Maria do Socorro Andrade Kato

Fire-free Land Preparation as an Alternative to Slash-and-burn Agriculture in the Bragantina Region, Eastern Amazon: Crop Performance and Phosphorus Dynamics

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Fire-free Land Preparation as an Alternative to Slash-and-burn Agriculture in the Bragantina Region, Eastern Amazon: Crop Performance and Phosphorus Dynamics

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Maria do Socorro Andrade Kato

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Nonnenstieg 8, 37075 Göttingen
Telefon: 0551-54724-0
Telefax: 0551-54724-21

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In memory of my dear father

With love and gratitude to Kato, Patricia and Victor

List of Abbreviations

EGI	efficiency grain yield index
FV4y	4-year-old fallow vegetation
FV10y	10-year-old fallow vegetation
HI	harvest index
Pi	inorganic phosphorus
Po	organic phosphorus
PEC	Physiologic efficiency of the cultivars
PEA	Agronomic efficiency of the cultivars
PUPE	phosphorus uptake efficiency
PUTE	phosphorus utilization efficiency
PHI	phosphorus harvest index
SE	standard error
*	significant (5 %)
**	significant (1 %)
***	significant (0.1 %)

1 Introduction

Shifting agriculture is probably still the most important agricultural land-use system in the Amazon. It is responsible for at least 80% of the region's total food production and is practiced by at least 500,000 small farmers, producing mainly beans, cassava, rice, corn and fruits (SERRÃO, 1995).

Small-scale production represents one of the most important aspects of the agricultural sector in the Pará State. Farms smaller than 100 ha contribute about 60% of the production of basic foodstuffs and employ about 78% of the rural labor force (DENICH, 1996).

Shifting cultivation predominates in small holding and is characterized by slashing and burning of a fallow vegetation (HOMMA, 1989) followed, in the majority of the cases, by agricultural crops involving the planting of rice, corn, cowpea and cassava. After a 2-years cropping period the land is abandoned for a fallow period of several years (in the region 3-7). In spite of criticism regarding its sustainability, expressed especially in decades past, this agricultural system has proved to be a sustainable system within a family-agriculture context and under conditions of low demographic pressure (THURSTONS, 1997; BANDY et al., 1993). The systems sustainability is closely associated with the vitality of the fallow vegetation, locally called *capoeira*.

Shifting cultivation has been considered to be one of the main activities responsible for deforestation. The areas used in this practice are generally small. According to SERRÃO (1995), the advance of deforestation could be reduced by at least 30% by merely increasing the level of sustainability of these shifting cultivation systems, employing technology which would permit an increase in the amount of time used in cultivating an area to three or more years instead of just two as practiced today.

The importance of the shifting cultivation system in northeastern Pará has been shown by CONCEIÇÃO (1990), KATO et al. (1992), DENICH AND KANASHIRO (1995) and SÁ et al. (1996), but it has not received much attention from the government. Almost nothing has been done to improve the system although its sustainability currently has been compromised. This is mainly due to an increase in population density, thereby requiring a reduction in the length of fallow periods, thus increasing the negative effects of burning (MACKENSEN et al., 1996; TINKER et al., 1996; HÖLSCHER et al., 1997a). Pressure resulting from land occupation is caused by two main processes: first, a large family requires more land to sustain itself and, second, the emergence of a group of farmers with greater capital resources and easier access to credit interested in cash crops and animal production. They take advantage of the proximity of consumer centers and existing highway infrastructure. This has caused an increase in the area dedicated to pasture and semi-perennial and perennial crops often involving mechanization in land preparation which leads to a reduction of the *capoeira* regeneration capacity (DENICH AND KANASHIRO, 1995; HONDERMANN, 1995; BILLOT, 1995).

Small farmers of the Amazon prefer to use areas with secondary vegetation due to the greater ease in land clearing. Slash burning is also preferred because 1) fields are more easily cleaned for planting and 2) because of the phyto-sanitary effect of fire as well as the immediate fertilizing effects afforded by the ashes of burned fallow vegetation biomass.

During burning, however, great loss of nutrients occurs through volatilization, constituting one of the main problems for sustaining the system. The loss of nutrients through leaching is small (HÖLSCHER et al., 1997b). Losses caused by harvest products are inevitable. This fact, associated with reduced fallow time, decreases the total nutrient stock in *capoeira* biomasss, (DENICH, 1989; HONDERMANN, 1995) and compromises the system's sustainability.

In order to replenish these losses, the use of fertilizers could be a solution. This option is, however, not viable due to the farmers low purchasing power. Another option would be to initially avoid loss by burning through better management of organic matter. Use of fallow vegetation as mulch could be an alternative to slash burning. According to SANCHEZ et al. (1989), management of organic matter is of great importance in maintaining soil productivity. Various authors (VANLAUWE et al., 1997; FERNANDES et al., 1993) have studied the use of alley cropping, the results, however, have not been very encouraging for farmers due to management difficulties. Moreover, the tree legumes utilized to produce organic matter in alley cropping systems appear to compete with the agricultural crops. Shifting cultivation has been practiced for centuries demonstrating that sequential fallow periods are easier to manage. This practice also tends to maintain the area's biodiversity (DENICH, 1989; BAAR, 1997; HONDERMANN, 1995). Consequently, optimizing the management of secondary vegetation constitutes one of the main challenges in improving the system.

One of the major questions of this thesis has been how to avoid nutrient losses through burning of above-ground *capoeira* biomass during the preparation of an area for an agricultural crop. With the simple cutting down of *capoeira* over three years old without burning, planting a crop is impracticable due to difficulties encountered in planting and crop husbandry. The other alternative would be to chop the biomass to be used as mulch and, consequently, as a source of organic matter. Few long-term studies have been carried out to evaluate the use of *capoeira* as a source of organic matter for agricultural crops. Literature is plentiful in promising studies on the use of legumes as green manure (FERNANDES et al., 1993), improved fallows (LUNA-OREA et al., 1996), crop residue (LAL, 1997a and 1997b; THOMAS et al., 1990) and the practice of direct planting (SÉGUY AND BOUZINAC, 1995).

Use of *capoeira* as a source of organic matter may be a viable alternative. DENICH (1989) and HONDERMANN (1995) have shown that a 4-year-old *capoeira* can produce an above-ground biomass of 28 t to 38 t ha^{-1}, depending on the previous land use system. Detailed studies to evaluate their effects as a source of organic matter, however, need to be carried out. In a 2-year-old *capoeira*, some farmers with capital in the region of Igarapé-Açu/Pará/Brazil have used various machines to incorporate slashed vegetation to prepare the soil for the planting of passion fruit, black pepper, and other cash crops, thereby avoiding use of fire.

How the small farmer will be able to chop biomass from a 4-year-old *capoeira* has so far been a un-resolved question. To this end, the Institute of Agriculture in the Tropic (IAT) of the University of Göttingen, in partnership with the Institute for Agricultural Engineering, also of the University of Göttingen, and EMBRAPA-Amazônia Oriental have developed a prototype of a bush-chopper to be connected to the front part of a tractor. At the moment, it is being tested in the field in Brazil. This technology, however, will not easily be adopted by an isolated small farmer and would only be economical for groups of farmers organized as an association, cooperative or other associative forms.

The objectives of this work are: 1) to evaluate the effects of land preparation methods (burning and non-burning) on crop performance and phosphorus dynamics and availability; 2) to evaluate the importance of chemical fertilizer use in systems with and without the use of fire; and 3) to select rice, maize, cowpea and cassava cultivars adapted to systems without the use of fire in land preparation.

2 Literature Review

2.1 Shifting cultivation system

Shifting cultivation is one of the most widespread cropping systems in the tropics, and it is often labeled as the most serious land use problem in the tropical world (GRANDSTAFF, 1981). Shifting cultivation is usually defined as an agricultural system in which temporary clearings are planted for a few years with annual or short-term perennial crops, and then allowed to remain fallow for a period longer than they were cropped (CHRISTANTY, 1986). Conditions that limit crop yields, such as soil fertility losses, weeds, or pest outbreaks, are overcome during the fallow time, and, after a certain number of years, the area is ready to be cleared again for cropping (SANCHEZ, 1976).

The reasons why the slash-and-burn system, an ancient method of the shifting cultivation, existed for so long in the world and became a means for the local farmer's subsistence may be described as follows: 1) it is a simple, extensive and easily operational farming pattern in which only very limited field management, labor, and very simple tools are needed; 2) burning of biomass leads to rapid increases in soil pH, exchangeable bases, effective cation exchange capacity and available P in surface soils; 3) in acid soils, ash neutralizes the levels of soluble and exchangeable Al in the soil; 4) kills weeds and pests thus controlling plant diseases. These beneficial effects of the burning for crop growth have been well explained by NYE AND GREENLAND (1960), SEUBERT et al. (1977), JUO AND LAL (1977), STROMGAARD (1984), TULAPHITAK et al. (1985), ANDRIESSE AND SCHELAAS (1987), LI YU et al. (1996) and JUO AND MANU (1996).

Shifting cultivation and related bush-fallow systems are rapidly becoming outdated because of their low productivity. These systems are characterized by low purchased off-farm inputs, low yields, and long fallow periods. With increasing population density, however, the stability of the system degenerates (SANCHEZ AND BUOL, 1975; SANCHEZ, 1976: GHUMAN AND LAL, 1991) because farmers are, out of necessity, are forced to intensively use the land for cultivation with none or few inputs.

Despite its advantages, today the slash-and-burn is being questioned due to the negative effect of burning on the atmosphere (KAUFFMAN et al., 1995; MACKENSEN et al., 1996; TINKER et al., 1996; HÖLSCHER et al., 1997a) and the risk of accidental fires that lead to great damages affecting the whole society (IPAN, 1998a; IPAN, 1998b). Several authors have emphasized the lack of soil fertility data relating to slash-and-burn agriculture. A significant portion of mineral nutrients released from burning may be lost through erosion, runoff, leaching (MACKENSEN et al., 1996), volatilisation (RAISON et al., 1985; ROMANYÀ et al., 1994: MACKENSEN et al., 1996) and removed by crops (JORDAN, 1985; VAN REULER AND JANSSEN, 1993). Thus, the total nutrient stock in the whole ecosystem gradually declines during the subsequent cycles of fallow and cropping (JUO AND MANU, 1996).

Considering these negative aspects, it was deemed necessary to seek new alternative techniques to the slash-and-burn system. Research organizations all over the world are working on the development of practices that promote soil fertility maintenance and soil conservation in shifting cultivation. Sustainable production should be based on such cultural practices, that alleviate resource/production constraints due to bio-physical and socio-economic factors. The major relevant alternative cultural practices or sub-systems that can be considered include: crop rotations including intercropping (AMADOR AND GLIESSMAN, 1991), improved fallow (WADE AND SANCHEZ, 1983; FERNANDES et al., 1993; LUNA-OREA et al., 1996), organic amendments such as crop residue, green manure, animal manure, mulches (WADE AND SANCHEZ, 1983; BALL-COELHO et al., 1993a; GEIGER et al., 1992), integration of trees and shrubs (e.g. alley cropping, FERNANDES et al., 1993), soil conservation practices and mineral fertilizers (STEINER, 1991). Such a system should make use of the recycling of nutrients, nutrient pumping by trees and bushes, nutrient addition and generation through biological nitrogen fixation and mycorrhizae as well as the addition of nutrients from external inputs.

The secondary vegetation plays a key role in maintaining the system's productivity in shifting cultivation due to the nutrient accumulation of the biomass, and these nutrients can be liberated for the following cultivation phase by the cutting of the vegetation (DENICH AND KANASHIRO, 1995). Nutrient contents of fallow vegetation in northeastern of Brazil have been reported by KAUFFMAN et al. (1995), in northeast Pará (Brazil) by DENICH (1989), in the Peruvian Amazon by SZOTT AND PALM (1996) and by JAFFRÉ (1985) in Taí, Ivory Coast. Quantity and composition of ash produced through burning have been reported by VAN

REULER AND JANSSEN (1993) in Taí, Ivory Coast, and for the Eastern Amazon by HÖLSCHER et al. (1997b) and EWEL et al. (1981). Diversity of the secondary vegetation as a function of use land intensity and soil properties have been reported by BAAR et al. (1997) in the Bragantina region of the Eastern Amazon and the use of the *capoeira* as a source of organic fertilizer by BRAZIL et al. (1986) in the northeast of Pará (Brazil).

The management of crop residues and mulches can be a strategy able to maintain and/or improve the productivity over time and the soil conditions through the supply of nutrients and thus minimizing the need for fertilizer. Some positive effects of mulches are: 1) decreases of evaporation (LAL, 1975), erosion, water runoff (NILL AND NILL, 1993; BUNCH, 1994) and soil temperature (COOK et al, 1978); 2) increase of soil organic matter content (SANCHEZ, 1976; COOK et al., 1978), soil nutrients (MORENO AND SÁNCHEZ, 1994) and crop yields over time (LAL, 1975; LAL 1997a; NILL AND NILL, 1993); 3) suppression of weed (LAL, 1975). The effects of mulches are not entirely positive, some of their potential drawbacks are as follows: 1) increase of labor costs (THURSTON, 1992) and 2) more favorable conditions for certain plant pathogens and pest (COOK et al., 1978; ABAWI AND THURSTON, 1994).

2.2 Organic matter management

The conversion from natural to managed ecosystems generally induces a substantial decrease in soil C storage. Decline in soil organic matter as a result of land management strategies, especially excessive removal of crop residues and soil disturbance, has an array of negative effects on plant productivity (AYANABA et al., 1976; LUGO AND BROWN, 1993). Land management alters the pattern of residue inputs and affects the relative proportion of soil organic matter pools in both cropped and grazed land (WOOMER et al., 1994).

The direction of change in organic matter, when soils are brought under cultivation depends upon the previous organic matter level as well as upon the cropping system (JUMA AND MCGILL, 1986). Continuous cultivation in conjunction with residue removal and tillage (FOLLET AND SCHIMEL, 1989) are known to induce a more rapid mineralisation of soil organic matter within the first few years of cultivation by disrupting macroaggregates and leading to the mineralisation of soil organic matter within aggregates (TIESSEN AND STEWART, 1983; LARSON et al., 1972).

Climatic and edaphic factors are major determinants of soil organic matter dynamics in tropical ecosystems because they influence the processes of decomposition, formation and mineralisation (ANDERSON AND FLANAGAN, 1989; LAL, 1997b). Factors operating on smaller spatial and temporal scales may, however, participate in a significant way in regulating soil organic matter dynamics.

Land clearing and cultivation induce a lower equilibrium level of soil organic matter, partly because of reduced organic inputs and removal of the harvest. Low organic matter contents may lead to severe limitations in plant growth and to the deterioration of crop land (VAN WAMBEKE, 1992). MARTINS et al. (1991) observed a 33-45% decrease in soil organic C content after 5 years of continuous cropping in a low-input agrosystem established after forest burning in Amazon. The decline in soil organic C was primarily the result of the mineralisation of 60% of the coarse fractions of soil organic matter. The method of clearing influences soil organic C (SANCHEZ et al., 1983). NYE AND GREENLAND (1960) already reported that the soil organic carbon levels decline during the cultivation phase following the burning the forest.

The effects of cultivation on the soil organic matter content of highly weathered clayey Oxisols over time is illustrated by the changes which occurred in the properties of Cerrado soils in Brazil (RESCK et al., 1991). After clearing the Cerrado, the soil organic matter content was 3.2% in the surface horizon. During the following 2 years of upland rice cultivation, it increased to about 3.9%. presumably because of the decomposition of root residue from the natural vegetation. Under continuous cultivation of soybean, soil organic matter content fell to less than 3.0%, because of a decrease in total residue inputs and an increase in microbial activities resulting from liming and fertilization. Loss of soil organic matter due to from long-term cultivation of tropical soils without residue management or green manuring, or from improper clearing of tropical lands (LAL et al., 1986), will result in highly degraded soil conditions for crop production.

Soil organic matter contributes substantially to the productivity of land as it is a source of plant nutrients and because it improves the physical conditions of the soil. However, some functions of soil organic matter in plant production can, however, be replaced by soil management practices, i.e. the use of fertilizer may correct nutrient deficiencies. Although all amendments increase cost either in capital or in labor, some systems are economically feasible in low-input agriculture. The organic matter incorporates into the soil essential elements, that may be in short supply in the soil. WOOMER AND INGRAM (1990) consider improved nutrient retention another benefit of the soil organic matter in low-input agroecosystems.

There is ample evidence that organic amendments to the soil can improve crop yield. Effects on nutrients supply can be direct (nutrients supplied by the added organic matter) or indirect (effect of the added organic matter on the availability of soil nutrients). Nutrient release and availability of organic inputs (mulch) depends on the rate of decomposition, which is controlled, in part, by temperature, moisture, soil texture, and mineralogy, as well as by the rate of application, placement, timing, and quality of the organic inputs (SANCHEZ et al., 1989; SWIFT et al., 1981).

Mineralisation of decomposing residues is a major source of plant nutrients in highly weathered soils with little inherent mineral fertility (SANCHEZ et al., 1989). The amount of organic matter in the soil is a function of the amount of plant residues returned to the soil and the rate at which those residues decompose (GREGORICH et al., 1996). In many tropical cropping systems, little or no agricultural residues are returned to the soil. This leads to a decline in soil organic matter (LAL, 1986; POST AND MANN, 1990; WOOMER et al., 1994) which frequently results in lower crop yields (LAL, 1986) or lower plant biomass productivity (WOOMER AND INGRAM, 1990).

The above-ground crop residues may provide a significant organic input and therefore can help reduce soil-C losses in cropping systems. Long-term experiments have demonstrated that, after several decades of cultivation, organic matter dynamics are largely governed by management decisions such as crop rotation, tillage intensity and nutrient application (BIEDERBECK et al., 1994; CAMPBELL et al., 1990; GLENDINING AND POWLSON, 1991). The placement of organic additions affects the physical and biological properties of the soil. This process has important consequences for the temporal and spatial availability of nutrients and the potential for nutrient loss (SANCHEZ et al., 1989). The biological environment for decomposition is quite different for organic inputs left as mulches on the soil surface than for those incorporated into the soil by tillage (HOLLAND AND COLEMAN, 1987). FELLER et al. (1987) showed that mulching on a sandy soil cultivated for 3 years with a millet/peanut rotation led to a slight increase in soil organic matter. The incorporation of crop residue provides substrate to microbial biomass, resulting in increased soil aggregation mainly through the production of mucigels and gums. The application of crop residue reduces soil erosion and bulk density (DALAL AND MAYER, 1986) and improves water conservation (LAWSON AND LAL, 1979 cited by SANCHEZ et al., 1989; LAL et al., 1980 and SANCHEZ et al., 1989).

The introduction of manure into a cropping system limits soil-C losses and maintains soil microbial biomass (SRIVASTAVA AND SINGH, 1989). BIEDERBECK et al. (1994) observed that by manipulating the timing of residue input and moisture through cropping practices, it may be possible to maintain adequate labile organic matter concentrations and improve the synchrony of mineralisation with crop requirements.

2.3 Phosphorus dynamics

Phosphorus is one of the main limiting elements for crop production. In many natural ecosystems P availability limits overall ecosystems productivity through its effect on plant production.

The P content of soils in their natural state varies considerably, depending on the nature of the parent material, degree of weathering, and extent to which P has been lost through leaching . Soils contain 100 to 3000 mg P kg^{-1}, almost entirely as orthophosphate (PO_4) (HARRISON, 1987). In general, at least 75% of the P in surface soils are found in soil organic matter. The magnitude of soil organic matter P pools emphasizes the potential importance of soil organic matter in the cycling of these elements. Phosphorus dynamics are critical to the productivity of ultisols and oxisols which are highly P-fixing and are depleted of all primary P-containing minerals (FERNANDES AND SANCHEZ, 1990).

A large proportion of the total nutrient stock in the humid tropics are in organic form and exist primarily in the biomass, litter, and soil organic matter. Since the main soil constraints in the humid tropics are chemical rather than physical, it is evident that the management or organic inputs and soil organic matter is crucial for sustaining soil productivity in the tropics.

The P cycle and plant-available P

The P cycle in soil is a dynamic system involving soils, plants, and microorganisms. Processes involved in P cycling can be inorganic or biological. Inorganic processes include physico-chemical reactions, such as precipitation/dissolution and sorption/desorption. Higher plants and microorganisms which uptake of P released during the weathering of primary and secondary minerals and the active solubilisation of soil P minerals are the initiation factors of the biological process. The inorganic P generated is then recycled via complex food chains through a series of mineralisation reactions (FROSSARD et al., 1995).

Phosphorus cycle (Figure 1) through both inorganic (Pi) and organic (Po) pools of soil, plant, microorganisms and animal in natural and agricultural systems (GIJSMAN, 1996).

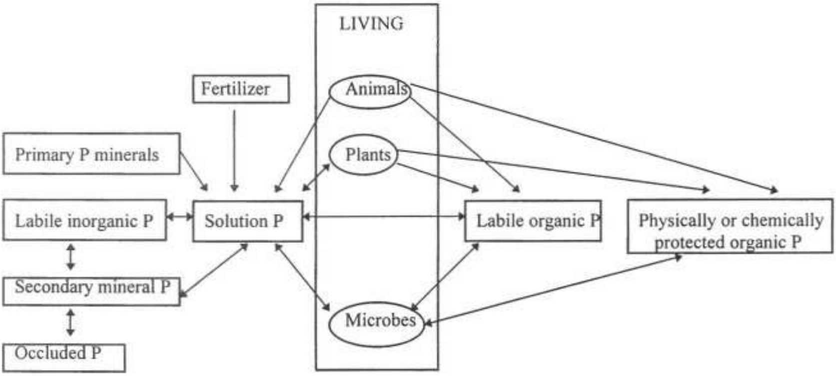

Figure 1 - A conceptual model of the P cycle in an ecosystem (after STEWART AND SHARPLEY, 1987, and TIESSEN et al., 1994a cited by GIJSMAN et al., 1996).

Soil P is shown to be in an equilibrium with a given quantity of labile inorganic P. This means that when P is taken up by the plant, or immobilized by microorganisms, additional inorganic P is solubilized. Although plants take up P exclusively in inorganic form from the soil solution (BARBER, 1984; MOREL AND PLENCHETTE, 1994), the dissolved-Pi pool satisfies plant demand for only a few hours during periods of intensive growth, even in soils with an ample P supply. The depleted solution therefore has to be replenished constantly from labile and moderately labile Pi and Po pools (GIJSMAN et al., 1996).

Inorganic P pools replenishing solution Pi conventionally estimated to use soil tests that separate Pi into an extractable (available) and a nonextractable fraction. Soil solution Pi and exchangeable Pi can both be considered as plant available, however, other less-soluble forms of Pi, associated with primary and secondary Ca, Fe, and Al minerals in the soil, may also contribute to the available pool in the longer term (GIJSMAN et al., 1996). WALKER AND SYERS (1976) suggest that the proportion of P in labile, non-labile, non-occluded, and occluded fractions should vary between soil taxa along a gradient of soil weathering intensity. In ecosystems with young, slightly weathered soils, most of the P should be found in primary minerals, such as hydroxyapatite. In ecosystems with a moderate weathering regime, most of the P should be found in organic compounds or adsorbed to secondary clay minerals. And, finally, in ecosystems with highly weathered soils, most of the P should be in the non-labile, occluded, or stable organic forms.

CROSS AND SCHLESINGER (1995) suggested that the dominant processes that regulate the soil P cycle are the geochemical reactions. Within the labile pool (resin- and $NaHCO_3$- extractable P), the percentage held in organic form ($NaHCO_3$-Po) increases with soil weathering, indicating an increasing importance of organic P as a source for plant available P with soil age. Data from fractionation by HEDLEY et al. (1982a) support the ideas of WALKER AND SYERS (1976) and STEWART AND TIESSEN (1987) that the pool of primary phosphate declines and the stable organic pool increases during soil development. P moves from the labile pools into the non-occluded and occluded pools.

Solution Pi can also be replenished by biological and biochemical mineralisation of Po. Biological processes regulate the movement and distribution of labile forms of P, and organic P recycling is important for the availability of soil P (STEWART AND TIESSEN, 1987). The biological portion of the P cycle is controlled primarily by bacterial and fungal decomposition, immobilization, and mineralisation, and secondarily via plant uptake (WOOD et al., 1984; JURINAK et al., 1986; BOLAN, 1991). Rates of plant litter decomposition depend, among other substrate quality parameters, on the C/P ratios (MCGILL AND COLE, 1981). Microbial immobilization and mineralisation of P varies depending on P availability (HARRISON 1982).

The microbial biomass is the active part of the soil organic matter, contributing to the maintenance of soil fertility and soil quality and controlling key processes in soil (TURCO et al., 1994). The microorganisms represent 60-80% of the living components of total soil organic matter (SMITH et al., 1993). The importance of the microbial biomass nutrient pool is further magnified by its more rapid turnover compared to total soil organic matter. Thus, it constitutes a large part of the active fraction (DUXBURY et al., 1989), and comprises about 2-3% of the total organic carbon in soil (BROOKES et al., 1982). It is therefore a more important repository of plant nutrients than its small size might indicate and is a key site for mineralisation of organic P in soils (JENKINSON AND LADD, 1981). Next to N, P is the most abundant nutrient contained in microbial tissue, making up as much as 2% of the dry weight. Mainly for this reason, P is the second most abundant nutrient in soil organic matter (STEVENSON AND ELLIOT, 1989).

