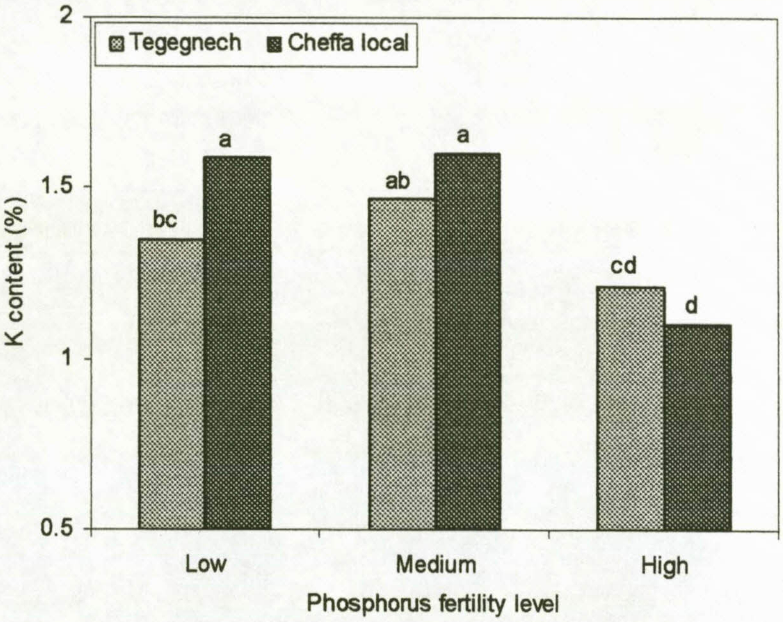

Figure 4.36 Effect of phosphorus fertility level x cultivar on the K content of above-ground biomass during physiological maturity of peas planted at the Cheffa site. Values of LSD by DMRT = 0.17 at p = 0.05. No significant difference between bars with the same letter.

4.3.2.3.3 Grain at physiological maturity

The effects of the various treatments on the nutrient contents of the grain at physiological maturity are summarized in Table 4.9. It is evident that the differences resulted mainly from the phosphorus fertility level and cultivar treatments.

Table 4.9 Summary on the analyses of variance computed with nutrient data of grain at physiological maturity of field peas from the Ilala and Cheffa soils indicating significant effects of treatments at confidence levels of $p < 0.05*$ or $p.<.0.01**$.

Factor[1]	Ilala					Cheffa				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
A		*		*			**			
B										
C	**	**	**	**			**	*	**	**
AB										
AC	**						**			
BC										
ABC										
Mean	3.51	0.28	0.95	0.07	0.11	3.30	0.27	0.78	0.07	0.10
CV%	6.50	10.26	8.87	17.19	9.13	6.33	8.23	14.22	12.41	14.10

[1] A =. phosphorus fertility level, B = phosphorus application rate and C = cultivar.

At Ilala, only the P and Ca contents differed significantly as a result of the phosphorus fertility level (Figure 4.37). The P content of the grain increased with increasing levels of phosphorus fertility while the Ca content of the grain decreased with increasing phosphorus fertility levels. Significant differences in the P, K and Ca contents were recorded between the cultivars (Figure 4.38). The grain of cv. Holetta had a higher P content than that of the cv.G22763-2C, while the grain of the G22763-2C cultivar had a higher K and Ca content than that of cv.Holetta. As illustrated in Figure 4.39, the significant interaction between phosphorus fertility levels and cultivars resulted in higher N content in the grain of cv. Holetta than cv.G22763-2C at the medium phosphorus fertility level.

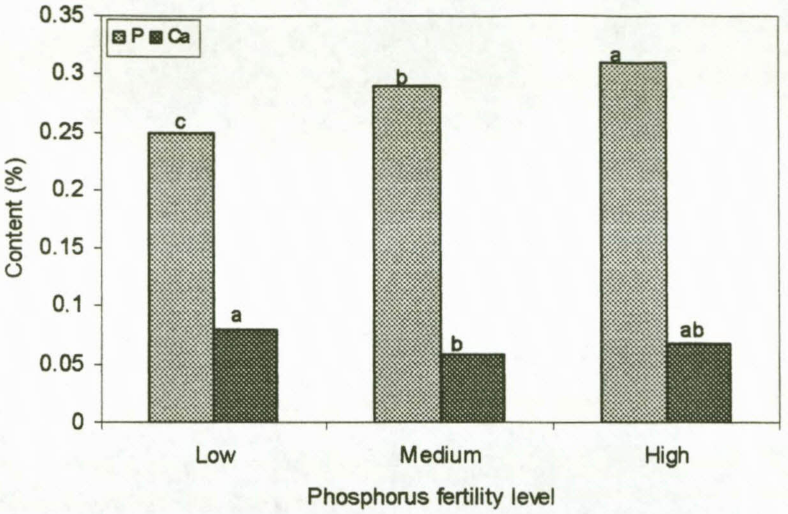

Figure 4.37 Effect of phosphorus fertility level on the P and Ca contents of grain during physiological maturity of peas planted at the Ilala site. Values of LSD by DMRT = 0.014 at p = 0.01. No significant difference between bars with the same letter.

