INCREASING THE USE EFFICIENCY OF APPLIED PHOSPHATE FERTILIZER BY CROPS ON NIGERIAN ACID SOILS

BY

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DECLARATION

I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of information have been specifically acknowledged by means of references.

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CERTIFICATION

This dissertation entitled "**Increasing the Use Efficiency of Applied Phosphate Fertilizer by Crops on Nigerian Acid Soils**" by J.M. Jibrin meets the regulations governing the award of degree of Doctor of Philosophy (Soil Science) of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

To

My late Father, Alhaji M.B. Jibrin

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ABSTRACT

Phosphorus deficiency is a major constraint that limits food production in Nigeria, especially under acidic soil conditions. Presently, successful production of high nutrient requiring crops such as maize is only possible with the use of inorganic phosphate fertilizers which are very costly and often unavailable to the farmer. In an attempt to address this problem, field trials were conducted on two fields located at Samaru ($11^0$11'N,$7^0$38'E) and one field at Heipang (9°38'N, 8°53'E) to evaluate the response of various cover crops and maize to native and applied phosphate, and to evaluate the effects of these treatments on the performance and P nutrition of succeeding maize in rotation. The two locations selected for the trials had widely contrasting soil phosphate properties. Samaru soil, classified as Kanhaplic Haplustalf following the USDA soil taxonomy system, had low P sorption capacity with pH values of 5.5, available soil P concentration of between 6.04 to 9.86 and total P content of between 154 to 196 mg Kg^{-1}. Heipang soil on the other hand, was classified as Typic plinthustult and had very high P fixing capacity with pH value of 5.4, available soil P concentration of 0.69, and total P content of 473 mg Kg^{-1}.

Results of the study at Samaru showed that among the cover crops evaluated, *Crotalaria ochroleuca* was the most P efficient in terms of total amount of above ground biomass per unit P taken up, while *Phaseolus vulgaris* (brown) and *Clitoria ternatea* were the least efficient.

The yield of maize preceded by *Lablab purpureus* (white), *Lablab*

purpureus (black), *Chamaechsta rotundifolia, and Mucuna pruriens* was increased by over 50% at Samaru in the first year after cover cropping. The positive effects of these cover crops on yield of succeeding maize did not manifest in the second. On Heipang soil, with high P sorption capacity, only *Chamaecrista rotundifolia* produced some significant improvement in the performance of succeeding maize in terms of height and stover yield. However, *Chamaecrista rotundifolia, Zeamay* intercropped with *Chamaecrista rotundifolia, Mucuna pruriens* (white), and *Lablab purpureus* (white) reduced the leaf Al concentration of succeeding maize by more than 38% at Heipang.

Effects of Sokoto phosphate rock on maize yields and available soil P at Samaru started manifesting only in the third year of cropping when the soil P was sufficiently depleted (< 5.0 mg Kg^{-1}) to force the dissolution of phosphate rock. At Heipang, on the other hand, where the available soil P was extremely low (< 1 mg Kg^{-1}), the effect of Sokoto phosphate rock on maize yield manifested in both years of cropping.

Optimum yield of maize at Samaru was obtained with the application of 30 Kg P ha^{-1} in form of single superphosphate., while at Heipang even the application of 60 Kg P ha^{-1} did not produce optimum yield.

Application of 1.35 t CaO ha^{-1} to Heipang soil in 1997 significantly raised the soil pH value by about 0.2 and improved the total P uptake of maize grains but did not improve available soil P and grain yield.

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CHAPTER ONE

INTRODUCTION

Widespread phosphorus deficiency has been observed and reported in soils of the Nigerian savanna ecological zone (Enwezor and Moore, 1966; Jones and Wild, 1975; Uzu *et al.*, 1975; Udo and Ogunwale, 1977). Next to nitrogen, phosphorus is the most limiting nutrient for food production in this zone. Limitations to crop production due to phosphorus deficiency could attain such severe levels that plant growth ceases as soon as the phosphorus stored in the seed is exhausted (Jones and Wild, 1975; Mokwunye et al.,1986). The problem of bioavailability of soil phosphorus is particularly more pronounced where the soil is acidic due to the preponderance of iron, aluminum and manganese ions which reduce phosphorus availability through fixation as insoluble phosphate complexes of these metals (Uzu *et al.*, 1975; Udo and Ogunwale, 1977; Mokwunye *et al.*, 1986).

Generally, nutrient deficiencies and soil acidity may be corrected by fertilizer application and liming respectively. However, due to high cost of fertilizers and the low level of resources available to most Nigerian farmers, the key to sustainable food production in this part of the world lies in

the development of a cropping system that requires low external input. Critical agronomic aspects of such a strategy for managing the phosphate fertility of acidic soils include the choice of P efficient and Al and Mn tolerant plant species, and the proper management of soil organic matter through green manuring, cover cropping and return of crop residues.

Tremendous positive effects of green manuring and cover cropping on yields of subsequent crops have been widely acknowledged (Wilson *et al.*, 1982; Agboola, 1982; Hairiah and Noordwijk, 1989; Oikeh *et al.*, 1998). These positive effects are attributed to a range of factors such as improving soil physical properties and control of erosion (MacRae and Mehuys, 1985), increasing soil organic matter content (Lal *et al.*, 1979), and control of weeds (Dyke *et al.*, 1976). With regard to nutrient supply to subsequent food crops much emphasis has been on the quantification of the N contribution of leguminous green manure and cover crops. The positive effects of cover crops on P nutrition is less studied.

Although green manures and cover crops do not add phosphate into the soil/plant system, they may improve the use efficiency of soil and fertilizer P by subsequent food crops

in rotation by mobilizing "non-available" P. The strategy is to increase P recovery from less accessible forms using crop and forage species and cultivars that more efficiently take up P, and to integrate these species and cultivars into crop production systems for more effective recycling of native and applied P. Copious literature exist on evidence of considerable variations among plant species and even among varieties of the same species in their efficiency of P acquisition from soils. Phosphorus acquisition efficiency is found to be influenced by root/shoot ratio (Gerloff and Gabelman, 1983; Föhse *et al.*, 1988), size and distribution of root system (Nielsen, 1979; O'Toole and Bland, 1987), root hairs (Föhse *et al.*, 1991; Gahoonia and Nielsen, 1996) and kinetic uptake parameters (Nielsen and Barber, 1978; Föhse *et al.*, 1988). Other factors that influence P acquisition include root induced pH changes in the rhizosphere (Gahoonia *et al.*, 1992), excretion of chelating compounds (Marschner, 1995), phosphatase activity at the root surface (Asmar *et al.*, 1995), and symbiosis with root colonizing mycorrhizal fungi (Crush, 1974).

In Nigeria, presently, alot of data exist on management of soil and applied N, but limited information is available on the use of green manures, cover crops and crop residues in the

management of soil and applied P. The broad objective of this study was to develop cultural practices, with emphasis on use green manures and cover crops, which increase the use efficiency of native and applied P and reduce the impact of soil acidity. While the specific objectives were:

1. Characterization of different cover crops with regard to P use efficiency.
2. To study the effect of different cover crops on subsequent crop (maize) growth and yields, P uptake, and P dynamics in the soil.
3. To study the interaction of cover crops with P fertilizers on subsequent crop yields and P uptake
4. To study the effects of crop and crop rotations including cover crops on P dynamics in the soil.
5. To study the interaction of cover crops with lime and P fertilizer applications on subsequent crop growth and yield, P uptake, and soil P dynamics.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Soil acidity

Soil acidity is manifested by an excess of protons in the soil solution accompanied by increases in levels of Al and Mn, and decreases in levels of Ca, Mg and K (Gillman, 1991). In most acid tropical soils having pH values below 5.5, the chemistry of soil Al plays the most dorminant role in soil acidity and it's effects on crop growth (Juo, 1972). In addition to being toxic to the crop, Al also binds phosphorus on root surfaces, cell walls and in free space of plant roots, thus preventing phosphate from being available for root metabolism. The most notable effects of soil acidity are drastic reductions of crop yields, poor stands of crops, poor root growth, and reduced uptake of nutrient elements especially Ca, Mg, K, and P (Uexkull, 1986).

The major types of acid soils occurring in the tropics that present problems to food crop production are the oxisols, ultisols,acid vulcanic ash soils, and acid sulphate soils (Juo, 1972). About 1.5 billion hectares of land in the

tropics, representing around one-third of the total land area, have sufficiently strong soil acidity for soluble Al to be toxic to most crop species (Sanchez and Logan, 1992). According to Nicholaides *et al.* (1983) as reported by Oguntoyinbo *et al.* (1996), acid soils cover about 17 million hectares of land in Nigeria representing about 18% of the total land area.

Sources of acidity in oxisols, ultisols and acid vulcanic ash soils arise primarily from the hydrolysis of aluminium ions and the production of hydrogen ions in the soil solution (Juo, 1972; Kamprath, 1972). This may be generalized in the following equation:

$$Al(H_2O)_6^{3+} + 3H_2O \longleftrightarrow Al(OH)_3(H_2O)_3 + 3H_3O^+$$

The activity of Al in the soil solution is controlled by the amount and degree of saturation of exhangeable Al in the soil, cation exchange characteristics, as well as surface chemistry of Fe and Al oxides and hydrous oxides, allophanes, kaolinitic clays, and other alumino-silicates (Juo, 1972; Kamprath, 1972; Wild, 1988). Acidity on acid sulphate soils, on the other hand, arises mainly from the chemical and microbiological oxidation of sulphides (Juo, 1972). This is illustrated in the following equation:

$4FeS_2 + 15O_2 + 2H_2O$ <----------> $2Fe_2(SO_4)_3 + 2H_2SO_4$

The pH values of acid sulphate soils are normally much lower and the acidity of the soil solution much stronger compared with other acid soils (Juo, 1972; Wild, 1988).

The factors that lead to the development of soil acidity include the nature of parent material; depletion of basic cations such as Ca, Mg, K, and Na through leaching and crop removal; decomposition of crop residues; application of fertilizers, particularly ammoniacal nitrogen sources; and atmospheric acidity (acid rain) (Jenny, 1961; Juo, 1972; Sanchez, 1976; Wild, 1988).

Application of liming materials is the management practice used in rehabilitating acid soils. The overall effects of liming acid soils include increased soil pH, higher Ca and Mg saturation, neutralization of toxic concentrations of Al and Mn, increase in pH dependent CEC resulting in absorption and hydrolysis of Ca^{2+} and Mg^{2+}, increase in P availability, and improved nutrients elements uptake by plants (Sanchez, 1976; Wild, 1988; Oguntoyinbo *et al.*, 1996). The materials commonly used for liming are oxides, hydroxides, carbonates, and silicates of calcium and magnesium. For a

material to qualify for use as lime, the anion must be capable of depressing the activities of H^+ and Al^{3+} ions in the soil solution. In Nigeria liming has not been widely accepted as a management practice, the major constraint to it's use being the exorbitant cost of liming materials which are mostly imported into the country (Oguntoyinbo *et al.*, 1996).

2.2 Phosphorus status of Nigerian savanna soils

Compared to other essential major elements for plant growth, the phosphorus content of the earth crust (500-1200 mg Kg^{-1}) is low (Wild, 1988). Similarly, the total P content of mineral top soil (50 - 1100mg Kg^{-1}) is relatively low (Tisdale et al.,1985; Brady, 1990). In soils of the Nigerian savanna, widespread phosphorus deficiency has been reported (Enwezor and Moore, 1966; Jones and Wild, 1975; Uzu *et al.*, 1975; Udo and Ogunwale, 1977). According to Jones and Wild (1975) and Mokwunye *et al.* (1986), P deficiency could be so severe in some soils that plant growth virtually ceases as soon as the seed reserves of phosphate has been used up. The total P content of the soil seem to be influenced by parent rock and vegetation. Uzu *et al.* (1975) reported higher total P for soils on basement complex than soils on sedimentary materials.

The highest P containing soils are formed on basic rock relatively high in P (Udo and Ogunwale, 1977), such soils could be found around Heipang (Hill and Rackham, 1973). Goldsworthy and Heathcote (1963) and Enwezor and Moore (1966) reported the total phosphorus content of surface savanna soils to vary from 80 to 150 mg Kg^{-1}. Jones and Wild (1975) reported total P in 334 top soil samples from the savanna to range between 13 to 630 mg Kg^{-1} with a mean of 143 mg Kg^{-1}. In a more recent study, Manu *et al.* (1991) put the amount of total P in the west African savanna to range from 25 to 349 mg Kg^{-1} with a mean of 109 mg Kg^{-1}. The available (Bray 1) P was also generally low ranging from 1 to 30 mg Kg with an average of 6 mg Kg^{-1}. About 77% of the soils in the region had available P values of less than 8 mg Kg^{-1} (Manu *et al.*, 1991)

Due to the nature of the parent materials of Nigerian savanna soils, and the colloidal system present (Kaolinitic), P sorption capacities are often low and the quantities of P fertilizers required to obtain maximum crop yields are also often low (Mokwunye, 1977; Fox and Kang, 1978; and Bationo *et al.*, 1986). However, in a few areas associated with lateritic caps, such as the Jos-Heipang area, (Hill and Rakham, 1973), P fixing power of the soil is high despite the high total P

content and applied P readily gets immobilized (Udo and Uzu, 1972; Juo and Fox 1977; Mokwunye *et al.*, 1986).

Organic phosphorus constitutes less than half the total P in Nigerian savanna soils. Goldsworthy and Heathcote (1963) reported 36% of the total P in 54 savanna soils to be in organic form. Enwezor and Moore (1966) recorded 25% for 4 soils, while Ipinmidun (1972) found 39% for 12 selected savanna soils. This low values of organic P are expected in view of the low levels of organic matter in this region.

The magnitude of occurrence of various inorganic P fractions in Nigerian soils follow the order: Occluded-P > Iron-P > Aluminum-P > Calcium-P (Bates and Baker, 1960; Enwezor and Moore, 1966). The chemical stage of weathering determines the inorganic P form present in a soil. The proportion of Fe-P increases with weathering while that of Ca-P decreases. The activities of Fe and Al increases with soil acidity and the relatively soluble Ca-P is converted to less soluble Fe and Al phosphates (Kamprath, 1973; Lindsay and Vlek, 1977). Most of the inorganic P in Nigerian soils are found to be associated with Fe and Al minerals. Adepetu and Corey (1975) reported that most of the mineralized P as well

as any added P (fertilizer) was converted to Fe-P and Al-P. Also Udo and Uzu (1972) found over 80% of P added to the soil could be recovered as Fe-P and Al-P.

2.3 Reactions of phosphate fertilizers with soils

There is generally poor (<25%) efficiency of recovery of an annual application of P in the growing crop (Barrow, 1980; Haynes, 1984). After the dissolution of P fertilizers in the soil water, a number of reactions occur among the phosphate, soil constituents, and the non-phosphatic fertilizer compounds which remove P from the soil solution phase and render the phosphate less soluble (Sample *et al.*, 1980; Brady, 1990). As a result, P nutrition of field crops is largely dependent on the subsequent release of P from these reaction products to the soil water (Morgan, 1997).

Phosphorus in soil could be immobilized by oxides and hydrous oxides of Fe, Al and Mn, and by alumono-silicates, soil carbonates, and soil organic matter. Irrespective of soil pH, all mineral soils contain aluminium and iron oxides and hydrous oxides, which occur as discrete coatings on other soil particles, especially clay (Morgan, 1997). In addition,

amorphous aluminium hydroxy compounds, which may be present in interlayer locations of expandable aluminium silicates, have high P absorbing efficiency. The general consensus is that immobilization occurs as a result of exchange between the $H_2PO_4^-$ and OH^- ions associated with the aluminium and/or iron (Sample *et al.*, 1980; Brady, 1990; Morgan, 1997).

Concurrent with these adsorption reactions, precipitation of poorly soluble hydroxy metal phosphates (eg. $Al(OH)_2(H_2PO_4)$) may occur under acid (pH < 5.0) conditions as a result of the presence of active aluminium, iron and manganese (Sample et al., 1980; Brady, 1990; Morgan, 1997).

Under alkaline conditions in the presence of free calcium carbonate, adsorption of $H_2PO_4^-/HPO_4^{2-}$ on to the calcite may occur by replacement of water, HCO_3^-, or OH^- ions present on the calcite particles. Concurrently, the presence of active calcium causes precipitation of dicalcium phosphate anhydrous (Brady, 1990).

There is evidence that soil organic matter can fix added phosphorus in soils by forming complexes in association with cations such as Fe^{3+}, Al^{3+} and Ca^{2+} (Wild, 1950; Wier and Soper,

1963; Hinga, 1973; Holford and Mattingly, 1975). However, most of the reactions of added phosphates with organic matter in the soil result in higher P concentration in the soil solution. Additions of inorganic phosphate along with organic matter, particularly to calcareous soils, reportedly increase phosphate solubility with time more than single additions of inorganic phosphate (O'Connor *et al.*, 1986; Meek *et al.*, 1979; Abbot and Tucker, 1973). Some breakdown products of organic matter have been found to reduce P retention in soils. Andrew (1985) found P sorption to be strongly inhibited by organic acids.

2.4 Role of phosphorus in plants

Unlike other anions such as nitrates and sulphates, phosphate is not reduced in plants after uptake but remains in it's highest oxidized form. It exists either as inorganic phosphate or esterified through a hydroxyl to a carbon chain as simple phosphate ester or attached to another phosphate by the energy-rich pyrophosphate bond as in adenosine triphosphate (ATP). Phosphorus is a major constituent of nucleic acids, phospholipids, and enzymes required for the synthesis of proteins, carbohydrates and lipids. It serves as

a structural element in nucleic acids by acting as a bridge between ribonucleoside units to form macromolecules. In biomembranes phosphorus diesters form bridges between diglycerides and other molecules, usually amino acids, amines, or alcohols.

Energy-rich phosphates and phosphate esters represent the metabolic machinery of the cells. In many enzyme reactions, phosphorus is either a substrate or an end product, controlling some key enzyme reactions. In fruit tissue, the release of phosphate from the vacuoles into the cytoplasm initiates the respiratory burst correlated with fruit ripening (Woodrow and Rowan, 1979,.

The most striking effects of phosphorus deficiency are reductions in leaf expansion and leaf surface area (Fredeen *et al.*, 1989), and number of leaves (Lynch *et al.*, 1991). Leaf expansion in phosphorus deficient plants is impaired due to impaired extension of epidermel cells resulting from low phosphorus content of the cells (Treeby *et al.*, 1987) and decreased hydraulic condutivity (Radin, 1990). Unlike the severe inhibition in leaf expansion, protein (Rao and Terry, 1989) and chlorophyll (Marschner, 1995) contents per unit leaf

area are not much affected. The content of clorophyll is even increased under phosphorus deficiency (Rao and Terry, 1989), and leaves take a darker green color as cell and leaf expansion are more retarded than cloroplast and chlorophyll formation (Hecht-Buchholz, 1967).

Unlike shoot growth, root growth is less inhibited under phosphorus deficiency leading to a decrease in shoot-root ratio. Phosphorus deficiency might even enhance the elongation rate of individual root cells and of the root (Anuradha and Marayanan, 1991).

Apart from retarded growtn, phosphorus deficiency results in delayed flower initiation (Rositer, 1978), decreased number of flowers (Bould and Parfitt, 1973), restricted seed formation (Barry and Miller, 1989) and premature senescence of leaves (Marschner, 1995).

2.5 Role of green manuring and cover cropping on sustainable soil productivity

Green manuring is a farming practice that has been known to the ancient Chinese and Romans (Atallah and Lopez-Real,

1991). It is defined as the use of green plant material, grown *in situ* or cut and brought in for incorporation to improve soil productivity (Meelu *et al.*, 1994). Tremendous positive effects of green manuring on yields of subsequent crops have been widely reported (Wilson *et al.*, 1982; Hairiah and Noordwijk, 1989). Positive effects associated with green manuring include suppression of weeds, protection against pathogens, increase in soil organic carbon, improving soil physical properties and contributions to N fertility.

2.5.1 Effects of green manures and cover crops on soil physical properties

By improving the organic matter content of the soil, green manuring improves a number of soil physical properties such as aggregation, bulk density, water retention and transmission and soil erodibility, thereby encouraging greater penetration and proliferation of crop roots.

2.5.1.1 Aggregation

Green manuring has been reported to appreciably increase the contents and size of water stable aggregates (Hermanwan

and Bomke, 1987; Meelu *et al.*, 1994). This benefit is thought to be obtained from the cementing action on soil particles of microbial cells and polysaccharide released during decomposition of organic matter (Meelu *et al.*, 1994).

Over 30% increase in > 0.5 mm soil aggregates with green manuring was reported by Ram and Zwerman (1960). The effects of green manures on soil aggregates vary with the soil texture and plant species used. Rennie *et al.*, (1954) observed that more-readily decomposable legumes produced more stable aggregates in the short term, while non-leguminous plant materials produced longer lasting effects. MacRae and Mehyus (1985) reported that the effect of green manuring on soil aggregate stability are short-lived unless continuous additions are made. Yaacob and Blair (1981) observed that in a granite soil, proportions of water-stable aggregates > 2 mm were 39.4% after incorporation of residues from one soybean crop, and 77.1% after six crops had been grown. A number of authors (Browning and Milam, 1944; Chester *et al.*, 1957; Wisniewski *et al.*, 1958; Ram and Zwerman 1960) have reported silt-loam soils to be the most likely to show increases in aggregate stability from green manuring, with sandy and clayey soils showing variable response.

2.5.1.2 Bulk density

Organic matter, of whatever origin, has been reported by many authors (Ram and Zwerman, 1960; Darra *et al.*, 1968; Gu and Wen, 1982; Jiao *et al.*, 1986; and Liu, 1988) to produce positive effects on soil physical condition by lowering bulk density and consequently increasing porosity. However, Hageman and Shrader (1979) found no significant differences in bulk density after 20 to 28 years cropping using leguminous green manures. Mortensen and Young (1960) also found no relationship between bulk density effects and improved aggregate stability produced by green manure treatments. This contrasts with the reports of Ram and Zwerman (1960), Jiao *et al.*(1986) and Liu (1988) who found bulk density to appear to be related to improved aggregation due to green manuring.

2.5.1.3 Water retention and transmission

Kang *et al.* (1985) observed that repeated application of leucaena prunings increased the moisture retention capacity of sandy-loam soil. Joshi *et al.* (1990) found 4% increase in water retained in the top 30 cm soil of a rice field treated with sesbania green manure.

Green manuring has also been shown to improve soil water-transmission properties such as hydraulic conductivity (Benoit *et al.*, 1962; Chaudhary and Bajwa, 1979), infiltration rate (Yaacob and Blair, 1981; Wilson *et al.*, 1982; Touchtom *et al.*, 1984), drainage capacity (Liu 1988) and porosity (Darra *et al.*, 1968; Liu, 1988).

2.5.1.4 Soil erodibility

In addition to the positive influence of green manuring on soil stability (and therefore erodibility), green manure cover reduces the impact of rain drops, protects the soil surface and reduces the velocity of moving rain water over the surface (Kang and Wilson, 1987; Meelu *et al.*, 1994).

Hale *et al.*, (1984) observed that with no-tillage plus a crown-vetch cover crop, average annual runoff reduced to 0.21 cm compared with 5.71 cm for conventional tillage and soil losses were 0.02 and 14.22 t/ha respectively. Frye *et al.*, (1985) reported that the use of green manure cover crops with no-tillage would allow maize to be grown on soils with slopes up to 20%, while keeping erosion below the tolerance limit. Considerable reductions in run-off and soil erosion have been

reported with the inclusion of Leucaena in the cropping system (Metzner, 1982; Kabeerathumma *et al.*, 1985; O'Sullivan, 1985; and Kang and Wilson, 1987).

2.5.2 Effect of green manures and cover crops on soil chemical properties

2.5.2.1 Soil pH

Green manuring may decrease soil pH by producing organic acids and CO_2 during decomposition (Motomura, 1962). It may also result in soil pH rise through mineralization of organic anions to CO_2 and water (Meelu *et al.*, 1994). According to Ponnamperuma (1965), organic reducing substances formed during decomposition may reduce Fe/Mn oxides thereby causing soil pH to rise. Kute and Mann (1968) observed decline in soil pH only when green manure was applied with P. Swarup (1987) observed a soil pH decrease of 0.2 units after a rise crop had been green manured with Sesbania. Morachen *et al.*, (1972) and Maurya and Ghosh (1972) observed decreases in soil pH with green manuring.

According to Meelu *et al.* (1994) changes in soil pH due to green manuring are complex and dependent on soil type and

condition. In an experiment on an oxisol, Hunter *et al.*, (1995) reported pH increases of up to 0.5 units with the incorporation of 7.5 t/ha cowpea leaf as green manure. They speculated that ligand exchange reactions between manure derived organic anions and terminal OH^- of the sesquioxide-rich solid phase may be involved in such pH increase. Asghar and Kanehiro (1980), Hue and Amien (1989) and Hue (1992) have also reported such pH increases for highly weathered soils.

2.5.2.2 Nutrient transformations

According to Agboola (1974) carbon dioxide and organic acids released during decomposition of green manures may act on insoluble soil minerals thereby releasing nutrients into the soil solution. Due to their higher root-respiratory characteristics, leguminous green manure plants are thought to possess strong abilities to absorb difficultly available K and P from soil (Meelu *et al.*, 1994). Several authors (Debnath and Hajra, 1972; Katyal, 1977; Nagarajah *et al.*, 1989; Tiwari *et al*, 1980; Swarup, 1987) have reported increased availability of K in soils as a result of green manuring.

Kang *et al*, (1985) and Atta-Krah (1990) observed

significant increase in organic carbon and exchangeable K, Ca, and Mg in long term studies of incorporating leucaena prunings on soil chemical properties. Higher levels of P, K, Ca and Mg in the soil were observed by Groffman *et al.* (1987) after ploughing-in of crimson clover. Significant increases in water-soluble Ca and Mg were also observed by Khind *et al.* (1987) with application of green manures to flooded soils.

Using ^{35}S-labelled green manure, Dhillon and Dhillon (1991) observed that cluster-bean and cowpea plants containing 2.7 and 3.3 mg g^{-1} total S supplied 20.0 and 18.4 percent S, respectively to *Brassica campestris* var. tori. According to Biederbeck (1978) as reported by Meelu *et al.* (1994), organic manures with S content of more than 1.5 mg g^{-1} will undergo S release during decomposition.

Copious literature exist on the contributions of leguminous green manures to N transformations and N fertility of the soil, this will not be reviewed here. The effects of green manures and cover crops on soil P dynamics is discussed in section 2.6.

2.5.3 Effect of green manures and cover crops on soil biological properties

Gopalaswamy and Vidhyasekara (1987) found nearly a six-fold increase in microbial activity in soils amended with *gliricidia*. Bolton *et al.* (1985) found soil under long term legume cultivation to have higher urease, phosphatase and dehydrogenase activities than soil that was treated with inorganic fertilizers. Thomas and Shantaram (1984) also observed similar results in the rhizosphere of coconut amended with green manure. These higher soil enzyme activities give an indication of the higher microbial activity in the green manure amended soil.

Considerable increase in the population of *Azotobacter* and other bacteria, and microbial biomass in soils amended with green manure was recorded by Ramaswami and Raj (1973) and Thomas and Shantaram (1984).

According to Meelu *et al.* (1994) by providing energy and nutrients, green manure promote the growth and activity of desirable micro-organisms that play key roles in transforming and liberating plant nutrients in the soil and also discourage

some undesirable ones.

The use of certain green manures is known to increase the soil populations of vesicular arbuscular mycorrhizal fungi (discussed in section 2.6.). Germani *et al.*,(1983) reported a marked decrease in nematode population in rice soil in the presence of green manure. Reddy *et al.*, (1986) found that the use of selected leguminous green manures in a multi-cropping system reduced soil populations of root-knot nematodes. Ko and Schmitt (1996) observed a marked decline in populations of *Rotylenchulus reniformis* following the use of cover crops during pineapple inter-cycle planting periods. McSorley and Dickson (1995) recorded suppression of population densities of the parasitic nematode *Melodogyne incognita* with the use of *Mucuna deeringina*, *Vigna unguiculata*, *Aeschynomene americana* and *Gossypium hirsutum* rotations.

However, the use of some green manures may encourage population build-up of some pathogenic organisms. Ko and Schmitt (1996) observed a 9 to 15 fold increase in population densities of *Helicotylenchus dihystera* after introducing oat as cover crop.

2.6 Mobilization of soil and fertilizer P by plants

Considerable variations exist among plant species and even among varieties of the same species in their efficiency of P acquisition from soils. Among the range of strategies developed by plants to survive on soils with low P status are extensive rooting, symbiosis with root colonizing fungi, H^+ and OH^- extrusion, exudation of organic acids and increased phosphatase activity.

2.6.1 Modification of rhizosphere pH

Rhizosphere soil pH may differ from the bulk soil pH by up to two units depending on plant and soil factors (Marschner, 1995). The most important factor for root-induced changes in rhizosphere pH is imbalance in cation/anion ratio. Plant roots extrude protons when cation uptake exceeds anion uptake. The ratio of cation uptake to anion uptake and thus rhizosphere pH mainly depends on whether nitrogen is taken up as ammonium, nitrate, or symbiotically fixed nitrogen. The rhizosphere is acidified when ammonium or symbiotically fixed nitrogen is the main nitrogen source and alkalinized when nitrate is the main nitrogen source (Marschner, 1995).

In neutral or alkaline soils rhizosphere acidification in plants fed with ammonium can enhance mobilization of sparingly soluble calcium phosphates and therefore favor the uptake of phosphorus (Gahoonia *et al.*, 1992). Rhizosphere acidification is particularly important in the uptake of P from rock phosphate. Bekele *et al.* (1983) demonstrated that soil pH was lower and phosphate uptake from rock phosphate two to four times greater when Rhodes grass (*Chloris gayana*) and ryegrass (*Lolium perenne*) were grown with ammonium instead of nitrate as nitrogen source. Symbiotic nitrogen fixation by soybean, alfalfa (Aguilar and van Diest, 1991), and field bean (Bekele *et al.*, 1983) was found to lower rhizosphere pH and induce increased phosphate uptake from phosphate rock. Rape and sunflower grown on P deficient soils responded by acidifying the rhizosphere thereby mobilizing calcium bunded P (Hoffland, 1991).

2.6.2 Exudation of organic acids

The release of di- and tricarboxylic acids was shown to increase the solubility of phosphates in soils (Earl *et al.*, 1979; Marschner *et al.*, 1989). According to Gerke (1992) the

application of citric acid could raise soil solution P concentrations by a factor of 10-1000 depending on the P fractions present. The effect is assumed to be caused by the complexing ability of the carboxylate anion and not by changes in pH (Earl *et al.*, 1979). However, Gerke and Meyer (1995) observed similar concentrations of P - mobilizing citrate in the rhizosphere of red clover and black mustard, but red clover took up nearly twice more P. They found out that whereas red clover decreased rhizosphere pH from 5.8 to 4.0 (in 0.01m $CaCl_2$), black mustard did not acidify the rhizosphere. They concluded that simultaneous acidification and excretion of citrate compared to citrate excretion alone had consequences for P mobilization processes in the rhizosphere.

Organic acids excreted by roots of plants are predominantly citric and malic acids (Scheffer *et al.*, 1962; Dinkelaker *et al*, 1989), however in forest soils oxalic acid appears to be more prominent (Smith, 1969; Fox and Comerford, 1990). Plant species which form clusters of roots (proteoid roots) accumulate citric and malic acid in the rhizosphere (Dinkelaker *et al.*, 1989; Grierson, 1992; Gerke *et al.*, 1994). Hoffland (1991) found that rape excreted citric and malic

acid as a result of P starvation. Phosphorus deficient *cajanus cajan* has been reported by Ae *et al.* (1990) to release pisidic acid into the rhizosphere thus solubilizing especially P bound to Fe oxides.

Kamh *et al.* (1998a) observed varying concentrations of citrate and fumarate in the rhizosphere of *Zea mays, mucuna pruriens, lablab purpureus, Phaseolus vulgaris, Glycine max, Cajanus cajan, Clitoria ternatea* and *Centrosema pubescens* grown on Samaru soil in a green house experiment. They also found malate and succinate in the rhizosphere of *Lablab purpureus* and *Clitoria ternatea*.

2.6.3 Phosphatase activity

The general name phosphatase has been used to describe a broad group of enzymes that catalyze the hydrolysis of both esters and anhydrides of H_3PO_4 (Schmidt and Laskowski, 1961). Phosphatase in rhizosphere may function either as a transport agent for inorganic P or to render P in phosphate esters in the rhizosphere available for uptake (Bieleski, 1973). Tarafdar and Jungk (1987) observed that plants can utilize organic P in the rhizosphere by means of phosphatases.

Soil phosphatase activity originates from the soil microbial biomass and the plant root. The enzyme's activity at root surface increases when inorganic P concentration is low and is inhibited by high soil solution inorganic P concentration (Speir and Ross, 1978; Amann and Amberger, 1988). In an experiment to study the relationship between activity of soil and root phosphatase and utilization of added inositol phosphate, Helal and Sauerbeck (1989) found out that root rather than soil phosphatase activity is a significant factor of P nutritional efficiency under conditions of limited supply of inorganic P. Hedley *et al.* (1982) and Helal and Sauerbeck (1989) reported no relationship between soil phosphatase activity and the availability of organic P in the rhizosphere.

Kamh *et al.* (1998a) observed decreasing phosphatase activities with increasing inorganic P supply in rhizosphere of *Cajanus cajan, Mucuna pruriens, Lablab purpureus, Phaseolus vulgaris, Glycine max* and *Zea mays* grown on Samaru soil in a green house experiment.

2.6.4 Symbiosis with root colonizing fungi

The roots of most soil grown plants are usually mycorrhizal. On global basis mycorrhizas occur in 83% of dicotyledonous and 79% of monocotyledonous plants, and all Gymnosperms are mycorrhizal (Wilcox, 1991). Mycorrhizal associations are either mutualistic, neutral or parasitic, however, as a rule mutualism dominates (Marschner, 1995). Vesicular-Arbuscular Mycorrhizas (VAM) have a distinct growth enhancement effect on the host plant by improving the supply of mineral nutrients of low mobility in the soil solution, particularly phosphorus. According to Tinker *et al.*, (1992), external hyphae of VAM can absorb and translocate phosphorus to the host plant from soil outside the root depletion zone of non-mycorrhizal plants. In mycorrhizal white clover with large hyphal compartments phosphorus was uniformly depleted from the soil more than 11 cm from the rhizoplane (Li *et al.*, 1991a). In mycorrhizal plants uptake rate of phosphorus per unit root length is 2-3 times higher than in non-mycorrhizal plants (Tinker *et al.*, 1992). Mycorrhizal hyphae could contribute as much as 70 to 80% of the total phosphorus in mycorrhizal plants (Li *et al.*, 1991b).

Phosphorus uptake in VAM plants is usually from the same labile pool from which the roots take up phosphorus (Bolan *et al.*, 1991), and the greatest benefit for the host plant comes with supply of least soluble source of phosphorus such as crystalline iron phosphate (Bolan *et al.*, 1987) or sparingly soluble organic phosphate sources like RNA (Jayanchandran *et al.*, 1992) or phytate (Tarafdar and Marschner, 1994).

In calcareous soils the higher rates of respiration, and therefore CO_2 production, of mycorrhizal roots increase the solubility of sparingly soluble calcium phosphates thereby increasing the efficiency of phosphorus acquisition (Knight *et al.*, 1989). This could also be important for the mobilization of phosphorus from rock phosphate.

2.6.5 Root length and root hairs

In phosphorus deficient plants roots are the dominant sink not only for photosynthates but also for phosphorus from the shoot. Phosphorus deficiency leads to an increase in root/shoot dry weight ratio (Gerloff and Gobelman, 1983; Marschner, 1995). This capacity to divert an increased proportion of plant resources to root development under P

deficiency has been demonstrated in sugar beets (Ulrich and Berry, 1961) and in maize genotypes (Shenk and Barber, 1979). According to Marschner (1995), increasing the duration of phosphorus starvation increases root dry weight, and root length in particular. The roots also become finer. An increase in root surface area in P deficient plants is considered a strategy for enhancing P acquisition from the soil (Marschner, 1995). According to Powell (1974) as reported by Barber (1984) roots growing in soils low in available phosphate have more and longer root hairs than roots growing in high-phosphate soils. In rape, spinach and tomato grown at high nutrient concentration (>100μM), Föhse and Jungk (1982) as reported by Barber (1984) observed that root hairs were absent or rudimentary whereas at low concentrations (<10μM) long root hairs were abundant. In soil-grown maize, however, a fall in P availability was reported to have no effect on root hair length, but distinctly increased the density of root hairs per unit root length (Marschner, 1995).

Gerloff and Gabelman (1983) reported that the number and length of seminal roots and the number of primary roots on two barley cultivars (Maris Badger and Proctor) were unaffected by P deficiency; the length of the primary roots was , however,

much reduced. They reported that under P deficiency the formation of secondary lateral roots was stimulated greatly in the Proctor cultivar resulting in three times more secondary laterals than Maris Badger. Under adequate P supply Maris Badger had far more secondary laterals than Proctor (Gerloff and Gabelman, 1983).This underscores the genetic variation in rooting behavior among plants under different phosphorus supply conditions.

In certain plant species such as rape (Hoffland, 1989) and lupin (Kamh et al.,1998b) formation of root clusters is another type of root response to P deficiency.

2.7 Genotypic differences in Al tolerance

The toxic actions of Al on plant growth are mainly root-related (Taylor, 1988). The root system becomes stubby as a result of inhibition of elongation of the main axis and lateral roots (Klotz and Horst, 1988). The severity of inhibition of root growth is a good index of genotypic differences in Al toxicity. In Al sensitive wheat genotypes, Delhaize et al.(1993) observed distinct inhibition of root

growth within four hours of treatment with Al. In tolerant plants such as rye and yellow lupin, between 3 to 4 mg Al g^{-1} dry weight might accumulate in root apical zones before growth is inhibited (Horst and Göppel, 1986).

Root exudates such as organic acids and mucilage play crucial role in Al avoidance. According to Marschner (1995), for a given genotype an increase in root exudation by mechanical impedance increases Al tolerance more than ten-fold. Puthota et al. (1991) showed the role of mucilage for genotypical differences in aluminum tolerance in wheat. In the absence of aluminum they observed mucilage production to be three times higher in the tolerant cultivar, and mucilage production ceased at 20μM Al supply in the sensitive and at 400μM in the tolerant cultivar.

According to Marschner (1995) an important feature of plant species adapted to highly acid mineral soils is the release of relatively large amounts of organic acids. Complexing of aluminum by organic acids such as citric acid has important consequence not only in the acquisition of phosphorus, but also provides protection against the harmful effect of Al on root growth (Marschner, 1995). In wheat

cultivars differing in Al tolerance Christiansen-Weniger et al.(1992) observed the release of organic acids to be much higher in aluminum tolerant cultivars. The formation of complexes of Al with polyphenols or organic acids leached from leaves or litter is believed to be responsible for the ability of certain *Eucalyptus* species to achieve both high aluminum tolerance and acquisition of phosphorus from extremely deficient soils (Ellis, 1971).

Root colonization with mycorrhizas is another crucial factor in the adaptation of plant species to acid mineral soils with inherent low phosphorus availability and high aluminum concentrations. The possible dependency on VAM for plant growth on aluminum-toxic tropical soils has been reported for a number of arable tropical crop species (Howeler et al., 1987) and for *Stylosanthes guaianensis* (Lambais and Cardoso,1990).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location

The trials were conducted on-station between 1995 and 1997 on three fields. Fields I and II were located at Samaru (11°11'N, 7°38'E) near Zaria, while field III was located at Heipang (9°38'N, 8°53'E) near Jos (Fig. 3.01). The two locations had contrasting geology and soil properties (Fig. 3.02, Table 3.1).

Samaru soil was formed on drift material overlaying basement complex (Klinkenberg and Higgins, 1968), and was classified as Kanhaplic haplustalf (Appendix 1) following the soil taxonomy system (USDA Soil Survey Staff, 1975). The soil had low CEC, low organic matter content, low total phosphorus, moderate Bray-1-P and low P sorption (Table 3.01, Fig. 3.02). Average soil pH values were around 5.5 in H_2O and 4.9 in 0.01m $CaCl_2$ solution. The area has an altitude of 686 M and a mean annual rainfall of about 1050 mm stretching from May to September (Kowal and Knabe, 1972). The temperature and rainfall distribution at Samaru between 1995 and 1997 are

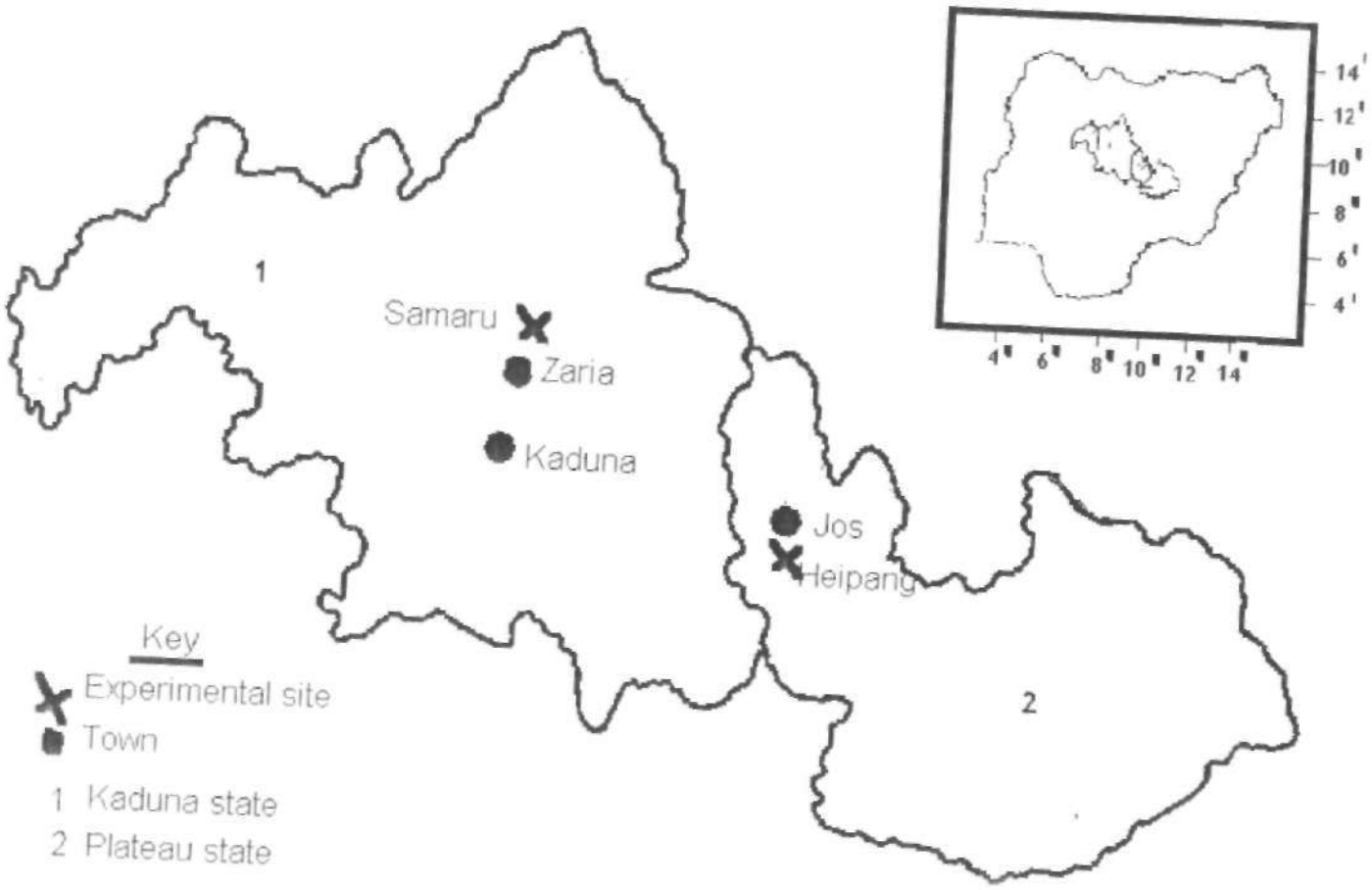
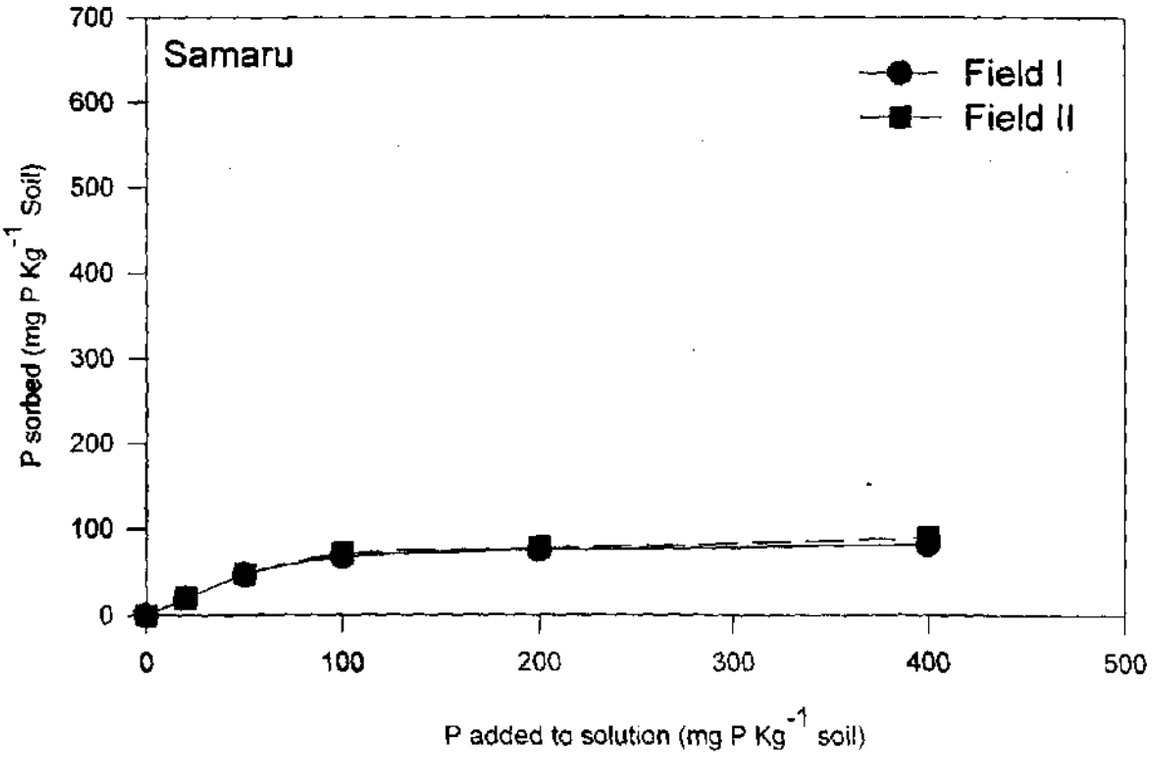


Fig. 3.01: Map of Kaduna and Plateau states showing experimental sites (inset:Map of Nigeria showing Kaduna and Plateau states)



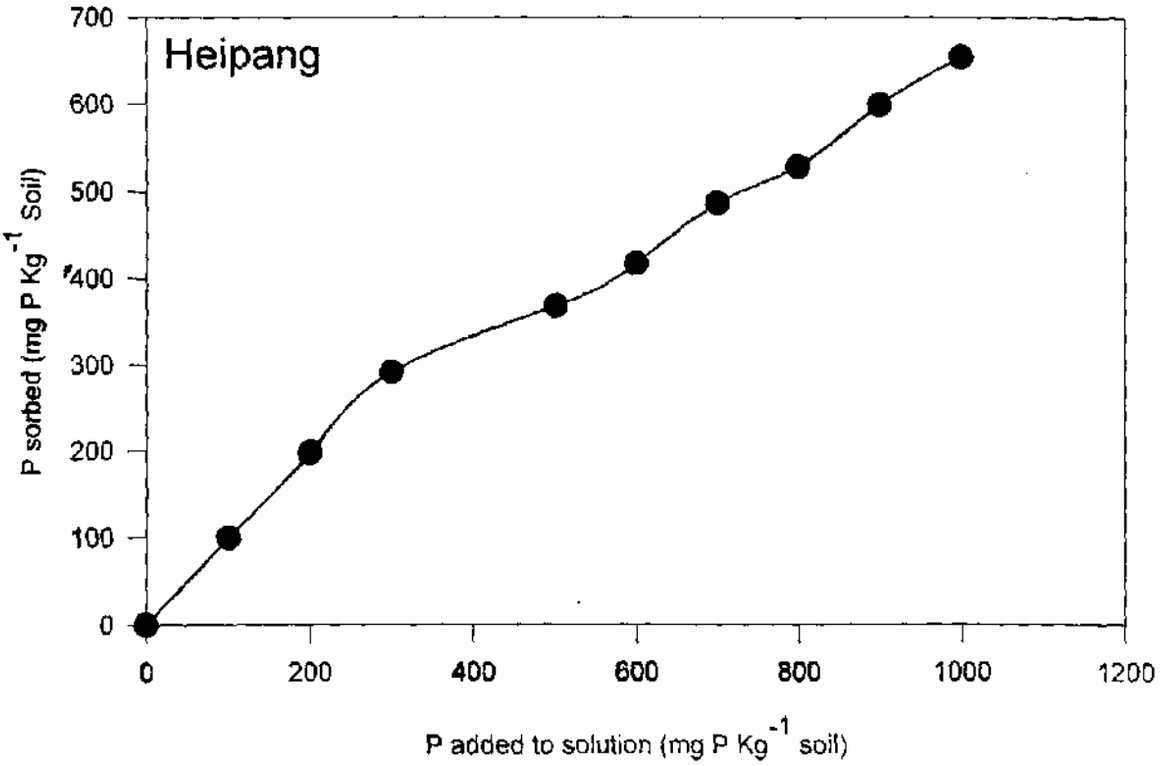


Figure 3.02: Phosphate sorption properties of soils of the trial sites.

Table 3.01: Physico-chemical soil characteristics of the experimental sites

Soil Property	Location		
	Zaria I	Zaria II	Heipang
Clay (g Kg^{-1})	120	160	520
Silt "	440	420	240
Sand "	460	420	240
Textural Class	Sandy loam	Loam	Clay
pH (H_2O; 1:2.5 w/v)	5.5	5.4	5.4
pH (0.01m $CaCl_2$; 1:2.5 w/v)	4.9	4.9	4.4
Bray 1 P (mg Kg^{-1})	6.04	9.86	0.69
Resin-P "	5.38	6.45	2.03
$NaHCO_3$-P_i "	8.66	9.84	10.04
$NaHCO_3$-P_o "	5.19	8.25	26.26
NaOH-P_i "	10.20	18.96	62.20
NaOH-P_o "	17.85	17.54	67.40
Total P "	154	196	473
Total Soluble Al "	0.59	0.49	23.2
Free Oxides (g Kg^{-1})			
Fe	10.10	7.0	61.8
Al	1.1	0.8	7.5
Mn	0.1	0.1	0.4
Organic Carbon (g Kg^{-1})	5.3	5.6	13.0
Total N "	0.42	0.46	1.60
Exchangeable Acidity(cmol Kg^{-1})	0.3	0.2	0.9
Exchangeable Al "	0.0	0.0	0.6
Cation exchange Capacity "	5.10	5.30	16.30

shown in Figs. 3.03 and 3.04.

Heipang soil, on the other hand, was classified as typic plinthustult (Appendix 2), and was formed on ferrugenised basalt (Hill and Rackham, 1973). It had high CEC, low content of exchangeable bases, moderate organic matter content, high total P content, low available P and very high P fixing capacity (Fig. 3.02, Table 3.01). Soil pH is 5.4 in H_2O and 4.4 in 0.01m $CaCl_2$. The mean annual rainfall at Heipang is around 1270 mm over a period of about 190 days (Hill, 1976). Figures 3.05 and 3.06 show the temperature and rainfall distribution at Heipang in 1996 and 1997.

3.2 Samaru field I

3.2.1 Design and treatments

3.2.1.1 First year (1995)

The experiment was established on July 1, 1995 in a split-plot design with four replications. The sub-plots of size 4 x 3.75 m^2 were 0 Kg P ha^{-1} (CRL), 30 kg P ha^{-1} in form of single superphosphate (SSP), and 30 kg P ha^{-1} as Sokoto phosphate rock (SPR). The result of X-ray fluorescence spectrometry showing the elemental composition of SSP and SPR

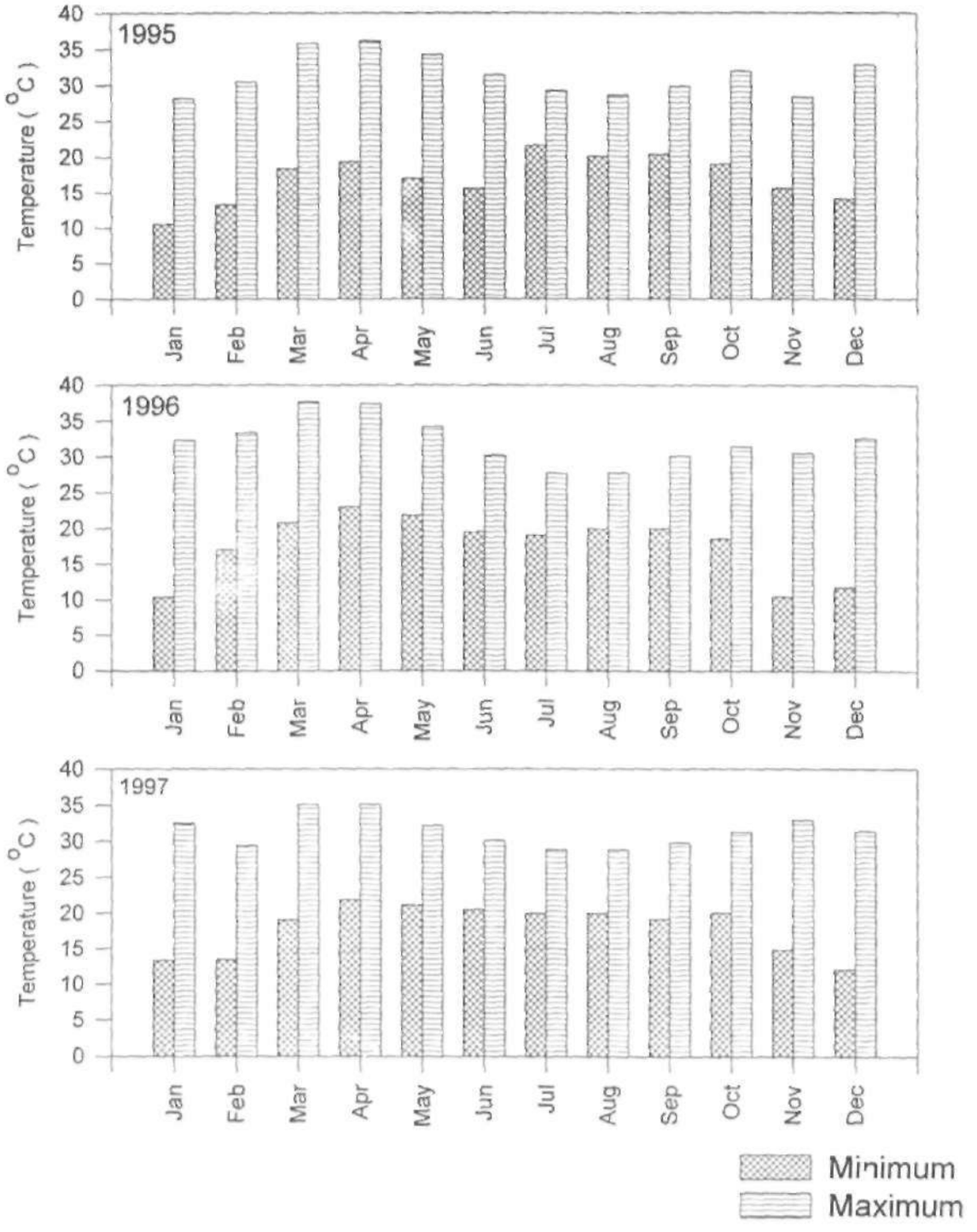


Figure 3.03: Minimum and maximum temperatures at Samaru between 1995 and 1997

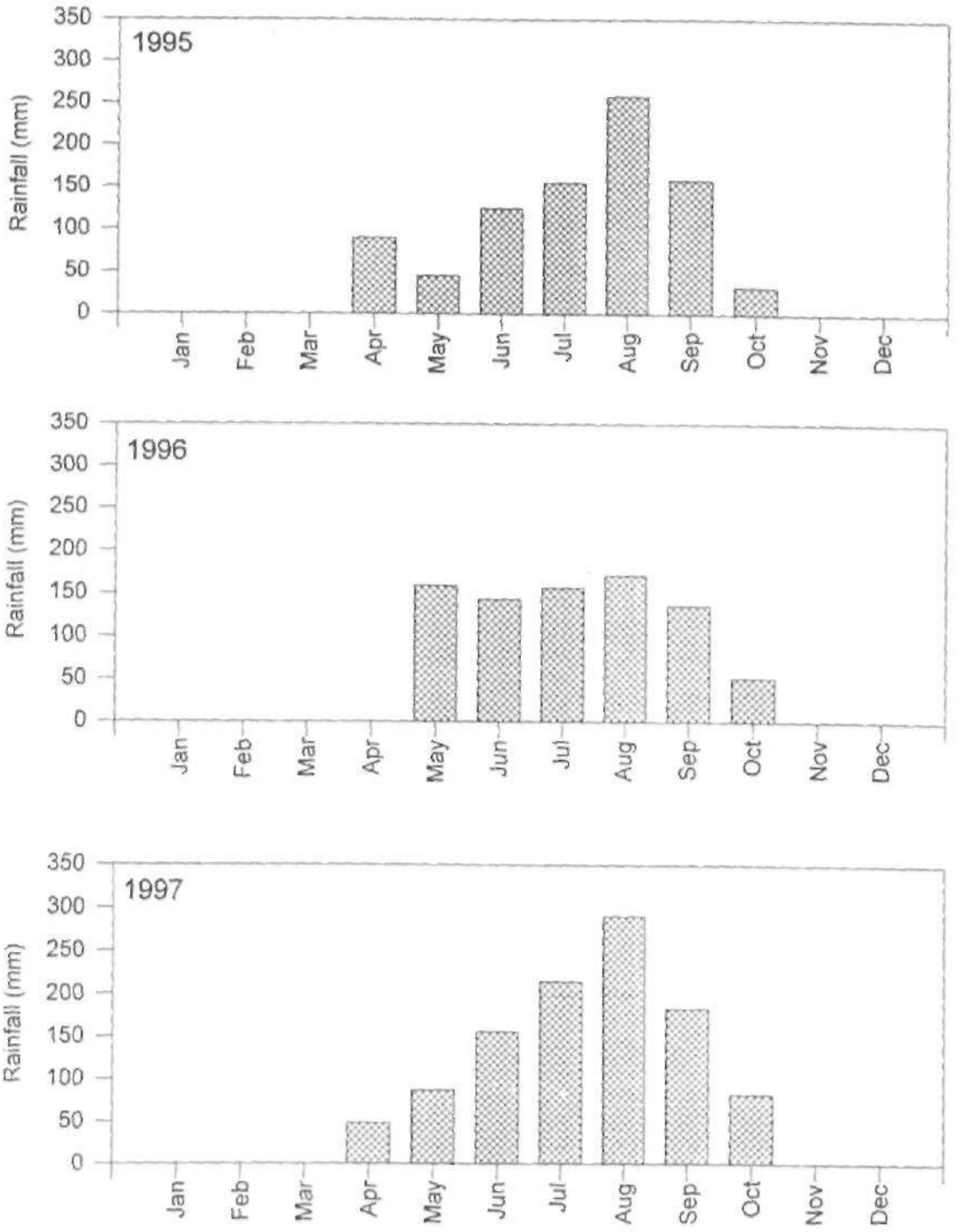


Figure 3.04: Rainfall distribution at Samaru between 1995 and 1997

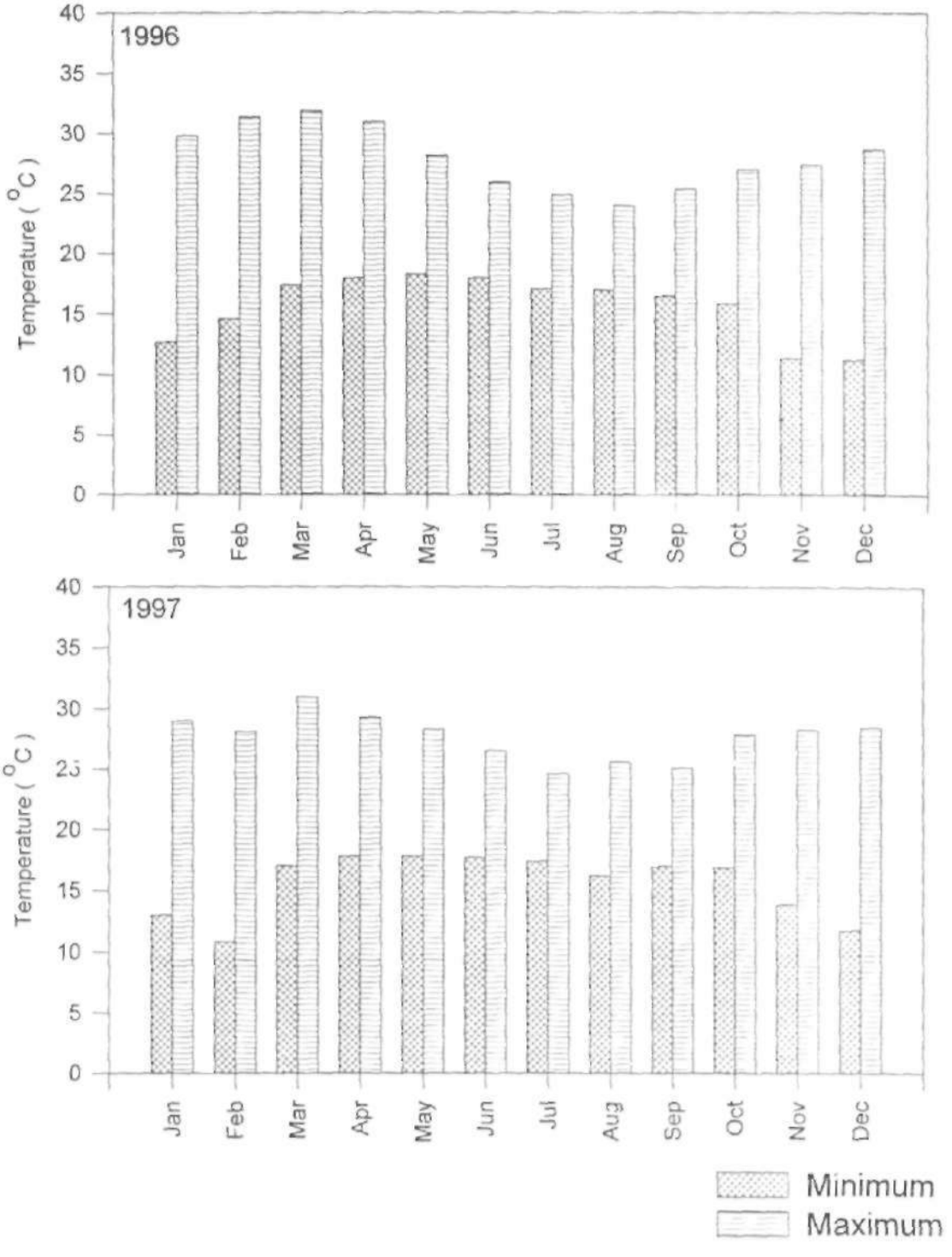


Figure 3.05: Minimum and maximum temperatures at Heipang in 1996 and 1997

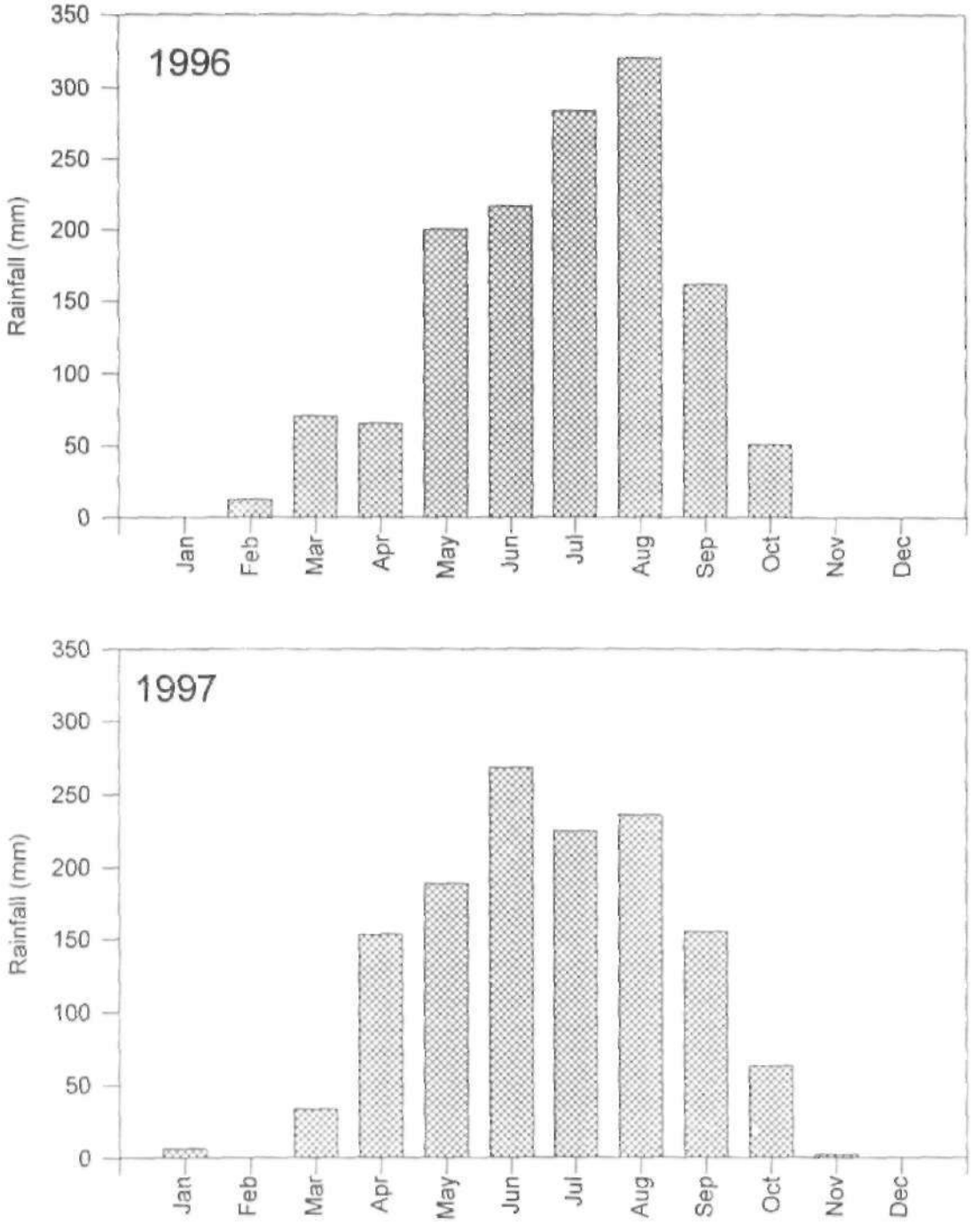


Figure 3.06: Rainfall distribution at Heipang in 1996 and 1997

is presented in Table 3.02. The main plots measuring 13 x 3.7 m^2 comprised of different plant species as follows:

1. *Zea mays* L.
2. *Zea mays* L
3. *Zea mays* L. + *Chamaecrista rotundifolia* cv. wyn
4. *Zea mays L.* + *Cajanus cajan* (L.) Millsp.
5. *Stylosanthes hamata* cv. verano
6. *Phaseolus vulgaris* L. (Brown)
7. *Phaseolus vulgaris* L. (Variegated)
8. *Cajanus cajan* (L.) Millsp
9. *Chamaecrista rotundifolia* cv. wyn
10. *Lablab purpureus* (L.) Sweet (Black)
11. *Lablab purpureus* (L.) Sweet (White)
12. *Mucuna pruriens* (L.) DC (White)
13. *Crotalaria ochroleuca* G. Don
14. *Glycine max* L. Merr
15. *Centrosema pubescens*
16. *Centosema macrocarpum*
17. *Stylosanthes guaianensis*
18. *Aeschynomena histrix*
19. *Phaseolus vulgaris* L. (black)
20. *Clitoria ternatea* L.