Since the soil microbial biomass responds much more rapidly than soil organic matter as a whole to changes in management and climate it has been proposed as an indicator of the state and changes of total soil organic matter (WICK, 1997; POWLSON, 1994). CHAUHAN et al. (1981) shows that the total content of P in microbial biomass was affected only slightly by the addition of organic residue and/or fertilizer P to a soil with a high available-P status. The author reports that the continued addition of cellulose without P for a longer period of time would exhaust the reserve of labile Pi and leave the microbial population dependent on the mineralisation rate of the Po forms. SRIVASTAVA AND SINGH (1989) report that about 96% of the variability in microbial biomass in dry tropical ecosystems could be explained by the variability in soil microbial biomass. SRIVASTAVA (1992) reports that soils with a relatively high organic matter input usually develop a larger microbial biomass.

Additions of fertilizer P could lead to increased soil organic P through net immobilization. Generally, net immobilization of P occurs when the C/P ratios of crop residues are 300 or more; net mineralisation of organic P occurs when the ratio is 200 or less (STEVENSON, 1986). Large C returns to soil in crop residues could be expected to increase soil organic P (ZHANG AND MACKENZIE, 1996).

In the temperate zone, Po mineralisation makes only a minor contribution to plant-available Pi for crops within a single growing season (FARDEAU, 1993), but in perennial plants and natural ecosystems it is necessary to consider P cycling rather than the size of the available- Pi pool

(TIESSEN AND MOIR, 1993). Under tropical conditions, Po contributes significantly to crop P uptake (ADEPETU AND COREY, 1976) and plays a major role in the short-term P fertility of highly weathered tropical soils (TIESSEN et al., 1992; BALL-COELHO et al., 1993).

Characterization of the soil's Pi and Po pools is fundamental to improving the understanding of P cycling in plant-soil systems. The sequential P extraction method developed by HEDLEY et al (1982a) currently forms the basis to estimate the labile and stable forms of Pi and Po, using a series of increasingly aggressive extractants. Forms of Pi extracted are, respectively, Pi in equilibrium with the soil solution, Pi associated with the surface of sesquioxides or carbonates, Pi associated with Fe and Al compounds (WILLIANS et al., 1980), and Ca-bound Pi, including primary-mineral P (WILLIANS et al., 1971). Organic P in these extracts ranges from easily mineralizable Po in the H_2O and $NaHCO_3$ extracts (BOWMAN AND COLE, 1978) to more stable Po forms in the NaOH extract, thought to be involved in long-term transformations in temperate soils (BATSULA AND KRIVONOSOVA, 1973) but undergoing seasonal transformations in tropical soils (BALL-COELHO et al., 1993). The final hot-HCl step (TIESSEN AND MOIR, 1993) extracts most of the remaining P (approximately 20 to 60% of total P), including Po associated with particulate organic matter which may participate in short-term transformations (TIESSEN, 1993; OBERSON et al., 1996). Comparing the P compositions of different soils, each of these extracts was empirically assigned a role in natural P transformations associated with microbial uptake (HEDLEY et al., 1982a), plant roots (HEDLEY et al., 1982b), cultivation (TIESSEN et al., 1983), or soil development (TIESSEN et al., 1984). This rather empirical sequential-extraction method is currently the only moderately successful approach for evaluating available Pi as well as Po, although the nature of the extractable Po pools is even less well defined than that of the Pi pools (TIESSEN et al., 1994b). TIESSEN (1993) reports on the difficulty to assign specific roles in soil P transformations to chemically extracted Po fractions, because Po turnover frequently depends on the mineralisation of organic matter during which P is released as a side product.

This procedure showed marked differences in P-fraction changes between fertilized and non fertilized plots over the five years of the experiment. Inadequate fertilizer P may deplete Po more than Pi, and, in fertilized plots, Pi fraction increased and the Po fraction was not depleted. As a result, ZHANG AND MACKENZIE (1996) conclude that $NaHCO_3$-Pi and NaOH-Pi appeared to a very important factor for the assessment of soil fertility changes in soils which are fertilized over long period of time. BECK AND SANCHEZ (1994) using a similar procedure, found that organic P was the primary source of plant-available P in a non-fertilized Typic Paleudult soil in Peru.

When P availability is decreased, less C and N can be retained by the ecosystem (COLE AND HEIL, 1981) suggesting that long-term soil fertility can be improved by conserving P. It is necessary to understand the short-term P dynamics associated with primary production and crop residue decomposition as well as the long-term P dynamics occurring during pedogenesis in soil, to develop management strategies that maintain or improve long-term productivity and soil condition while maximizing organic P inputs and minimizing fertilizer P inputs.

Investigators have studied the effect of residue placement on P distribution (BECK AND SANCHEZ, 1994; HUFFMAN et al., 1996), P fertility (HUFFMAN et al., 1996; ZHANG AND MACKENZIE, 1997), P leaching (MACKENSEN et al., 1996), and P mineralisation (SHARPLEY AND SMITH, 1989) and shown that P distribution increased when crop residues were allowed to decompose on the soil surface rather than being incorporated. HUFFMAN et al. (1996) reports, that the effect of residue additions and placement depends on the level of nutrients at the time when the residue is added to the soil.

2.4 Selection of cultivars suitable for slash-and-mulch systems

Plant breeding has played an important role in the tropics. During the past decade considerable progress has been made in developing crop cultivars for specific environments. For example, there are now salt, adverse-water, and acid tolerant rice cultivars for areas which suffer from these problems. There are also drought tolerant maize cultivars and tailor-made versions for specific length-of-seasons (BEETS, 1990).

Acids soils cover approximately 30% of the total ice-free land area or about 3,950 million hectares of the earth's surface (SALAZAR et al., 1997). About 49% of the total potentially arable land in the world is considered to have acidic soils - 64% of tropical South America, 32% of tropical Asia, and 10% of Central America, Caribbean and Mexico (SANCHEZ, 1977). Acid soils of the tropics represent the largest pool of potential land for future agricultural development (VON UEXKULL AND MUTERT, 1995). For example, between eight (PANDEY AND GARDNER, 1992) and 26 (VON UEXKULL AND MUTERT, 1995) million hectares of maize are planted on acidic soils and achieve low yields. Plant growth limiting factors in acid soils include deficiencies (N, P, Ca, Mg, Mo, Zn; BREWBAKER, 1985) and toxicities (Al, Fe, Mn, H) of elements. The efficiency of added fertilizers (N,P,K) is very low in acid soils. The integrated plant nutrient management system is important to improve crop yield potentials in acid, infertile soils.

Genetic variation which a higher tolerance to soil acidity have been reported for maize (BAHÍA FILHO et al., 1997; PANDEY et al., 1994; MIRANDA et al., 1984; DUQUE-VARGAS et al., 1994; LIMA et al., 1992; KASIM et al.,1990), upland rice (BALIGAR AND FAGERIA, 1997; GUPTA AND TOOLE, 1986; RANGEL et al., 1986), cassava (WHYTE, 1987; BUENO et al., 1986) and cowpea (SILVA et al., 1986).

Genotypie improvements of rice, maize, cowpea and cassava for the humid tropics are directed mainly to the selection of disease resistant cultivars adapted to acid soils and, more recently, to low soil fertility, especially with regard to phosphorus.

The amounts of phosphates removed by tropical crops vary by a wide margin limits, depending on the crop and even the crop cultivars concerned, as well as the soil, the climate, and the yield level. The fact that different cultivars of the same crop may differ considerably in their phosphorus needs can be taken asconsidered to be an advantage for the screening of cultivars with respect to their tolerance of low phosphate soils (AHN, 1993). Responses to phosphatic fertilizers in the tropics are very widespread, both with traditional farming and with more intensive systems.

In Brazil, most research for the improvement of rice cultivars cultivars is done at the Instituto Agronômico de Campinas-IAC in São Paulo and at EMBRAPA-Arroz e Feijão in Goiânia, for cowpea at EMBRAPA-Meio Norte in Teresina, for maize at EMBRAPA-Milho e Sorgo in Sete Lagoas, Minas Gerais, and for cassava at EMBRAPA-Mandioca e Fruticultura in Cruz das Almas, Bahia. In Colombia, research is conducted at the Centro Internacional de Agricultura Tropical - CIAT (Cali) for rice and cassava and, in Mexico, at the Centro Internacional de Mejoramento de Maiz y Trigo-CIMMYT. Most of these national institutions focus their research on varietal selections at the advanced germplasm stage and are trying to solve national or regional problems.

With the perspective of using an alternative land preparation method without the use of fire, selection of cultivars adapted to acid soils with low available nutrient levels is necessary. But, there is little information to be found on varietal adaptation to slash-and-mulch systems.

Development of cultivars for these systems has not been high on the list of priorities for plant breeders. SMITH (1994), however, reviewed the available literature and used the information on varietal performance from other agricultural production systems to speculate on the potential for genetic improvement which might increase the productivity of slash-and-mulch systems. Most of the cultivars developed for slash-and-mulch systems have been landraces developed over centuries or millennia by traditional farmers. The maize cultivar chococito or chococeño, for example, used in slash-and-mulch systems on the western coast of South America from Ecuador to Panama (THURSTON, 1997).

One of the few slash-and-mulch systems in which cultivar evaluations have been made is the *frijol tapado* or covered beans systems used in Central America. Cultivars utilized in these systems are highly competitive with weeds (DE LA CRUZ, 1994). Bean cultivars are classified as indeterminate prostrate or indeterminate climbing. In the early 1980's a collaborative project between CIAT and several organizations in Costa Rica released two new cultivars (Talamanca 1 and Brunca) for Costa Rica (PACHICO AND BORBON, 1987; SMITH, 1994). Characteristics of the bean cultivar adapted to *frijol tapado* differed in important properties from those improved cultivars adapted to row planting systems (SMITH, 1994; THURSTON, 1994).

In the Bragantina region, rice (*Oryza sativa* L.) can be grown in *várzeas* areas. Rice, however, is usually grown in upland areas. Yields currently obtained by small farmers are generally low (635 kg ha^{-1}; IBGE, 1997), mainly due to the use of low yielding cultivars, the use of inadequate or no fertilizer et all as well as inadequate disease and weed control. Planting is done amongst stumps and is often associated with maize and cassava.

In Brazil, upland-rice breeding programs focus on drought, soil problems (P and Zn deficiency, Al toxicity) disease and pests as well as problems such as lodging, growth duration and shattering. Most Brazilian upland cultivars were developed at IAC. The EMBRAPA Arroz e Feijão germplasm bank has collected more than 800 traditional Brazilian upland rice cultivars (GUPTA AND TOOLE, 1986). In Colombia, CIAT has identified about 640 suitable cultivars.

In selecting cultivars for the northeast of Pará, EMBRAPA Amazônia Oriental, takes a certain level of technology, such as plowing and harrowing in land preparation and use of fertilizers (NPK) for granted, as well as, the use of fire to prepare the area. The selection of new germplasm adapted to the slash-and-mulch system is necessary since cultivar selection for this crop system does not exist in the region.

Research with rice cultivars developed for slash-and-burn by research centers in the northern region of Brazil has made it possible to recommend the cultivars IAC 47, IAC 125, IAC 164 and IAC 165 (RANGEL et al., 1986). Currently, the Xingú, CNA 6226, CNA 6224 and CNA 4216 cultivars, with yields between 1.5 to 1.9 t ha^{-1} (LOPES et al., 1991), have shown the best results in the slash-and-burn planting system in low fertility soils. At the moment, the Xingú cultivar is the most widely used cultivar amongst farmers in the Pará State.

Maize (*Zea mays* L.) is an important component in the production systems of small farmers who practice slash-and-burn in the northeast of Pará. In general, it is planted in intercropping with cassava (KATO et al., 1991) with production destined mainly for animal consumption (PEREIRA NETO, 1986; KATO et al., 1991). According to official data from the Fundação Instituto Brasileiro de Geografia e Estatística (IBGE, 1997), yields for maize in the Pará State are around 1.5 t ha^{-1}, the average yield for the municipality of Igarapé Açu is, however, only 0.7 t ha^{-1}. This low level of productivity may be associated with the naturally low fertility of the soil, reduced fallow periods, low technological levels and use of low yielding cultivars, especially the use of the local cultivar known as 'Pontinha' (KATO et al., 1991). In spite of the EMBRAPA recommendations to use high yielding cultivars (GAMA AND GARCIA, 1986; EMBRAPA, 1987; SOUZA AND BOTELHO, 1987), new cultivars have not been well accepted by small farmers because some of their characteristics, such as big grain size, do not meet their needs. The maize mainly serves as chicken-feed and the chickens have problems swallowing big grains (KATO et al., 1991). More recently, progress has been made in the selection of genotypes adapted to acid soils (GRANADOS et al., 1993; DUQUE-VARGAS et al., 1994; PANDEY et al., 1994; PANDEY, et al., 1995; BAHIA FILHO et al., 1997).

Cowpea (*Vigna unguiculata* L.) is a high-protein grain for human consumption in the tropics (TIMSINA et al., 1994) and constitutes a alternative crop due to its capacity to grow in naturally acid, low fertility soils (WATT et al., 1985) and in an environment with high relatively humidity. In addition, it is resistant to diseases and pests, especially a disease known as *mela* caused by the fungus *Thanatephorus cucumeris,* which prohibits the cultivation of the common bean (*Phaseolus vulgaris* L.) in the northeast of Pará (SARTORATO AND ZIMMERMANN, 1986). Cowpea is adapted to the regional conditions (SARTORATO AND

ZIMMERMANN, 1986; SILVA et al., 1986), and is normally planted right after the cereal crops (rice and maize) during the transition of the rainy to the dry season, as a single crop or intercropped with cassava.

Research activities with cowpea in this region are aimed at identifying and adapting new cultivars to increased yields and resistance to pests and diseases. Studies made between 1968 and 1974 by the Instituto de Pesquisa e Experimentação Agropecuária do Norte (IPEAN), presently EMBRAPA Amazônia Oriental, on the behavior of cowpea cultivars have evaluated them in relation to their performance and their adaptation to different environments (OLIVEIRA et al., 1980). Subsequently, in 1981, the cultivars known as '40 dias' and 'Vagem Roxa' were selected with yields of 1.1 t ha^{-1} and 'V-5 PE' with 1.8 t ha^{-1}. Currently, the cultivars BR-3 and BR-2, with yields between 1.0 and 2.3 t ha^{-1} are the most promising, both in relation to their capacity for adaptation and yield (SILVA et al., 1986), and are recommended by EMBRAPA Amazonia Oriental (SILVA, 1989). Today, they are grown in the majority of the micro-regions of the State of Pará (SILVA et al., 1986; SILVA, 1989; SILVA et al., 1991).

The cassava crop (*Manihot esculenta* Crantz) constitutes the main and most important component of various systems adopted by small farmers in the northeast of Pará. Interest in cassava is associated with various aspects, such as robustness, reasonable yields (even in low fertility soils), capacity for staggered yield, in addition to its multiple utilization in human nutrition. For many subsistence farmers, cassava is a "security crop", which will produce even when other crops fail. Cassava is also considered to be a financial reserve and, whenever the need arises for cash, it is harvested and transformed into *farinha* (cassava meal) for sale.

The cassava root yield is considered to be low (10 t ha^{-1}) and factors which contribute to this are: 1) the planting of a great number of cultivars, some of low yield potential, in the same field, 2) root rot caused by the fungi *Phytophthora drechsleri* and *Phytophthora nicotiana* (CARDOSO, 1989; POLTRONIERI et al., 1993).

Cassava improvement programs were begun in 1946 in the north of Brazil when the first introductions were made by the now extinct Instituto Agronomico do Norte (IAN). Once EMBRAPA was created and, especially, EMBRAPA Mandioca e Fruticultura, the majority of the work focused on higher yields, as well as at the root's starch contents and resistance to pests and diseases. More than 3,000 clones and cultivars have emerged from the experimental fields of EMBRAPA Mandioca e Fruticultura for testing in different site conditions. In CIAT, the germplasm bank has, since 1982, collected more than 1,500 cultivars and breeding lines, and many cultivars with a high level of adaptation to low P have been identified (PORTO, 1986; CIAT, 1992; PELLET et al., 1993).

After various years of evaluating cultivars in the State of Pará, it has been determined that the cultivars Mameluca, Jurara, Tataruaia, Pretinha and Pai Lourenço were the most outstanding in the region, with high root yields (above 20 t ha^{-1}) and starch content (BUENO et al., 1986). For the northeast of Pará, the cultivars Amarela, Peruana, IM 186, Itapuia and IM 280 show currently a tolerance to root-rot (CARDOSO, 1991).

3 Material and Methods

3.1 Description of the study site

3.1.1 Location

The municipality of Igarapé Açu is located east of Belém (Bragantina region, Pará State, Brazil) between 0° 55' and 1° 20' S and 47° 20' and 47° 50' W (Figure 2). It covers a geographic area of 783 km^2, and has a population of 27,307 inhabitants (53 % in rural areas) and a demographic density of 34.8 inhabitants/km^2 (IBGE, 1991). The experiments were installed in the community of Cumaru which is located between 1° 11' S and 47° 34' W.

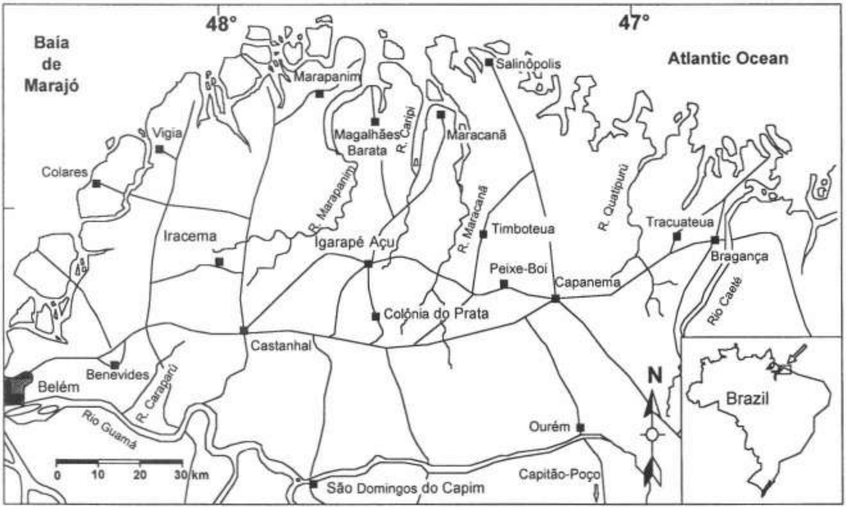

Figure 2 - Map of the northeast of Pará State

3.1.2 Climate

Average annual rainfall in the region is approximately 2,500 mm, with seasonal variations. The months of greater and lesser rainfall are March to April, and September to November, respectively (Figure 3). Monthly variations in the mean temperature range between 25.5°C and 26.8°C and the relative humidity is between 80% and 89% (Source: DNAEE).

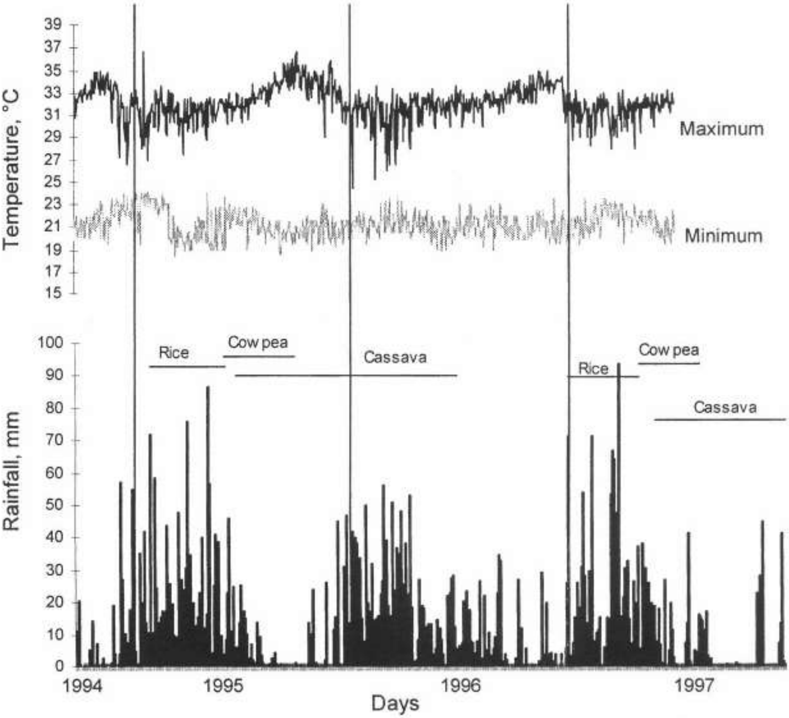

Figure 3 - Rainfall and maximum and minimum temperature during the study period of October 94 to December 97. Source: Laboratory of agricultural climatology of EMBRAPA Amazônia Oriental.

During the period in which the experiments were conducted, data relative to rainfall, and maximum and minimum temperatures were collected in the meteorological station at km 7 of

During the period in which the experiments were conducted, data relative to rainfall, and maximum and minimum temperatures were collected in the meteorological station at km 7 of the Ramal do Prata (Figure 3) which is located approximately 3 km from the experimental area.

3.1.3 Vegetation cover

The potential zonal vegetation of the municipality of Igarapé Acu is an evergreen Amazonian forest. The majority of the vegetation types of the region - primary upland forest, *várzea*, and *igapó* forest, as well as flooded grasslands - occur very sparsely at present, and are limited to only a few locations. Today, the region has an agricultural landscape and the vegetation cover is dominated by cropped fields which alternate with secondary vegetation (*capoeira*), due to slash-and-burn farming. In the rural properties of Igarapé Acu more than half of the area is occupied by *capoeira* (16% up to 4 years old and 50% more than 4 years old), whereas the forests (natural and planted) occupy only 7.5% of the usable area (DENICH AND KANASHIRO, 1993). In the municipality, small farmers account for 86% of the agricultural area and small holders hold 97 % of the farm properties.

3.1.4 Soil

3.1.4.1 Morphological description

Recent upland soils of the region developed during the Tertiary and Quarternary Period from fresh water continental sediments. These sediments were produced by meteorization of granite, gneiss and sandstone of the Guyanese and Brazilian Shield, deposited during the Pliocene and Pleistocene Period in the landscape of Central Amazon rivers and lakes. Due to the characteristics of the original material and by virtue of leaching processes, the sediments are extremely oligotrophic, giving rise to soils with a low nutrient supply (DENICH, 1989).

According to the exploratory survey of the RADAMBRASIL Project (1973), the predominant soil in the region is medium-textured, yellow Latosol (Oxisol). In the experimental areas, two profiles were opened to describe the soil. According to the Brazilian classification, (FALESI, personal communication) described the soil of the FV4y (4-year-old fallow vegetation) area and classified it as quartzose sand (Entisol), well drained, with very few micropores in the Ap (0-7cm) and AB (7-15cm) horizons. The soil of the FV10y (10-year-old fallow vegetation) area was classified as well drained yellow Latosol (Oxisol) with a predominance of sand up to a depth of 19 cm and, subsequently, a prevalence of sandy clay.

3.1.4.2 Physical description

In order to evaluated soil texture, samples were collected in the aforementioned profiles. Results show that the FV4y soil had a higher fine-sand content and a lower total clay content, while the FV10y soil is characterized by a greater clay content (Table 1).

Table 1 - Sand (coarse and fine), silt and clay (total and water dispersed) contents of soil in the experimental areas (FV4y and FV10y) at various depths

Depth	Coarse sand	Find sand	Silt	Total clay	Clay in water-dispersed
[cm]	-------------------------------		[%]	-------------------------------	
FV4y					
0 – 7	71	21	4	4	0
7 – 15	66	26	4	4	0
15 – 29	56	27	11	6	0
29 – 61	50	28	10	12	2
61 – 96	52	26	10	12	2
96 – 150	48	28	10	14	2
FV10y					
0 – 7	71	18	7	4	0
7 – 19	65	17	10	8	0
19 – 45	55	16	11	18	10
45 – 70	49	14	9	28	14
70 – 110	49	12	9	30	22
110 – 150	45	14	9	32	16

Six profiles measuring 0.50m x 0.50cm x 0.50cm were opened in the experimental areas to determine the soil's bulk density, porosity and water retention capacity. Using the core method, samples were taken for analysis from each profile at depths of 0 – 10cm, 10 – 20cm, 20 – 30cm and 30 – 50cm (BLAKE AND HARTGE, 1986).