At Cheffa, the grain of the Tegegnech cultivar had significantly lower K, Ca and Mg contents than the grain of the Cheffa local cultivar (Figure 4.40). As illustrated in Figure 4.41, the P content of both cultivars increased significantly from the low to medium phosphorus fertility levels with no significant differences between the cultivars. However, from the medium to high phosphorus fertility level the P content of the cv. Tegegnech grain remained the same while that of the Cheffa local cultivar declined significantly.

From these results of the nutrient content of the above-ground biomass at either flowering and physiological maturity and of the grain at physiological maturity, it is evident that the effects of the various treatments were very inconsistent which complicated interpretation. However, in general far less significant differences were recorded at Ilala than at Cheffa, especially with regard to the nutrient content of the above-ground biomass at both growing stages. The results indicated without doubt differences between the cultivars planted at the respective sites, and to a lesser extent differences between the phosphorus fertility levels of the soils. Surprisingly, the nutrient contents of the above-ground biomass and grain were rarely affected by the phosphorus application rates, especially at the medium and high phosphorus fertility levels.

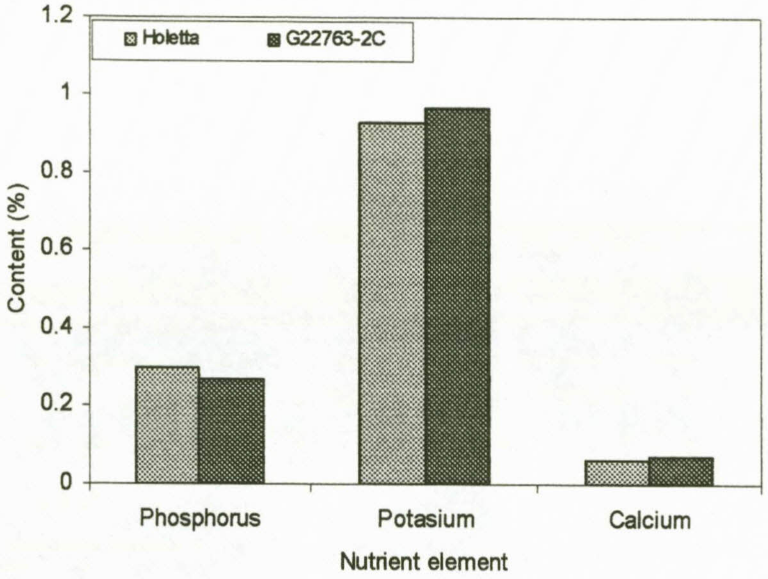

Figure 4.38 Effect of cultivars on the P, K and Ca contents of grain during physiological maturity of peas planted at the Ilala site. Values of SE = 0.004 for P, 0.011 for K and 0.002 for Ca.

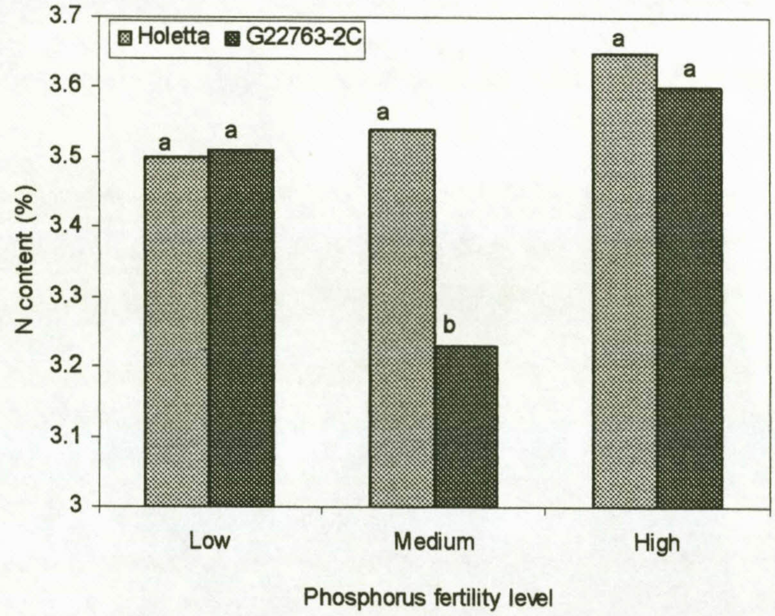

Figure 4.39 Effect of phosphorus fertility level x cultivars on the N content of the grain during physiological maturity of peas planted at the Ilala site. Values of LSD by DMRT = 0.19 at p = 0.01. No significant different between bars with the same letter.