After harvesting the seeds of each crop as soon as they

Table 3.02: Chemical composition of the phosphate fertilizers used

Element		Sokoto Phosphate Rock	Single Superphosphate
P_2O_5	g Kg^{-1}	340.1	173.9
Al_2O_3	"	23.5	13.2
Fe_2O_3	"	79.3	35.5
CaO	"	447.7	432.3
S	"	5.9	162.0
K_2O	"	1.4	2.6
Cl	"	2.1	2.6
MnO	"	5.3	3.2
TiO_2	"	2.8	3.0
Co	mg Kg^{-1}	221	1.60
Cu	"	87	76
Zn	"	82	133
As	"	33	45
Pb	"	47	65
Sr	"	983	758
Th	"	16	15
Y	"	392	322
U	"	53	78
Zr	"	59	67

matured, plant residues were immediately incorporated into the soil except in the case of treatment 1 above. The time of incorporation varied between August and December depending on the time of maturity of the crop.

3.2.1.2 Second year (1996)

In June 1996 maize (*Zea mays* (L.) cv. TZE-SR-W) was planted on all the 1995 plots with no fresh P application so as to evaluate the residual effects of the preceding cover crops and P treatments on yield and P nutrition of the succeeding maize. At the end of the season the maize stovers were incorporated into the soil except in the *maize minus residue* treatment.

3.2.1.3 Third year (1997)

In 1997 maize (TZE-SR-W) was again planted on all plots with no additional P application to further evaluate the residual effects of the 1995 cover crop and P treatments.

3.3 Samaru field II

This trial was established on a site close to the 1995 trial to validate the results obtained on field I as well as screen more plant species.

3.3.1 Design and treatments

3.3.1.1 First year (1996)

The trial was established in June 1996 in a split-plot design with three replications. A sub plot size of 4 x 5.25 m^2 was used, with sub plot treatments being the same as in field I. The main plot size was 13 x 5.25 m^2. The main plot treatments were as in field I except for the substitution of *Centrosema macrocarpum*, *Aeschynomene histrix*, *Phaseolus vulgaris* (black), and *Stylosanthes guaianensis* with *Arachis hypogaea*, *Canavalia ensiformis*, *Vigna unguiculata* and *Mucuna pruriens* (black) respectively. The substitution was due to the poor establishment of the former in 1995.

After harvesting the seeds, the remaining above ground biomass were incorporated into the soil except in the case of the *maize minus residue* treatment just as in field I.

3.3.1.2 Second year (1997)

In 1997 the sub plots of 1996 were further split into 2 with one half getting a fresh treatment of 30 kg P ha^{-1} as SSP irrespective of 1996 P fertilization. This makes the experimental design split-split plot in 1997. The sub sub plot size was 4 x 2.3 m^2. Maize (*Zea mays* L. cv.8644-27) was the test crop on all plots. The fresh P treatment was to verify if any observed differences in maize growth and yields were due to P effects of the preceding crop.

3.4 Field III (Heipang)

3.4.1 Design and treatments

3.4.1.1 First year (1996)

The design in 1996 was split-split plot in 4 replicates with the sub-sub plots of 4 x 5.25 m^2 being 0 kg P ha^{-1}, 30 kg P ha^{-1} as SSP, and 30 kg P ha^{-1} as SPR. The subplot treatments were 0 and 250 kg lime ha^{-1} with subplot size of 4 x 11 m^2. The main plots of size 13 x 11 m^2 comprised of the following treatments:

1. *Zea mays* L (Minus residue)

2. *Zea mays* L (Residue incorporated)
3. *Zea mays* L + *Chamaecrista rotundifolia*
4. *Zea mays* L + *Cajanus cajan*
5. *Chamaecrista rotundifolia*
6. *Cajanus cajan*
7. *Lablab purpureus* (White)
8. *Mucuna pruriens* (White)
9. *Glycine max*
10. *Phaseolus vulgaris* (brown)

As in fields I and II, the plant residues were incorporated into the soil at the end of the season except in the case of the *maize minus residue* treatment.

3.4.1.2 Second year (1997)

In the second year the sub-sub plots were further split into two with one half receiving a fresh P treatment of 60 kg P ha^{-1} in the form of SSP. Additional 1.35 t Lime ha^{-1} based on the soils liming requirement was applied to all previously limed plots to maintain the pH at around 5.5. Maize (*Zea mays* cv.8644-27) was the test crop on all plots.

3.5 Spacing and fertilizer application

3.5.1 Spacing

All crops were planted on ridges 0.75 m apart (except in 1997 on fields II and III where the ridges were 0.58m apart). Maize was sown at a spacing of 0.25 m within rows in 1995 (except in 1997 on fields II and III where a spacing of 0.20 m was used). *Lablab purpureus, Canavalia ensiformis* and *Mucuna pruriens* were planted at a spacing of 0.50 m within rows, while *Cajanus cajan, Centrosema pubescens, Centrosema macrocarpum, Arachis hypogaea, Vigna unguiculata, Clitoria ternatea* and *Phaseolus vulgaris* were planted 0.25 m apart within rows. *Glycine max* was drilled about 0.05 m apart while *Chamaecrista rotundifolia, Stylosanthes hamata, Stylosanthes guaianensis, Aeschynomene histrix* and *Crotalaria ochroleuca* were drilled along the rows at the seed rate of 15 kg per hectare.

3.5.2 Fertilizer application

In the first year on each of the three fields, all plots were treated with 10 kg S ha^{-1} and 50 kg K ha^{-1} as $MgSO_4$ and KCl respectively. Additional 20 kg S ha^{-1} in the form of elemental

sulphur was applied to all plots except those treated with SSP. Urea was applied to maize plots at the rate of 120 kg N ha^{-1} in two equal doses at planting and six weeks later. The leguminous plants received a maintenance dose of 20 kg N ha^{-1} at 5 weeks after planting (WAP). In the succeeding years all plots were treated with 120 kg N ha^{-1} and 50 kg K ha^{-1} in form of urea and KCl respectively. The first dose of urea and all the other fertilizers were broadcast at planting time and incorporated with hand hoes, while the second dose of urea was top dressed. Phosphate fertilization was according to treatment (sections 3.2.1, 3.3.1, 3.4.1)

3.6 Plant growth and yield analysis

Development of the plants was monitored through biomass assessment, measurement of plant height (for maize), and days to 50% flowering. Root length density at 50% flowering was determined. The root samples were taken from 0-15 and 15-30 cm depths using a root auger (Eijkemp) of 8 cm diameter. Root length density was calculated using line intersect method (Tennant, 1975). At maturity, grain/seed yields, shelling percentage, and crop residues were assessed. In the case of maize, cob length, cob diameter, number of grains per cob, and kernel depth were determined.

3.7 Plant and soil analysis

3.7.1 Plant analysis

A 0.5g sample of plant material was weighed into glass vials and ashed at 450°C for 9 hours in a muffle furnace. After cooling, the ashed samples were heated in 5 ml of 1:3 HNO_3 solution at 100°C for about 10 minutes. The solution was then diluted and filtered. Phosphorus in the diluted digest was determined calorimetrically by the vanadomolybdate method using PERKIN-ELMER Lambda 15 UV/VIS spectrophotometer, while K, Ca, S, Mg, Mn, Cu, Zn, Fe and Al were determined using the inductively coupled plasma (ICP) spectrometry.

3.7.2 Soil analysis

Soil samples from 0-15 and 15-30 cm depths were taken either with soil auger or along with roots using the root auger. Four core samples were randomly taken from each plot and bulked by depth. All soil samples taken from the field were air-dried on trays. After drying, the clods were broken using a porcelain mortar and the ground soil sieved through 2 mm - mesh sieve. The sieved samples were stored in polythene bags for physical and chemical analysis.

Particle size analysis was carried out by the hydrometer method (Day, 1965). Soil pH was determined in water and in 0.01m $CaCl_2$ at a soil/solution ratio of 1:2.5 (weight/volume) with a glass electrode pH meter. Organic carbon was determined by the wet oxidation method of Walkley and Black as described by Allison (1965). Exchangeable acidity was determined by shaking the soil with 1N KCl and titrating with 0.5N NaOH (Juo, 1979). Exchangeable bases were displaced with 1N NH_4OAC buffered at pH 7.0. Potassium and Na in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrophotometry. Cation exchange capacity was determined using the 1N NH_4OAC (pH 7.0) method. Total N was determined by the macro-Kjeldahl procedure described by Bremner (1965). Copper, Mn, Zn and Fe were extracted in 0.1N HCl and determined by atomic absorption spectrophotometry. Oxides of Fe, Al and Mn were extracted using the citrate-bicarbonate-dithionite (Mehra and Jackson, 1960) and the acidified ammonium oxalate (Shwartzman, 1973) methods. Iron, Al and Mn in the extracts were determined using the ICP.

Available phosphorus was determined by the Bray 1 method. Phosphate fractionation was done using the Hedley *et al*

(1982) method (Fig. 3.07).

3.8 Analysis of phosphate fertilizer materials

The fertilizer materials were analyzed for total elemental content using X-ray fluorescence spectrometry at the Center for Energy Research and Training, Ahmadu Bello University, Zaria. Samples of the fertilizer materials were ground to 125μm particle size, sieved and then clamped to an octagon sieve shaker for one
hour to obtain homogeneity. They were then made into pellets of 25mm diameter and 1mm thickness using ten tonnes pressure. Spectral acquisition was done with EMCAPLUS^{R} software while spectral analysis was done using QAXIL software, detector was silina model 9300/7. Radio-isotopes used were Fe^{55} and Cd^{109} sources.

3.8 Statistical analysis

All the data collected were subjected to analysis of variance (ANOVA) using the GENSTAT V (1993) package for statistical analysis.

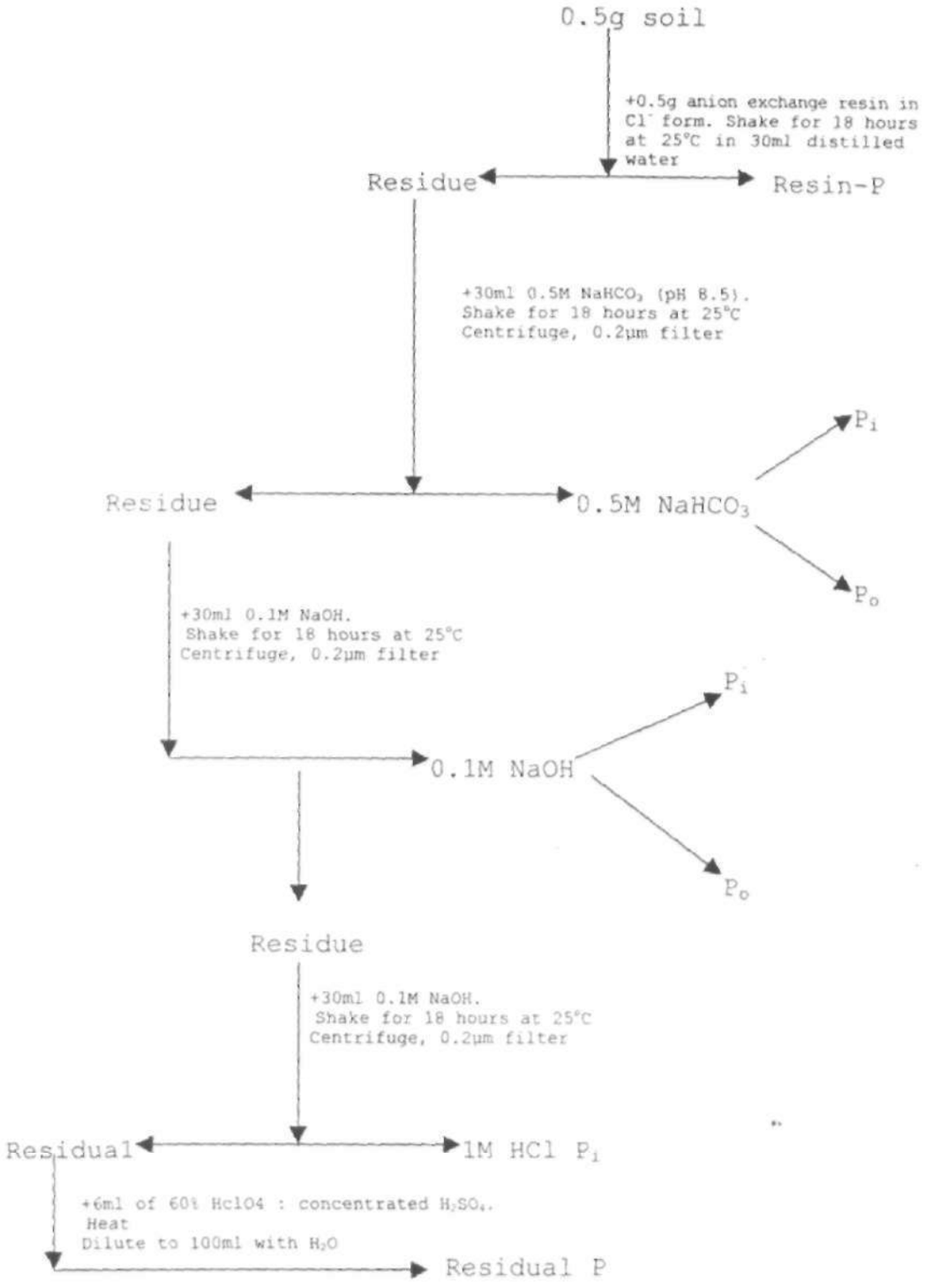


Fig. 3.07: Flow chart of fractionation proceedure of soil P into inorganic (P_i) and organic forms (P_o)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Field I (Samaru)

4.1.1 First year (cover crops and maize)

4.1.1.1 Effect of P application on growth of cover crops in 1995

The various cover crops had different growth patterns which were manifested in their above ground biomass production at 50% flowering (Table 4.01). *Crotalaria ochroleuca* produced the highest amount of dry matter at 50% flowering, while the two varieties of *Phaseolus vulgaris* produced the least. Responses of the various cover crops to phosphate fertilization in terms of dry matter at 50% flowering also varied. Both SSP and SPR produced significant increases (*P=0.05*) in dry matter production at 50% flowering in *Stylosanthes hamata*, *P. vulgaris* (b), and *L. purpureus* (b), while *C. ochroleuca* and *G. max* responded only to SSP application. *Cajanus cajan* (sole crop), *P. vulgaris* (v), *L. purpureus* (w), *M. pruriens* (w) and *C. rotundifolia* (sole crop) did not respond to phosphate fertilization, indicating that the native soil P is sufficient enough for the growth of these crops. However, Kamh *et al.* (1998a) observed increased growth

Table 4.01: Effect of P application to cover crops on above ground biomass at 50% flowering in 1995 at Samaru (field I)

Cover crop	Biomass (kg ha^{-1})					
	CRL[€]	SSP	SPR	F ratio	SE±	%CV
Chamaecrista rotundifolia(sole)	786	786	736	ns	-	-
Chamaecrista rotundifolia(intercrop)	390	298	403	*	37.0	10.2
Cajanus cajan(sole)	2945	4301	3754	ns	-	-
Cajanus cajan(intercrop)	1924	1379	2561	**	262	13.4
Phaseolus vulgaris(brown)	296	480	444	*	71.6	17.6
Phaseolus vulgaris(variegated)	391	345	378	ns	-	-
Phaseolus vulgaris(black)[#]	-	-	-	-	-	-
Crotalaria ochroleuca	6719	9725	6590	**	847	11.0
Mucuna pruriens (white)	2651	3020	2386	*	245	9.1
Aeschynomene histrix[#]	-	-	-	-	-	-
Lablab purpureus(black)	1931	2349	2439	*	208	9.3
Lablab purpureus(white)	2014	1819	1865	ns	-	-
Glycine max	1871	2213	1971	*	120	5.9
Stylosanthes hamata	843	1104	1068	**	75.7	7.5
Stylosanthes guianensis[#]	-	-	-	-	-	-
Clitoria ternatea[#]	-	-	-	-	-	-
Centrosema pubescens[#]	-	-	-	-	-	-
Centrosema macrocarpum[#]	-	-	-	-	-	-

[#]Not assessed due to poor germination; [€]CRL= control;SSP=single superphosphate; SPR= Sokoto phosphate rock; *Significant at 5% level; **Significant at 1% level

of these crops with increasing phosphate supply in a pot experiment using Samaru soil. Lower dry matter production was recorded for the two cover crops intercropped with maize. The application of SSP depressed dry matter production of *Cajanus cajan* (intercrop) and *Chamaecrista rotundifolia* (intercrop), possibly due to the shading effect of the taller maize plants on the SSP treated plots and the depression of root volume by more aggressive maize roots.

The germination *Aeschynomene histrix, Stylosanthes guaianensis, Clitoria ternatea, Centrosema macrocarpum, Phaseolus vulgaris* (black), and *Centrosema pubescens* was very poor in 1995. Their performances were therefore not assessed.

Tables 4.02 and 4.03 show the root length densities of the various cover crops within the 0-15 and 15-30 cm soil depths. All the cover crops had greater rooting density within the o-15 cm depth. Only *S. hamata* and *P. vulgaris* (v) showed any significant response to P fertilization. Application of both SSP and SPR to *P. vulgaris* (v) produced significant (p=0.05) increase within the 0-15 cm soil depth and decrease within the 15-30 cm depth. This shows that the development of *P. vulgaris* roots was enhanced in the top soil where most of the applied P was present.

Table 4.02: Effect of P application to cover crops on rooting density within 0-15 cm depth at 50% flowering in 1995 at Samaru (field I)

Cover crop	Root length density (cm cm^{-3})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Chamaecrista rotundifolia(sole)	0.73	1.34	1.00	ns	-	-
Cajanus cajan(sole)	0.08	0.05	0.13	ns	-	-
Phaseolus vulgaris(brown)	1.34	1.59	1.10	ns	-	-
Phaseolus vulgaris(variegated)	0.70	1.14	1.41	*	0.29	26.5
Phaseolus vulgaris(black)[1]	-	-	-	-	-	-
Crotalaria ochroleuca	1.48	1.47	1.78	ns	-	-
Mucuna pruriens (white)	0.43	0.43	0.49	ns	-	-
Aeschynomene histrix[1]	-	-	-	-	-	-
Lablab purpureus(black)	0.20	0.27	0.26	ns	-	-
Lablab purpureus(white)	0.29	0.18	0.33	ns	-	-
Glycine max	1.81	1.82	1.76	ns	-	-
Stylosanthes hamata	0.74	0.89	0.91	ns	-	-
Stylosanthes guianensis[1]	-	-	-	-	-	-
Clitoria ternatea[1]	-	-	-	-	-	-
Centrosema pubescens[1]	-	-	-	-	-	-
Centrosema macrocarpum[1]	-	-	-	-	-	-

[1]Not assessed due to poor germination; *Significant at 5% level; **Significant at 1% level

Table 4.03: Effect of P application to cover crops on rooting density within 15-30 cm depth at 50% flowering in 1995 at Samaru (field I)

Cover crop	Root length density (cm cm^{-3})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Chamaecrista rotundifolia(sole)	0.28	0.24	0.20	ns	-	-
Cajanus cajan(sole)	0.04	0.04	0.04	ns	-	-
Phaseolus vulgaris(brown)	0.23	0.24	0.26	ns	-	-
Phaseolus vulgaris(variegated)	0.52	0.25	0.24	*	0.12	20.4
Phaseolus vulgaris(black)[1]	-	-	-	-	-	-
Crotalaria ochroleuca	0.45	0.34	0.37	ns	-	-
Mucuna pruriens (white)	0.04	0.08	0.07	ns	-	-
Aeschynomene histrix[1]	-	-	-	-	-	-
Lablab purpureus(black)	0.04	0.10	0.07	ns	-	-
Lablab purpureus(white)	0.04	0.04	0.05	ns	-	-
Glycine max	0.93	0.53	0.89	ns	-	-
Stylosanthes hamata	0.27	0.14	0.36	ns	-	-
Stylosanthes guianensis[1]	-	-	-	-	-	-
Clitoria ternatea[1]	-	-	-	-	-	-
Centrosema pubescens[1]	-	-	-	-	-	-
Centrosema macrocarpum[1]	-	-	-	-	-	-

[1] Not assessed due to poor germination; *Significant at 5% level; **Significant at 1% level

4.1.1.2 Effect of P application on tissue P content of cover crops

Tissue P concentration and P uptake at 50% flowering is shown in Table 4.04. Both SSP and SPR application resulted in significant (p=0.05) increase in tissue P concentration of *C. rotundifolia*. Application of SSP also raised the tissue P concentration in *G. max* at 50% flowering. Slightly higher non-significant P concentrations were observed in the tissues of the other cover crops with SSP application, suggesting the ability of these crops to effectively utilize the native soil P. Among the crops, *P. vulgaris* (v), *G. max* and *C. rotundifolia* had the highest tissue P concentrations while *C. ochroleuca* and *L. purpureus* (w) had the least (Table 4.04). The cover crops with higher biomass production appeared to have lower tissue P concentrations, indicating their greater P use efficiency. According to Marschner (1995), genotypic differences in nutrient efficiency are related to differences in efficiency in acquisitionby the roots, or in utilization by the plant or both. Efficiency in acquisition is often defined in terms of total uptake per unit plant or specific uptake rate per unit root length, and efficiecy in utilization expressed as dry matter production per unit nutrient in dry matter (Marschner, 1995). Expressing P efficiency in terms of

Table 4.04: Effect of P application to cover crops on tissue P concentration at 50% flowering in 1995 at Samaru (field I)

Cover crop	Phosphorus concentration (g kg^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Chamaecrista rotundifolia(sole)	2.62	3.44	3.94	*	0.55	16.5
Cajanus cajan(sole)	1.75	2.44	2.19	ns	-	-
Phaseolus vulgaris(brown)	2.81	3.25	2.94	ns	-	-
Phaseolus vulgaris(variegated)	4.25	4.44	4.37	ns	-	-
Phaseolus vulgaris(black)#	-	-	-	-	-	-
Crotalaria ochroleuca	1.56	2.00	1.94	ns	-	-
Mucuna pruriens (white)	1.81	2.25	2.12	ns	-	-
Aeschynomene histrix#	-	-	-	-	-	-
Lablab purpureus(black)	2.50	2.69	2.31	ns	-	-
Lablab purpureus(white)	1.44	1.75	1.63	ns	-	-
Glycine max	3.13	3.94	3.45	*	0.27	7.7
Stylosanthes hamata	2.38	2.50	2.19	ns		
Stylosanthes guianensis#	-	-	-	-	-	-
Clitoria ternatea#	-	-	-	-	-	-
Centrosema pubescens#	-	-	-	-	-	-
Centrosema macrocarpum#	-	-	-	-	-	-

#Not assessed due to poor germination; *Significant at 5% level; **Significant at 1% level

total uptake, *C. ochroleuca* had the highest P uptake at 50% flowering (Table 4.05). Figure 4.01 shows the phosphate use efficiencies of the various cover crops at 50% flowering expressed as kilograms of above ground biomass produced per kilogram of P taken up. *Crotalaria ochroleuca, L. purpureus* (w) and *M. pruriens* (w) had the highest P use efficiencies with *P. vulgaris* (v) having the least.

4.1.1.3 Effect of P application on maize performance in 1995

Figures 4.02 and 4.03 show the effect of P application and intercropping on maize performance. Intercropping maize with *Chamaecrista rotundifolia* and with *Cajanus cajan* had no significant effect on maize height and maize grain and stover yields. Nigerian farmers are usually reluctant to plant sole crops that do not have immediate food or cash value. The non-depression of maize yield when intercropped with *C. rotundifolia* could have important bearing on the adoption of this technology by farmers in future. Application of SSP produced very significant (p=0.01) increase in plant height at 44 days after planting (DAP), but this effect disappeared at 65 DAP. Both SSP and SPR did not increase grain yield significantly, a sign that the native soil P did not limit grain yield in this first year of growth. However SSP produced very significant (p=0.01) increase in stover yield (Fig.

Table 4.05: Effect of P application to cover crops on tissue P uptake at 50% flowering in 1995 at Samaru (field I)

Cover crop	P uptake (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Chamaecrista rotundifolia(sole)	2.00	2.67	2.89	ns	-	-
Cajanus cajan(sole)	6.88	10.4	8.21	ns	-	-
Phaseolus vulgaris(brown)	0.85	1.57	1.31	*	0.24	19.4
Phaseolus vulgaris(variegated)	1.66	1.53	1.64	ns	-	-
Phaseolus vulgaris(black)[#]	-	-	-	-	-	-
Crotalaria ochroleuca	10.6	19.5	12.8	**	2.68	18.8
Mucuna pruriens (white)	4.80	6.92	5.03	ns	-	-
Aeschynomene histrix[#]	-	-	-	-	-	-
Lablab purpureus(black)	4.81	6.29	5.67	-	-	-
Lablab purpureus(white)	2.91	3.17	3.03	-	-	-
Glycine max	5.84	8.73	7.02	**	0.60	8.3
Stylosanthes hamata	2.01	2.76	2.33	*	0.31	13.0
Stylosanthes guianensis[#]	-	-	-	-	-	-
Clitoria ternatea[#]	-	-	-	-	-	-
Centrosema pubescens[#]	-	-	-	-	-	-
Centrosema macrocarpum[#]	-	-	-	-	-	

[#]Not assessed due to poor germination; *Significant at 5% level; **Significant at 1% level.

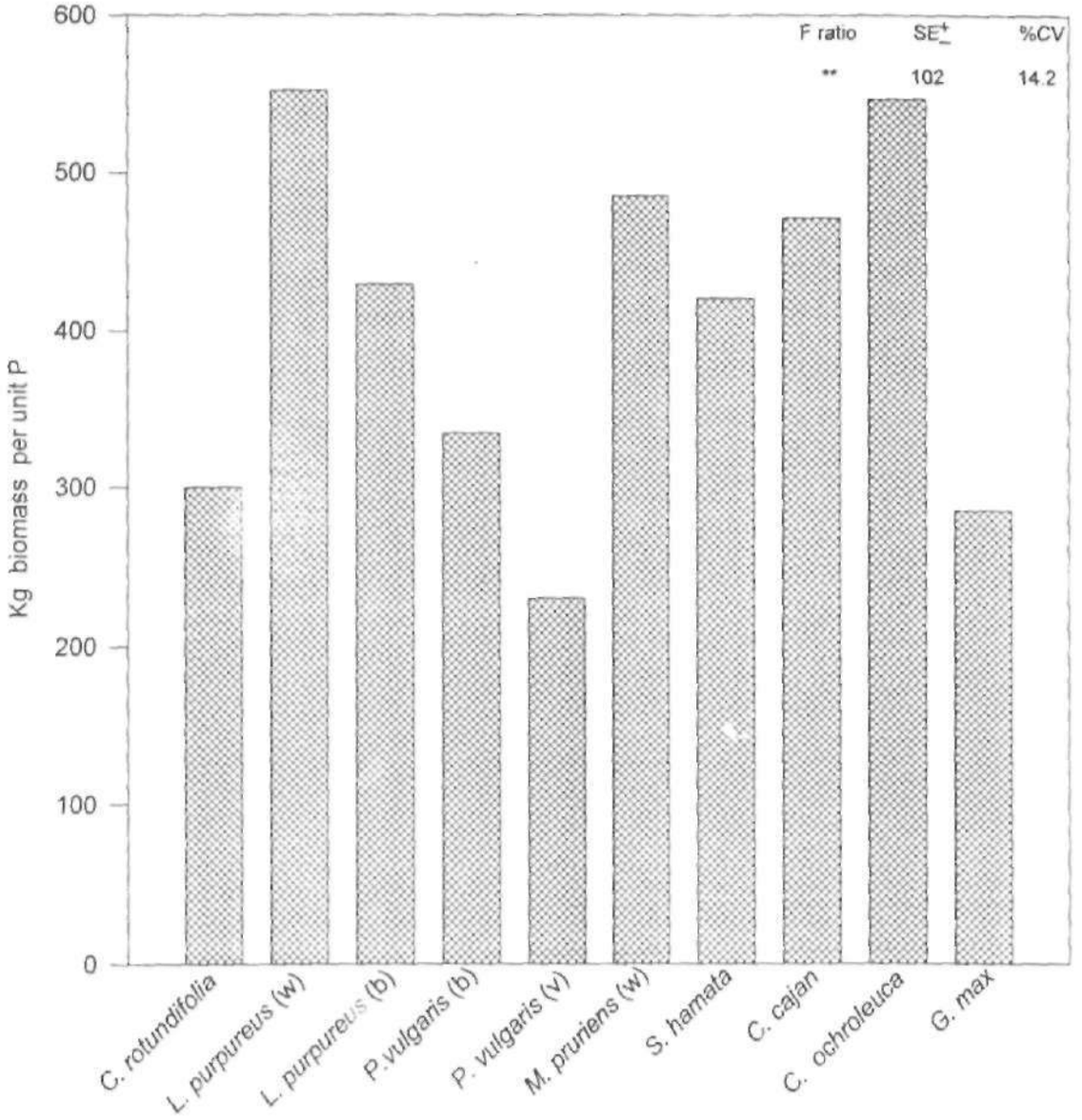


Figure 4.01: Phosphate use efficiency of the various cover crops at 50% flowering at Samaru (field I) in 1995

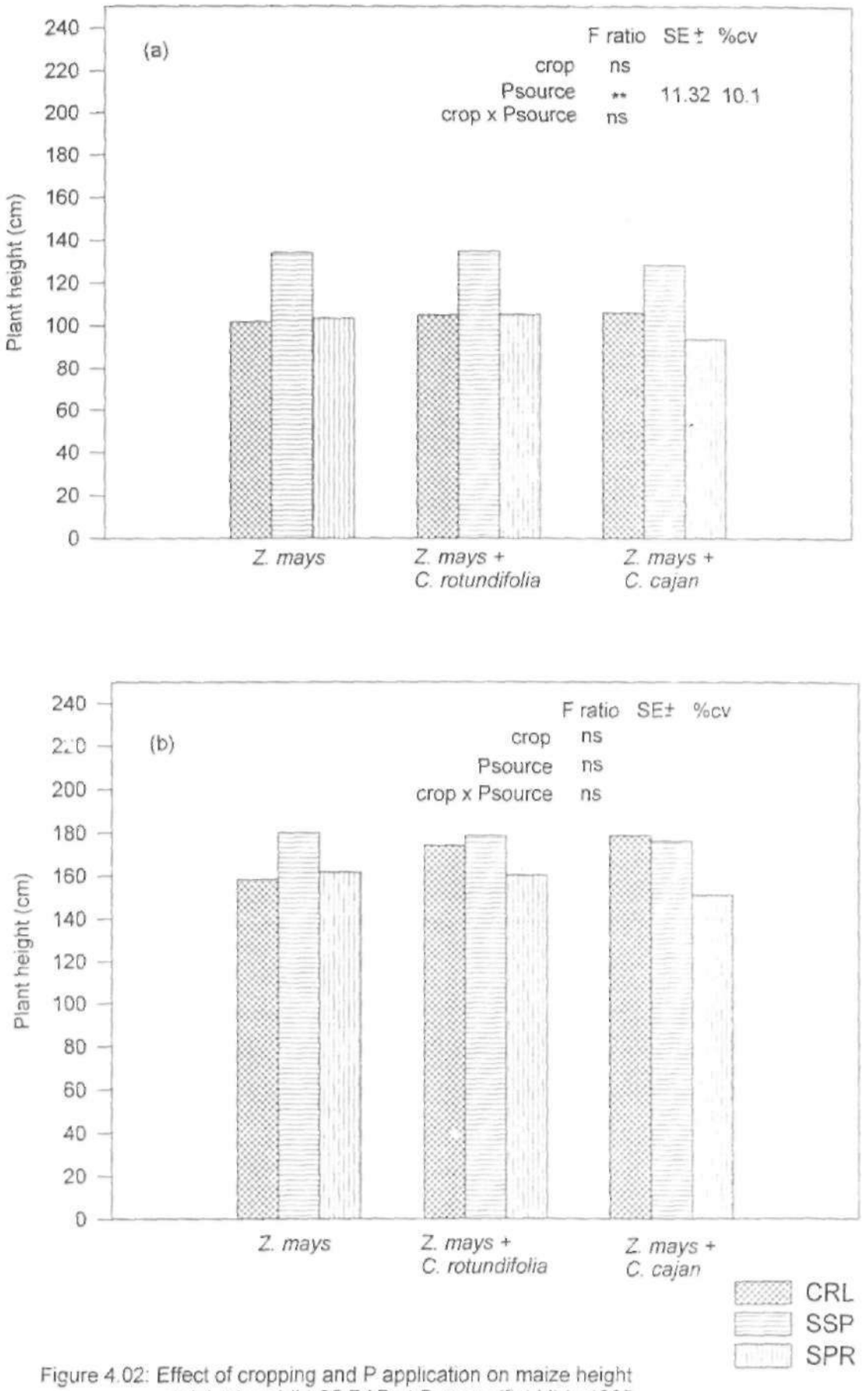


Figure 4.02: Effect of cropping and P application on maize height at (a) 44 and (b) 65 DAP at Samaru (field I) in 1995

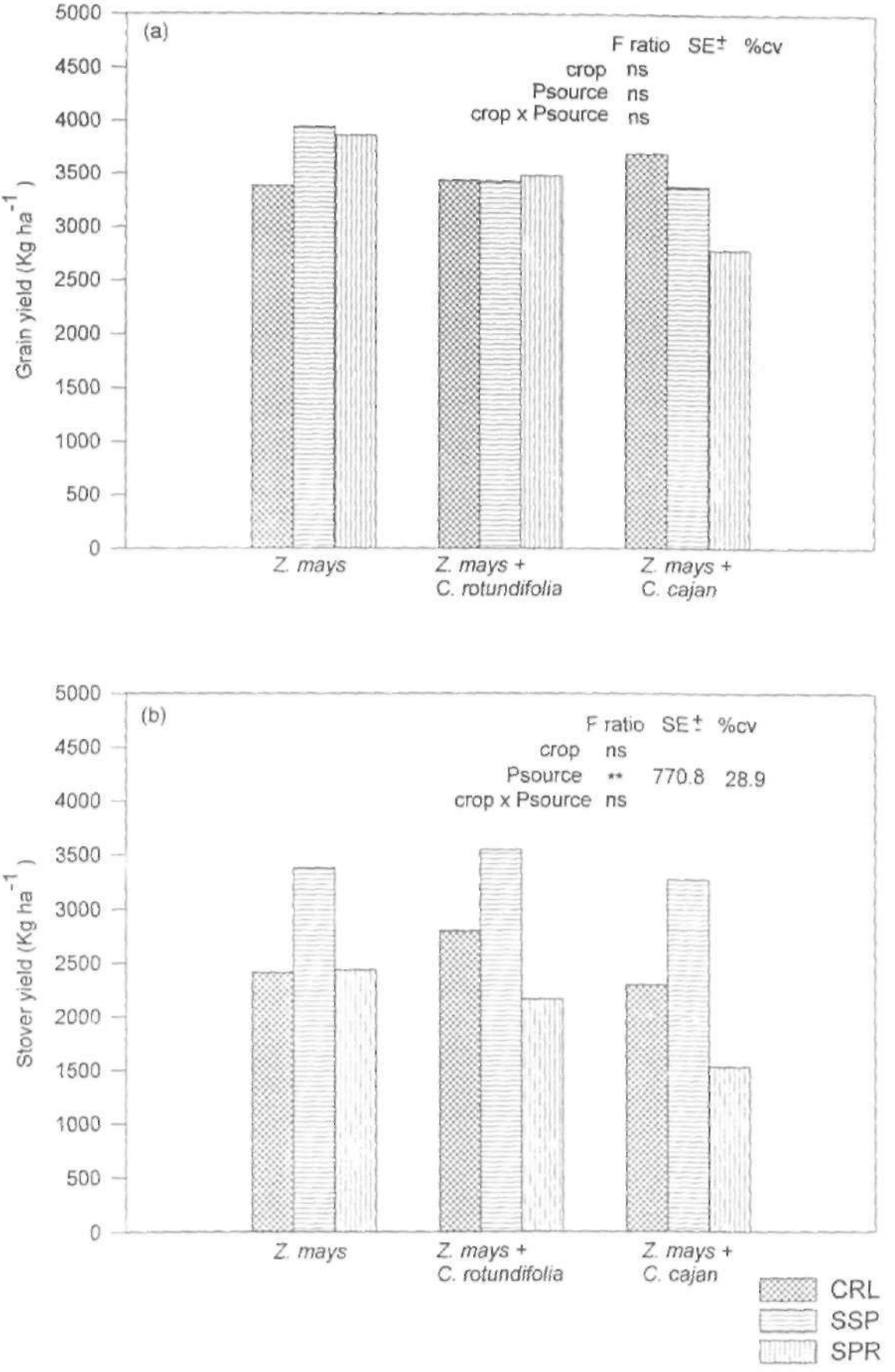


Figure 4.03: Effect of intercropping and P application on maize (a) grain yield (b)stover yield at Samaru (field I) in 1995

4.03). Number of days to 50% silking was significantly (p=0.01) shortened by SSP but was unaffected by intercropping (Table 4.06). Shelling percentage, 1000-grain weight ,cob length, cob diameter and kernel depth were unaffected by both intercropping and P application.

Figure 4.04 shows the effect of intercropping and P application on P uptake by maize. Intercropping did not have any significant effect on P uptake , while the application of SSP resulted in significantly (p=0.01) higher total P uptake by maize.

4.1.1.4 Effect of cover crops and P application on soil P and pH

Effect of cover cropping and P application on soil pH at 50% flowering is shown in Tables 4.07 and 4.08. Averaged over all cover crops, SPR significantly (p=0.05) increased soil pH within the 0-15 cm soil depth. Although not significant, such increase was also observed within 15-30 cm soil depth. This trend is not surprising in view of the reported liming property of Sokoto phosphate rock (Amapu, 1999).

Averaged over all P sources, plots cropped with *Cajanus cajan*, *Chamaecrista rotundifolia*, *Stylosanthes hamata* and

Table 4.06: Effect of P application and intercropping on some maize performance parameters

Cropping	P source	Days to 50% silking	Shelling %	Grains/ cob	1000-grain weight (g)	Coblenght (cm)	Cob diameter (cm)	Kernel depth (cm)
Zea mays	°CRL	62.5	81.28	355	216	12.39	4.00	1.21
	SSP	60.4	82.45	405	232	13.10	4.18	1.30
	SPR	62.5	84.70	352	233	12.62	4.07	1.35
Zea mays +	CRL	63.0	82.28	381	210	12.02	4.00	1.28
C.rotundifolia	SSP	60.0	87.52	396	209	12.93	4.05	1.23
	SPR	62.8	84.50	336	221	11.48	4.05	1.28
Zea mays + C.cajan	CRL	61.1	79.63	429	214	13.29	4.17	1.29
	SSP	60.8	81.75	338	237	12.20	4.08	1.38
	SPR	64.5	82.67	307	205	11.45	3.90	1.18
SE± for cropping		ns	ns	ns	ns	ns	ns	ns
SE± for P source		1.67**	ns	46**	ns	ns	ns	ns
SE± for cropping x P source		ns	ns	46**	ns	ns	ns	ns
%CV		2.7	5.6	12.4	-	-	-	-

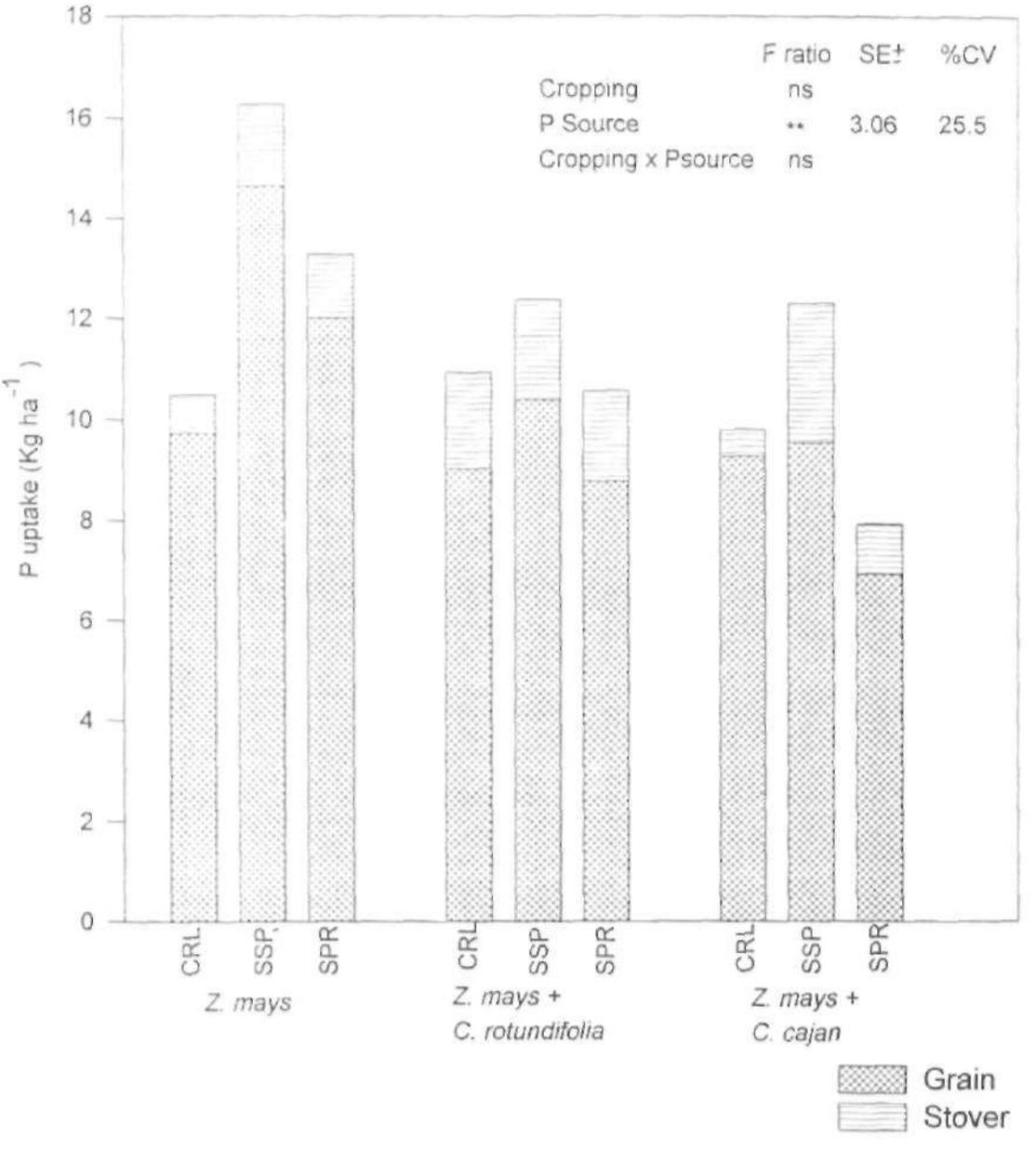


Figure 4.04: Effect of intercropping and P application on total P uptake by maize at Samaru (field I) in 1995

Table 4.07: Effect of cover crops on soil pH at 50% flowering in 1995 at Samaru (field I)

	Soil pH	
Cover crop	0-15cm	15-30 cm
Zea mays	5.67	5.58
Z.mays + Chamaecrista rotundifolia	5.80	5.56
Z.mays + Cajanus cajan	5.73	5.45
Chamaecrista rotundifolia	5.91	5.72
Cajanus cajan	6.03	5.80
Phaseolus vulgaris(brown)	5.65	5.90
Phaseolus vulgaris(variegated)	5.79	5.64
Crotalaria ochroleuca	5.60	5.64
Mucuna pruriens (white)	5.62	5.75
Lablab purpureus(black)	5.72	5.73
Lablab purpureus(white)	5.88	5.38
Glycine max	5.92	5.84
Stylosanthes hamata	5.92	5.71
F ratio	**	**
SE±	0.12	0.16
%CV	2.1	2.9

Table 4.08: Effect of P application on soil pH at 50% flowering in 1995 at Samaru (field I)

	Soil pH	
P Source	0-15cm	15-30 cm
CRL	5.75	5.61
SSP	5.75	5.67
SPR	5.83	5.69
F ratio	*	ns
SE±	0.19	-
%CV	3.3	-

Glycine max had their pH raised within the 0-15 cm soil depth. In the 15-30 cm region, *L. purpureus* (w) lowered the soil pH while *P. vulgaris* (v), *C. cajan* and *G. max* raised the pH.

The application of SSP resulted in higher levels of available soil P under all cover crops within 0-15 and 15-30 cm soil depths except for *G. max* and *C. cajan* in the 15-30 cm region (Tables 4.09 and 4.10). Sokoto phosphate rock raised the available soil P content within the 0-15 cm depth in *Chamaecrista rotundifolia*, *Phaseolus vulgaris* (v), *Cajanus cajan* and *Z. mays* + *Cajanus cajan* treatments by more than 30%, possibly due to the ability of these crops to solubilize P from SPR in excess of the crops's requirements. The ability of some green manures to mobilize P from soil in excess of their own demand and to even benefit a food crop in mixed culture has been demonstrated for *Lupinus albus* and wheat mixed culture in a pot experiment with acid soil (Horst and Waschkies, 1986) and under field conditions (Gardner and Boundy, 1983). Hofland (1991) concluded that P deficient rape mobilized more P from phosphate rock by root exudates than was actually needed to meet it's own requirements. Higher concentrations of available soil P were observed under the two varieties of *L. purpureus* within the 15-30 cm depth (Table 4.10).

Table 4.09: Effect of P application to cover crops on available soil P within 0-15 cm depth at 50% flowering in 1995 at Samaru (field I)

	Bray 1 P(mg kg^{-1})		
Cover crop	CRL	SSP	SPR
Zea mays	10.14	15.54	12.03
Z. mays + Chamaecrista rotundifolia	9.85	18.18	8.57
Z. mays + Cajanus cajan	7.20	12.90	11.60
Chamaecrista rotundifolia	10.73	20.60	16.36
Cajanus cajan	7.65	15.07	9.75
Phaseolus vulgaris(brown)	11.58	17.45	10.10
Phaseolus vulgaris(variegated)	11.20	26.45	15.70
Crotalaria ochroleuca	11.05	16.13	9.45
Mucuna pruriens (white)	8.07	21.50	8.10
Lablab purpureus(black)	9.22	18.00	8.07
Lablab purpureus(white)	9.40	18.12	9.00
Glycine max	12.97	20.75	14.55
Stylosanthes hamata	8.32	18.10	9.20
SE± for crop	1.72**		
SE± for Psource	2.74**		
SE± Crop x Psource	2.74**		
%CV	20.9		

Table 4.10: Effect of P application to cover crops on available soil P within 15-30 cm depth at 50% flowering in 1995 at Samaru (field I)

	Bray 1 P(mg kg^{-1})		
Cover crop	CRL	SSP	SPR
Zea mays	4.52	6.74	5.47
Z. mays + Chamaecrista rotundifolia	4.50	7.32	4.50
Z. mays + Cajanus cajan	3.76	4.73	3.70
Chamaecrista rotundifolia	4.28	5.72	5.17
Cajanus cajan	5.95	6.30	7.17
Phaseolus vulgaris(brown)	3.60	5.18	4.15
Phaseolus vulgaris(variegated)	0.90	7.85	2.70
Crotalaria ochroleuca	4.50	5.40	6.18
Mucuna pruriens (white)	4.50	9.13	5.50
Lablab purpureus(black)	7.53	12.43	9.32
Lablab purpureus(white)	6.53	12.95	6.75
Glycine max	6.40	5.62	6.52
Stylosanthes hamata	1.68	3.60	2.03
SE± for crop	1.73**		
SE± for Psource	2.24**		
SE± Crop x Psource	ns		
%CV	41.4		

Effect of cropping on various soil P fractions at 50% flowering in 1995 is shown in Fig. 4.05. For logistic reasons, soils from only two replicates were analyzed. The data generated was therefore not subjected to the usual analysis of variance. Table 4.11 shows the matrix of coefficient of correlation between the various phosphate fractions. Only sodium bicarbonate extractable inorganic P ($NaHCO_3$-Pi) correlated significantly (r=0.676**) with resin extractable P (resin P). Significant positive correlations were observed between $NaHCO_3$-Po and NaOH-Pi, $NaHCO_3$-Po and Residual P, and NaOH-Pi and residual P (r=0.701**, r=0.654*, r=0.689* respectively). The relationships between $NaHCO_3$-Pi and $NaHCO_3$-Po, NaOH-Pi, and residual P were negative (r=-0.546*, r=-0.547*, and r=-0.619* respectively). The relationship between NaOH-Pi and NaOH-Po was also negative (r=-0.618*).

Result of path coefficient analysis showing the direct and indirect contributions of $NaHCO_3$ and NaOH extractable organic and inorganic soil P fractions to the resin extractable (bioavailable) P fraction is presented in Fig. 4.06. About 77% of the resin extractable P fraction in this soil is contributed directly by $NaHCO_3$ extractable inorganic P fraction.

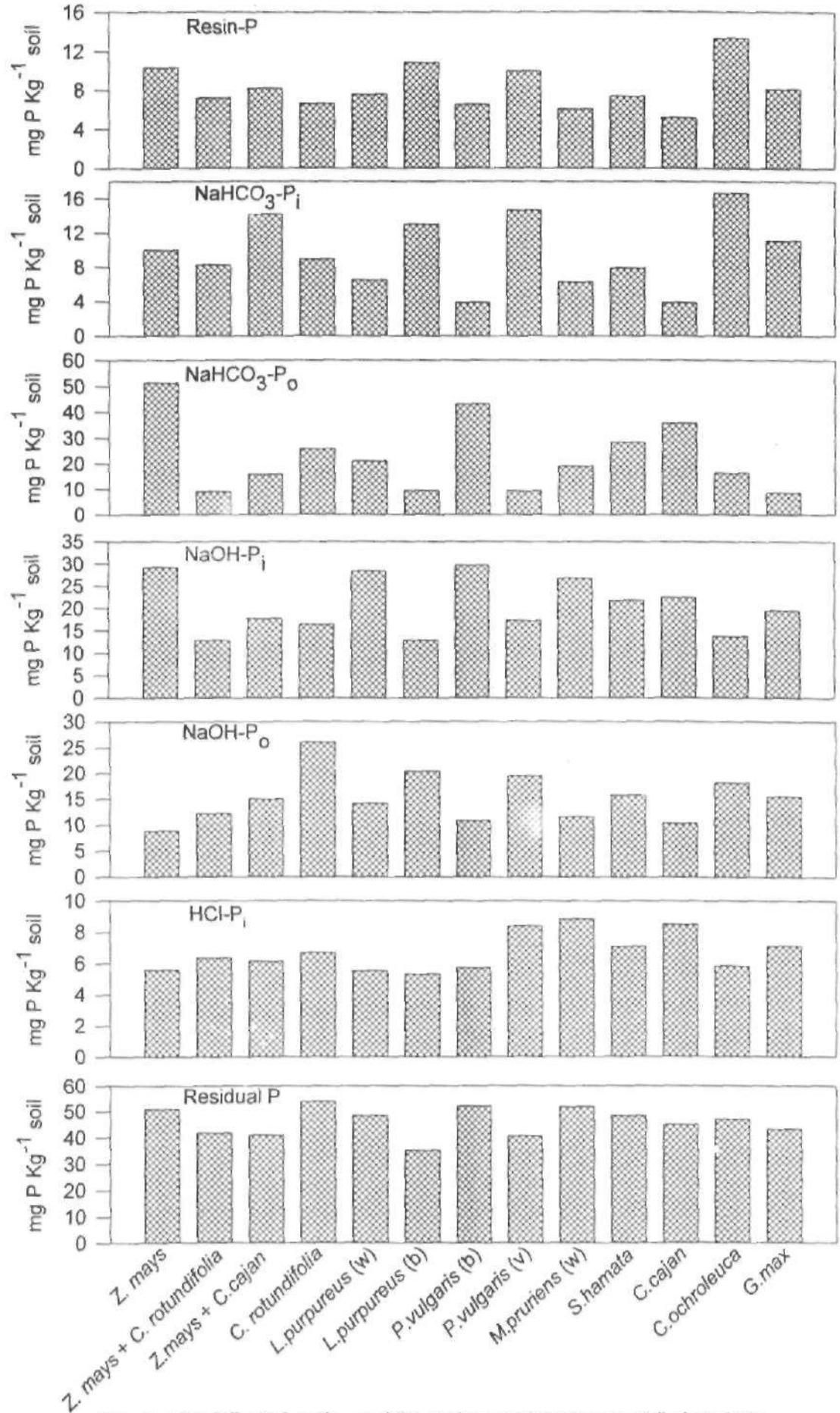


Figure 4.05: Effect of maize and the various cover crops on soil phosphate fractions at 50% filowering in 1995 (Samaru, Field I)

Table 4.11: Matrix of coefficients of correlation between various soil phophate fractions at 50% flowering in 1995 (Samaru, field I)

	Resin-P	NaHCO3-Pi	NaHCO3-Po	NaOH-Pi	NaOH-Po	HCl-Pi	Residual P
Resin-P	1.000						
NaHCO3-Pi	0.676**	1.000					
NaHCO3-Po	-0.153	-0.546	1.000				
NaOH-Pi	-0.206	-0.547	0.701**	1.000			
NaOH-Po	0.144	0.428	-0.454	-0.618*	1.000		
HCl-Pi	-0.326	-0.115	-0.139	-0.057	-0.018	1.000	
Residual P	-0.487	-0.619*	0.654*	0.689**	-0.159	0.067	1.000

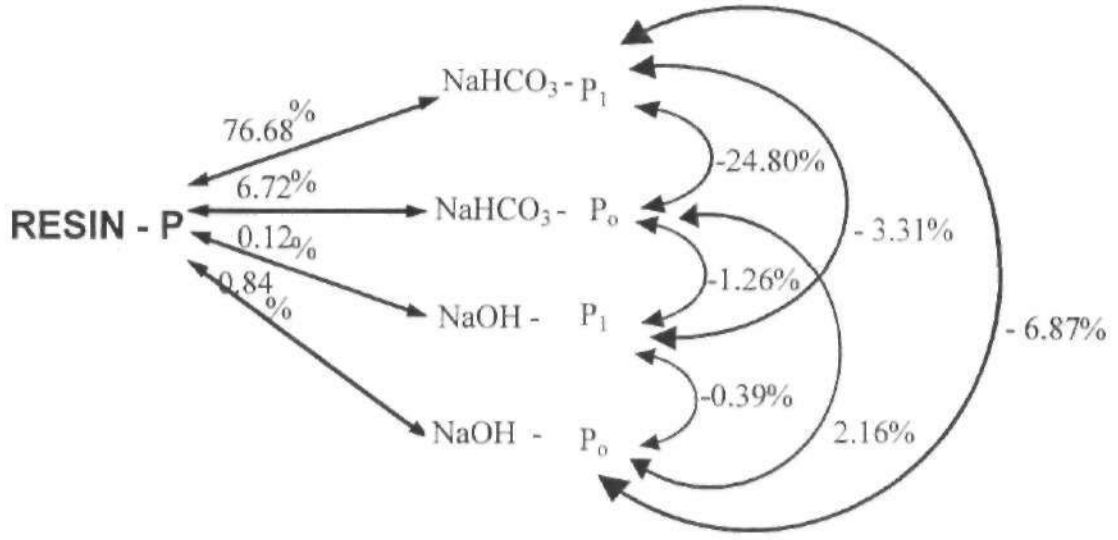


Fig. 4.06: : Percentage contributions of $NaHCO_3$ and NaOH extractable organic and inorganic soil P fractions to resin extractable P fraction.

4.1.2 Second and third years (succeeding maize)

4.1.2.1 Effect of P application to previous crops on the performance of succeeding maize in 1996 and 1997

Maize height was monitored at intervals during the growth of the crop. In 1996, no significant interaction effects of P source and preceding cover crops on plant height were observed through out the growth of the crop. However there were clear effects of P source (Fig. 4.07) and preceding cover crops (Fig. 4.08) on plant height. Averaged over all preceding cover crops, significantly ($p=0.01$) taller plants were observed at 6, 8 and 10 WAP on all plots previously (1995) treated with SSP. At 12 WAP, though SSP treated plots produced taller maize than the control, the differences were not significant. Effect of 1995 SPR application did not manifest in maize height at any stage of the crop's growth in 1996 (Fig. 4.07). Plots preceded by *L. purpureus* (b), *C. rotundifolia*, *M. pruriens* (W), *L. purpureus* (w), *S. hamata*, *G. max*, *C. cajan* and *Z. mays* + *C. cajan* produced significantly ($p=0.01$) taller maize plants through out the growth of the crop compared to plots preceded by *Z. mays* without crop residue incorporation (Fig. 4.08). The beneficial effect of incorporation of *C. ochroleuca* in 1995 on maize height in 1996 started manifesting only at 10 WAP.

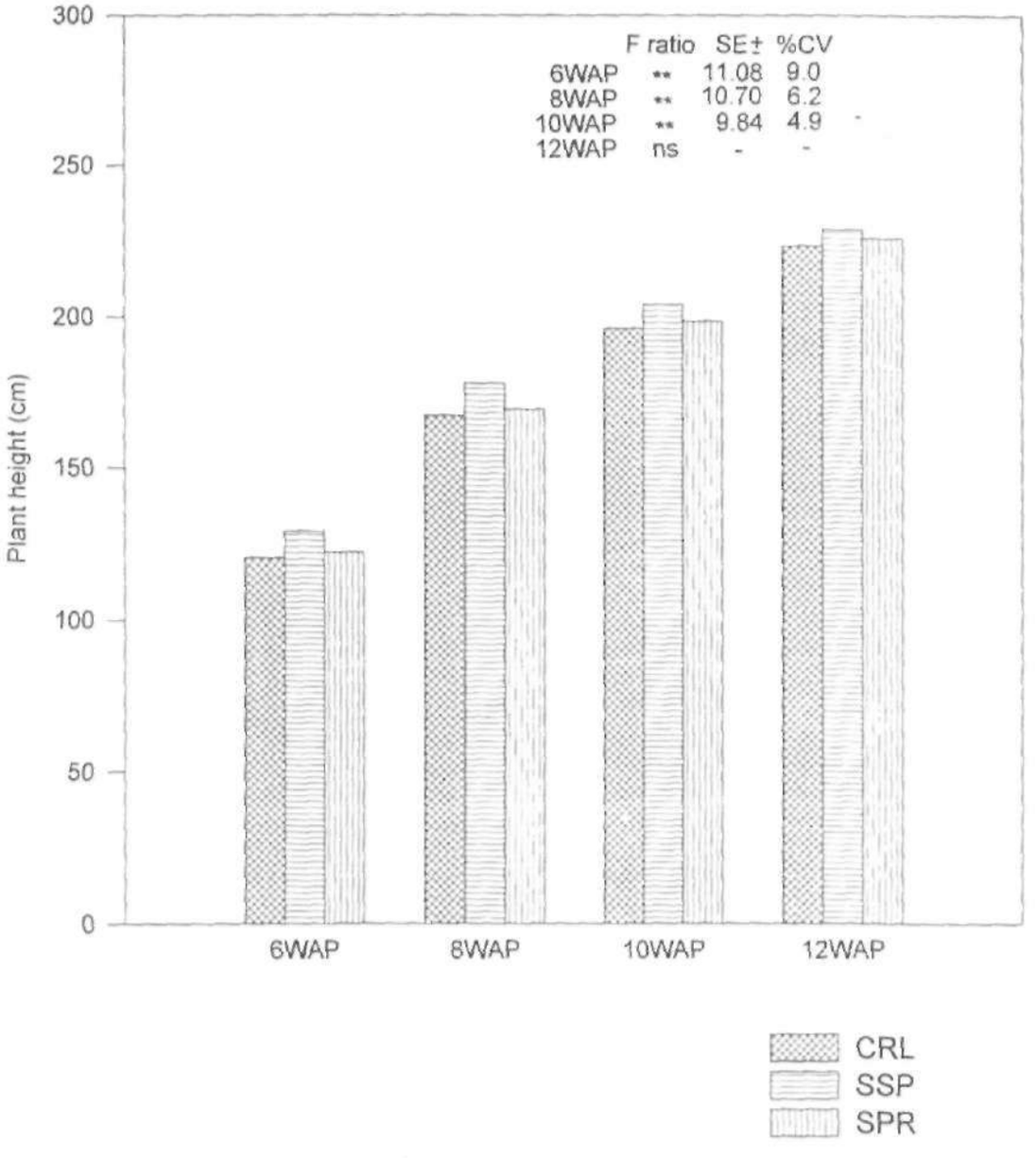


Figure 4.07: Effect of 1995 P application to cover crops on maize height in 1996 at Samaru (averaged over preceding cover crops)

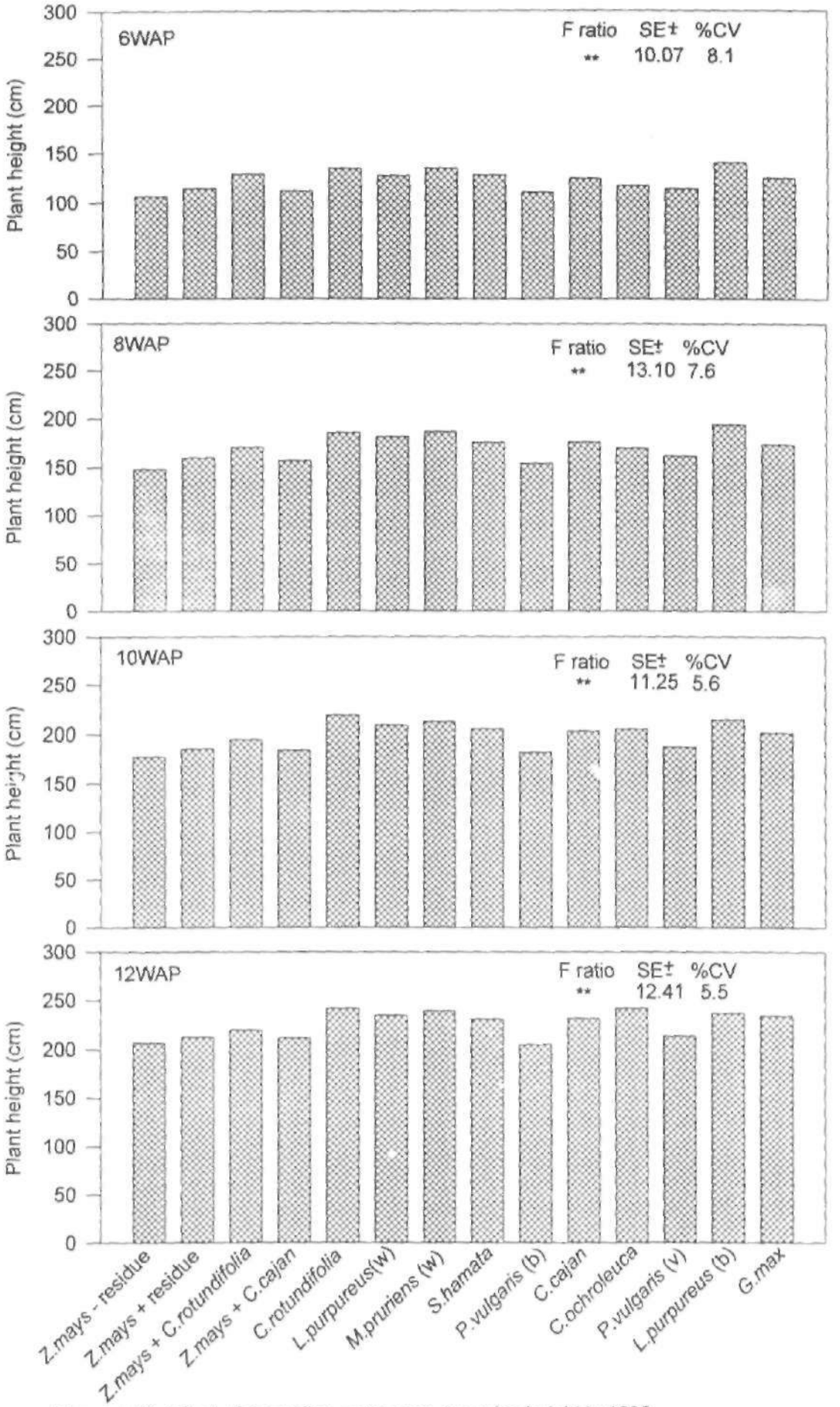


Figure 4.08: Effect of preceding cover crop on maize height in 1996 at Samaru (averaged over P sources)

In 1997, all the 1995 crop treatments produced significantly (P=0.01) taller maize at 6 WAP than the control (maize without crop residue incorporation)(Fig. 4.09). However, at 8, 10 and 12 WAP, the differences between the various crop treatments in terms of maize height were not obvious. This shows that the beneficial effect of the various cover crop treatments on height (growth) of subsequent maize was only manifested in the first year after incorporation. Agboola (1982) reported that the effects of green manures and crop residues in tropical African soils are short-lived. Pooled over all previous cover crop treatments, maize height in 1997 was significantly taller at all periods of growth on plots treated with SSP in 1995 compared to SPR or CRL (Fig. 4.10). However, SPR produced significantly taller maize than CRL at 8 and 10 WAP.