Due to variations in sand and clay contents in the two soils under study, the FV4y area was found to have a higher macro-porosity than the FV10y area, whereas the opposite was true in relation to micro-porosity and, for this reason, the water retention rate is different in the two areas, with FV10y having a greater capacity for moisture retention (Table 2).

Table 2 - Water content, bulk density and porosity of the soil in the experimental areas (FV4y and FV10y) at various depths

Depth	Water content [%]					Bulk	Porosity		
[cm]	Tensions [kPa]					density	Total	Macro	Micro
	6	10	30	100	1500	[kg dm^{-3}]	------[m^3 m^{-3}]------		
FV4y									
0 - 10	14	10	8	7	4	1.26	53	39	14
10 – 20	17	12	9	7	4	1.38	47	30	17
20 – 30	18	15	11	8	5	1.47	44	25	19
30 – 50	19	15	11	9	6	1.43	45	26	19
FV10y									
0 - 10	16	13	12	11	4	1.21	52	36	16
10 – 20	21	18	15	13	7	1.46	43	22	21
20 – 30	24	22	19	18	12	1.55	40	16	24
30 – 50	27	25	23	21	16	1.50	43	16	27

3.1.4.3 Chemical description

With the aid of a soil-core sampler, 6 compound samples, each one comprising of 10 sub-samples, were taken in the *capoeira* area before clearing was begun at depths of 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, and 30 – 50 cm. Samples were air dried and subsequently sieved (2mm mesh size), then stored for later chemical analysis.

Soil pH was determined in water (1:2.5); total nitrogen by combustion in a Carlo Erba autoanalyzer, available phosphorus and potassium extracted with a Mehlich I solution (HCl + H_2SO_4). Phosphorus was determined by colorimetry and K by flame photometry. Exchangeable aluminum, calcium and magnesium extracted with a 1N KC1 solution. Al was determined by titration with NaOH (0.lN), and Ca and Mg by atomic absorption spectrophotometry. Mineral N (N_{min}) was determined by the micro-Kjehldal method described by KEENEY AND NELSON (1982).

Chemical characteristics of the soil in the two experimental areas (Table 3) did not show great variation in nutrient contents, except N_{min} (mineral-N) which, in FV10y, was 83 mg kg^{-1} (0-10 cm), whereas in FV4y, it was 53 mg kg^{-1} (0-10 cm).

Table 3 - Average values for pH, content of N (total and mineral), P, K, Ca, Mg, Al, C_{total} and C/N ratio the soils in the experimental areas (FV4y and FV10y) at various depth

Depth [cm]	pH	N_{total} [%]	N_{min}	P	K	Ca	Mg	Al	C_{total} [%]	C/N
			-----[mg kg^{-1}]-----			-----[cmol kg^{-1}]-----				
FV4y										
0 – 10	5.2	0.07	53	3.0	15	0.8	0.4	0.2	1.07	15.3
10 – 20	5.1	0.04	52	1.5	9	0.4	0.2	0.4	0.58	14.5
20 – 30	5.2	0.04	53	1.1	8	0.3	0.2	0.4	0.59	14.7
30 – 50	5.3	0.03	48	0.1	7	0.3	0.2	0.4	0.51	17.0
FV10y										
0 – 10	5.1	0.07	83	2	21	0.7	0.4	0.2	0.99	14.2
10 – 20	5.1	0.06	n.d.	1	16	0.7	0.2	0.4	0.81	13.4
20 – 30	5.2	0.05	n.d.	0.1	10	0.3	0.2	0.5	0.72	13.1
30 – 50	5.1	0.04	n.d.	0.1	7	0.3	0.2	0.6	0.58	14.5

n.d. - not determined

3.2 Land preparation experiment

3.2.1 Aboveground biomass of fallow vegetation

Studies were conducted on two neighboring sites with 4-year-old (FV4y) and 10-year-old secondary vegetation (FV10y). Before cropping, aboveground plant biomass of the secondary vegetation was evaluated in 10 plots of 10 m^2 each, distributed in 3 transects. For litter the area was $0.25m^2$ (n =10). Dry weight was obtained separately for leaves, wood and litter. Aboveground plant biomass in the FV4y stand, measured before slashing, was 24 t ha^{-1}, of which 21% were leaves, 62% woody material and 17% litter. Figures for FV10y were 59 t ha^{-1}, with 13% leaves, 74% wood and 13% litter (Table 4). Except for the P stock which did not change with the amount of biomass accumulated (Table 4), stock of N, K, Ca and Mg in FV10y were more than double that of FV4y, reflecting the amount of biomass.

Table 4 - Dry matter of aboveground biomass and nutrient stocks of the 4-year-old and 10-year- old fallow vegetation on the experimental areas (FV4y and FV10y)

	Biomass [t ha^{-1}]	N	P	K [kg ha^{-1}]	Ca	Mg
FV4y						
Leaves[1]	5 (±0.42)	57 (±15.6)	3 (±0.1)	26 (±5.0)	48 (±8.3)	14 (±2.6)
Wood	15 (±2.5)	52 (±6.8)	4 (±0.5)	41 (±6.1)	57 (±10.5)	18 (±3.2)
Litter[2]	4 (±0.18)	34 (±3.4)	2 (±0.4)	5 (±0.4)	45 (±0.8)	10 (±1.4)
Total	**24** (±2.6)	**143** (±10.6)	**9** (±0.7)	**72** (±7.6)	**150** (±10.5)	**42** (±3.2)
FV10y						
Leaves[1]	8 (±0.84)	94 (±21.6)	4 (±0.8)	74 (±6.8)	54 (±10.8)	20 (±3.7)
Wood	44 (±7.6)	181 (±28.9)	3 (±0.8)	106 (±21.2)	312 (±71.4)	56 (±8.3)
Litter[2]	7 (±0.32)	57 (±8.0)	1 (±0.2)	7 (±0.6)	64 (±8.2)	11 (±1.4)
Total	**59** (±6.8)	**332** (±21.7)	**9** (±0.6)	**186** (±15.9)	**430** (±46.6)	**87** (±8.0)

[1] Including herbs and grasses

[2] Including standing dead

(±SE; n=10 for biomass and litter; n=5 for nutrients in FV4y and n=6 for nutrients in FV10y)

3.2.2 General description of the experiments

Two land preparation experiments were conducted in the FV4y and FV10y areas previously characterized. Work was begun in October 94 with the clearing of the vegetation. In FV10y, trunks and branches with diameters greater than 7.5cm were removed to be used as firewood or to produce charcoal, which corresponded to a removal of 7.8 t ha^{-1} of wood and the export of 2.4 kg ha^{-1} of P (Table 5). In FV4y no biomass removal took place.

Table 5 – Dry matter and amounts of exported phosphorus of trunks and branches (Ø> 7.5cm) debris piles and stumps removed for the experimental areas (FV4y and FV10y)

	FV4y		**FV10y**	
	Yield [t ha^{-1}]	P [kg ha^{-1}]	Yield [t ha^{-1}]	P [kg ha^{-1}]
Trunks and branches	-	-	7.8(±1.7)	2.4(±0.6)
Debris piles	1.5(±0.2)	0.3(±0.04)	3.2(±0.3)	0.8(±0.08)
Stumps	12.7(±1.1)	4.0(±0.4)	13.3(±2.1)	4.0(±0.6)

(±SE; n=6 for trunks;n=12 for debris piles and stumps)

Three treatments for land preparation were tested with and without fertilizer, thereby totaling six treatments, arranged in a Latin square (6 x 6). Each plot measured 10m x 12m. The treatments were:

- Burning ± NPK fertilization
- Mulching ± NPK fertilization
- Incorporation ± NPK fertilization

3.2.2.1 Treatment description

Burned plots

The procedure adopted was similar to that used by the small farmers of the region, i.e., after the vegetation was cut manually, it was left to dry for 4 to 5 weeks in FV10y and for 3 weeks in FV4y, then burned. In this treatment, the phosphorus content of ash and plant material which did not burn (debris piles) was evaluated. Total phosphorus concentration was similar in the two areas (Table 6). The amount of phosphorus in the debris piles was two times greater in FV10y, reflecting the amount of unburned wood in the area (Table 5).

Table 6 - Ash production and phosphorus content in fallow vegetation of the experimental areas (FV4y and FV10y)

	FV4y		**FV10y**	
	[mg g^{-1}]	[kg ha^{-1}]	[mg g^{-1}]	[kg ha^{-1}]
Ash	-	450	-	960
Phosphorus				
P-total	6.2	2.8	6.6	6.3
P-HCl	4.3	1.9	2.5	2.4
P-H_2O	1.1	0.5	0.7	0.7

Mulched plots

a) FV4y – after the manual clearing of the vegetation, aboveground plant biomass was immediately chopped with a tractor-propelled silage chopper and the material was distributed uniformly over the experimental area.

b) FV10y - Due to the existence of a large amount of coarse woody material, which was impossible to chop mechanically as in FV4y, chopping of plant material was accomplished in two ways after the manual clearing. Coarse woody material was therefore, separated and chopped manually into pieces of approximately 2-5 cm and the herbaceous and fine woody material was chopped with the tractor-propelled silage chopper. After all the material was chopped, the two products were mixed and uniformly distributed over the plots.

Incorporated mulch plots

In this area (incorporated mulch plots), clearing and chopping of the plant material was similar to what was done in the treatment with mulch. Before distribution of the chopped material, however, stumps were manually removed, roots of the stumps were cut to a depth of approximately 20 cm and this material was totally removed from the area. In both areas, similar amounts of stumps were removed which represented an exportation of 4 kg ha^{-1} of P in both areas (Table 5).

After the stumps were removed, the chopped material was uniformly distributed in the plot and, subsequently incorporated manually into the soil with the aid of a hoe, to an approximate depth of 15 cm. Dates at which operations were carried out during the experimental period are listed in Table 7.

Table 7 – Calendar of principal operations carried out during the land preparation phase in (1994) in the experimental areas (FV4y and FV10y)

Treatment	Slash	Wood removal	Chopping of biomass	Stump removal	Distribution/ incorporation	Burn	Final piling
FV4y							
Burning	06.10	-	-	-	-	25.11	07.12
Mulching	06.10	-	17-21.11	-	28-30.11	-	-
Incorporation	06.10	-	17-21.11	22-25.11	06-08.12	-	-
FV10y							
Burning	18.10	20.10-10.11	-	-	-	24.11	06.12
Mulching	18.10	20.10-10.11		-	16.11	-	-
Incorporation	18.10	20.10-10.11		20-30.10	28.11-05.12	-	-

Control treatments - For the purpose of comparing chemical changes in the soil of the treatments areas with an area having spontaneous vegetation, an 820m^2 area of *capoeira,* was left as a control area in each experiment beside the experiment plots.

3.2.3 Cropping system

The cropping system adopted was the planting of rice followed by planting cowpea and cassava in the first and second cropping period (Figure 4).

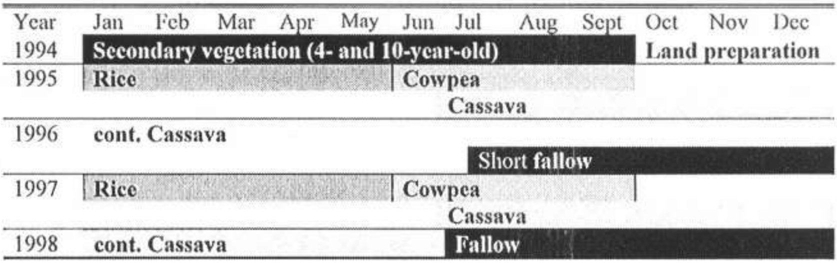

Figure 4 - Calendar of the first (1994-1996) and second (1997-1998) cropping period

Rice (January to May 95) – The Xingú cultivar, improved and recommended by EMBRAPA - Amazônia Oriental for Pará State, was used. Seeded by hand in January 95, spaced at 0.30 m x 0.30 m. In treatments where fertilization was applied, applications of 50 kg ha^{-1} of N were made in the form of urea in holes between the rice plants, divided into two applications of 25 kg each (24 and 45 days after planting). Phosphorus at 25 kg ha^{-1} and K also at 25 kg ha^{-1} were broadcast before seeding as triple superphosphate and potassium chloride, respectively.

It was necessary to replant the rice, especially in the areas FV10y with mulch, due to difficulties with penetration of rice seedlings in the soil. During the growth phase, manual weeding was performed.

Cowpea (June to August 95) - After the rice harvest, all remaining straw was uniformly distributed as mulch over the plots, after the area was weeded. BR3, a cowpea cultivar, also improved and recommended by EMBRAPA-Amazônia Oriental, was planted 27 days after the rice harvest with a manual seeder, spaced at 0.50 m x 0.30 m. Phosphorus and Potassium fertilizers were broadcast by hand, at the rate of 22 and 42 kg ha^{-1}, respectively. Seven days after sowing 10 kg ha^{-1} of N were applied in holes. NPK sources were urea, triple superphosphate and potassium chloride, respectively. Two weedings were carried out during the growth phase.

Cassava (July 95 to August 96) - Cassava was planted 20 days after sowing the cowpea with a spacing of 1.0 m x 1.0 m between the cowpea rows, using mature stem cuttings (ca. 20 cm long) planted horizontally at a depth of approximately 5 cm. Pretinha cultivar, recommended by EMBRAPA-Amazônia Oriental and widely used by small farmers in the region, was used. Cassava received no fertilization, thus permitting the evaluation of the residual effect of fertilization applied to the rice and cowpea. Manual weeding with a hoe was done after the cowpea harvest (August 95), followed by two hand clearings using machetes (December 95 and April 96).

Short Fallow Period (July to December 96) - After the cassava harvest in August 96, no other intervention was made in the area which was left fallow for 6 months. After this short fallow period, in December 96, the aboveground plant biomass accumulated during the period was evaluated in a 2.25 m^2 area in the center of each plot and the stock of phosphorus was determined in each treatment (Table 8). Subsequently, manual clearing of vegetation in this area was done in order to begin a new (second) cropping period (rice, cowpea and cassava).

The biomass of the short fallow period was uniformly distributed over the plots in the form of mulch, with no need for mechanical or manual chopping.

Table 8 - Dry matter of aboveground biomass and phosphorus content in the short-fallow vegetation (July-December 1996) on the experimental areas (FV4y and FV10y)

Treatment	Biomass		Phosphorus	
	FV4y	**FV10y**	**FV4y**	**FV10y**
	[t ha^{-1}]		[kg ha^{-1}]	
Burning	6.6 (±0.35)	5.2 (±0.27)	4.1 (±0.28)	4.2 (±0.27)
Mulching	6.4 (±0.30)	8.0 (±0.44)	3.7 (±0.18)	4.9 (±0.28)
Incorporation	6.4 (±0.36)	5.2 (±0.28)	4.4 (±0.35)	3.3 (±0.18)
Burning + NPK	6.2 (±0.37)	5.2 (±0.37)	3.3 (±0.18)	4.7 (±0.41)
Mulching + NPK	6.5 (±0.43)	6.5 (±0.39)	6.0 (±0.47)	5.0 (±0.33)
Incorporation + NPK	6.4 (±0.48)	5.1 (±0.33)	5.9 (±0.60)	4.2 (±0.34)
Means	6.4	5.9	4.6	4.4

(±SE; n=6)

The cultivation system used in this second period was the same as in the first (Figure 4), during the rice phase, however, plots were subdivided into three sub-plots of 10m x 4m to test three cultivars simultaneously: Xingú, recommended for the region; CNA 7706; and Progresso, selected for acid soil by EMBRAPA-Arroz and Feijão.

3.2.4 Evaluation of the cropping performance

3.2.4.1 Yields

Rice and Cowpea - Evaluation of grain production with 13% moisture and accumulation of dry matter of grains, rice straw and cowpea pods was under taken in an area of 6m^2 in the center of the plot. For dry matter, sub-samples were oven-dried at 65°C with forced ventilation until obtaining a constant weight.

Cassava - Fresh root yield and accumulation of dry matter in the roots, branches and foliage were evaluated in an area of 16 m^2 in the center of the plot. The procedures used for rice and cowpea were also used to evaluate the production of dry matter.

3.2.4.2 Other agronomic characteristics

Rice - Panicle length, number of panicles per plant, number of tillers per plant and plant height as well as 1000 grains weight were measured according to the methodology adopted by EMBRAPA- Arroz and Feijão.

Cowpea - Weight and number of grains per pod, pod length, height and 1000 grains weight, were measured according to the methodology adopted by EMBRAPA- Meio Norte.

3.2.4.3 Phosphorus uptake

In order to determine the phosphorus content in plant tissues, samples utilized in the evaluation of dry matter production (grains, roots, straw, pods, branches, and foliage) were ground in a "Willey" type mill with a 1mm mesh and analyzed in the EMBRAPA-Amazônia Oriental - Soil and Plant Laboratory. Phosphorus was determined colorimetrically after wet digestion with perchloric and nitric acid. As the product of dry matter and concentration, phosphorus contents were calculated for grain and straw for rice, grain and pod for cowpea and roots, branches and foliage for cassava.

In order to measure the efficiency of phosphorus applied as a fertilizer, as well as the influence of land preparation methods on the efficiency in the uptake and utilization of phosphorus, the P-utilization efficiency (PUTE) and the recovery fraction of fertilizer (apparent recovery) were calculated (MOLL et al., 1982; VAN REULER AND JANSSEN,1996; MANSKE, 1998); see chapter 3.3.1.

3.2.5 Soil

3.2.5.1 Sampling procedure and sample preparation

To evaluate the phosphorus availability of the soil during the cropping period, periodic sampling was done in the treatment as well as in the *capoeira* left next to the experiments to serve as a reference. Each sample was composed of 10 sub-samples/treatment using a soil-core sampler to a depth of 0 - 10 cm. Sampling was done in the months of October 94 to

October 96, according to the schedule shown in Table 9. After collection in the field, samples were air dried and sieved through a 2 mm mesh sieve.

Samples for microbial biomass phosphorus were collected at a depth of 0 - 10 cm with each sample composed of 10 sub-samples/treatment. The sub-samples of two replications were composed to have a single sample, yielding 3 field repetitions per treatment. Soil for microbial biomass determination was kept field moist, passed through a 2mm sieve and stored frozen until analysis which occurred 4 days after field sampling.

Table 9 - Calendar of soil sampling in the experimental areas (FV4y and FV10y) during the period from 1994 to 1996

	1994			1995											1996					
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Feb	Mar	Apr	Jul	Aug	Oct
FV4y																				
pH	6*	9	2	5	-	-	-	23	-	-	18	-	-	-	14	-	-	-	20	-
		17	15	17	-	-	-		-	-		-	-	-		-	-	-		-
P microbial	-	-	-	-	-	13	-	23	20	-	-	-	-	-	-	-	-	-	-	9
Decomposition	-	17	-	17	-	-	15	-	-	17	-	-	-	17	-	-	-	-	-	-
P fraction	12	-	-	5	-	-	17	-	20	-	18	-	-	-	-	-	-	-	20	-
Soil solution	-	-	-	-	2	3	11	11	7	5	1	14	-	-	-	27	10	17	14	-
					15	14	28	23	21	20	16		-	-	-		24	31		
						30					20		-	-	-					
Biotest	-	-	-	-	10	13	17	23	20	-	18	-	18	-	14	-	-	-	-	17
FV10y																				
pH	12*	18	1	18	-	-	-	24	-	-	18	-	-	-	14	-	-	-	20	-
			14		-	-	-		-	-		-	-	-		-	-	-		-
P microbial	-	-	-	-	-	13	-	24	20	-	-	_	-	-	-	-	-	-	-	9
Decomposition	-	17	-	17	-	-	15	-	-	17	-	-	-	17	-	-	-	-	-	-
P fraction	12	-	-	6	-	-	-	-	-	-	18	-	-	-	-	-	-	-	20	-
Biotest	-	-	-	-	10	13	17	24	20	-	18	-	18	-	14	-	-	-	-	17

*Day

3.2.5.2 Chemical characteristics of the experiments

- pH

Soil pH was determined in a 1:2.5 ratio of soil and H_2O. Soil suspension was allowed to equilibrate for 1 h after which pH values were measured with a Beckman glass electrode pH meter (ANDERSON AND INGRAM, 1993).

- Phosphorus extraction

Sequential fractionation of phosphorus

Phosphorus was fractionated by a sequential extraction according to HEDLEY et al. (1982a) with modifications by TIESSEN AND MOIR (1993) and WICK (1997). The procedure used is the chemical extraction of decreasingly available phosphorus forms due to stronger adsorption and affinity to soil components. It is aimed at quantifying labile inorganic phosphorus-Pi (Resin-Pi, $NaHCO_3$-Pi), Fe + Al associated Pi, Ca-associated Pi, as well as labile and more stable forms of organic phosphorus-Po, in subsequent steps. Thus, the differentiation of these fractions should reflect their bio-availability. Orthophosphate P in all extracts and digests were determined colorimetrically by the molybdate-ascorbic acid method (MURPHY AND RILEY, 1962, as cited by OLSEN AND SOMMERS, 1982) at 712 nm with a spectrophotometer. The spectrophotometer was fitted with a 5cm cuvette.

The fractions extracted by this procedure correspond to the following hypothetical soil P-pools (TIESSEN et al., 1992, 1994a; BECK AND SANCHEZ, 1994; PANIAGUA et al, 1995; WICK, 1997)

-Resin membrane-Pi: freely exchangeable, adsorbed on surface of more crystalline P-compounds, sesquioxides or carbonates,

- $NaHCO_3$-Pi and Po: labile inorganic and organic P absorbed from soil minerals,

- NaOH-Pi: non-occluded phosphorus, associated with amorphous and some crystalline Al an Fe phosphates,

- NaOH-Po: labile organic P of the fulvic acid fraction - indicator of P status and soil fertility.

- Evaluation of P availability using a plant extractor (Bio-assay)

In order to evaluate P availability of the treatments in comparison with the original *capoeira*, soil samples were collected in the layer at 0 – 10 cm depth during the months of February 95 to August 96 (Table 9). Soil for this study was collected in each treatment in all 6 replications. Subsequently, samples (composed of three sub-sample per plot) of each treatment were mixed, homogenized, air dried and sieved to remove impurities.

Experiments were set up in a greenhouse using a randomized complete block design with 7 treatments and 4 replications for each area (FV4y and FV10y). After processing, 500 g of soil/treatment were placed in pots and one maize seedling per pot was planted. These seedlings were pre-germinated in washed sand and, before transplanting, all sources of nutrients were eliminated to guarantee that, from that moment on, the nutrient source for the plant was the soil. Three weeks after planting, harvesting was commenced and the accumulation of dry matter in the aboveground part and the amount of P uptake was assessed. Phosphorus in the plant material was extracted by digestion with nitric-perchloric acid and P concentration was determined colorimetrically at 420 nm with a Technicon autoanalyzer (IITA, 1981).

- Soil solution

Soil solution was extracted by suction-cup lysimeters continuously from January 95 to September 96 (Table 9), except during the dry period from October to December 95. A pair of lysimeters had been installed at 40cm and 100cm depths in all 6 replications of the 3 land preparation treatments without fertilization in the 4-year-old secondary vegetation area. The bulked soil solution of the two lysimeters per plot were sampled bi-weekly. In the water samples, P was analyzed by atomic emission spectroscopy (ICP-AES).

3.2.5.3 Microbial biomass phosphorus

A method for measuring the amount of P held in soil micro-organisms biomass is the fumigation extraction method described by JENKINSON (1976), BROOKES et al. (1982) and LÖDING (1994). Biomass P is calculated as the difference between the amount of inorganic P extracted by 0.5M $NaHCO_3$ (pH 8.5) from fresh soil fumigated with $CHCl_3$ and the amount extracted from non-fumigated soil. Inorganic P was analyzed in neutralized aliquots of soil extract by the ammonium molybdate-ascorbic acid method described by MURPHEY-RILEY (1962). The microbial P content of the soil was calculated from $CHCl_3$-released Pi by dividing by 0.4, i.e. by assuming that 40% of the P in the biomass is rendered extractable as Pi by $CHCl_3$.

3.2.6 Study of decomposition

The purpose of this study was to evaluate the release of P from the decomposition of chopped secondary vegetation, which was utilized as mulch, and *capoeira* litter. Polyethylene netted bags with 2 mm mesh size were used. The bags (30 cm x 15 cm), containing chopped secondary vegetation material or litter were distributed a the unburned treatments (mulch and incorporated) and *capoeira*, respectively. Eight replications per treatment were used. Collections were made at 0, 60, 150, 240 and 360 days after distribution in the field. In the plots with incorporation of the plant material, bags were placed at a depth of approximately 10 cm.

Initial average weights of the exposed material were determined in 8 samples collected on the day the material was distributed in the field. The rate of decomposition was determined by weighing the exposed materials after drying at 65°C. After drying the samples, they were ground in a "Willey" type grinder and P contents were determined after nitric-perchloric digestion. The decomposition rate was expressed as the difference in weight in relation to the initial weight. In order to assess the sand content present in the samples, a sub-sample/treatment/replication of the material was burned in a muffle furnace at 700 °C for 2 hours and the residue weighted. The calculated decomposition rate was corrected for the percentage of sand contained in the sample.