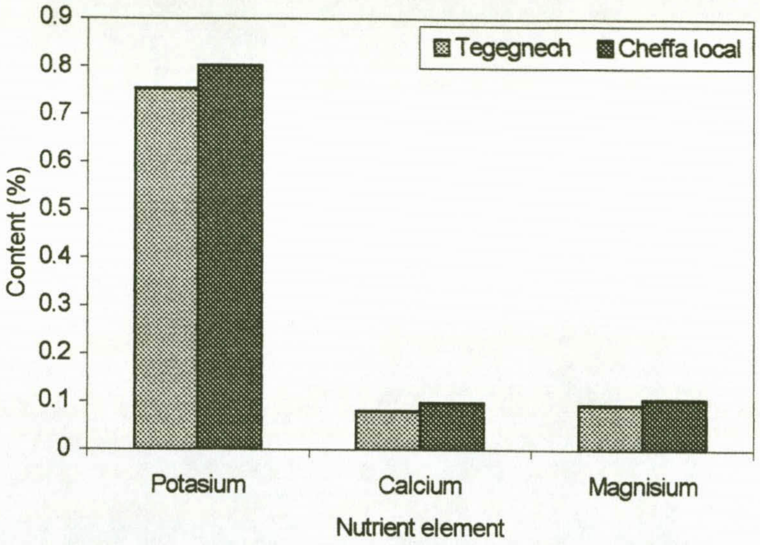

Figure 4.40 Effect of cultivar on the K, Ca and Mg contents of grain during physiological maturity of peas planted at the Cheffa site. Values of SE = 0.014 for K at p = 005, 0.0014 for Ca at p = 0.01 and 0.008 for Mg at p = 0.01.

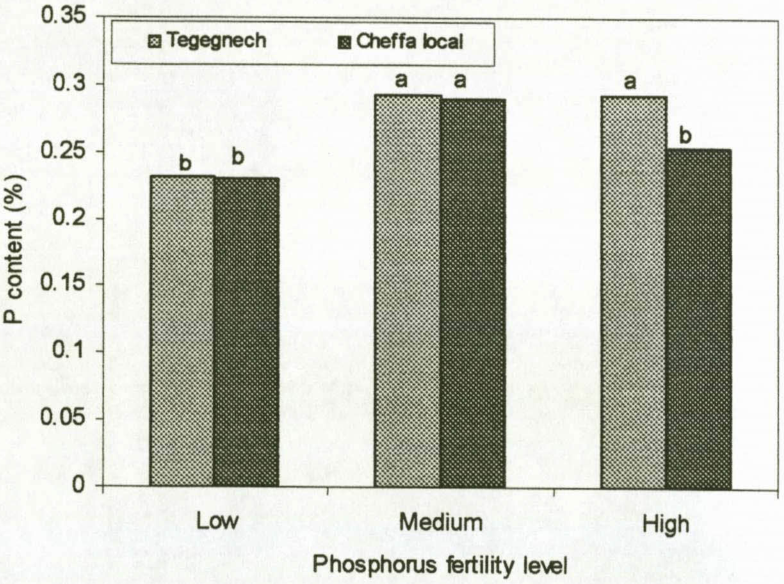

Figure 4.41 Effect of phosphorus fertility level x cultivar on the P content of grain during physiological maturity of peas planted at the Cheffa site. Values of LSD by DMRT = 0.026 at p = 0.01. No significance difference between bars with the same letter.

4.3.2.4 Marginal rate of return

The response of grain yield to phosphorus fertilization was negligible at Ilala as described in Section 4.3.2.2.1. However, grain yield response to phosphorus fertilization at Cheffa significant especially at the low fertility level and to a lesser extent at the medium fertility level. Therefore, MRRs as a result of phosphorus fertilization were calculated for those two phosphorus fertility levels only by using the relevant grain and phosphorus prices given in Section 4.3.1.5. For the partial budget analyses, the Mitscherlich equations established for the relationships between grain yield and phosphorus application at the low and medium phosphorus fertility levels (See Figure 4.22) were used to generate grain yield data for 1 kg P ha^{-1} application intervals, starting at 0 and ending at 100 kg P ha^{-1}. At the low phosphorus fertility level, a 13 kg P ha^{-1} application resulted in a MRR of 100%, while at the medium phosphorus fertility level a 1 kg P ha^{-1}application resulted in a MRR of only 2%. As explained in Section 4.3.1.5, under this experimental conditions phosphorus fetilization was economically viable only at the low phosphorus fertility level.