The mean effects of 1995 cover cropping and P treatments on heights of succeeding maize crop in 1996 and 1997 are shown in Figs. 4.11, 4.12, 4.13 and 4.14. All cover crop treatments except *C. ochroleuca*, *P. vulgaris* (v) and *Z. mays* + *C. cajan* at 6 WAP; *P. vulgaris* (b) at 8 WAP; *P. vulgaris* (b), *P. vulgaris* (v) and *Z. mays* + residue at 10 WAP; and *P. vulgaris* (b), *P. vulgaris* (v), *Z. mays* + residue, and *Z. mays* + *C. cajan* at 12 WAP produced taller maize than the control. Taller maize plants were produced on SSP treated plots at all

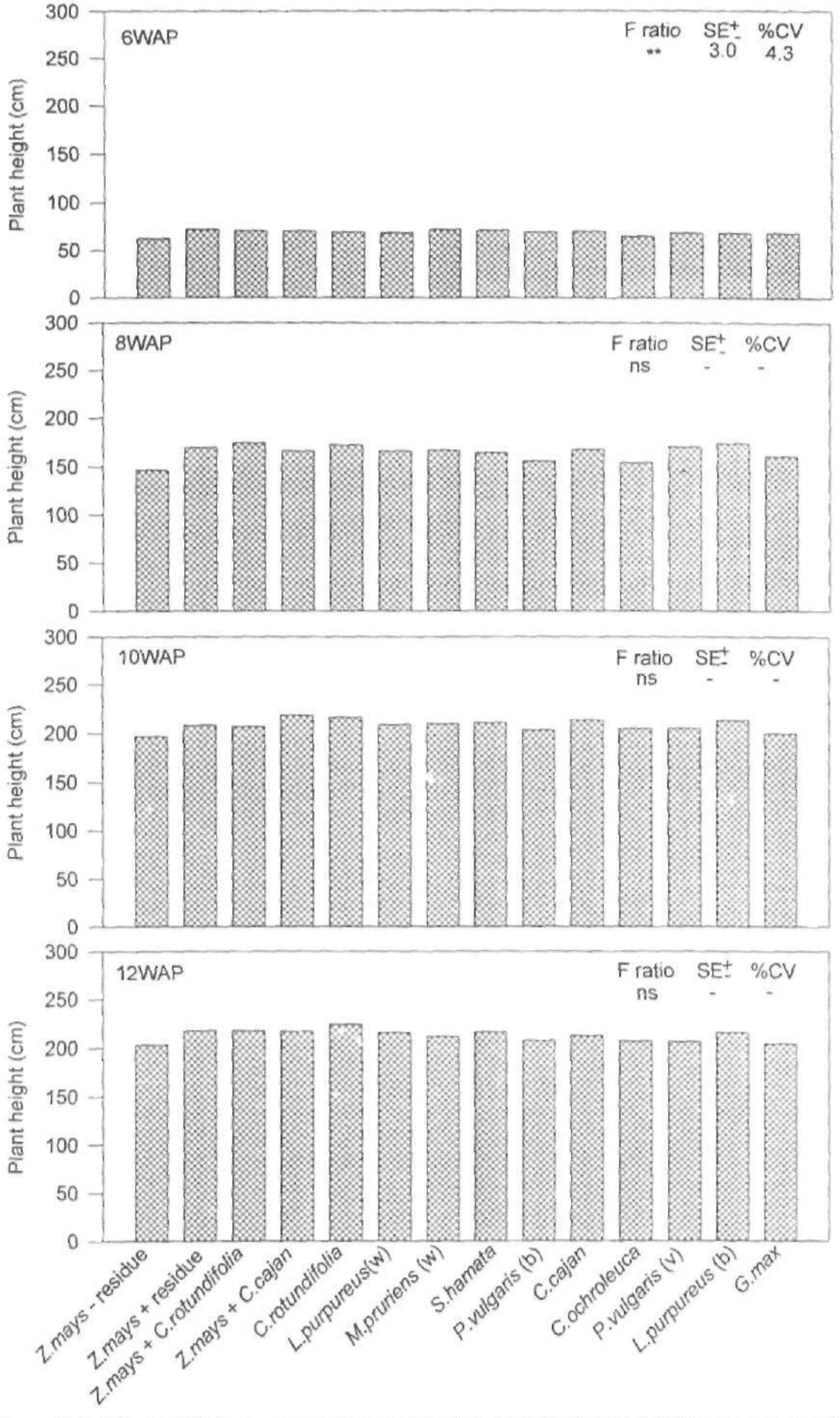


Figure 4.09: Effect of 1995 cover cropping on maize height at Samaru in 1997 (averaged over P sources)

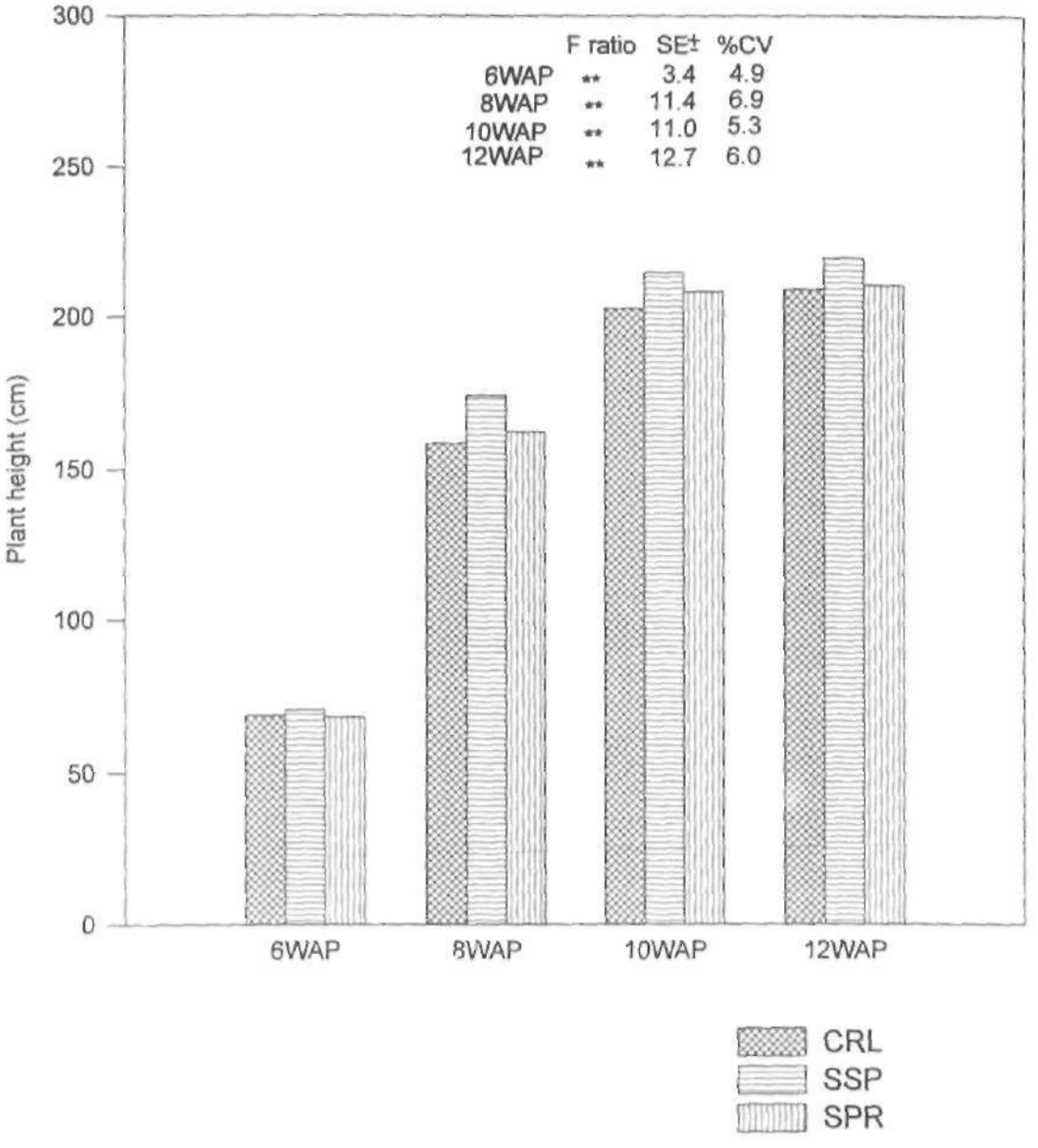


Figure 4.10: Effect of 1995 P application to cover crops on maize height at Samaru in 1997 (averaged over preceding cover crops)

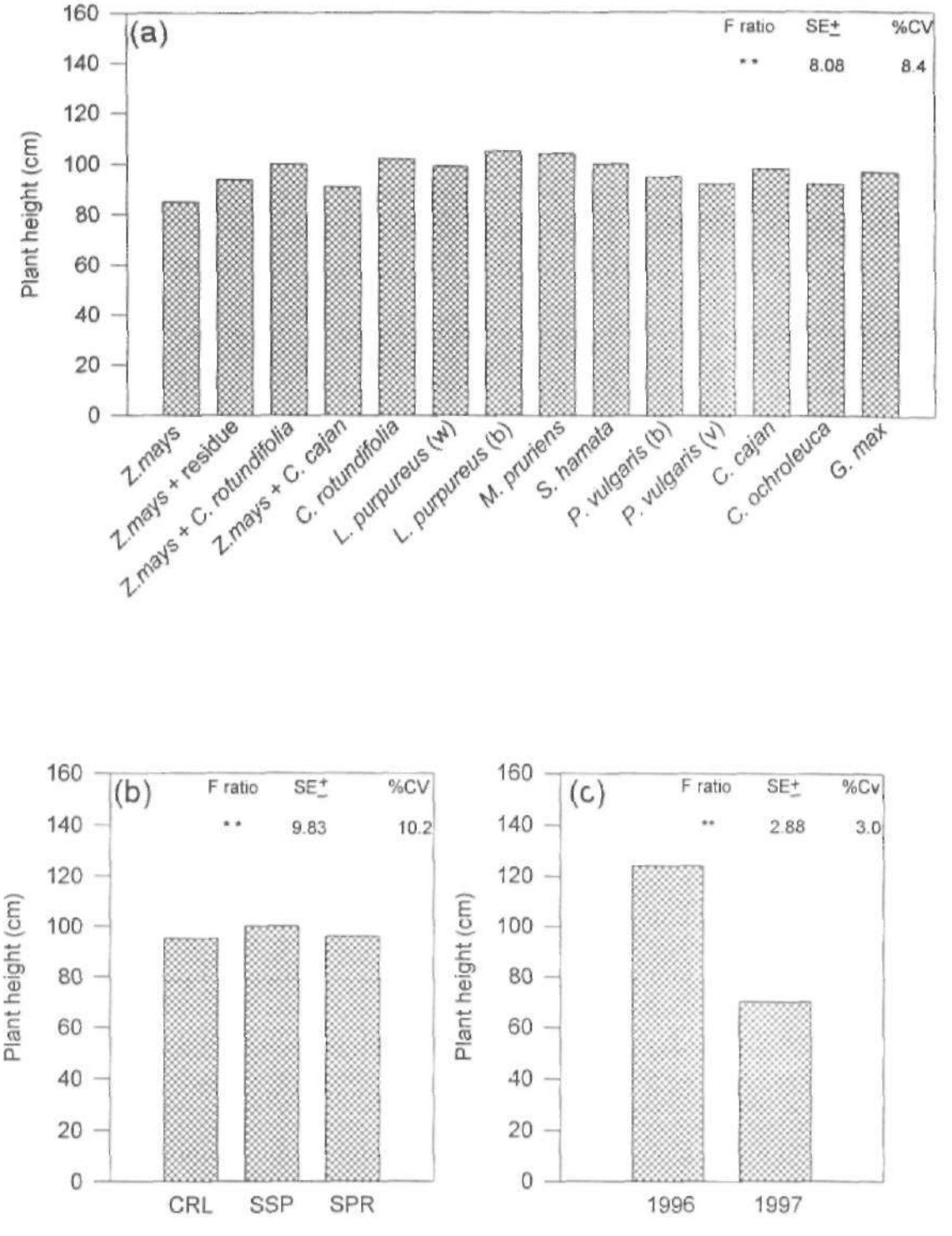


Fig. 4.11: Mean effects of treatments on maize height at 6 WAP (a) pooled over years and preceding crops (b) pooled over years and P sources (c) pooled over preceding crops and P sources

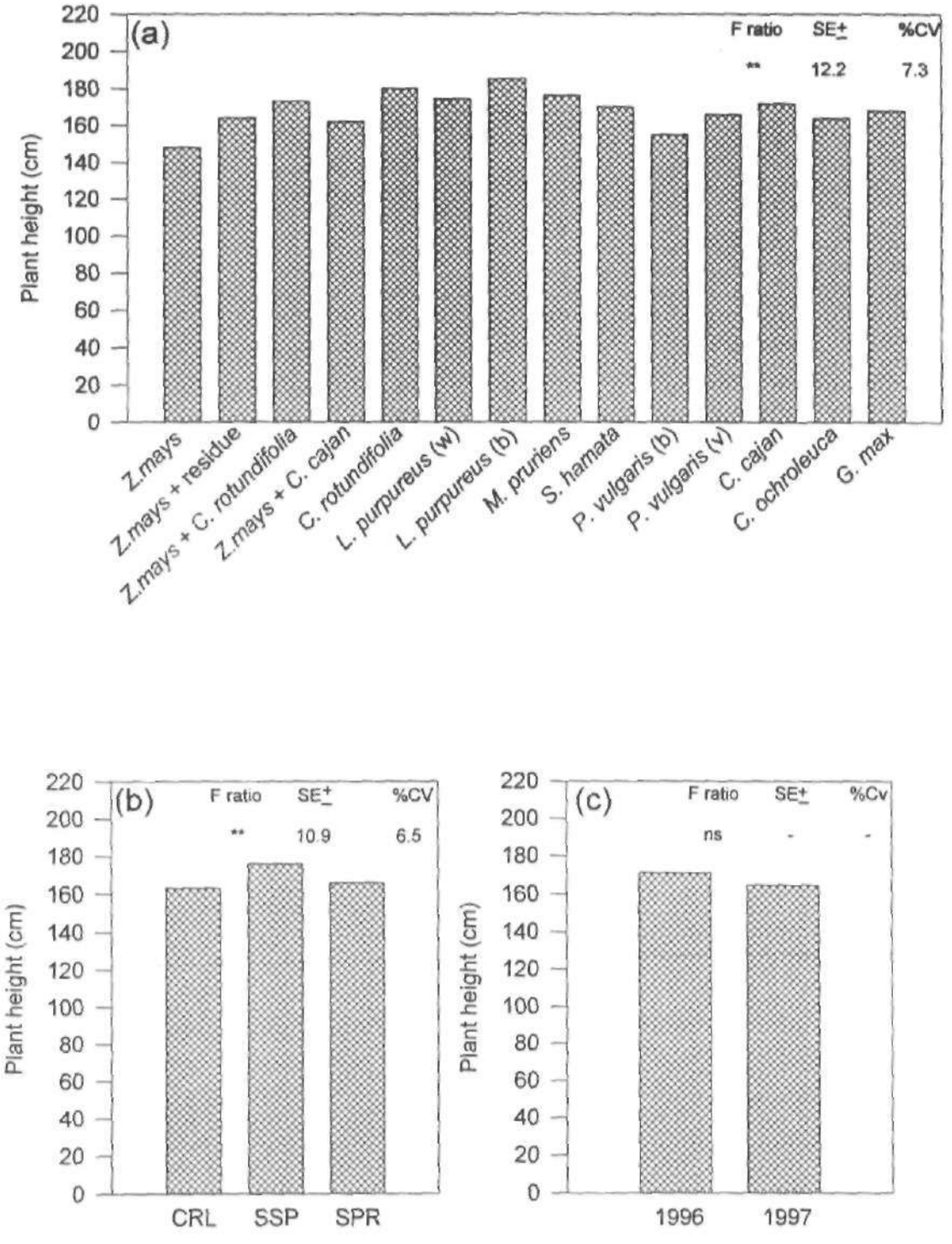


Fig. 4.12: Mean effects of treatments on maize height at 8 WAP (a) pooled over years and preceding crops (b) pooled over years and P sources (c) pooled over preceding crops and P sources

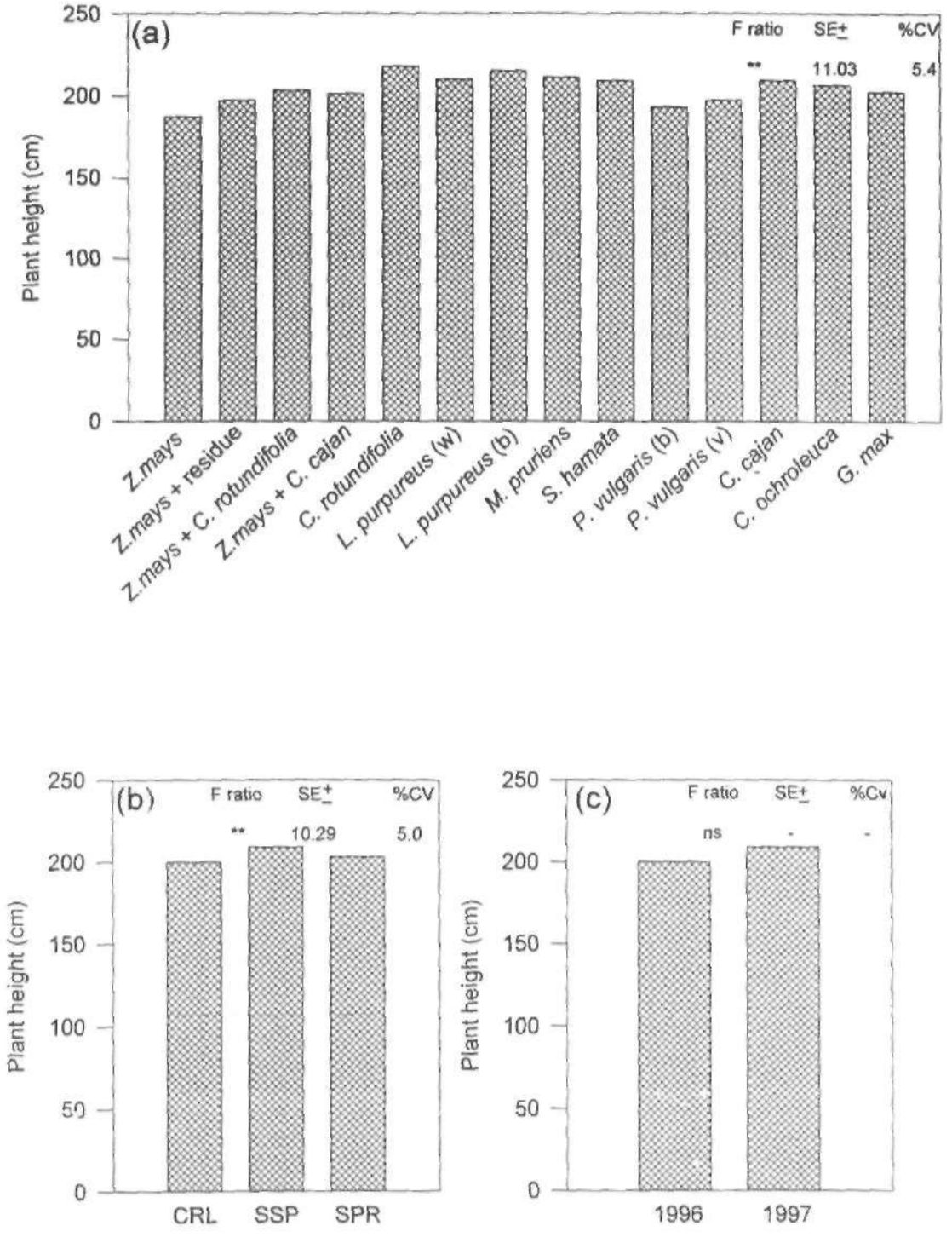


Fig. 4.13: Mean effects of treatments on maize height at 10 WAP (a) pooled over years and preceding crops (b) pooled over years and P sources (c) pooled over preceding crops and P sources

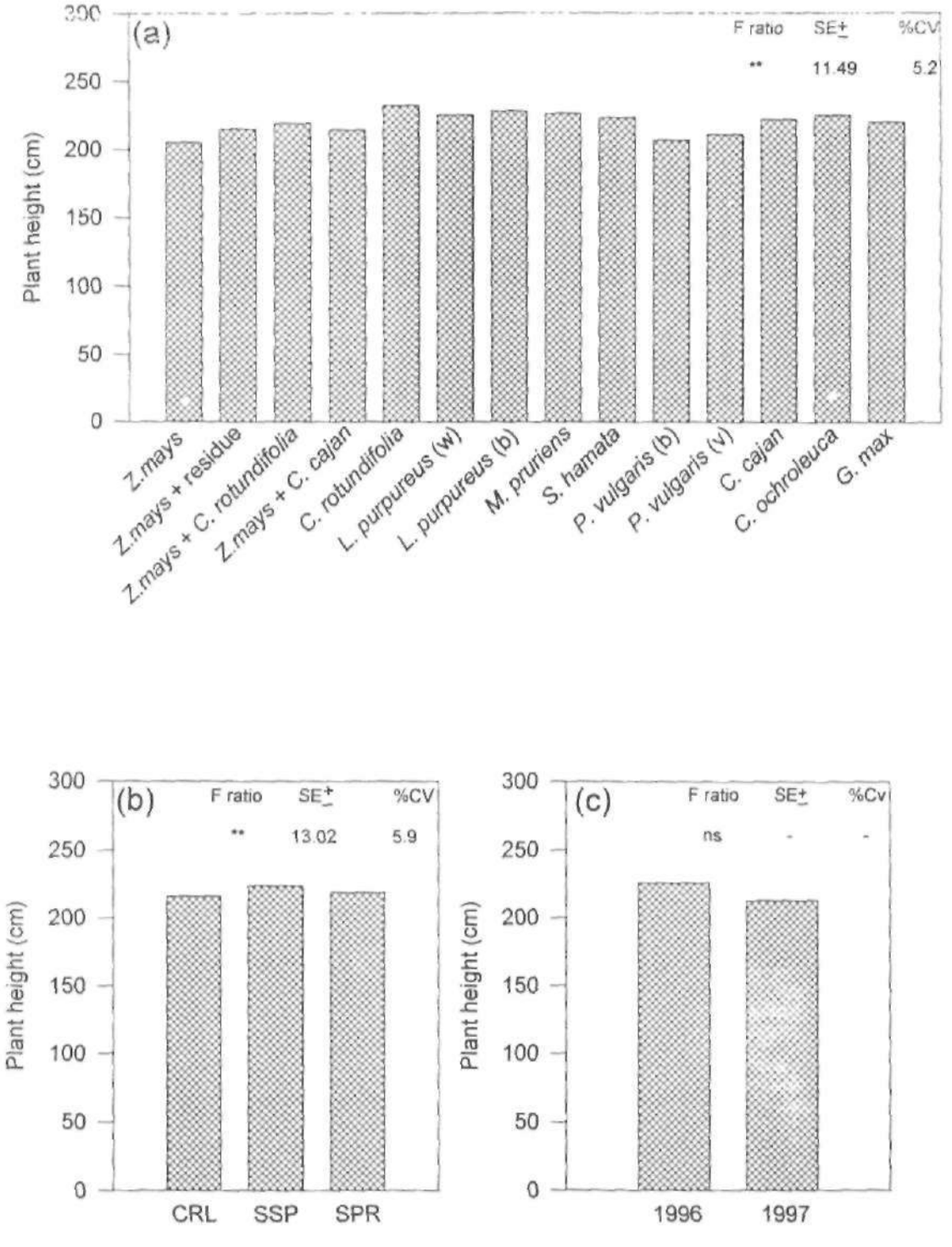


Fig. 4.14: Mean effects of treatments on maize height at 12 WAP (a) pooled over years and preceding crops (b) pooled over years and P sources (c) pooled over preceding crops and P sources

intervals, while SPR produced taller maize than CRL only at 10 WAP. The difference between mean heights of maize in 1996 and 1997 was significant only at 6 WAP.

Figures 4.15 and 4.16 show the effect of preceding cover crop and P application in 1995 on above ground biomass production by succeeding maize crop at 6 WAP in 1996. Plots preceded by *S. hamata, G. max, M. pruriens, C. rotundifolia,* the two varieties of *L. purpureus,* and *Z. mays + C. rotundifolia* produced significantly greater amounts of biomass at 6 WAP relative to the control plots. Averaged over all preceding crops, application of P in 1995 did not produce statistically significant effect on maize biomass at 6 WAP in 1996. In 1997 , biomass at 6 WAP was not sampled.

Grain yields of succeeding maize crop in 1996 was significantly influenced by the 1995 cover cropping (Fig. 4.17). Highest yields were obtained on plots preceded by *C. rotundifolia, L. purpureus* (b), and *L. purpureus* (w) which respectively produced 60.34, 59.82 and 52.34% more yield than the control . *Glycine max, P. vulgaris* (b), *P. vulgaris* (v), *Z mays + C. cajan, Z. mays + C. rotundifolia,* and *Z. mays +* residue had no significant effect on maize yield in 1996. Phosphate fertilization in 1995 did not significantly affect maize grain yield in 1996 (Fig. 4.18). No significant

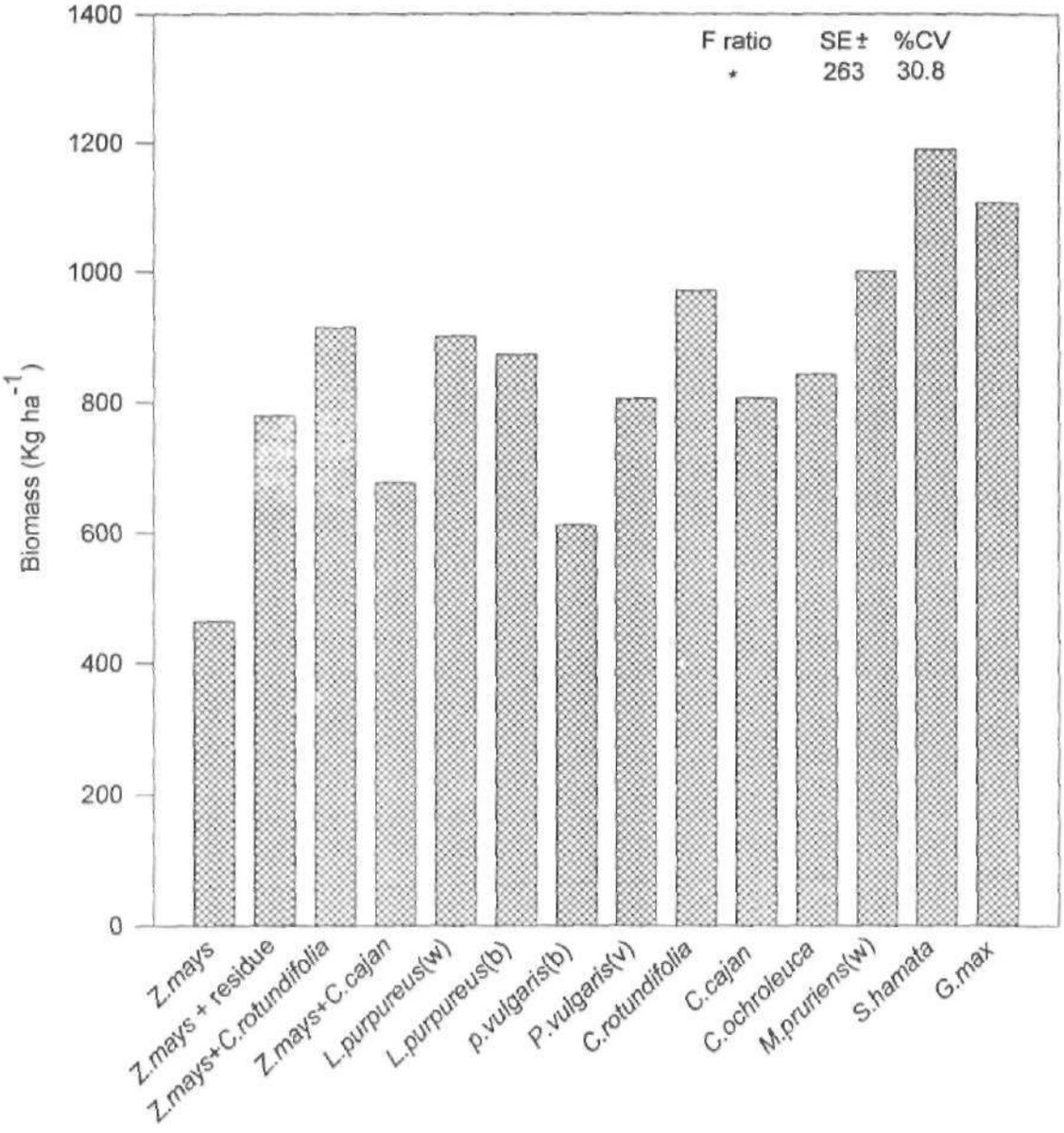


Figure 4.15: Effect of preceding cover crop on maize biomass at 6WAP in 1996 at Samaru field I (averaged over all P sources)

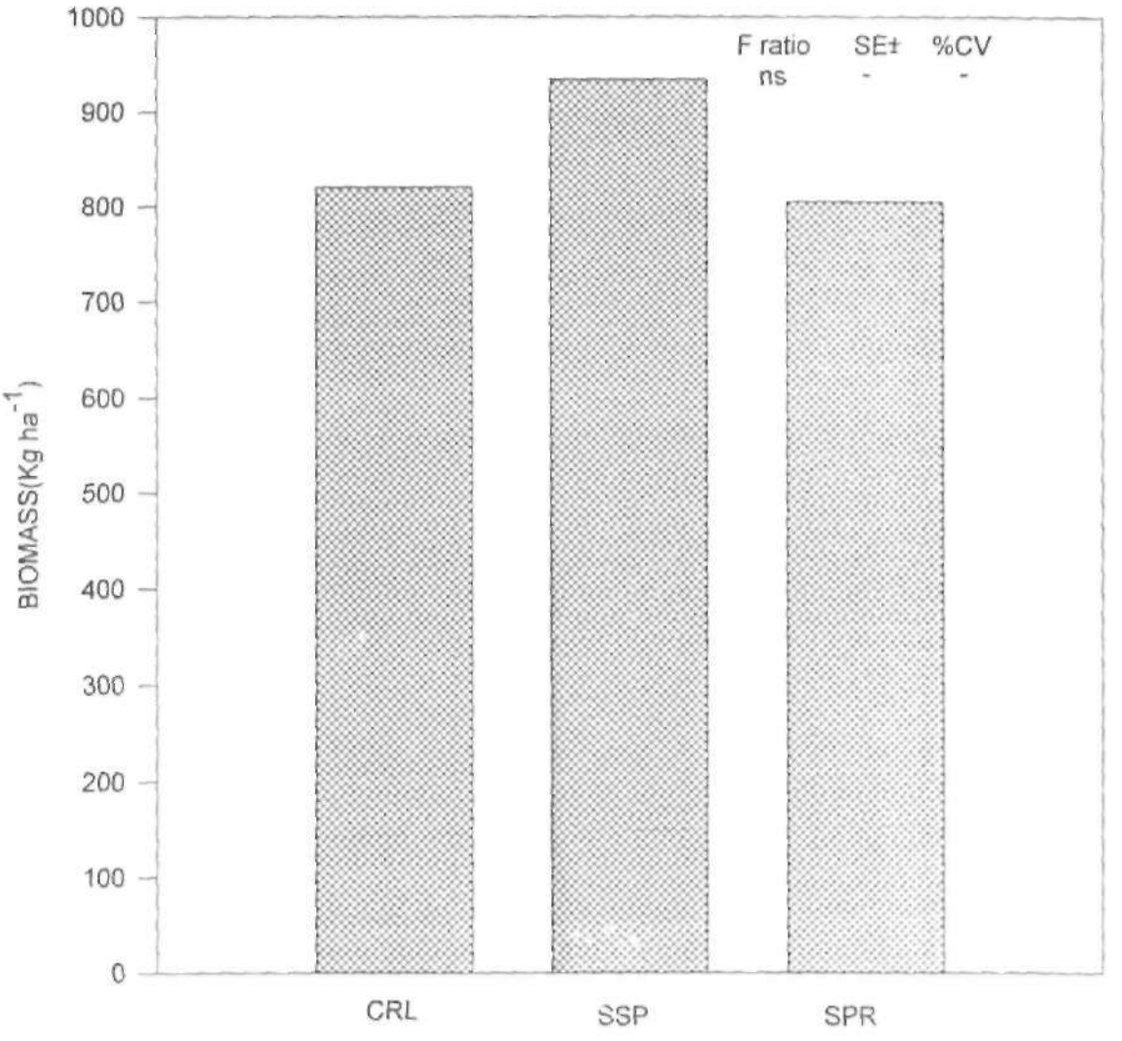


Figure 4.16: Effect of P application to preceeding cover crop on maize biomass at 6 WAP in 1996 at Samaru field I (averaged over preceeding crops)

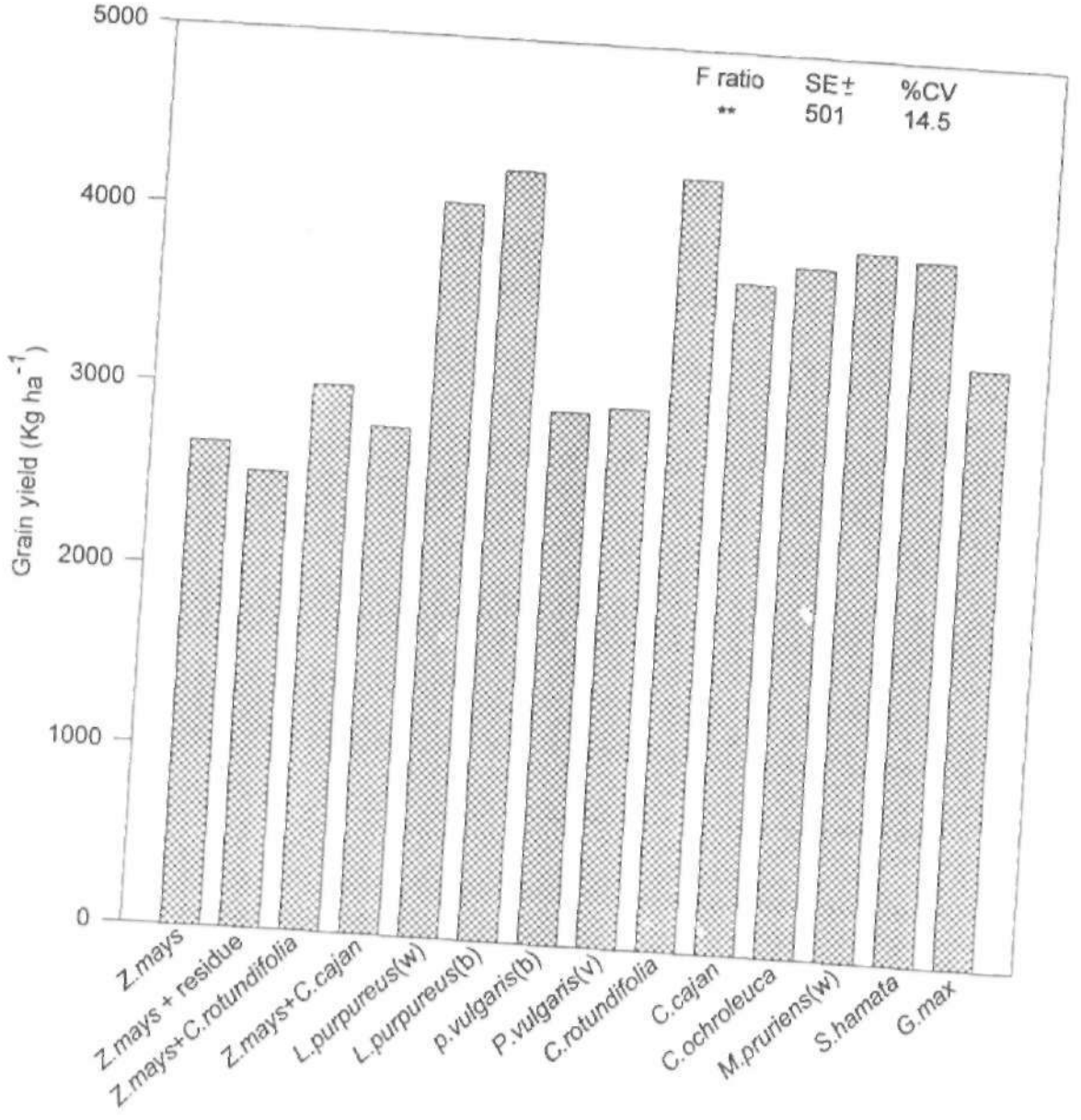


Figure 4.17: Effect of preceeding cover crop on maize *grain yield* in 1996 *at Samaru* (averaged over all P sources)

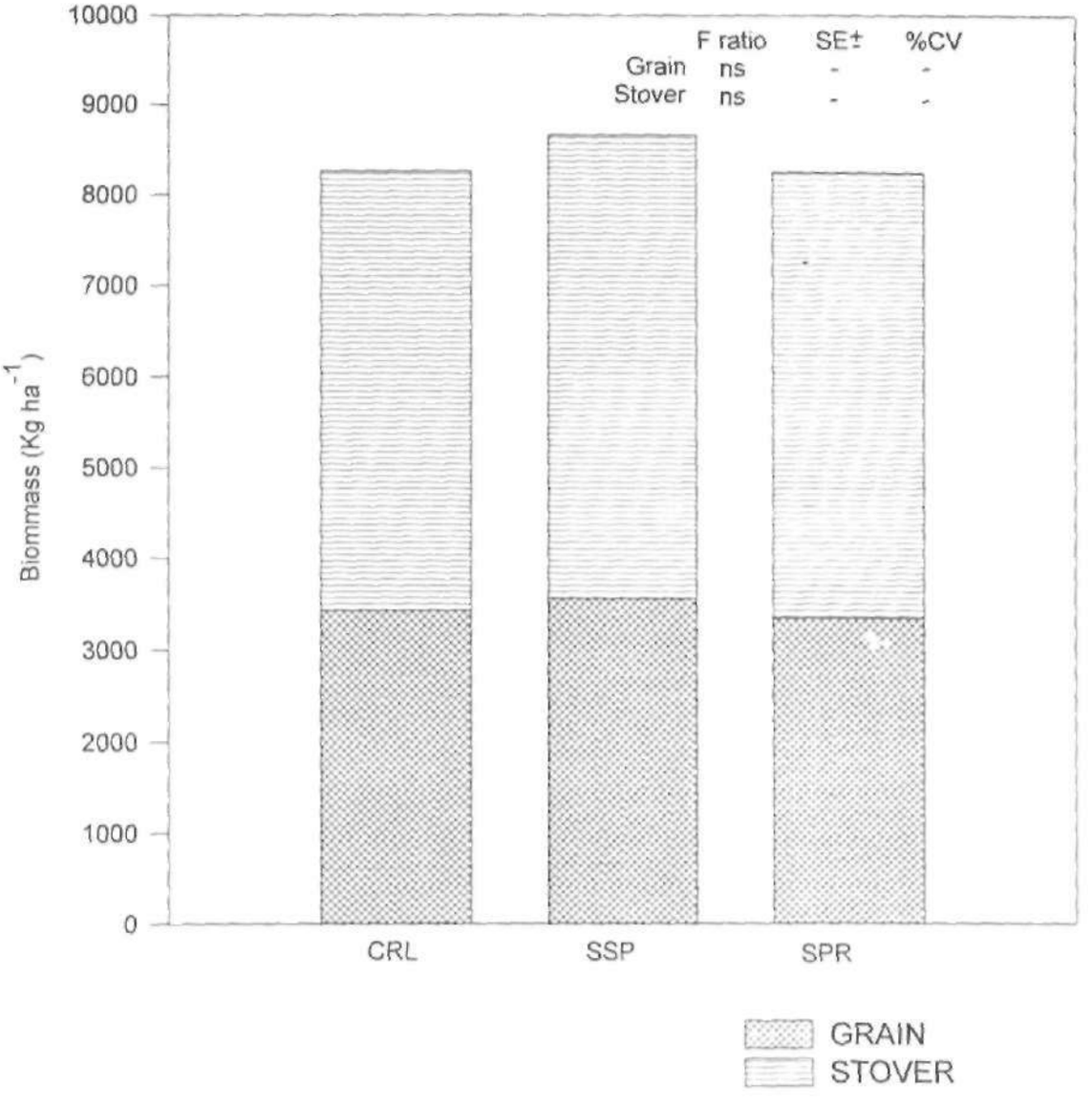


Figure 4.18: Effect of P application to preceeding cover crop on maize grain and stover yields in 1996 at Samaru (averaged over all preceeding crops)

interaction effect between 1995 P source and preceding cover crop was observed on maize grain yield in 1996. The significant grain yield increases observed on plots preceded by *C. rotundifolia* and the two varieties of *L. purpureus* may not have been due to P effect. Improvement of soil physical properties, organic matter, and total N content could also be responsible for increased yield of succeeding crop (Wilson *et al.*, 1982; Agboola, 1982; Adetunji, 1997).

In 1997, maize grain yields produced on plots preceded in 1995 by *C. cajan, C. rotundifolia, S. hamata, P. vulgaris*(v) and the two varieties of *L. purpureus* were non-significantly higher (Fig. 4.19). This further confirms the fact that the beneficial effect of residue incorporation is short-lived. Averaged over all cover crop treatments, the residual effects of both SSP and SPR in terms of grain yield were quite obvious in 1997. Plots previously treated with SSP significantly out-yielded those preceded by SPR and CRL, while SPR significantly out-yielded CRL (Fig. 4.20). This shows that the initial (native) soil P (Table 3.01) was sufficient enough to support crop growth for two seasons, and the effect of P fertilizer application only starts manifesting after two years of cropping without fresh P application. The good performance of SPR in 1997 is an indication of it's high residual value. High residual effects of SPR on maize yields have also been

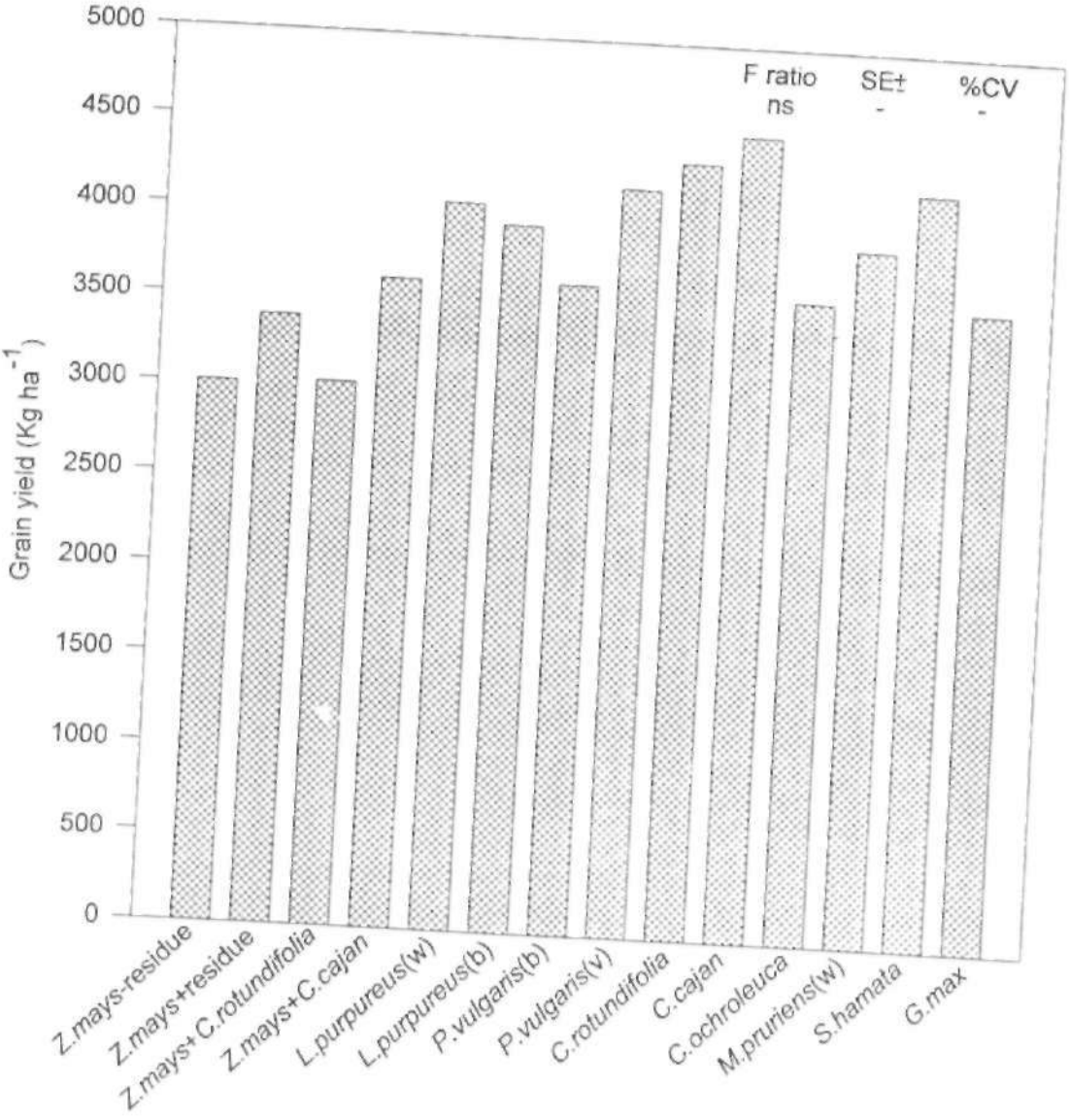


Figure 4.19: Effect of 1995 cover cropping on maize grain yield at Samaru in 1997 (averaged over P sources)

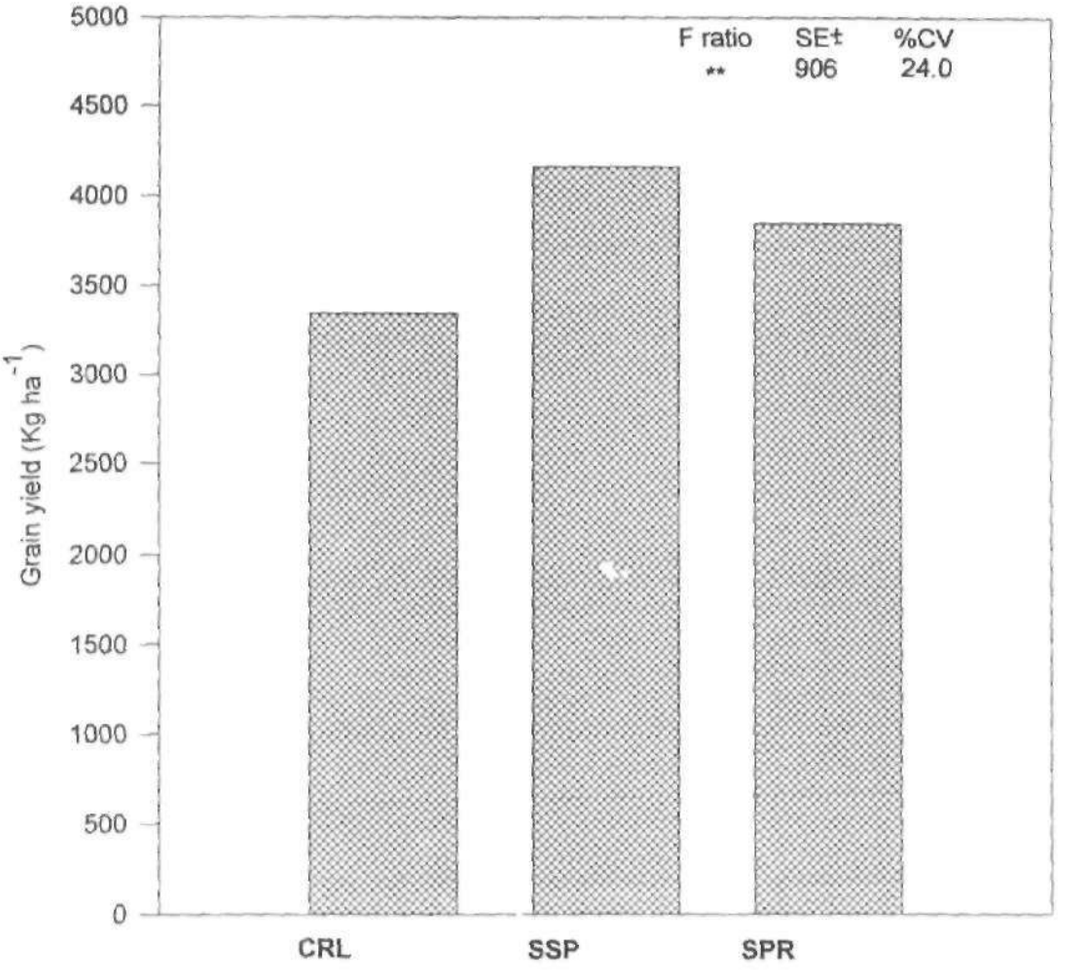


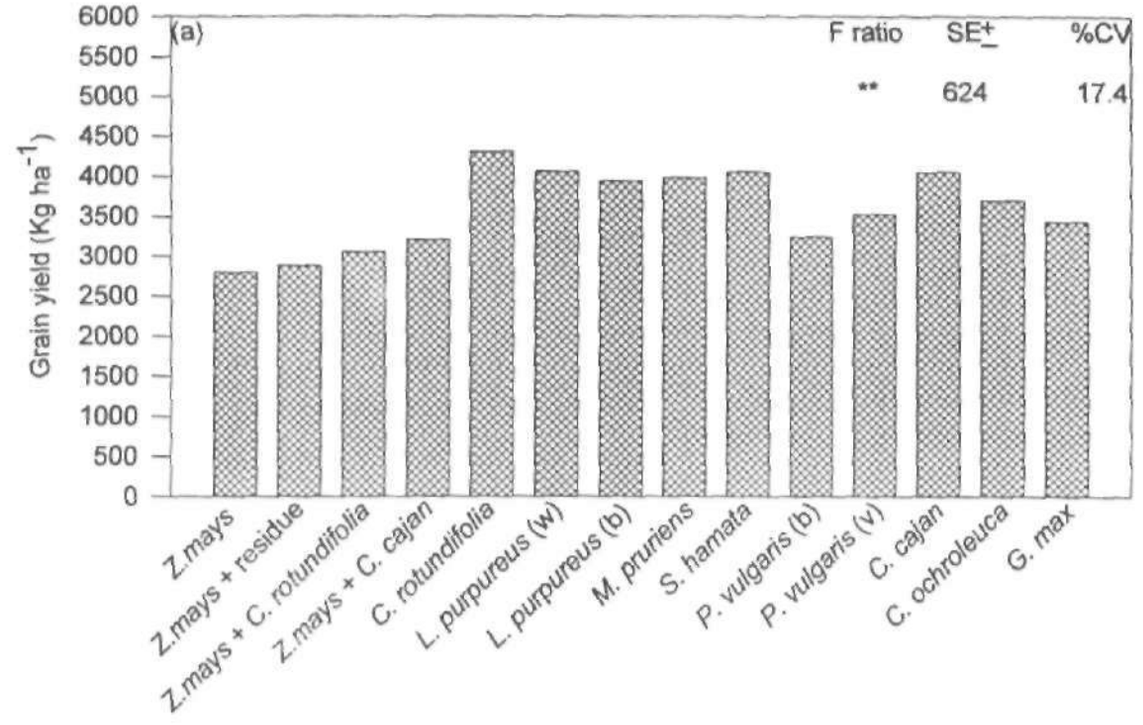
Figure 4.20: Effect of 1995 P application to cover crops on maize grain yield at Samaru in 1997 (averaged over cover crops)

reported by Jibrin (1995) and Chude *et al.* (1997) in studies conducted at Samaru.

Mean values for 1996 and 1997 maize grain yield is shown in figure 4.21. *Phaseolus vulgaris* (b), *Z. mays*+residue, *Z. mays + C. rotundifolia* and *Z. mays + C. cajan* treatments did not significantly affect the mean grain yield. All other cover crop treatments significantly improved grain yield, with *C. rotundifolia, C. cajan*, the two varieties of *L. purpureus, S. hamata* and *M. pruriens* (W) each producing more than 40% increase. Mean grain yield for the two years was significantly higher on SSP treated plots than on plots previously treated with SPR or CRL which were at par. Although mean grain yield for 1996 was higher, there was no significant yield difference between 1996 and 1997.

Similar to grain yield, phosphate fertilization in 1995 did not significantly affect stover yield of maize in 1996 (Fig. 4.18). However, there were significant (P=0.01) effects of cover cropping on stover yields of succeeding maize crop (Fig. 4.22). Maize plots preceded by *L. purpureus* (b), *C. rotundifolia*, and *S. hamata* yielded more stover relative to the control treatment.

In contrast to 1996, SPR yielded more stover in 1997



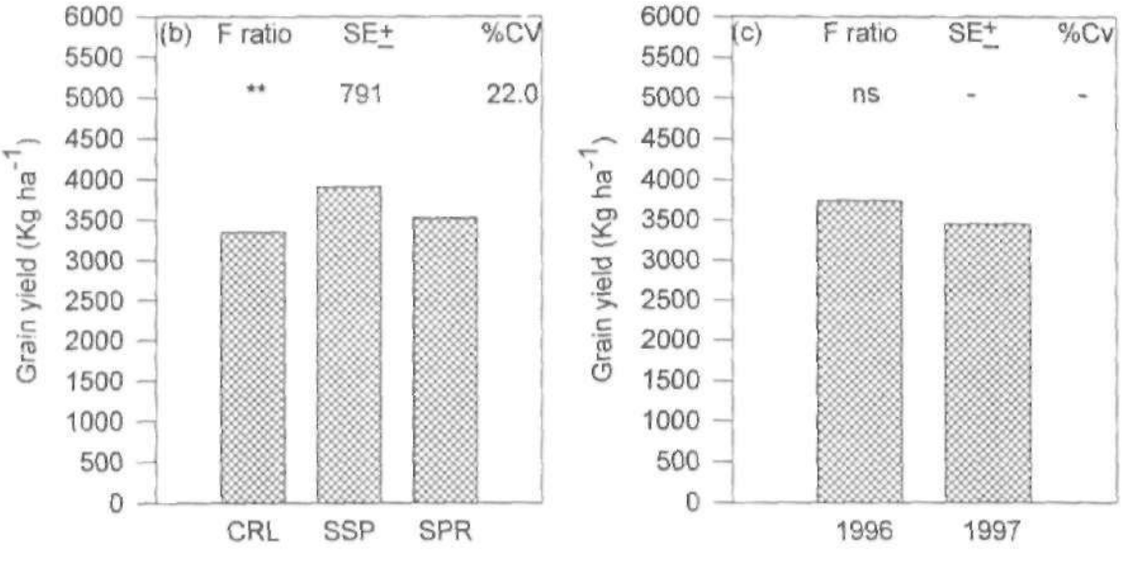


Fig. 4.21: Mean effect of treatments on maize grain yield at Samaru (Field I) (a) pooled over 1996 and 1997 P treatments (b)pooled over preceding crops and 1997 P treatments (c) pooled over preceding crops and 1997 P treatments.

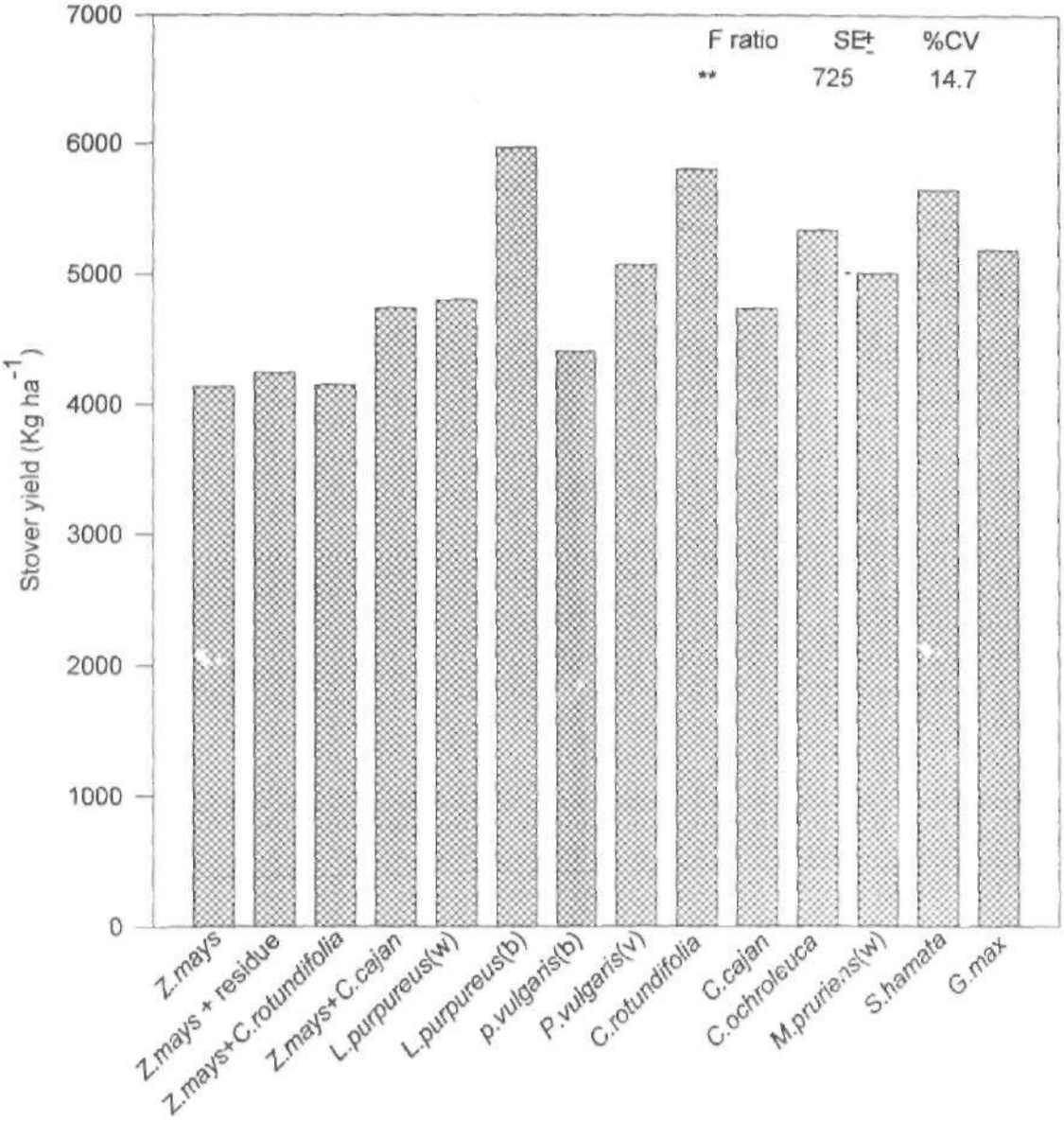


Figure 4.22: Effect of preceeding cover crop on maize stover yield in 1996 at Samaru (averaged over all P sources)

than SSP or CRL (Fig. 4.23). This is a further confirmation of the high residual value of SPR. Stover yields in 1997 were highest on plots preceded by *L. purpureus* (b), *P. vulgaris* (v), *C. cajan* and *Z. mays* + *C. rotundifolia* (Fig. 4.24).

Mean stover yield for 1996 and 1997 show both SSP and SPR yielding significantly greater amounts of stover than CRL (Fig. 4.25). Averaged over P sources and years, mean stover yields on plots preceded by *L. purpureus* (b), *C. rotundifolia*, *S. hamata*, *P. vulgaris* (v) and *G. max* were significantly (P=0.05) higher than on the control plots.

4.1.2.2 Effect of 1995 cover cropping and P application on tissue P concentration of succeeding maize

Figure 4.26 shows the effect of preceding cover crops and previous P fertilization on P concentration in the shoot of succeeding maize crop at 6 WAP in 1996. Both previous P fertilization and 1995 cover cropping did not significantly affect tissue P concentration of maize shoot at 6 WAP in 1996.

Phosphorus concentration of maize grains in 1996 is shown in Figs. 4.27, 4.28 and 4.29. Averaged over all P sources, all the preceding crop treatments except *Z. mays* + residue, *P.*

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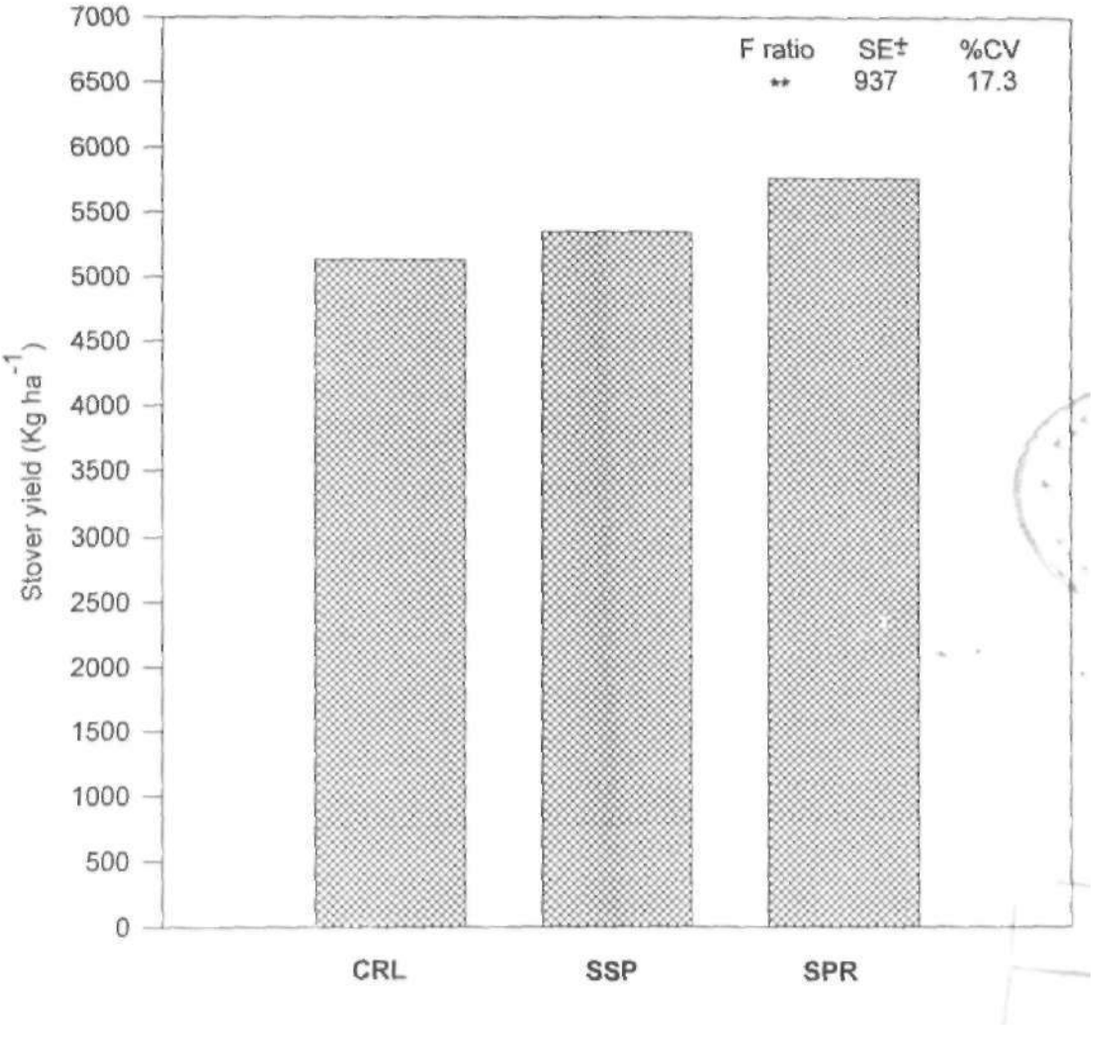


Figure 4.23: Effect of 1995 P application to cover crops on maize stover yield at Samaru in 1997 (averaged over cover crops)

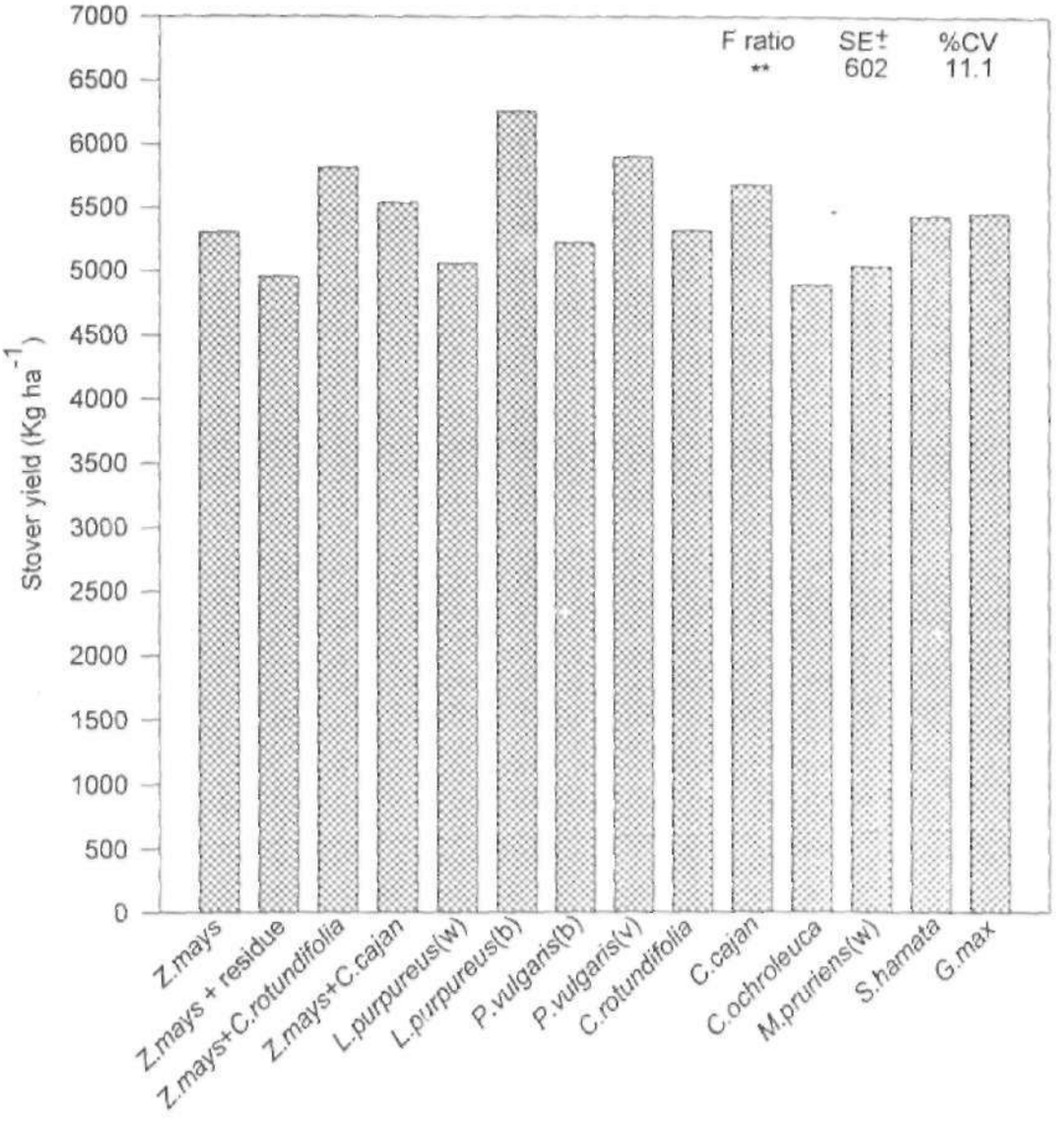


Fig. 4.24: Effect of 1995 cover cropping on maize stover yield at Samaru in 1997 (averaged over P sources)

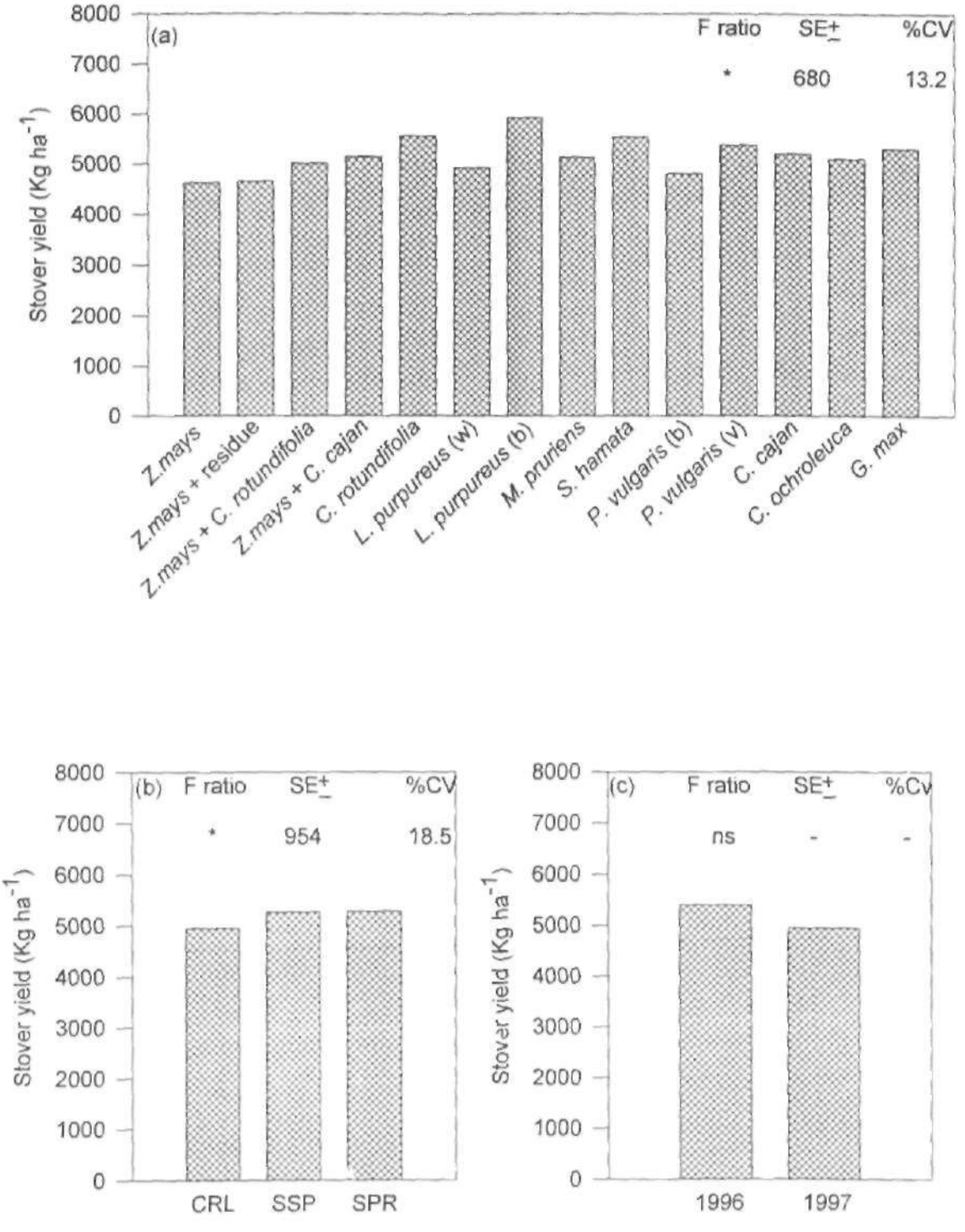


Fig 4.25:Mean effect of treatments on maize stover yield at Samaru (Field I) (a) averaged over 1996 and 1997 P treatments (b) averaged over preceding crops and 1997 P treatments (c)averaged over preceding crops and 1997 P treatments

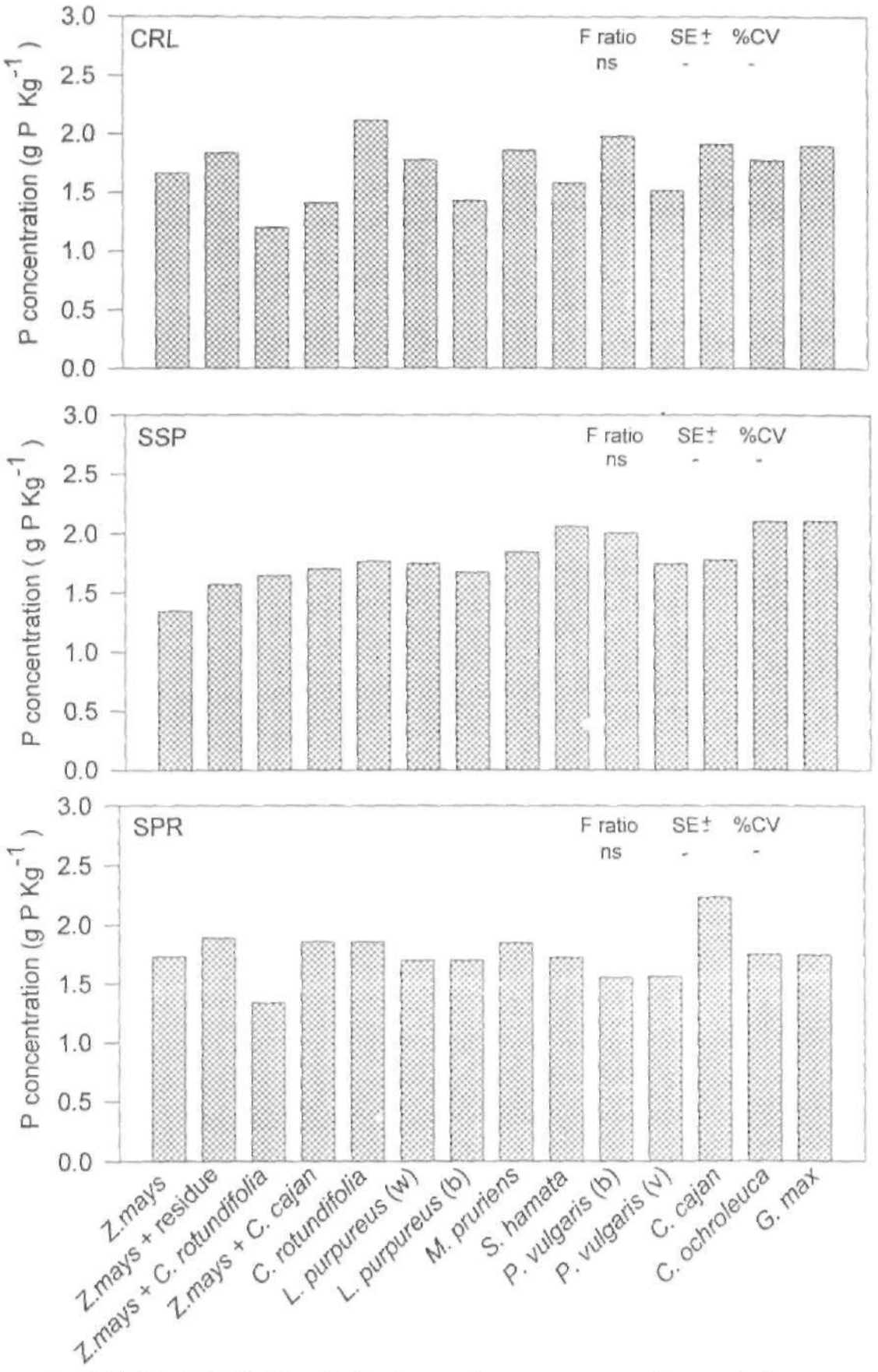


Fig. 4.26: Effect of 1995 P application to preceding cover crops on P concentration in the shoot of succeding maize crop at 6 WAP in 1996 at Samaru.