3.3 Screening experiments

To set up the rice, maize, cowpea and cassava cultivars testing experiments, a 4-year-old fallow vegetation was cut down and chopped as in the experiment mentioned above. Experiments were laid out in split-plot randomized block designs, with and without fertilizer. In the plot the cultivars and in the sub-plot the fertilizer effect was tested. In the experimental area, in 1995, rice was followed by cowpea and maize by cassava. In 1996, only cowpea was tested in the same area as in 1995. In 1997, maize cultivars were tested in a new experimental area (4-year-old fallow vegetation).

3.3.1 Rice

The experiment was conducted in an area next to the land preparation experiment, and the results of soil analysis are shown in Table 10.

Table 10 - Results of soil analysis in the screening experiment before and after rice crops,1995

	$PH_{[H_2O]}$	Al	Ca	Ca + Mg	N	P	K
			----------[cmol kg^{-1}]---------		[%]	-----[mg kg^{-1}]-----	
Before planting	5.1	0.17	1.04	1.49	0.07	5.6	43.6
	(±0.05)	(±0.04)	(±0.11)	(±0.13)	(±0.002)	(±0.51)	(±2.14)
After harvest							
No fertilizer	5.5	0.07	1.39	1.84	0.07	4.2	32.0
	(±0.05)	(±0.02)	(±0.10)	(±0.15)	(±0.002)	(±0.20)	(±2.0)
Fertilizer	5.6	0.04	1.29	1.71	0.08	4.6	39.8
	(±0.07)	(±0.02)	(±0.03)	(±0.05)	(±0.002)	(±0.51)	(±3.73)

(±SE; n = 5)

A total of 8 cultivars (Table 11), available locally or from the EMBRAPA-Arroz e Feijão, were tested in individual 6.0m x 3.5m plots, with 5 replications. Plant-spacing of 0.30m x 0.30m was used. In the fertilized plots an application of 50, 25 and 25 kg ha^{-1} of N, P and K was used in the form of urea, triple superphosphate, and potassium chloride, respectively.

Grain yield (13% moisture), dry matter production in the straw and grain, the number of tillers, the number of panicles, length of panicles, 1000 grains weight, nutrient uptake and index of phosphorus use efficiency were evaluated.

In order to evaluate grain yield, dry matter and nutrient uptake, plants were harvested from the center of the plot in an area of $4.32 m^2$. To evaluate the characteristics of the panicles, 5 plants were harvested from the center of the plot.

For P use efficiency evaluation, the indexes proposed by MOLL et al. (1982), VAN REULER AND JANSSEN, (1996b), BALIGAR AND FAGERIA, (1997) and MANSKE (1998) and efficiency grain yields proposed by FAGERIA et al. (1988) were used.

Use efficiency was defined as grain yield per unit of P available in the soil. There are two primary components of P use efficiency (expressed in the same units): 1) P-utilization efficiency and 2) P-uptake efficiency. These are expressed as follows: (F= fertilizer plot and NF= non fertilized plot)

- P- utilization efficiency (PUTE) = $$\frac{\text{grain yield [kg ha}^{-1}]}{\text{P uptake in total biomass [kg ha}^{-1}]}$$

- P- uptake efficiency (PUPE) = $$\frac{\text{P uptake in total biomass [kg ha}^{-1}]}{\text{P applied [kg ha}^{-1}]}$$

- P- harvest index (PHI) = $$\frac{\text{P uptake in grains [kg ha}^{-1}]}{\text{P uptake in total biomass [kg ha}^{-1}]}$$

- Recovery fraction of fertilizer:

Apparent recovery [kg ha^{-1}] = P uptake in F plot - P uptake in NF plots.

Apparent recovery [%] = $$\frac{\text{Apparent recovery [kg ha}^{-1}]}{\text{quantity of P applied, [kg ha}^{-1}]} \times 100$$

- Physiological Efficiency (PE) = $$\frac{\text{yield F [kg ha}^{-1}] - \text{yield NF [kg ha}^{-1}]}{\text{P-uptake F [kg ha}^{-1}] - \text{P-uptake NF [kg ha}^{-1}]}$$

$$\text{- Agronomic efficiency (PAE)} = \frac{\text{yield F, [kg ha}^{-1}\text{] - yield NF [kg ha}^{-1}\text{]}}{\text{quantity of P applied [kg ha}^{-1}\text{]}}$$

$$\text{- Efficiency grain yields} = \frac{\text{yield F [kg ha}^{-1}\text{] * yield NF [kg ha}^{-1}\text{]}}{\text{Average yields the exper. F [kg ha}^{-1}\text{] * average yields the exper. NF [kg ha}^{-1}\text{]}}$$

Table 11 - Rice, maize, cassava and cowpea cultivars tested in the screening experiment

Rice[1]	Maize		Cassava[1]	Cowpea	
Araguaia	BR 106[1]	CMS 473[1]	Aipim Rosa	TE 86-80-3G[4]	BR 3[4]
CNA 7706	BR 5102[2]	Cincalli 93SA3[3]	Mameluca	TE 86-80-86F[4]	Vita 7[4]
CNA 6843-1	CMS 04C[2]	Cincalli 93SA4[3]	Milagrosa	TE 89-149-3G[1]	TE 86-73-3G[4]
Caiapó	CMS 28[1]	Cincalli 93SA5[3]	Pretinha	TE 89-149-11G[1]	TE 89-149-7G[1]
Ligeiro	CMS 39[1]	Cincalli 93SA6[3]	Tapioqueira	TE 89-149-10G[1]	TE 86-80-120F[1]
Progresso	CMS 50[1]	Sikuani TCA-V110[3]		TE 86-80-111F[1]	TE 89-149-5G[4]
Rio Parnaiba	CMS 59[1]	Pontinha[2]		TE 86-80-75F[1]	Canindé[4]
Xingú	CMS 453[1]	Saracura[1]		TE 89-149-4G[1]	TE 89-158-2G[4]
	CMS 14[3]			TE 89-149-1G[1]	TE 89-149-8G[1]
	CMS 36[3]			TE 86-80-73F[1]	TE 89-149-6G[1]
				TE 89-149-2G[1]	

[1] cultivars tested in 1995, [2] cultivars tested in 1995 and 1997, [3] cultivars tested in 1997
[4] cultivars tested in 1995 and 1996

3.3.2 Cowpea

In 1995, the experiment was conducted in the same area where previous rice screening had taken place. After the rice harvest, the field was weeded and the rice crop residues (straw) were left on the field. The soil conditions before and after the planting and harvesting of cowpea cultivars were screened (Table 12).

In 1995, a total of 21 runner types (Table 11) from EMBRAPA - Meio Norte were tested in individual plots measuring 1.75m x 3.0m, spaced at 0.30m x 0.50m intervals, with 4 replications. The fertilized plots received an application of 10, 22, 42 kg ha^{-1} of N, P and K in the form of urea, triple superphosphate, and potassium chloride, respectively. Evaluations were made of the grain yield with 13% moisture, accumulation of dry matter in the grains and pods, pod characteristics of each cultivar (length of pod, number and weight of grains per pod), accumulation of phosphorus in the grains and pods and phosphorus use efficiency in the plants. The harvested area in the center of the plots was $2.4m^2$.

Table 12 – Results of soil analysis in the screening experiment before and after cowpea crops in 1995

	$PH_{(H_2O)}$	Al	Ca	Ca+Mg	N	P	K
	--------[cmol kg^{-1}]--------				[%]	-----[mg kg^{-1}]----	
Before planting							
No fertilizer	5.5	0.07	1.39	1.84	0.07	4.2	32
	(±0.05)	(±0.02)	(±0.10)	(±0.15)	(±0.002)	(±0.2)	(±2.0)
Fertilizer	5.6	0.04	1.29	1.17	0.08	4.6	40
	(±0.07)	(±0.02)	(±0.03)	(±0.05)	(±0.002)	(±0.51)	(±3.7)
After harvest							
No fertilizer	5.3	0.18	0.95	1.27	0.07	2.3	33
	(±0.06)	(±0.06)	(±0.13)	(±0.15)	(±0.002)	(±0.25)	(±2.3)
Fertilizer	5.4	0.11	0.80	1.09	0.06	6.8	47
	(±0.21)	(±0.04)	(±0.05)	(±0.06)	(±0.002)	(±1.18)	(±4.2)

(±SE; n = 4)

In 1996, a total of 9 cultivars were tested in the same area, 8 of which were selected from the 1995 experiment (Table 11). Only the grain production with 13% moisture was measured. In fertilized plots, 22, 42 kg ha^{-1} of P and K, in the form of triple superphosphate and potassium chloride, were applied, respectively.

3.3.3 Maize

In 1995, a total of 11 cultivars from EMBRAPA - Milho e Sorgo (Table 11) were tested in individual plots measuring 8.0m x 2.0m, spaced at 1.0m x 0.50m intervals with 5 replications. The planted area was $6.4m^2$. Fertilized plots received an application of 60, 25, 25 kg ha^{-1} of N, P and K in the form of urea, triple superphosphate, and potassium chloride, respectively. The results of soil analysis before and after maize cropping are shown in Table 13.

Measurements were made of grain yield (13% moisture), accumulation of dry matter and N in the grains and aboveground biomass, plant height, height of ear insertion, 1000 weight grains and P use efficiency.

Table 13 - Results of soil analysis in the screening experiment before and after maize crop in 1995

	$PH_{[H_2O]}$	Al	Ca	Ca+Mg	N	P	K
			--------[cmol kg^{-1}]--------		[%]	-----[mg kg^{-1}]-----	
Before planting	5.7	0.11	1.27	1.84	0.07	4.0	23.4
	(±0.05)	(±0.04)	(±0.10)	(±0.16)	(±)	(±0.71)	(±1.66)
After harvest							
No fertilizer	5.6	0.03	1.77	2.49	0.08	3.2	22.4
	(±0.04)	(±0.02)	(±0.18)	(±0.17)	(±0.002)	(±0.20)	(±1.00)
Fertilizer	5.7	0.03	1.84	2.29	0.07	4.0	23.4
	(±0.05)	(±0.02)	(±0.22)	(±0.20)	(±0.004)	(±0.71)	(±1.66)

(±SE; n = 5)

In 1997, a total of 10 cultivars ware tested in a new area where the biomass of the 4-year-old secondary vegetation has been chopped recently. Five cultivars came from CIMMYT, Colombia, and the other five were from EMBRAPA-Milho e Sorgo, all pre-selected for acid, low fertility soils (Table 11). The experiment was made up of 4 replications with plots measuring 5.0m x 4.0m. To evaluate plant yield, the material was harvested from the center of the plot in an area measuring 4.5m^2. Management, harvesting methods and fertilization were similar to those of the experiment conducted in 1995.

3.3.4 Cassava

After maize was harvested (1995), the field was weeded and five cassava cultivars were planted (Table 11). Each plot measured 8m x 4m with 1.0m x 1.0m spacing. The tuber yield of the cassava (fresh weight) was determined on the central 12m^2 of the plots. The cassava itself was not fertilized, but a residual effect of fertilizers applied to the previous crop was expected. Fresh tuber yield, accumulation of dry matter and nitrogen phosphorus in the roots, leaves and branches were measured, as well as P use efficiency.

Table 14 - Results of soil analysis in the screening experiment before and after cassava crops in 1995

	PH$_{[H_2O]}$	Al	Ca	Ca + Mg	N	P	K
		---------[cmol kg^{-1}]----------			[%]	----[mg kg^{-1}]----	
Before planting							
No fertilizer	5.6	0.03	1.77	2.49	0.08	3.2	22.4
	(±0.04)	(±0.02)	(±0.18)	(±0.17)	(±0.002)	(±0.20)	(±1.00)
Fertilizer	5.7	0.03	1.84	2.29	0.07	4.0	23.4
	(±0.05)	(±0.02)	(±0.22)	(±0.20)	(±0.004)	(±0.71)	(±1.66)
After harvest							
No fertilizer	4.9	0.08	1.64	2.05	0.08	7.6	28.0
	(±0.14)	(±0.02)	(±0.16)	(±0.21)	(±0.006)	(±0.93)	(±8.35)
Fertilizer	4.94	0.07	1.56	1.99	0.08	5.8	21.0
	(±0.15)	(±0.03)	(±0.19)	(±0.22)	(±0.008)	(±0.37)	(±1.10)

(±SE; n = 5)

3.4 Statistical analysis

Statistical analyses were conducted using as analysis of variance the General Linear Model procedure of the Systat Program (Systat, 1992).

For the land preparation experiment the data of the grain and root yields were analyzed using block design with two factors (land preparation and fertilizer effects). Due to the additional treatment (*capoeira*) a randomized complete block design had to be used for analysis of soil data. To evaluate which treatments were different from others the Least Significant Difference (LSD) test was used at significance levels P=0.05.

Screening experiments were analyzed statistically as randomized block design at each fertilizer level. To evaluate which treatments were different from others the Least Significant

Difference (LSD) test were used at significance levels P=0.05. The data for number lodging were transformed in arcsin (SQR(X + 0.5).

Pearson's correlation coefficient r was used to describe the degree of the linear association between two variables. The significance of the simple linear correlation was expressed with *** at P≤0.001, with ** at P≤0.01 and with * at P≤0.05.

4 Results and Discussion

4.1 Effect of land preparation

4.1.1 Crop performance of rice, cowpea and cassava

4.1.1.1 Rice yields

In the plots which received no fertilization burning of the fallow vegetation significantly increased the grain yields of rice in the first cropping period as compared to cropping without burning (Table 15). In the second period, no differences were detected in FV10y due to an increase in the production of non-fertilized plots were burning was not applied. The yield reduction under mulched or incorporated treatments in the first cropping period was most likely due to the slow release of nutrients from the plant material, possibly exacerbated by P immobilization. The yield increase in the second cropping period may be related to the liberation of nutrients associated with the decomposition of mulch (Figure 8). The use of fertilizer significantly increased the rice grain yields in the two cropping periods in both areas and erased the land preparation effect seen without the use of fertilizers (Table 15).

Table 15 -Grain (13 % moisture) yields of rice, Xingu cultivar, in two successive cropping periods in the experimental areas (FV4y and FV10y), with and without fertilizer

Land preparation	FV4y			FV10y		
	Fertilizer	No fertilizer	Means	Fertilizer	No fertilizer	Means
		[t ha^{-1}]			[t ha^{-1}]	
1995						
Burning	2.7 (±0.2)	1.5 (±0.9)	2.1	3.0 (±0.2)	2.2 (±0.2)	2.6
Mulching	2.5 (±0.2)	0.9 (±0.1)	1.6	2.3 (±0.3)	0.5 (±0.1)	1.4
Incorporation	2.1 (±0.2)	0.9 (±0.1)	1.5	2.6 (±0.1)	0.4 (±0.1)	1.5
Means	2.4	1.1	1.7	2.6	1.0	1.8
LSD (p= 0.05)	F= 0.2	LP= 0.3	F*LP= n.s.	F= 0.3	LP= 0.3	F*LP= 0.5
	S= n.s.					
1997						
Burning	2.7 (±0.4)	1.4 (±0.1)	2.0	3.9 (±0.2)	1.4 (±0.3)	2.6
Mulching	3.2 (±0.3)	1.5 (±0.1)	2.3	3.6 (±0.2)	1.7 (±0.3)	2.7
Incorporation	3.1 (±0.1)	2.2 (±0.3)	2.7	4.1 (±0.4)	1.3 (±0.1)	2.7
Means	3.0	1.7	2.3	3.9	1.5	2.7
LSD (p= 0.05)	F= 0.3	LP= 0.4	F*LP= n.s.	F=. 0.4	LP= n.s.	F*LP= n.s.
	S= 0.2					

F= Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y); n.s.= not significant

With the traditional slash-and-burn technology and in the absence of fertilizers, the rice productivity expressed in grain yield was higher following FV10y (2.2 t ha^{-1}) than after FV4y (1.5 t ha^{-1}) (Table 15). The reverse effect was observed (0.5 vs 0.9 t ha^{-1}), however, when the plant material was chopped and left in the field. The use of fertilizers overcame the differences in yield due to fallow duration and land preparation, increasing rice yields to 2.4 to 2.6 t ha^{-1}.

In the slash-and-burn system, without the application of fertilizers rice yields in 1997 showed an overall reduction in the order of 7 and 36% in FV4y and FV10y, respectively. The inverse effect is observed in systems without the use of fire, which showed an increase in yields compared to the first crop in 1995 of 117 and 233%, respectively (Table 15).

The reduction of yield in the second cropping period may be due to the decrease in the available nutrients provided by ash due to losses and plant uptake. This may be expressed as a gradual decline in the mineral nutrient stock of the system for the subsequent cropping period (JUO AND MANU, 1996; JORDAN, 1985). Comparing the rice grain yield in a cropping system with and without burning in the Taí region of southwestern Ivory Coast, in fields of 4- and 10-year-old fallow vegetation, VAN REULER AND JANSSEN (1993) observed significantly higher yields in the burned plots in the first year. In the non burned plots yields of the successive crop were higher, which was attributed to a stable level of soil fertility in these plots.

The decline of yields due to a decreasing availability of nutrients and an increase of weeds in the subsequent crops, have been the main reason for the farmers of northeast Pará to abandon the area and install new crops in adjacent areas. According to SANCHEZ (1976), Latin American farmers abandon their fields when they do not expect that the subsequent crop will yield more than 50% of the first crop.

Morphological characteristics associated with the production (number of panicles per plant, length of panicles, plant height, number of tillers, 1000 grains weight and harvest index) of the rice crop were not influenced by the land preparation method when fertilizer were applied. The differences observed were mainly between the use or non-use of fertilizers (Table 16).

Table 16 - Harvest index, number of panicle per plant, number of tillers, plant height and 1000 grain weight of rice in the first cropping period (1995) in the experimental areas (FV4y and FV10) with (F) and without fertilizer (NF)

Land Preparation	FV4y			FV10y		
	F	NF	Means	F	NF	Means
Harvest index						
Burning	0.4	0.4	0.4	0.3	0.4	0.4
Mulching	0.4	0.4	0.4	0.4	0.3	0.4
Incorporation	0.4	0.4	0.4	0.4	0.3	0.4
Means	0.4	0.4	0.4	0.4	0.3	0.4
LSD (p= 0.05)	F= n.s.	LP= n.s.	F*LP= n.s.	F= 0.02	LP= n.s.	F*LP= 0.05
	S= n.s.					
Panicle/plant						
Burning	12	11	12	14	13	14
Mulching	13	9	11	15	0	7
Incorporation	13	8	11	14	0	7
Means	13	9	11	14	4	9
LSD (p= 0.05)	F= 1.2	LP= n.s.	F*LP= 2.1	F= 1.7	LP= 2.1	F*LP= 3.0
	S= 1.1					
Panicle length [cm]						
Burning	20	18	19	22	19	21
Mulching	19	17	18	19	0	9
Incorporation	20	16	18	20	0	10
Means	20	17	18	20	6	13
LSD (p= 0.05)	F= 0.6	LP= 0.8	F*LP= 1.1	F=0.7	LP= 0.9	F*LP= 1.2
	S= 0.5					
Number of tillers						
Burning	15	10	12	19	17	18
Mulching	14	8	11	17	12	14
Incorporation	14	8	11	19	15	17
Means	14	9	11	18	15	16
LSD (p= 0.05)	F= 0.9	LP= 1.1	F*LP= n.s.	F= 3.0	LP= n.s.	F*LP= n.s.
	S= 2.0					
Plant height [cm]						
Burning	93	74	.83	109	90	100
Mulching	89	59	73	99	48	74
Incorporation	90	62	76	102	56	79
Means	90	65	77	103	65	84
LSD (p= 0.05)	F= 4.6	LP= 5.7	F*LP= n.s.	F= 4.9	LP= 6.0	F*LP= 8.5
	S= 3.0					
1000 grains weight [g]						
Burning	29	30	30	31	32	31
Mulching	29	29	29	32	30	31
Incorporation	29	29	29	30	29	30
Means (F)	29	29	29	31	30	31
LSD (p= 0.05)	F= n.s.	LP= n.s.	F*LP= n.s.	F= n.s.	LP= n.s.	F*LP= 1.6
	S= 0.7					

F= Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant

Without fertilizer, burning positively influenced the number of panicle per plant, panicle length and plant height, in both areas. Statistical differences were observed among the sites for morphological characteristics with the exception of the harvest index. When fertilizer was used, the number of panicles per plant, number of tillers and length of panicles constituted the yield components which contributed to the yield increase (Table 16).

The harvest index was, an average, 0.40 for FV4y and FV10y, with no significant differences between treatments. A high harvest index is associated with a higher grain yield, as long as there nutrient supply, mainly phosphorus, is adequate. In the Ivory Coast, VAN REULER AND JANSSEN (1993) also observed values of the harvest index of around 0.3-0.4 for rice, with and without the use of fire in land preparation

In the second cropping period (1997/1998), the application of NPK fertilizer contributed to the increase in yields as much as in 1995 (Table 15), the increase was, however, significantly higher in the second crop cycle. In 1995, the addition of fertilizer led to an increase of the rice grain yields of about 79% and 37% in the burned plots of FV4y and FV10y, respectively. In 1997, the increase was 98% and 183%. In the plots without burning, the application of fertilizer increased rice grain yield in 1995 by 202% and 335% (FV4y and FV10y), in 1997 by 112% and 110%, showing the beneficial effects of the decomposition of organic matter in the second period of the slash-and-mulch system. The reduction of the beneficial effects of ash in the second cropping period is related to the capacity of the soil to retain and store nutrients in forms that are readily available to the plants (JORDAN, 1985; TULAPHITAK et al., 1985; JUO AND MANU, 1996).

Yields of the cultivars CNA 7706 and Progresso were also not influenced by the land preparation method in the second crop period in FV10y. On other hand, burning in FV4y decreased the rice yields(Table 17). The Progresso cultivar showed a greater grain yields in FV10y. The application of fertilizers increased the grain yields of the CNA 7706 and Progresso cultivars in both areas (Table 17). Yields without fertilizers varied between 1.2 to 1.8 t ha^{-1} in FV4y, and 1.1 to 1.5 t ha^{-1} in FV10y, whereas with fertilizers a 3 to 4 times higher result could be achieved. Thus, the two cultivars constitute viable option for planting in slash-and-mulch system.

Although farmers are aware of the benefits of the accumulation of nutrients in above-ground biomass with *capoeira* age (HONDERMANN, 1995), small farmers of northeast Pará have preferred to use 3- to 4-year-old *capoeira*. Their principle constraint is their reliance on family labor for slashing. From the results of rice yields it is evident, that the productivity of the crop is greater after a 10-year-old *capoeira* when slash-and-burn technology is used. When burning is eliminated, however, the use of supplementary NPK fertilization can compensate for the nutrients immobilized by micro-organisms during the decomposition of organic matter. In this case, the yield is not influenced by the length of the fallow period, in the first cropping period, however, in the second cropping period rice yield were greater in the FV10y.

Table 17 – Yields of rice grains in the second cropping period (1997) in the experimental areas (FV4y and FV10) with and without fertilizer

Land Preparation	**FV4y**			**FV10y**		
	Fertilizer	No fertilizer	Means	Fertilizer	No fertilizer	Means
		[t ha^{-1}]			[t ha^{-1}]	
CNA 7706						
Burning	2.6 (±0.2)	1.5 (±0.1)	2.0	3.4 (±0.2)	1.4 (±0.1)	2.4
Mulching	3.9 (±0.4)	1.7 (±0.3)	2.8	3.8 (±0.3)	1.5 (±0.1)	2.6
Incorporation	3.2 (±0.1)	1.5 (±0.1)	2.4	3.8 (±0.1)	1.1 (±0.2)	2.5
Means	3.2	1.6	2.4	3.7	1.3	2.5
LSD (p= 0.05)	F= 0.4	LP= 0.5	F*LP= n.s.	F= 0.4	LP= n.s.	F*LP= n.s.
	S= n.s.					
Progresso						
Burning	3.1 (±0.2)	1.2 (±0.3)	2.1	4.1 (±0.2)	1.5 (±0.2)	2.8
Mulching	3.5 (±0.3)	1.7 (±0.1)	2.6	4.8 (±0.3)	1.2 (±0.1)	3.0
Incorporation	3.6 (±0.2)	1.8 (±0.1)	2.7	4.3 (±0.3)	1.2 (±0.1)	2.7
Means	3.4	1.6	2.5	4.4	1.3	2.8
LSD (p= 0.05)	F= 0.4	LP= 0.4	F*LP= n.s.	F=. 0.3	LP= n.s.	F*LP= 0.5
	S= 0.2					

F= Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant, (±SE, n=6)

4.1.1.2 Cowpea yields

The crop traditionally following rice is cowpea which is always fertilized by the farmers. As seen in Table 18, when no fertilizer was used the yields were around 0.3 t ha^{-1} in burned fields, which makes planting hardly worth the effort. When no fire was used (mulch and incorporation) the yields were around 0.20 t ha^{-1} in FV4y, but in FV10y cowpea did not produce at all. With fertilization, in the first cropping period, cowpea grain yields were around 1.5 t ha^{-1}, regardless of the length of the fallow period and land preparation method used.