4.4 Conclusion

Two sets of field trials were conducted to estabilish optimum phosphorus application rates for various field pea cultivars on soils with varying phosphorus fertility levels in different cropping systems. In the Holetta zone the grain yield response of the field pea crop to phosphorus application was poor regardless of the phosphorus fertility level of the soil or the cultivars that were planted. As a result of this low MRR were calculated which implicated that phosphorus fertilization is not economically viable with the current price of grain and fertilizer in the zone. However, in the Bekoji zone the grain yield response of the field pea crop to the application of phosphorus was better with differences between phosphorus fertility levels and cultivars. This resulted in high MRR which implicated that phosphorus fertilization to all the cultivars at the low phosphorus fertility level was economically viable with the current prices of grain and fertilizer in the zone. In general, the improved field pea cultivars responded better to phosphorus fertilization than the local field pea cultivars, an aspect that warrants thorough research in the future. Unfortunately, no critical soil phosphorus with either the absolute or relative grain yield could be estabilished for the two zones, viz. Holetta and Bekoji.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

In Ethiopia, field pea (*Pisum sativum* L.) is the third most important food legume occupying about 1.82 % of the total cultivated area, viz. 8.7 million ha. It is grown in 12 of the 49 sub-agroecological zones of which all are distributed throughout the highlands ranging from 1800 to 3200 m.a.s.l. In the lower altitudes peas are grown in the main rainy season from June to October, but the season extends into December in extremely high altitudes where crop growth is seldom limited by water stress during the growing season.

The soils in the field pea growing sub-agroecological zones originated from different parent materials: igneous, metamorphic and sedimentary rocks in descending order, and the former contains more P than the other two rock types. Deforestation and soil erosion are severe problems in these sub-agroecological zones where field pea grows on a wide range of well-drained soil types. Of the various soil types, Nitosols is the major arable soil with high P fixing capacities which increase as weathering increases.

The field pea crop plays a vital role in being a protein source to the majority of the people, a break crop in cereal farming system of the highlands and a soil ameliorator through biological atmospheric nitrogen fixation. Although field pea is a low-input crop, DAP is applied to improve the productivity of the cultivars in some areas recently. However, in Ethiopia, fertilization guidelines for grain legumes are very general and vague as they are neither based on soil nor plant analyses. Information in the literature indicates that field pea responds to phosphorus fertilization depending on the residual phosphorus status of the soil. The currently recommended blanket application of 100 kg DAP ha^{-1} has not been based on research work and has been questioned time and again by field pea producers and development workers.

In general, despite the importance of field pea in the Ethiopian agriculture, its yields have remained low due several factors which include soil fertility problems. Hence, experiments have been conducted with the major objective of quantifying the response of Ethiopian field pea cultivars to phosphorus fertilization of Nitosols under both glasshouse and field conditions.

Glasshouse experiments

In order to achieve the above-mentioned objective, topsoils (0-0.3 m) were collected from farm lands at Ilala and Cheffa for the glasshouse experiments. Two pilot experiments were conducted to determine the lime and phosphorus requirements of the soils. Accordingly, the pH (H_2O) was modified to 6.1 and three batches of low, medium and high phosphorus fertility levels, viz. 5, 15 and 30 mg P kg^{-1} (Bray 2) were created and incubated in plastic bags for 67 days in a lath house at Holetta Agricultural Research Center. At the end of the incubation period, the soil was transported to the National Soil Research Center in Addis Abeba where the experiments were conducted with the pre-treated Ilala and Cheffa soils from July to September 2001. The experiments were laid out in a split plot design with three phosphorus fertility levels (low = 5 mg P kg^{-1}, medium = 15 mg P $kg^{-1}$and high = 30 mg P kg^{-1}) as the main plot treatments and the factorial combination of two field pea cultivars (Holetta and G227763-2C for Ilala soil and Tegegnech and Cheffa local for Cheffa soil) and six phosphorus application rates (0, 7.5, 15, 30, 60 and 120 mg P kg^{-1}) as the sub-plot treatments in a randomized complete block design with four replications. In each pot three seeds of peas were sown at a depth of 5 cm. In addition, all the essential nutrients for plant growth were added in solution form together with the P treatments. The source of P was $Ca(H_2PO_4).2H_2O$. Twenty-nine days after planting, soils were carefully sampled from each pot, and the trials terminated after all plants flowered. Plant parameters collected included plant height, nodulation characteristics, root and shoot dry weight. Soil samples were analyzed for pH (H_2O and KCl), extractable P (Bray 2 and Olsen) and plant tissue samples for the macronutrients N, P, K, Ca and Mg.

Results indicated that the pH and extractable P of both soils were modified successfully. The application of lime resulted in pH values of 5.90 for the Ilala soil and 5.74 for the Cheffa soil. In both soil types, the extractable P increased with increasing P fertility levels and rates.

The phosphorus fertility levels together with the phosphorus application rates had positive influences on the growth and development of the pea crop as manifested in the height and biomass of the field pea cultivars. The position, size and colour of the nodules were affected by the phosphorus fertility levels of both soils, viz. Ilala and Cheffa. However, phosphorus application rates had only a significant effect on the size and colour of the nodules recovered from the Cheffa soil. All cultivars showed excellent nodulation characteristics regardless of phosphorus fertility levels and application rates. The N and P contents of the shoots increased with increasing phosphorus application rates, but stabilized sooner at the high than the low phosphorus fertility level. The medium phosphorus fertility level was intermediate in stabilizing. There were some differences in the shoot nutrient contents of the cultivars but these differences were not consistent.