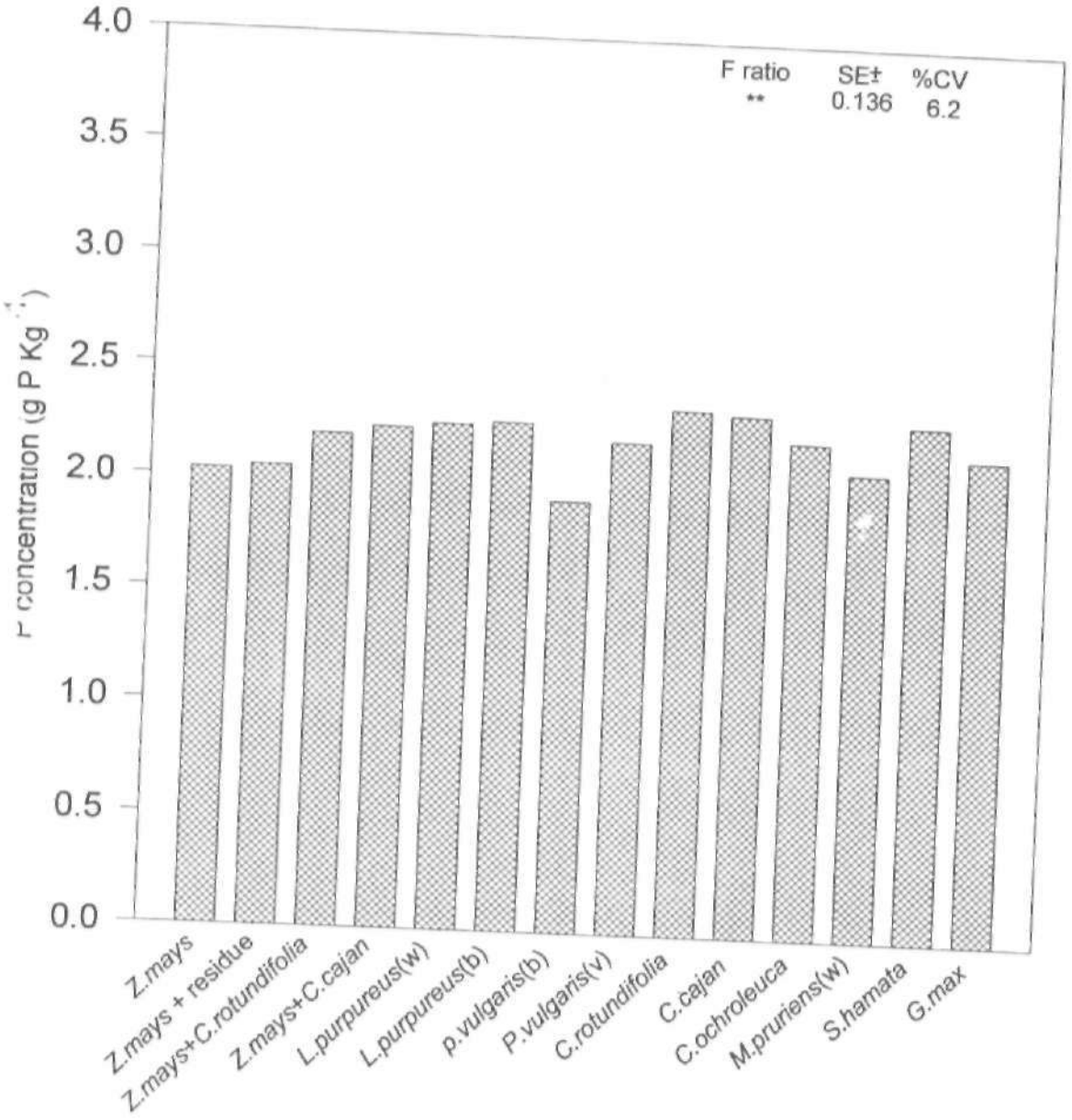


Figure 4.27 : Effect of preceding cover crop on maize grain P concentration in 1996 at Samaru (averaged over all P sources)

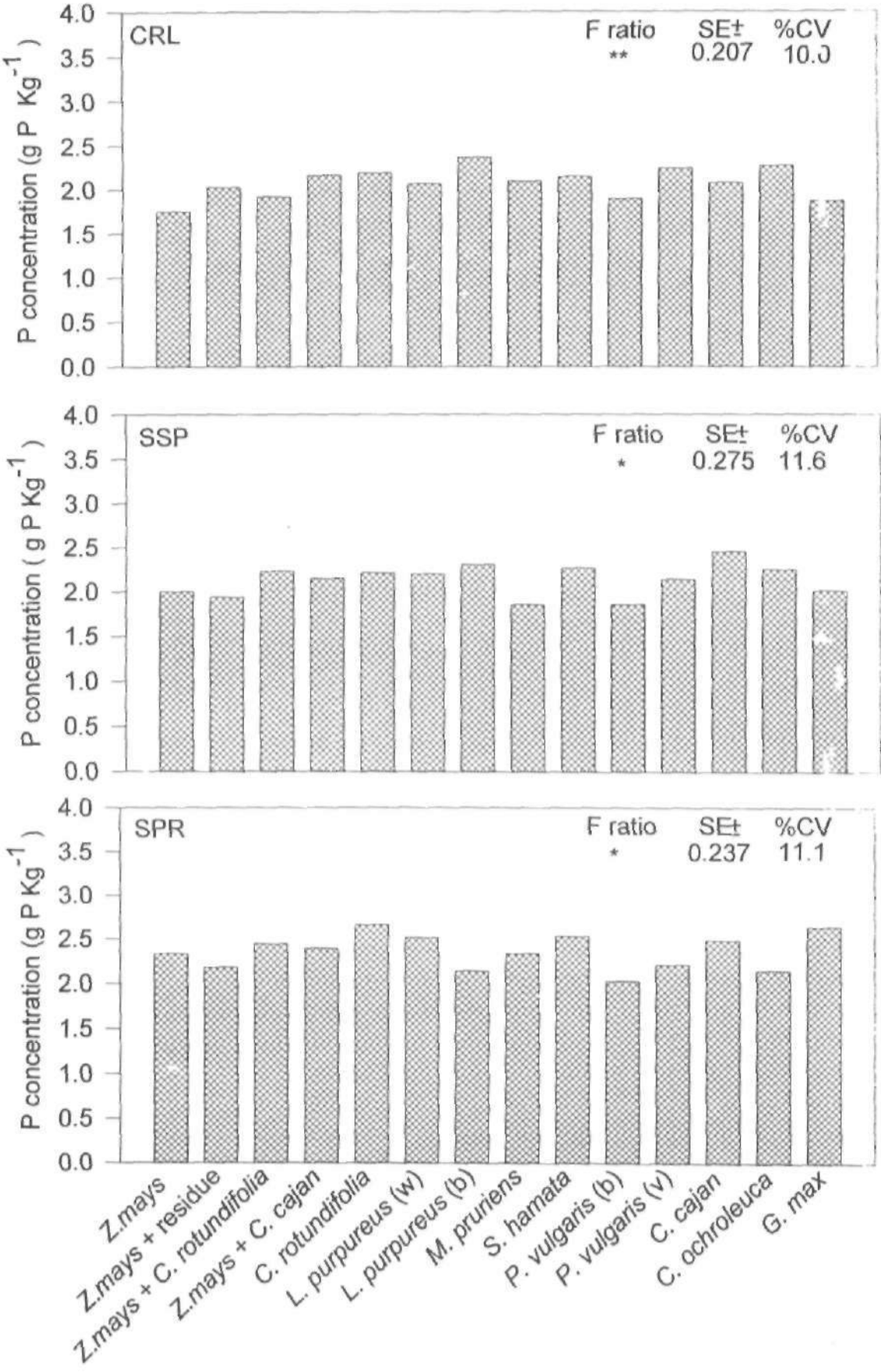


Figure 4.28: Effect of 1995 P application to preceding cover crop on P concentration in the grains of succeding maize crop in 1996 at Samaru.

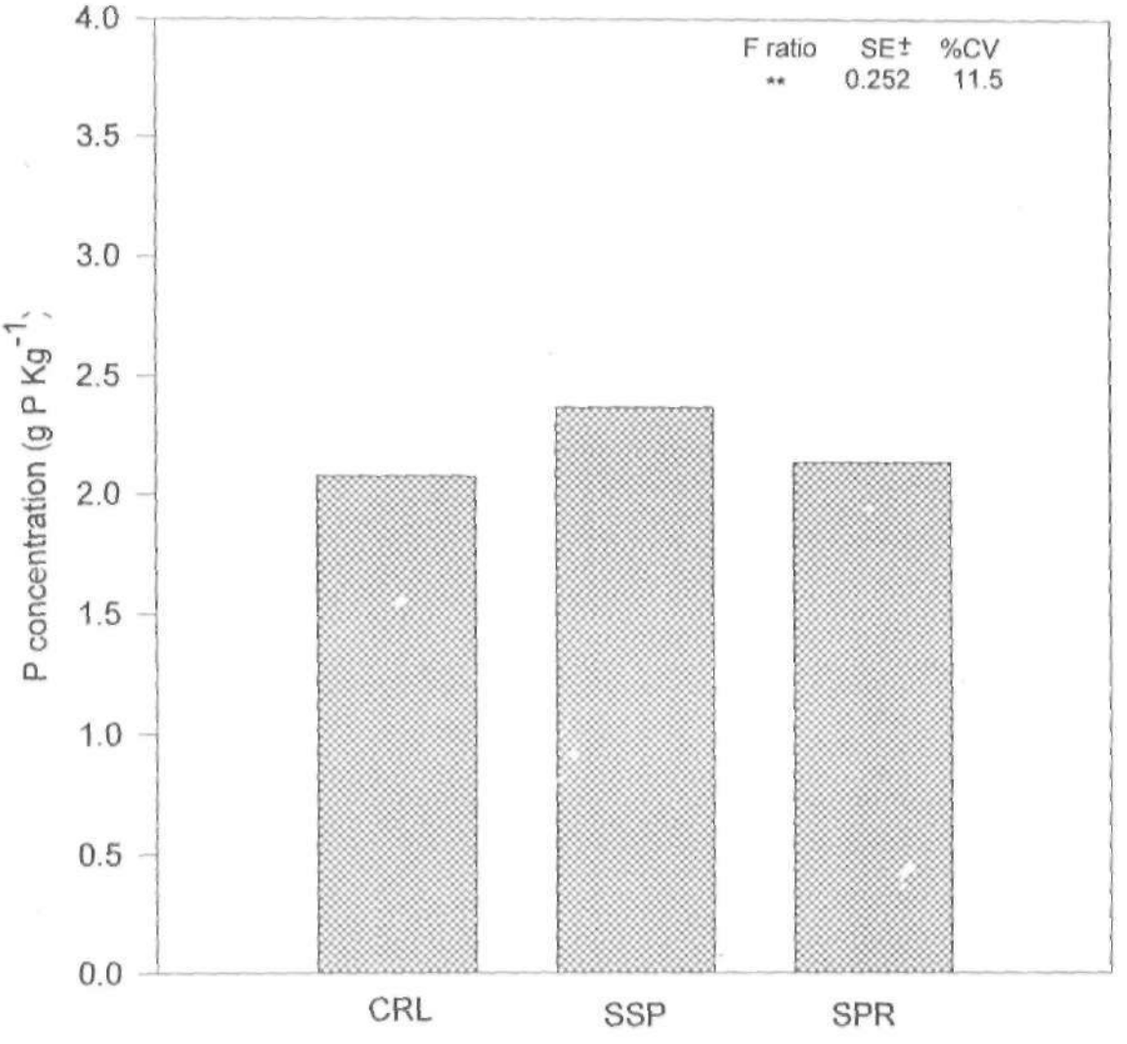


Figure 4.29: Effect of P application to preceeding cover crop on maize grain P concentration at Samaru in 1996 (averaged over all preceding cover crops)

vulgaris (b) and *M. pruriens* (W) produced significantly (p = 0.05) higher P concentrations in grains over the control (Fig. 4.27). Looking at the grain P concentrations separately for each P source, plots preceded by *G. max* and *C. rotundifolia* gave higher concentrations under SPR compared to other preceding crop treatments, indicating their better ability to utilize P from SPR (Fig. 4.28). Averaged over all cover crops, SSP treated plots gave significantly (p = 0.01) higher P concentration in maize grains in 1996 compared to CRL and SPR which were statistically at par (Fig.4.29).

Interaction between SPR and preceding crops, and CRL and preceding crops did not affect P concentration in the stover of maize in 1996 (Fig. 4.30). There was however, interaction effects between SSP and preceding cover crops on stover P concentration. *Lablab purpureus* (w), and *M. pruriens* (W) gave significantly higher P concentrations in the stover of succeeding maize crop in 1996 under 1995 SSP treatment.

Figures 4.31 and 4.32 show the residual effects of 1995 treatments on P concentrations in the index leaves, grains and stover of maize in 1997. The effects of preceding cover crops on tissue P concentrations in index leaves, grains and stover of maize were not obvious in 1997. The concentrations of P in grains and stover were generally lower than the values

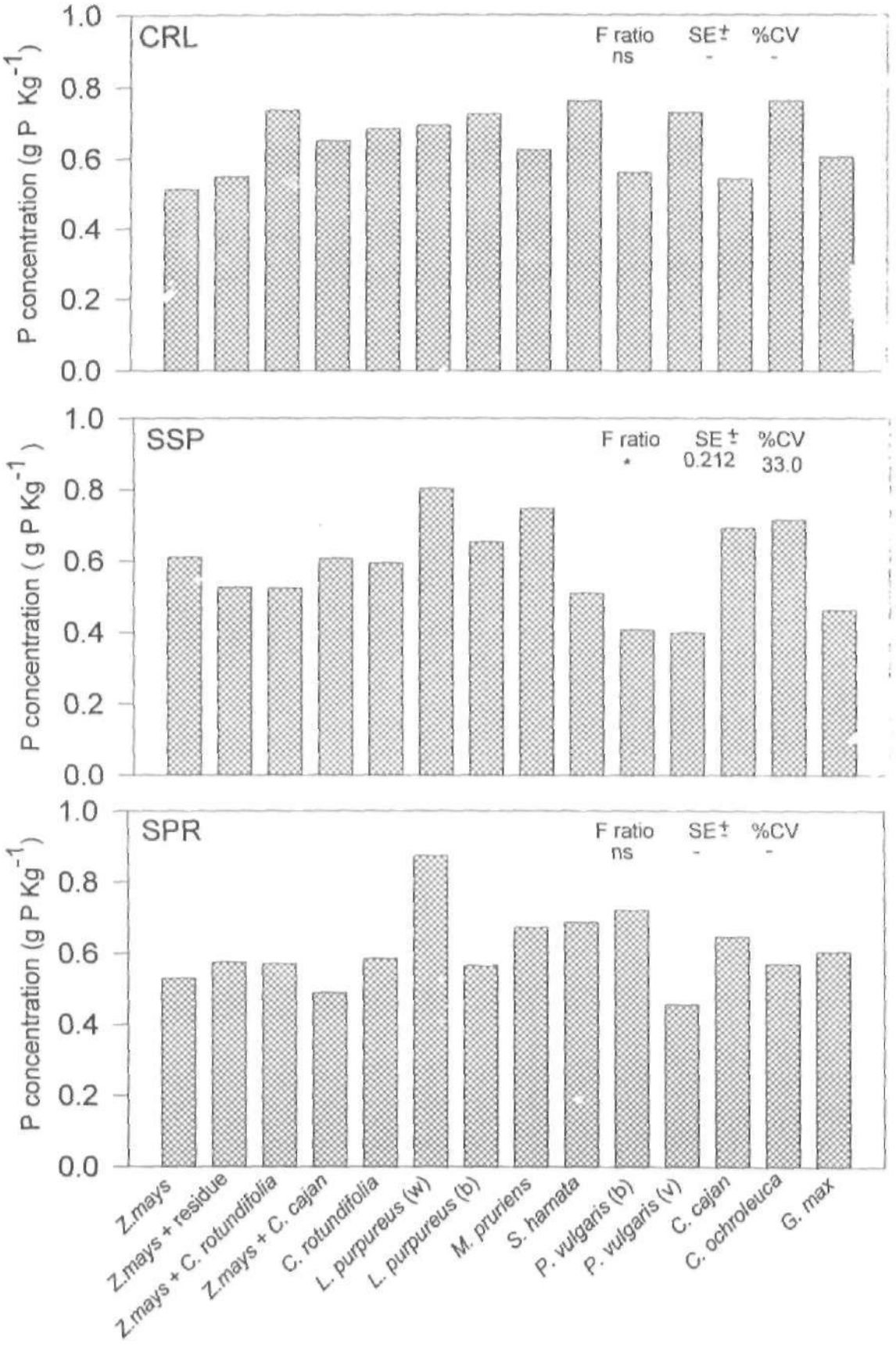


Fig. 4.30: Effect of 1995 P application to preceding cover crop on P concentration in the stover of succeding maize crop in 1996 at Samaru.

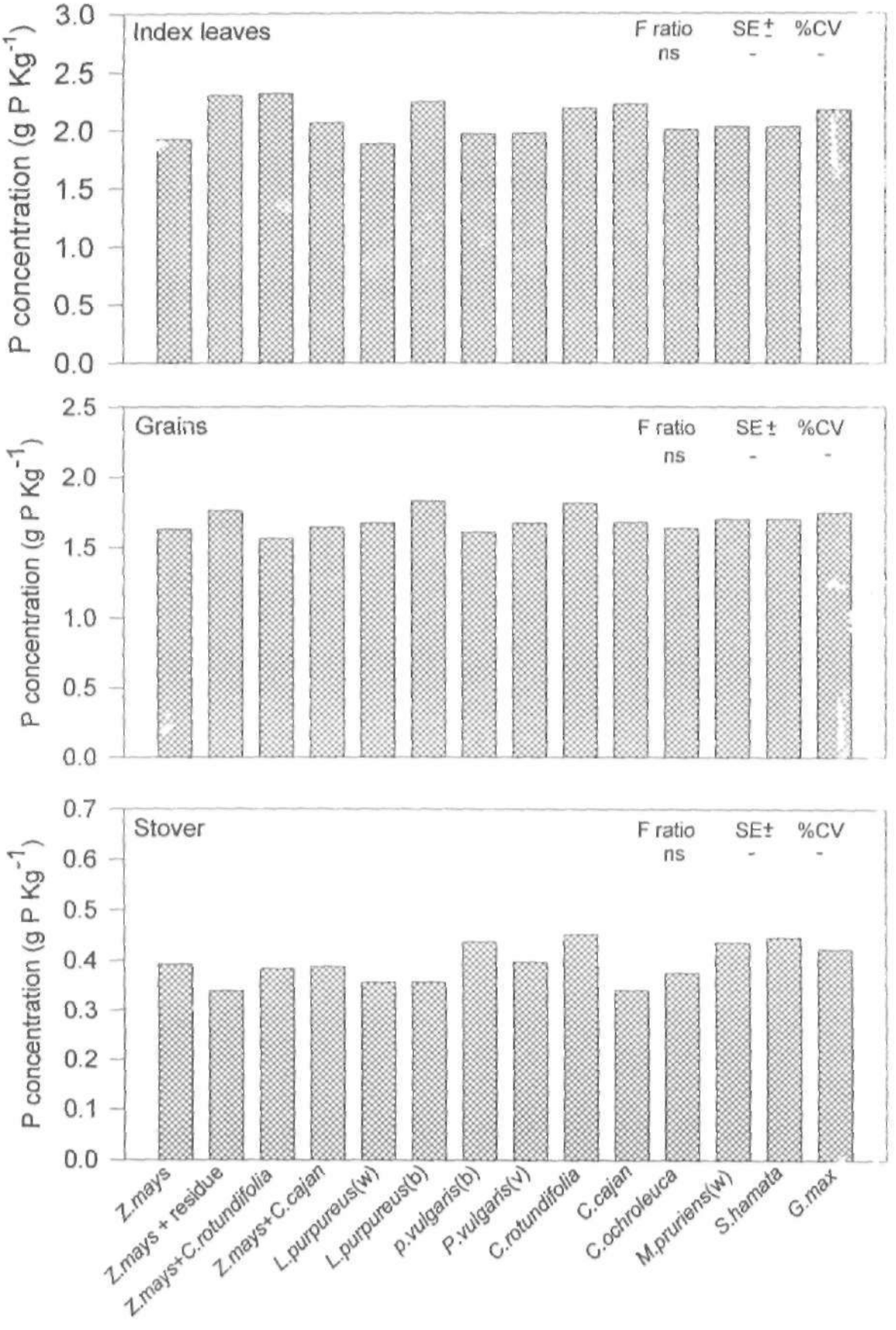


Figure 4.31: Effect of 1995 cover cropping on maize tissue P concentration at Samaru in 1997 (averaged over all P sources)

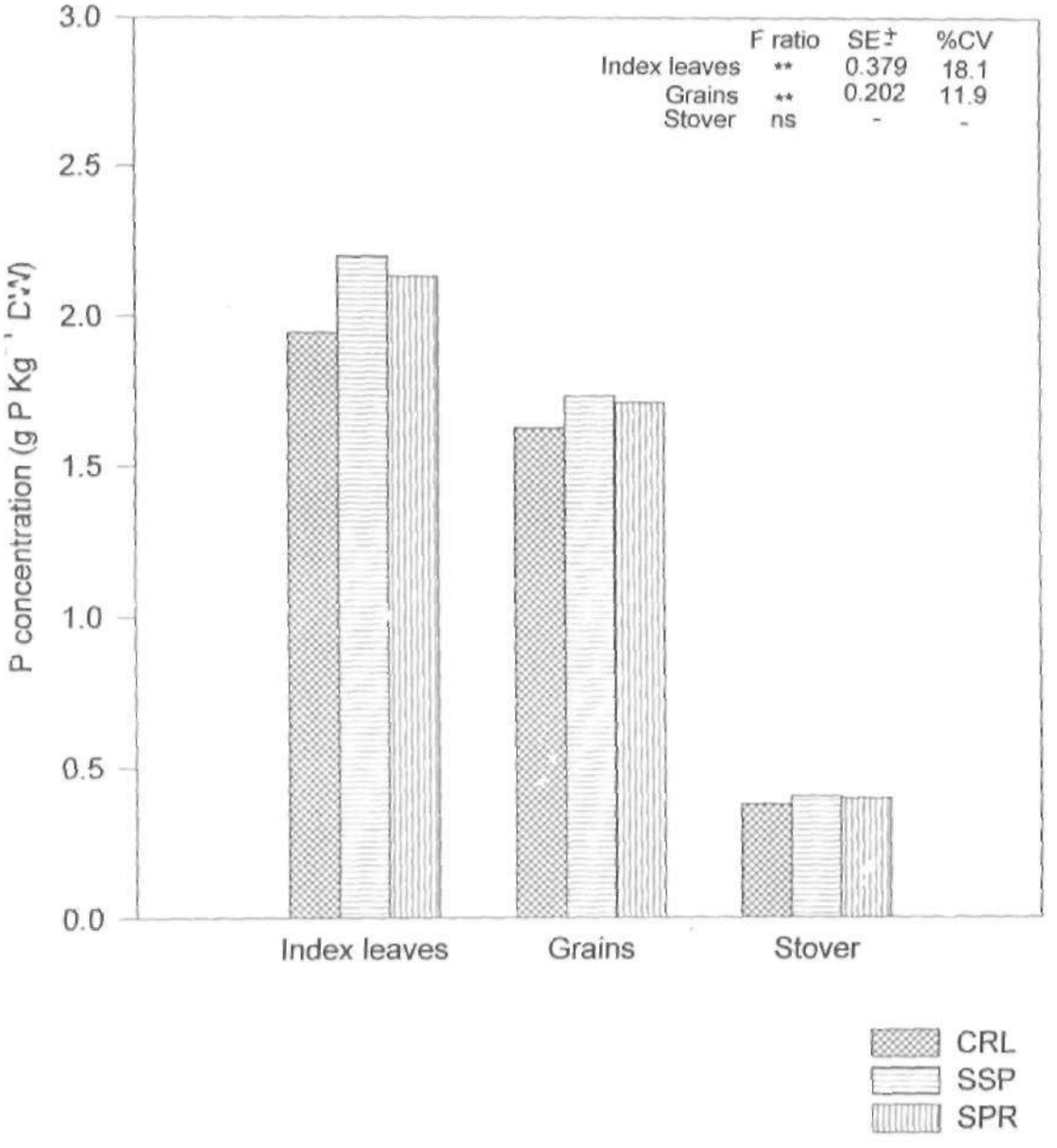


Fig. 4.32: Effect of 1995 P application on maize tissue P concentration at Samaru in 1997 (averaged over cover crops)

obtained in 1996. Effects of 1995 P application (averaged over cover crops) on P concentration of index leaves and grains were very significant (P = 0.01) (Fig. 4.32). Both SSP and SPR gave higher concentrations than CRL. This corroborates the earlier observation that the effect of P fertilization on this soil becomes quite obvious only after more than one year of cultivation without new P additions. The differences between SSP and SPR were not statistically significant, a further evidence of the high residual value of SPR.

4.1.2.3 Effect of 1995 cover cropping and P application on P uptake by succeeding maize

Phosphate uptake by succeeding maize crop at 6 WAP in 1996 was significantly influenced both by previous (1995) P application and by preceding cover crop treatments as well as the interaction between the two (Fig. 4.33). Plots preceded by S. hamata with SPR application in 1995 gave the highest P uptake at 6 WAP. On the average, plots treated with SSP in 1995 gave higher P uptake at 6 WAP in 1996. Influence of preceding cover crops on total P uptake by succeeding maize at maturity is shown in Fig. 4.34. Maize preceded by the two varieties of *L. purpureus*, *C. rotundifolia*, *S. hamata*, *C. cajan* and *C. ochroleuca* had greater P uptake at maturity. *Lablab purpureus* (b) was particularly better able to take up

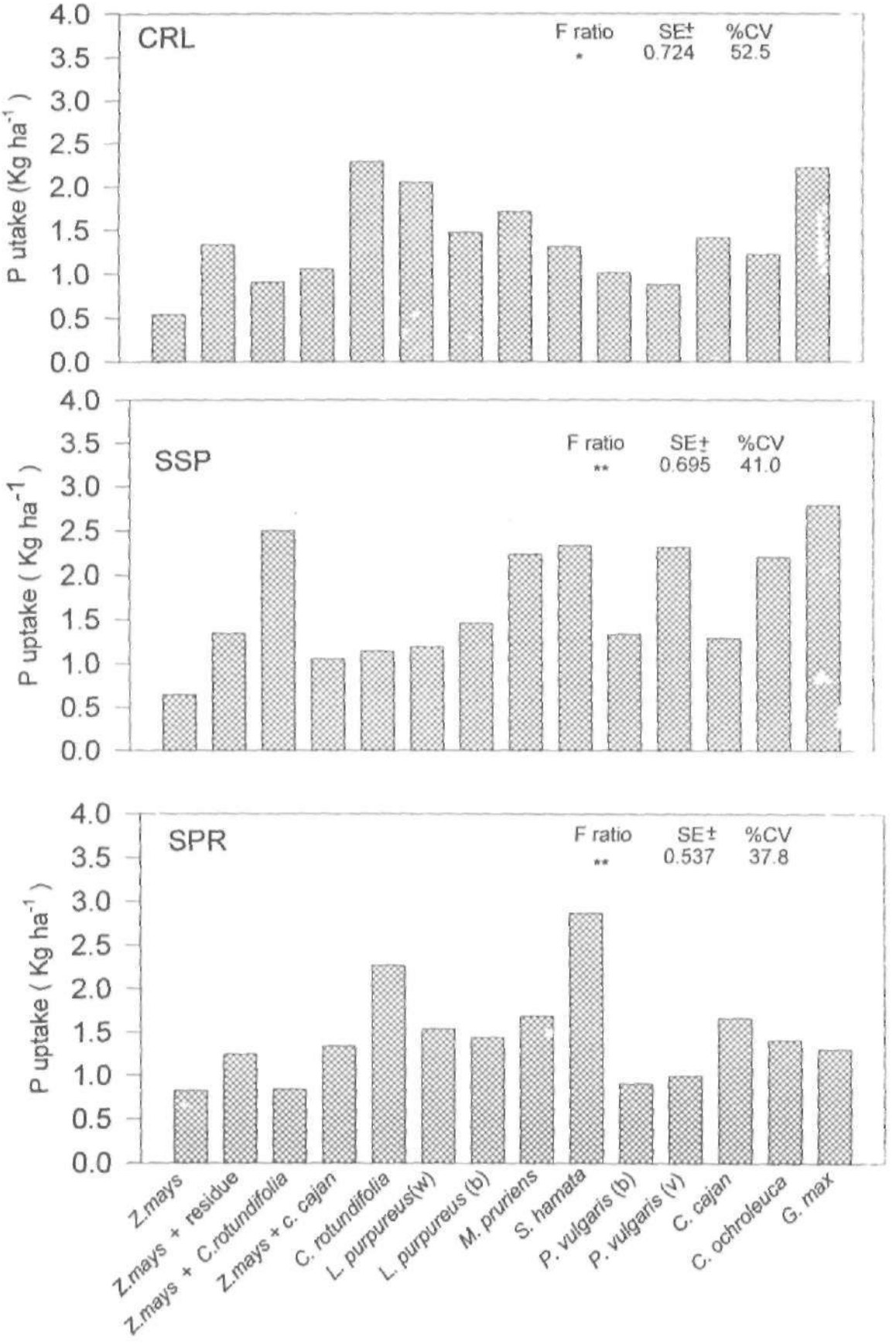


Figure 4.33 : Effect of 1995 P application to preceding cover crop on P uptake by shoot of succeding maize crop at 6 WAP in 1996 at Samaru.

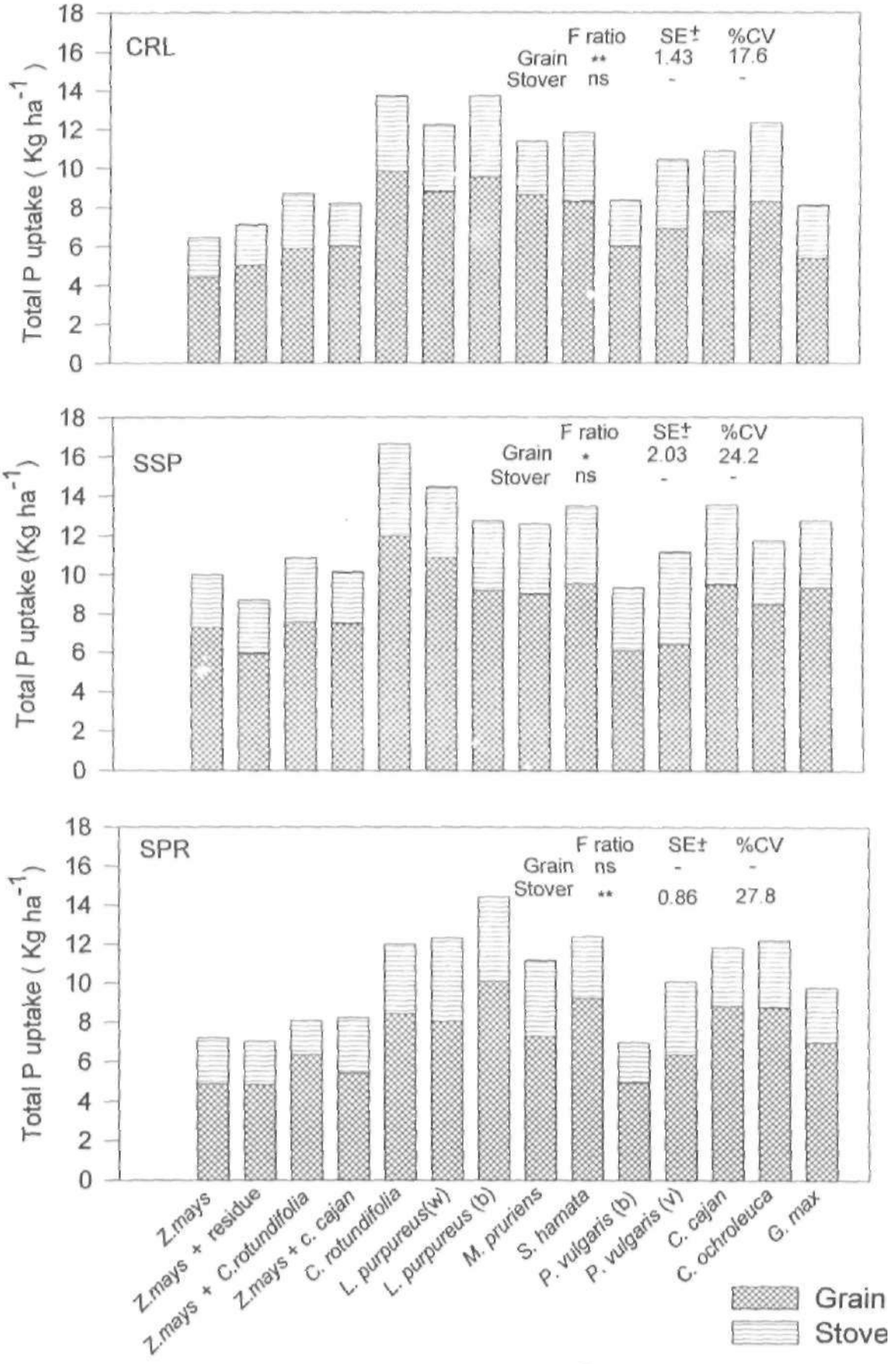


Figure 4.34: Effect of 1995 P application to cover crop on total P uptake by succeding maize crop in 1996 at Samaru

P from SPR compared to the other crops. Phosphate uptake from plots preceded by *Z. mays* + residue, *Z. mays* + *C. rotundifolia*, *Z. mays* + *C. cajan*, and *P. vulgaris* (b) was not better than the control.

Figure 4.35 shows the effect of 1995 treatments on total P uptake by maize at the end of 1997 season. Plots preceded by *C. rotundifolia*, the two varieties of *L. purpureus*, *C. cajan* and *P. vulgaris* (v) gave significantly higher P uptake in grains relative to the control treatment. Effect of preceding crop on stover P uptake was not significant. Pooled over preceding crops, both SSP and SPR significantly improved the total P uptake. Differences between SPR and SSP in terms of P uptake by both grains and stover were not statistically significant.

4.1.2.4 Influence of previous cover crops and P application on soil P and pH in 1996 and 1997

Tables 4.12 and 4.13 show the effect of 1995 treatments on available soil P (Bray 1) in 1996 and 1997. At the beginning of 1996 season and at silking, no significant effects were produced by the various cover crop treatments on available soil P (Table 4.12). However, at the start of 1997 season, plots preceded by *P. vulgaris* (v) and *G. max* had

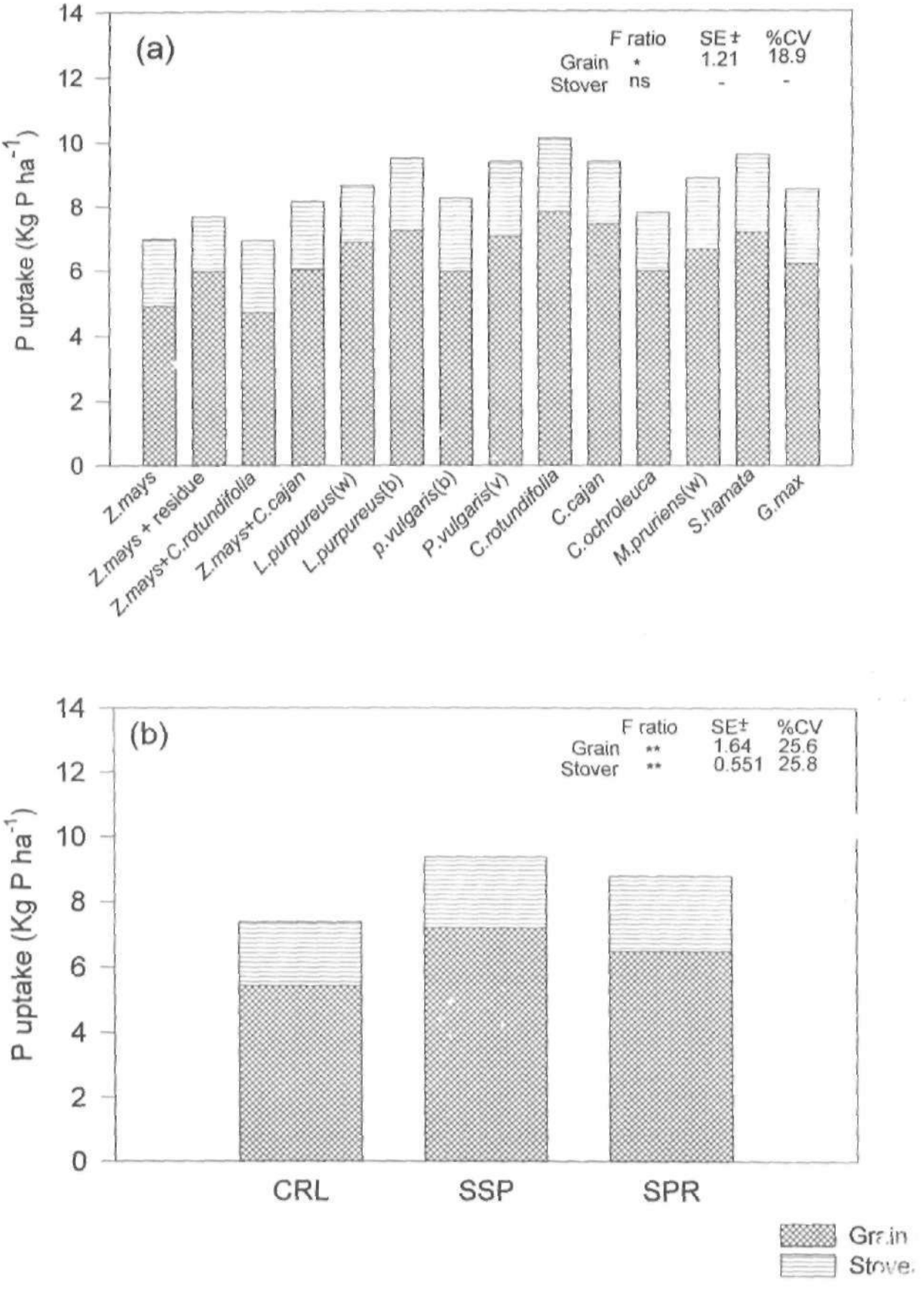


Figure 4.35: Effect of 1995 P application to cover crops on total P uptake by succeding maize in 1997 at Samaru (a) averaged over P sources (b) averaged over cover crops

Table 4.12: Effect of preceding crops on Bray-1 soil P within the 0-15 cm layer in 1996 and 1997

Preceding crop	1996		1997	
	Preplanting	50% silking	Preplanting	50% silking
	<..... mg Kg^{-1} .....>			
Z. mays	7.55	6.19	3.19	3.98
Z. mays + residue	6.00	5.21	4.34	4.01
Z. mays + C. rotundifolia	6.94	4.75	3.77	4.04
Z. mays + C. cajan	6.60	5.83	4.69	4.92
C. rotundifolia	5.35	5.81	3.92	5.01
L. purpureusI (w)	4.21	5.91	3.19	5.36
L. purpureus)b)	6.64	4.09	3.36	5.80
S. hamata	4.64	8.71	3.06	3.78
M. pruriens (w)	5.92	6.78	3.25	4.82
P. vulgaris (b)	6.67	5.79	3.73	5.29
P. vulgaris (v)	4.39	4.79	5.48	6.06
C. cajan	4.30	6.92	4.05	4.95
C. ochroleuca	4.41	5.33	3.98	4.63
C. mix	6.50	4.70	4.71	4.99
F ratio	ns	ns	**	ns
SED	-	-	0.83	-
CV	-	-	21.2	-

Table 4.13: Effect of 1995 P treatments on Bray-1 soil P within the 0-15cm layer in 1996 and 1997

P source	1996		1997	
	Preplanting	50% silking	Preplanting	50% silking
	<..... mg Kg^{-1} .....>			
CRL	5.77	5.56	3.24	4.31
TSP	5.62	6.08	4.54	5.32
SPR	5.79	5.67	3.94	4.86
F ratio	ns	ns	**	**
SE±	-	-	0.86	1.11
%CV	-	-	21.9	22.9

significantly higher available soil P than the control. This trend was, however, not maintained at silking . Values for available soil P (Bray 1) in 1997 were generally lower than in 1996. The available soil P in 1997 was generally higher at silking than at the beginning of the season, possibly due to mineralization of the maize residue incorporated at the end of 1996 season and the subsequent release of P.

Previous fertilization did not significantly affect available P values in 1996 (Table 4.13). Significant ($P = 0.01$) differences were, however, observed between the P treatments in 1997 both at the start of the season and at silking. At both periods SSP treated plots gave significantly higher concentrations of available soil P than plots treated with SPR or CRL. Sokoto phosphate rock, however, gave significantly higher available soil P concentration than CRL.

Effect of cover crops on various soil P fractions at 50% silking of maize in 1996 is shown in Fig. 4.36. Concentration of resin extractable (bioavailable) P in the soil was not significantly influenced by preceding crop, this corroborates an earlier observation that 1995 cover cropping did not significantly affect available soil P concentration in 1996 (Table 4.12). Similarly, preceding cover crops did not significantly affect the $NaHCO_3$ extractable inorganic P

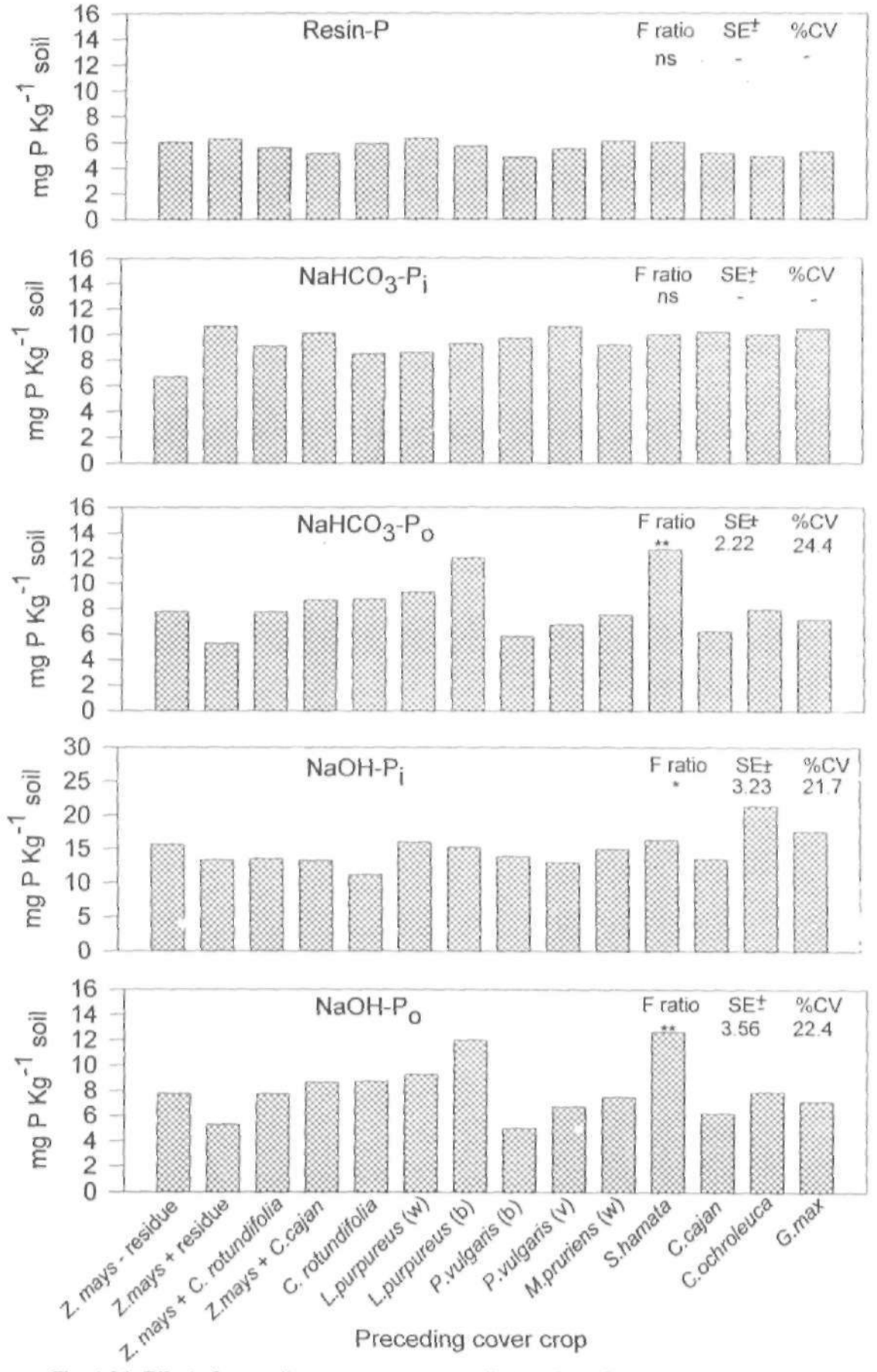


Fig. 4.36: Effect of preceding cover crops on soil phosphate fractions at Samaru in 1996 (sampled at 50% silking)

fraction of the soil. However, the $NaHCO_3$ extractable inorganic P fractions and both organic and inorganic fractions of NaOH extractable P were significantly affected by preceding crop. *Lablab purpureus* (b) and *S. hamata* produced very significant (P=0.01) increases in the concentrations of both $NaHCO_3$ and NaOH extractable organic P fractions of the soil, while *C. ochroleuca* produced significant (P=0.05) increase in the concentration of NaOH extractable inorganic P fraction. Results of path coefficient analysis (Fig. 4.37) show that $NaHCO_3$-Pi gave the highest percentage contribution to resin P fraction (19.26%). This is a drop from the 76.68% observed at 50% flowering in 1995 (Fig. 4.06).

Effect of preceding cover crops on soil pH was only significant at silking in 1996 (Table 4.14). At this period all the cover crops significantly lowered soil pH except *M. pruriens* (w). Effect of P treatments on soil pH was not significant at all periods in 1996 and 1997. Generally, there was a reduction in soil pH values in 1997 compared to 1996. This could be due to acidifying effects of continuous use of urea.

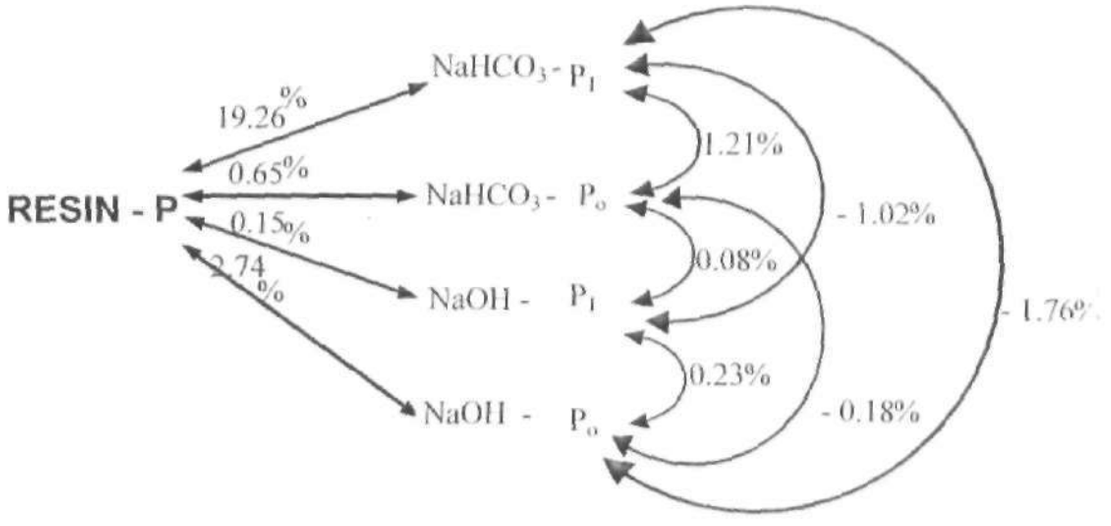


Fig. 4.37 : Percentage contributions of $NaHCO_3$ and NaOH extractable organic and inorganic soil P fractions to resin extractable P fraction at 50% silking of maize in 1996.

Table 4.14a: Effect of preceding crops on soil pH within the o-15cm layer in 1996 and 1997

Preceding crop	1996		1997	
	Preplanting	50% silking	Preplanting	50% silking
Z.mays	5.9	5.9	5.4	5.3
Z.mays + residue	6.0	5.5	5.2	5.2
Z. mays+C. rotundifolia	5.9	5.4	5.3	5.2
Z. mays + C. cajan	5.7	5.3	5.2	5.0
C. rotundifolia	5.8	5.7	5.5	5.1
L. purpureusI (w)	5.7	5.4	5.4	5.0
L. purpureus)b)	5.9	5.3	5.5	5.1
S. hamata	5.9	5.7	5.5	5.1
M. pruriens (w)	5.8	5.8	5.3	5.1
P. vulgaris (b)	5.8	5.2	5.4	4.9
P. vulgaris (v)	6.0	5.4	5.4	5.2
C .cajan	5.9	5.7	5.5	5.3
C. ochroleuca	5.7	5.2	5.3	5.2
G. max	5.8	5.2	5.4	5.2
F ratio	ns	**	ns	ns
SE±	-	0.1	-	-
%CV	-	2.5	-	-

Table 4.14b: Effect of 1995 P treatments on soil pH within the 0-15cm layer in 1996 and 1997

P source	1996		1997	
	Preplanting	50% silking	Preplanting	50% silking
CRL	5.8	5.5	5.4	5.2
SSP	5.8	5.5	5.4	5.1
SPR	5.8	5.5	5.4	5.2
F ratio	ns	ns	ns	ns
SE±	-	-	-	-
%CV	-	-	-	-

4.2 Field II (Samaru)

4.2.1 First year (cover crops and maize)

4.2.1.1 Effect of P application on growth of cover crops in 1996

Biomass production by the various cover crops was monitored during the growth of the crops. At 6 WAI, *C. ochroleuca* and *C. rotundifolia* produced the greatest amounts of biomass while *C. ternatea* and *V. unguiculata* produced the least (Table 4.15). At this period, only *M. pruriens*(w), *C. ochroleuca* and *C. rotundifolia* (intercrop) showed response to SSP while SPR significantly increased biomass in *M. pruriens* (b) and *P. vulgaris* (b).

At 50% flowering, the two varieties of P. vulgaris produced the least amount of biomass while *C. ochroleuca* produced the highest (Table 4.16) just as in field I in 99. Only *C. cajan* and *C. rotundifolia* (intercrop) responded to SSP application, while no response to SPR was observed at this period. Less biomass was produced by the two intercropped cover crops than the sole crops just as in field I. However, unlike field I, the application of SSP did not depress biomass production by cover crops in mixture.

Table 4.15: Effect of P application to cover crops on above ground biomass at 6 WAP in 1996 at Samaru (field II)

Cover crop	Biomass (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	CV
Arachis hypogaea	883	938	803	ns	-	
Mucuna pruriens (white)	418	666	323	*	117	25
Mucuna pruriens (black)	328	288	559	*	24.9	6.4
Canavalia ensiformis	725	962	695	ns	-	-
Glycine max	1049	1389	920	ns	-	-
Phaseolus vulgaris (brown)	363	416	518	*	27.3	6.3
Phaseolus vulgaris (variegated)	413	580	390	ns	-	-
Crotalaria ochroleuca	1618	2809	1840	**	241	11.6
Clitoria ternatea	106	120	53	ns	-	-
Stylosanthes hamata	373	426	391	ns	-	-
Centrosema pubescens	107	160	178	ns	-	-
Lablab purpureus (white)	212	282	236	ns	-	-
Lablab purpureus (black)	365	377	397	ns	-	-
Vigna unguiculata	66	114	106	ns	-	-
Cajanus cajan	818	907	909	ns	-	-
Cajanus cajan (intercrop)	1093	907	978	ns	-	-
Chamaecrista rotundifolia	2748	2184	2952	ns	-	-
Chamaecrista rotundifolia (intercrop)	889	1902	1005	*	16.3	13

Table 4.16: Effect of P application to cover crops on above ground biomass at 50% flowering in 1996 at Samaru (field II)

Cover crop	Biomass (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	883	938	803	ns	-	-
Mucuna pruriens (white)	4516	5150	4618	ns	-	-
Mucuna pruriens (black)	3851	3833	3879	ns	-	-
Canavalia ensiformis	1303	1405	1369	ns	-	-
Glycine max	2797	3125	2317	ns	-	-
Phaseolus vulgaris	363	416	518	ns	-	-
Phaseolus vulgaris	413	580	390	ns	-	-
Crotalaria ochroleuca	10514	12053	11070	ns	-	-
Clitoria ternatea	1107	1272	570	ns	-	-
Stylosanthes hamata	5240	5772	5585	ns	-	-
Centrosema pubescens	2006	1986	2426	ns	-	-
Lablab purpureus (white)	4766	5429	4708	ns	-	-
Lablab purpureus (black)	3744	4454	3758	ns	-	-
Vigna unguiculata	1521	1691	1579	ns	-	-
Cajanus cajan	4827	5669	4884	*	249	4.9
Cajanus cajan (intercrop)	3385	3249	3649	ns	-	-
Chamaecrista rotundifolia	2748	2184	2952	ns	-	-
Chamaecrista rotundifolia (intercrop)	889	1902	1005	*	164	13.0

Table 4.17 shows the amount of cover crop residues left at the end of season after seed removal. *Crotalaria ochroleuca* still had the greatest amount of biomass while the two varieties of P. vulgaris (b) had the least. *Canavalia ensiformis* showed significant response to SSP in terms of crop residue produced, while *A. hypogaea* responded to both SSP and SPR. Response of groundnut to phosphate rock at Samaru has earlier been observed by Lombin (1979). The other cover crops did not show significant response to either SSP or SPR, suggesting that the native soil P was sufficient to satisfy their nutritional needs.

Tables 4.18 and 4.19 show the root length densities of the various cover crops within 0-15 and 15-30 cm soil depths. As in field I, there was greater rooting density within the 0-15 cm depth by all cover crops. In both 0-15 and 15-30 cm depths, *A. hypogaea, G. max* and *C. rotundifolia* had the greatest rooting densities while the two varieties of *M. pruriens* had the least. Application of SSP produced significant increase in rooting density within the 0-15 cm depth in *M. pruriens* (w). In the 15-30 cm depth, SSP application significantly increased root length density of *C. ternatea* and depressed that of *C. rotundifolia* while SPR significantly increased the rooting density of *C.*

Table 4.17: Effect of P application to cover crops on crop residue at th[illegible]d of 1996 season at Samaru (field I1)

Cover crop	Biomass (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	5398	7083	6839	*	291	4.5
Mucuna pruriens (white)	4781	4843	4263	ns	-	-
Mucuna pruriens (black)	8041	9906	9895	ns	-	-
Canavalia ensiformis	2658	3620	2654	*	326	10.9
Glycine max	1824	1765	2000	ns	-	-
Phaseolus vulgaris	350	310	248	ns	-	-
Phaseolus vulgaris	122	129	103	ns	-	-
Crotalaria ochroleuca	21843	19490	18235	ns	-	-
Clitoria ternatea	2755	2431	2374	ns	-	-
Stylosanthes hamata	9847	9525	9177	ns	-	-
Centrosema pubescens	4603	6096	4915	ns	-	-
Lablab purpureus (white)	5618	6926	5744	ns	-	-
Lablab purpureus (black)	5433	5850	5060	ns	-	-
Vigna unguiculata	1817	2164	1884	ns	-	-
Cajanus cajan	10394	11541	9391	ns	-	-
Cajanus cajan (intercrop)	5666	6878	7050	ns	-	-
Chamaecrista rotundifolia	3985	3971	3780	ns	-	-
Chamaecrista rotundifolia (intercrop)	2657	3064	2653	ns	-	-

Table 4.18: Effect of P application to cover crops on rooting density wi
0-15 cm depth at 50% flowering in 1996 at Samaru (field 11)

Cover crop	Root length density (cm cm^{-3})					
	CRL	SSP	SPR	F ratio	SED	CV
Arachis hypogaea	1.030	1.550	1.260	ns	-	-
Mucuna pruriens (white)	0.026	0.134	0.026	*	0.03	47.0
Mucuna pruriens (black)	0.055	0.040	0.046	ns	-	-
Canavalia ensiformis	0.464	0.264	0.423	ns	-	-
Phaseolus vulgaris (brown)	1.230	0.960	1.230	ns	-	-
Phaseolus vulgaris (variegated)	0.520	0.040	0.650	ns	-	-
Glycine max	2.750	3.070	2.470	ns	-	-
Vigna unguiculata	0.230	0.620	0.330	ns	-	-
Cajanus cajan	0.200	0.291	0.344	ns	-	-
Lablab purpureus (black)	0.070	0.079	0.052	ns	-	-
Lablab purpureus (white)	0.079	0.108	0.066	ns	-	-
Stylosanthes hamata	0.178	0.117	0.135	ns	-	-
Clitoria ternatea	0.416	0.279	0.418	ns	-	-
Chamaecrista rotundifolia	1.882	1.590	2.210	ns	-	-
Crotalaria ochroleuca	0.088	0.116	0.105	ns	-	-
Centrosema pubescens	0.143	0.080	0.062	ns	-	-

Table 4.19: Effect of P application to cover crops on rooting density within 15-30 cm depth at 50% flowering in 1996 at Samaru (field II)

Cover crop	Root length density (cm cm^{-3})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	0.264	0.281	0.182	ns	-	-
Mucuna pruriens (white)	0.022	0.025	0.028	ns	-	-
Mucuna pruriens (black)	0.011	0.017	0.038	ns	-	-
Canavalia ensiformis	0.091	0.146	0.126	ns	-	-
Phaseolus vulgaris (brown)	0.140	0.102	0.179	ns	-	-
Phaseolus vulgaris (variegated)	0.077	0.107	0.101	ns	-	-
Glycine max	0.192	0.258	0.255	ns	-	-
Vigna unguiculata	0.040	0.063	0.024	ns	-	-
Cajanus cajan	0.043	0.062	0.061	ns	-	-
Lablab purpureus (black)	0.031	0.031	0.035	ns	-	-
Lablab purpureus (white)	0.057	0.053	0.049	ns	-	-
Stylosanthes hamata	0.074	0.076	0.036	ns	-	-
Clitoria ternatea	0.066	0.145	0.065	**	0.01	11.6
Chamaecrista rotundifolia	0.170	0.023	0.355	*	0.07	39.9
Crotalaria ochroleuca	0.058	0.069	0.091	ns	-	-
Centrosema pubescens	0.054	0.025	0.032	ns	-	-

rotundifolia.

4.2.1.2 Effect of P application on tissue P content of cover crops in 1996

Effect of P application on P concentration in tissues of the cover crops at 6 WAP and at flowering is shown in Tables 4.20 and 4.21. Highest tissue P concentrations were recorded with *P. vulgaris* (b), *C. ternatea* and *V. unguiculata* both at 6 WAP and at flowering. Like in field I, the faster growing crops had the lowest tissue P concentrations. At 6 WAP, SPR significantly (P = 0.05) raised the tissue P concentration of *C. pubescens* while at flowering both SSP and SPR significantly raised the tissue P concentration of *G. max*. The P concentration in the tissue of the other cover crops were not significantly affected by P application. Phosphate application did not also significantly affect the P concentration in the residues of the various cover crops (Table 4.22).