In the second cropping period the greatest response in grain yield in relation to the first period were in the plots with mulch, with and without fertilizer (Table 18). Grain yields were, on average, 0.5 and 0.2 t ha^{-1} without fertilizer, and 1.7 and 2.1 t ha^{-1} with fertilizer in FV4y and

FV10y areas, respectively (Table 18). Residual effects of fertilizer applied to previous crops and the decomposition of rice, cowpea and cassava residues of the first period which were left in the field contributed effectively to the better plant development and crop yields in the second cropping period. Capoeira biomass was also a contributing factor.

Table 18 – Yields of cowpea grains (13 % moisture) in two successive cropping periods in the experimental areas (FV4y and FV10y), with and without fertilizer

Land Preparation	FV4y			FV10y		
	Fertilizer	No Fertilizer [t ha^{-1}]	Means	Fertilizer	No Fertilizer [t ha^{-1}]	Means
1995						
Burning	1.6(±0.05)	0.3(±0.02)	1.0	1.5(±0.10)	0.3(±0.04)	0.9
Mulching	1.5(±0.09)	0.2(±0.04)	0.9	1.5(±0.10)	0.0	0.8
Incorporation	1.6(±0.13)	0.2(±0.04)	0.9	1.6(±0.12)	0.0	0.8
Means	1.6	0.2	0.9	1.5	0.1	0.8
LSD(p=0.05)	F= 0.1	LP= n.s.	F*LP= n.s.	F= 0.1	LP= n.s.	F*LP= 0.2
	S= 0.09					
1997						
Burning	1.6(±0.19)	0.3(±0.06)	0.9	2.0(±0.19)	0.3(±0.03)	1.1
Mulching	2.0(±0.23)	0.6(±0.11)	1.3	2.3(±0.14)	0.2(±0.05)	1.2
Incorporation	1.5(±0.14)	0.5(±0.10)	1.0	2.1(±0.17)	0.2(±0.07)	1.2
Means	1.7	0.5	1.1	2.1	0.2	1.2
LSD(p=0.05)	F= 0.3	LP= n.s.	F*LP= n.s.	F= 0.2	LP= n.s.	F*LP= n.s.
	S= n.s.					

F= Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant (±SE, n= 6);

Oliveira et al. (1992) studied the residual effects of fertilizer on the cowpea yield on yellow Latosol in the Amazon. Their results show that the phosphorus content in the plant and grain yields increased proportionally with the levels of phosphorus in the soil. The concentration of nitrogen in the plant was greater in the plants of the control plot. Oliveira et al. (1992) concluded that phosphorus was the most limiting element for plant development, followed by nitrogen. Bünemann (1998) studied the effects of increasing rates of nitrogen, phosphorus and potassium on a cowpea crop in a slash-and-mulch system. She confirmed that phosphorus is a prime limiting element in cowpea yield in northeast Pará.

Cowpea is a crop widely adapted to acid, low-fertile soils and represents an alternative both in income (sale of the product) and as a source of protein for the nutrition of the farmer's family. In spite of its adaptation to a low soil fertility status, it requires the application of fertilizer to obtain a good yield. This is a well known fact among small farmers in the region, as cowpea is practically the only annual crop that receives small doses of fertilizer (KATO et al., 1992).

FAGERIA et al. (1991) report that yield components are utilized frequently to evaluate the response of cowpea plants to the application of nutrients. Characteristics of the pods, such as length, number of grains per pod, grain weight per pod and 1000 grains weight, were not hardly influenced by the length of the fallow period, land preparation and fertilizer (data not shown).

4.1.1.3 Cassava yields

In the traditional system the final crop harvested in the cropping sequence, prior to abandoning the field is cassava. Compared to the plots where fire was not used, in the first cropping period, burning resulted in the lowest cassava yield in FV4y, and in the highest yield following the 10-year-old fallow (FV10y). Differences due to type of land preparation were not significant, indicating that limitations due to the nutrient immobilization had gradually disappeared by the time the cassava was planted (Table 19).

Table 19 - Yields of cassava fresh root in two successive cropping periods in the experimental areas (FV4y and FV10y), with and without fertilizer

Land Preparation	**FV4y**			**FV10y**		
	Fertilizer	No Fertilizer [t ha^{-1}]	Means	Fertilizer	No Fertilizer [t ha^{-1}]	Means
1995/1996						
Burning	30.2 (±1.3)	16.3 (±1.6)	23.2	30.0 (±1.9)	15.5 (±1.6)	22.8
Mulching	28.8 (±2.1)	17.7 (±1.2)	23.2	26.8 (±2.5)	12.7 (±0.9)	19.7
Incorporation	36.1 (±1.1)	18.8 (±3.1)	27.4	31.9 (±1.1)	12.7 (±1.0)	22.3
Means	31.7	17.6	24.6	29.6	13.6	21.6
LSD(p=0.05)	F= 3	.2LP= n.s	F*LP= n.s.	F= 2.4	LP= 3.0	F*LP= 4.3
	S= 2.0					
1997/1998						
Burning	24.6 (±1.6)	11.3 (±1.1)	17.9	29.0 (±2.7)	10.2 (±1.1)	19.6
Mulching	26.0 (±2.2)	17.4 (±0.8)	21.7	23.8 (±1.2)	13.5 (±0.8)	18.7
Incorporation	27.5 (±3.9)	14.6 (±0.7)	21.1	21.3 (±1.0)	12.4 (±0.9)	16.9
Means	26.0	14.4	20.2	24.7	12.0	18.4
LSD(p=0.05)	F= 3.4	LP= n.s.	F*LP= n.s.	F= 2.6	LP= n.s.	F*LP= 4.5
	S= n.s.					

F= Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant; (±SE, n= 6);

Cassava is normally not fertilized, but benefits from residual fertilizer effects. Without residual fertilizer of the previous crops, fresh yields of cassava roots were between 16.3 and 18.8 t ha^{-1} in FV4y and 12.7 and 15.5 t ha^{-1} in FV10y. With residual NPK, the cassava yields doubled and no clear effect of land preparation was discernible (Table 19).

In the second period, cassava root yield showed similar results. Without residual NPK, root yields varied from 11.3 to 17.4 t ha^{-1} in FV4y and from 10.2 to 13.5 t ha^{-1} in FV10y. With residual NPK, yield varied from 24.6 to 27.5 t ha^{-1} in FV4y and from 21.3 to 29.0 t ha^{-1} in FV10y. Residual fertilizer effects were the dominant factor for the increase of the cassava root yields in both cropping periods (Table 19).

In the second cropping period and absence of residual NPK, the cassava yield decreased in burned plots by 30% and 34% in FV4y and FV10y, respectively, in comparison to the first period. Regardless of the fallow duration, this reduction was not observed in plots with mulch and for incorporated plant material in FV4y.

Despite the fact that cassava extracts high amounts of nitrogen and potassium, yield increases due to fertilization with these elements are small and less frequent than increases induced by phosphorus (GOMES, 1982; GOMES et al., 1983; PERIM et al., 1983; DEFELIPO et al., 1984).

Cassava is a crop of great economic importance for farmers of the Bragantina region because good yields in acid and low fertility soils can be achieved. The production of cassava, which is often transformed into meal, plays an important role in supplying the needs of the family through its sale. The crop is so important to the small farmers' income that even at the expense of productivity, that it is planted during several seasons of the year to guarantee year round root availability for meal production.

4.1.2 Phosphorus uptake by crop

The results of the uptake of P by rice, cowpea and cassava refer to the first cropping period only.

4.1.2.1 Phosphorus uptake by rice

Total dry matter production and P uptake in the burned fields were significantly higher than when burning was omitted (Table 20) suggesting that, even with fertilizer application, low P availability affected rice dry matter production in the non-burned plots. The greater quantity of burned biomass found in FV10y apparently resulted in higher nutrient availability which was reflected in a 52 % increase in total rice biomass as well as 44 % increase in P content in the aboveground parts (Table 20).

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Table 20 - Dry matter yield and phosphorus content in grain, straw and total biomass of rice in the experimental areas (FV4y and FV10), with and without fertilizer

Land Preparation	Dry matter $[\mathrm{t\ ha^{-1}}]$						Phosphorus content $[\mathrm{kg\ ha^{-1}}]$					
	FV4y			**FV10y**			**FV4y**			**FV10y**		
	F	NF	Means	F	NF	Means	F	NF	Means	F	NF	Means
Grain												
Burning	2.4	1.3	1.8	2.6	1.9	2.3	6.1	2.6	4.4	7.1	3.2	5.2
Mulching	2.1	0.7	1.4	2.0	0.5	1.2	4.8	1.0	2.9	3.8	0.7	2.2
Incorporation	1.9	0.7	1.3	2.3	0.4	1.3	4.1	1.0	2.5	4.4	0.6	2.5
Means	2.1	0.9	1.5	2.3	0.9	1.6	5.0	1.5	3.3	5.1	1.5	3.3
LSD(p=0.05)	F= 0.2		LP= 0.2	F= 0.2		LP= 0.3	F= 0.7		LP= 0.9	F=0.8		LP= 1.0
		F*LP= n.s.			F*LP= 0.4			F*LP= n.s.			F*LP= n.s.	
	S= n.s.						S= n.s.					
Straw												
Burning	4.0	1.8	2.9	5.0	2.8	3.9	4.1	1.0	2.5	4.0	2.0	3.0
Mulching	3.2	1.0	2.1	3.1	0.9	2.0	2.3	0.6	1.5	2.9	0.7	1.8
Incorporation	3.3	1.1	2.2	3.3	0.9	2.1	2.2	0.7	1.5	2.5	0.7	1.6
Means	3.5	1.3	2.4	3.8	1.5	2.7	2.9	0.8	1.8	3.1	1.1	2.1
LSD(p=0.05)	F= 0.3		LP= 0.4	F= 0.4		LP= 0.5	F=0.3		LP= 0.4	F=0.5		LP= 0.6
		F*LP= n.s			F*LP= n.s.			F*LP= 0.5			F*LP= n.s.	
	S= n.s.						S= 0.3					
Total												
Burning	6.3	3.1	4.7	7.6	4.7	6.1	10.2	3.6	6.9	11.1	5.2	8.2
Mulching	5.3	1.7	3.5	5.1	1.4	3.2	7.1	1.6	4.4	6.6	1.4	4.0
Incorporation	5.2	1.9	3.5	5.6	1.3	3.4	6.3	1.6	4.0	6.8	1.2	4.0
Means	5.6	2.2	3.9	6.1	2.5	4.3	7.9	2.3	5.1	8.2	2.6	5.4
LSD(p=0.05)	F= 0.4		LP= 0.5	F= 0.6		LP= 0.7	F= 0.8		LP= 1.0	F= 1.1		LP= 1.3
		F*LP= n.s.			F*LP= n.s.			F*LP= n.s.			F*LP= n.s.	
	S= n.s.						S= n.s.					

F= Fertilizer; NF= No Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s:= not significant

The increase in total biomass and total P uptake found in rice in the burned plots is related to the improvement in soil conditions, such as increased pH (see chapter 4.1.1.1) and the availability of other nutrients (i.e. Ca - liming effect) coming from the ash. BALIGAR AND FAGERIA (1997) report that the increase in pH, resulting from the ash acting as lime, could reduce the detrimental effect of surface soil and subsoil acidity during root growth, supply necessary Ca and thus increase the plant's efficiency in absorbing nutrients. VAN REULER AND JANSSEN (1996b) found that per unit kg P absorbed from the ash more grains were produced than per unit P absorbed from triple superphosphate, suggesting that the presence of other nutrients contained in the ash contributed to the higher efficiency in phosphorus utilization. It was also observed by VAN REULER AND JANSSEN (1993) that P absorption by rice was gradually reduced in the burned plots due to the decrease in nutrient availability from the ash

Phosphorus content in grains and straw followed the same tendency found for the total uptake (Table 20), i.e. greater uptake was observed in the burned plots as compared to those without burning. The accumulation in the rice grains corresponded to 65% (3.3 kg ha^{-1} grain for 5.1 t ha^{-1}- total biomass) and 57% (3.3 kg ha^{-1} grain for 5.4 t ha^{-1} total biomass) of the total amount of nutrients absorbed by the plant, in FV4y and FV10y, respectively.

In the system where fire is not applied, the release of nutrients depends mainly on microbial activity. Thus, the nutrients are first immobilized by microorganisms and then later released into the soil, which explains the data obtained in the non-burned plots (see chapter 4.1.2).

In spite of the higher uptake observed in the burned areas, the efficiency of P (Table 21) was higher in the non-burned areas. In this area, average values of 376 and 613 kg of grains per kg of P absorbed by the crop, were found in FV4y and FV10y, respectively. In the burned plots these values were 297 and 504 kg of grains per kg of absorbed P in FV4y and FV10y, respectively (Table 21). A high efficiency of P utilization found in the non-burned plots indicates that the P was less available in these plots. The P release by burning the vegetation contributed to an increase in the P uptake by the total rice biomass (VAN REULER AND JANSSEN, 1993). The decreased level of P available for the rice crop in the non-burned plots may be due to the fact that P was not available at that time, since its release depends on the process of mulch decomposition and on the immobilization by microorganisms in the soil (DIEKMANN, 1997).

Table 21 - Apparent recovery-P fraction and P-utilization efficiency by rice in the experimental areas (FV4y and FV10), with and without fertilizer

Land Preparation	P-apparent recovery				P-utilization efficiency [kg kg^{-1}]					
	FV4y		**FV10y**		**FV4y**			**FV10y**		
	[kg ha^{-1}]	[%]	[kg ha^{-1}]	[%]	F	NF	Means	F	NF	Means
Burning	6.6	26	5.9	23	232	363	297	458	550	504
Mulching	5.6	22	5.3	21	311	439	375	500	729	614
Incorporation	4.7	19	5.6	22	303	454	378	503	721	612
Means	5.5	22	5.5	22	282	419	350	487	667	577
LSD(p=0.05)	LP= n.s.		LP= n.s.		F= 37.8		LP= 46.4	F= 83.8		LP= n.s.
					F*LP= n.s.			F*LP= n.s.		
	S= n.s.				S= 47.6					

F= Fertilizer; NF= No Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant

The efficiency of P utilization was on average, 40 % higher in FV10y, where approximately 577 kg of grains were produced per kg of absorbed P. In FV4y, this value was around 303 kg of grains per kg of absorbed P. VAN KEULEN AND VAN HEEMST (1982) and JANSSEN et al. (1990) found a maximum value of 600 kg of grains per kg of absorbed P and considered this parameter the best to estimate for the potential P supply in the soil.

Fallow length and land preparation method did not influence the efficiency of rice in absorbing fertilizer. The apparent recovery of P-fraction, for both areas, was therefore around 22%, i.e. from the 25 kg P ha^{-1} applied as fertilizer, rice recovered, on average, 5.5 kg (Table 21). This trend was also reflected in the production of grain, where no differences between the two areas did occur. The apparent recovery of fractions of fertilizer P are, generally, not higher than 10-15% due to the adsorption process and the low mobility of this nutrient in the soil (BRADY, 1989).

The continuous application of phosphate fertilizers will increase, with time, the amount of this nutrient in the soil. This means that, although a great part of P added in the fertilizers is not used during the year of application, it may be considered an important source for future years (BRADY, 1989).

4.1.2.2 Phosphorus uptake by cowpea

In the burned fields without fertilization, P uptake in the aboveground parts was 0.8 and 0.6 kg ha^{-1} in FV4y and FV10y, respectively. In non-burned non-fertilized plots, nutrient content was reduced by 50 % in FV4y. In FV10y the level of P was not measured since no grain was produced (Table 22). The higher P content found in the burned and non-fertilized treatments could be attributed mainly to the residual ash effect (Table 6) and to the decomposition of the rice straw residues.

When fertilizer was applied, phosphorus content in total biomass was not affected by the land preparation method and fallow period. In FV4y, P content varied from 4.8 (incorporation) to 5.4 kg ha^{-1} (burning) and in FV10y from 4.2 (burning) to 4.3 kg ha^{-1} (mulching). In the present study the P content in total biomass of cowpea, only reflects the amount of grains and pods produced in both areas.

Table 22 - Dry matter and P content in grain, pod and total (grain + pod) of cowpea in the experimental areas (FV4y and FV10) with and without fertilizer

	Dry matter [t ha^{-1}]						Phosphorus content [kg ha^{-1}]					
	FV4y			**FV10y**			**FV4y**			**FV10y**		
	F	NF	Means	F	NF	Means	F	NF	Means	F	NF	Means
Grain												
Burning	1.4	0.3	0.9	1.3	0.3	0.8	5.0	0.7	2.9	3.9	0.5	2.2
Mulching	1.3	0.2	0.8	1.3	0.0	0.7	4.6	0.4	2.5	4.0	0.0	2.0
Incorporation	1.4	0.1	0.8	1.4	0.0	0.7	4.4	0.3	2.4	3.9	0.0	2.0
Means	1.4	0.2	0.8	1.3	0.1	0.7	4.7	0.5	2.6	3.9	0.2	2.1
LSD(p=0.05)	F= 0.09		LP= n.s.	F= 0.12		LP= n.s.	F= 0.4		LP= n.s.	F= 0.4		LP= n.s.
		F*LP= n.s.			F*LP= 0.21			F*LP= n.s.			F*LP= n.s.	
	S= n.s.						S= 0.28					
Pod												
Burning	0.4	0.09	0.3	0.4	0.08	0.2	0.4	0.07	0.2	0.3	0.1	0.2
Mulching	0.4	0.05	0.2	0.4	0.00	0.2	0.4	0.03	0.2	0.3	0.0	0.2
Incorporation	0.4	0.05	0.2	0.4	0.00	0.2	0.3	0.04	0.2	0.3	0.0	0.2
Means	0.4	0.06	0.2	0.4	0.03	0.2	0.4	0.05	0.2	0.3	0.03	0.2
LSD(p=0.05)	F= 0.03		LP= n.s.	F= 0.04		LP= n.s.	F= 0.04		LP= n.s.	F= 0.04		LP= n.s.
		F*LP= n.s.			F*LP= 0.06			F*LP= n.s.			F*LP= n.s.	
	S= n.s.						S= 0.03					
Total												
Burning	1.8	0.4	1.1	1.7	0.4	1.0	5.4	0.8	3.1	4.2	0.6	2.4
Mulching	1.7	0.3	1.0	1.7	0.0	0.9	5.0	0.4	2.7	4.3	0.0	2.2
Incorporation	1.8	0.2	1.0	1.8	0.0	0.9	4.8	0.4	2.6	4.2	0.0	2.1
Means	1.8	0.3	1.0	1.7	0.1	0.9	5.1	0.5	2.8	4.2	0.2	2.2
LSD(p=0.05)	F= 0.11		LP= n.s.	F= 0.15		LP= n.s.	F= 0.40		LP= n.s.	F= 0.42		LP= n.s
		F*LP= n.s.			F*LP= 0.26			F*LP= n.s.			F*LP= n.s.	
	S= n.s.						S= n.s.					

F= Fertilizer; NF= No Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant

The importance of P for the cowpea grain production is demonstrated by the positive and significant correlation between grain yields and P uptake ($r=0.99$ $p\leq0.001$) found in the two areas studied. OLIVEIRA et al. (1992) also reported that in the western Amazon even the residual effect of increased P doses, increased the P content in the plant proportionally to P levels found in the soil and, consequently, to leas to higher grain production. HAGGAR et al. (1991) attributed the enhancement in growth and P uptake by beans grown in plots with mulch of *Erythrina poeppigiana* in relation to the ones without mulch, to the higher P availability in the soils under mulch treatments.

4.1.2.3 Phosphorus uptake by cassava

Phosphorus content in cassava was not significantly affected by land preparation and fallow length, but by the residual effect from previous fertilizer applications (Table 23). The P content in the aboveground parts, particularly the leaves, is higher in FV10y than in FV4y, due to higher dry matter production.

In relation to the plants without residual NPK, the NPK residual effect increased the amounts of P absorbed in the cassava total biomass by 37% and 42% on average in FV4y and FV10y, respectively. Apparently, the availability of P becomes the most important yield limiting factor over time, a finding that agrees with the results reported by GEHRING et al. (1998).

The phosphorus content in roots corresponded to 58% and 47% of total P absorbed by cassava plants, in FV4y and FV10y, respectively. HOWELER (1991) reports that about 34% of the total amount of absorbed N, 60% of P and 60% of K were found in the cassava roots and mentioned that absorbed N could partly return to the soil through the decomposition of the crop residues. P and K, however, are largely exported with the roots so that continuous cultivation may eventually result in soil exhaustion, unless fertilizers is applied.

Table 23 - Dry matter and phosphorus content in roots, stems, leaves and total biomass of cassava in the experimental areas (FV4y and FV10), with and without fertilizer

	Dry matter [t ha^{-1}]						Phosphorus Content [kg ha^{-1}]					
	FV4y			FV10y			FV4y			FV10y		
	F	NF	Means	F	NF	Means	F	NF	Means	F	NF	Means
Roots												
Burning	13.2	7.2	10.2	13.3	6.9	10.1	8.4	4.7	6.5	7.1	3.8	5.4
Mulching	12.2	7.3	9.8	12.0	5.5	8.8	7.5	5.2	6.4	6.9	3.2	5.0
Incorporation	15.3	7.9	11.6	13.7	5.4	9.6	9.8	5.2	7.5	7.8	3.1	5.5
Means	13.6	7.5	10.5	13.0	5.9	9.5	8.6	5.0	6.8	7.3	3.4	5.3
LSD(p=0.05)	F= 1.4 LP= n.s. F*LP= n.s.			F= 1.2 LP= n.s. F*LP= n.s.			F= 1.7 LP= n.s. F*LP= n.s.			F= 0.9 LP= n.s. F*LP= n.s.		
	S= 0.9						S= 1.0					
Stem												
Burning	5.5	3.5	4.5	7.8	4.8	6.3	3.6	2.1	2.8	3.7	3.0	3.3
Mulching	5.6	4.3	5.0	8.1	5.5	6.8	3.4	2.9	3.2	4.3	3.3	3.8
Incorporation	7.1	4.2	5.7	8.0	4.4	6.2	5.3	2.7	4.0	4.4	2.1	3.3
Means	6.1	4.0	5.1	8.0	4.9	6.4	4.1	2.6	3.3	4.1	2.8	3.5
LSD(p=0.05)	F= 0.8 LP= 0.9 F*LP= n.s.			F= 0.8 LP= n.s. F*LP= n.s.			F= 0.9 LP= n.s. F*LP= n.s.			F= 0.3 LP= n.s. F*LP= n.s.		
	S= 0.56						S= n.s.					
Leaves												
Burning	0.7	0.5	0.6	2.0	1.3	1.7	1.6	1.0	1.3	3.7	2.3	3.0
Mulching	0.7	0.8	0.8	1.9	1.4	1.7	1.6	2.0	1.8	3.6	2.7	3.2
Incorporation	0.9	0.5	0.7	1.6	1.2	1.4	1.9	1.2	1.6	3.1	2.3	2.7
Means	0.8	0.6	0.7	1.8	1.3	1.6	1.7	1.4	1.6	3.5	2.4	3.0
LSD(p=0.05)	F= 0.17 LP= n.s. F*LP= n.s.			F= 0.3 LP= n.s. F*LP= n.s.			F= n.s. LP= n.s. F*LP= n.s.			F= 0.6 LP= n.s. F*LP= n.s.		
	S= 0.16						S= 0.3					
Total												
Burning	19.4	11.1	15.3	23.0	13.0	18.0	13.5	7.8	10.7	14.5	9.1	11.8
Mulching	18.6	12.5	15.5	22.0	12.4	17.2	12.5	10.1	11.3	14.8	9.2	12.0
Incorporation	23.2	12.6	17.9	23.2	11.0	17.1	17.1	9.1	13.1	15.3	7.5	11.4
Means	20.4	12.1	16.2	22.7	12.1	17.4	14.4	9.0	11.7	14.9	8.6	11.7
LSD(p=0.05)	F= 1.4 LP= n.s. F*LP= n.s.			F= 0.6 LP= n.s. F*LP= n.s.			F= 2.5 LP= n.s. F*LP= n.s.			F= 1.6 LP= n.s F*LP= n.s.		
	S= n.s.						S= n.s.					

F= Fertilizer; NF= No Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant

The importance of P to root production has also been recognized by GOMES AND HOWELER (1980), PAULA et al. (1983) and PERIM et al. (1983). The authors observed that although N and K are the macronutrients absorbed in higher quantities by cassava, was the element P led to a significant yield increase of this crop.

Amounts 12% of P was apparently recovered, this number, however, refers to the recovery of the residual phosphorus (Table 24). It is worth to point out that cassava needs very little P (PERIM et al., 1983; HOWELER, 1991), the total omission of this element, however, may significantly reduce plant and root production (PERIM et al., 1980).

Table 24 - . Apparent P recovery, P uptake efficiency and P utilization efficiency in cassava under different land preparation methods at FV4y and FV10y areas.