Critical phosphorus levels were established by relating relative total biomass to extractable soil phosphorus. In the case of the Bray 2 extractions, the critical phosphorus levels for the Ilala soils were 14 and 15 mg P kg $^{-1}$ for cvs. G22763-2C and Holetta respectively and for the Cheffa soil 17 and 20 mg P kg $^{-1}$ for cvs. Cheffa local and Tegegnech respectively. In the case of the Olsen extractions, the critical phosphorus levels for the Ilala soil were 17 and 27 mg P kg $^{-1}$ for cvs. Holetta and G22763-2C respectively, and for Cheffa soil 20 and 22 mg P kg $^{-1}$ for cvs. Cheffa local and Tegegnech respectively.

Field experiments

Two sets of experiments were conducted to achieve the objectives mentioned earlier. The first set of two experiments were conducted respectively on fields of the Holetta Agricultural Research Center (HARC) from 1996 to 1999 and on farm fields near Bekoji sub-center from 1996 to 1998. In 2001 the second set of two experiments were conducted respectively on farm fields at Ilala (about 3 km north from HARC) and Cheffa (about 2 km west of Bekoji sub-center).

First set of experiments

At both sites a factorial combination of five phosphorus levels (0, 10, 20, 40 and 60 kg P ha^{-1}) and three field pea cultivars (Tegegnech, G22763-2C and Holetta local at Holetta and Tegegnech, G22763-2C and Cheffa local at Bekoji) were laid out in a randomized complete block design with four replications. Before planting, 20 kg N ha^{-1} and phosphorus at the above-mentioned rates were applied in rows and incorporated to the soils using wooden pegs . The source of phosphorus was $Ca\ (H_2PO_4)_2\ H_2O$. Seeds of each cultivar were drilled in plots of 5x 2.4 m at the rate of 150 kg ha^{-1} with a spacing of 5 cm between plants and 20 cm between rows. The trial fields were managed according to the agronomic practices recommended for the respective sites.

At Holetta the effect of year and phosphorus application rates on grain yield, plant height, above-ground biomass and pods per plant were significant with very few interactions. Differences between cultivars as manifested in plant height and above-ground biomass were also recorded, but with no consistency. However, the average yield of the cultivars increased from less than 1 ton ha^{-1} with no fertilization to more than 1.2 ton ha^{-1} with a 60 kg ha^{-1} application. The marginal rate of return (MRR) showed that phosphorus fertilization of peas at this site was not economically viable.

On the other hand, at Bekoji significant effects of year, phosphorus application rate and cultivar on grain yield, plant height and pods per plant were found, with some interactions between these factors. The interaction between phosphorus application rate and cultivar was significant with regard to grain yield, indicating that the response of cv. Cheffa local to phosphorus application was relatively poor compared to that of cv.Tegegnech with cv. G22763-2C intermediate. A 100% MRR was obtained at an application of 21 kg P ha^{-1} for cv.Tegegnech, 10 kg P ha^{-1} for cv. G22763-2C and 5 kg P ha^{-1} for cv.Cheffa local, indicating the most economically phosphorus application rates.

No conclusive critical soil phosphorus levels could be established with either absolute or relative grain yields at the Holetta and Bekoji sites.

Second set of experiments

The farm fields at Ilala and Cheffa were divided into three strips, and representative soil samples were taken from each to determine phosphorus fertility levels. Based on these determinations, three levels of phosphorus fertility were created three months prior to planting through the incorporation of $Ca(H_2PO_4).2H_2O$ into soil with the local plough drawn by oxen at the rate of 0, 3 and 6 kg P ha^{-1} at Ilala and 0, 10 and 25 kg P ha^{-1} at Cheffa to the respective strips. A month before planting, $Ca(OH)_2$ was also incorporated into the soil of both fields at a rate of 3 ton ha^{-1} for increasing pH to acceptable lvels. On both sites a split plot design was used with the three phosphorus fertility levels (Bray 2 extractable P in mg kg^{-1} for Ilala: low = 6.60, medium = 11.20, high = 22.80 and Cheffa: low = 4.80, medium = 14.40 and high = 34.60) as the main plot treatments and factorial combination of the five phosphorus application rates (0, 10, 20, 40 and 80 kg P ha^{-1}) and two pea cultivars (Holetta and G22763-2C at Ilala while Tegegnech and Cheffa local at Cheffa) as the sub-plot treatments which were replicated four times. The pH and extractable P of both the Ilala and Cheffa soils were modified successfully as planned.

At Ilala the response of field pea crop to phosphorus fertilizer levels and application rates as manifested in the grain yield, plant height, above-ground biomass and pods per plant was very poor. However, the grain yield of Holetta incresased and that of G22763-2C decreased with increasing phosphorus application rates. Phosphorus fertilization was therefore not at all economically viable at this site as indicated by the low MRR.

Analysis of variance on data from Cheffa indicated a significant interaction between phosphorus fertility level and phosphorus application rate with regard to grain yield of field pea. Grain yield increased with increasing phosphorus application rate for the low and medium phosphorus fertility level, but decreased for the high phosphorus fertility level. The result of this is that at the low phosphorus fertility level a 13 kg P ha^{-1} application gave a MRR of 100% while at the medium phosphorus fertility level a 1 kg P ha^{-1} application gave a MRR of only 2%. Therefore, it was concluded that phosphorus fertilization was only economically viable at the low phosphorus fertility level.