Table 4.23 shows the total P uptake by the various cover crops at 50% flowering and the total amount of P returned to the soil with crop residue. Both at 50% flowering and in crop residues, *C. ochroleuca* and *C. cajan* had the highest P uptake

Table 4.20: Effect of P application to cover crops on tisuue P concentration at 6 WAP in 1996 at Samaru (field II)

Cover crop	P concentration (g kg^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	2.38	2.58	2.55	ns	-	-
Mucuna pruriens (white)	2.54	2.69	2.29	ns	-	-
Mucuna pruriens (black)	2.18	2.58	2.15	ns	-	-
Canavalia ensiformis	2.53	1.82	1.78	ns	-	-
Glycine max	1.71	2.28	2.27	ns	-	-
Phaseolus vulgaris (brown)	3.51	3.24	3.07	ns	-	-
Phaseolus vulgaris (variegated)	2.35	2.70	2.38	ns	-	-
Crotalaria ochroleuca	2.06	2.16	2.01	ns	-	-
Clitoria ternatea	2.54	2.97	2.16	ns	-	-
Stylosanthes hamata	2.45	2.19	2.33	ns	-	-
Centrosema pubescens	2.16	2.04	2.36	*	0.7	3.1
Lablab purpureus (white)	2.89	2.70	2.52	ns	-	-
Lablab purpureus (black)	2.75	2.96	2.76	ns	-	-
Vigna unguiculata	2.90	3.24	3.00	ns	-	-
Cajanus cajan	2.41	2.67	2.51	ns	-	-
Chamaecrista rotundifolia	1.96	2.28	2.92	ns	-	-

Table 4.21: Effect of P application to cover crops on tisuue P concentration at 50% flowering in 1996 at Samaru (field II)

Cover crop	P concentration (g kg^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	2.38	2.58	2.55	ns	-	-
Mucuna pruriens (white)	1.59	1.83	1.56	ns	-	-
Mucuna pruriens (black)	1.82	1.64	1.63	ns	-	-
Canavalia ensiformis	1.71	2.30	2.15	ns	-	-
Glycine max	2.14	2.77	2.83	*	0.54	25.6
Phaseolus vulgaris (brown)	3.51	3.24	3.07	ns	-	-
Phaseolus vulgaris (variegated)	2.35	2.70	2.38	ns	-	-
Crotalaria ochroleuca	1.51	1.68	1.50	ns	-	-
Dolichos ternatea	2.67	3.12	3.11	ns	-	-
Sesbania rostrata	1.80	1.67	1.37	ns	-	-
Centrosema pubescens	1.66	1.89	1.55	ns	-	-
Lablab purpureus (white)	1.75	1.70	1.73	ns	-	-
Lablab purpureus (black)	1.32	1.44	1.56	ns	-	-
Vigna unguiculata	2.62	3.07	2.04	ns	-	-
Cajanus cajan	2.09	2.31	2.38	ns	-	-
Chamaecrista rotundifolia	1.96	2.28	2.92	ns	-	-

Table 4.22: Effect of P application on P concentration in cover crop residues at the end of 1996 season at Samaru (field II)

Cover crop	P concentration (g kg^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	1.66	2.05	1.16	ns	-	-
Mucuna pruriens (white)	1.53	1.27	1.68	ns	-	-
Mucuna pruriens (black)	1.48	1.61	1.71	ns	-	-
Canavalia ensiformis	1.22	1.34	1.30	ns	-	-
Glycine max	1.48	1.37	1.46	ns	-	-
Phaseolus vulgaris (brown)	2.40	2.15	2.08	ns	-	-
Phaseolus vulgaris (variegated)	1.40	1.44	1.57	ns	-	-
Crotalaria ochroleuca	1.13	1.19	1.48	ns	-	-
Vigna ternatea	2.08	1.79	1.85	ns	-	-
Mucosanthes hamata	1.54	1.82	1.41	ns	-	-
Centrosema pubescens	1.59	1.58	1.14	ns	-	-
Lablab purpureus (white)	2.05	1.87	2.18	ns	-	-
Lablab purpureus (black)	1.18	1.71	1.45	ns	-	-
Vigna unguiculata	2.72	2.43	2.32	ns	-	-
Cajanus cajan	1.56	2.09	2.15	ns	-	-
Chamaecrista rotundifolia	2.64	2.20	1.48	ns	-	-

Table 4.23: Effect of P application on total P content of cover at 50% flowering in 1996 at Samaru (field II)

Cover crop	P uptake (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	3.10	1.95	1.55	ns	-	-
Mucuna pruriens (white)	7.05	9.39	7.29	ns	-	-
Mucuna pruriens (black)	6.42	5.69	6.31	ns	-	-
Canavalia ensiformis	2.22	3.23	2.92	*	0.32	11.5
Glycine max	6.02	8.57	8.07	*	1.27	15.3
Phaseolus vulgaris (brown)	1.44	1.42	1.65	ns	-	-
Phaseolus vulgaris (variegated)	1.01	1.56	0.95	ns	-	-
Crotalaria ochroleuca	15.70	20.20	16.30	ns	-	-
Clitoria ternatea	2.31	3.61	2.55	ns	-	-
Stylosanthes hamata	9.11	9.56	7.37	ns	-	-
Centrosema pubescens	3.05	3.85	3.52	ns	-	-
Lablab purpureus (white)	9.06	8.91	8.65	ns	-	-
Lablab purpureus (black)	5.00	5.55	5.00	ns	-	-
Vigna unguiculata	4.00	5.21	3.28	ns	-	-
Cajanus cajan	12.61	15.06	11.99	*	1.30	13.2
Chamaecrista rotundifolia	5.53	5.19	8.64	ns	-	-

while the two varieties of *P. vulgaris* had the least. At 50% flowering application of SSP significantly increased P uptake by *C. cajan*, while both SSP and SPR increased P uptake by *C. ensiformis* and *G. max*. Phosphate application did not affect the final amount of P returned to the soil with the cover crop residues (Table 4.24).

Characterizing the P use efficiency of the cover crops in terms of the amount of above ground biomass produced at 50% flowering per unit P taken up, *C. ochroleuca*, the two varieties of *L. purpureus*, *S. hamata*, *C. cajan* and the two varieties of *M. pruriens* were the most efficient while *P. vulgaris* (b) and *C. ternatea* were least efficient (Fig. 4.38).

4.2.1.3 Effect of intercropping and P application on maize growth in 1996

Figures 4.39 and 4.40 and Table 4.25 show the effects of intercropping and P application on maize performance at Samaru (field II). Similar to the observation on field I in 1995, intercropping did not produce any significant effect on maize performance. Application of SSP produced significant increase in maize height at 6, 8,10 and 12 WAP (Fig. 4.39). Higher biomass production at 6 WAP and at 50% flowering were also

Table 4.24: Effect of P application on total P uptake by cover crop at the end of 1996 season at Samaru (Field II)

Cover crop	P uptake (kg ha^{-1})					
	CRL	SSP	SPR	F ratio	SE±	%CV
Arachis hypogaea	8.78	14.42	8.10	ns	-	-
Mucuna pruriens (white)	7.41	6.18	7.13	ns	-	-
Mucuna pruriens (black)	12.50	15.20	16.30	ns	-	-
Canavalia ensiformis	3.24	4.67	3.36	ns	-	-
Glycine max	2.67	2.67	2.58	ns	-	-
Phaseolus vulgaris (brown)	0.65	0.66	0.59	ns	-	-
Phaseolus vulgaris (variegated)	0.17	0.18	0.16	ns	-	-
Crotalaria ochroleuca	22.80	20.50	25.90	ns	-	-
Centrosema pubescens	8.50	8.89	6.47	ns	-	-
Lablab purpureus (white)	10.77	12.80	12.13	ns	-	-
Lablab purpureus (black)	9.80	11.20	7.00	ns	-	-
Pueraria phaseoloides	4.95	4.93	3.95	ns	-	-
Cajanus cajan	15.70	22.60	21.50	ns	-	-
Tephrosia vogelii	11.44	8.44	6.37	ns	-	-

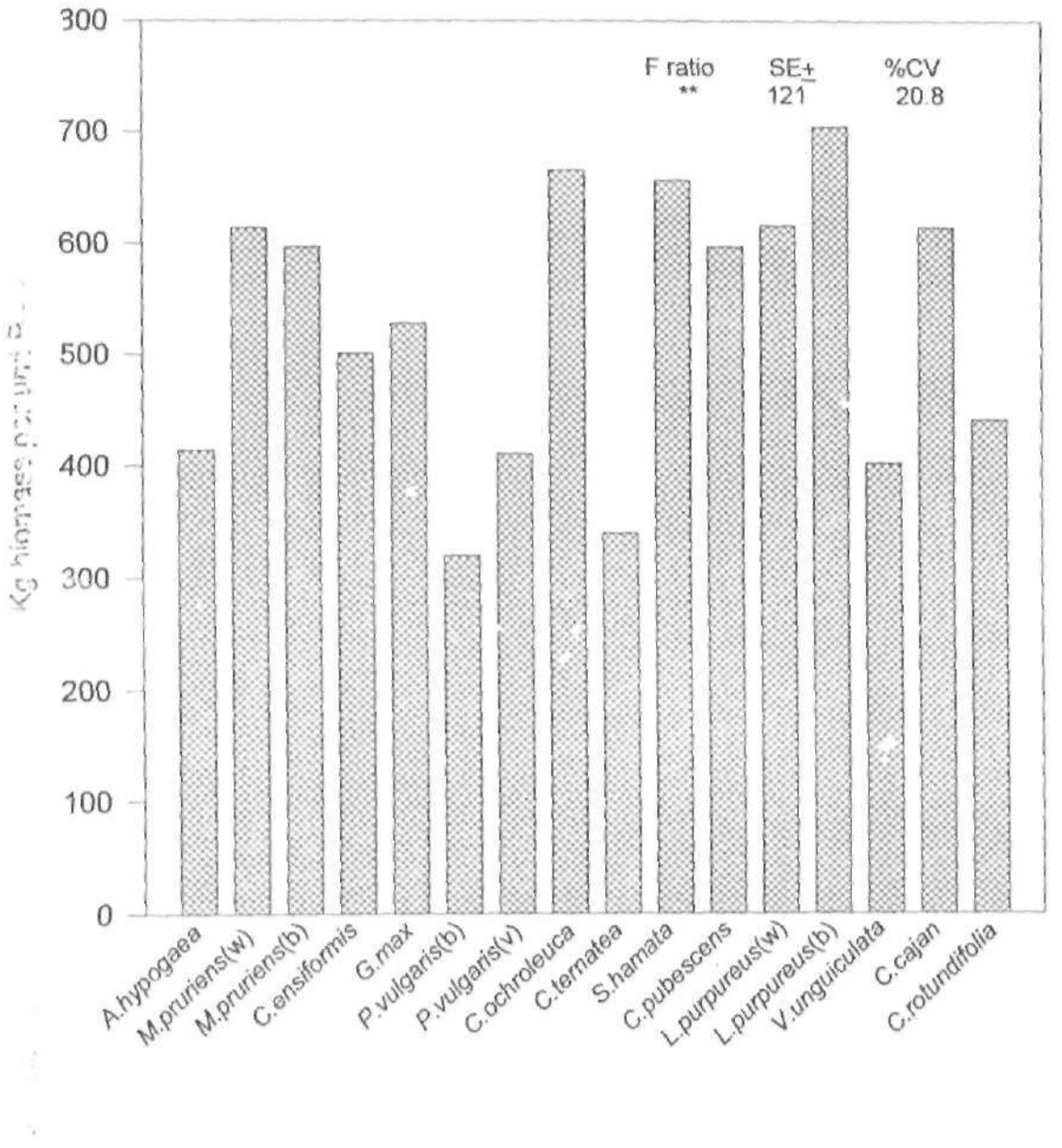


Figure 4.38: Phosphate use efficiency of the various cover crops at 50% flowering (Samaru Field II)

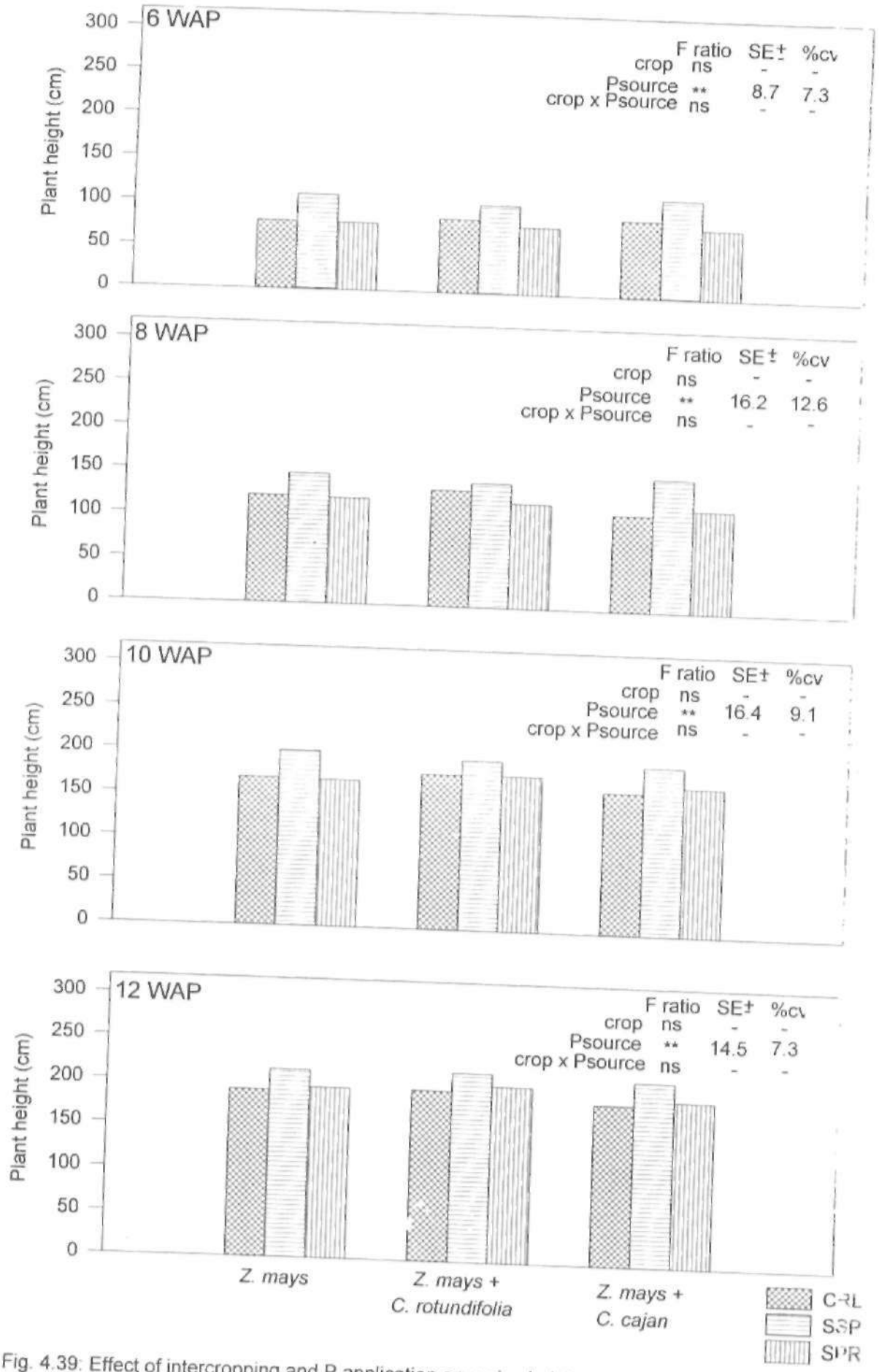


Fig. 4.39: Effect of intercropping and P application on maize height at Samaru in 1996 (Field II)

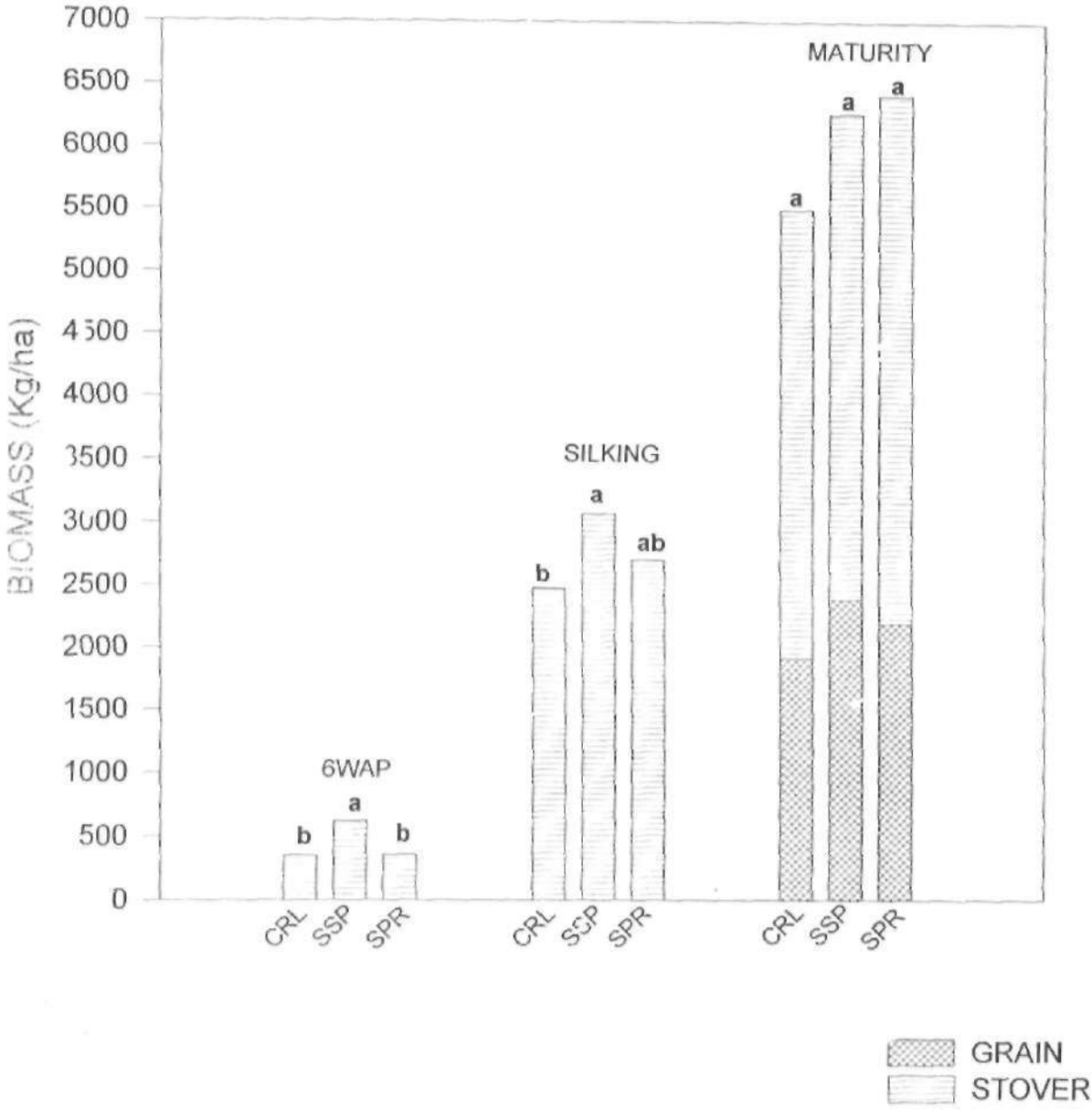


Figure 4.40: Effect of P application on Maize biomass at Samaru in 1996 (field II)

Table 4.25: Effect of P application and intercropping on some maize performance parameters

cropping	P source	Days to 50% Tasseling	Days to 50% silking	Grains/ cob	Shelling %	Coblength (cm)	Cobs per plant
Zea mays	CRL	67.8	76.8	380	80.9	12.5	0.95
	SSP	64.8	68.8	467	82.7	13.3	0.98
	SPR	68.5	74.8	452	81.3	14.3	0.92
Zea mays +	CRL	68.0	79.0	403	80.9	11.8	0.80
C.rotundifolia	SSP	63.0	68.0	417	80.9	11.8	0.80
	SPR	68.0	76.0	423	80.8	12.3	0.81
Zea mays + C.cajan	CRL	68.0	76.7	325	79.0	10.7	0.76
	SSP	64.3	69.0	475	78.5	13.5	0.92
	SPR	67.0	72.3	460	79.0	11.9	0.83
SE± for cropping		ns	ns	ns	ns	ns	ns
SE± for P source		0.6**	3.1**	84.4*	ns	ns	ns
SE± for croppingxP source		0.6**	ns	ns	ns	ns	ns
%CV		0.9	4.2	19.9	-	-	-

recorded with SSP (Fig. 4.40). Phosphate application, however, did not significantly affect grain yield (as was the case on field I) and stover yield. Days to 50% silking and tasseling were significantly shortened and number of grains per cob increased with SSP application (Table 4.25). Sokoto phosphate rock did not produce any significant effect on maize performance.

Figure 4.41 shows the P concentration in maize tissue at 6 WAP and in the stover. Intercropping and P application did not significantly affect P concentration. This suggests that the available soil P was sufficient to meet the demand of maize in the first year, as was the case on field I.

4.2.2 Second year (maize)

4.2.2.1 Effect of preceding cover crops and P application on maize performance in 1997

To verify if the observed beneficial effects of some of the cover crops on succeeding maize on field I were due to P effect or not, each sub-plot on field II was split into two in 1997 with one half getting fresh 30 Kg P ha^{-1} as SSP.

Effect of preceding cover crops on maize height at various intervals in 1997 at Samaru (field II) is shown in

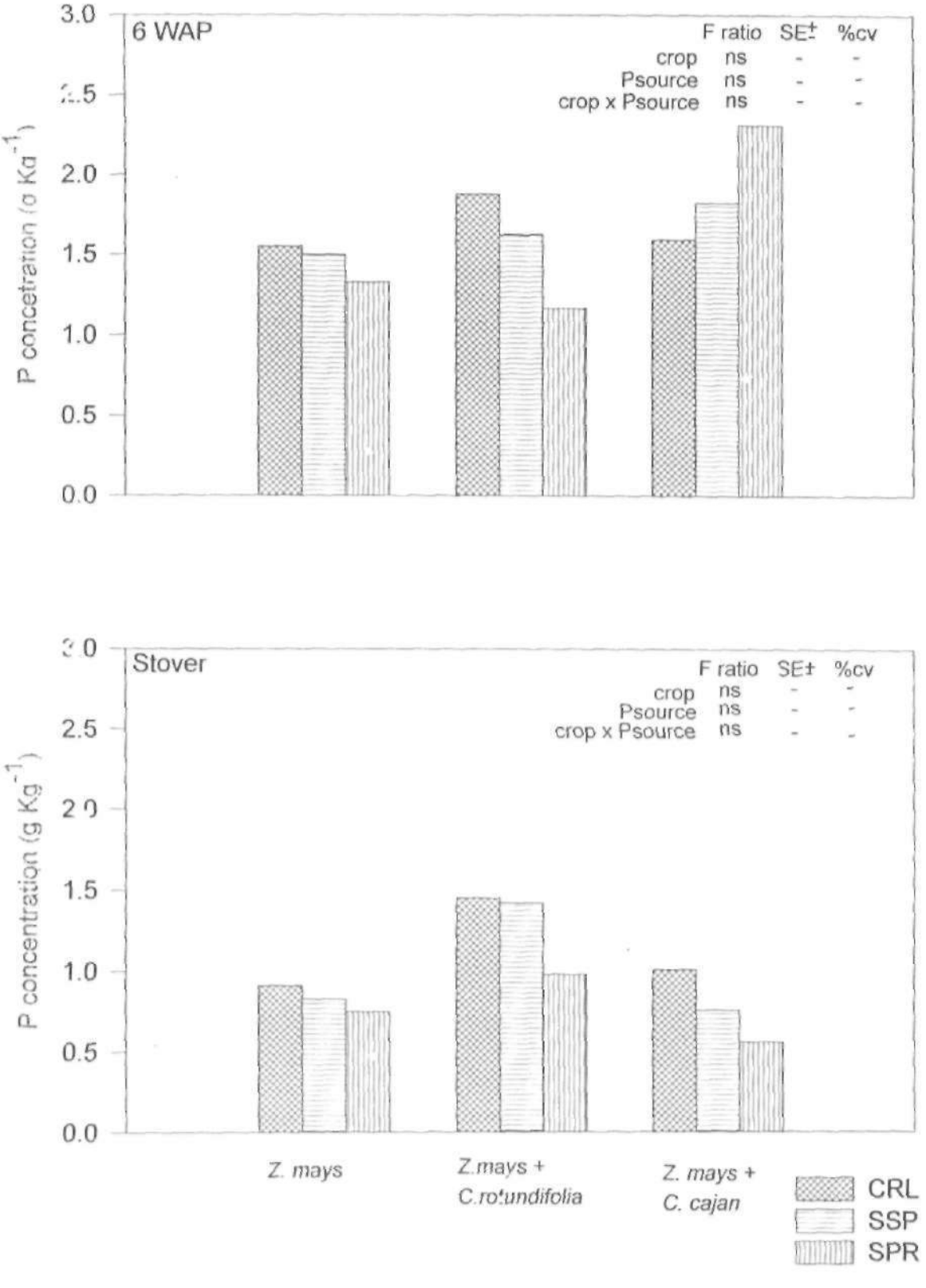


Figure 4.41: Effect of P application and intercropping on P concentration in maize tissue (Samaru Field II)

Fig. 4.42. Plots preceded by *L. purpureus* (w) consistently gave taller maize plants through out the growth period with and without fresh P application in 1997. Interaction between preceding crop and 1997 (fresh) P application did not influence maize height. Figure 4.43 shows the effect of 1996 and 1997 P application on maize height in 1997. Without fresh P application in 1997, plots treated with SSP in 1996 produced significantly taller maize plants at 6, 8 and 12 WAP than those treated with SPR or CRL. Previous (1996) phosphate application, however, did not influence maize height where fresh P application was made in 1997.

Figures 4.44 and 4.45 show the effect of preceding cover crops and P application on maize grain yield in 1997. Without fresh P application in 1997, plots preceded by L. purpureus (w) L. purpureus (b) and M. pruriens(b) produced significantly higher grain yields than the control. Plots preceded by Z. mays + C. cajan gave the lowest grain yields. However, with P application in 1997, the effect of preceding crops on maize yield disappeared. This suggests that the positive effect of *L. purpureus* (w), *L. purpureus* (b) and *M. pruriens* (b) on grain yield observed without fresh P application in 1997 may in part be due to P effect. Averaged over all preceding cover crops, 1996 SSP application significantly increased maize grain yield in 1997, but this effect was not observed where

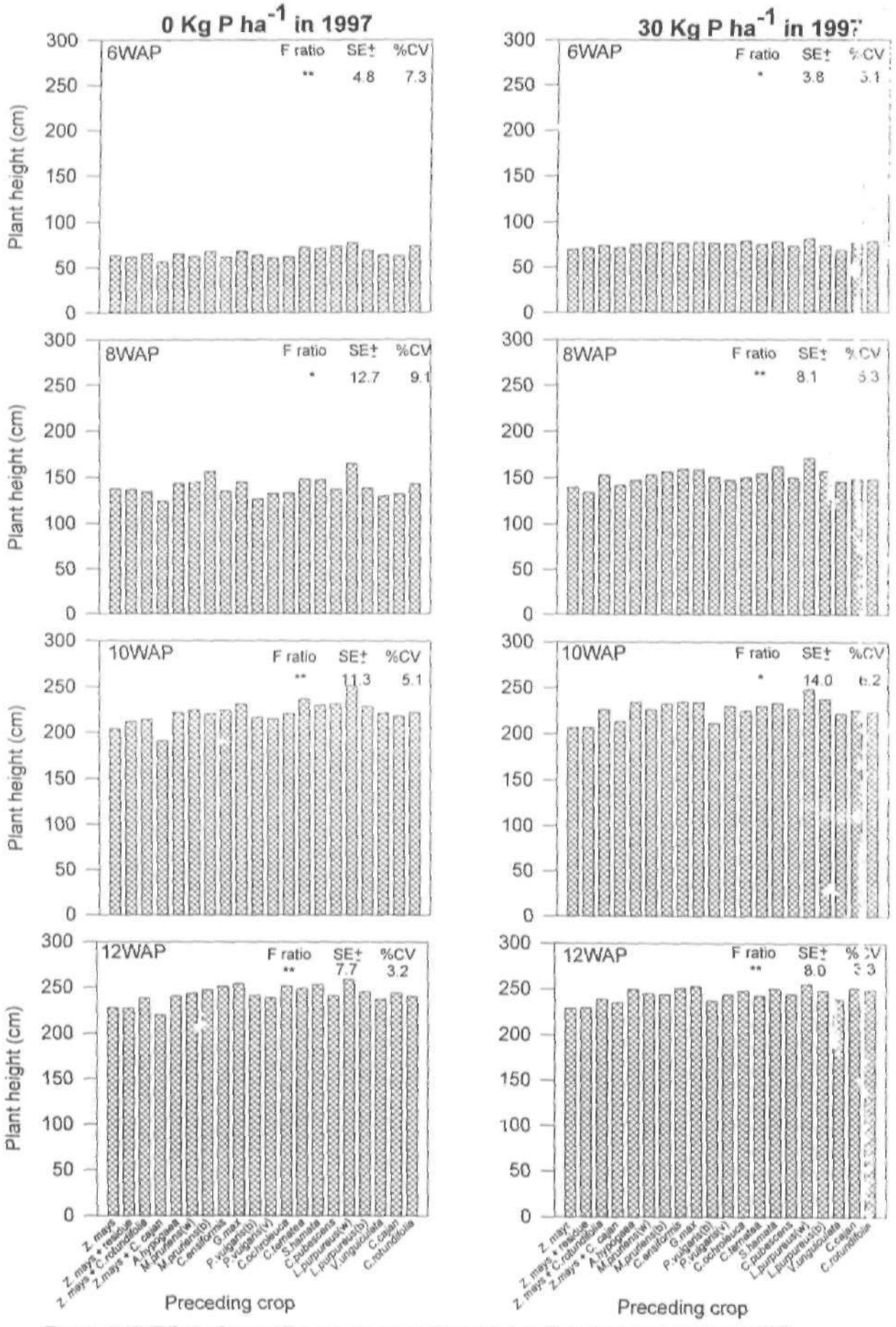


Figure 4.42: Effect of preceding cover crops on maize height at Samaru in 1997 (field II)

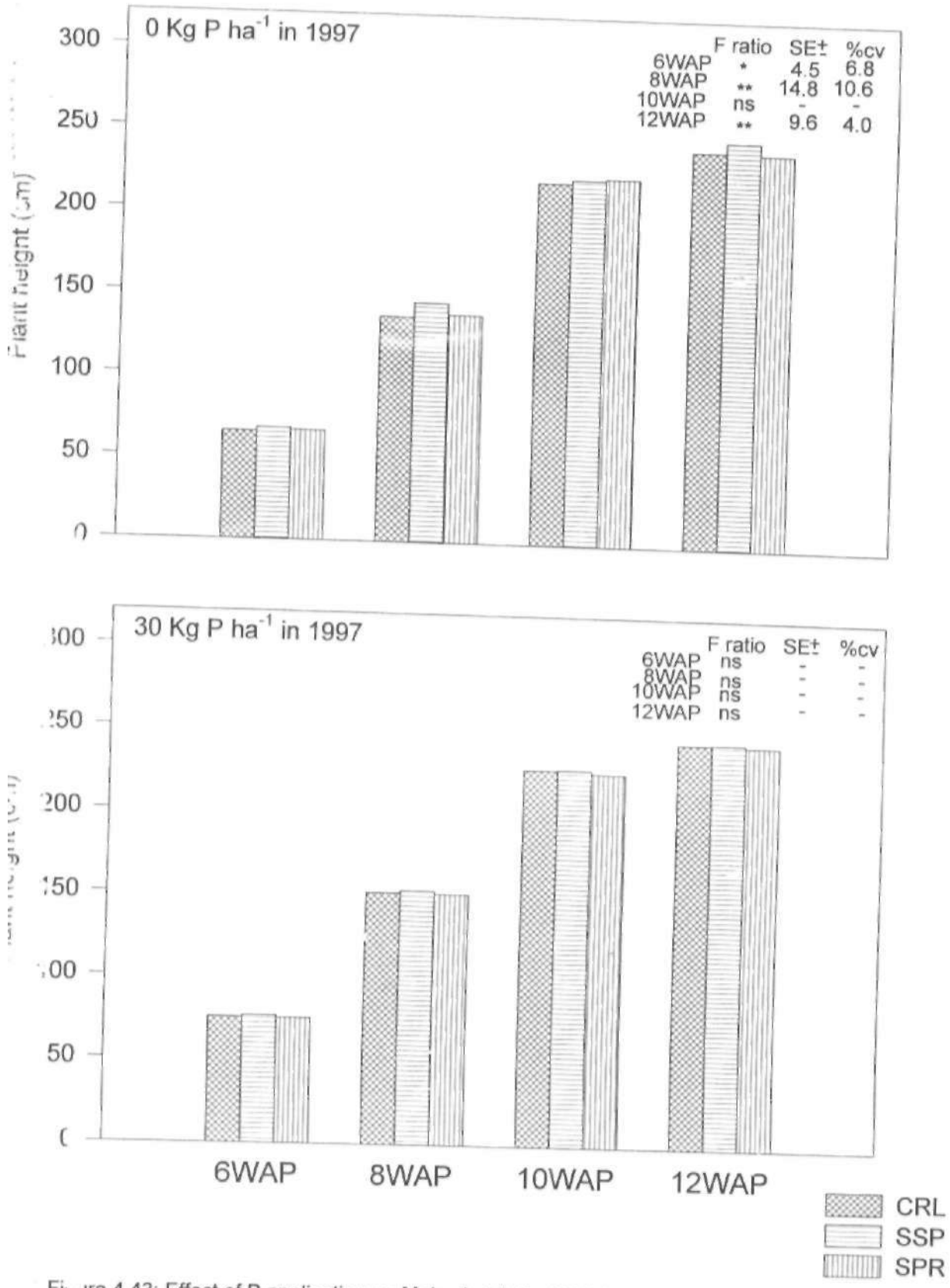


Figure 4.43: Effect of P application on Maize height in 1997 (averaged over cover crops)

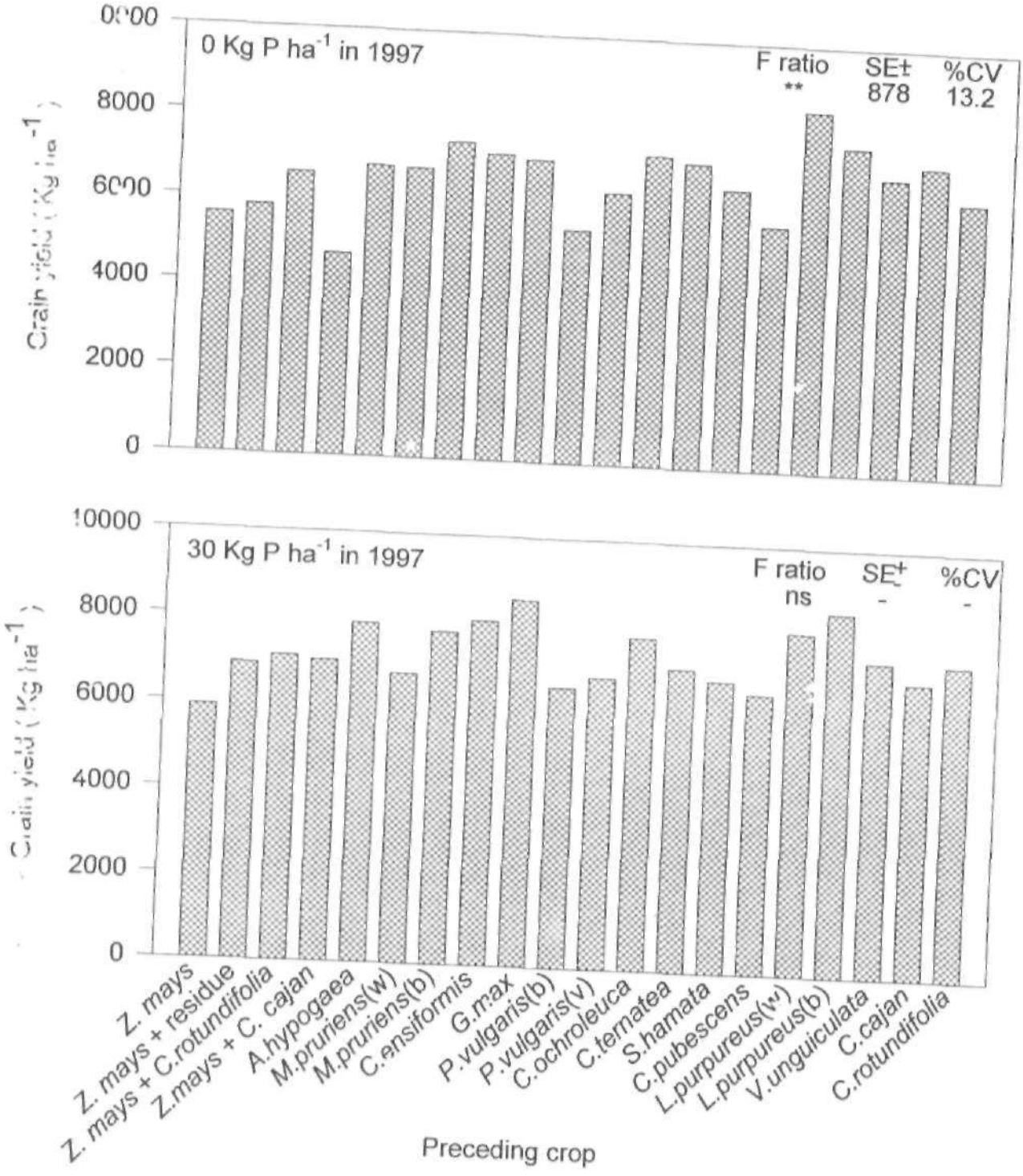


Figure 4.44: Effect of 1996 cover cropping on maize grain yield in 1997 (Samaru Field II)

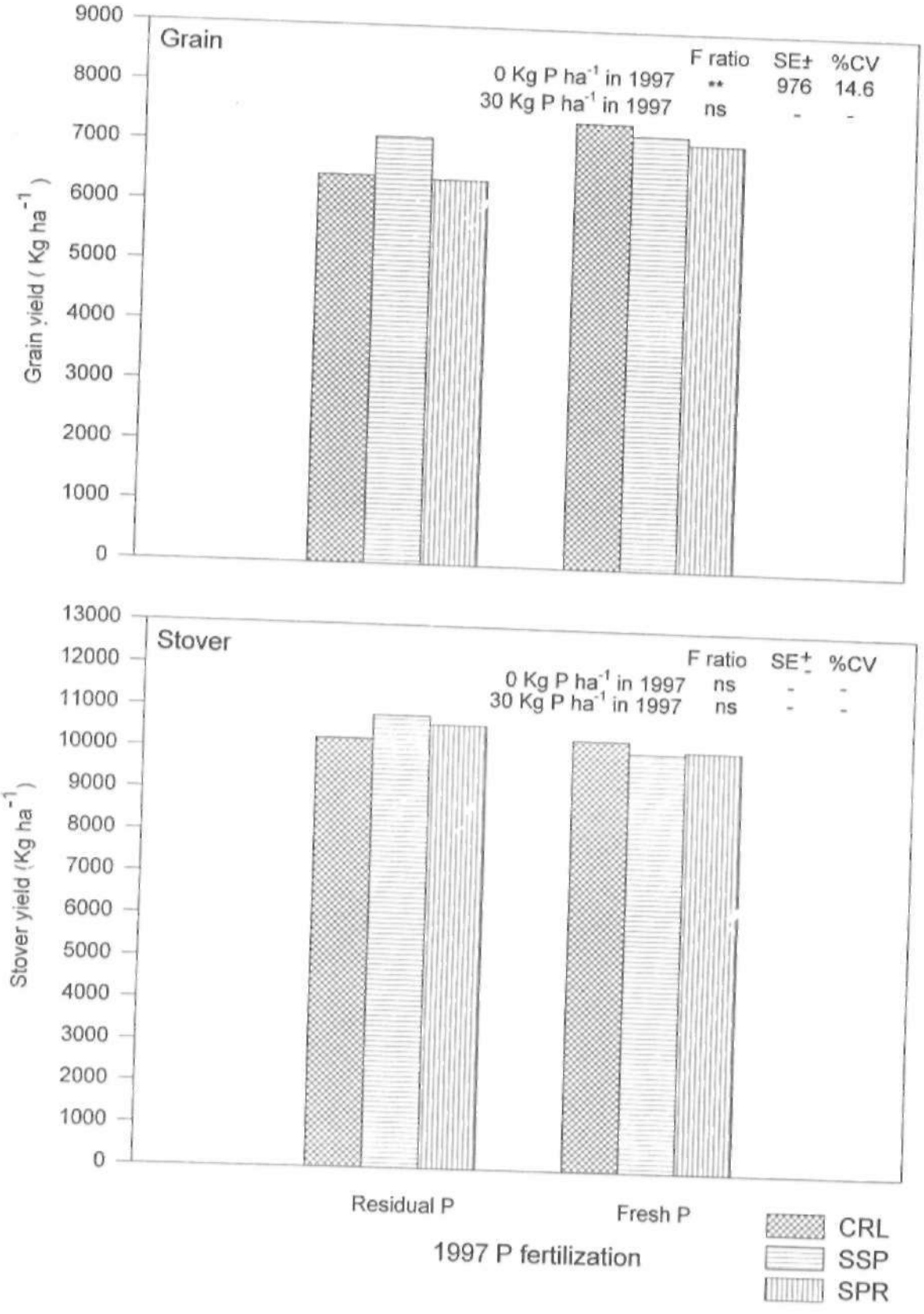


Figure 4.45: Effects of 1996 and 1997 P fertilization on maize grain and stover yields at Samaru (fieldII)

fresh P was applied in 1997 (Fig. 4.45).

The trend in stover yield was similar to what was observed with grain yield (Fig. 4.46). Preceding cover crops generally (significantly) improved stover yields over the control. Although there were increases in stover yields over the control as a result of 1996 cover cropping even with fresh P application in 1997, such increases were not significant. Averaged over all preceding crops, 1996 phosphate application did not affect maize stover yield in 1997 (Fig. 4.45).

4.2.2.2 Effects of treatments on nutrient elements contents of maize tissue

Figures 4.47 and 4.48 show the effect of preceding crops and P application on tissue P concentration of index leaves at 50% flowering, grains and stover of maize at Samaru (field II) in 1997. There were no significant effects of preceding crops, 1996 P fertilization or 1997 P fertilization on tissue P concentrations.

Similarly no significant effects of preceding crops or P application were observed on total P uptake by maize in 1997 (Fig. 4.49 and 4.50).

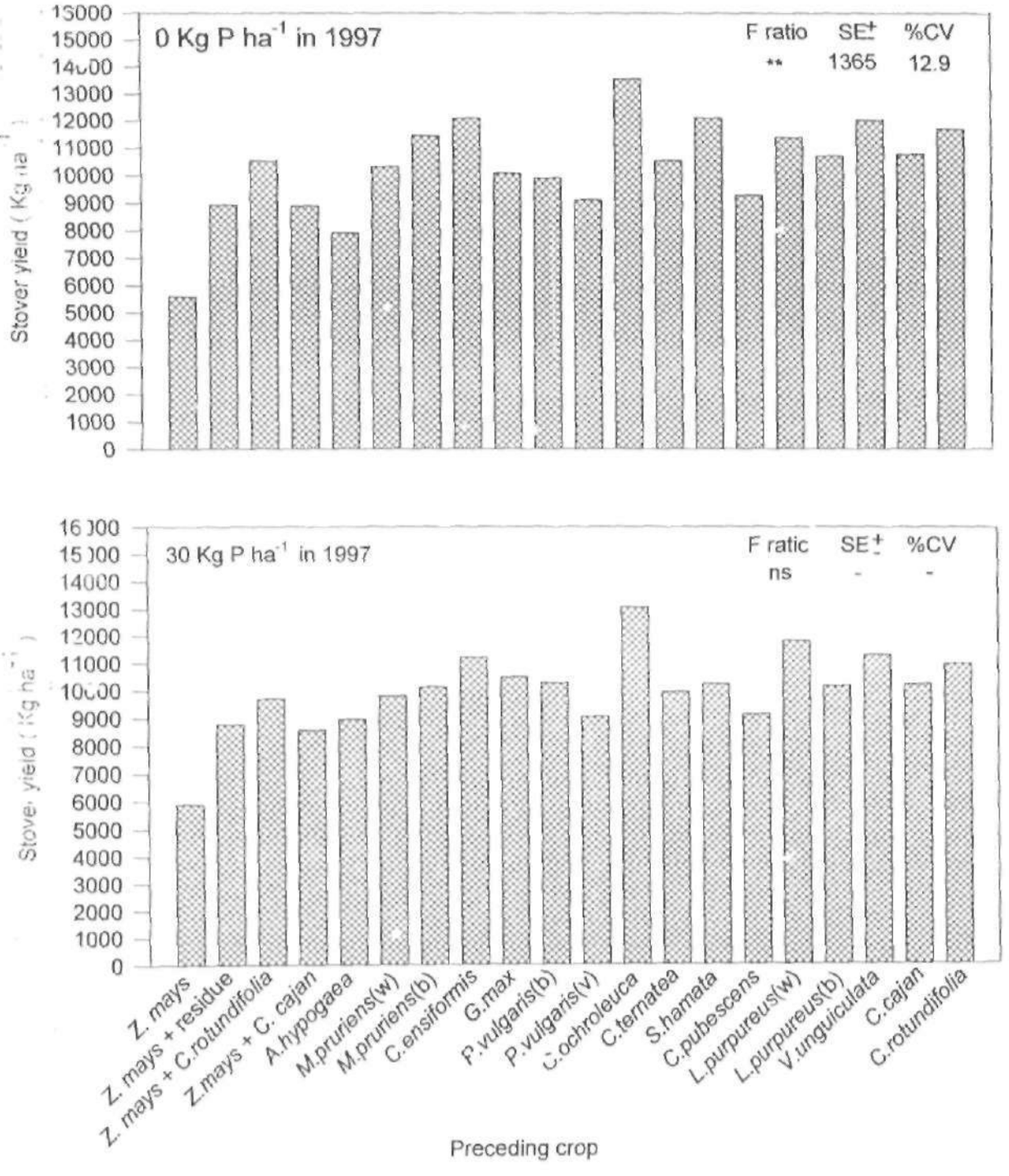


Figure 4.46: Effect of 1996 cover cropping on maize stover yield in 1997(Samaru Field II)

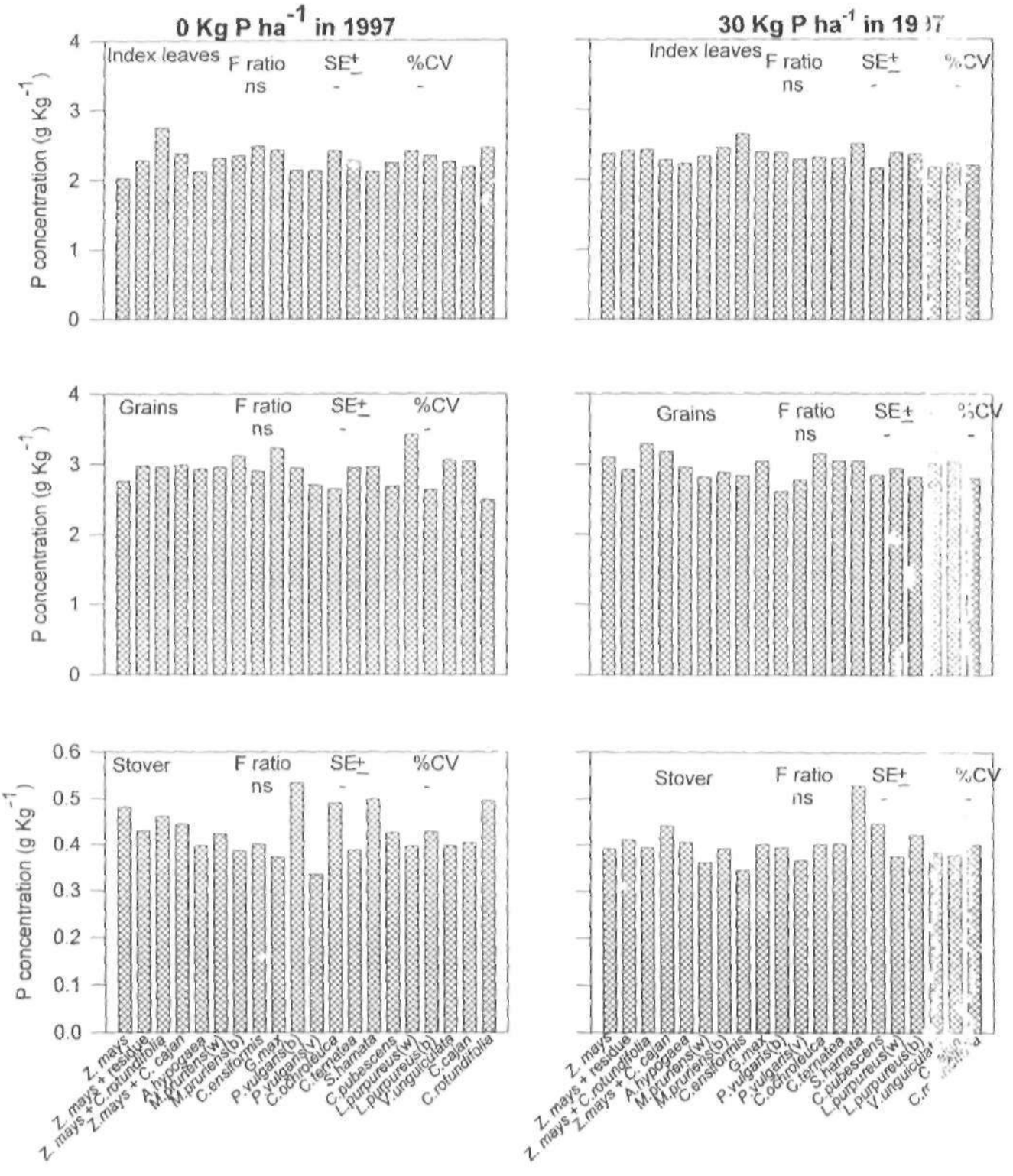


Figure 4.47: Effect of preceding crops on maize tissue P concentration in 1997 at Samaru (averaged over 1996 P sources)

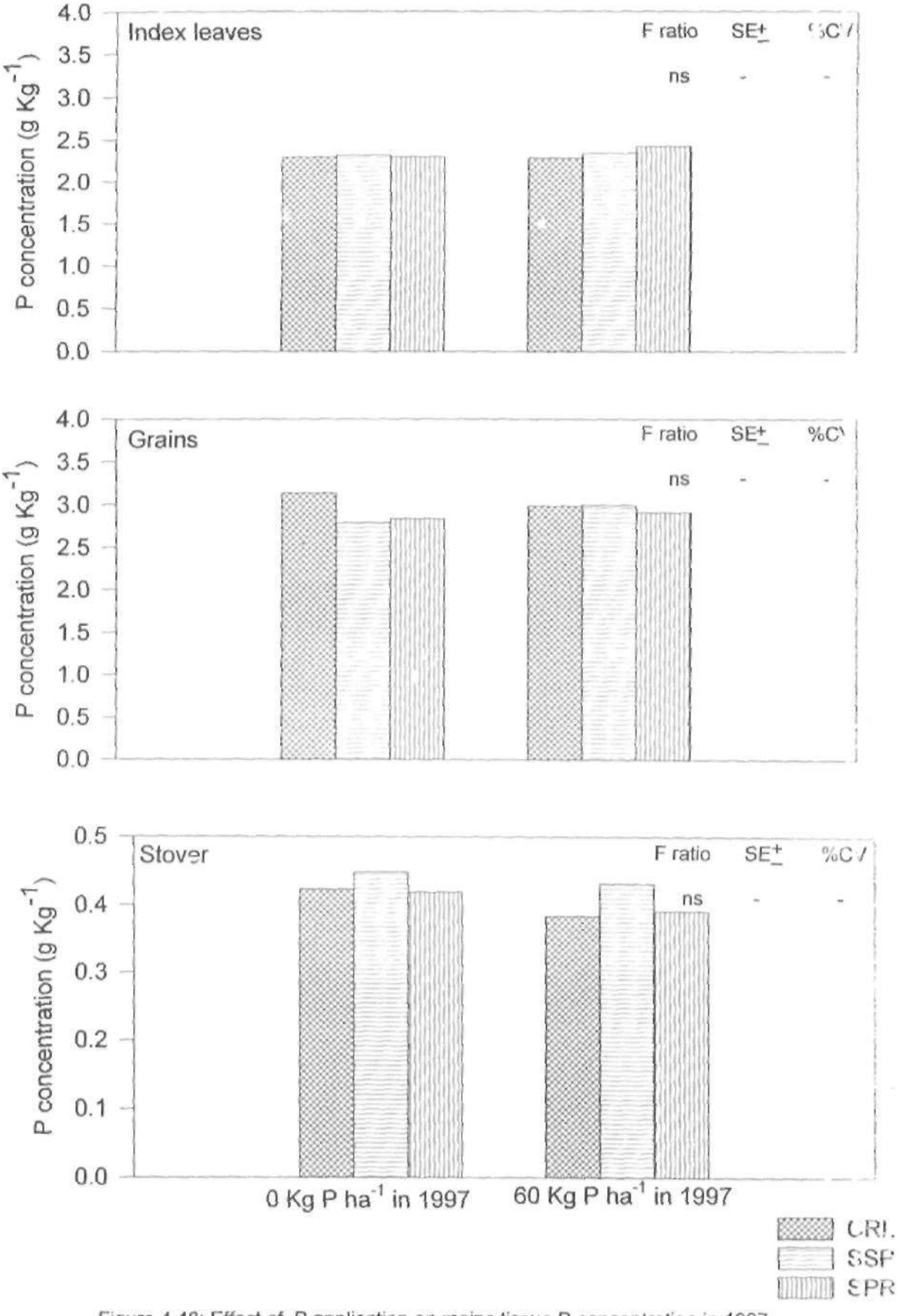


Figure 4.48: Effect of P application on maize tissue P concentration in 1997 at Samaru field II (averaged over cover crop treatments)

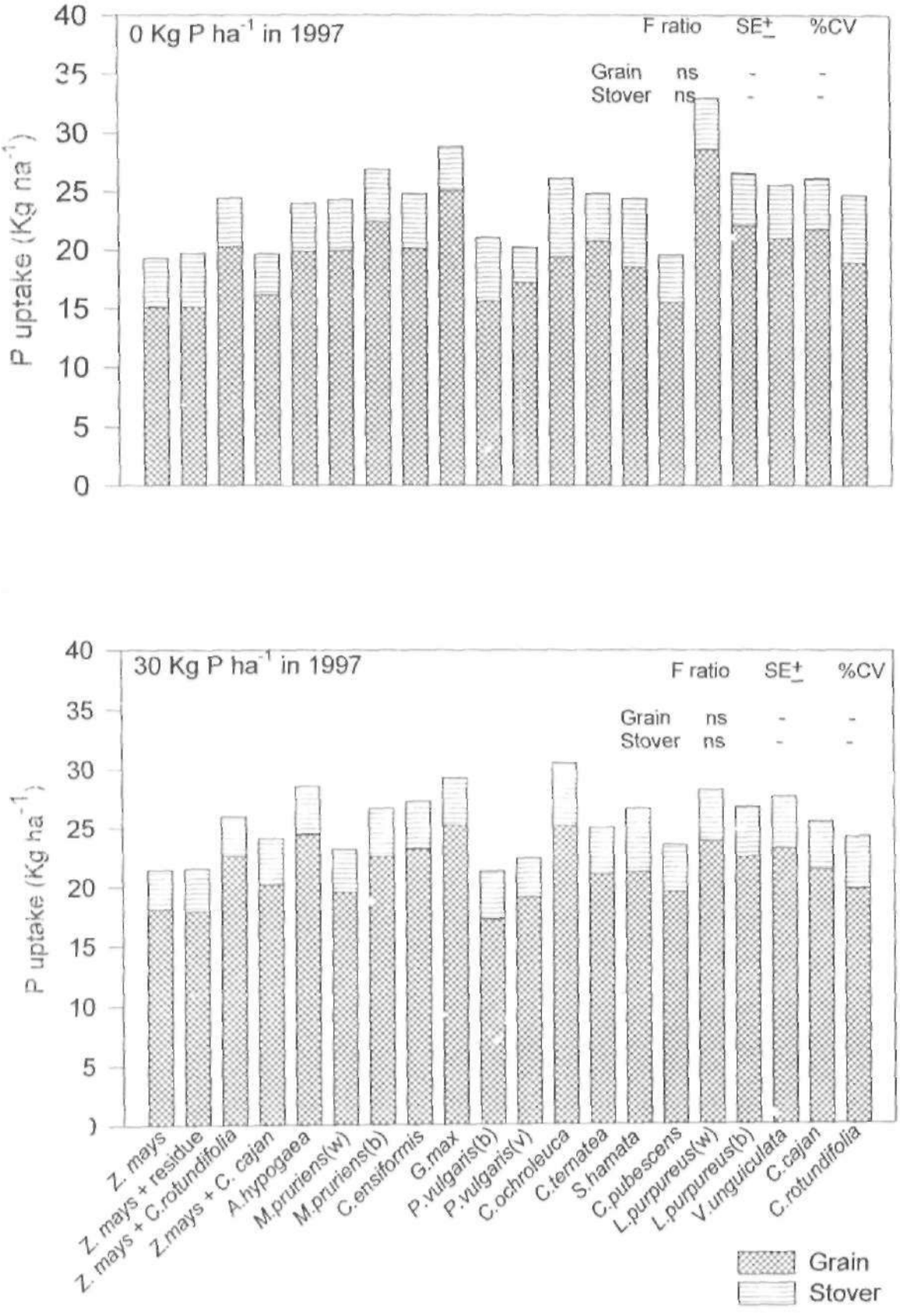


Figure 4.49: Effect of preceding crops on total P uptake by succeeding maize crop at Samaru in 1997 (Field II)

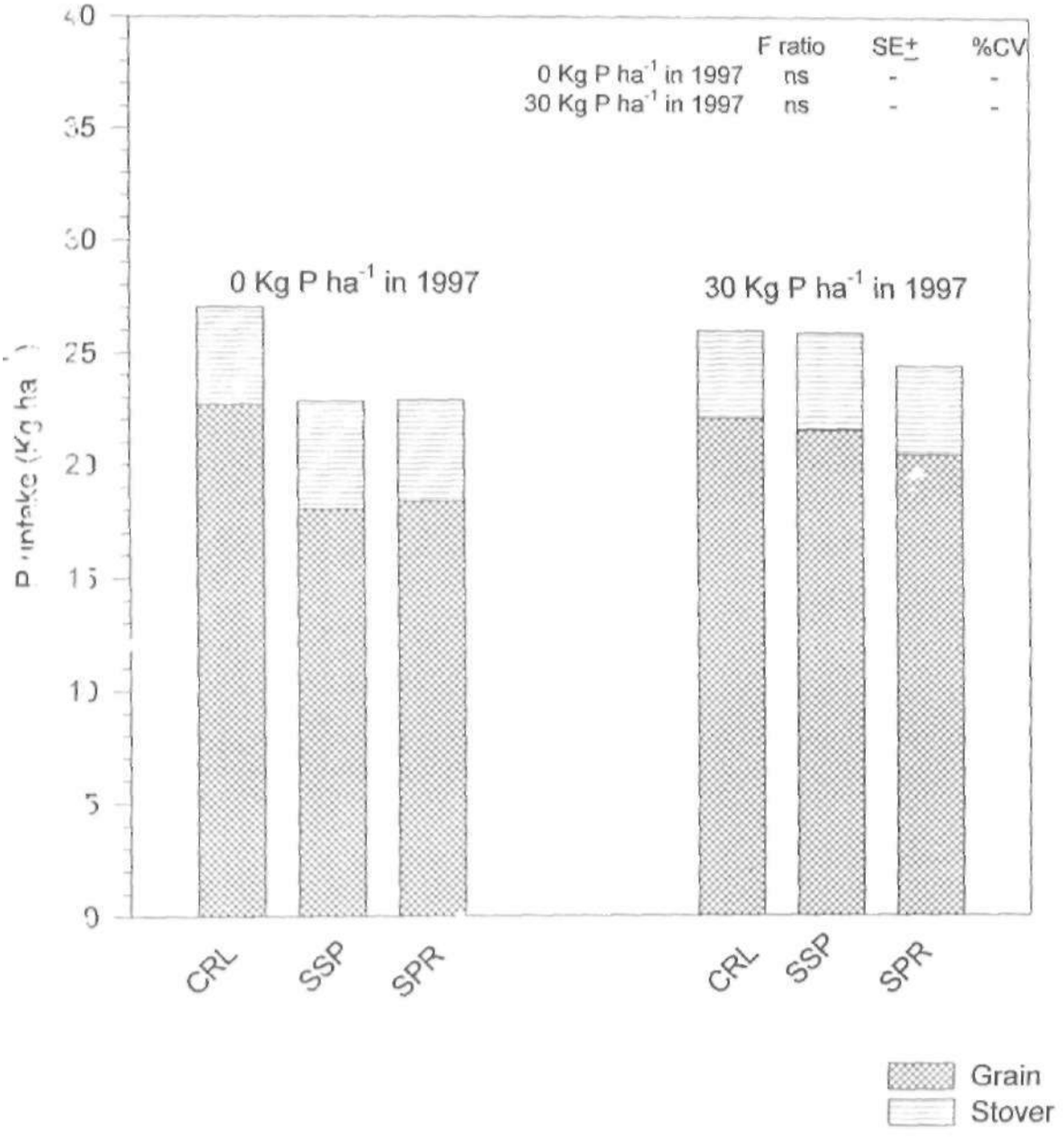


Figure 4.50: Effect of P application in 1996 and 1997 on total P uptake by maize in 1997 at Samaru field II (averaged over preceding crops)

Effect of preceding crops on concentrations of K, Ca, Mg, Al, Mn and Fe in the index leaves of maize at 50% flowering in 1997 were not significant (Table 4.26). The concentration of S in the index leaves was significantly raised on plots previously cropped with *Z. mays + C. rotundifolia* and *Z. mays + C. cajan*. All preceding crop treatments except *Z. mays* + residue and *V. unguiculata* significantly increased the concentration of Cu over the control. Concentration of Zn in the index leaves was significantly raised on plots preceded by *A. hypogaea, M. pruriens* (w), *C. ensiformis, C. ochroleuca,* the two varieties of *L. purpureus, G. max, C. cajan* and the two varieties of *P. vulgaris*.

The relationships between nutrient element concentrations of the index leaves and yields of maize in 1997 are shown in Table 4.27. Phosphorus concentration in the index leaves did not correlate significantly with grain and stover yields. Zinc concentration of index leaves correlated positively with grain yield (r=0.450*), while S negatively affected grain yield (r=-0.561**). Yield responses to Zn application by maize at Samaru have also been reported by Iwuafor *et al.* (1991) and Oluwookere (1997). Stover yield increased with increased Mg concentration in the index leaves and decreased when the S concentration increased (r=0.504* and r=-0.714** respectively).

Table 4.26: Effect of preceding crops on nutrient element concentrations in index leaves of maize at 50% silking in 1997 at Samaru.

Preceding crop	Ca	Mg	K	S	Fe	Mn	Cu	Zn	Al
	g kg^{-1}				mg kg^{-1}				
Z.mays	2.72	0.98	11.36	0.94	105	29.34	3.96	11.34	96
Z.mays + residue	2.52	1.09	11.02	0.83	84	34.26	5.12	12.82	79
Z.mays + C.rotundifolia	2.94	1.25	12.60	1.22	111	34.98	6.68	16.04	98
Z.mays + C.cajan	2.98	1.16	13.02	1.32	106	32.34	6.08	15.22	93
A. hypogaea	3.76	1.39	15.20	0.91	127	40.18	6.72	22.02	102
M. pruriens (w)	2.76	1.11	12.38	0.80	101	31.98	6.08	20.22	93
M. pruriens (b)	3.04	1.34	11.74	1.02	102	32.64	6.10	15.36	87
C. ensiformis	3.34	1.35	13.48	0.94	103	26.22	7.24	21.84	93
G. max	3.40	1.40	14.32	0.96	119	42.28	5.78	21.56	70
P. vulgaris (b)	3.12	1.21	12.52	0.83	109	33.64	6.36	18.78	88
P. vulgaris (v)	2.92	1.17	12.94	1.05	115	28.88	5.78	17.90	99
C. ochroleuca	3.22	1.52	1[illegible].14	0.81	105	36.22	6.56	21.18	81
C. ternatea	2.68	1.18	12.20	0.76	95	32.96	5.66	16.26	88
[illegible]. hamata	2.94	1.21	13.32	0.72	142	41.36	5.84	17.04	107
[illegible]. pubescens	2.80	1.17	12.14	0.82	97	29.[illegible]8	5.84	15.00	87
[illegible].purpureus (w)	2.92	1.37	13.4	0.82	103	31.14	6.72	18.36	88
L. purpureus (b)	2.92	1.24	13.68	0.94	111	45.00	6.56	20.28	97
V. unguiculata	3.00	1.29	13.44	1.01	106	29.74	5.24	17.36	99
C. cajan	2.96	1.67	12.78	0.93	102	26.30	7.20	18.10	80
C. rotundifolia	2.82	1.26	13.04	0.74	108	26.62	6.54	15.88	94
F ratio	ns	ns	ns	**	ns	ns	*	*	ns
SE±	-	-	-	0.168	-	-	0.966	3.738	-
%CV	-	-	-	18.2	-	-	15.9	21.2	-

Table 4.27: Matrix of correlation coefficients between nutrient concentrations in index leaves, yields of maize in 1997 and amount of crop residue returned to the soil at the end of 1996 season

	Grain yield	Stover yield	P	Ca	Mg	K	S	Fe	Mn	Cu	Zn	Al	Residue
Grain yield	1.000												
Stover yield	0.744**	1.000											
P	0.216	0.107	1.000										
Ca	0.002	0.065	0.103	1.000									
Mg	0.194	0.504*	0.183	0.719**	1.000								
K	0.294	0.179	-0.203	0.755**	0.531*	1.000							
S	-0.561**	-0.714**	-0.077	0.166	-0.036	0.106	1.000						
Fe	-0.042	-0.007	-0.305	0.541*	0.261	0.663*	0.025	1.000					
Mn	0.081	0.025	-0.199	0.328	0.300	0.393	-0.042	0.516*	1.000				
Cu	0.396	0.349	0.160	0.475*	0.573**	0.468*	0.019	0.143	0.003	1.000			
Zn	0.450*	0.354	0.119	0.742**	0.695**	0.716**	-0.124	0.375	0.351	0.656**	1.000		
Al	-0.042	-0.046	-0.274	0.019	-0.201	0.255	0.122	0.507*	0.033	-0.039	-0.069	1.000	
Residue	-0.074	0.206	-0.084	0.140	0.403	-0.130	-0.035	0.090	0.186	0.306	0.143	-0.128	1.000

4.2.2.3 Effect of previous cropping and P application on some soil properties

Table 4.28 shows the effect of 1996 P application to cover crops on available soil P and pH at the start of 1997 season. Averaged over preceding cover crops, SSP gave significantly higher concentration of available soil P than GPR and CRL. The impact of preceding cover crops on available soil P at the start of 1997 season was not significant. Effect of the interaction between cover crops and 1996 P application also did not influence the concentration of available soil P.

Soil pH at the start of 1997 season was not significantly affected by both 1996 P application and cover cropping (Table 4.28).

Table 4.29 shows the effect of 1996 cover cropping on citrate-bicarbonate-dithionite (CBD) extractable (crystalline) and oxalate extractable (amorphous) oxides of Mn, Fe, and Al in the soil at the start of 1997 season. Although no statistically significant reductions were observed, C. ensiformis considerably decreased the concentrations of all three oxides extracted with both CBD and oxalate.

Table 4.30 shows the relationships between maize yields,

Table 4.28: Effect of preceding cover crop and 1996 P applicatio on soil pH and available P at the start of 1997 season.

Preceding crop	pH			Bay 1 P (mg Kg^{-1})		
	CRL	SSP	SPR	CRL	SSP	SPR
Z.mays - residue	5.3	5.2	5.5	8.12	8.51	8.76
Z.mays + residue	5.4	5.4	5.3	7.25	7.83	7.55
Z.mays + *C.rotundifolia*	5.3	5.4	5.4	11.80	15.58	12.81
Z.mays + *C.cajan*	5.1	5	5.1	4.64	6.74	6.93
A. hypogaea	5.3	5.5	5.7	7.23	11.64	6.60
M. pruriens (w)	5.3	5.4	5.2	4.53	5.78	6.33
M. pruriens (B)	5.3	5.4	5.4	10.21	11.91	9.81
C. ensiformis	5.2	5.6	5.4	5.16	7.81	7.29
G. max	5.3	5.3	5.4	10.26	12.66	12.35
P. vulgaris (b)	5.4	5.4	5.3	7.45	11.39	10.57
P. vulgaris (v)	5.5	5.4	5.5	5.35	10.97	5.88
C. ochroleuca	5.5	5.2	5.5	4.73	9.56	9.63
C. ternatea	5.4	5.6	5.3	7.84	11.04	7.71
C. hamata	5.5	5.4	5.6	7.45	10.53	7.04
C. pubescens	5.4	5.6	5.6	6.21	10.89	8.28
L. purpureus (w)	5.6	5.6	5.6	8.50	15.04	8.61
L. purpureus (b)	5.6	5.5	5.4	8.82	11.71	7.88
V. unguiculata	5.5	5.3	5.7	9.80	12.58	12.13
C. cajan	5.5	5.3	5.3	7.79	9.71	8.05
C. rotundifolia	5.5	5.5	5.5	10.26	9.47	8.73
SE± for crop		ns			ns	
SE± for P source		ns			2.77**	
SE± for crop x P source		ns			ns	
%cv		-			31.0	

Table 4.29: Effect of preceding crops on crystalline and amorphous oxides of Fe, Al and Mn in Samaru soil at the start of 1997 season

Preceding crop	Fe_2O_3	Al_2O_3	MnO	Fe_2O_3	Al_2O_3	MnO
	CBD -extractable			Oxalate-extractable		
	<----------mg Kg-1---------->					
Z mays	13566	6246	276	1096	218	106
Z mays + residue	12267	5623	208	930	192	76
Z mays + C.rotundifolia	12754	5868	231	838	180	80
Z. mays + C.cajan	12019	5238	176	792	188	66
A hypogaea	12543	5687	215	818	186	76
M. pruriens (w)	12205	5658	194	790	190	72
M. pruriens (b)	11931	5533	239	842	198	88
C. ensiformis	10246	4751	152	658	170	54
G. max	14065	6041	259	946	194	88
P. vulgaris (b)	13085	5781	261	900	194	90
P. vulgaris (v)	13662	5675	248	1124	192	94
C. ochroleuca	11623	5091	190	792	186	76
C. ternatea	11994	5627	245	1186	218	104
S. hamata	11979	5474	225	956	190	86
C. pubescens	11403	5297	197	680	170	76
L purpureus (w)	14442	6102	259	972	188	94
L. purpureus (b)	11251	5225	204	688	170	74
V. unguiculata	12291	5670	213	812	188	76
C. cajan	12673	5547	181	898	176	68
C. rotundifolia	11143	5457	235	834	190	90
F. prob.	ns	ns	ns	ns	ns	ns
SE±	-	-	-	-	-	-
CV%	-	-	-	-	-	-

Table 4.30: Matrix of correlation coefficients between nutrient elements concentrations in index leaves, maize yields and some soil properties.