Land Preparation	P-apparent recovery				P-utilization efficiency [kg kg^{-1}]					
	FV4y		**FV10y**		**FV4y**			**FV10y**		
	[kg ha^{-1}]	[%]	[kg ha^{-1}]	[%]	F	NF	Means	F	NF	Means
Burning	6	12	5	12	1092	972	1032	931	843	887
Mulching	3	6	6	12	1114	805	959	829	634	731
Incorporation	8	17	8	17	1026	938	982	955	749	852
Means	6	12	6	14	1077	905	991	905	742	823
LSD(p=0.05)	LP= n.s.		LP= n.s.		F= 37.8		LP= 46.4	F= 83.8		LP= n.s.
					F*LP= n.s.			F*LP= n.s.		
	S= n.s.				S= 47.6					

F= Fertilizer; NF= No Fertilizer; LP= Land Preparation; F*LP= interaction; S= Sites (FV4y and FV10y)
n.s.= not significant

The P utilization efficiency averaged 991 and 823 kg of dry roots per kg of absorbed P in FV4y and FV10y, respectively (Table 24). The land preparation method did not influence P utilization efficiency of cassava in both areas. Residual NPK increased between 11 and 14% the P efficiency in FV4y and FV10y, respectively, in contrast with the results obtained by PELLET et al. (1993), who observed that the use of fertilizer reduces P efficiency of cassava.

Capoeira with of higher amount of biomass is not preferred by the farmers of the region, because, according to their experience, areas with these characteristics are prone to promote higher cassava aboveground biomass rather than roots. Our data confirms this belief (Table 19). On the other hand, the higher amount of mulch in FV10y could contribute to the increase in the incidence of soft root-rot caused by *Phytophthora drechsleri* and *Pytium scleroteichum*, a growing problem in northeastern Pará (POLTRONIERI et al., 1997).

4.1.3 Soil chemistry characteristics

4.1.3.1 pH

After burning, pH$_{(water)}$ in the topsoil (0 - 10cm) increased by approximately 1.5 units in both areas (Figure 5). The temporary pH increase in the burned plots was due to the cation solubilization and the liming effect of the ash. A large number of studies have reported the effects of ash in relation to soil pH and nutrient availability for crops (JUO AND MANU 1996;

Van Reuler and Janssen 1996b; Lessa et al. 1996; Ulery et al. 1993; Stromgaard 1984; Suebert et al. 1977).

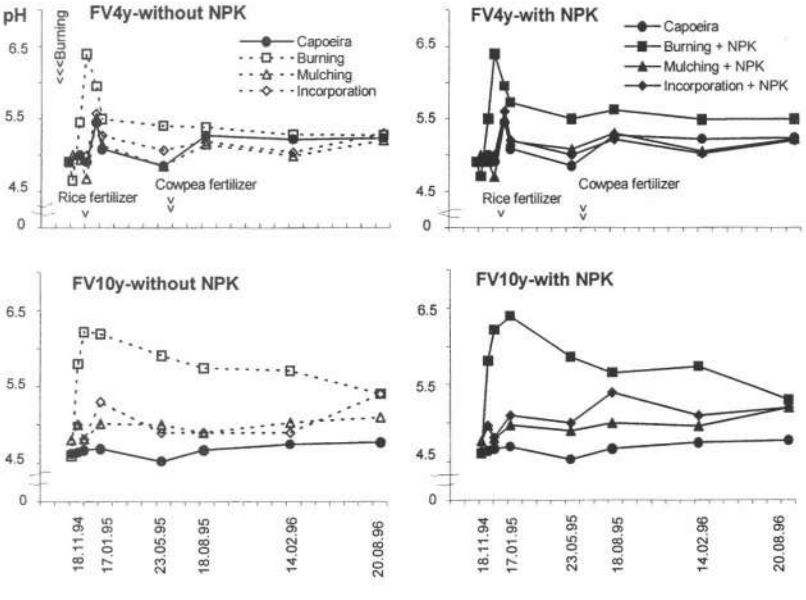

Figure 5 - Soil pH(water) dynamics as a function of land preparation and fertilizer treatments in experimental areas (FV4y and FV10y) in 0 -10 cm depth.

The pH level in the burned plots dropped less rapidly in FV10y. During the entire rice phase it read more than 5.9 whereas in FV4y these levels dropped to 5.4 (Figure 5). The slow reduction of pH at FV10y may have been related to the increased capacity of the soil to retain nutrients, due to its mineralogical and physical characteristics (Table 1). Compared to FV4y (Table 6), the amount of ash coming from the fallow vegetation biomass had doubled. In the FV4y soil there was an accentuated reduction of pH in the beginning of the rice phase due to leaching of nutrients (sandy soil) which were detected in the solution, collected at 40 cm depth (Kato, 1998). For most of the treatments, fertilization with NPK had no influence on pH during the study period. At the end of the first cropping period (August 1996) pH differences between burned and plots where no fire was applied were not observed any more.

Without burning the increase of pH was not very accentuated (maximum 0.6 units) but was maintained with small variations during the entire study period. Even with fertilization there was no mulch-effect detected in pH. The small increase in pH in the first 2 months from 4.8 to 5.1, after slashing may have been due to a reduced uptake of soil cations. This effect was caused by on interruption of nutrient absorption through the cutting down of the vegetation and the beginning of the rainy season (SWIFT et al., 1981). According to VAN RAIJ (1981), acidification of the soil consists of the removal of the alkaline cations from the cation exchange complex.

The uptake of inorganic phosphorus by plants is strongly affected by soil pH, which influences the reaction of the phosphorus with various soil ions and minerals. The availability of P to plants is largely determined by its ionic form. The ionic form, however, is determined by the pH of the solution in which the ion is found. Thus, in very acid solutions, only the $H_2PO_4^-$ ions are present. When the pH level is increased in the beginning, the HPO_4^{2-} ions dominate and are followed by the PO_4^{3-} ions (BRADY, 1989).

4.1.3.2 Changes in soil phosphorus fractions

4.1.3.2.1 Extractable phosphorus

In January 1995 the concentration of available P (Mehlich extract) of the top 10 cm of the soil had increased in both areas (FV4y and FV10y). The increase was greater in the burned plots than in the non-burned ones (Table 25).

Table 25 - Dynamics of available P (P-Mehlich) as a function of land preparation and fertilizer treatments in experimental areas (FV4y and FV10y) in 0 -10 cm depth

	FV4y				**FV10y**			
Treatments	Oct 94*	Jan 95**	Aug 95	Aug 97	Oct 94*	Jan 95**	Aug 95	Aug 97
				[mg kg^{-1}]				
Capoeira	3.0	3.3	2.3	2.0	2.0	2.0	1.7	3.0
Burning	-	12.7	3.0	4.7	-	13.3	5.7	2.7
Mulching	-	6.0	3.0	4.7	-	3.0	3.3	3.3
Incorporation	-	6.0	4.0	4.3	-	3.3	2.3	2.7
Burning + NPK	-	12.7	16.3	13.3	-	13.3	17.7	12.7
Mulching + NPK	-	6.0	13.0	13.7	-	3.0	10.3	10.0
Incorpor. + NPK	-	6.0	11.7	14.7	-	3.3	10.3	12.0
$LSD_{[P=0.05]}$			4.6	4.6			2.5	2.5

* n =10; **n = 6; data not included in statistical analyses

Burning has increased the available P content with regard to the initial values of October 1994 by factor 4.2 (3.0 mg kg^{-1} to 12.7 mg kg^{-1}) and 6.7 (2.0 mg kg^{-1} to 13.3 mg kg^{-1}) in FV4y and FV10y, respectively (Table 25), confirming the previous finding of the P content in the aboveground of biomass of the two *capoeiras*. These results agree with the observations of the various authors (ELLIS AND GRALEY, 1983; SIMMS, 1987; ROMANYÀ et al., 1994) who also found increases in the available phosphorus in the superficial layers of the soil after burning the fallow vegetation for land preparation purposes.

The increased amount of phosphorus available after burning (16.5 kg P ha^{-1} at FV4y and 17.3 kg P ha^{-1} at FV10y) exceeded the amounts of phosphorus found in the ashes (2.8 and 6.3 kg P ha^{-1} at FV4y and FV10y, respectively) at 0 - 10 dm depth. This surplus may come from: a) mineralisation of phosphorus from soil organic matter and from the biomass of the vegetation decomposed in the small interval between the slashing and the burning/chopping of the vegetation (MACKENSEN et al., 1996); b) burning of the vegetation which made the phosphorus stored in the biomass of the vegetation quickly available; c) effect of liming of the ash (JUO AND MANU, 1996) that increased pH, reduced phosphorus adsorption in the soil and favored the action of the microorganisms in the mineralisation of the organic matter; and d) the decomposition of the fine roots of the vegetation which according to LESSA et al. (1996) constitutes source of nutrients of rapid mineralisation.

The elimination of burning also increased the amount of available P by a factor 2 and 1.5 (3.0 to 6.0 kg P ha^{-1} and 2.0 to 3.0 kg P ha^{-1}), in FV4y and FV10y, respectively. In FV10y the available P content was lower than in FV4y, probably due to the immobilization by microorganisms caused by the high amount of woody material -twice as high as in FV4y (Table 5)- and lower P concentration of the vegetation at FV10y. Nine months after land preparation (August 1995) a decrease of available P was determined in the treatments without fertilizer, mainly due to the uptake by rice and cowpea (Table 20 and Table 22). Similar results were observed by RAISON et al. (1993) and JUO AND MANU (1996). In the fertilized plots, a significant increase of available P was observed due to the application of 25 and 22 kg P ha^{-1} of triple superphosphate to rice and cowpea, respectively. The available phosphorus content, in these plots, varied from 11.7 to 16.3 mg kg^{-1} in FV4y and 10.3 to 17.7 mg kg^{-1} in FV10y. Differences between the land preparation methods were not observed in the first period.

Despite the fact that the differences are not significant, it is worth mentioning that, during the second cropping period, the available P content in the soil (Mehlich extract) differed between the land preparation methods, at the two sites under observation (Table 25). With fertilizer, there was a reduction of 20% and 28% of the available P content in the burned plots of FV4y and FV10y, respectively, whereas in the mulched plots the available P content was unaffected and in the incorporation plots there was even an increase of 25% and 16% of available P at FV4y and FV10y, respectively. Without fertilizer, available P was slightly reduced in all three land preparation treatments of site FV10y, but with a greater reduction in the burned plots, whereas in FV4y there was an increase of available P in all three land preparation treatments.

4.1.3.2.2 Inorganic phosphorus pool (Pi-fractions)

The fraction of the readily available inorganic phosphorus, extracted with resin (resin-Pi), always showed a significant difference between treatments at all times, regardless of the two areas and hence the age of the previous fallow vegetation (Figure 6).

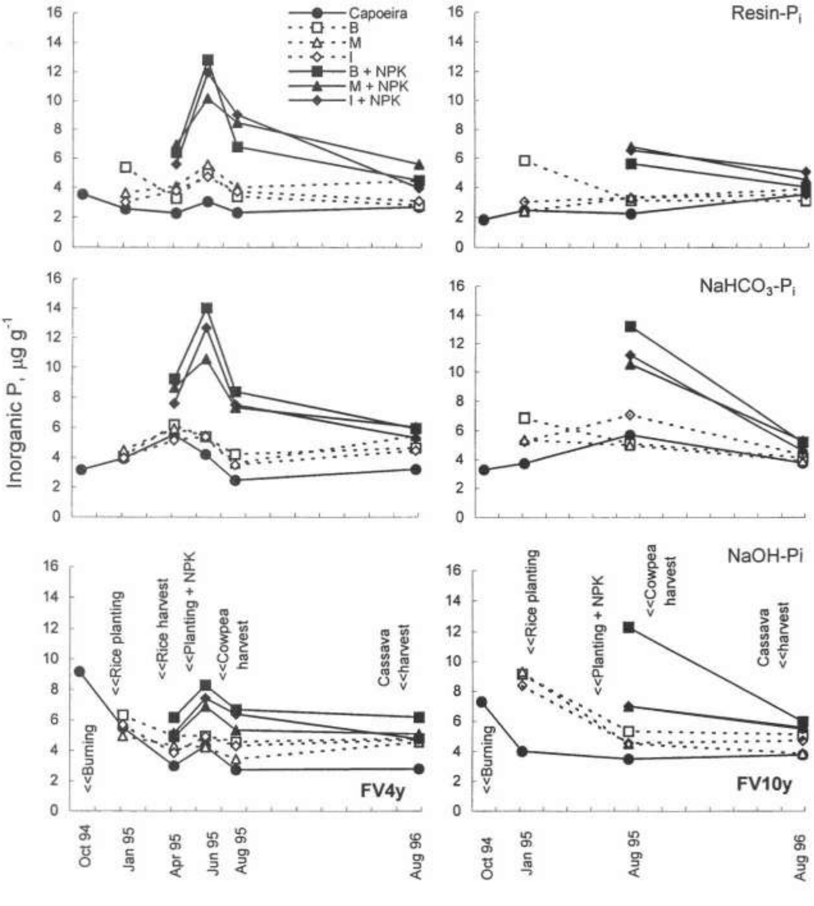

Figure 6 - Dynamics of Pi fractions as a function of different land preparation and fertilizer levels in experimental areas (FV4y and FV10y) in 0 -10 cm depth.

At the beginning of the rice cultivation (January 1995) the burned treatments showed greater phosphorus contents (5.4 and 5.8 mg kg^{-1} in FV4y and FV10y, respectively) than the no-burned treatments. The only slight difference in the increase of resin-Pi between the two study areas reflects the stock of phosphorus in the aboveground biomass of the fallow vegetation, as shown in Table 4. The trends of resin-Pi increase with time as a function of land preparation are similar to that observed with the Mehlich extraction, which was discussed previously. The increase in the resin-Pi fraction in FV4y in June 1995 is probably associated with the decomposition of fine roots and straw of the rice harvested in May (Figure 6).

Following the fast increase of the resin-Pi fraction after burning, this P-fraction decreased rapidly during the rice cropping season. This short-lived fertilization effect of burning has also been reported by SEUBERT et al. (1977), SANCHEZ et al. (1983) and BECK AND SANCHEZ (1994). The resin-Pi pool is the most easily available P sources for plant growth (BOWMAN al., 1978) and reflects short-term changes in plant availability (HEDLEY et al., 1982b).

The resin-Pi fraction was higher with fertilizer than without; fertilization having the greatest impact in June 1995 (Figure 6). This effect was mainly due to fertilizer application to cowpea beginning of June. After June a reduction was observed in the resin-P_i fraction, which was caused by P uptake of cowpea and cassava.

This tendency in the $NaHCO_3$-Pi fraction in FV4y was similar to that observed in the resin-Pi fraction (Figure 6) in all treatments, with the exception of January of 1995, were the effect of burning was not observed. In FV10y a gradual decrease of this fraction was observed (burning- and incorporation plots). After the fertilization was stopped, SCHMIDT et al. (1996) observed a decline in the amount of inorganic phosphorus in the resin and $NaHCO_3$ fraction over a long period of 17 years of continuous cultivation in two soil types (Norfolk Loamy Sand and Davidson Clay Loam) caused by the removal of crops.

A significant positive correlation was obtained between resin-Pi and $NaHCO_3$-Pi fractions in the burned plots (FV4y $r = 0.81$, $p \leq 0.001$; FV10y $r = 0.58$, $p \leq 0.01$) and in the mulched plots (FV4y $r = 0.77$, $p \leq 0.001$; FV10y $r = 0.62$, $p \leq 0.001$) (Table 26), suggesting that the decrease of the amount of inorganic phosphorus in the resin fraction due to removal of the crops is accompanied by a decrease in the inorganic phosphorus fraction extractable by $NaHCO_3$ (SCHMIDT et al., 1996).

Table 26 - Pearson correlation coefficients for P-fractions as a function of two land preparation methods (burning and mulching) at the experimental areas (FV4y and FV10y)

	Resin-Pi		$NaHCO_3$-Pi		NaOH-Pi		$NaHCO_3$-Po	
	FV4y	**FV10y**	**FV4y**	**FV10y**	**FV4y**	**FV10y**	**FV4y**	**FV10y**
Burning								
$NaHCO_3$- P_i	0.81***	0.58**						
NaOH- Pi	0.69***	0.58**	0.67***	0.63**				
$NaHCO_3$-Po	0.19	0.03	-0.07	0.46*	0.30	0.10		
NaOH-Po	-0.05	-0.17	0.19	0.46	-0.05	-0.08	0.13	0.40
Mulching								
$NaHCO_3$- Pi	0.77***	0.62**						
NaOH- Pi	0.46**	-0.27	0.40*	0.31				
$NaHCO_3$-Po	0.36*	0.35	0.13	0.15	0.18	-0.25		
NaOH-Po	0.33*	0.71***	0.51**	0.39	-0.08	-0.54**	0.19	0.12

Significant level: *** at $P \leq 0.001$; ** at $P \leq 0.01$;* at $P \leq 0.05$
FV4y: n=20; FV10y: n=12

The NaOH-Pi fraction was increased by P fertilization in both areas. Increases in levels of the inorganic NaOH-Pi fraction indicate the built up of a sink for future plant uptake (Figure 6). In FV10y a clearly higher NaOH-Pi fraction level was observed in all treatments in January 1995 when compared to the *capoeira*. Over time the level decreased significantly in all treatments except in the *capoeira* until similar levels in August 1995 and more so in August 1996 were reached. The dynamics of the inorganic phosphorus levels of resin-Pi and $NaHCO_3$-Pi fractions coincide with the dynamics of the inorganic phosphorus levels of the NaOH-Pi fraction, showing a relationship within the three inorganic fractions.

Significant correlations were found between the resin-Pi fraction and the NaOH-Pi fraction in the burned plots (FV4y $r = 0.69$, $p \leq 0.001$; FV10y $r = 0.58$, $p \leq 0.01$) and in the mulched plots which were not burned (FV4y $r = 0.46$, $p \leq 0.01$). WICK (1997) and SCHMIDT et al. (1997) also found a high correlation between the following three inorganic fractions (resin-Pi, $NaHCO_3$-Pi and NaOH-Pi). HEDLEY et al. (1982) indicated that inorganic phosphorus not utilized by the plant is reabsorbed by the soil components, and built weakly to strongly adsorbed fractions (resin-Pi > $NaHCO_3$-Pi > NaOH-Pi).

4.1.3.2.3 Organic phosphorus pool (Po-fractions)

Data on $NaHCO_3$- and NaOH- extractable organic phosphorus is presented in Figure 7. With respect to the $NaHCO_3$-Po pool neither the land preparation method nor the fertilizer treatment had any impact in either area, as the comparisons to the *capoeira* show. In general, a seasonal dynamic in the $NaHCO_3$-Po levels could be observed (Figure 7). This agrees with BECK AND SANCHEZ (1994), who studied short-term dynamics of phosphorus fractions in the Peruvian Amazon, confirming low concentrations of organic phosphorus in the $NaHCO_3$ fraction and very little influence of burning and mineral fertilization. During the short observation period of the present study $NaHCO_3$-Po pools were not depleted. TIESSEN et al. (1983), however, reported of soils at Blaine Lake that after an initial increase in organic phosphorus levels due to the incorporation of the prairie vegetation, all organic P fractions were depleted and simultaneously inorganic P fractions were increased.

As opposed to burning and incorporation, a slight but not significant increase of $NaHCO_3$-Po with time was observed in the mulched treatments in both areas. This increase was probably due to the decomposition process of the organic matter. ZHANG AND MACKENZIE (1997) reported that the return of great amounts of C to the soil by plant residues increases the soil organic phosphorus.

In both areas the NaOH-Po pool of the top 10 cm was significantly influenced by cultivation as compared to the *capoeira* and among different land preparation methods (Figure 7). Independent of the land preparation methods, seasonal changes were observed in this fraction. NaOH-Po was the fraction that showed the highest short-term increments as compared to other fractions. Furthermore, an increase in NaOH-Po was concomitant with a decrease in NaOH-Pi and resin-Pi in burned areas (FV4y).

Several authors are considering the NaOH-Po as an indicator of phosphorus status and fertility of the soil. This pool is thought to represent the overall changes in soil organic matter and organic phosphorus levels by functioning as an active reservoir (source and sink) of P when the soil is stressed by cultivation and net P-export (STEWART AND TIESSEN, 1987; TIESSEN et al., 1992; TIESSEN et al., 1994; MAGID AND NIELSEN, 1992; BECK AND SANCHEZ, 1994; PANIAGUA et al., 1995). LINDSAY (1979) considers the dynamics of this pool to be much more complex than the one of the inorganic pool.

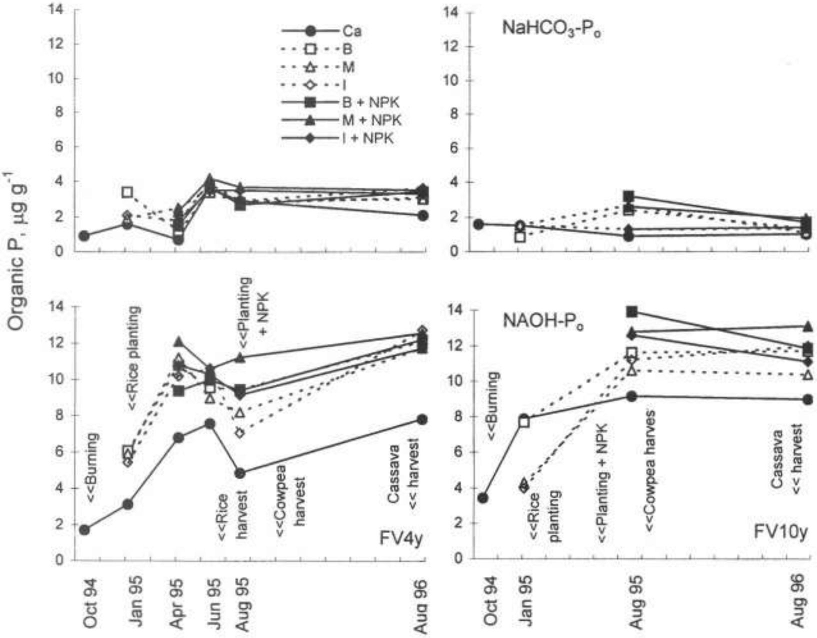

Figure 7 - Dynamics of Po fractions as a function of different land preparation and fertilizer treatments in experimental areas (FV4y and FV10y) in 0 - 10 cm depth.

The NaOH-Po fraction in the mulched treatment showed a significantly negative correlation with the resin-P$_i$ fraction in FV4y ($r = 0.33$, $p \leq 0.05$) and in FV10y ($r = 0.71$, $p \leq 0.001$). In the burned plots, however, these relations were not observed (Table 26). This shows the importance of this pool in replacing the inorganic pool in slash-and-mulch systems.

4.1.3.3 Phosphorus in soil solution

In the first year (1995), after burning, the phosphorus in the soil solution at 40 cm depth was maintained at around 0.1 mg l^{-1} for 2 months and then dropped below detection levels (data not shown). The mulched fields had a similar spike in solution P, which lasted for only one week, whereas the incorporation of biomass led to a complete tie-up of P, and thus, to undetectable P levels in solution at any give time. In fact, DIEKMANN (1997) demonstrated in a slash-and-mulch system at the same location, that the reduction in available P (Mehlich extract) in the topsoil (5 cm) during maize growth was to a large extent explained by an increase in microbial P. In the second year (1996) the P concentration in the soil solution varied between 0.13 - 0.15 mg l^{-1}, 0.12 - 0.17 mg l^{-1} and 0.12 - 0.18 mg l^{-1} in the burned, mulched and incorporated plots, respectively.

Low initial soil phosphorus levels, low mobility, low quantities in the fallow vegetation biomass and high harvest removal by demanding crops (rice and cowpea) are the reasons for low P concentrations in the soil solution in the first year. In the second year P mineralization of the organic fraction and the decomposition of the mulch and of crop residues as well as decreased harvest removal by less demanding crops (cassava) contributed to some P leaching. Despite the low mobility of phosphorus in the soil (BECK AND SANCHEZ, 1996), the leaching of P beyond arable soil horizons has been observed in sandy soils (KAMPRATH, 1991; WEAVER et al., 1988a; WEAVER et al., 1988b) which supports the present results of phosphorus found in the soil solution collected in a depth of 40 cm in FV4y.

4.1.3.4 Soil P availability: a bioassay of soil phosphorus

Phosphorus extracted from the soil by test plants (maize) showed significant differences between soils from different land preparation methods and sampling periods in both areas (Table 27). Plant extractable phosphorus in FV4y was, on average, 22% higher (0.98 mg kg soil^{-1}) than in FV10y (0.80 mg kg soil^{-1}). Higher available P levels in FV4y than in FV10y were also observed in the resin-P_i fraction.