In this second set of experiments as was the case in the first set of experiments no conclusive critical soil phosphorus levels could be estabilished with either the absolute or relative grain yields.

Some significant differences were recorded in the nutrient contents of the shoots at flowering and physiological maturity, and the seeds at physiological maturity. Unfortunately these differences in N, P, K, Ca and Mg were not consistent and, therefore, interpretation was difficult.

The lack of response of the field pea crop at Ilala and to a lesser extent at Cheffa to either increasing phosphorus fertility levels and/or phosphorus application rates may be ascribed to the fact that the soil at both sites were limed before planting. As a result of the liming and hence, the increase in pH, the soil phosphorus in immobile forms could be converted to mobile forms from which the plants will then benefit.

Based on the results that evolved from the glasshouse and field experiments that were conducted the following recommendations can be made:

- The critical soil phosphorus levels that were established in the glasshouse should be validated in the field. However, the fact that the field pea crop did respond to phosphorus application mainly at the low phosphorus fertility level confirms already to some extent their validity. The critical soil phosphorus levels can, therefore, be of immediate use on the Nitosols of Holetta and Bekoji zones.
- In general, the improved field pea cultivars responded better to phosphorus fertilization than the local cultivars. A thorough investigation on the phosphorus use efficiency of pea cultivars should be done. Knowing the pea cultivars that are efficient in phosphorus use could be very beneficial to the resource poor farmers who cannot afford fertilizer costs.
- The lack of field pea response to phosphorus fertilization in some instances may be attributed to a higher availability of phosphorus as a result of liming of the soils. This aspect warrants

further investigation since it is known that liming improves not only the availability of residual phosphorus but also the efficiency of fertilizer phosphorus applied.

- The field pea crop is a legume which should obtain most of its nitrogen through biological nitrogen fixation. However, by using DAP as phosphorus source nitrogen is unnecessarily applied and resulted in additional costs for the resource poor farmers. This matter should be addressed through thorough research.
- From the partial budget analysis it seems that the price of field pea grain is low in relation to the cost of phosphorus fertilization. In order to encourage phosphorus fertilization for improving field pea production, a subsidy on fertilizer for this crop could be considered.
- Soil is a natural resource and government should take some responsibility in improving the quality thereof, especially when used by resource poor farmers who can not afford lime or fertilizer. Soil pH and phosphorus levels could be for example increased to optimum levels through government intervention whereafter it is expected that the farmers maintain those levels.

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APPENDICES

Appendix 1. Profile description of the three experimental areas.

Pedon: I Holetta Agricultural Research Center

Classification

FAO/UNESCO(1989) : Haplic Nitosol

Soil Survey Staff (1999) Typic Rhodustalf

Other diagnostic properties

Location: 9°03' N latitude, 38°30' E longitude and 2390 m.a.s. l

Described by: Amare Ghizaw and Eylachew Zewdie

Physiography: Undulating to hilly

Parent material: Basalt

Vegetation: Eucalyptus

Evidence of erosion: Slight sheet erosion on stable slope

Land use: Arable farming with high level input

Drainage: Well drained

Moisture condition: Dry

Effective soil depth: 170 cm

Profile description

Ap 0-30 Dark reddish brown (5YR 3/3 moist and 5YR 3/4 dry), clay; strong crumby structure, friable when moist, slightly sticky when wet, many horizontally oriented micro to fine continuous tubular (>200 pores/dm^3) pores distributed both inped and exped, highly porous, many fine to very fine plant roots throughout the horizon

B_{t1}	30-70	Dark reddish brown (5YR 3/4 dry and 5YR 3/3 \ moist), clay; moderate sub-angular blocky structure, hard when dry and friable when moist, plastic when wet, common (50-200 pores/dm^3) horizontally oriented fine to medium continuous tubular pores distributed both inped and exped, highly porous, few fine roots throughout the horizon
B_{t2}	70-120	Dark reddish brown (5YR 3/4 wet), clay; smooth and diffused boundary, weak sub angular blocky structure, friable when moist, sticky when wet, fine horizontally oriented moderate continuous pores distributed both inped and exped, very few and very fine roots throughout, few faint (< 2 %) reddish black (10 R 2.5/1) mottles with clear boundary, moderate patchy clay cutant
B_{t3}	120-142	Dark reddish brown (5YR 3/4 moist), clay; weak very fine sub-angular blocky structure, friable when moist, sticky when wet, common randomly oriented very fine discontinuous tubular pores distributed both inped and exped, slightly porous; no roots, common medium size dark reddish brown (5YR 3/4 moist) mottles with distinct clear boundary, common moderate clay cutant, nitic property,