Soil properties	Nutrients elements in index leves										Grain yield	Stover yield
	P	Ca	Mg	K	S	Fe	Mn	Cu	Zn	Al		
Bray 1 P	-0.002	-0.024	0.133	0.109	0.104	0.129	0.182	-0.059	-0.210	-0.033	0.187	0.193
pH	-0.385	-0.245	0.142	0.042	-0.516*	0.076	0.102	0.093	0 087	0.044	0.458*	0.635**
CBD extractable Mn	-0.200	0.017	-0.087	0.074	0.143	0.151	0.094	-0.299	-0.086	-0.202	-0.047	-0.304
CBD extractable Fe	-0.031	-0.153	-0.264	-0.052	0.011	0.084	0.077	-0.478*	-0.302	-0.084	0.055	-0.206
CBD extractable Al	0.072	-0.140	-0.120	-0.090	-0.140	0.183	0.147	-0.470*	-0.298	-0.015	0.0 4	-0.059
Oxalate extractable Mn	0.144	-0.318	-0.335	-0.235	-0.135	0.043	-0.066	-0.500*	-0.360	-0.053	-0.038	-0.147
Oxalate extractable Fe	0.370	-0.284	-0.318	-0.367	-0.143	+0.082	-0.041	-0.674**	-0.442	-0.057	-0.213	-0.141
Oxalate extractable Al	0.157	-0.309	0.211	-0.244	-0.264	0.079	0.044	-0.536*	-0.408	0.014	0.036	0.009

nutrient concentrations of index leaves at 50% silking and some soil properties at the start of 1997 season. Grain and stover yields were higher with higher soil pH (r=0.458* and r=0.635** respectively). Concentration of S in index leaves increased with decreasing soil pH (r=-0.516*). No significant relationships were observed between Bray 1 P and grain and stover yields (r=0.187 and r=0.193 respectively). Concentration of Cu in index leaves was negatively correlated with oxalate and CBD extractable oxides of Fe, Al and Mn.

4.3 Field III (Heipang)

4.3.1 First year (cover crops and maize)

4.3.1.1 Effect of liming and P application on growth of cover crops in 1996

The response of the cover crops to phosphate fertilization and liming in terms of their above ground biomass production at 6 WAP and plant residues at the end of season is shown in Fig. 4.51. Due to slow establishment of *C. rotundifolia* at Heipang, it's biomass production at 6 WAP was not assessed. *Glycine max* produced the highest amount of biomass at 6 WAP while *C. cajan* produced the least. However, at the end of the season, *C. cajan* and *C. rotundifolia* produced the greatest amounts of residues while *P. vulgaris*

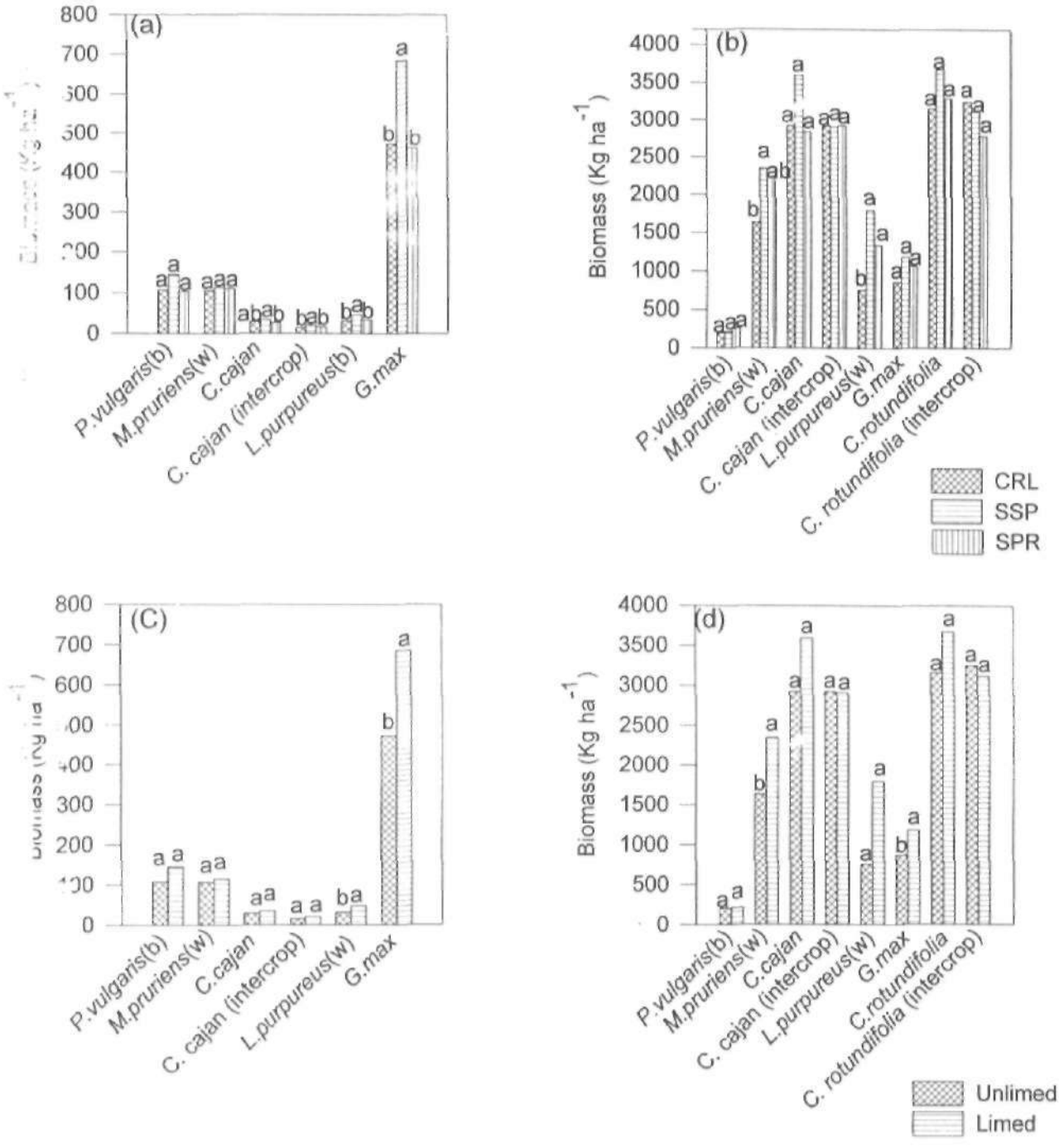


Fig. 4.51: Effect of P application on green manure biomass at 6WAP (a) averaged over lime rates (c) averaged over P sources; and residue at the end of season (b) averaged over lime rates (d) averaged over P sources

had the lowest. Application of SPR did not produce significant effect on biomass production at 6 WAP in any of the cover crops. But at the end of season, SPR significantly improved the amount of residue produced by *L. purpureus* (W), and slightly (though not statistically significant) increased the amount of *M. pruriens* (W) residue produced. Single superphosphate, on the other hand, produced significant increases in *G. max*, *C. cajan* (intercrop), and *L. purpureus* (W) biomass at 6 WAP, and *L. purpureus* (W) and *M. pruriens* (W) residues at the end of the season. Although not statistically significant, SSP produced 35, 13 and 16% increase in biomass at 6 WAP in *P. vulgaris* (b), *M. pruriens* (W) and *C. cajan* respectively.

Lime application produced significant increase in above ground biomass of only *G. max* and *L. purpureus* (W) at 6 WAP, and residues of *G. max* and *M. pruriens* (W) at the end of season. Although not statistically significant, all the other cover crops except *C. rotundifolia* (intercrop) and *C. cajan* (intercrop) showed positive response to liming in terms of quantities of crop residues produced.

4.3.1.2 Effect of liming and P application on tissue P content of cover crops in 1996

Effects of P application and liming on tissue P concentration and P uptake at 6 WAP and in crop residues at the end of season are presented in Figs. 4.52 and 4.53. At 6 WAP only *L. purpureus* (W) had it's tissue P concentration significantly raised as a result of P application, with both SSP and SPR increasing the tissue P content. In terms of P uptake at 6 WAP, only *G. max* responded significantly to SSP. Both SSP and SPR significantly raised the tissue P concentration of *C. cajan* residue and the amount of P taken up by the residues of *C. cajan* and *L. purpureus* (W). *Cajanus cajan* (intercrop) and *G. max* had their residue P concentrations raised as a result of fertilization with SSP. Single superphosphate also significantly improved the amount of P taken up in the residues of *G. max* and *C. rotundifolia*.

Liming did not significantly affect the tissue P concentration of the cover crops both at 6 WAP and at the end of the season. However, P uptake by *M. pruriens* (W) at 6 WAP and *G. max* residues were significantly improved by liming.

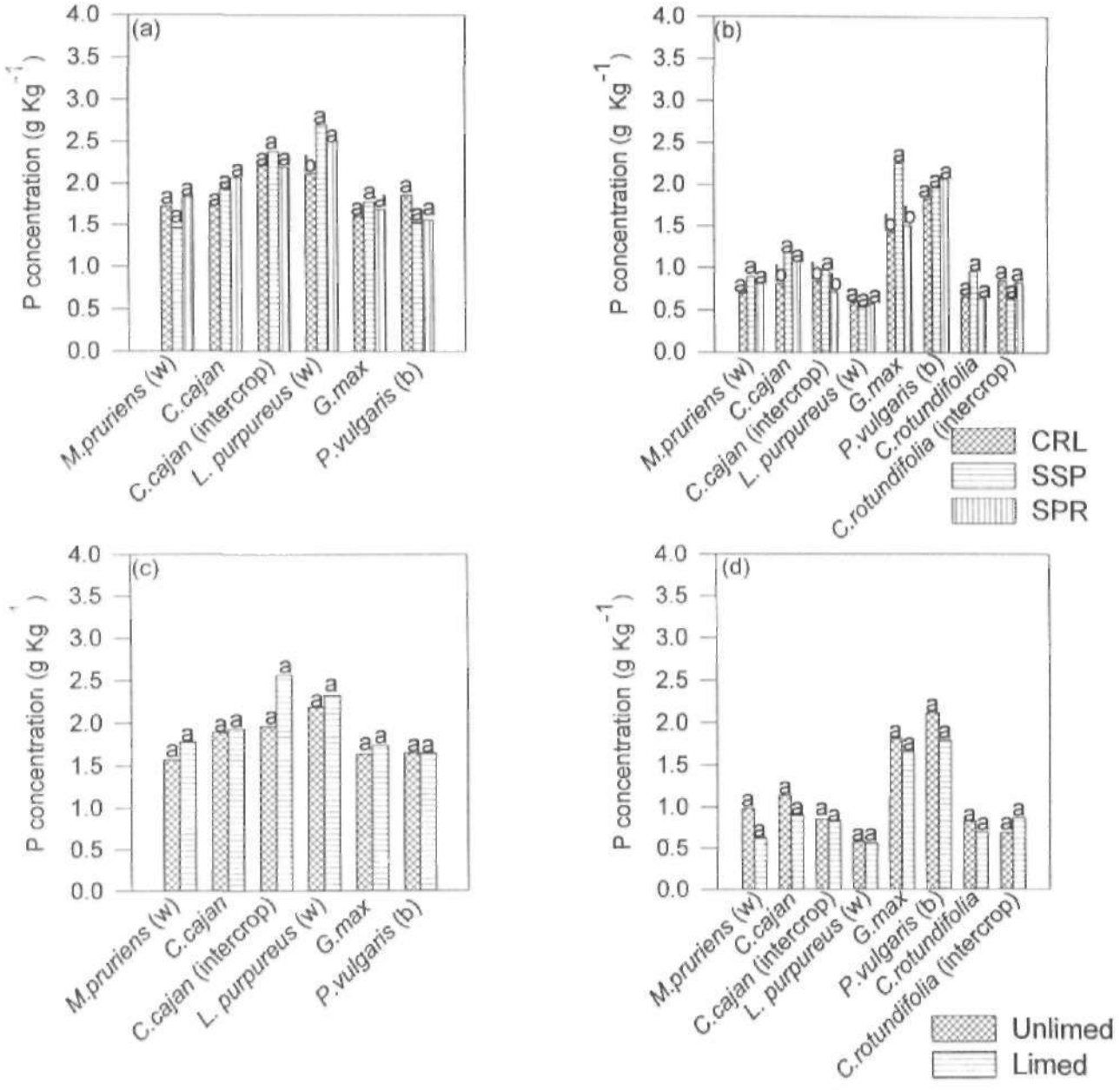


Fig. 4.52: Effect of P application and liming on tissue P concentration at 6 WAP
(a) averaged over lime rates (c) averaged over P sources; and in residue
(b) averaged over lime rates (d) averaged over P sources

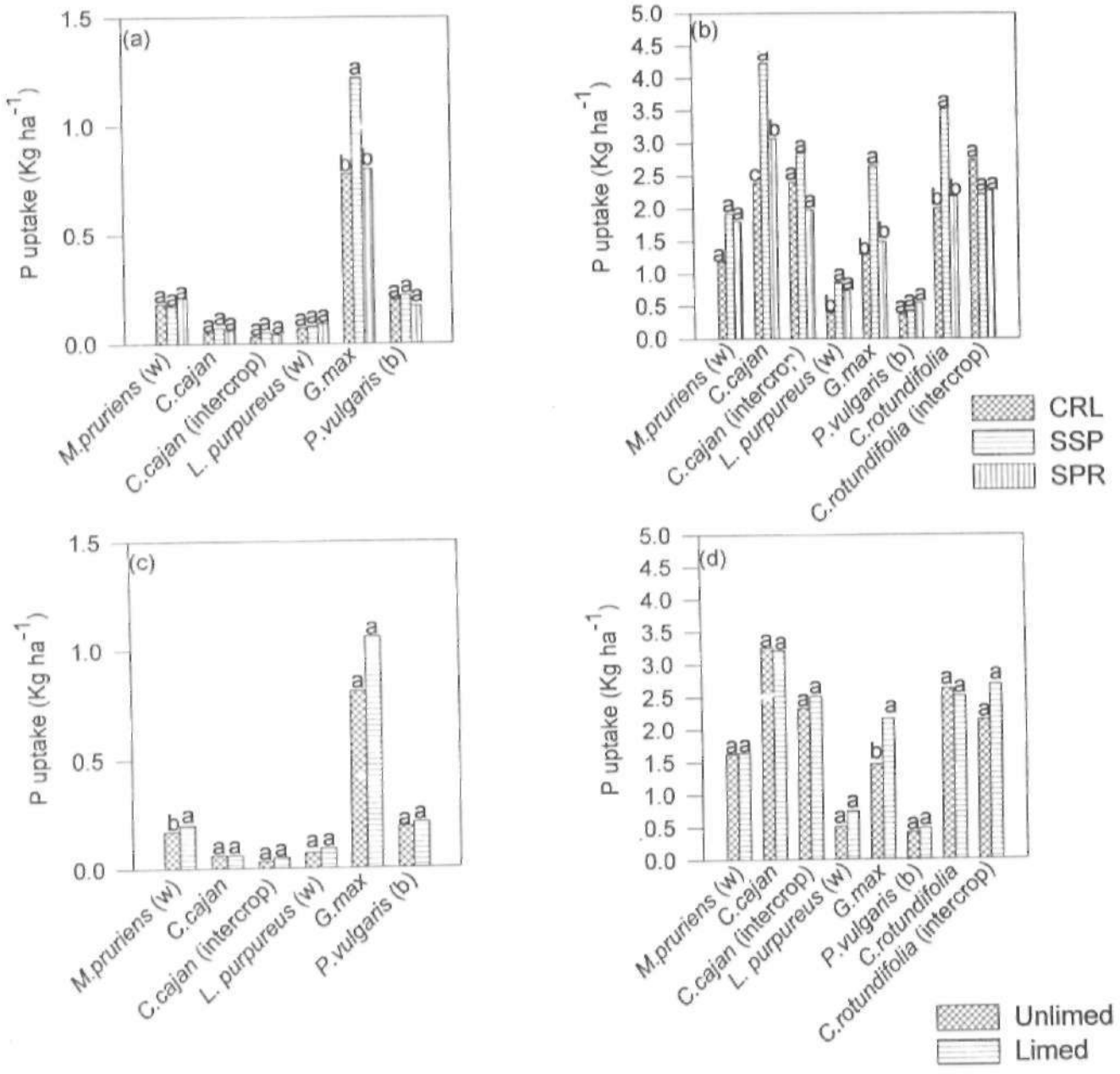


Fig. 4.53: Effect of P application and liming on total P taken up by tissues of cover crops at 6 WAP (a)averaged over lime rates (c)averaged over P sources; and in residues (b)averaged over lime rates (d)averaged over P sources

4.3.1.3 Effect of liming and P application on maize performance in 1996

Maize height was monitored through the growth of the plant. Application of SSP produced significantly taller maize plants through out the growth period (Fig. 4.54). Although increases in maize heights were recorded with SPR at 10 and 12 WAP, the increases were not statistically significant. Similar to the results on fields I and II at Samaru, intercropping did not significantly affect maize height. There were also no significant interaction effects of intercropping and P source on maize height. Application of lime did not produce any significant effect on maize height through out the growth of the plant (Fig. 4.55), possibly because the amount applied in 1996 was too low (250 Kg CaO ha^{-1}).

Effects of P application on above ground biomass at 6 WAP, stover yield, and grain yield are presented in Fig. 4.56. Both at 6 WAP and at maturity, SSP produced significantly greater quantities of biomass than SPR and CRL. However, SPR produced significantly higher grains and stover yields than CRL in contrast to what was observed at Samaru. The ability of SPR to produce significant increase in maize yield at Heipang in the first year of application shows that SPR is more effective in more acidic soils with low available P content.

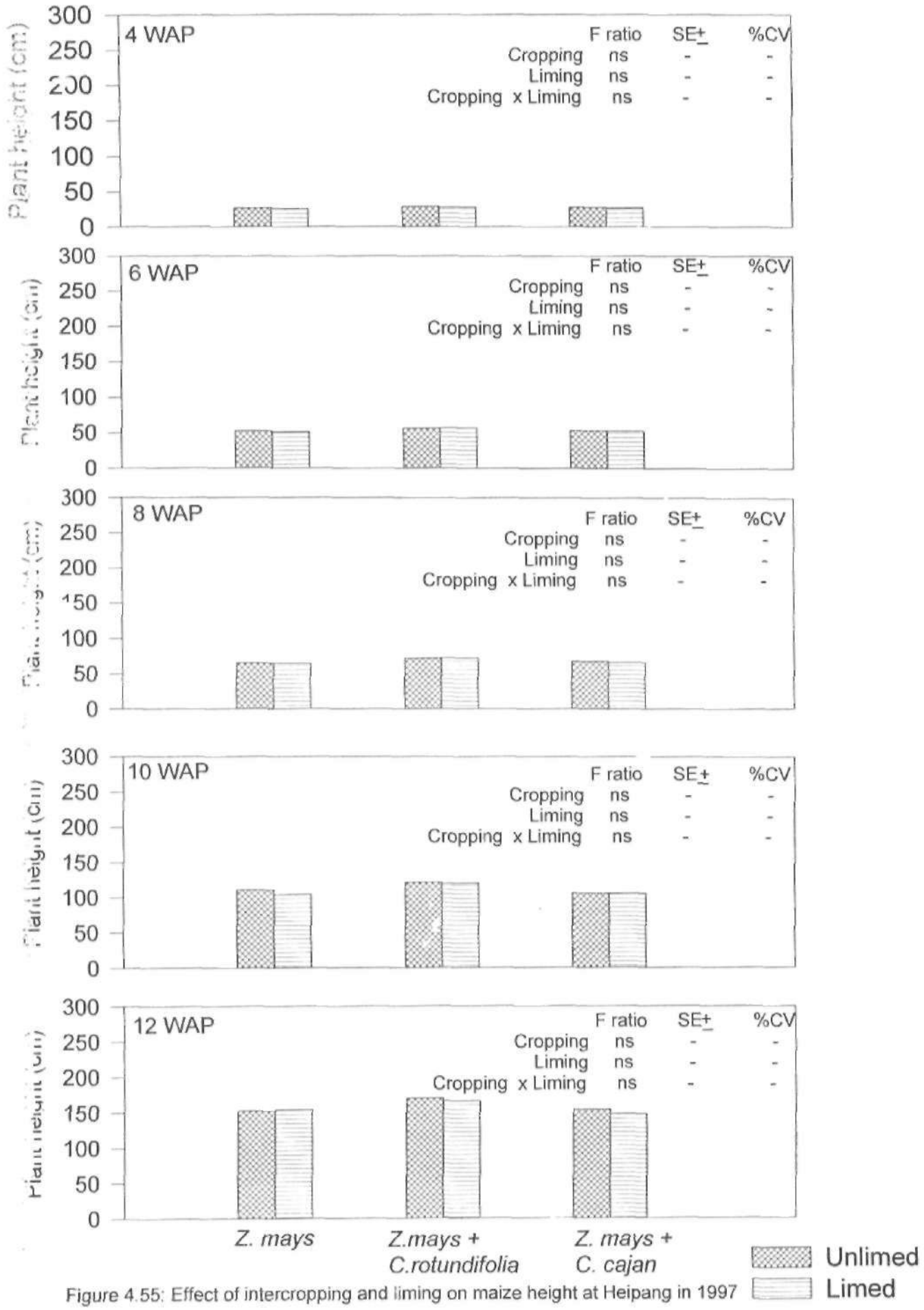


Figure 4.55: Effect of intercropping and liming on maize height at Heipang in 1997

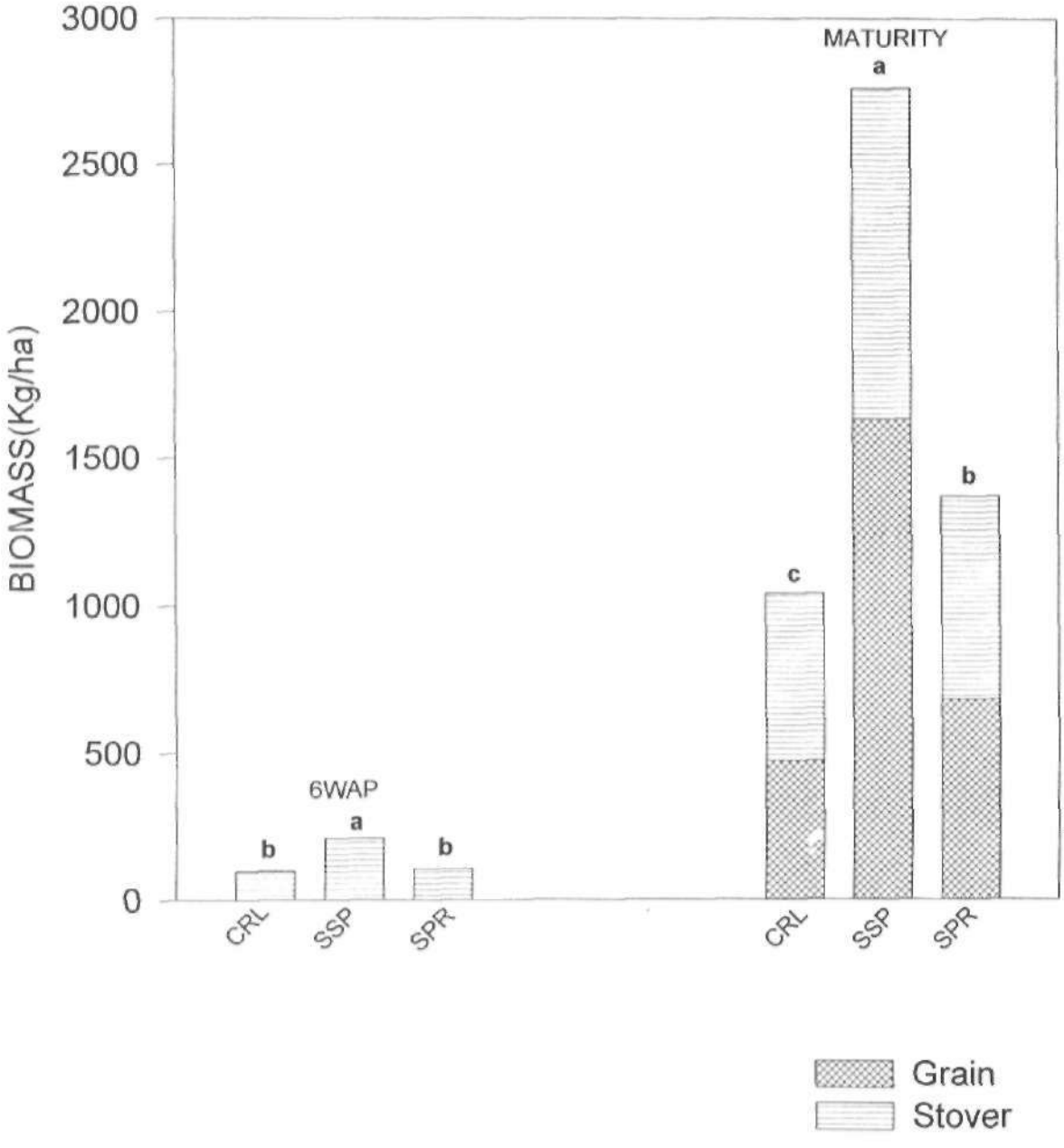


Figure 4.56:Effect of P application on maize biomass at Heipang in 1996 (averaged over lime rates)

Liming and intercropping did not significant affect maize biomass production (data not shown).

Figure 4.57 shows the effect of P application and liming on maize tissue P concentration. No effects of P application, liming nor intercropping were observed on P concentration of maize stover and maize above ground tissue at 6 WAP. Phosphate taken up at 6 WAP and in stover (Fig. 4.58) were however significantly higher with SSP.

4.3.2 Second year (succeeding maize)

4.3.2.1 Effect of P fertilization, liming and preceding cover crops on maize performance in 1997

Figure 4.59 shows the mean effect of treatments on maize height at 4 WAP in 1997. Differences in maize height due to preceding crops were not significant at this period. Phosphate treatments of 1996 did not also significantly affect maize height at 4 WAP, however the fresh application of 60 kg P ha^{-1} in 1997 produced significant increase in maize height. The effect of lime application on maize height at this period was negative, possibly because no incubation period was allowed between the time of lime application in 1997 and planting. Figures 4.60 and 4.61 show the effect of the preceding cover crops on maize height at 4 WAP under the various phosphate

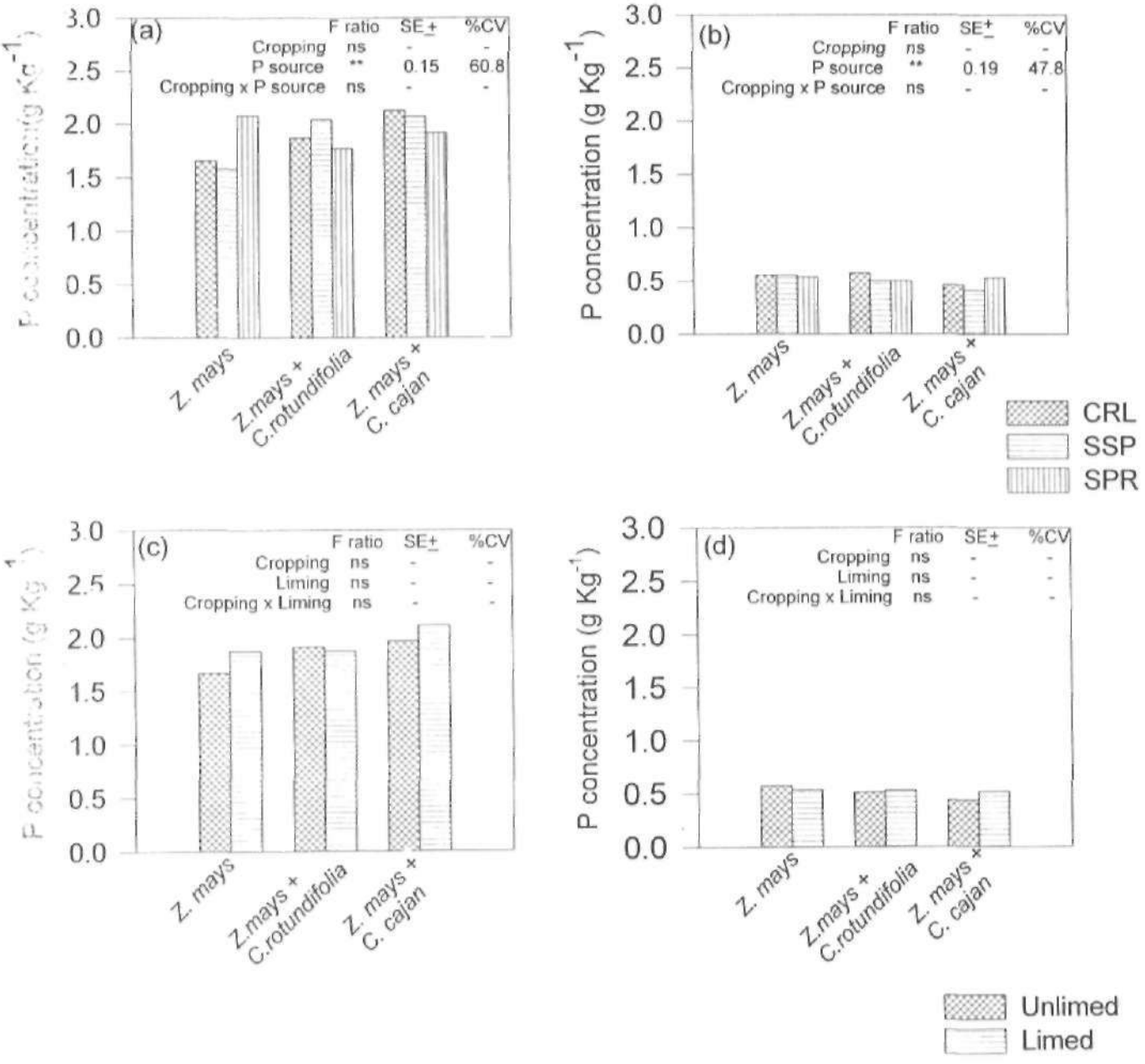


Fig. 4.57: Effect of P application and liming on maize tissue P concentration at 6 WAP (a) averaged over lime rates (c) averaged over P sources; and stover (b)averaged over lime rates (d) averaged over P sources

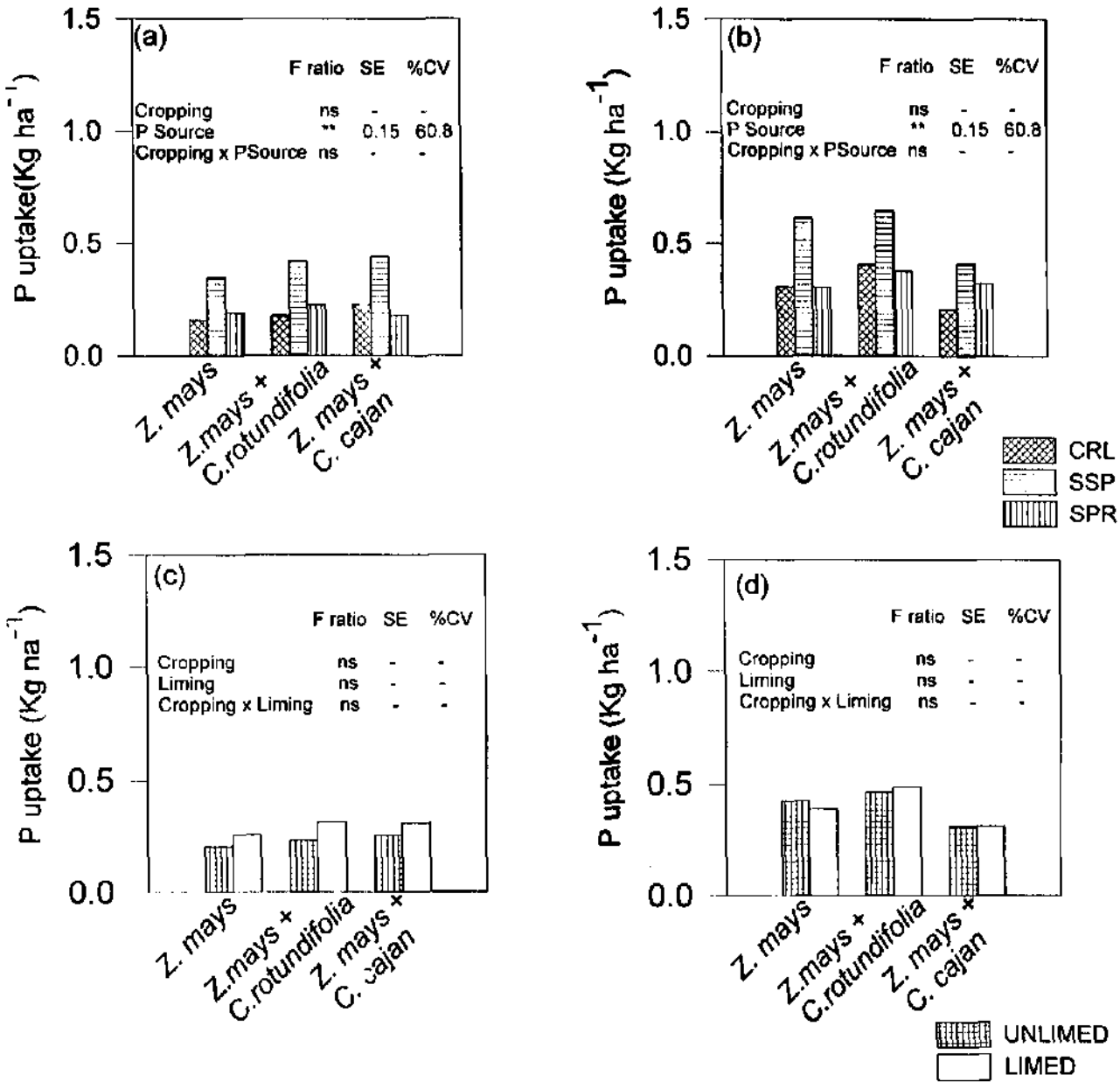


Figure 4.58: Effect of P application and liming on P uptake by maize tissue at 6WAP
(a) averaged over lime rates (c) averaged over P sources; and stover
(b) averaged over lime rates (d) averaged over P sources

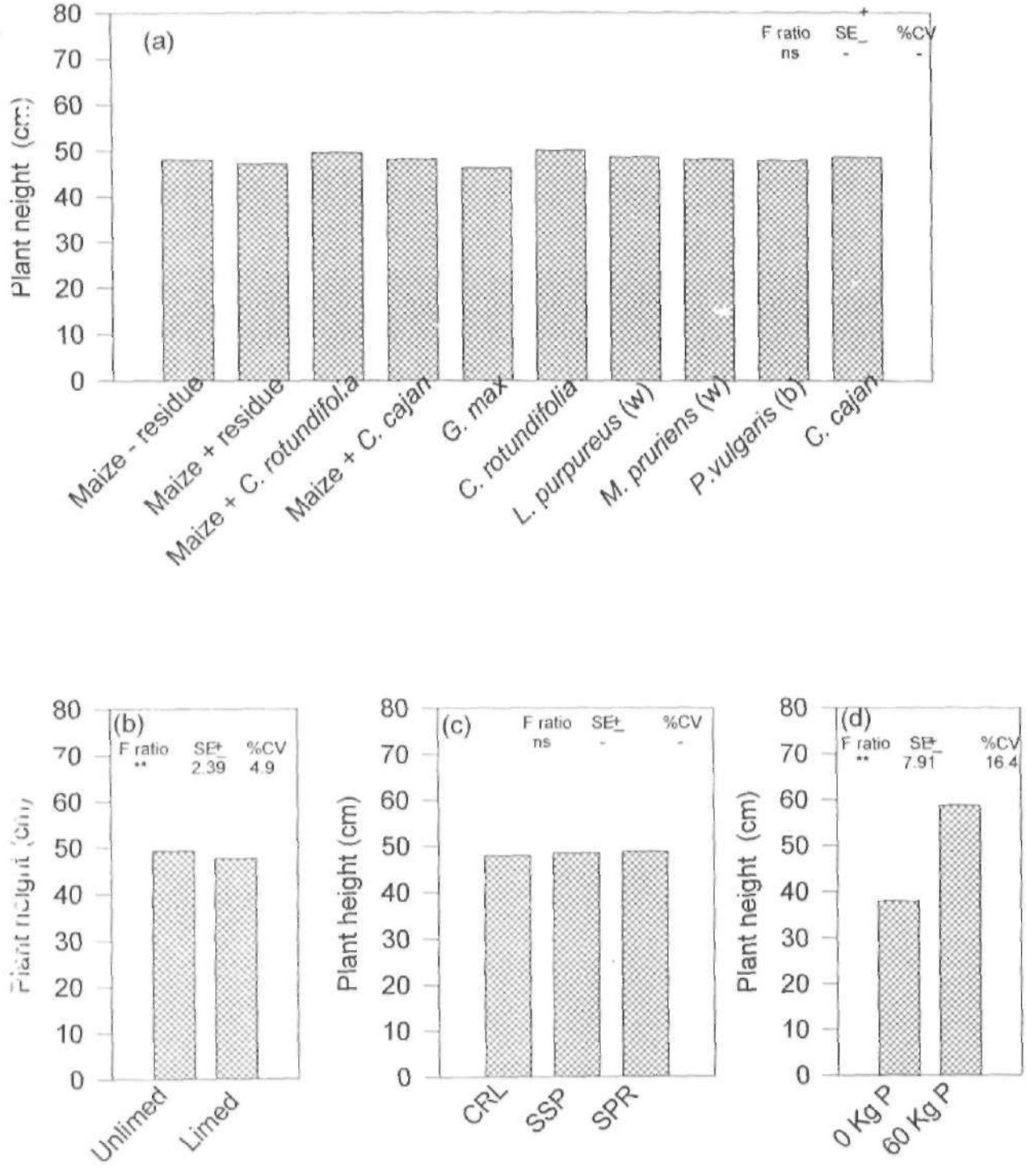


Fig. 4.59: Effect of treatments on maize height at 4 WAP in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

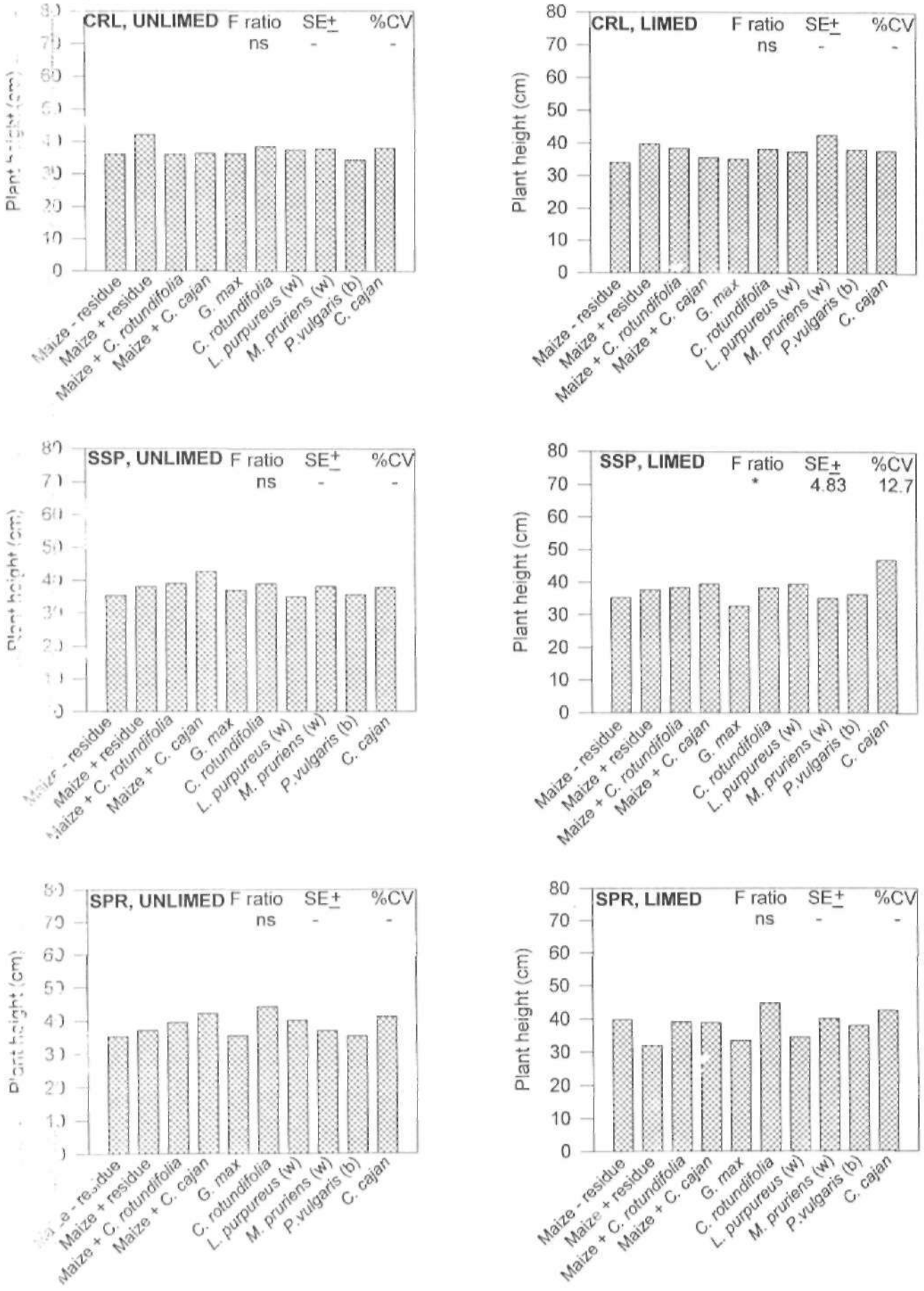
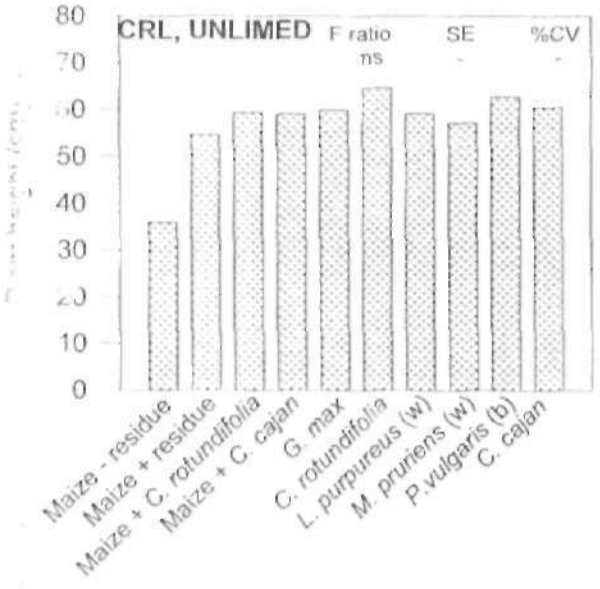
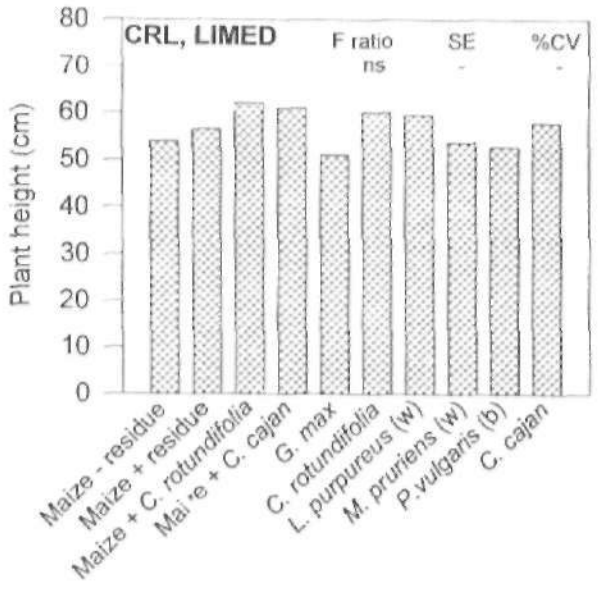
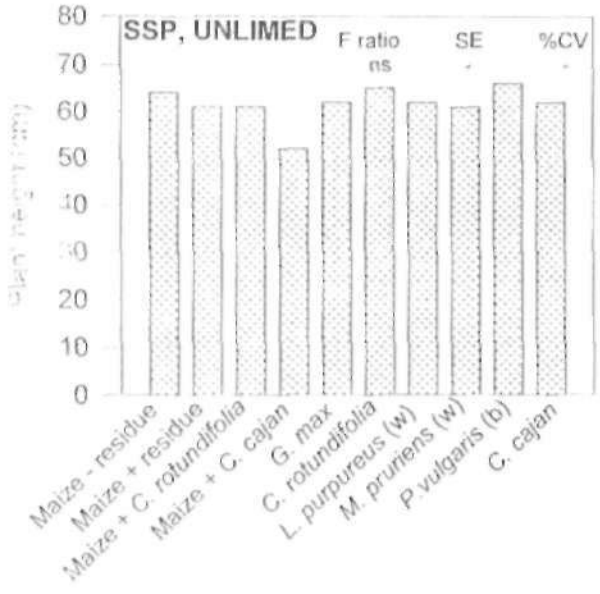
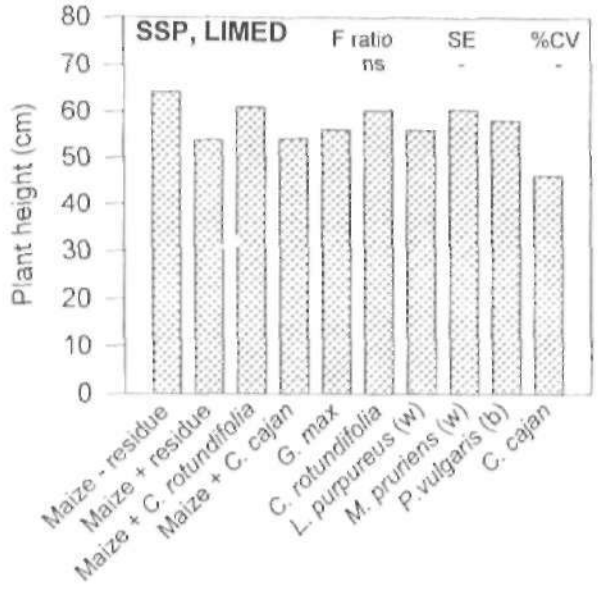


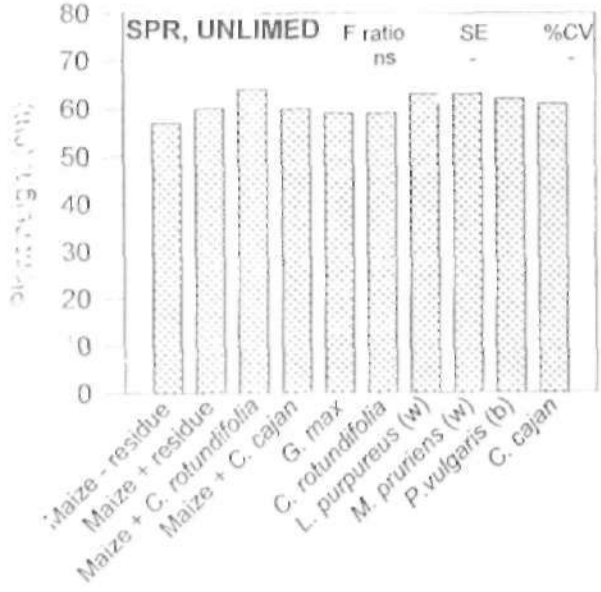
Figure 4.60: Effect of preceding crops and 1996 P application on maize height at 4 WAP in 1997 at Heipang











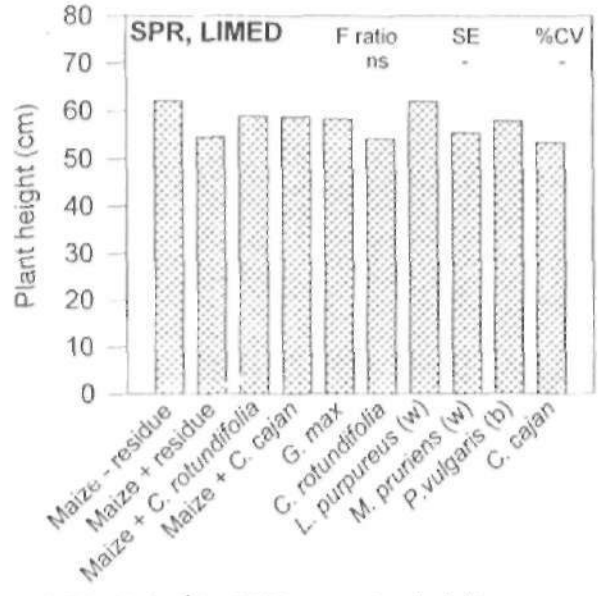


Figure 4.61: Effect of preceding crops, 1996 P application and 60KgP ha^{-1} in 1997 on maize height at 4WAP in 1997 at Heipang

treatments. Effect of preceding crops only manifested under SSP without liming and no fresh P in 199', where C. cajan produced significantly taller maize than other preceding crop treatments.

At 7 WAP, plots preceded by *C. rotundifolia*, on the average, gave significantly taller maize plants compared to other cover crop treatments (Fig. 4.62). Significant increases in height were also recorded on plots preceded by *Z. mays + C. rotundifolia, M. pruriens* (W) and *L. purpureus* (W). Effect of liming on maize height was not significant at this period. Both SSP and SPR application in 1996 produced significant increase in maize height at 7 WAP in 1997, with SSP being superior. Taller maize plants were produced with application of fresh 60 kg P ha^{-1} in 1997. *Chamaecrista rotundifolia* consistently produced taller maize plants under all P treatments (Figs. 4.63 and 4.64), the effects being more pronounced with liming. *Glycine max*, on the other hand, appeared to retard maize growth.

The trend in maize height at 10 WAP was similar to what was observed at 7 WAP (Figs. 4.65, 4.66 and 4.67). At 12 WAP, the positive effects of liming manifested in maize height (Fig. 4.68) with the limed plots producing significantly taller plants. Effects of preceding crops and P treatments on

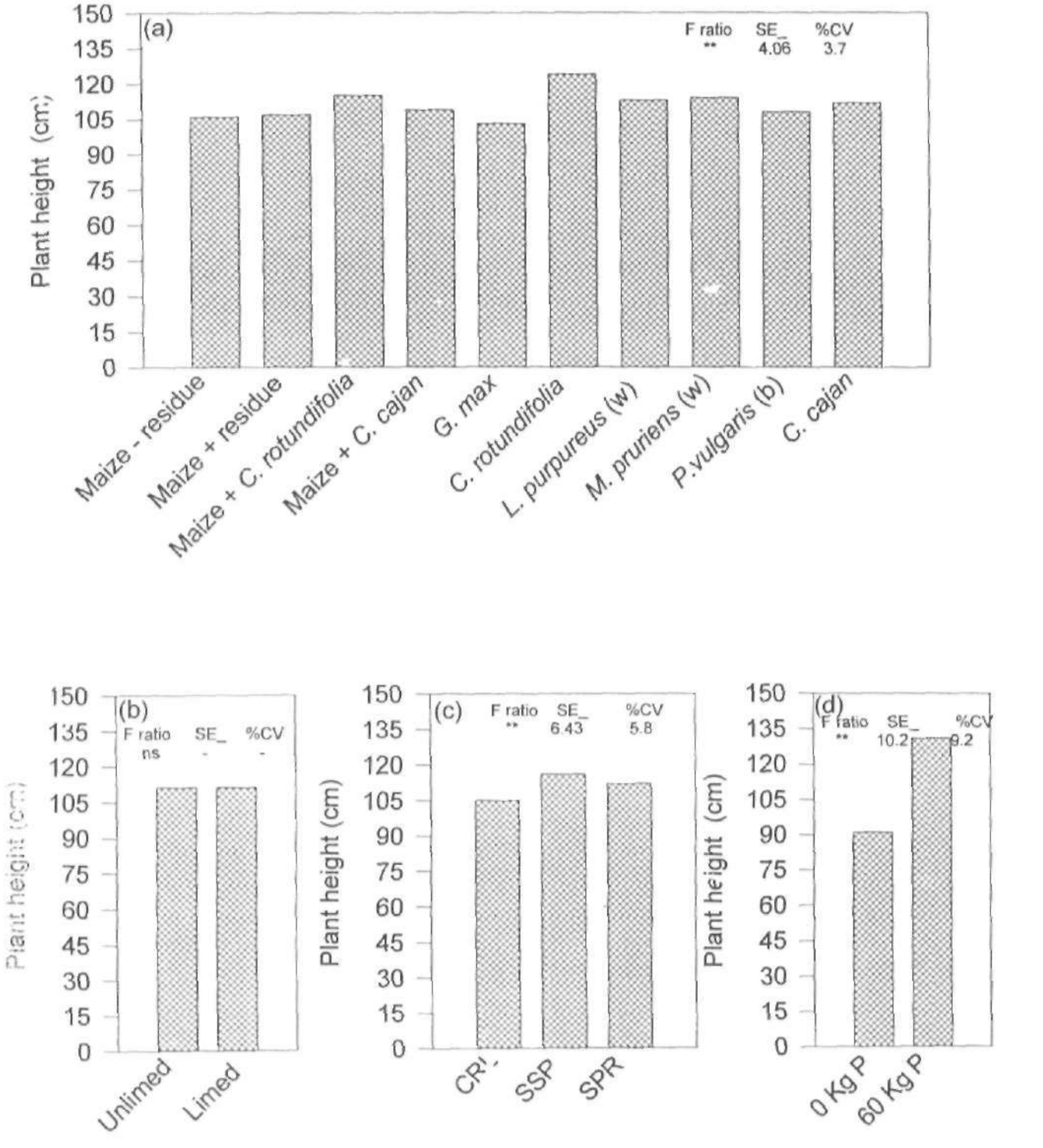


Fig. 4.62: Effect of treatments on maize height at 7WAP in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

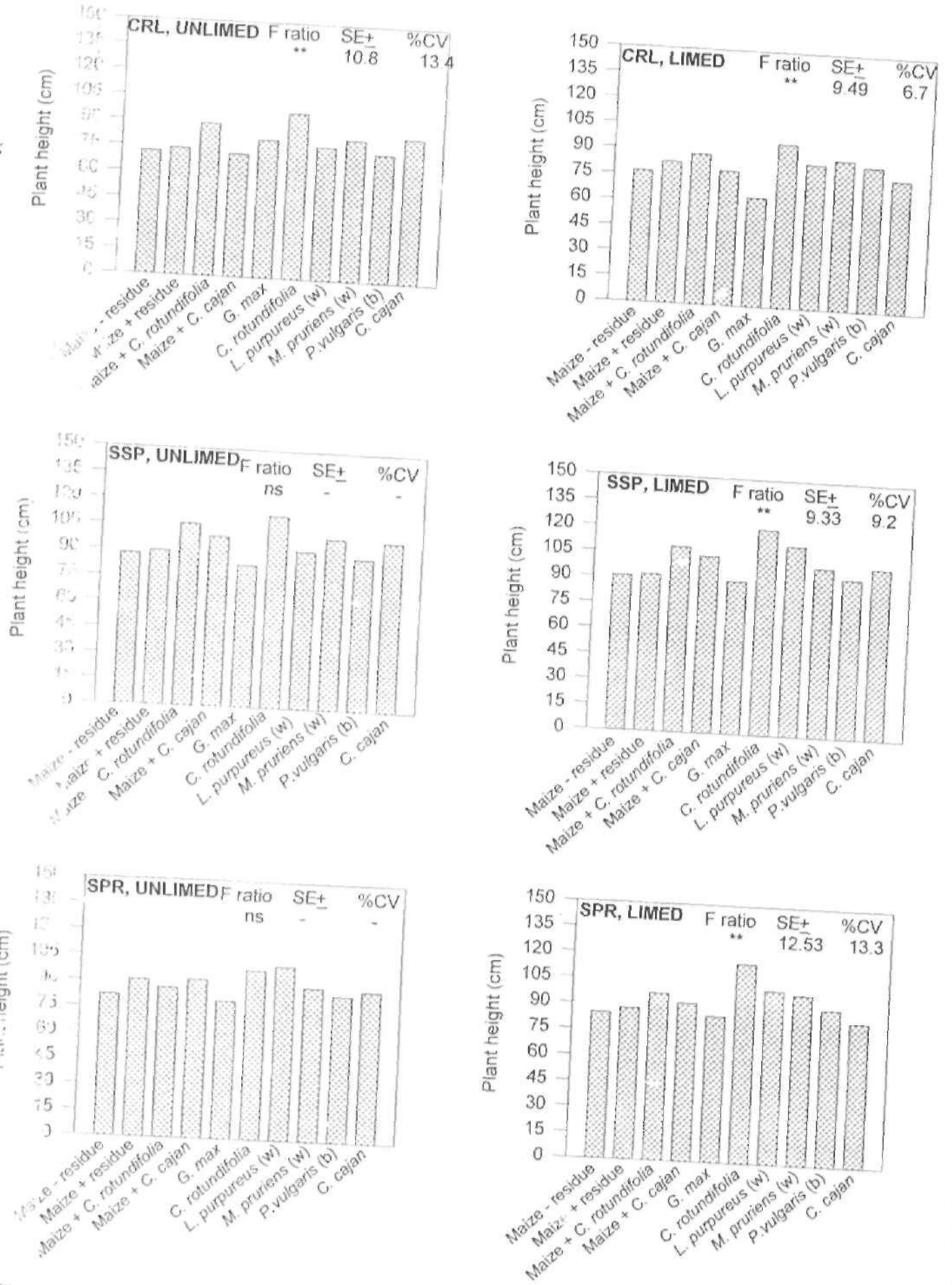


Figure 4.63: Effect of preceding crops and 1996 P application on maize height at 7 WAP in 1997 at Heipang

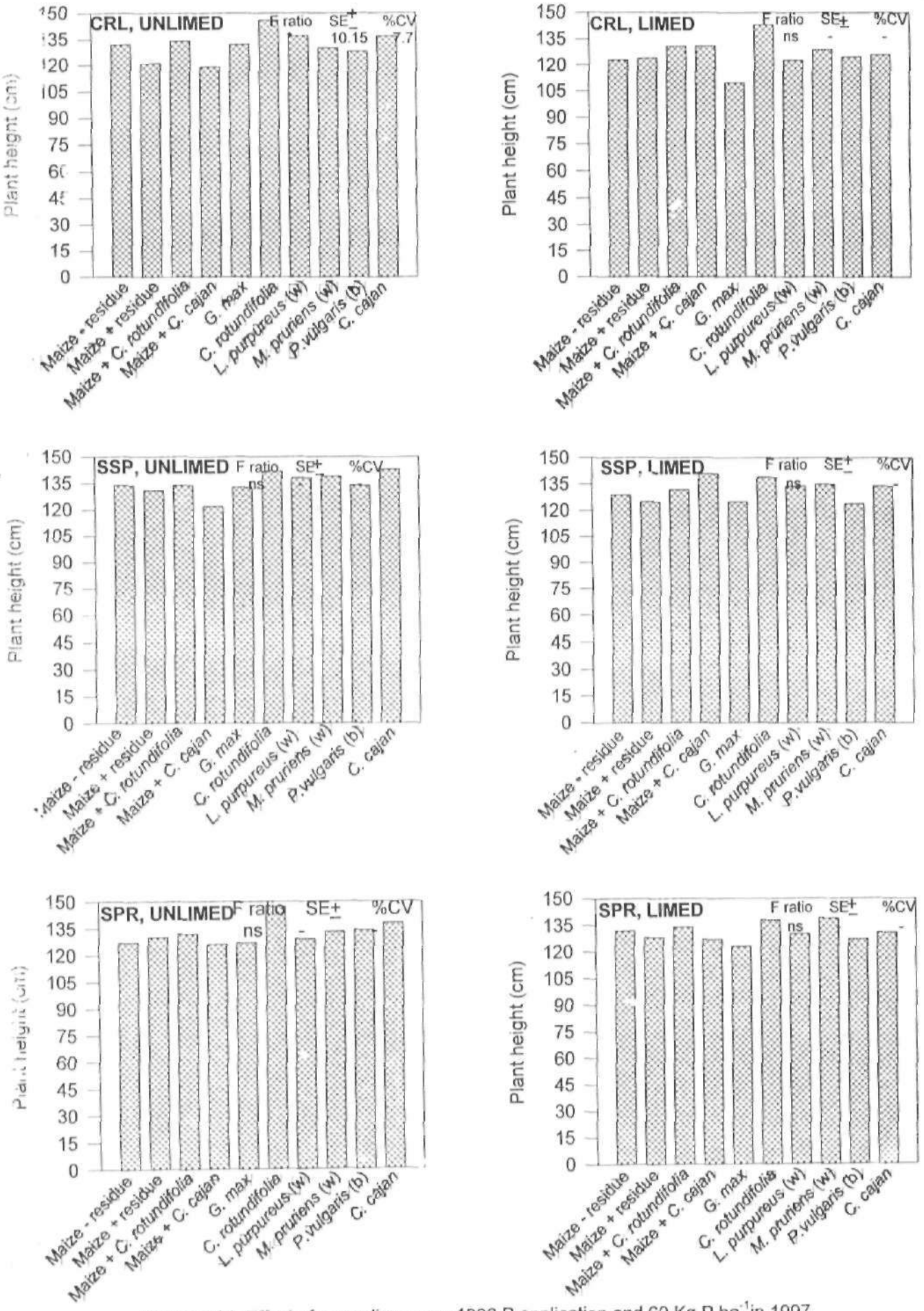


Figure 4.64: Effect of preceding crops,1996 P application and 60 Kg P ha^{-1} in 1997 on maize height at 7 WAP in 1997 at Heipang

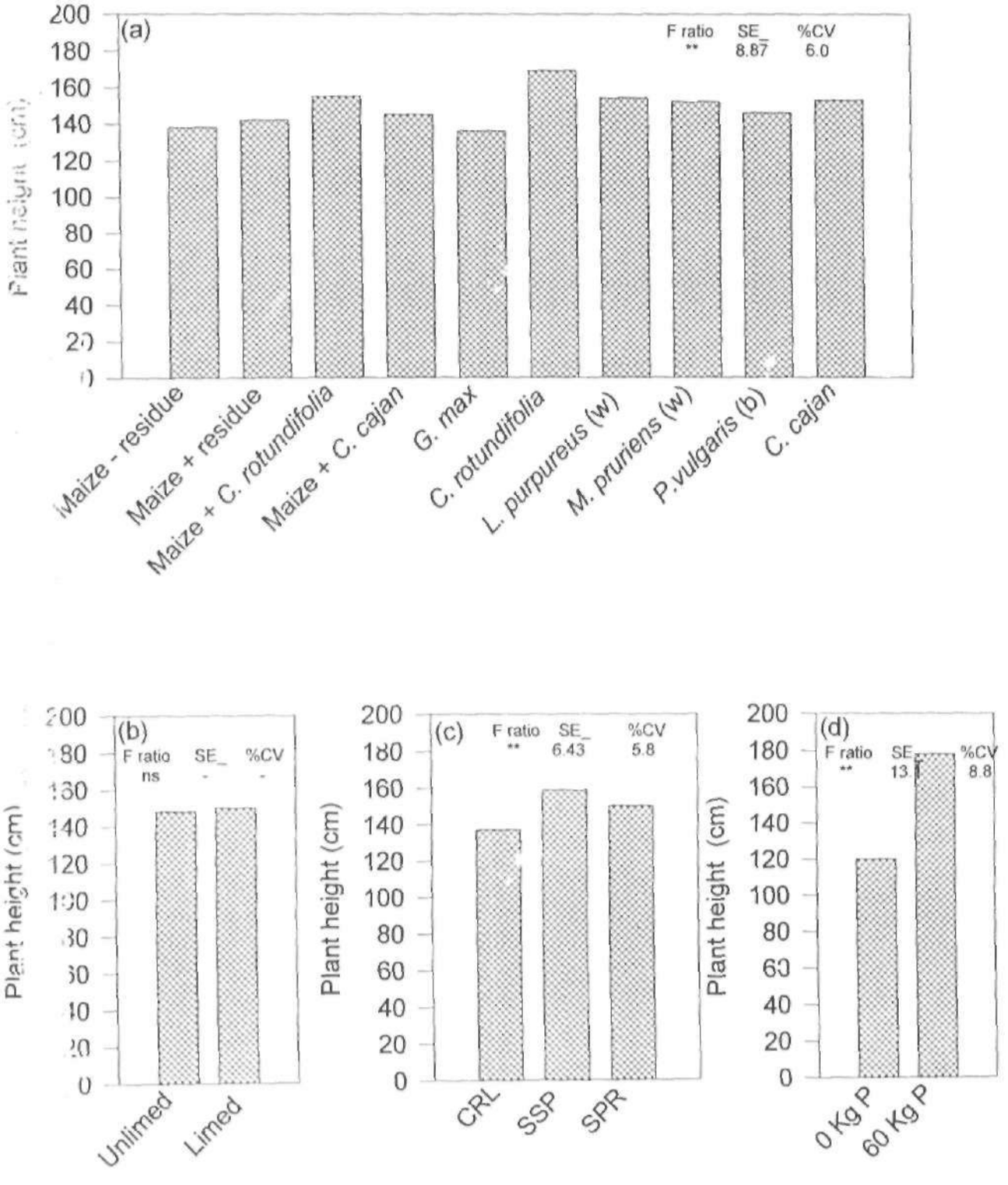


Fig. 4.65: Effect of treatments on maize height at 10 WAP in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