Averaged from both areas and both fertilizer treatments, bio-assayed phosphorus in the mulched soil was significantly higher than in the soil from burned (Table 27). With fertilization, the differences between extractable phosphorus levels of the burned and the not-burned plots were greater in FV10y than in FV4y. This could be due to the greater uptake by rice, cowpea and cassava plants (Table 20, 22 and 23)(VAN REULER AND JANSSEN, 1996b; STROMGAARD, 1984; JUO AND MANU, 1996). The gradual decomposition of mulch and plant residues (rice, cowpea and cassava) influences the P uptake by the test plants from soil of unburned plots. No differences in available P were found by LE MARE et al. (1987) on a dark-red Latosol in Brazil between green manured and control treatments. The authors assumed that the adsorbed phosphorus was more labile in green manure treatments due to a change of the phosphorus kinetics in the soil.

Table 27 - Dynamics of bio-assayed phosphorus of two areas (FV4y and FV10y) as a function of three different land preparation methods and two fertilizer treatments, using maize as test plant

Treatments	1995							1996		Means
	Feb	Mar	Apr	May	Jun	Aug	Oct	Feb	Aug	
					[mg P kg soil^{-1}]					
FV4y										
Capoeira	0.42	0.60	0.62	0.40	0.20	0.16	0.47	0.34	0.45	0.41
Burning	0.66	1.51	0.43	0.76	0.52	0.22	0.51	0.46	0.42	0.61
Mulching	1.00	1.52	0.72	0.78	0.80	0.38	0.56	1.34	0.90	0.89
Incorporation	0.38	0.82	0.46	0.74	0.64	0.29	0.42	0.97	0.50	0.57
Burning + NPK	1.00	2.36	1.23	0.74	2.46	0.52	1.12	0.47	0.43	1.15
Mulching + NPK	1.84	2.93	0.98	1.40	2.80	0.54	1.14	1.48	1.25	1.60
Incorporation+ NPK	1.92	2.85	1.27	1.58	2.80	1.14	0.91	1.24	0.72	1.60
LSD$_{(P=0.05)}$	0.26	0.50	0.23	0.19	0.35	0.16	0.26	0.52	0.20	
FV10y										
Capoeira	0.43	0.74	0.35	0.43	0.40	0.24	0.39	0.32	0.79	0.45
Burning	0.80	0.50	0.41	0.30	0.31	0.32	0.40	0.41	0.47	0.46
Mulching	0.96	0.85	0.48	0.56	0.52	0.32	0.54	0.61	0.57	0.60
Incorporation	0.28	0.51	0.63	0.46	0.30	0.33	0.53	0.68	0.54	0.47
Burning + NPK	0.86	1.26	0.67	0.64	0.35	0.54	0.61	0.55	1.11	0.73
Mulching + NPK	1.72	3.28	0.79	1.00	1.18	1.98	0.82	1.23	1.51	1.50
Incorporation+ NPK	1.40	3.10	0.82	1.18	0.58	1.18	1.18	0.98	1.08	1.15
LSD$_{(P=0.05)}$	0.46	0.42	0.20	0.20	0.23	0.25	0.16	0.24	0.18	

In FV4y the bio-assayed phosphorus showed a positive correlation with the resin-Pi ($r = 0.67$, $p \leq 0.01$), NaHCO$_3$-Pi fraction ($r = 0.65$, $p \leq 0.01$) and NaOH-Pi ($r = 0.51$, $p \leq 0.01$). In FV10y, the Pearson correlation was significant for resin-Pi and NaOH-Pi, but the correlation coefficient was low ($r = 0.38$, $p \leq 0.01$; $r = 0.29$, $p \leq 0.01$, respectively). Significant correlation were observed between bio-assayed P and the rice grain yields (FV4y $r = 0.76$, $p \leq 0.01$; FV10y $r = 0.49$, $p \leq 0.05$), cowpea grain yields (FV4y $r = 0.92$, $p \leq 0.01$; FV10y $r = 0.71$,

$p \leq 0.01$), and fresh cassava root yields (FV4y $r = 0.82$, $p \leq 0.01$; FV10y $r = 0.66$, $p \leq 0.01$) in both areas.

4.1.4 Soil biological characteristics

4.1.4.1 Microbial biomass P

The microbial biomass P was evaluated in May 1995 (rice harvest), June 1995 (cowpea planting) and October 1996 (cassava harvest). The microbial biomass P of the different land preparation methods at 0-10 cm depth are shown in the Table 28.

Time averaged microbial biomass P under different land preparation methods fell in the range of 13.8 to 25.1 µg g^{-1} in FV4y and of 11.5 to 26.7 µg g^{-1} in FV10y. In the *capoeira* of FV4y and FV10y, these values were 12.2 µg g^{-1} and 13.0 µg g^{-1}, respectively (Table 28). Microbial P in FV4y was similar that of FV10y. Results obtained by LÖDING (1994) in the northeast of Pará in *capoeiras* of 0, 1, 4, 15 and 30 years and in 0-5 cm soil depth showed that microbial P increased with the age of the *capoeira* (from 10.5 to 17.0 µg g^{-1})

The elimination of burning resulted in higher microbial P (21.0 µg g^{-1} in FV4y and 22.3 µg g^{-1} in FV10y) as compared to the burned plots (17.9 µg g^{-1} in FV4y and 18.0 µg g^{-1} in FV10y) averaged over fertilization. The highest levels of microbial P in the treatments without burning were also observed by CHAUHAN et al. (1981). These authors conclude that the cellulose addition on the soil surface increases microbial activity and, subsequently, the amount of immobilized organic and inorganic P. In low phosphorus soils, an increase of organic P could only be observed when P fertilizer was added to the cellulose. In both areas, no significant differences in microbial biomass P were found between mulching and incorporation, suggesting that the application technique does not affect microbial P (Table 28).

In the present work, fertilization (NPK) increased microbial P significantly (Table 28) which gives evidence for the microbial immobilization of phosphorus applied as fertilizer.

Table 28 - Dynamics of microbial biomass P in soil as a function of different land preparation and fertilizer treatments in experimental areas (FV4y and FV10y) in 0 - 10cm depth

Treatments	Time (month)			Means
	Mai/95	Jun/95	Oct/96	
	[µg microbial P g^{-1}]			
FV4y				
Capoeira	4.3	20.5	11.8	12.2
Burning	5.9	18.7	16.7	13.8
Mulching	8.3	16.9	25.4	16.9
Incorporation	6.2	20.9	16.4	14.5
Burning + NPK	18.4	28.8	18.4	21.9
Mulching + NPK	21.6	24.3	29.5	25.1
Incorporation + NPK	19.8	20.7	32.4	24.3
$LSD_{(P=0.05)}$	6.4	n.s.	5.8	-
FV10y				
Capoeira	7.4	16.6	14.9	13.0
Burning	4.8	18.1	11.6	11.5
Mulching	15.3	16.6	22.1	18.0
Incorporation	21.7	25.5	18.2	21.8
Burning + NPK	24.3	33.7	15.3	24.4
Mulching + NPK	20.1	36.7	23.2	26.7
Incorporation + NPK	19.3	20.7	26.4	22.1
$LSD_{(P=0.05)}$	7.1	7.8	6.7	-

n.s.= not significant

SINGH AND SINGH (1995), evaluating the effect of the incorporation of plant residues (rice and wheat) and mineral fertilization under reduced tillage in an Inceptisol, observed that straw + fertilizer resulted also in a significant increase of microbial biomass P and that this effect was smales with straw alone. They concluded that higher microbial biomass levels lead to higher nutrient release and better plant growth and grain yields. Various authors (RAGHUBANSHI, 1991; LADD, 1992; RITZ et al., 1992; SANTRUCKOVA, 1992; WICK, 1997) reported that variation of microbial biomass P are influenced by the quantity and quality of the organic matter input, moisture conditions, temperature, plant growth, and fertilization.

In both areas, a significant Pearson correlation was found between microbial P and rice and cowpea grain yields as well as cassava root yield, with the exception of for the rice grain yield of FV10y (Table 29). Similar results have been reported by other authors (BROOKES et al., 1984; BROOKES et al., 1985; SRIVASTAVA AND SINGH, 1989; SRIVASTAVA AND LAL, 1994) for tropical arid forests. The correlations between grain yield and microbial biomass P indicate that the microbial biomass can provide P for the crops through organic matter mineralisation. This has been observed by SRIVASTAVA AND LAL (1994) in tropical agricultural systems with the application of farmyard manure and NPK fertilizer. The poor correlation for rice in FV10y reflects the large quantity and the strong demand for P by the microbial biomass in P-poor soils.

Table 29 - Pearson correlation coefficients for relationships between microbial biomass P and crop yields

	Microbial biomass P	
	FV4y	**FV10y**
Rice yields	0.706***	-0.011
Cowpea yields	0.742 ***	0.622**
Cassava yields	0.738***	0.595**

* Significant level: *** at P≤0.001; ** at P≤0.01;* at P≤0.05; n=18

4.1.4.2 Decomposition study

4.1.4.2.1 Chemical composition of plant residues

The chemical composition of the fallow vegetation used in the decomposition experiments are shown in Table 4. The phosphorus concentration in the mulch was higher in FV4y (0.45 mg g^{-1}) than in FV10y (0.25 mg g^{-1}). The litter collected at the same sites before slashing had P concentrations of 0.53 and 0.30 mg g^{-1} in FV4y and FV10y, respectively.

4.1.4.2.2 Decomposition patterns of plant residues and phosphorus release

Loss of dry matter during the decomposition of the litter was more rapid in FV4y (Figure 8). Rapid decomposition of the litter in FV4y occurred during the first 60 days (29% weight reduction), whereas in FV10y the weight reduction was only 11%. Decomposition in FV4y slowed down considerably after 150 days. For litter of different tree species and crop residues as a source of organic matter for agricultural crops, this pattern of decomposition has also been observed by PALM AND SANCHEZ (1990), SCHROTH et al. (1992), TIAN et al. (1992), HANDAYANTO et al. (1994), ARUNACHALAM et al. (1996) and JAMA AND NAIR (1996).

Decomposition of litter in FV10y was linear during the entire 240 days of observation and showed a slower pattern similar to that of the decomposition of its mulch. In Puerto Rico, ZOU et al. (1995) found litter decomposition in a secondary forest to be faster than in a mature forest. Rapid decomposition of humid tropical forest litter has been observed by KATO, 1995. DENICH (1989), however, found a weight reduction of only 2% after 6 months in young secondary vegetation of northeastern Pará.

Decomposition of the aboveground biomass at 150 days after application of mulch ranged from 17% to 36%, regardless of the use of *capoeira* (FV4y, FV10y). In spite of the greater C:P ratio of the material from FV10y (Figure 8), the rates of decomposition were similar for the two materials throughout the study period. This effect differed from the process of litter decomposition, which was faster in FV4y.

In both study areas, the decomposition rate of the incorporated material was slower than that of the mulched material. These results do not agree with the observations made by HOLLAND AND COLEMAN (1987) cited by SANCHEZ et al. (1989) who found the decomposition rate of the mulch incorporated into the soil, to be faster than that of the mulch applied to the surface of the soil. JAMA AND NAIR (1996), on the other hand, reported that the decomposition of mulch of *Leucaena leucocephala* and *Cassia siamea* applied to the surface of the soil was faster than when incorporated into the soil. JAMA AND NAIR (1996), however, related this behavior to the artificial humidity conditions created in the mulch bags as compared to mulch placed freely on the soil. The incorporation of mulch for the decomposition studies was, furthermore, done by placing the bags below the surface of the soil, simulating an incorporation which did not match with the real incorporation of organic residues mixed with the soil. These arguments could apply to our study as well.

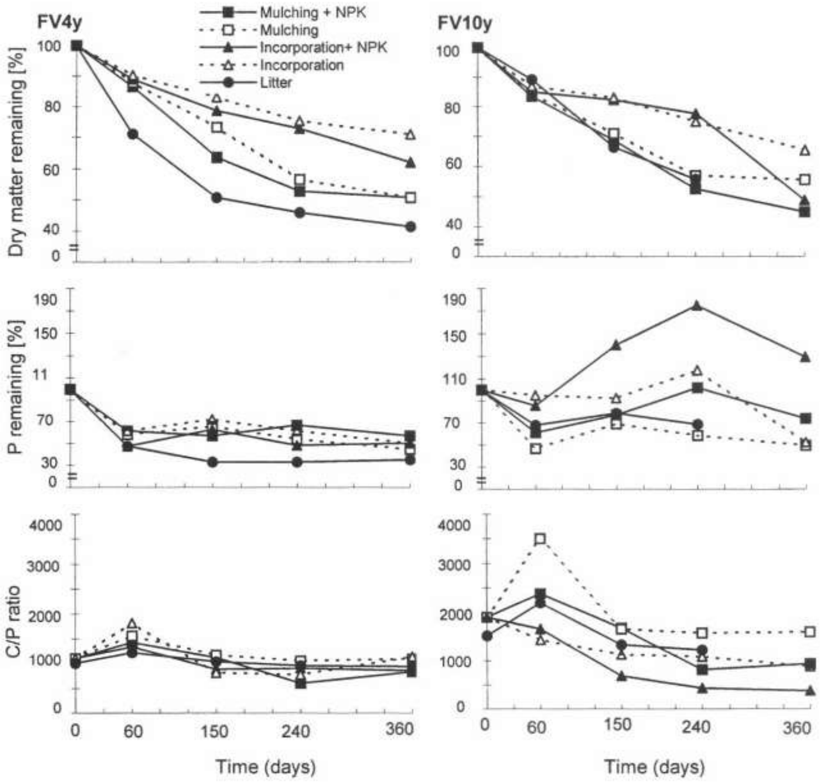

Figure 8 - Dynamics of dry matter, phosphorus and changes in the C:P ratio in aboveground plant residues as a result of decomposition processes measured in litterbags in the experimental areas (FV4y and FV10y)

The factors that could have contributed to a faster decomposition rate of surface mulch than of incorporated material were 1) presence of oxygen - because the decomposition of plant residues is a process mediated by organisms and favored by the presence of oxygen - (VAUGHAN AND ORD, 1985; SPARLING, 1985; ANDERSON AND FLANANGAN, 1989; FROSSARD et al., 1995) and 2) the alternate drying and rewetting processes (MEENTEMEYER, 1978; BABBAR AND EWEL, 1989).

The climatic impact on the mulch and litter decomposition were not evaluated in this study (December 1994 to December 1995). The decomposition rates of the mulch during the first 150 days could, however, have been favored by the rainy season (December to April). The seasonal climatic conditions, mainly precipitation (Figure 3), influence decomposition dynamics and hence nutrient availability (SWIFT et al., 1981; LOWMAN, 1988; ALVARÉZ-SÁNCHEZ AND BECERRA, 1996).

The reduction of P levels in the unburned treatments, was high after 60 days of decomposition: around 45%, when the mulch was applied to the soil surface and 51%, when incorporated. From that time on, the P content stabilized in FV4y, whereas in FV10y it increased, especially when fertilizer was applied (Figure 8). As the initial concentration of P was higher at FV4y, this immobilization effect was not observed with the mulch decomposition. According to EDWARDS AND GRUBB (1982), DENICH (1989) and PALM AND SANCHEZ (1990) the decomposition rate is closely related to the initial concentration of the nutrients in the plants.

After 60 days, the P levels of FV4y and FV10y in the litter showed a decrease of 53% and 33%, respectively. No further changes occurred during the observation period. The difference between the litter decomposition rates in the two areas might be related to differences in the lignin and polyphenol contents and C:N ratios in the biomass of the respective vegetations. TIAN et al. (1992) observed a high correlation between the decomposition rate and C:N:P ratio, lignin and polyphenol contents and litterbag mesh size, indicating that all of these factors need to be considered in the estimation of plant residue quality to predict their decomposition and nutrient release. The rapid P release in the initial phase also has been reported by EWEL (1976), BABBAR AND EWEL (1989), SCHROTH et al. (1992), and SWIFT et al. (1981). Initial decrease of remainder P content in litter decomposition in humid forest was observed by KATO (1995). DENICH (1989), studying decomposition of *capoeira* biomass in the Northeast of the state of Pará, found that P concentrations in the mulch material did not vary during the decomposition process.

The low P content in mulch and litter of the *capoeira* corresponds with a high C:P ratio. In FV4y, the C:P ratio in the mulch material was around 1100 and varied little with time. Differences between mulch and litter were not observed. In FV10y, the C:P ratio was around 1300 being slightly higher in the mulch (Figure 8). SCHLESINGER AND HASEY (1981) suggest that C:P ratios are important for the decomposition of litter. The C:P ratio of the material affects the release of P during the decomposition of organic inputs (SANCHEZ et al. 1989).

The N:P ratio was higher in litter (43 and 55 in FV4y and FV10y, respectively) than in mulch (25 and 20 in FV4y and FV10y, respectively) (Figure 9). There was no significant correlation between N:P ratio and remaining dry matter suggesting that nitrogen has no influence on the P dynamics. PALM AND SANCHEZ (1990) reported that N:P ratios close to 10 imply that nitrogen is controlling the phosphorus dynamics in the decomposition process. Such conditions developed only in FV10y when the biomass was incorporated after fertilization. VOGT et al. (1986) reports that N:P ratios determine whether phosphorus immobilization will occur.

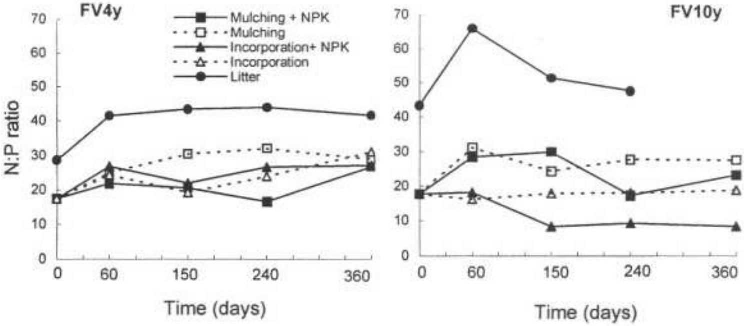

Figure 9 - Dynamics of N:P ratios in mulch and litter in experimental areas (FV4y and FV10y) in 0 –10 cm depth

4.2 Screening of cultivars for slash-and-mulch systems

Breeding for slash-and-mulch systems has been neglected by plant breeders in the past. The development of slash-and-mulch systems, however, requires adapted cultivars, but, until today, little information about the suitability of cultivars for these systems can be found.

4.2.1 Rice cultivars

Crop performance

Within the eight rice cultivars tested under slash-and-mulch conditions, grain yields varied between 0.95 (Ligeiro) and 1.3 t ha^{-1} (CNA 7706) in the non-fertilized plots (Figure 10). The new CNA 7706, released by EMBRAPA, yielded 39% more than the local cultivar Ligeiro, although the difference was not significant. These yields are considerably higher than those obtained in the first cropping period in the land preparation experiment which ranged from 0.4 (mulch) to 0.5 t ha^{-1} (incorporation) and may thus not be representative for fire-free land preparation. The grain yield without fertilizer in the screening test may, however, be considered excellent if we take into consideration the productivity of the Bragantina region, which is about 0.64 t ha^{-1} in the traditional slash-and-burn system (IBGE, 1997). The low production in this region is due to the use of cultivars unsuitable for low input and low technology conditions; a result of the limited access to capital and the low prices for agricultural products, amongst other factors. The Xingú, Araguaia and Rio Parnaíba cultivars were also tested by LOPES et al. (1991) on burned and fertilized fields and yielded between 0.9 and 1.5 t ha^{-1}. In the Cerrado region of Brazil, FAGERIA et al. (1995) reported, on average, grain yield of 2.8 t ha^{-1} for the Rio Parnaíba, Araguaia, Caiapó and CNA 7706 cultivars in burned plots without fertilizer. These results reveal the potential of these cultivars in soils of low fertility.

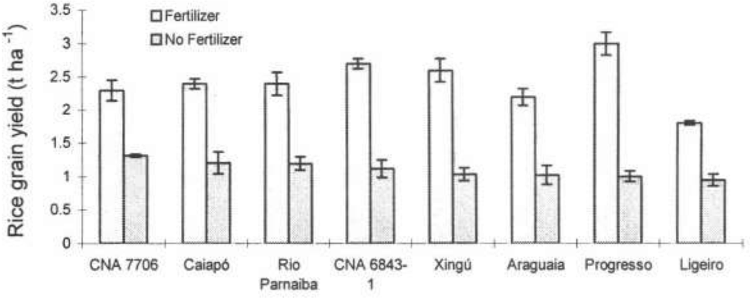

Figure 10 - Average grain yield (13% moisture) of eight rice cultivars tested in 1995 under mulch conditions with and without fertilizer application. Bars= SE; n=5

With fertilizer application, the average yields of the 8 cultivars under slash-and-mulch conditions increased by 76% (CNA 7706) to 200% (Progresso) compared to the yields in plots without fertilizer. The yields varied from 1.8 t ha $^{-1}$ for Ligeiro to 3.0 t ha $^{-1}$ for Progresso, the locally improved cultivar (Figure 10). These yield levels are in line with those found in the land preparation experiments. The use of adequate levels of fertilizers is a prerequisite for higher yields on the low fertility soils of northeast Pará. SANTOS et al. (1982) showed that 40% of the increase in the upland rice yield in the acid soil of the Brazilian Cerrado could be attributed to fertilizer application.

Optimizing nutrient use efficiency is an increasingly important aspect of crop production due to economic and environmental concerns. Different indices were used in order to differentiate between cultivars for nutrient use efficiency and adaptation to the slash-and-mulch system.

The efficiency in grain yield (EGI) was calculated according to the method suggested by FAGERIA et al. (1988). According to this index, the Rio Parnaíba, Progresso, Caiapó, CNA 6843-1 and CNA 7706 were the most efficient in grain production (Table 30). These cultivars also showed efficiency indices higher than 1 in studies done by FAGERIA et al. (1995) in the Cerrado region of Brazil. None of the cultivars tested had a low efficiency, with the exception of the local Ligeiro with an EGI of 0.66.

Table 30 - Efficiency in grain yield index (EGI), grain, straw and total dry matter production of the eight rice cultivars under mulch conditions with (F) and without (NF) fertilizer

Cultivars		Dry matter production [t ha^{-1}]					
	EGI	Grain		Straw		Total	
		NF	F	NF	F	NF	F
CNA 7706	1.14	1.14	2.00	1.24	3.26	2.38	5.26
Caiapó	1.07	1.04	2.04	1.99	3.91	3.03	5.95
Rio Parnaíba	1.08	1.03	2.10	1.95	3.16	2.98	5.26
CNA6843-1	1.12	0.96	2.34	1.48	3.08	2.44	5.42
Xingú	0.99	0.89	2.22	0.99	3.08	1.88	5.30
Araguaia	0.87	0.89	1.94	1.47	3.86	2.36	5.80
Progresso	1.13	0.87	2.57	1.27	2.96	2.14	5.52
Ligeiro	0.66	0.82	1.61	1.19	2.66	2.01	4.27
Means	1.01	0.96	2.1	1.45	3.25	2.40	5.35
$LSD_{(P=0.05)}$	0.46	n.s.	0.33	0.51	0.58	0.73	0.84

n.s. = not significant

The differences in the total dry matter yields were statistically significant (Table 30). The total dry matter yields in the fertilized plots were, on average, 2.2 times (5.4 t ha^{-1}) higher than in the plots without fertilizer (2.4 t ha^{-1}).

The harvest index shows significant differences between cultivars (Table 31). In plots without fertilizer the harvest index varied from 0.34 to 0.48, whereas in fertilized plots it varied from 0.34 to 0.46. In the Ivory Coast, VAN REULER AND JANSSEN (1993) also observed harvest index values of about 0.3 to 0.4 for rice, with and without the use of fire during land preparation. With fertilizer, the harvest index was positively correlated with grain production ($r=0.55$, $p\leq0.001$), whereas without fertilizer there was no significant correlation. The Progresso, CNA 6843-1 and Xingú cultivars rated high on the harvest index, regardless of fertilizer use. The CNA 7706 and Ligeiro cultivars showed higher grain yields in the plots without fertilizer, whereas the Rio Parnaíba, Xingú, Progresso and CNA 6843-1 yielded higher in the fertilized plots.

Table 31 - Harvest index, plant height, number of tillers, lodging and 1000 grains weight of eight rice cultivars under mulch conditions with (F) and without fertilizer(NF)

Cultivars	Harvest index		Plant height [cm]		Number of tillers		Number of lodged tillers [no plot^{-1}]*		1000 grains weight [g]	
	NF	F	NF	F	NF	F	NF	F	NF	F
CNA 7706	0.48	0.38	61	82	12	19	3	2	22	21
Caiapó	0.34	0.34	72	96	15	21	2	3	27	26
Rio Parnaíba	0.35	0.40	80	101	14	17	1	11	32	33
CNA 6843-1	0.41	0.43	63	78	17	24	2	3	22	20
Xingú	0.48	0.42	69	89	10	16	1	3	28	30
Araguaia	0.37	0.34	68	98	8	11	1	3	28	27
Progresso	0.41	0.46	57	75	17	30	2	2	23	21
Ligeiro	0.42	0.38	83	106	6	10	9	15	31	28
Means	0.41	0.39	69	90	12	19	3	3	27	26
LSD$_{(P=0.05)}$	0.06	0.03	9.8	7.8	2.8	4.7	0.9	1.6	2.5	3.1

*Plot = 4.3 m^2

The plant height varied from 57 cm (Progresso) to 83 cm (Ligeiro) in the plots without fertilizer and from 75 cm (Progresso) to 106 cm (Ligeiro) in the fertilized plots (Table 31). Higher plants generally led to a higher rate of lodging (Table 31) which corresponds with results reported by CHANG AND LI (1991). In fertilized plots, Rio Parnaíba and Ligeiro cultivars showed higher numbers of lodged plants, whereas without fertilizer only the local cultivar Ligeiro lodged. Lodging reduces the rice production. FAGERIA (1984) reported that lodging reduces the movement of photosynthates and the nutrients absorbed by the roots. Moreover, the production of grains decreases due to increased shading, leading to a larger number of sterile grains.