B_{t4}	142-170	Many coarse mottle with sharp boundary (20%), abundant clay cutant
BC	170+	All mottles Fe and Mn

Pedon II: Illala on farm

Classification

FAO/UNESCO (1989): Haplic Nitosol

Soil Survey Staff (1999) Typic Rhodustalf

Other diagnostic properties

Location→ About 5 km north of 9°03' N latitude, 38°30' E longitude and 2390 m.a.s. l

Described by: Amare Ghizaw & Eylachew Zewdie

Physiography: Undulating to hilly

Parent material: Basalt

Vegetation: Eucalyptus (secondary vegetation)

Evidence of erosion: Slight sheet erosion on stable slope

Land use: Arable farming with high level input

Drainage: Well drained

Moisture condition: Dry

Effective soil depth: 170 cm

Profile description

Ap	0-25	Very dusky red (10R 2.5/2 moist and dry), clay; weak crumby structure; diffused and smooth boundary; friable when moist and sticky when wet, few randomly oriented micro tabular

		pores distributed inped, moderately porous, many very fine to medium sized roots throughout the horizon,
AB-	25-40	Dark reddish brown (5YR 3/3 moist and dry), clay; moderate to strong and medium to coarse sub angular structure; hard when dry, sticky when wet, friable when moist, few horizontally oriented micro tubular pores distributed inped, moderately porous, few fine to very fine roots distributed throughout the horizon, no mottles, continuous clay cutant on horizontal ped faces
B_{t1}	45-92	Reddish brown (5YR3/4 when moist and wet), clay, strong medium to coarse sub-angular and angular blocky structure, firm when moist, sticky when wet; few horizontally oriented fine to micro-tubular pores and distributed inped, few very fine roots throughout the horizon, abundant thick clay cutan throughout
B_{t2}	92-125	Dark reddish brown (5YR3/3 moist), clay; diffused and smooth boundary; moderately fine to medium sub angular blocky structure; friable when moist and sticky when wet, common horizontally oriented fine to medium tubular pores distributed inped; moderately porous, few fine roots on the upper part of the horizon, few fine and faint mottles with diffused boundary, broken and distinct clay cutan on ped faces,

Bt3	125+	10R 3/4 when moist, clay, weak very fine to fine sub angular blocky structure developed from the breaking down of massive structure; friable when moist and sticky when wet, many fine to medium horizontally oriented tubular pores distributed both inped and exped, very few fine roots, many prominent black mottles (7.5 YR2/6) with sharp boundary composed of Fe and Mn; abundant thick clay cutan throughout the horizon.

Pedon III Cheffa on farm

Classification

FAO/ UNISCO (1989):	Haplic Nitosol
Soil Survey Staff (1999)	Typic Rhodustalf

Diagnostic horizon: Argilic horizon, abrupt textural change

Location: 7°32'N and latitude, 39° 15' E longitude and 2761 m.a.s.l.)

Described by: Amare Ghizaw & Eylachew Zewdie

Physiography: undulated to hilly

Parent material: Basalt

Vegetation: ,Eucalyptus (secondary vegetation)

Drainage: Well drained

Erosion: Slight sheet erosion on stable slope

Land utilization: arable farming with medium level input and intensive use of cereal (barley and wheat) legume rotation of rain fed farming system

Profile description

Ap	0-24Cm	Dark reddish brown (5YR2.5/2), silty clay, moderate fine to medium crumby structure, friable when moist, many randomly oriented fine continuous vascular pores distributed both inped and exped, high total porosity, common fine roots distributed throughout the horizon, absence of mottles, cutan inclusion, rocks and biological activity
A_{11}	24-69	Very dark brown (10YR2/2 dry and moist), clay clear and smooth boundary, columnar types of structure that breaks easily into sub angular blocky, soft and friable; sticky when moist and plastic when wet, few vertically oriented fine continuous vascular pores distributed exped, moderately porous, common fine roots throughout the horizon; mottles, cutan, inclusion and rocks are absence.
BA (E)	69-90	Dark brown (7.5YR3/4 moist),clay, diffused and smooth boundary; moderate to strong and medium to coarse size massive structure that breaks easily to columnar type, friable when moist and sticky and plastic when wet; very few randomly oriented micro, discontinuous vascular pores distributed both inped and exped; slightly porous, very few fine roots distributed throughout the horizon; few distinct and sharp

mottles; inclusion, cutant, rock and biological activity are absence.

B_{t1} 90-129 Dark reddish brown (5YR 3/4 moist and dry), strong coarse massive structure that breaks easily to sub angular blocky; hard when dry, friable when moist and sticky and plastic when wet; common randomly oriented discontinue vascular micro-pores; slightly pores; roots are not observed, many heterogeneous size mottles (7.5YR 2/0); broken common cutant; rock, inclusion and biological activity are absence.

B_{t2} Dark reddish (5YR3/3 moist and wet), clay; medium to coarse massive structure that breaks into sub angular blocks; very hard when dry, firm when moist and very sticky and very plastic when wet; many micro-pores vascular forms, randomly oriented, discontinue distributed both inped and exped, slightly porous and abundant thick clay cutant and no mottles

Appendix 2. Soil physical characteristics of the three soil profiles.