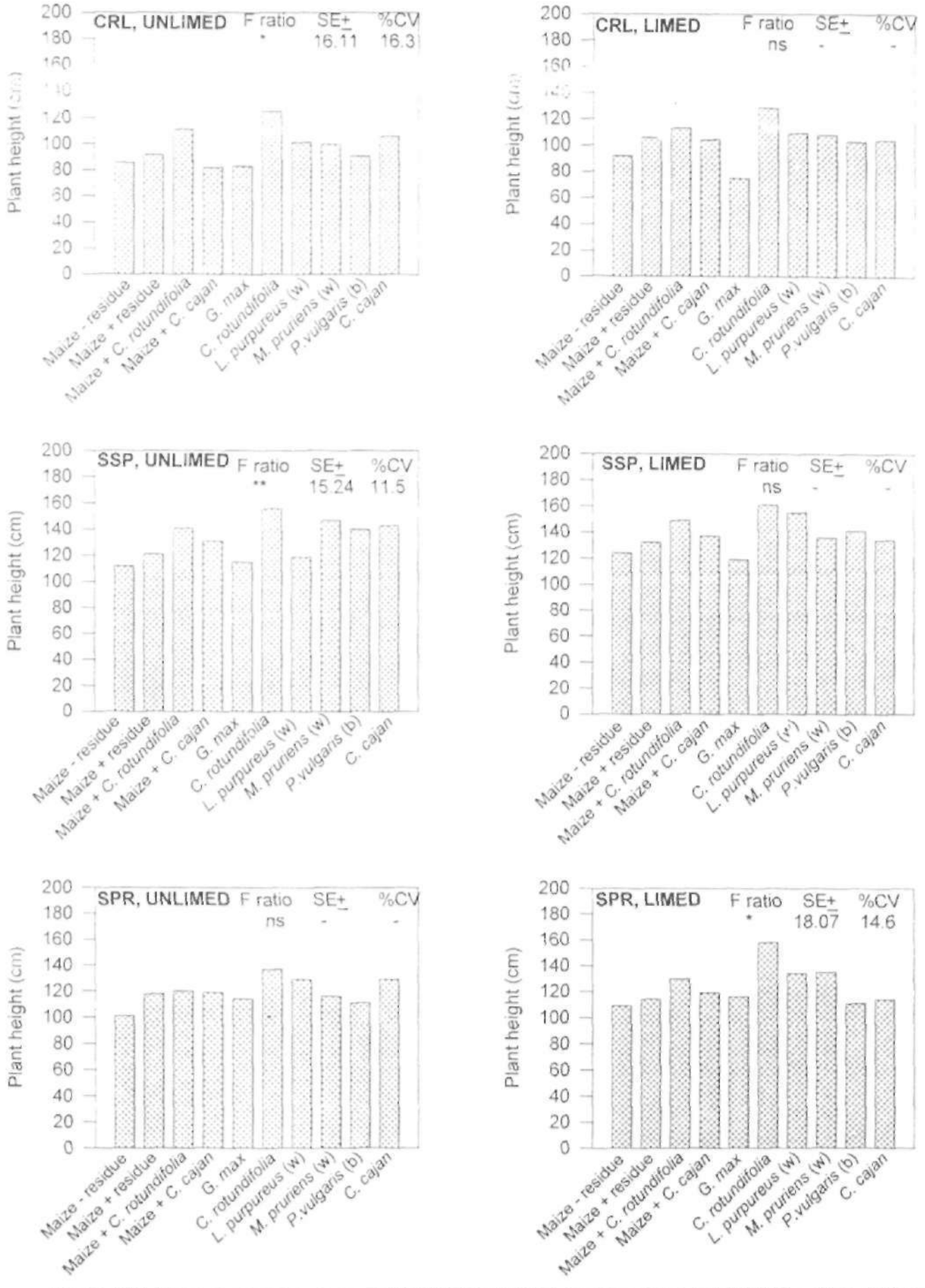


Figure 4.66: Effect of preceding crops and 1996 P application on maize height at 10 WAP in 1997 at Heipang

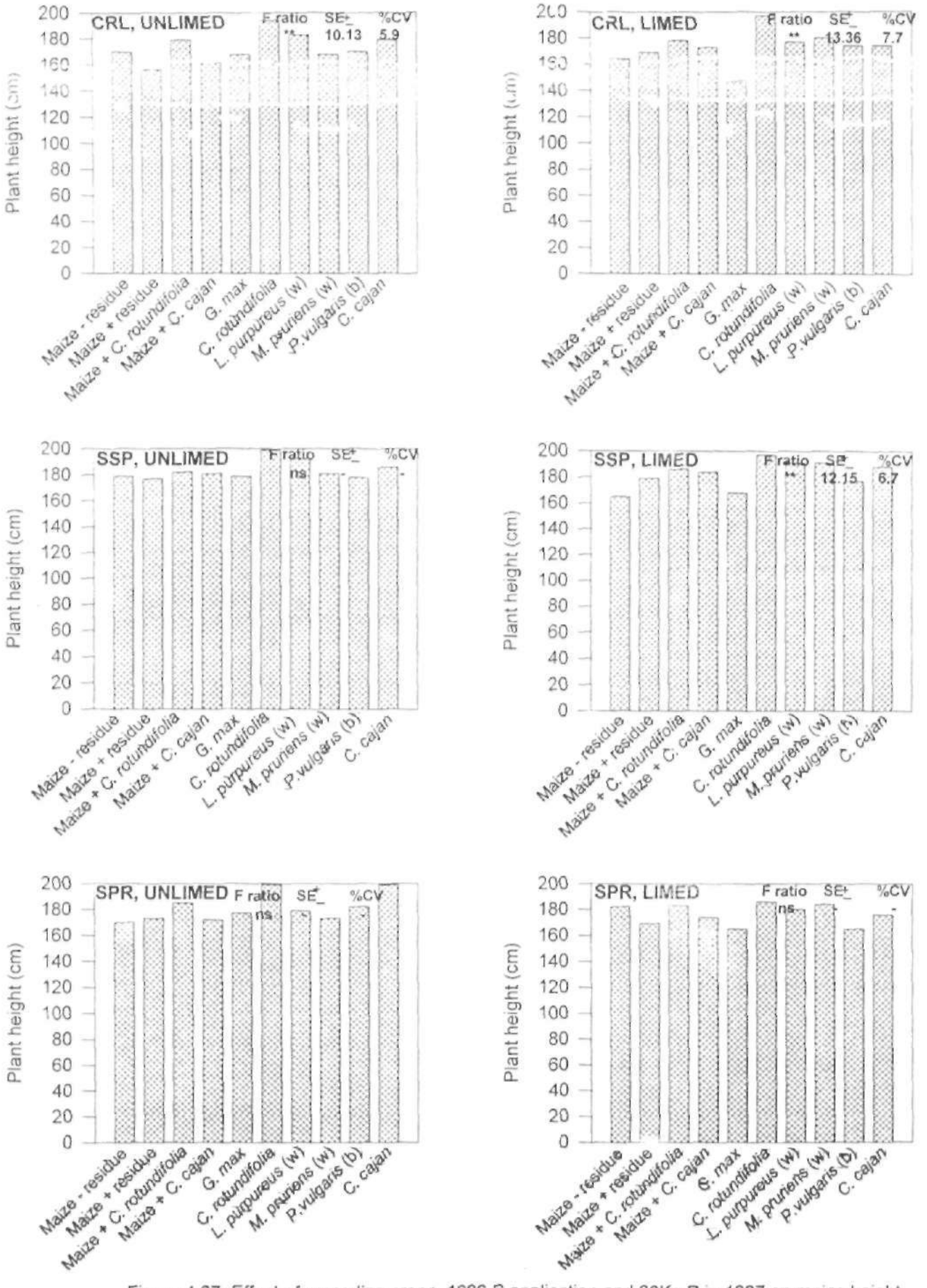


Figure 4.67: Effect of preceding crops, 1996 P application and 60Kg P in 1997 on maize height at 10 WAP in 1997 at Heipang

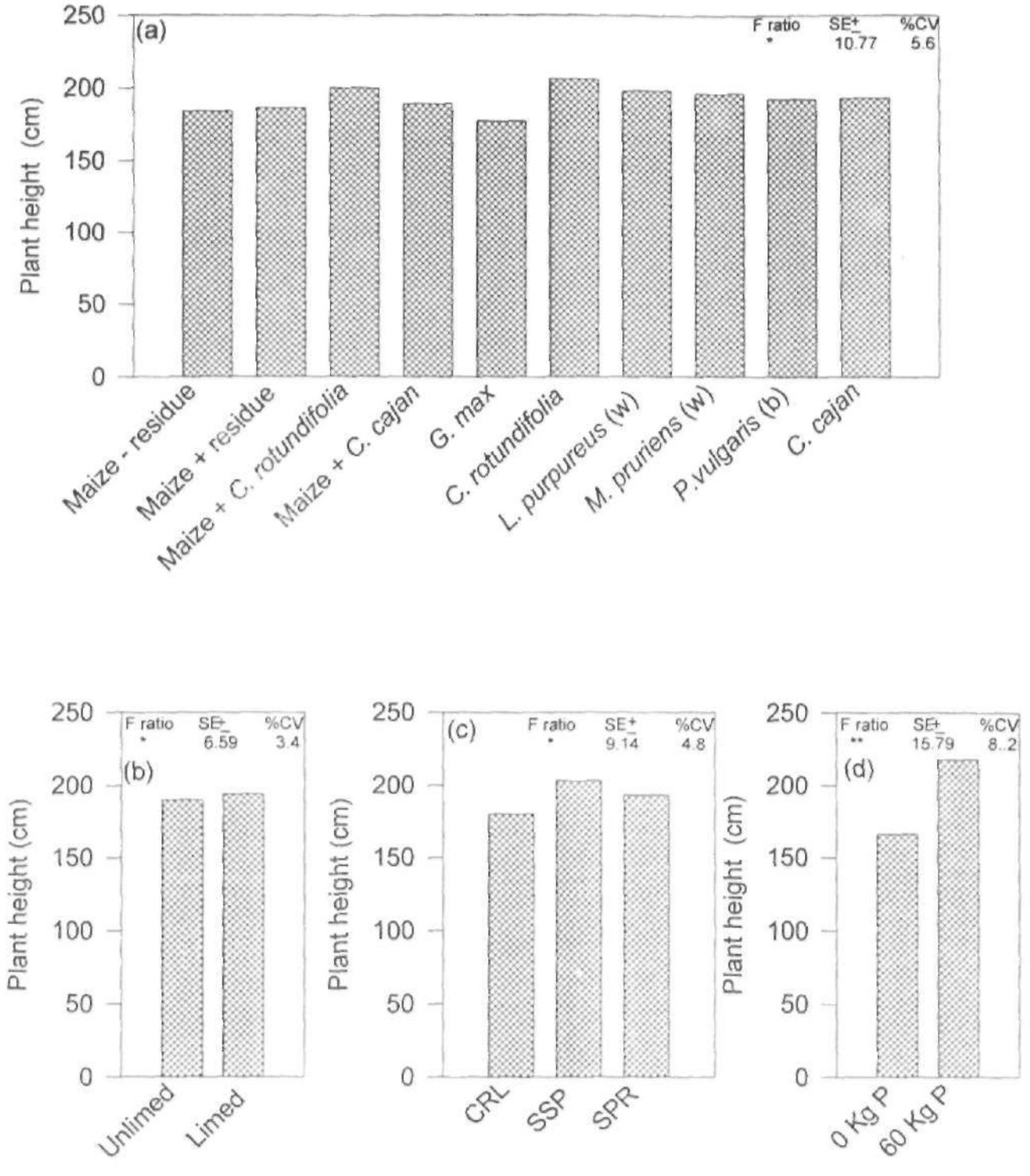


Fig. 4.68: Effect of treatments on maize height at 12WAP in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

maize height at 12 WAP were similar to what were observed at 7 and 10 WAP (Figs. 4.69 and 4.70).

The mean effects of treatments on maize grain yield in 1997 is presented in Fig. 4.71. Preceding cover crop treatments did not exert any significant effect on maize grain yield. Liming did not also affect grain yield significantly. However, both 1996 and 1997 P treatments produced significant effects on maize grain yield. Application of both SSP and SPR in 1996 produced significant grain yield increases in 1997, with SSP being superior to SPR. The ability of SPR to increase maize grain yield on this soil in both 1996 and 1997 confirms its suitability on soils with low available P content. Fresh application of 60 kg P ha^{-1} in 1997 produced about 130% increase in grain yield. Without liming and no fresh P application in 1997, *C. rotundifolia* produced significantly higher grain yields under CRL and SSP (Fig. 4.72). Generally, slightly lower grain yields were observed on plots preceded by *G. max* (Figs. 4.72 and 4.73). There were significant interaction effects of 1996 and 1997 P treatments on grain yield, with plots treated with SSP in 1996 and fresh 60 kg P ha^{-1} in 1997 producing the highest yields. This suggest that even the application of 60 kg P ha^{-1} was not sufficient enough to give maximum yield on this soil.

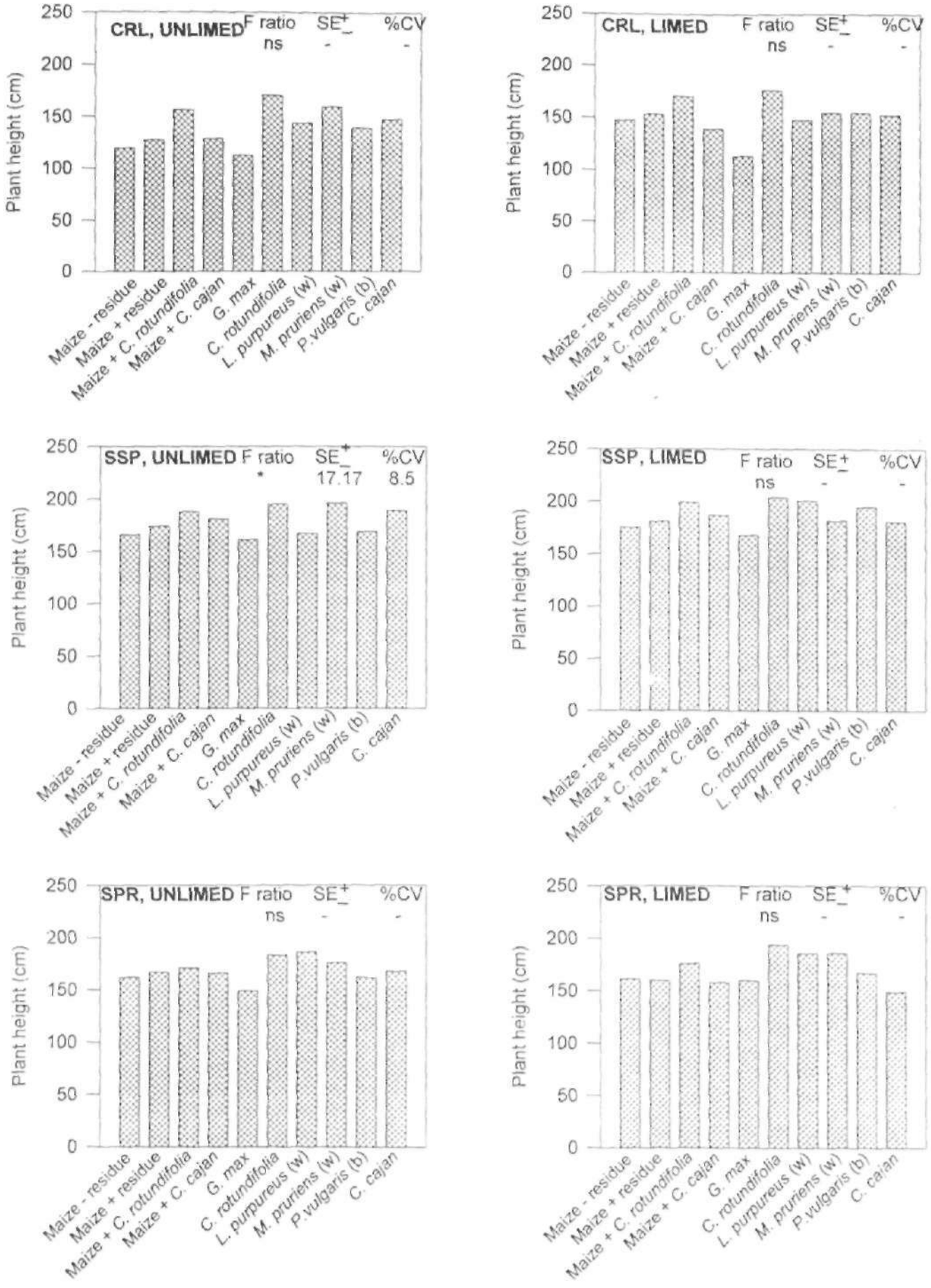


Figure 4.69: Effect of preceding crops and 1996 P application on maize height at 12 WAP in 1997 at Ukiang

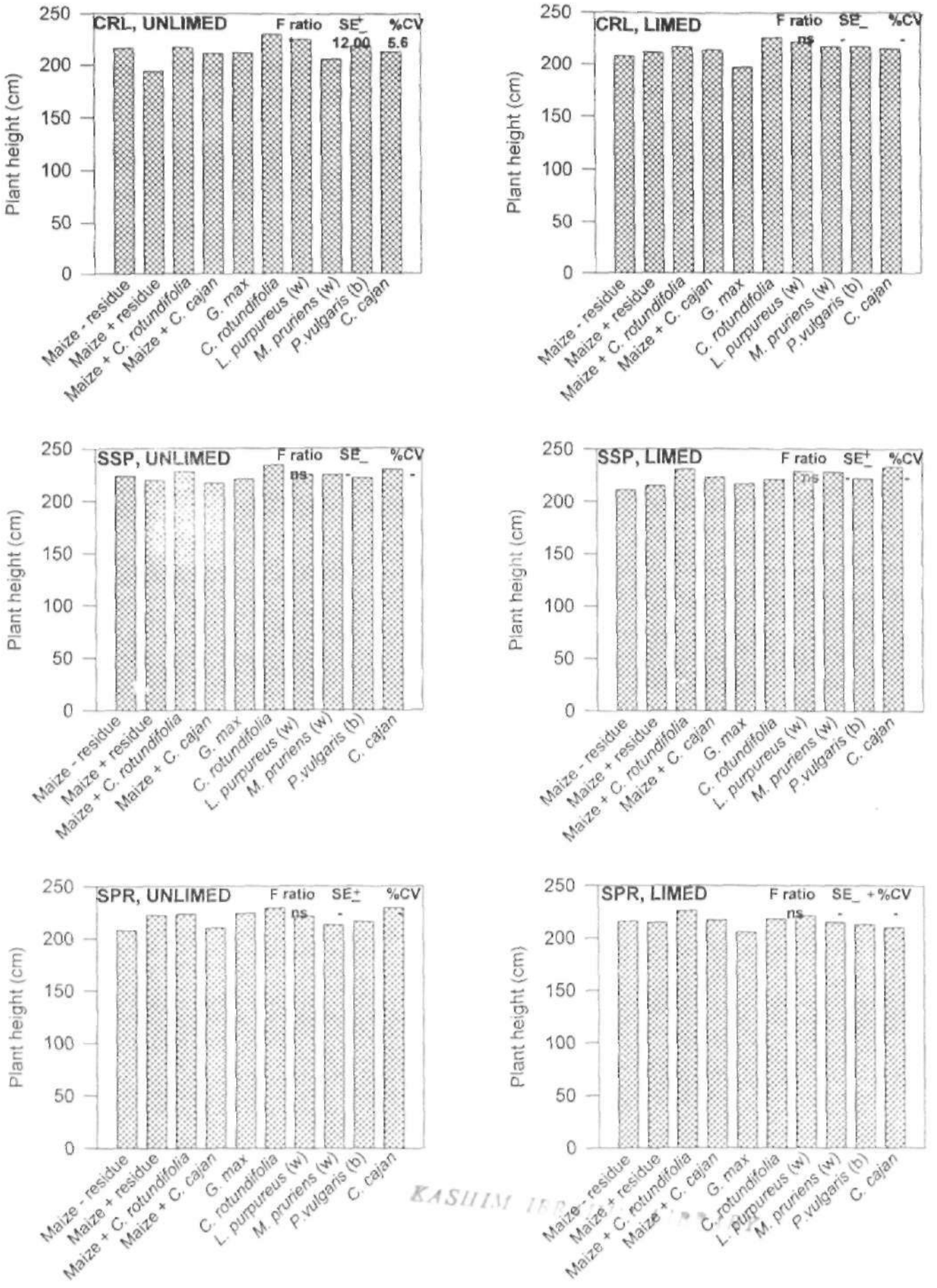


Figure 4.(i): Effect of preceding crops, 1996 P application and 60Kg P in 1997 on maize height at 12 WAP in 1997 at Heipang

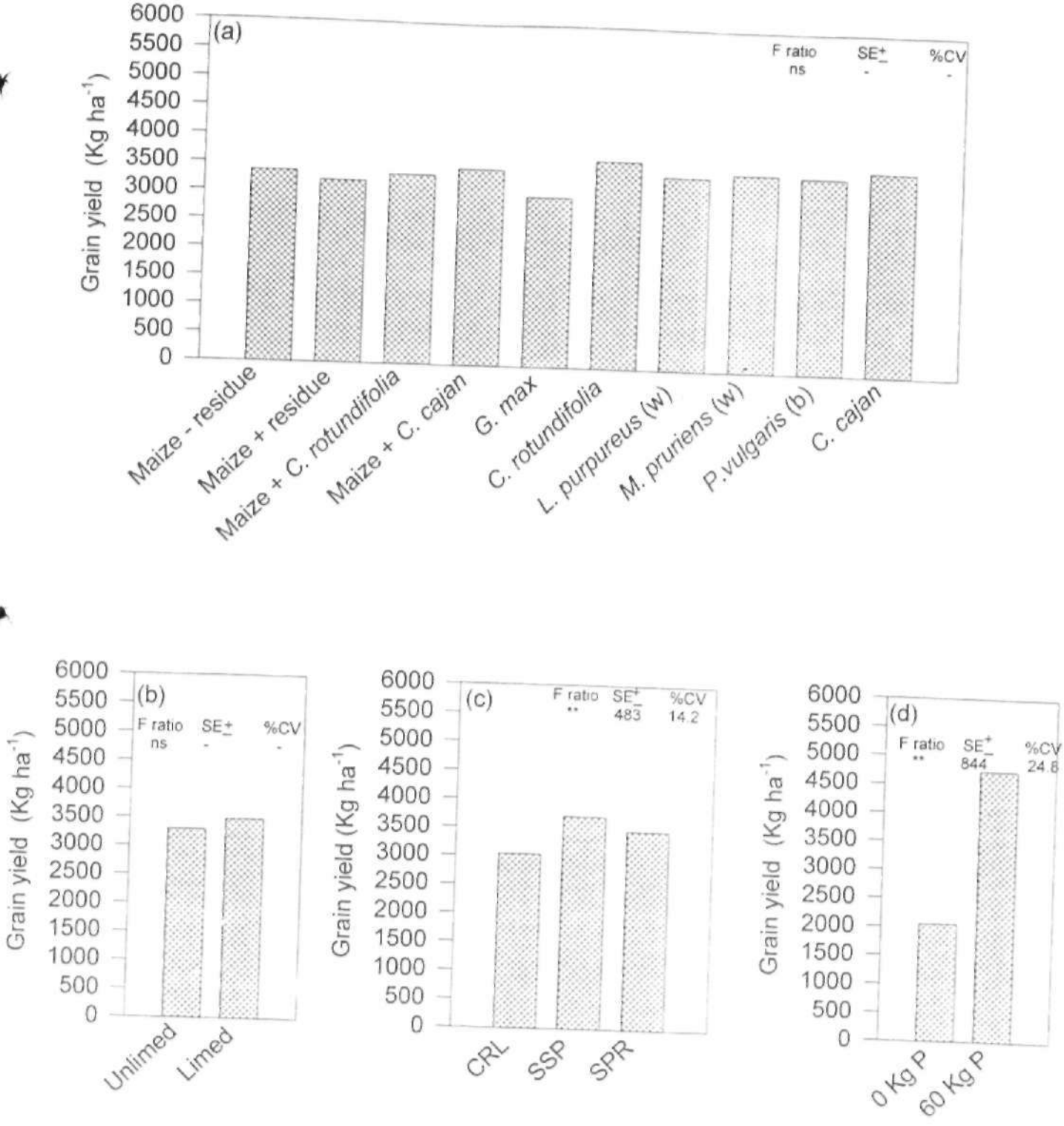


Fig. 4.71: Effect of treatments on maize grain yield in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaed over other treatments

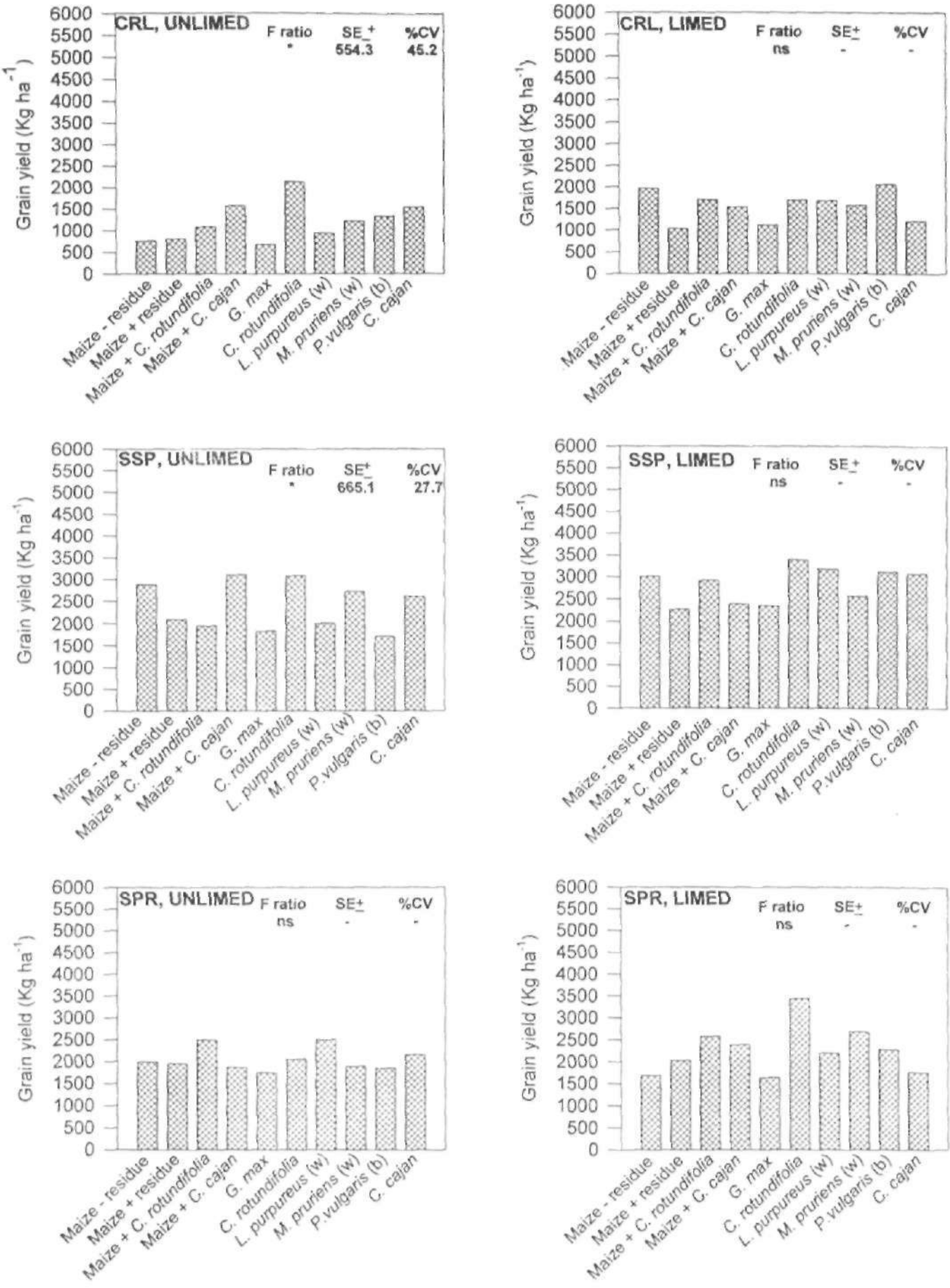


Figure 4.72: Effect of preceding crops and 1996 P application on maize grain yield in 1997

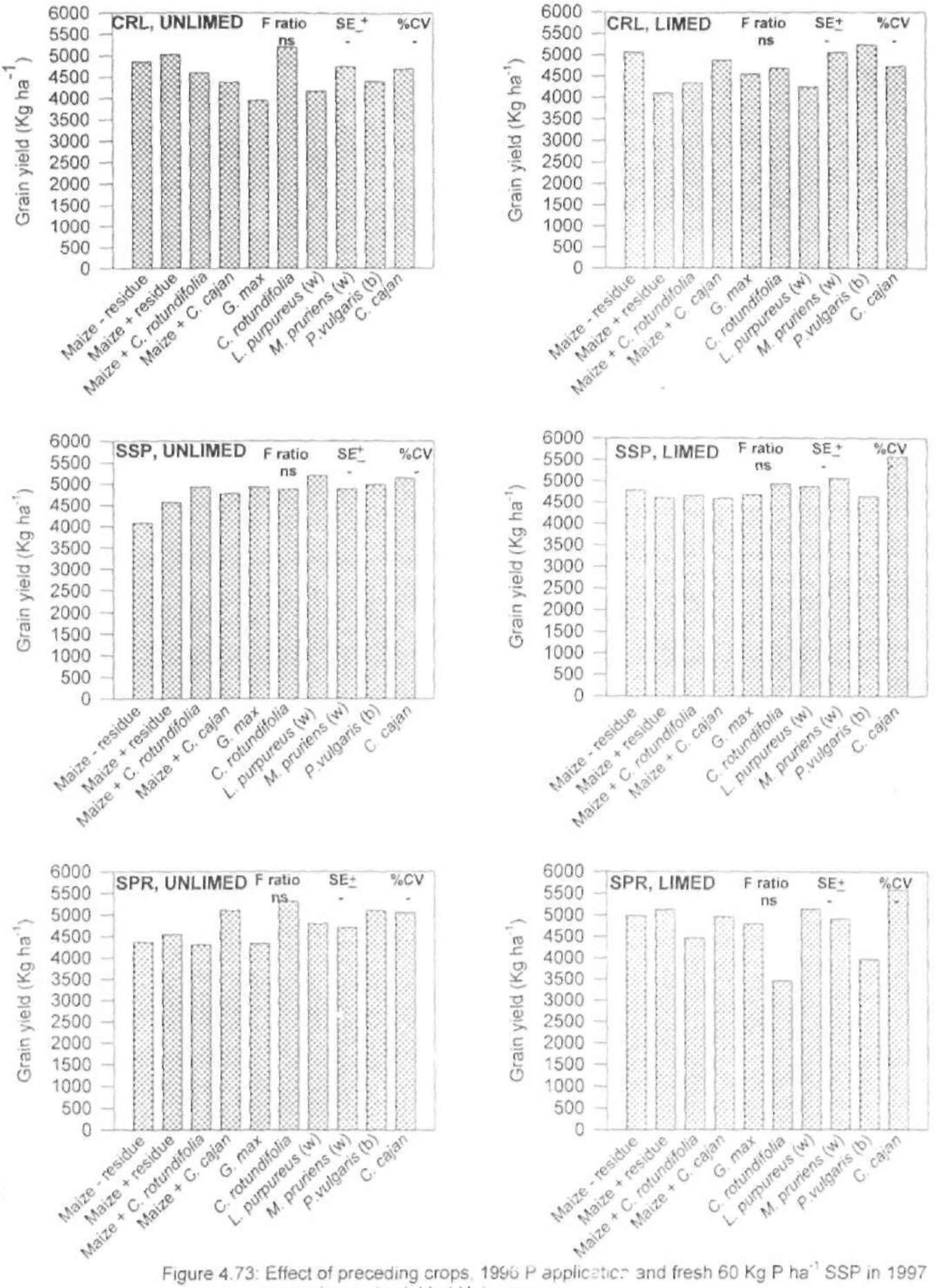


Figure 4.73: Effect of preceding crops, 1996 P application and fresh 60 Kg P ha^{-1} SSP in 1997 on maize grain yield at Helbang

Mean effects of treatments on stover yield are shown in Fig. 4.74. Stover yields were significantly improved on plots preceded by *C. rotundifolia*, *C. cajan*, *Z. mays* + *C. rotundifolia*, and *Z. mays* + *C. cajan*. Effect of liming on stover yield was not obvious, while SSP and SPR application in 1996 produced positive effects on maize stover yield in 1997. Single superphosphate was, however, superior to SPR. Fresh application of 60 kg P ha^{-1} in 1997 also produced significant increase in stover yield. Effects of preceding cover crops on stover yields under the various P treatments are shown in Figs. 4.75 and 4.76. Generally, slightly lower stover yields were observed on plots preceded by *G. max*.

4.3.2.2 Nutrient elements contents of maize tissue as influenced by P fertilization, liming and preceding crops

Mean effects of preceding cover crops on P concentration of index leaves were not significant (Fig. 4.77). Similarly, the effects of preceding crops under the individual P treatments were not significant (Figs. 4.78 and 4.79) except in the case of CRL with lime and fresh P application in 1997 where *M. pruriens* (w) produced significant increase in P concentration of index leaves. Averaged over all treatments

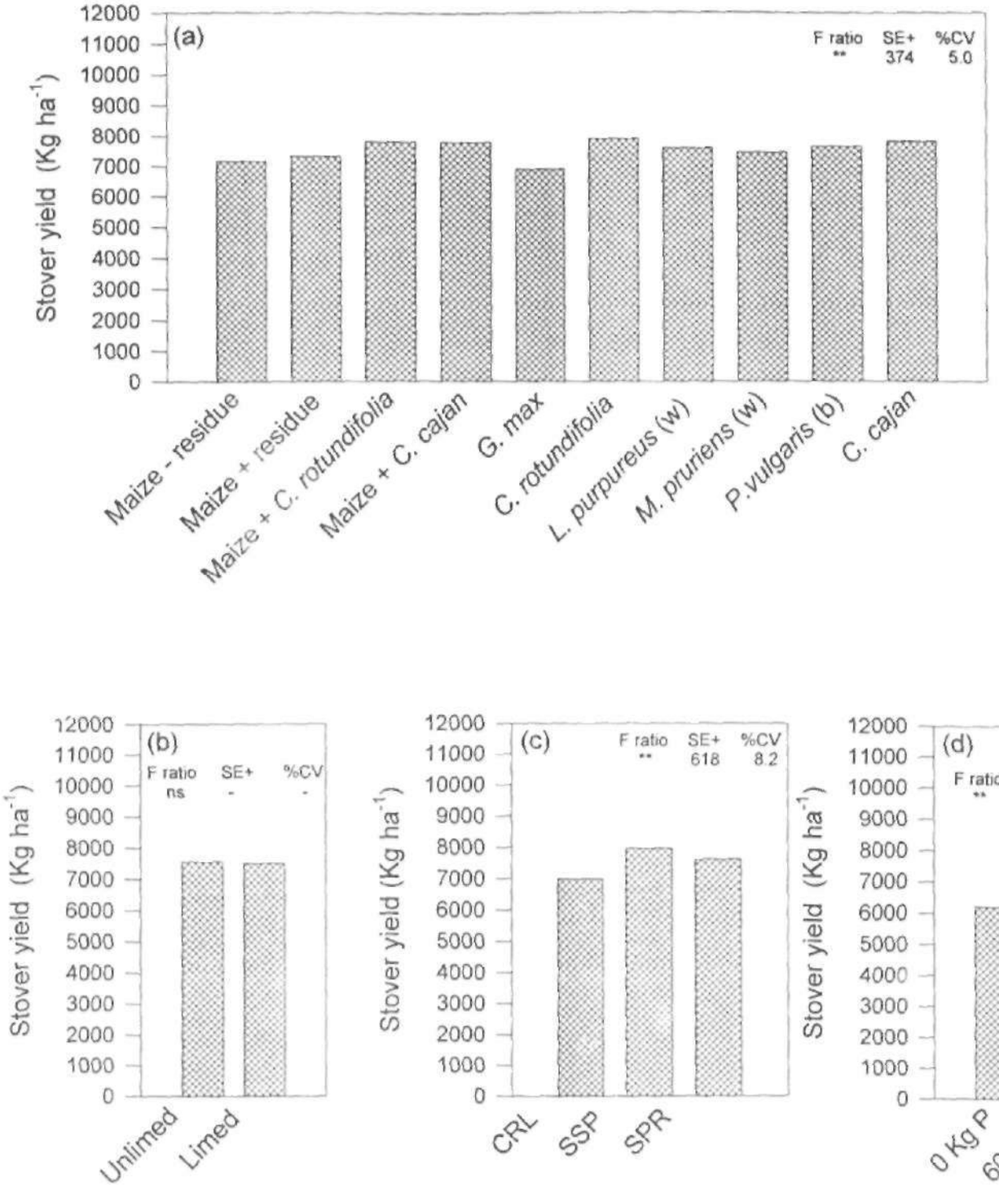
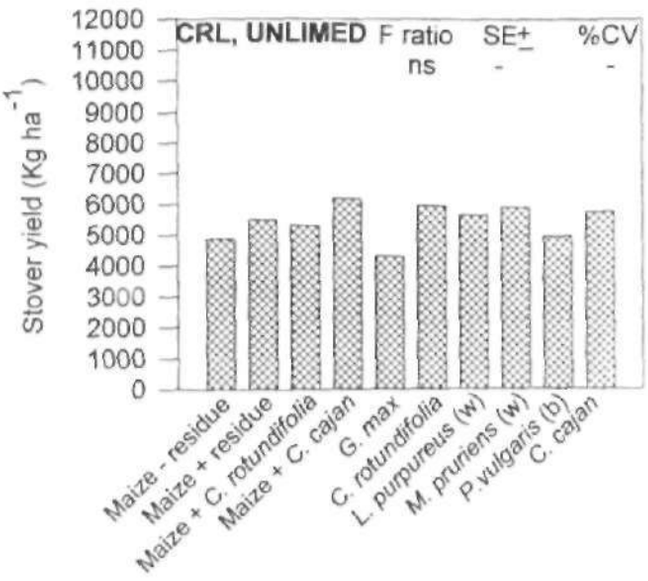
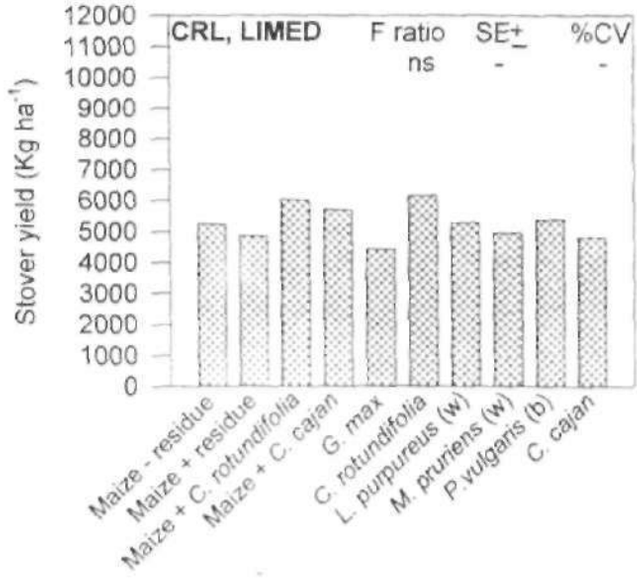
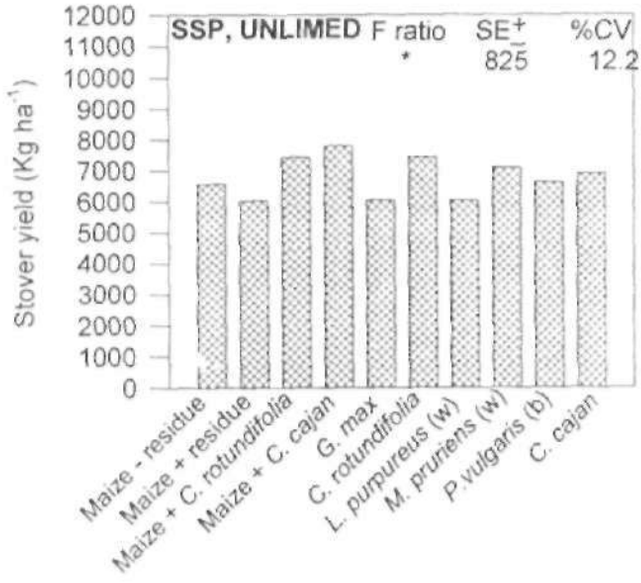
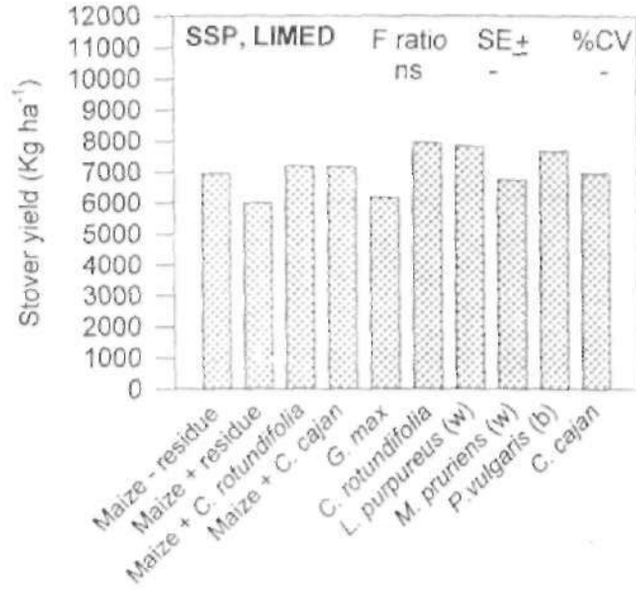


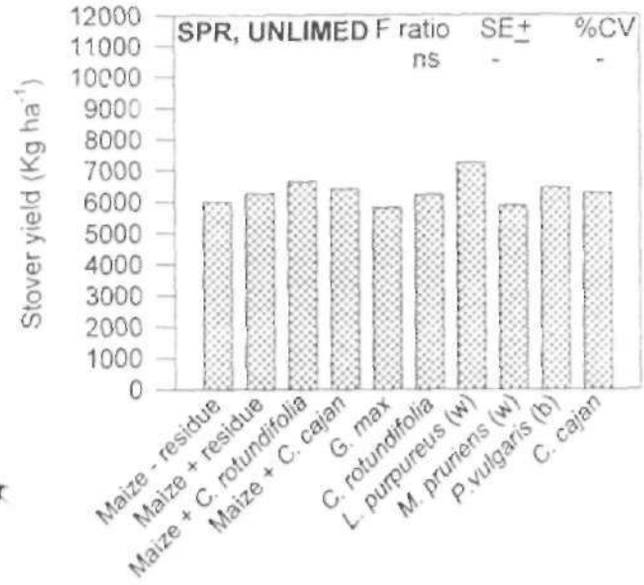
Fig. 4.74: Effect of treatments on maize stover yield in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments











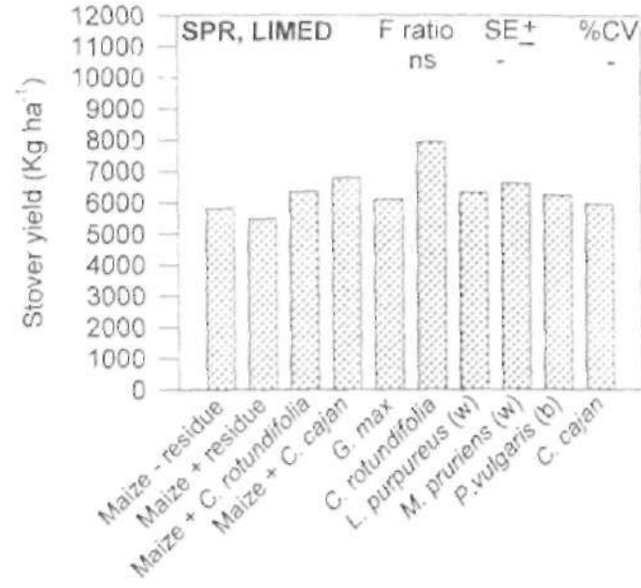


Figure 4.7b. Effect of preceding crops and 1996 P application on maize stover yield in 1997 at Heipang

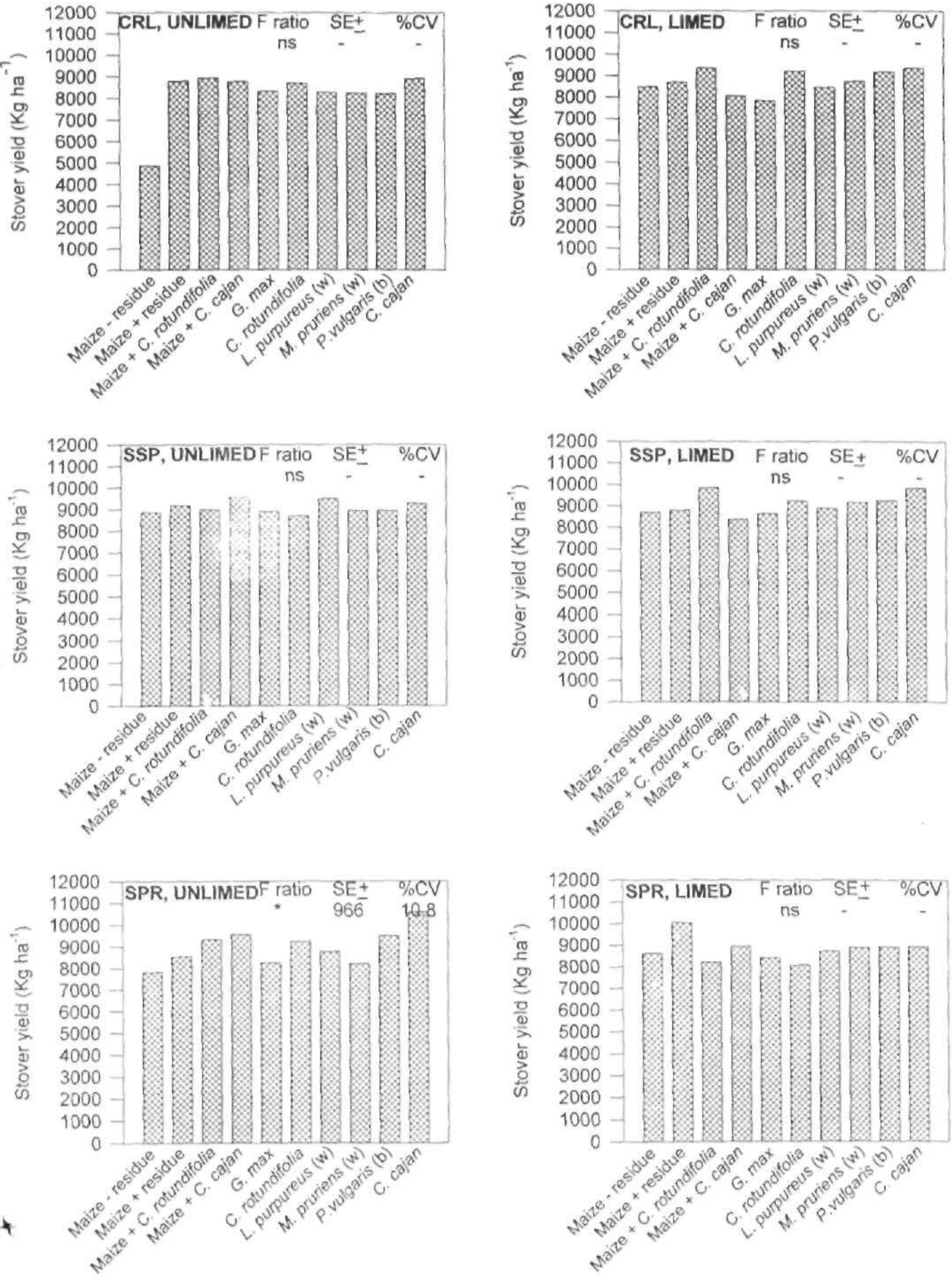


Figure 4.76: Effect of preceding crops, 1996 P application and fresh 60 Kg P ha^{-1} SSP in 1997 on maize stover yield at Heipang

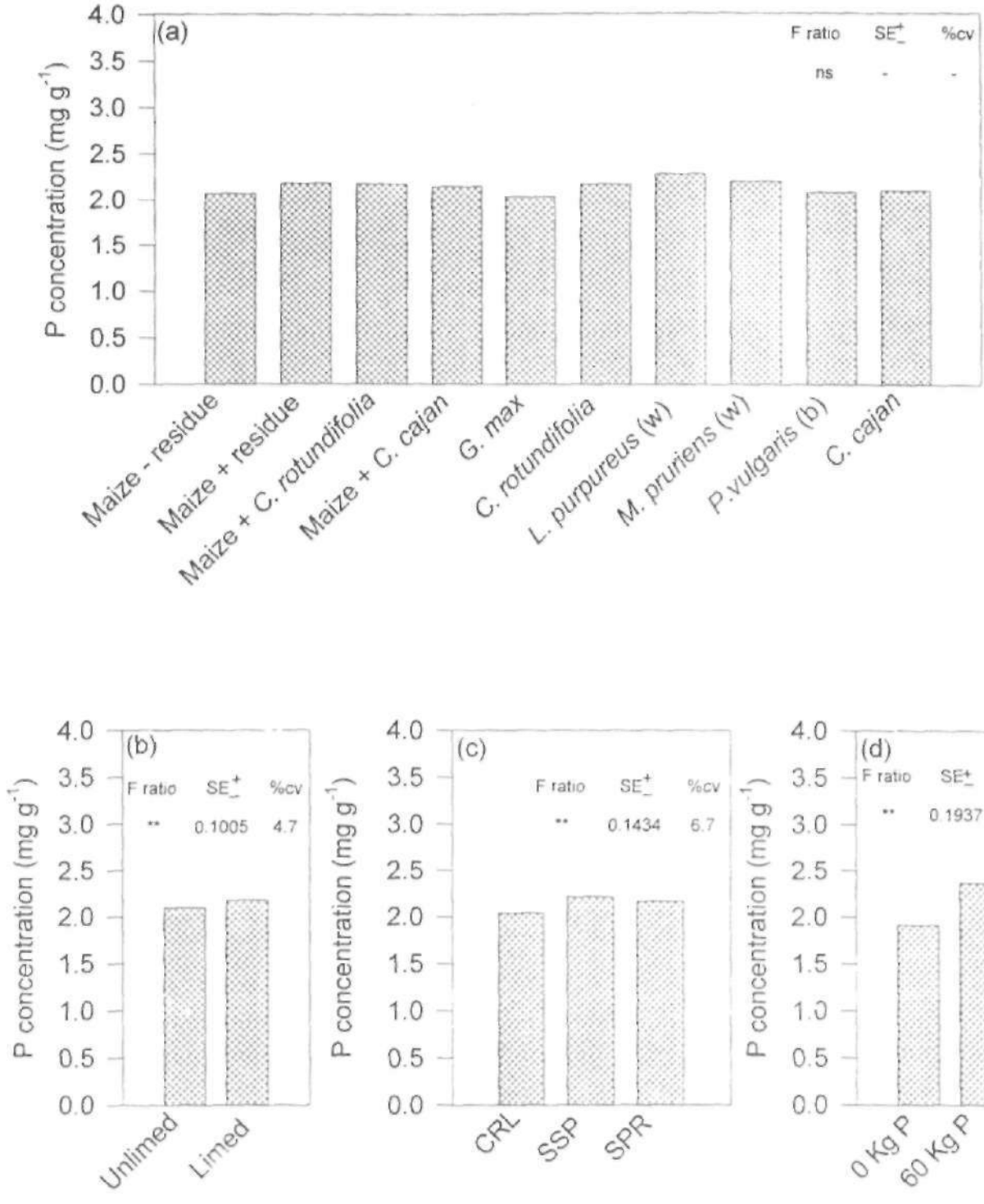


Fig.4.77: Effect of treatments on P concentration in maize index leaves in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

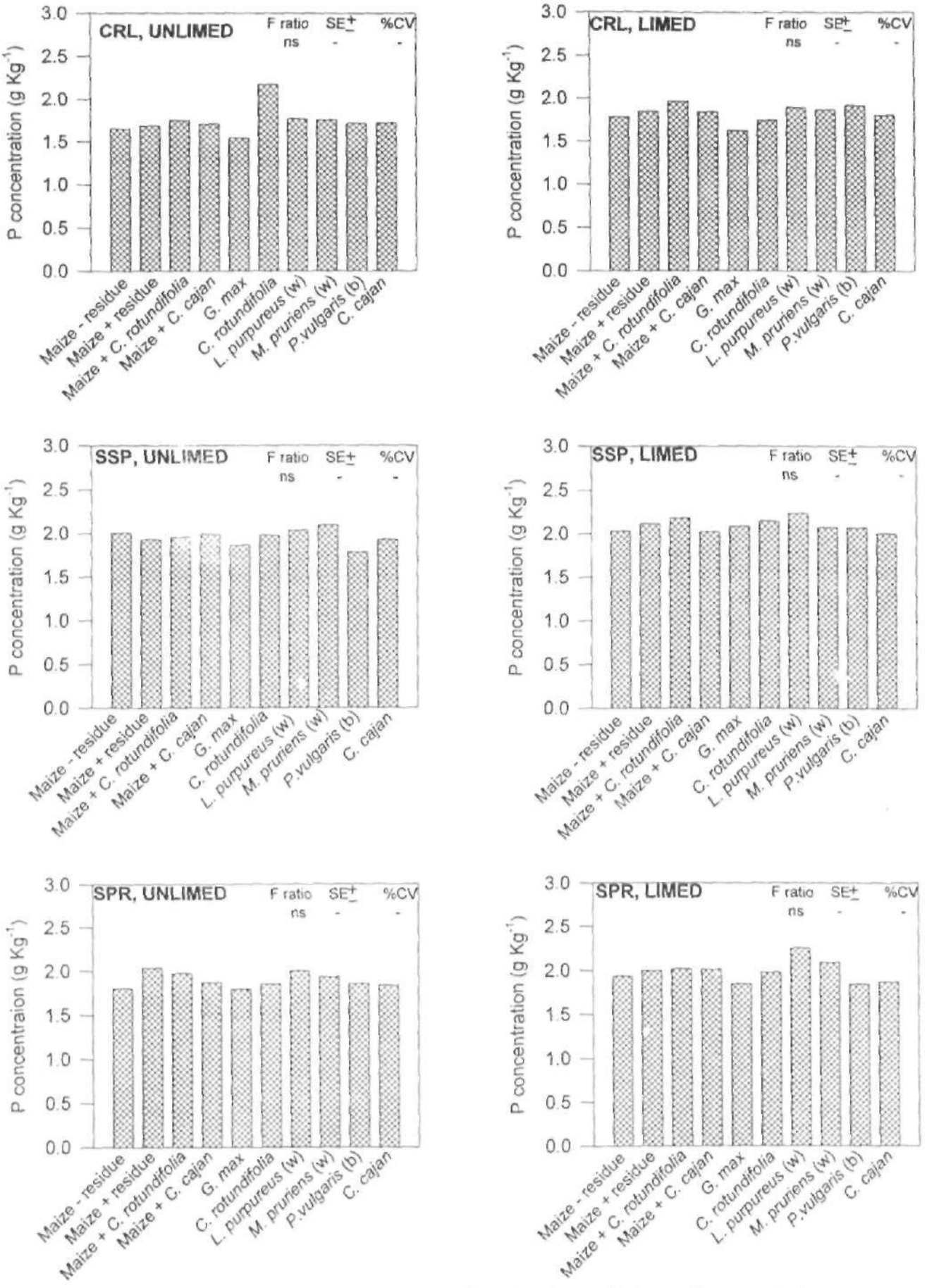


Figure 4.78: Effect of preceding crops, 1996 P application and liming on P concentration in the index leaves of maize at 50% silking in 1997 at Serpang

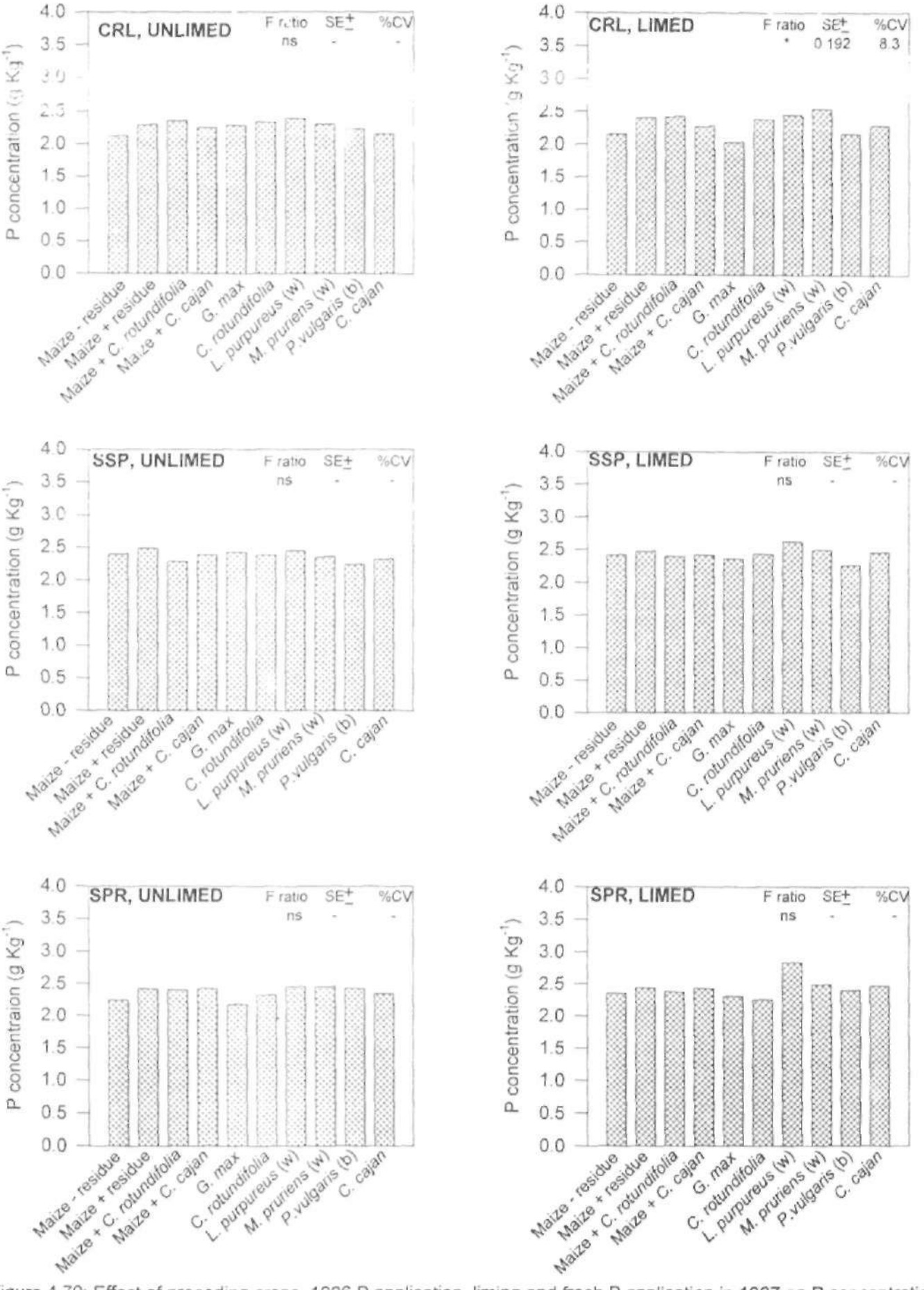


Figure 4.79: Effect of preceding crops, 1996 P application, liming and fresh P application in 1997 on P concentration in the index leaves of maize at 50% silking in 1997 at Heipang

liming significantly raised the P concentration of index leaves. Both SSP and SPR application in 1996 and fresh P application in 1997 resulted in significant increase in P concentration of index leaves.

Figures 4.80, 4.81 and 4.82 show the effects of the various treatments on maize grain P concentration. There were no significant variations in grain P concentration due to preceding cover crop treatments. Liming did not also significantly affect grain P content. However, 1996 SSP application significantly improved grain P concentration (Fig. 4.80). Similarly, fresh P application in 1997 produced significant increase in grain P concentration. Effects of treatments on stover P concentration were not significant (Figs. 4.83, 4.84 and 4.85).

Effects of preceding cover crops on total P uptake by maize in 1997 were not significant (Figs. 4.86, 4.87 and 4.88). The mean effects, however, show that liming produced significant increase in total P uptake (Fig. 4.86). Application of SSP and SPR in 1996 also significantly increased the total P taken up by maize in 1997, with SSP however being superior to SPR. Higher total P uptake was recorded with fresh 60 kg P application in 1997.