		Texture (%)				BD	FC	PWP
Horizon	Depth	Sand	Silt	Clay	Class	g/cm3	%	%
		Holetta Agricultural Research Center						
Ap	0-30	18	34	48	C	1.208^{ds}	32.25	20.92
B_{t1}	30-70	4	18	78	C	1.248^{ds}	38.17	25.87
B_{t2}	70-120	4	18	78	C	1.054^{ds}	35.25	24.84
B_{t3}	120-142	6	18	76	C	1.336^{ds}	35.61	25.53
B_{t4}	142-170	6	16	78	C	1.231^{ds}	34.52	25.15
		Illala						
Ap	0-25	18	38	44	C	1.258^{ds}	33.46	20.30
AB	25-45	14	26	60	C	1.096^{ds}	34.17	22.74
B_{t1}	45-92	6	20	74	C	1.261^{ds}	37.53	25.88
B_{t2}	92-125	8	18	74	C	1.217^{ds}	40.07	25.08
B_{t3}	125+	4	18	78	C	1.084^{ds}	30.90	25.67
		Cheffa						
Ap	0-24	24	44	36	Si/CL	0.96	36.67	19.32
A_{11}	24-69	26	32	42	C	1.14	32.84	21.1
BA	69-90	20	24	56	C	1.44	29.52	21.56
B_{t1}	90-129	14	14	72	C	1.49	35.98	25.55
B_{t2}	129+	12	12	76	C	1.57	35.05	25.95

ds=Determined from disturbed soil

Appendix 3 Soil chemical properties of the three soil profiles.

Horizon	Depth	pH		EC	OC	N_t	P. Avail.; ppm			Exchangeable (cmole kg $^{-1}$)					Fe	Mn	Zn	Cu
		H_2O 1:2.5	KCL	(ds/m)	(%)	(%)	Olsen	Bray II	C/N	Na^+	K^+	Ca^{2+}	Mg^{2+}	Sum		ppm		
Holetta Agricultural Research Center																		
Ap	0-30	5.6	4.6	0.046	1.615	0.14	12.6	11.8	12	0.13	1.65	7.04	3.46	12.28	9.7	18.14	0.62	1.00
B_{t1}	30-70	5.8	4.4	0.023	0.957	0.13	4.2	1.4	7	0.13	1.09	7.19	4.12	12.53	4.52	4.82	0.08	0.64
B_{t2}	70-120	6.1	4.7	0.014	0.917	0.09	2.2	0.9	10	0.2	0.43	6.99	4.94	12.55	2.80	4.18	Trace	0.40
B_{t3}	120-142	6.2	4.8	0.012	1.216	0.09	2.6	0.9	14	0.89	0.38	6.69	5.84	13.8	1.98	4.22	0.04	0.26
B_{t4}	142-170	6.2	4.9	0.012	0.917	0.14	4.8	1	7	0.24	0.25	7.14	5.76	13.39	2.06	4.88	0.10	0.22
Illala																		
Ap	0-25	5.3	4.1	0.038	1.715	0.16	20	21.3	11	0.08	0.97	7.44	2.17	10.65	16.22	14.90	0.76	1.14
AB	25-45	5.4	4.3	0.041	1.017	0.12	21.6	11.3	6	0.29	0.65	9.83	2.39	13.15	9.34	14.02	0.60	1.50
B_{t1}	45-92	6.1	4.6	0.016	0.817	0.1	11.6	6.6	8	0.23	1	11.23	3.89	16.35	5.36	19.08	0.52	1.03
B_{t2}	92-125	6.4	4.7	0.019	0.817	0.09	8	3.4	9	0.2	0.13	8.68	4.21	13.22	2.84	14.02	0.22	0.72
B_{t3}	125+	6.4	4.8	0.017	0.778	0.07	4.8	2.2	11	0.26	1.5	7.19	4.36	13.3	2.06	11.14	0.36	0.44
Cheffa																		
Ap	0-24	6.0	4.3	0.053	1.835	0.27	5	6.4	7	0.35	1.13	11.58	1.32	14.4	28.38	16.22	1.80	0.68
A_{11}	24-69	5.1	4.4	0.028	1.615	0.19	3.8	1.4	9	0.67	0.41	8.93	2.96	13	9.04	3.82	0.22	0.82
BA	69-90	5.4	4.3	0.013	0.877	0.07	2.6	1.6	13	0.14	0.56	9.78	3.37	13.9	6.76	7.42	0.12	0.74
B_{t1}	90-129	5.8	4.5	0.02	0.718	0.08	3	0.6	9	0.21	0.52	13.22	4.61	18.6	9.10	9.10	0.02	0.30
B_{t2}	129+	5.8	4.4	0.02	0.758	0.07	0.6	0.4	11	0.05	0.61	6.69	6.09	7	6.94	6.94	0.22	0.22