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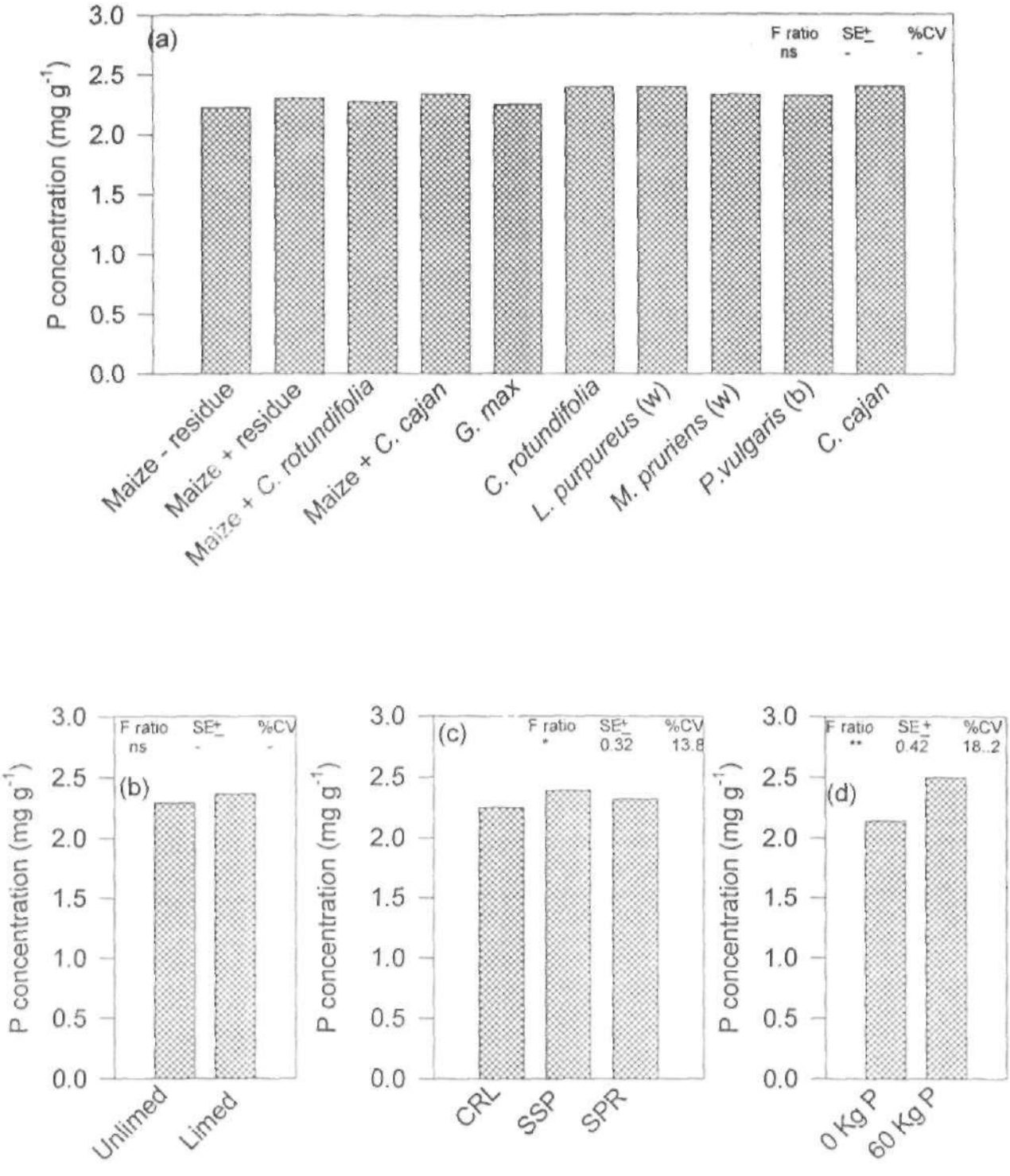


Fig. 4.80: Effect of treatments on maize grain P concentration in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

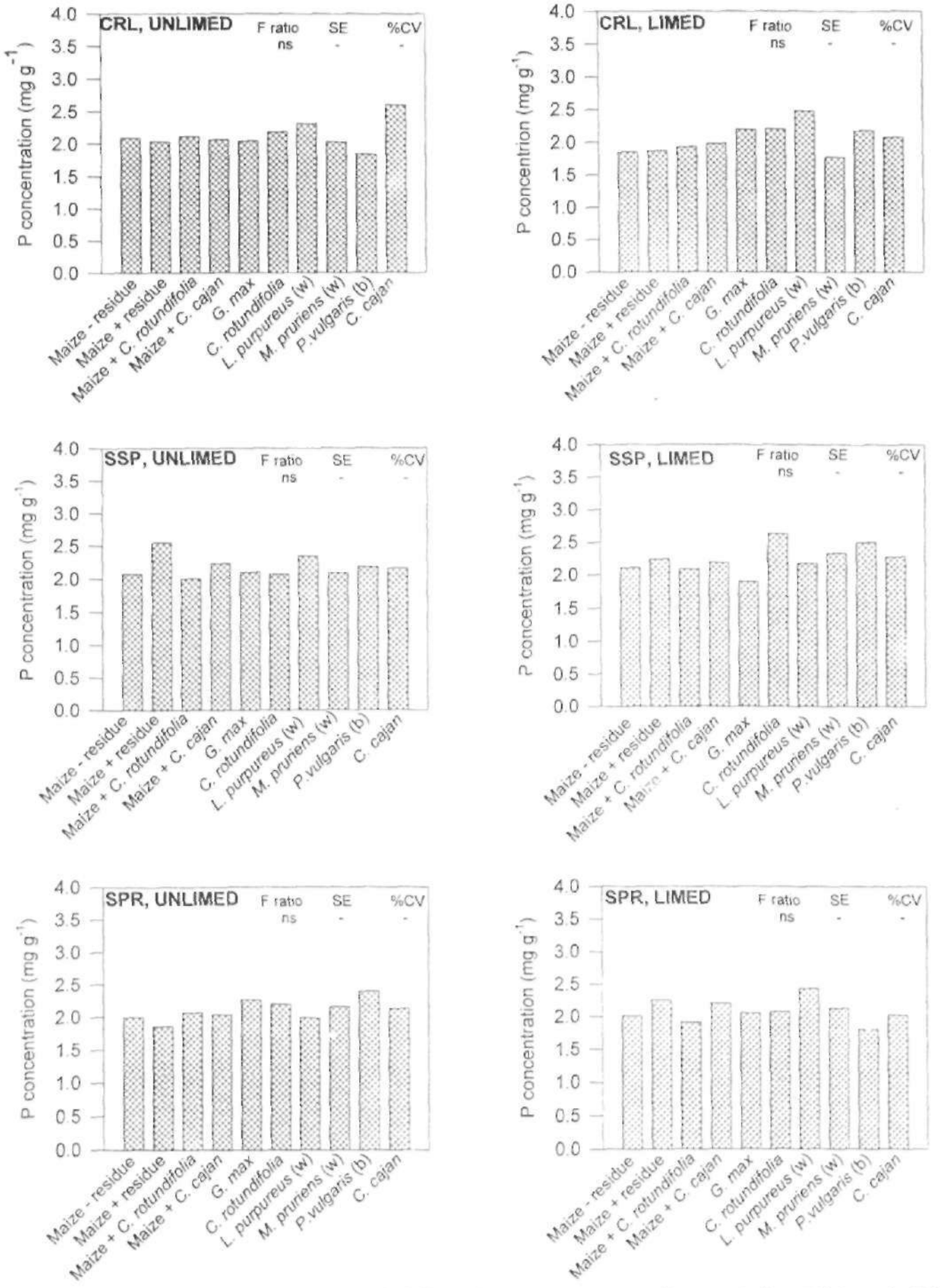


Fig. 4.81: Effect of preceding crops and 1996 P application on maize grain P concentration at Heipang in 1997

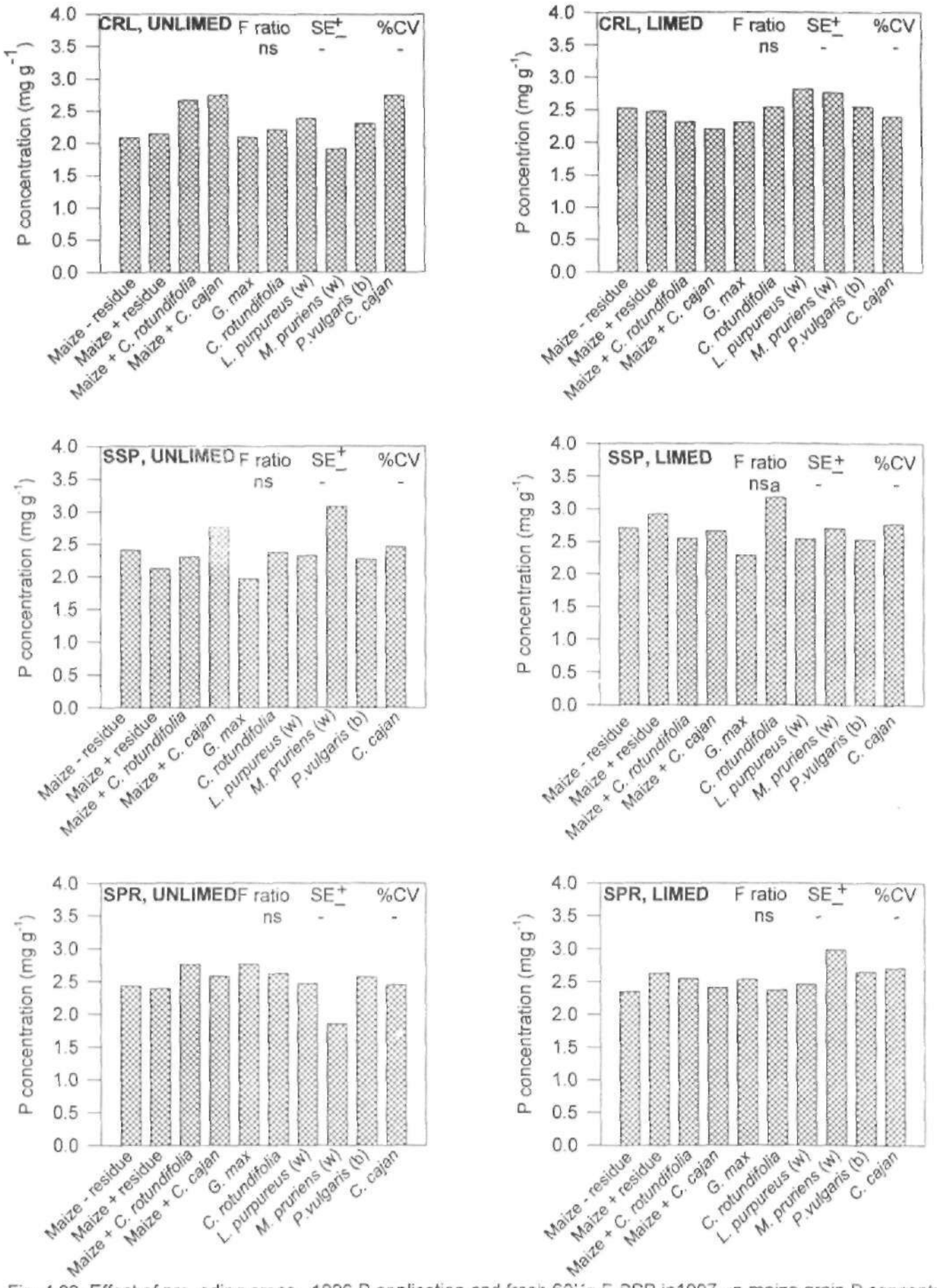


Fig. 4.82: Effect of preceding crops, 1996 P application and fresh 60Kg P SSP in1997 on maize grain P concentration at Heimang in 1997

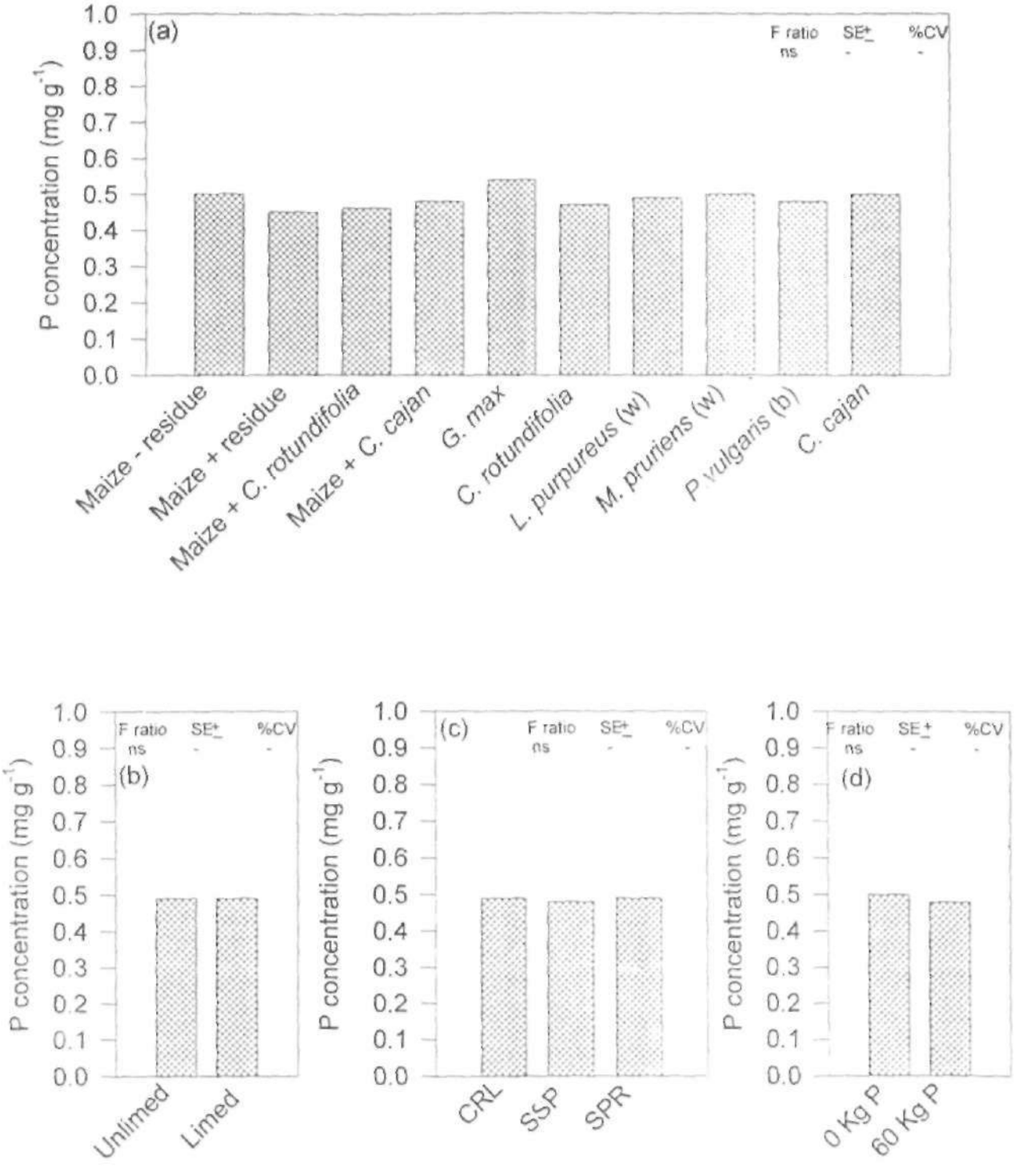


Fig. 4.83: Effect of treatments on maize stover P concentration in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

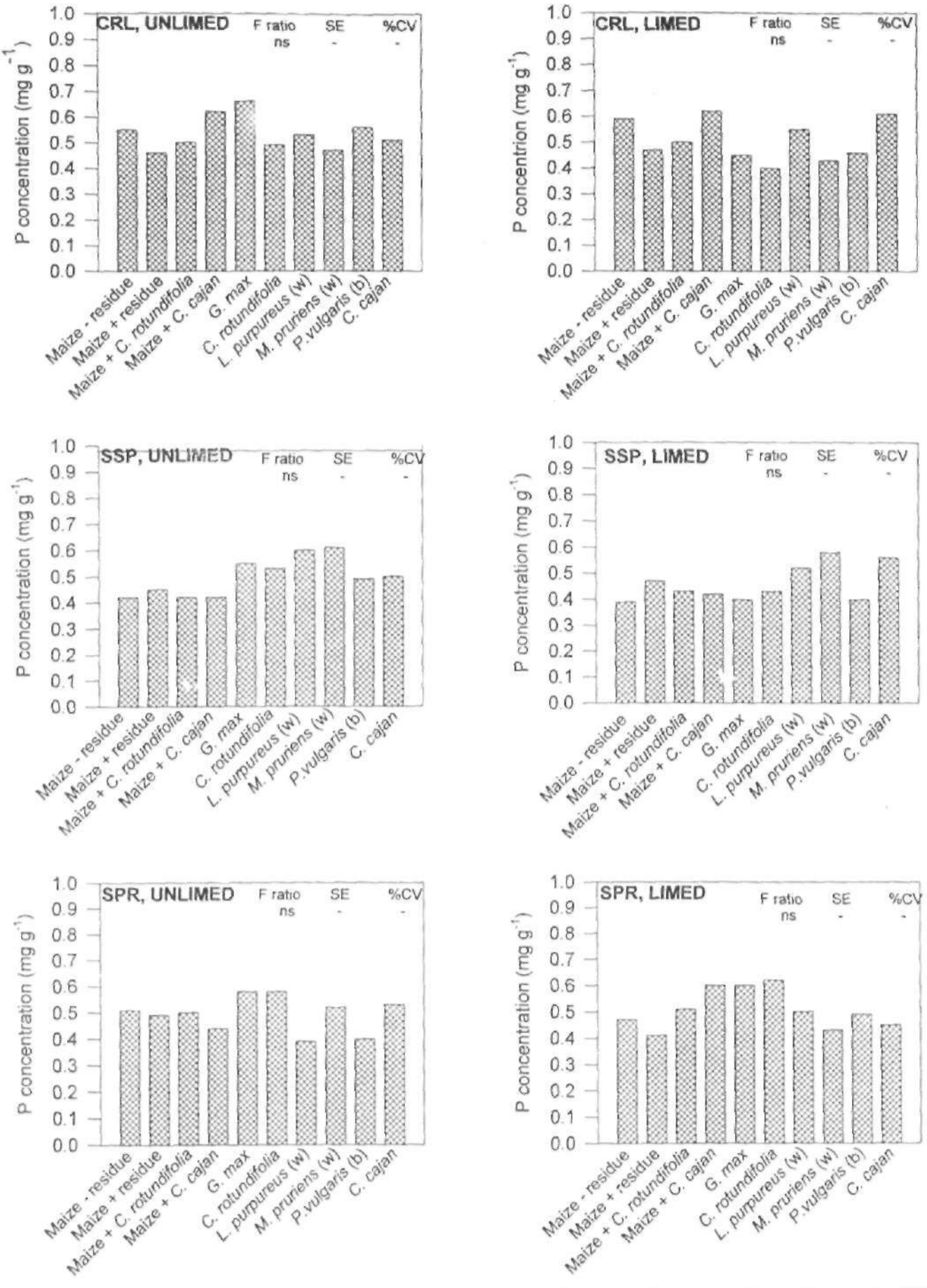


Figure 4.84: Effect of preceding crops and 1996 P application on maize stover P concentration at Ikenne in 1997

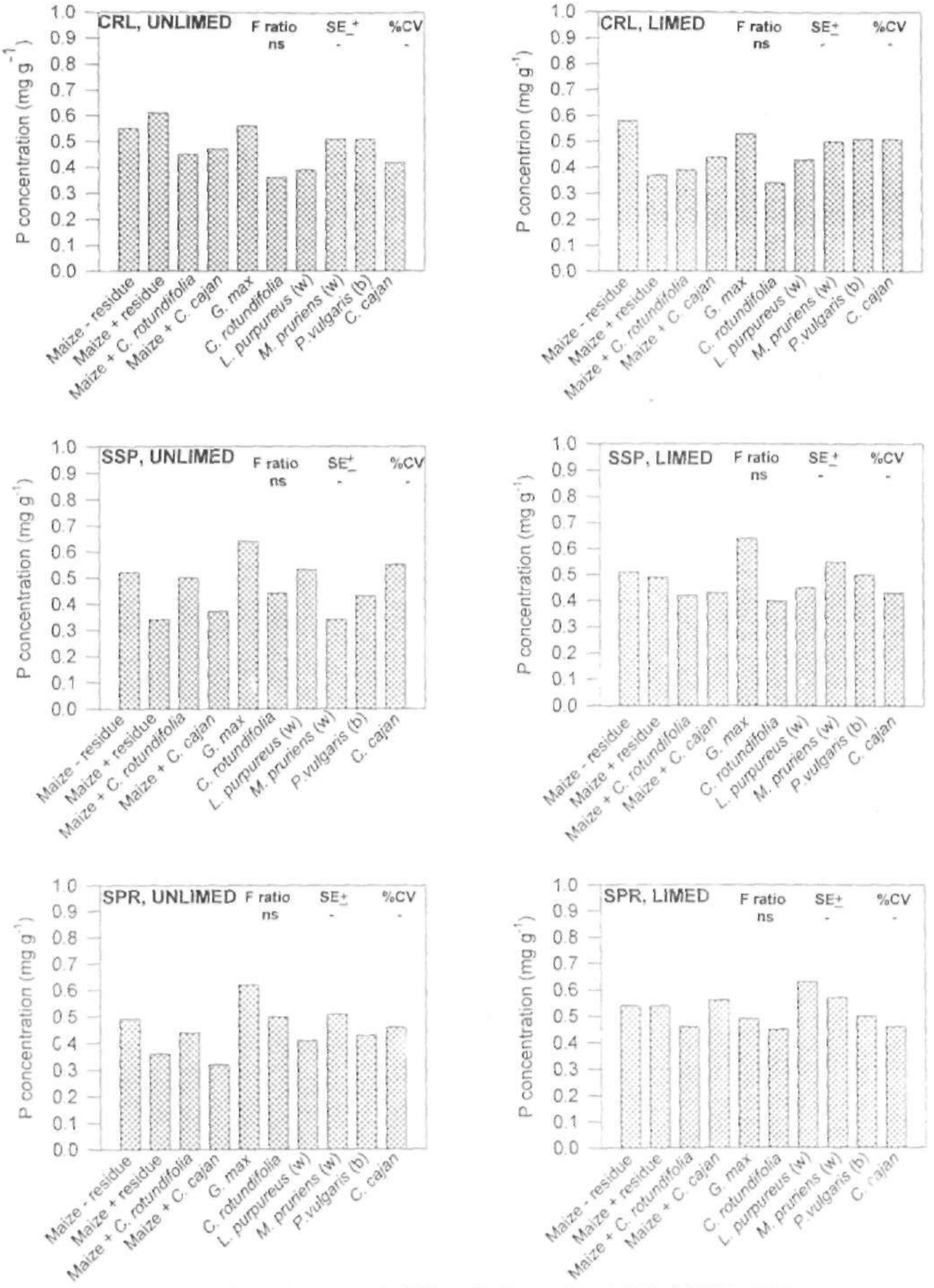


Figure 4.85: Effect of preceding crops, 1996 P application and fresh 60Kg P SSP in 1997 on maize stover P concentration at Laipang in 1997

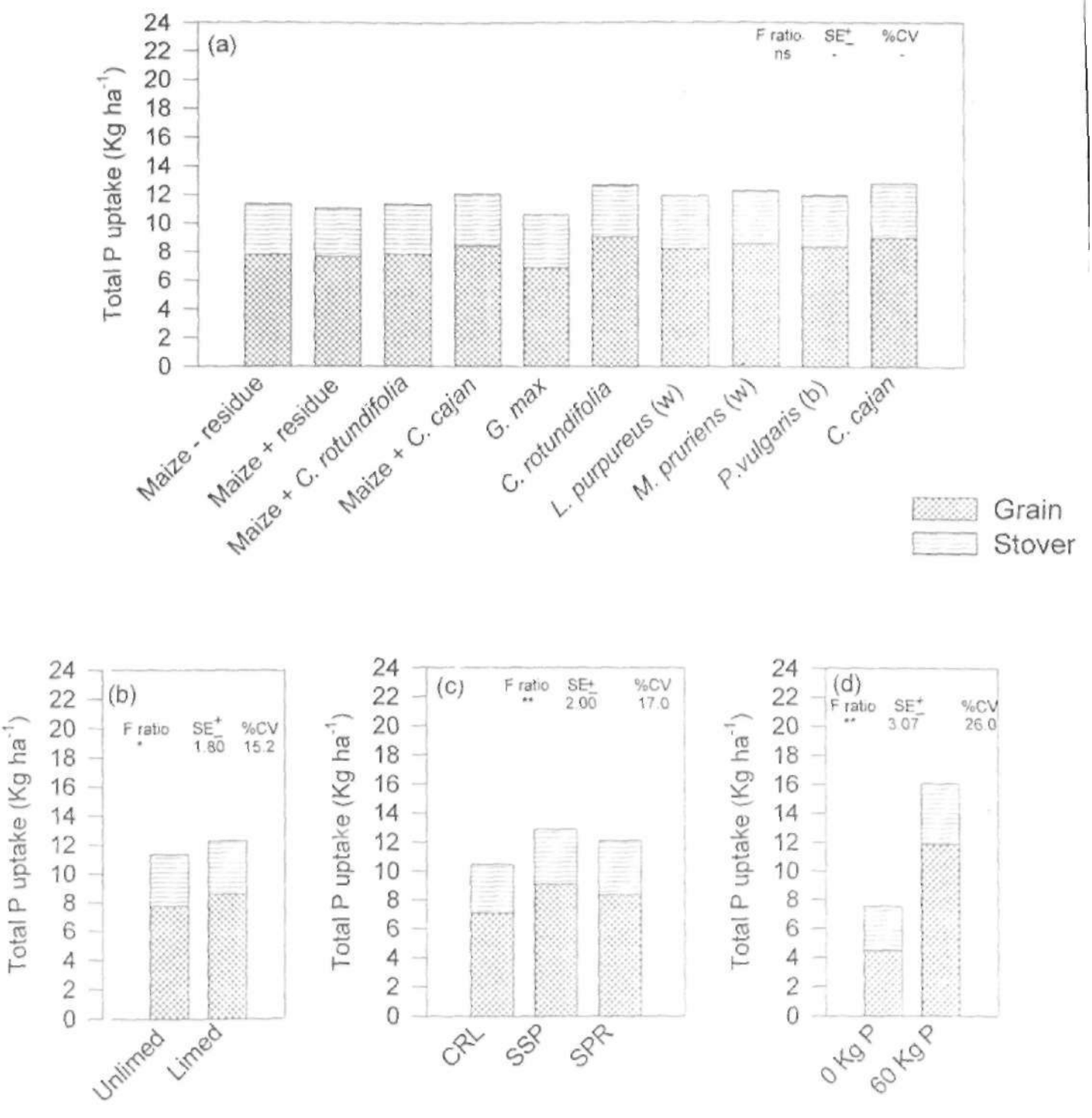


Fig. 4.86: Effect of treatments on total P uptake by maize at Heipang in 1997 (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

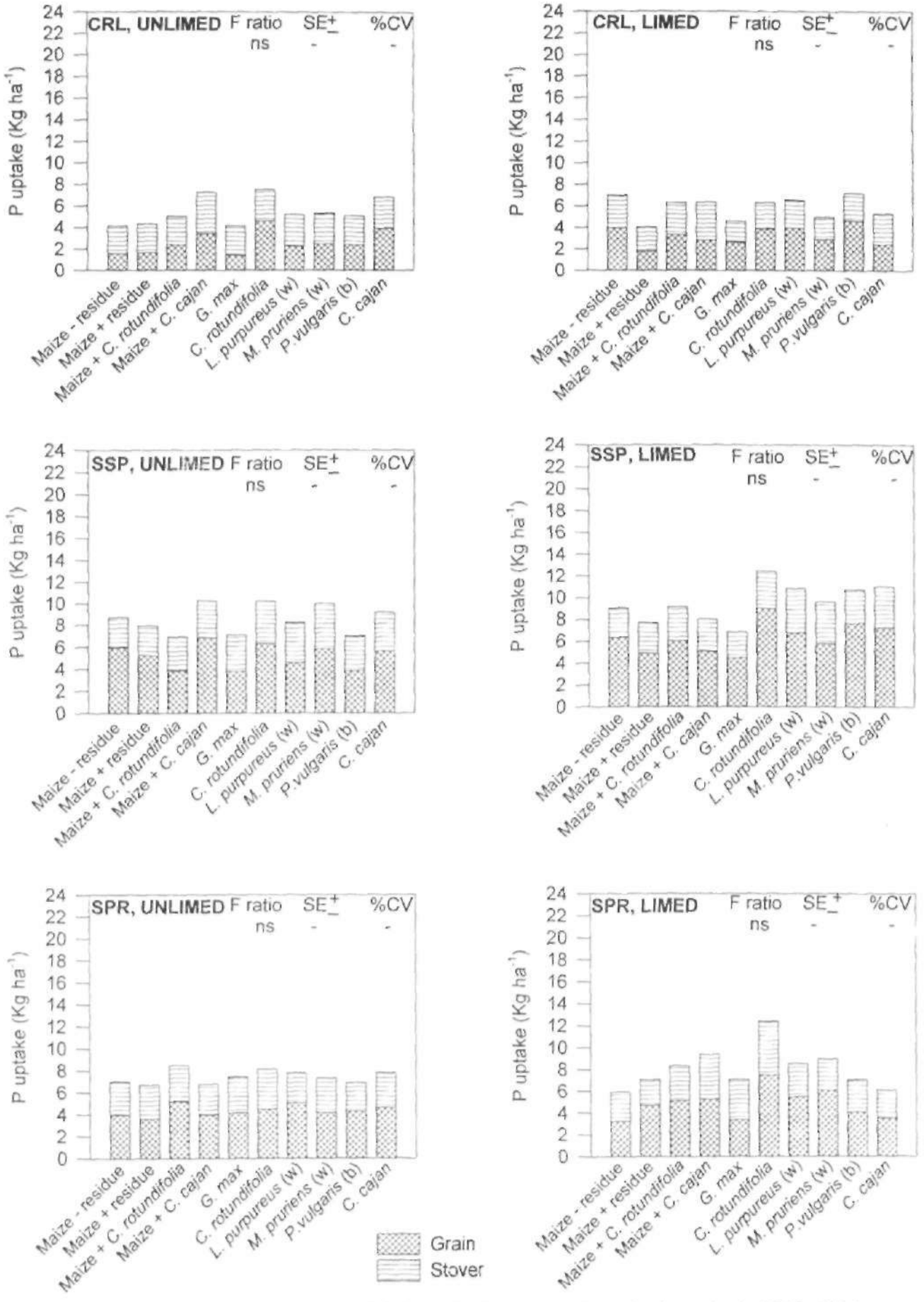


Fig. 4.87: Effect of preceding crop and 1996 P application on total P uptake by maize in 1997 at Heipang

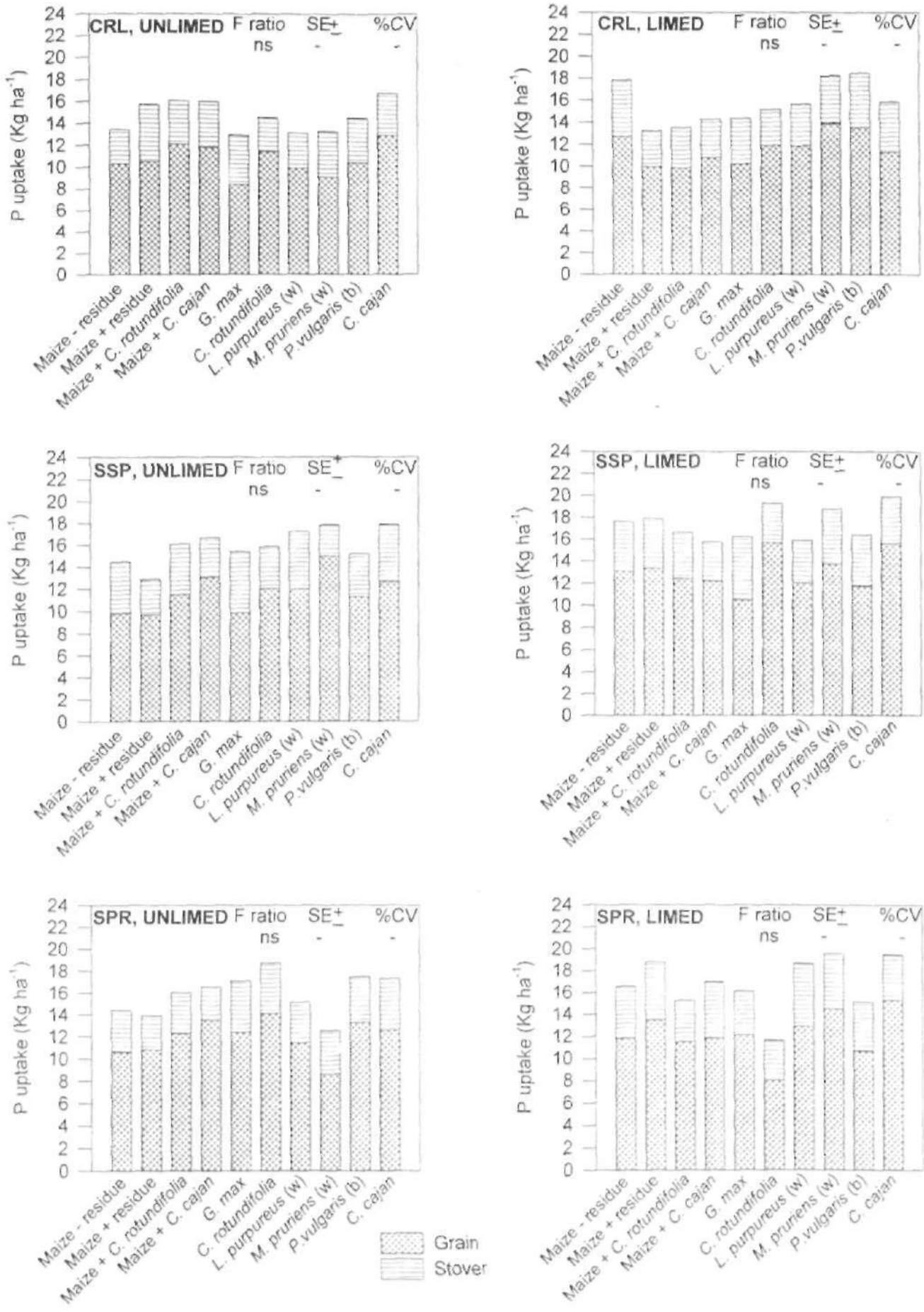


Fig. 4.80. Effect of preceding crop,1996 and 1997 P application on total P uptake by maize in 1997 at Heinang

Tables 4.31 and 4.32 show the effects of liming and preceding crops on concentrations of some nutrient elements in the index leaves of maize at 50% silking in 1997. Lime application significantly ($P = 0.05$) raised the concentrations of Ca, Mg and Cu in the index leaves, while the concentrations of K, S and Mn were significantly lowered. Effect of liming on leaf concentrations of Fe, Al and Zn was not obvious.

Chamaecrista rotundifolia, *M. pruriens*, *P. vulgaris* (b) and *Z. mays + C. rotundifolia* significantly raised the concentration of Mg in the index leaves of the succeeding maize crop, while G. max lowered the Mg concentration (Table 4.31). The concentrations of Mn and K were significantly raised on plots preceded by *G. max*. The increased Mn and decreased Mg concentrations in maize index leaves on plots preceded by *G. max* give a clue to the lower performance of maize observed on these plots. *Chamaecrista rotundifolia* significantly lowered the Cu concentration of the index leaves of maize at 50% silking. Although, statistically, the Al concentration of maize index leaves was not significantly lowered by preceding crop treatments, there were 42.4, 41.4, 39.1 and 38.4% reductions in the Al concentrations of index leaves preceded by *M. pruriens* (w), *Z. mays + C. rotundifolia*, *L. purpureus* (W) and *C. rotundifolia* respectively. Kretzschmar *et al.* (1991) observed more than 44% decrease in total and

Table 4.31: Effect of preceding crops on nutrient element concentrations in index leaves of maize at 50% silking in 1997

Preceding crop	Ca	Mg	K	S	Fe	Al	Mn	Cu	Zn
	g kg-1				mg kg-1				
Z.mays	4.00	2.53	16.70	2.82	109	151	33.44	8.55	20.50
Z.mays + residue	4.00	2.60	16.70	2.85	104	117	38.17	7.55	21.50
Z.mays + C.rotundifolia	4.23	2.87	16.85	2.99	103	89	36.50	7.90	23.00
Z.mays + C.cajan	4.01	2.51	17.21	2.85	106	111	35.05	10.16	22.70
G. max	3.54	2.27	18.22	3.09	116	169	41.16	8.50	18.36
C. rotundifolia	4.38	2.93	16.65	3.10	105	93	34.40	5.95	26.00
M.purpureus (w)	4.13	2.73	16.63	2.88	101	92	33.05	9.25	19.90
M.pruriens (w)	4.11	2.81	15.84	2.97	101	87	32.35	7.20	21.40
P.vulgaris (b)	4.08	2.81	15.99	2.08	104	109	38.00	6.86	20.50
C. cajan	4.16	2.63	17.10	3.26	105	104	31.19	8.44	20.50
F ratio	ns	**	*	ns	ns	ns	*	**	ns
SE ±	-	0.199	0.860	-	-	-	3.811	1.336	-
CV %	-	7.5	5.1	-	-	-	10.8	16.6	-

Table 4.32: Effect of liming on nutrient element concentrations in index leaves at 50% flowering in 1997

Preceding crop	Ca	Mg	K	S	Fe	Al	Mn	Cu	Zn
	g kg-1				mg kg-1				
UNLIMED	3.83	2.60	17.15	2.98	104	107	38.61	7.40	21.3
LIMED	4.29	2.73	16.41	2.95	107	118	32.06	8.67	21.5
F ratio	**	*	**	*	ns	ns	**	**	ns
SE ±	0.435	0.287	1.162	0.221	-	-	4.971	1.759	-
CV %	10.7	10.7	6.9	7.5	-	-	14.1	21.9	-

labile Al concentrations in the soil solution of an acid Psammentic Paleustalf in Niger republic after incorporation of millet residue.

The matrix of coefficients of correlation between nutrients concentrations of maize index leaves at 50% silking, and grain and stover yields is given in Table 4.33. Grain yield was significantly correlated with P (r=0.747**), Ca (r=0.598**), Mg (r=0.629**), and Zn (r=0.526*). The better performance of maize on plots preceded by *C. rotundifolia* reported earlier could be due to the higher Mg uptake by maize on these plots. Concentrations of Mn in the index leaves correlated negatively with grain yield (r=-0.526*). This give support to the assertion that the lower performance of maize on plots preceded by *G. max* was due to the increased Mn and decreased Mg concentrations in maize tissue on these plots. A negative relationship was observed between grain yield and K concentration of index leaves (r=-0.545*) which was possibly due to K/Mg and/or K/Ca imbalance on plots where K fertilizer was applied without liming. There were strong negative relationships between K and Ca, and K and Mg (r=-0.703** and r=-0.615**). Increasing K levels in soil solution has been known to cause reductions in both Ca and Mg uptake, Mg being affected more than Ca (Metson, 1974; Claasen and Wilcox, 1974; Claasen and Barber, 1977; Mayland and Grunes, 1979).

Table 4.33: Matrix of correlation coefficients between nutrient concentrations in index leaves, yields of maize in 1997 and amount of crop residue returned to the soil at the end of 1996 season

	Grain yield	Stover yield	P	S	Mn	Fe	Ca	Al	Mg	K	Cu	Zn	Residue	Residue P
Grain yield	1.000													
Stover yield	0.529*	1.000												
P	0.747**	0.496*	1.000											
S	-0.221	0.128	-0.064	1.000										
Mn	-0.550*	-0.196	-0.519*	0.196	1.000									
Fe	0.020	-0.300	-0.282	0.125	0.147	1.000								
Ca	0.598**	0.381	0.694**	-0.038	-0.638**	-0.178	1.000							
Al	-0.130	-0.532*	-0.444*	-0.088	0.211	0.879**	-0.264	1.000						
Mg	0.629**	0.429	0.734**	0.164	-0.432*	-0.230	0.678**	-0.435	1.000					
K	-0.545*	-0.197	-0.516	0.319	0.459*	0.401	-0.703**	0.292	-0.615**	1.000				
Cu	0.114	0.032	-0.013	-0.401	-0.383	0.271	-0.061	0.233	-0.348	0.246	1.000			
Zn	0.526*	0.599**	0.603**	0.184	-0.173	0.165	0.352	-0.149	0.528*	-0.027	-0.142	1.000		
Residue	0.318	0.619**	0.331	0.297	-0.146	-0.090	0.326	-0.361	0.314	0.049	0.006	0.585**	1.000	
Residue P	0.136	0.335	0.054	0.162	0.191	0.670	-0.051	-0.101	-0.030	0.218	-0.078	0.458*	0.760**	1.000

Stover yield was highly correlated with concentrations of P (r=0.496*), Zn (r=0.599**) and Al (r=-0.532) in the index leaves at 50% silking. Very strong relationship was recorded between the amount of crop residue incorporated into the soil in 1996 and stover yield in 1997 (r=0.613**).

Phosphorus concentration of the index leaves was negatively correlated with Mn (r=-0.500*), Al (r=-0.444*) and K (r=-0.516*) concentrations. Concentrations of calcium, Mg and Zn in the index leaves were strongly correlated with P concentration (r=0.694**, r=0.734**, and r=0.603** respectively). Zinc concentration was related to the amount of crop residue incorporated in 1996 (r=0.585**), and with the amount of P incorporated along with the residue (r=0.458*).

4.3.2.3 Effects of 1996 and 1997 treatments on some soil chemical properties

At the start of 1997 season (before application of fertilizers and lime) the effects of 1996 treatments did not manifest on available (Bray 1) soil P (Table 4.34) and pH (Table 4.35). The values for available soil P were extremely low, ranging from 0.5 to 1.44 mg Kg^{-1} soil. At mid-silking, effects of preceding crops, liming, and 1996 P treatments did not significantly influence the concentration of available P

Table 4.34: Effect of preceding crops, 1996 P application and liming on Bray 1 P at the start of 1997 season

Preceding crop	Bray 1 P (mg Kg^{-1})					
	Unlimed			Limed		
	CRL	SSP	SPR	CRL	SSP	SPR
Z. mays	0.85	1.07	0.96	0.86	0.82	1.15
Z. mays + residue	1.19	1.00	0.94	0.90	0.80	0.89
Z. mays + C. rotundifolia	1.05	0.87	0.98	0.71	0.70	0.99
Z. mays + C. Cajan	0.88	1.12	0.90	0.85	1.01	0.83
G. max	0.77	0.94	0.75	1.05	1.17	1.24
C. rotundifolia	1.44	0.88	1.10	0.70	0.98	0.85
L. purpureus (w)	1.03	1.03	1.21	1.02	1.26	1.31
M. pruriens (W)	0.97	1.10	0.91	1.09	1.17	0.93
P. vulgaris (b)	0.69	0.62	0.50	1.06	1.17	1.04
C. cajan	1.12	1.36	1.25	0.66	0.82	0.93

SE: Crop	ns
SE: Liming	ns
SE: Psource	ns
SE: Crop x Liming	ns
SE: Crop x Psource	ns
SE: Liming x PSource	ns
SE: Crop x Liming x Psource	ns

Table 4.35: Effect of preceding crops, 1996 P application and liming on soil pH at the start of 1997 season

	Soil pH					
	Unlimed			Limed		
	CRL	SSP	SPR	CRL	SSP	SPR
Z. mays	5.1	5.1	5.2	5.2	5.2	5.2
Z. mays + residue	4.9	4.7	4.9	5.0	5.2	4.9
Z. mays + C. rotundifolia	5.0	4.9	5.0	5.0	4.9	4.8
Z. mays + C. Cajan	5.1	5.2	5.0	5.0	5.2	5.2
G. max	4.8	5.0	4.9	5.0	5.1	5.2
C. rotundifolia	4.9	4.8	4.9	5.1	5.1	5.2
L. purpureus (w)	4.9	5.1	5.1	5.0	4.9	5.0
M. pruriens (W)	5.2	5.4	5.1	4.9	5.1	5.1
P. vulgaris (b)	4.7	4.8	4.8	5.0	5.2	5.4
C. cajan	4.8	5.3	5.4	5.1	5.1	5.0
SED Crop		ns				
SED Liming		ns				
SED PSource		ns				
SED Crop x Liming		ns				
SED Crop x Psource		ns				
SED Liming x PSource		ns				
SED Crop x Liming x PSource		ns				

in the soil (Fig. 4.89). However, the application of 60 Kg P ha^{-1} in 1997 significantly increased the concentration of Bray 1 P from 0.44 to 1.73 mg Kg^{-1}. The extremely low concentration of available soil P even with the application of 60 Kg P ha-1 in 1997 is a testimony to the very high P sorption capacity of this soil. Figure 4.90 shows the mean effects of treatments on soil pH at mid-silking. Mean soil pH value was significantly higher on limed plots.

Effect of preceding crop treatments on CBD extractable (crystalline) and oxalate extractable (amorphous) oxides of Fe, Al and Mn at the start of 1997 season is presented in Table 4.36. Non of the preceding crops appeared to have any significant effect on the concentrations of Fe, Al and Mn oxides in the soil. The effect of liming on CBD and oxalate extractable oxides of Fe, Al and Mn was also not at the beginning of 1997 season significant (Table 4.37).

Table 4.38 shows the coefficients of correlation between maize yields, nutrients concentrations of index leaves and some soil chemical properties. Concentrations of P in the index leaves was significantly correlated with available (Bray 1) soil P concentration at the beginning of the season ($r=0.461^{*}$). Soil pH at beginning of the season was negatively correlated with sulphur concentration of index leaves

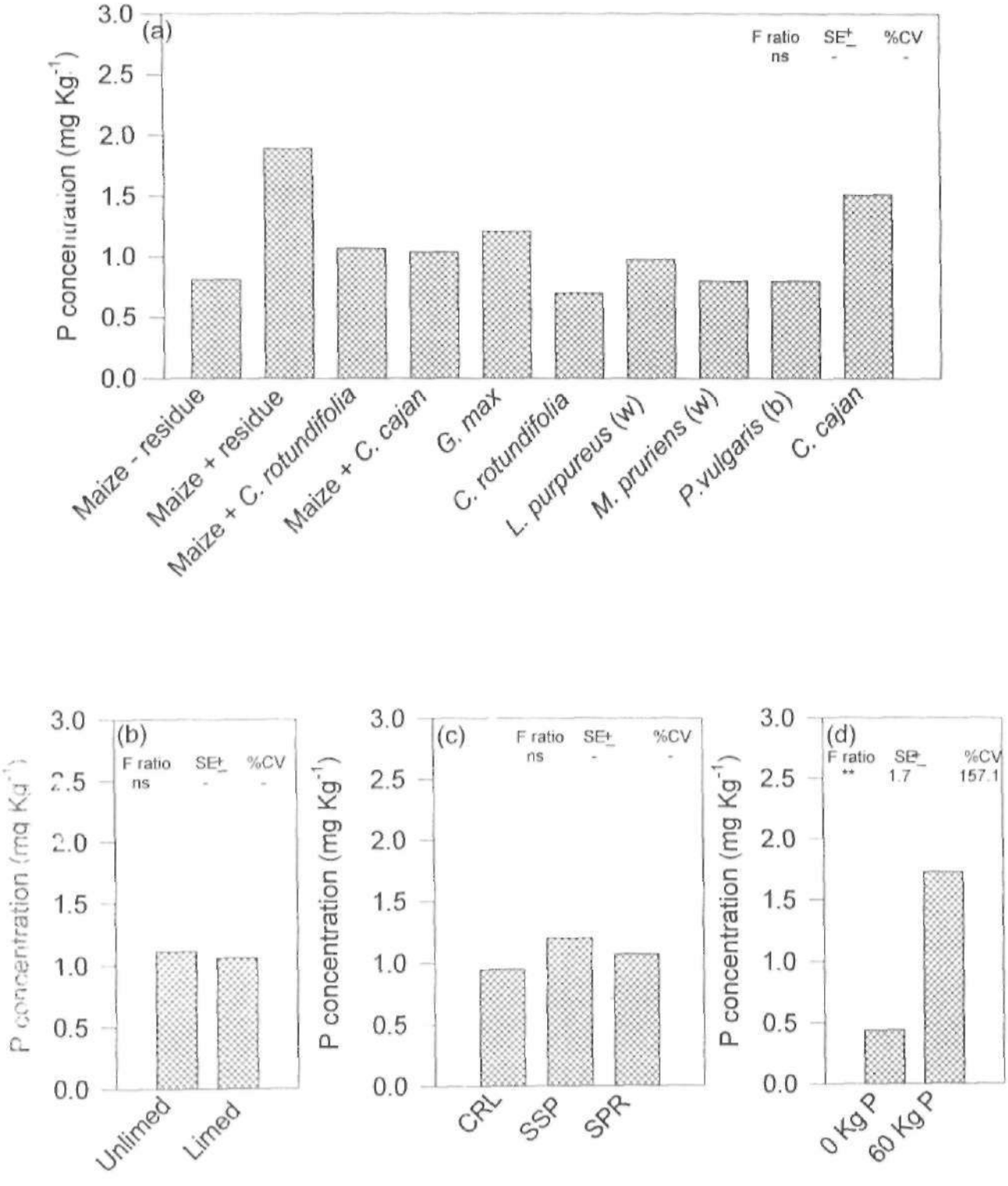


Fig. 1.89: Effect of treatments on Bray-1-P in 1997 at 50% silking (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

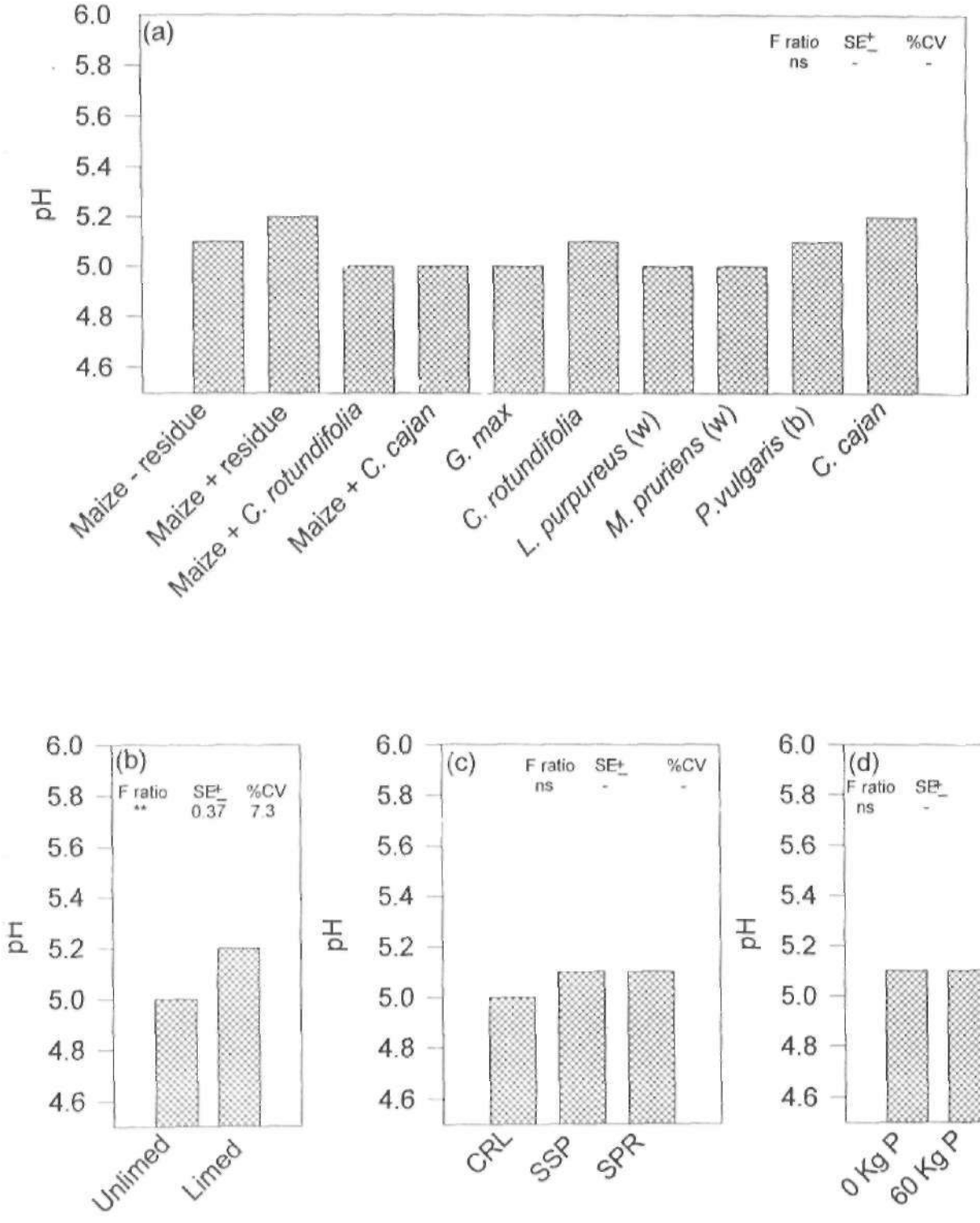


Fig. 4.90: Effect of treatments on soil pH in 1997 at 50% silking (a) preceding crops averaged over other treatments (b) liming averaged over other treatments (c) 1996 P fertilization averaged over other treatments (d) 1997 P fertilization averaged over other treatments

Table 4.36: Effect of cover cropping on crystalline and amorphous oxides of Fe, Al and Mn in Heipang soil at the start of 1997 season

Preceding crop	CBD extractable			Oxalate extractable		
	Fe2O3	Al2O3	MnO	Fe2O3	Al2O3	MnO
	<.....mg Kg-1 .....>					
Control	46867	28087	1353	1716	858	212
Z. mays + residue	39790	25630	1161	1476	716	188
Z. mays + *C. rotundifolia*	43102	24249	1136	1544	704	208
Z. mays + *C. cajan*	45730	27425	1223	1485	657	186
Z. mays	47045	27229	1183	1503	760	195
C. rotundifolia	43992	25438	1147	1611	776	202
M. purpureus (w)	48477	26196	1186	1557	739	197
M. pruriens (w)	38268	25053	1153	1556	757	192
D. volgaris (b)	60907	31157	1358	1496	801	200
C. cajan	38351	25864	1159	1650	870	203
F ratio	ns	ns	ns	ns	ns	ns
SED	-	-	-	-	-	-
CV	-	-	-	-	-	-

Table 4.37: Effect of liming on crystalline and amorphous oxides of Fe, Al and Mn in Heipang soil at the start of 1997 season

Preceding crop	CBD extractable			Oxalate extractable		
	Fe2O3	Al2O3	MnO	Fe2O3	Al2O3	MnO
	<.....mg Kg-1 .....>					
Unlimed	44677	26724	1205	1568	772	201
Limed	45828	26541	1205	1551	756	196
F ratio	ns	ns	ns	ns	ns	ns
SED	-	-	-	-	-	-
CV	-	-	-	-	-	-

Table 4.38: Matrix of correlation coefficients between nutrient elements concentrations in index leaves, maize yields and some soil properties.

Soil properties	Nutrients elements in index leves										Grain yield	Stover yield
	P	S	Mn	Fe	Ca	Al	Mg	K	Cu	Zn		
ray 1 P (preplanting)	0.461*	0.052	0.179	-0.013	0.091	0.000	0.326	-0.241	-0.323	0.347	0.167	0.076
Bray 1 P (silking)	-0.025	-0.017	-0.229	0.580**	-0.085	0.460*	-0.259	0 347	0.744**	0.081	0.091	-0.093
pH (preplanting)	0.006	-0.471*	-0.301	0.005	0.266	0.122	-0.152	-0.274	0.219	0.077	0.240	0.366
pH (silking)	0.417	-0.367	-0.142	-0.211	0.477*	-0.052	0.449*	-0.692**	-0.362	0.072	0.482*	0.100
CBD extractable Mn	-0.238	-0.234	0.015	-0.14	-0.034	0.127	-0.107	-0.176	-0.177	-0.449*	-0.047	-0.221
CBD extractable Fe	-0.196	-0.387	0.107	-0.159	-0.053	-0.016	-0.067	-0.139	-0.151	-0.429	0.093	-0.110
CBD extractable Al	-0.303	-0.393	0.103	-0.090	-0.245	0.070	-0.223	0.023	-0.019	-0.461*	0.021	-0.051
Oxalate extractable Mn	-0.098	0.199	-0.009	-0.177	-0.087	-0.087	-0.005	0.079	-0.302	-0.003	-0.086	-0.216
Oxalate extractable Fe	-0.039	0.114	-0.205	-0.066	0.171	0.018	-0.029	-0.046	-0.215	0.036	-0.036	-0.046
Oxalate extractable Al	-0.299	-0.301	-0.043	0.150	-0.138	0.227	-0.159	0.021	-0.152	-0.259	-0.003	-0.167

(r=0.471*).

Higher soil pH at 50% silking resulted in higher grain yields (r=0.482*). Soil pH at silking also correlated positively with Ca and Mg (r=0.477* and r=0.449* respectively), and negatively with K (r=-0.692**) concentrations of index leaves. This further confirms the existence of K/Mg and K/Ca imbalance at lower pH (unlimed plots) with K causing reduction in Ca and Mg uptake. Available P concentration of the soil at silking correlated positively with Fe, Al and Cu concentrations of the index leaves (r=0.580**, r=0.460* and r=0.744** respectively).

The concentration of Zn in the index leaves at 50% silking was negatively correlated with concentrations CBD extractable of Mn and Al oxides in the soil at the beginning of the season (r=-0.449* and r=-0.461* respectively).

CHAPTER FIVE

SUMMARY AND CONCLUSION

Phosphorus deficiency is a major factor limiting food production in Nigeria, particularly under acidic soil conditions. At present, the successful production of high nutrient requiring crops such as maize is only possible with the use of inorganic phosphate fertilizers. The present economic realities in Nigeria, however, place the cost of adequate inorganic fertilizers beyond the means of the peasant farmer. This study was an approach initiated to explore the potentials of cover crops in improving the P nutrition of succeeding food crop (maize) in a rotation. The strategy was to increase P recovery from less accesible forms using crop and forage species and cultivars that more effectively take up P, and to integrate these P efficient species and cultivars into crop production systems to promote a more effective recycling of P.

Field trials were conducted on-station on two fields located at Samaru (11°11'N, 7°38'E) and one field at Heipang (9°38'N, 8°53'E) to eveluate the response of various cover crops and maize to native and applied P (SSP and SPR), and to evaluate the effects of these treatments on the performance

and P nutrition of succeeding maize in rotation.

The soil of Samaru was classified according to the USDA soil taxonomy system as Kanhaplic Haplustalf while that of Heipang was classified as Typic Plinthustult. The two soils differed widely in their phosphate properties. Samaru soil had considerably lower P sorption capacity, higher concentrations of available P (6.04 - 9.86 mg Kg^{-1}), lower total P content (154 - 196 mg Kg^{-1}), and lower contents of free Fe, Al and Mn oxides (7 -10, 0.8 - 1.1 and 0.1 g Kg^{-1} respectively) compared to Heipang soil which had available P concentration of about 0.69 mg Kg^{-1}, 473 mg Kg^{-1} total P and 61.8, 7.5 and 0.4 g Kg^{-1} Fe, Al and Mn oxide concentrations respectively.

Growth patterns of the various cover crops varied. At all periods of growth *C. ochroleuca* produced by far the greatest amounts of above ground biomass while *P. vulgaris* (b) and *C. ternatea* produced the least. The cover crops with higher biomass production also had lower tissue P concentrations and, therefore, higher phosphate use efficiencies.

Intercropping *Chamaecrista rotundifolia* and *Cajanus cajan* with maize had no significant effects on maize performance even on P deficient soil of Heipang.

At Samaru, the two varieties of *L. purpureus*, *M.pruriens*, and *C. rotundifolia* all improved the yields of succeeding maize in the first year after cover cropping by more than 50%, and this yield increase was in part due to P effect. The positive effect of these crops on yields of succeeding maize did not manifest in the second year after cover cropping. On the very high P fixing soil of Heipang, only *C. rotundifolia* produced consistent significant improvement in the performance of succeeding maize in terms of height and stover yield.

The positive effects of Sokoto phosphate rock on maize yields and available soil P at Samaru manifested only in the third year of cropping when the soil P was sufficiently depleted (< 5.0 mg Kg^{-1}) to force the dissolution of phosphate rock. At Heipang, on the other hand, where the available soil P was extremely low (< 1 mg Kg^{-1}), the possitive effect of Sokoto phosphate rock on maize yield manifested in both years of cropping.

Application of 30 Kg P ha^{-1} in form of single superphosphate to Samaru soils was suficient for the growth of maize. While at Heipang even the application of 60 Kg P ha^{-1} did not produce maximum maize yield. Liming Heipang soil increased the total P uptake by grains but did not affect grain yield.

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At Heipang, *C. rotundifolia*, *M. pruriens* (w), *P. vulgaris* (b), and *Z. mays* + *C. rotundifolia* improved the Mg of leaf tissue of succeeding. The Al contents of maize index leaves were reduced by more than 38% as a result of previous cropping of *C. rotundifolia*, *Z. mays* + *C. rotundifolia*, *M. pruriens* (w), and *L. purpureus* (w). Liming Heipang soil raised the leaf tissue Ca and Mg contents of succeeding maize in 1997.

None of the cover crops was able to produce significant reductions in the concentrations of crystalline and amorphous oxides of Fe, Al and Mn at both samaru and Heipang. The application of lime at Heipang in 1996 did not also affect the concentrations of these oxides.

Lime application at the rate of 1.35 Mg CaO ha^{-1} to Heipang soil in 1997 significantly raised soil pH but did not improve the available soil P.

Future studies should focus on screening more cover crops, particularly at Heipang, for their P efficiency and tolerance to acidic conditions so as to come up with cover crops that could be integrated into the cropping system of the area with a view to improving P recovery from less accessible soil P forms. There is also a need to establish the optimum P rate for the production of maize at Heipang.

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Profile 1
General site description

Location:	Samaru, Zaria
Taxonomic classification:	Kanhaplic Haplustalf'USDA) Haplic Lixisol(FAO/UNESCO)
Elevation:	600m
Mean annual rainfall:	1060mm
Rainy period:	160-180 days
Soil moisture regime:	Ustic
Soil temperature regime:	Isohyperthermic
Soil parent material:	Granite/gneiss
Geology:	Basement complex
Geomorphology:	Gently undulating plain
Topography:	Middle slope;level to nearly level;0-2% slope
Vegetation:	Northern guinea savanna
Land use:	Cowpea
Erosion hazards:	None
Drainage:	Imperfectly drained
Surface characteristics:	No special features
Depth to impenetrable layer:	None at 160cm
Depth to water table:	Not encountered
Described by:	T.Kparmwang and J.M.Jibrin
Date:	October 20, 1995

Horizon	Depth(cm)	Description
Ap	0-10	Yellowish brown(10YR 5/4 moist); loam; weak medium subangular blocky structure; non sticky and non plastic (wet);friable (moist); hard (dry);common medium pores; common fine roots; clear wavy boundary
BA	10-27	Strong brown (7.5YR 5/6 moist); loam; moderate medium subangular blocky structure;sticky and plastic (wet);firm (moist);common medium pores; common fine roots; gradual smooth boundary
Bt1	27-57	Yellowish red (5YR 5/8 moist); clay; strong medium subangular blocky structure; sticky and plastic (wet); friable(moist); common coarse voids;few fine roots;common thin clay cutans on ped faces; gradual wavy boundary
Bt2	57-108	Yellowish red (5YR 5/8 moist); clay with common distinct fine red(2.5YR 4/8)mottles; strong medium subangular blocky structure;sticky and plastic(wet); friable (moist); few coarse voids;common fine roots;clear smooth boundary
Bt3	108-130	Reddish yellow (5YR 6/6 moist); clay with common distinct medium red (2.5YR 4/8)motles; strong medium subangular blocky structure; sticky and plastic(wet); friable (moist);few fine roots;clear smooth boundary
Bt4	130-160	Brownish yellow(10YR 6/6 moist) clay with many medium red (2.5YR 4/8) mottles;moderate medium subangular blocky

		structure; sticky and plastic(wet); friable(moist);few coarse voids; few very fine roots; many medium soft Fe nodules

Profile 2

General site information: As profile 1

Taxonomic classification: Kanhaplic Haplustalf (USDA)
Haplic Lixisol (FAO/UNESCO)

Depth to impenetrable layer: Petroplinthite at 171cm depth

Horizon	Depth(cm)	Description
Ap	0-15	Yellowish brown (10YR 5/6 moist)loam; structureless;massive; non sticky and non plastic(wet);very friable(moist); hard (dry);common medium pores; common fine roots; clear wavy boundary
BAp	15-34	Strong brown (7.5YR 5/8 moist) clay loam; weak coarse subangular blocky structure; sticky and plastic (wet); firm (moist); very hard (dry);common fine roots; gradual smooth boundary
Bt1	34-65	Yellowish red (5YR 5/8 moist) clay;moderate medium subangular blocky structure; sticky and plastic (wet); firm (moist);many medium pores; few coarse voids; common fine roots; gradual smooth boundary
Bt2	65-93	Yellowish red (5YR 5/8 moist) clay; weak medium subangular blocky structure; sticky and plastic (wet); friable (moist); common medium pores; few coarse voids;common fine roots; gradual smooth boundary
Bt3	93-132	Strong brown (7YR 5/8 moist) clay with common faint fine red (2.5YR 4/8) mottles; moderate medium subangular blocky structure;sticky and plastic (wet); very firm (moist); many medium pores; few fine roots; clear smooth boundary
Bt4	132-163	Yellowish red (5YR 5/8 moist) clay with common prominent medium red (2.5YR 4/8) mottles;weak subangular blocky structure; sticky and plastic (wet); firm (moist); few medium pores; few fine roots

APPENDIX 1

SOIL PROFILE CHARACTERISTICS OF ZARIA TRIAL SITE

Profile 1: Kanhaplic Haplustalf(USDA); Haplic Lixisol(FAO/UNESCO)

	Horizon and depth(cm)					
	Ap (0-10)	BA (10-27)	Bt1 (27-57)	Bt2 (57-108)	Bt3 (108-130)	Bt4 (130-160)
Clay(g Kg^{-1})	220	380	520	500	500	520
Silt "	460	380	280	280	260	280
Sand "	320	240	200	220	240	200
Textural class	Loam	Loam	Clay	Clay	Clay	Clay
pH(H_2O)	5.5	4.6	4.2	4.3	4.3	4.5
pH(0.001m $CaCl_2$)	4.5	3.7	3.6	3.7	4	4.3
Organic C (g Kg^{-1})	6.6	3.6	4	3.4	3.6	2
Total N "	0.84	0.56	0.56	0.42	0.14	0.07
Brayl P (mg Kg^{-1})	2.69	1.79	1.79	0.9	0.9	0
Exchangeable Ca (cmol Kg^{-1})	2.55	2.41	3.1	3.23	4	3.35
Mg "	1.08	1.11	1.2	1.31	1.56	1.5
K "	0.36	0.24	0.25	0.32	0.27	0.24
Na "	0.08	0.1	0.06	0.28	0.23	0.14
Exchangeable acidity "	0.4	1	1.4	1	0.8	0.6
CEC "	6	6.5	7.8	10.5	12.1	11
CEC_{clay} "	17	14	12	19	22	20
Base saturation (%)	67.8	59.4	59.1	50.0	50.1	47.6
Available Cu (mg Kg^{-1})	0.22	0.48	0.8	0.64	0.4	0.4
Zn "	2.2	1.72	0.22	1.11	2.6	2.4
Fe "	18	20	24	23.2	34	31.6
Mn "	68.25	58.61	38.44	40.42	12.75	14.71
B "	1.02	0.68	0.42	0.17	0.17	0

Profile 2:Kanhaplic Haplustalf (USDA); Haplic Lixisol (FAO/UNESCO)

	Horizon and depth (cm)					
	Ap (0-15)	BAp (15-34)	Bt1 (34-65)	Bt2 (65-93)	Bt3 (93-132)	Bt4 (132-163)
Clay (g Kg^{-1})	180	400	500	480	500	500
Silt "	400	300	260	280	260	280
Sand "	420	300	240	240	240	220
Textural class	Loam	Clayloam	Clay	Clay	Clay	Clay
pH(H_2O)	4.4	4.4	4.2	4.5	4.3	4.1
pH(0.001m $CaCl_2$)	3.9	3.4	4	4	3.7	3.5
Organic C (g Kg^{-1})	4.6	3.6	2.8	1.3	0.4	0.2
Total N "	0.7	0.56	0.28	0.28	0.14	0.07
Brayl P (mg Kg^{-1})	3.58	2.69	1.79	0.9	0.9	0.9
Exchangeable Ca (cmol Kg^{-1})	3.39	3.7	5.3	4.71	3.9	4.2
Mg "	1.25	1.4	1.33	1.9	1.3	1.56
K "	0.19	0.13	0.23	0.28	0.24	0.24
Na "	0.06	0.05	0.17	0.26	0.06	0.08
Exchangeable acidity "	0.6	0.8	0.4	1	1	1.2
CEC "	6.9	7.8	8.9	9.4	4.1	10.2
CEC_{clay} "	29	16	16	19	14	20
Base saturation (%)	78.3	67.7	79.0	76.1	77.5	59.6
Available Cu (mg Kg^{-1})	1.04	1.2	0.88	0.4	0.4	0.34
Zn "	0.72	1.11	2.72	1.54	1.68	1.34
Fe "	20	22	18	36	32	28.4
Mn "	63.25	59.3	31.75	30.6	22.6	20.4
B "	0.88	0.42	0.17	0	0	0

Profile 1

General site description

Location:	Heipang near Jos
Taxonomic classificatcn:	Typic plinthustult (USDA) Plinthic Acrisol(FAO/UNESCO)
Soil parent material:	
Geology:	Basement complex
Geomorphology and physiography:	Almost flat lying table with isolated low hills on Jos plateau
Topography:	Crested position of table land;Nearly level;0-2% slope
Vegetation:	Northern guinea savanna zone
Land use:	Maize
Erosion:	Slight sheet erosion
Drainage:	Moderately well drained
Surface characteristics:	Few scattered boulders
Depth to impenetrable layer:	Tough but penetrable plinthite as from 51 to 115cm
Depth to water table:	Not encountered within 115cm
Described by:	T. Kparmwang and J.M.Jibrin
Date:	July 1, 1997

Horizon	Depth(cm)	Description
Ap	0-10	Dark brown(7.5YR 4/4 moist);clay; moderate medium subangular blocky; sticky and plastic(wet);friable (moist);common medium pores;common very fine roots;abrupt smooth boundary.
Bt1	10-27	Strong brown (7.5YR 5/6 moist)clay with few very fine distinct dark red (2.5YR 3/6) mottles; weak coarse subangular blocky structure;sticky and plastic (wet);friable (moist); few medium pores;common fine roots;gradual smooth boundary.
Bt2	27-51	Strong brown(7.5YR 5/6 moist);clay with common medium prominent dark red (2.5YR 3/6)mottles;weak coarse subangular blocky structure;sticky and plastic (wet);friable (moist);common medium pores;common very fine roots;many Fe and Mn concretions occuring as mottles; clear wavy boundary.
Bv	51-115	Dark red (2.5YR 3/6 moist);sandy clay; moderate medium angular structure; slightly sticky and slightly plastic(wet);firm (moist); common thin clay cutans on ped faces and in pores;continuous Fe and Mn concretions.

Profile 2

General site information: As profile 1

Taxonomic classification: Typic plinthustult (USDA)
Plinthic Acrisol (FAO/UNESCO)

Horizon	Depth (cm)	Description
Ap	0-13	Dark brown (7.5YR 4/4 moist); clay; weak coarse subangular blocky structure; sticky and plastic (wet); friable (moist); common medium pores; medium fine roots; few medium termite nests; abrupt smooth boundary.
Bt	13-34	Dark brown (7.5YR 4/4 moist); clay; weak coarse subangular blocky structure; sticky and plastic (wet); friable (moist); common medium pores; common fine roots; few termite nests; gradual smooth boundary.
Bu	34-51	Yellowish brown (10YR 5/6 moist); gravelly sandy clay; with common medium distinct dark red (2.5YR 3/6) mottles; sticky and plastic (wet); very friable (moist); common medium pores; common fine roots; few medium termite nests; clear smooth boundary.
Bv	51-108	Dark red (2.5YR 3/6 moist); sandy clay; moderate medium angular blocky structure; slightly sticky and slightly plastic (wet); firm (moist); common thin clay cutans on ped faces and in pores; few medium pores; few very fine roots; decomposing rock encloesd by plinthite; common Mn concretions.

SOIL PROFILE CHARACTERISTICS OF HEIPANG TRIAL SITE

Profile1: Typic Plinthustult (USDA); Plinthic Acrisol (FAO/UNESCO)

Soil property	Horizon and depth			
	Ap (0-10cm)	Bt1 (10-27cm)	Bt2 (27-51cm)	Bv (51-115cm)
pH(H_2O)	5.4	5.4	5.6	5.7
pH(0.001m $CaCl_2$)	4.3	4.1	4.0	4.0
pH(1N KCl)	4.3	4.0	4.3	5.0
Exchangeable Ca (cmol Kg^{-1})	3.74	3.43	3.12	1.87
Mg "	1.28	1.01	0.78	0.37
K "	0.21	0.13	0.13	0.1
Na "	0.09	0.04	0.07	0.07
Exchangeable acidity "	0.9	0.8	0.9	0.6
Exchangeable Al "	0.6	0.5	0.5	0.2
CEC "	36.9	41.3	39.3	44.4
CEC_{clay} "	67.71	58.02	59.72	108.2
Base Saturation (%)	14.4	11.2	10.4	5.4
Organic C (g Kg^{-1})	12.3	8.6	6.5	3.2
Total N "	0.7	0.49	0.49	0.28
Bray-1 P (pg Kg^{-1})	0.25	0.03	0.0	0.03
Clay (g Kg^{-1})	480	660	620	400
Silt "	220	160	140	120
Sand "	300	180	240	480
Textural class	clay	clay	Clay	Sandy clay

Profile2: Typic Plinthustult(USDA); Plinthic Acrisol(FAO/UNESCO)

	Horizon and depth			
	Ap (0-13cm)	Bt (13-34cm)	Bu (34-51cm)	Bv (51-108cm)
pH (H_2O)	5.8	5.6	5.8	6.0
pH (0.001m $CaCl_2$)	4.6	4.6	5.0	4.0
pH (1N KCl)	4.7	4.4	4.6	4.5
Exchangeable Ca (cmol Kg^{-1})	4.05	3.43	3.43	3.12
Mg "	1.28	0.64	0.64	0.2
K "	0.27	0.12	0.1	0.11
Na "	0.16	0.05	0.06	0.13
Exchangeable acidity "	0.90	1.1	0.5	0.7
Exchangeable Al "	0.30	0.6	0.2	0.4
CEC "	19.6	16.4	16.3	16.4
CEC_{clay} "	35.5	24.0	37.83	43.2
Base Saturation (%)	28.9	25.9	6.0	21.7
Organic C (g Kg^{-1})	13.4	8.4	5.5	1.9
Totl N	0.63	0.49	0.35	0.28
Bray-1 P (mg Kg^{-1})	0.0	0.0	0.0	0.0
Clay (g Kg^{-1})	420	560	380	360
Silt "	300	200	20	140
Sand "	280	240	600	500
Textural class	clay	clay	Sandyclay	Sandyclay