The number of tillers showed significant differences between cultivars (Table 31). The smallest number of tillers was observed for the local cultivar Ligeiro. The Progresso and CNA 6843-1 cultivar grew the largest numbers of tillers, both in the fertilized and non-fertilized plots. The average number of tillers was 19 and 12 for the fertilized and non-fertilized plots, respectively. Tiller number and the resulting panicle number have a strong impact on grain yield (VERGARA, 1991).

The 1000 grain weight varied from 22 g to 32 g in the plots without fertilizer and from 20 g to 33 g in the fertilized plots (Table 31). The Rio Parnaíba, Xingú and Ligeiro cultivars had the highest 1000 grain weight at both fertilizer levels.

P uptake and P use efficiency

Significant differences between cultivars were observed for the phosphorus content of the grains, straw and aboveground total biomass (grains and straw), independent of fertilizer use. Only for the aboveground total biomass without fertilizer no significant difference between the cultivars could be shown (Table 32).

The total P uptake varied from 1.4 to 2.9 kg ha^{-1} in non-fertilized plots and from 5.2 to 13.1 kg ha^{-1} in fertilized plots. On average, 71 and 82 % of the P uptake (with and without fertilizer, respectively) were translocated to the grains, indicating that increasing P availability leads to an increase of grain production. The Progresso, Araguaia, and Xingú cultivars accumulated large amounts of P in the plant under slash-and-mulch conditions. Phosphorus uptake in total biomass was positively correlated with grain yields ($r=0.46$, $p \leq 0.001$) with and ($r=0.73$, $p \leq 0.001$) without fertilizer.

Table 32 - Phosphorus content in grain, straw and total biomass of the eight rice cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivars	Phosphorus content [kg ha^{-1}]					
	Grain		Straw		Total	
	NF	F	NF	F	NF	F
CNA 7706	2.4	3.6	0.6	1.7	2.9	5.2
Caiapó	1.5	5.0	0.8	2.2	2.3	7.2
Rio Parnaíba	1.2	8.3	0.9	1.2	2.1	9.6
CNA 6843-1	1.4	4.6	0.5	1.3	1.9	5.8
Xingú	2.2	9.3	0.4	1.9	2.6	11.2
Araguaia	1.5	10.3	0.7	1.4	2.1	11.7
Progresso	0.9	11.6	0.5	1.5	1.4	13.1
Ligeiro	1.3	6.5	0.5	1.3	1.7	7.7
Means	1.5	7.4	0.6	1.6	2.1	8.9
$LSD_{(P=0.05)}$	0.8	1.7	0.3	0.5	n.s.	1.9

n.s. = not significant

In order to compare the efficiency of fertilizer use, the physiological efficiency of the cultivars (PEP- biological production obtained per unit of absorbed nutrient), the agronomic efficiency (PEA - economic benefit per unit of applied nutrient), the apparent nutrient recovery efficiency (P absorbed per unit of P applied), the efficiency of utilization of absorbed P by the rice cultivars (PUTE), the uptake efficiency of applied P (PUPE) and the P-harvest index (PHI) were calculated (Table 33).

Table 33 - Physiological efficiency (PEP), agronomic efficiency (PEA), P uptake efficiency (PUPE), apparent recovery of P, P utilization efficiency (PUTE) and P harvest index (PHI) of the eight rice cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer, 1995 (for definitions see page 38)

Cultivars	PEP	PEA	PUPE	PUTE		Apparent recovery		PHI	
				NF	F			NF	F
	[kg kg^{-1}]	[kg kg^{-1}]	[kg kg^{-1}]	[kg kg^{-1}]		[kg ha^{-1}]	[%]	[%]	
CNA 7706	439	34	0.21	404	392	2.3	9	81	68
Caiapó	228	40	0.29	451	293	4.9	19	64	68
Rio Parnaíba	141	43	0.38	516	219	7.4	30	57	87
CNA6843-1	368	55	0.23	516	413	4.0	16	70	78
Xingú	151	53	0.45	348	199	8.6	35	84	83
Araguaia	118	42	0.47	493	170	9.6	39	64	88
Progresso	145	68	0.52	670	196	11.7	47	62	88
Ligeiro	130	31	0.31	485	209	6.0	24	73	83
Means	215	46	0.35	485	261	6.81	24.2	69	80
$LSD_{(P=0.05)}$	128	16	0.07	148	55.1	2.05	8.2	9	6

The physiological efficiency (PEP) and the agronomic efficiency (PEA) showed significant differences among the cultivars (Table 33). The highest values of PEP were found in the CNA 7706 and CNA 6843-1 cultivars (439 and 368 kg grain kg^{-1} P). The P uptake efficiency (PUPE) was larger in the Progresso, Araguaia and Xingú cultivars, reflecting the higher amount of absorbed P. The highest grain production per unit P applied (PEA) was observed in the Progresso (68 kg grain per kg), CNA 6843-1 (55 kg kg^{-1}) and Xingú (53 kg kg^{-1}) cultivars, indicating that to obtain satisfactory productions of grains, these cultivars need to be fertilized with P.

The P-fraction apparently recovered varied from 9 to 47%, showing the highest variation rate among the cultivars (Table 33). BRADY (1989) reports that, in general, the recovered fraction of fertilizer P is not greater than 10-15% due to the process of P-sorption and the low mobility of this nutrient in the soil. The Progresso, Araguaia and Xingú cultivars were the most efficient in recovering fertilizer P, with Progresso being the most efficient. From the

25 kg ha^{-1} of applied P, this cultivar recovered 11.7 kg ha^{-1} (47% of applied P) and it produced 3 t of grains ha^{-1}. The cultivar CNA 7706 showed a lower capacity to recover P from fertilizer. It only recovered 2.3 kg of P (9% of applied P) and produced 2.3 t grains ha^{-1}, showing its low demand for P. BALIGAR AND FAGERIA (1997) evaluating 6 genotypes of rice irrigated in lowland acid soil central of Brazil, reported that on average, 38 and 47% of P were recovered, under medium and high fertilizer level, respectively. VAN REULER AND JANSSEN (1996) found that the recovery of fertilizer-P by the rice plant in the Tai region of South-West Ivory Coast decreases with an increasing rate of P-fertilizer application.

In fertilized plots, from 170 to 413 kg of grains per kg of absorbed P (PUTE) were produced. The CNA 6843-1 and CNA 7706 cultivars had the larger PUTE (413 and 392 kg of grains per kg absorbed P, respectively). Without fertilizer, PUTE varied from 348 to 670 kg of grains per kg absorbed P with Progresso cultivar having the largest value (Table 33). VAN REULER AND JANSSEN (1996) reported values of around 600 kg of rice grains per kg absorbed P. They concluded that high values of PUTE indicate that P is the yield limiting nutrient element.

The PHI values of the cultivars varied from 57 to 84% in plots without fertilizer and from 68 to 88% in the fertilized plots (Table 33). Without fertilizer Xingú and CNA 7706 had the highest PHI, with fertilizer Progresso, Araguaia, Rio Parnaíba and Ligeiro. The Xingú cultivar showed a similar PHI with and without fertilizer, indicating its larger capacity to transform the P uptake into the grain in both levels of fertilization

Significant differences in nutrient efficiency of rice cultivars appear to exist and might be captured through the selection or breeding of cultivars adapted to the nutrient dynamics under heavy organic matter application or mulching. Without fertilizer the CNA 7706 cultivar was the overall best performing cultivar because of its high productivity and high PHI and PUTE. With fertilizer, Progresso, Xingú and Araguaia cultivars were the most suitable due to the fact that they have a high grain yield, a large capacity to absorb and to recover P applied as fertilizer.

4.2.2 Cowpea cultivars

Crop performance

This experiment was installed at the same experimental site as the screening of rice. The residues of the rice crop had been left on the field and manual weeding was done in the area before the planting of cowpea.

The results of the experiment installed in 1995 showed extremely low yields in the non-fertilized plots, varying from 0.1 t ha^{-1} (TE 86-80-73F) to 0.3 t ha^{-1} (TE 86-73-3G). With the use of fertilizer, the yields varied from 1.0 t ha^{-1} (TE 89-149-8G) to 1.5 t ha^{-1} (TE 86-80-86F) (Figure 11). No significant differences between cultivars could be detected. In the Bragantina region, SILVA et al. (1986) reported average yields of 0.9 t ha^{-1} for the climbing type and 1.5 t ha^{-1} for the runner type of cowpea under conditions of burning and fertilization.

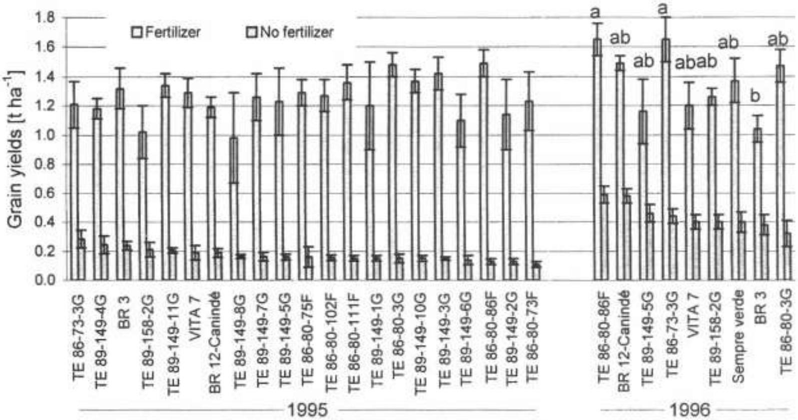

Figure 11 - Average grain yield (13% moisture) of cowpea cultivars tested in 1995 and 1996 under mulch conditions with and without fertilizer

Cultivars followed by the same letter(s) in each level of the fertilization are not significantly different at p=0.05 of the Tukey test. (Bars= SE; n = 4)

In 1996, the yields without fertilizer were higher than in 1995, varying from 0.3 t ha^{-1} (TE 86-80-3G) to 0.6 t ha^{-1} (TE 86-80-86F). Higher yields in 1996 might be attributed to the effect of the nutrient release by decomposition of remaining fallow-vegetation mulch and rice and cowpea plant residues. No significant differences were observed among the cultivars. In fertilized plots, the grain yields varied from 1.0 t ha^{-1} (BR 3) to 1.7 t ha^{-1} (TE 86-80-86F) (Figure 11). In both years, grain yields were 3 and 7 times higher when fertilized. In fertilized plots, the yield of the cultivars TE 86-80-86F, BR 12-Canindé, TE 86-73-3G and TE 89-158-2G increased compared to 1995, whereas the yields of the cultivars BR 3, VITA 7 and TE 89-149-5G declined.

The results of the non-fertilized plots in both years show that under conditions of slash-and-mulch, mineral fertilizer is required in order to obtain reasonable yields of cowpea. OLIVEIRA et al. (1992) showed that residual effects of fertilizer on cowpea yield in yellow Latosol in the Amazon were primarily affecting phosphorus content in the plant. Grain yield increased proportionately with the levels of phosphorus in the soil.

Pod dry matter yields showed significant differences among cultivars, although no significant differences were found for grain (Table 34). Without fertilizer, the cultivar TE 86-73-3G accumulated the highest amount of dry matter in the pod, although the yields were statistically not different from TE 89-149-11G, TE 86-80-75F, TE 86-80-111F, TE 89-149-4G, TE 89-149-7G, TE 89-158-2G, VITA 7, BR 12-Canindé and BR 3. With fertilizer, the cultivar TE 89-80-3G accumulated the highest amount of dry matter in the pod (Table 34). Due to the leaves drop before harvest, the efficiency index could not calculated for cowpea.

Table 34 – Grain, pod and total dry matter production of 21 cowpea cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

	Dry matter production [t ha^{-1}]					
	Grain		Pod		Total	
	NF	F	NF	F	NF	F
TE 86-73-3G	0.25	1.10	0.06	0.39	0.31	1.49
TE 89-149-4G	0.21	1.14	0.05	0.35	0.27	1.49
BR 3	0.21	1.28	0.03	0.31	0.23	1.59
TE 89-158-2G	0.18	0.99	0.05	0.33	0.23	1.32
TE 89-149-11G	0.18	1.30	0.03	0.38	0.21	1.67
VITA 7	0.17	1.25	0.05	0.38	0.21	1.63
BR 12-Canindé	0.16	1.16	0.03	0.35	0.20	1.51
TE 89-149-8G	0.14	0.94	0.02	0.30	0.17	1.24
TE 89-149-7G	0.14	1.21	0.03	0.32	0.17	1.53
TE 89-149-5G	0.14	1.19	0.02	0.34	0.16	1.53
TE 86-80-75F	0.14	1.24	0.03	0.36	0.17	1.61
TE 86-80-102F	0.13	1.22	0.02	0.33	0.16	1.55
TE 86-80-111F	0.13	1.31	0.03	0.39	0.16	1.70
TE 89-149-1G	0.13	1.16	0.03	0.35	0.16	1.51
TE 86-80-3G	0.13	1.42	0.02	0.45	0.15	1.87
TE 89-149-10G	0.13	1.32	0.02	0.35	0.15	1.67
TE 89-149-3G	0.13	1.38	0.02	0.36	0.15	1.73
TE 89-149-6G	0.12	1.06	0.02	0.29	0.15	1.35
TE 86-80-86F	0.11	1.43	0.02	0.42	0.13	1.85
TE 89-149-2G	0.10	1.10	0.02	0.33	0.13	1.43
TE 86-80-73F	0.0 9	1.18	0.02	0.37	0.11	1.55
Means	0.15	1.20	0.03	0.36	0.18	1.56
LSD$_{(P=0.05)}$	n.s.	n.s.	0.02	0.07	n.s.	n.s.

n.s.= not significant

The yield components such as pod length, number of seeds per pod, grain weight per pod and pod weight showed significant differences among cultivars in 1995 (Table 35). The pod length varied from 10.2 to 17.9 cm without fertilizer and from 12.6 to 19.0 cm with fertilizer. The number of grains per pods, without and with fertilization varied from 6 to 11 and from 7 to 15 grain per pod, respectively. The grain weight per pod varied from 0.45 to 1.59 g without fertilization and from 1.32 to 2.20 g with fertilization. The pod weight varied from 0.04 to 0.42 g and from 0.37 to 0.55 g without and with fertilizer, respectively.

Table 35 - Pod characteristics of 21 cowpea cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivars	Pod length		Grain number		Grain weight		Pod weight	
	NF	F	NF	F	NF	F	NF	F
	[cm]		[grains pod^{-1}]		[g pod^{-1}]		[g pod^{-1}]	
TE 86-73-3G	17.9	19.0	10	12	1.5	2.1	0.2	0.5
TE 89-149-4G	14.9	16.4	11	11	1.5	1.5	0.2	0.4
BR 3	13.3	15.6	6	7	1.5	2.2	0.3	0.5
TE 89-158-2G	14.9	16.6	10	11	1.2	1.3	0.3	0.4
TE 89-149-11G	15.4	17.0	11	13	1.6	1.9	0.2	0.5
VITA 7	12.7	15.5	8	12	1.0	1.9	0.2	0.5
BR 12-Canindé	10.2	12.6	9	12	0.9	1.5	0.1	0.4
TE 89-149-8G	14.9	15.9	10	12	1.4	1.7	0.2	0.4
TE 89-149-7G	13.5	16.7	8	13	1.0	1.9	0.3	0.5
TE 89-149-5G	14.9	16.8	9	12	1.3	1.9	0.2	0.4
TE 86-80-75F	11.0	14.8	8	13	0.5	1.8	0.1	0.5
TE 86-80-102F	14.9	16.0	11	13	1.6	1.5	0.3	0.4
TE 86-80-111F	13.5	16.3	10	14	1.0	1.8	0.3	0.5
TE 89-149-1G	14.5	17.2	9	12	1.2	1.6	0.2	0.5
TE 89-149-3G	14.6	17.1	9	12	1.3	1.9	0.4	0.5
TE 89-149-10G	13.1	15.6	9	13	1.0	1.7	0.1	0.4
TE 86-80-3G	13.0	14.8	11	14	1.4	1.6	0.3	0.5
TE 89-149-6G	14.2	16.7	10	12	1.6	2.02	0.4	0.6
TE 86-80-86F	13.7	16.4	10	13	1.1	1.84	0.2	0.5
TE 89-149-2G	14.8	17.2	9	11	1.2	2.0	0.3	0.5
TE 86-80-73F	14.6	17.2	11	15	0.8	1.9	0.2	0.5
Means	14.0	16.2	9.5	12.2	1.2	1.8	0.2	0.5
LSD$_{(P=0.05)}$	2.1	1.2	2.5	1.8	0.3	0.3	0.1	0.1

Several screenings of cowpea germplasm collections have been done in Pará (OLIVEIRA et al., 1980; SILVA, 1982; SILVA et al., 1986; SILVA et al., 1991) under slash-and-burn conditions and suitable cultivars have thus been identified. Among the best cultivars IPEAN V69, 40 dias VR, BR 2-Bragança and BR 3-Tracuateua could be mentioned. The latter is the most widely used in the northeast of Pará state, mainly due to the size of its grains (KATO et al. 1992). The yields of those cultivars are around 1.0 to 1.8 t ha^{-1} under conditions of burning and fertilization.

The cowpea cultivars that are available now, although known as adapted to acid soils and low levels of soil fertility, do not perform well in a slash-and-mulch system if no supplemental fertilizer is applied. Various studies have reported that without NPK fertilization, the cowpea yield is extremely low (STOLBERG-WERNIGERODE, 1984; BRASIL et al., 1986; BÜNEMANN, 1998)

P uptake

Although cultivars differ in their capacity to absorb and transport nutrients, no significant differences were found in P content in the grain. Significant difference were, however, found in the P content of pods (Table 36). A high variability without fertilizer was observed.

Table 36 - Phosphorus content in grain, pod and total (grain + pod) of 21 cowpea cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivar	Phosphorus content [kg ha^{-1}]					
	Grain		Pod		Total	
	NF	F	NF	F	NF	F
TE 86-73-3G	0.66	3.78	0.04	0.34	0.7	4.1
TE 89-149-4G	0.60	3.95	0.04	0.25	0.6	4.2
BR 3	0.49	3.93	0.02	0.26	0.5	4.2
TE 89-158-2G	0.52	3.59	0.03	0.26	0.6	3.9
TE 89-149-11G	0.46	4.38	0.01	0.25	0.5	4.6
VITA 7	0.40	3.88	0.02	0.22	0.4	4.1
BR 12-Canindé	0.41	3.90	0.02	0.26	0.4	4.2
TE 89-149-8G	0.38	3.20	0.01	0.20	0.4	3.4
TE 89-149-7G	0.38	4.34	0.02	0.27	0.4	4.6
TE 89-149-5G	0.33	3.94	0.01	0.30	0.3	4.2
TE 86-80-75F	0.51	4.19	0.02	0.19	0.5	4.4
TE 86-80-102F	0.34	4.15	0.02	0.27	0.4	4.4
TE 86-80-111F	0.38	4.52	0.02	0.27	0.4	4.8
TE 89-149-1G	0.37	3.98	0.02	0.37	0.4	4.4
TE 89-149-3G	0.31	4.55	0.02	0.36	0.3	4.9
TE 89-149-10G	0.36	4.59	0.01	0.34	0.4	4.9
TE 86-80-3G	0.37	5.22	0.01	0.26	0.4	5.5
TE 89-149-6G	0.29	3.47	0.02	0.23	0.3	3.7
TE 86-80-86F	0.31	5.06	0.02	0.25	0.3	5.3
TE 89-149-2G	0.28	3.64	0.02	0.28	0.3	3.9
TE 86-80-73F	0.32	4.06	0.01	0.26	0.3	4.3
Means	0.40	4.11	0.02	0.27	0.4	4.4
LSD$_{(P=0.05)}$	n.s.	n.s.	0.02	0.06	n.s.	n.s.

n.s. = not significant

Without fertilization, the P content in the pods varied from between 0.01 to 0.04 kg ha^{-1}, with fertilization between 0.19 to 0.37 kg ha^{-1}. On average, the phosphorus accumulation in the grains was 0.4 and 4.1 kg ha^{-1} and the total P accumulation in the grains and pods was 0.4 and 4.4 kg ha^{-1} without and with fertilizer, respectively. With fertilization the P content of the grains was approximately 10 times higher than without fertilizer.

With fertilization all cultivars tested in the slash-and-mulch system performed better than the mean slash-and-burn productivity level of the Igarapé Açu region with an average yield of around 700 kg ha^{-1} for cowpea. The TE 86-80-86F and TE 86-80-3G cultivars even yielded 1.4 t ha^{-1} in 1995 and 1996. Without fertilizer, these cultivars do also not produce satisfactory grains.

The efficiency index was not calculated because the aerial biomass (except grain and pod) could not be included in total biomass.

4.2.3 Maize cultivars

Crop performance

Figure 12 illustrates the yields for maize in the 1995 (11 cultivars) and 1997 (10 cultivars) growing seasons.

In 1995, significant differences in yields were only obtained with unfertilized maize. Under these conditions, the grain yields varied from 0.16 t ha^{-1} (Pontinha) to 0.54 t ha^{-1} (BR 5102). The cultivars BR 5102, Saracura and CMS 50 yielded between 215 and 231% higher than the local cultivar Pontinha. With NPK fertilization, yields varied from 2.2 t ha^{-1} (Pontinha) to 3.0 t ha^{-1} (CMS 50). On average, NPK fertilization increased the grain yields by 85% compared to the yields without fertilizer in both years (1995 and 1997).

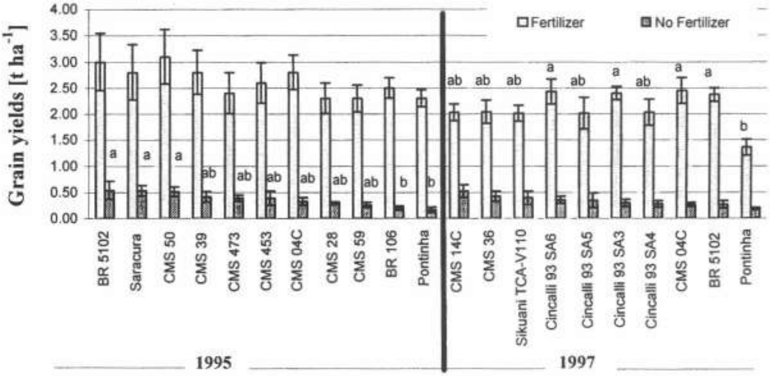

Figure 12 - Average grain yield (13% moisture) of maize cultivars tested in 1995 and 1997 under mulch conditions, with and without fertilizer.

Cultivars followed by the same letter(s) in each level of the fertilization are not significantly different at p=0.05 of the Tukey test. (Bars= SE; n = 4)

In 1997 differences were observed between cultivars (Figure 12). The grain yields varied from 1.4 t ha^{-1} (Pontinha) to 2.5 t ha^{-1} (CMS 04C). The cultivars Cincalli 93 SA6, Cincalli 93 SA3, CMS 04C and BR 5102 yielded significantly (74 to 81%) higher in grain than the local cultivar Pontinha. Without fertilizer, the yields varied from 0.12 t ha^{-1} (Pontinha) to 0.53 t ha^{-1} (CMS 04C and Saracura), although no significant differences were observed. Maize cultivars in the slash-and-mulch system with fertilizer reached the same yields as improved maize from CIMMYT (PANDEY et al., 1995) and from EMBRAPA-Milho e Sorgo (BAHIA FILHO et al., 1997) did on acid soils. At CIMMYT-Colombia, PANDEY et al. (1995) selected maize populations for the conditions of acid soils in the tropics, and found that populations of SA4, SA5, SA6 and SA7 produced 2.34, 2.58, 1.68 and 1.96 t ha^{-1}, respectively. When tested in soils with liming, the production increased to 6 t ha^{-1}.

The maize grain yields in 1997 decreased compared to 1995. On average, a reduction of 20% could be observed for the cultivars CMS 04C, BR 5102 and Pontinha which were tested both in 1995 and 1997. This reduction could probably be attributed to the variations of the environmental conditions, especially rainfall distribution as affected by the El Nino phenomenon.

The low yields of the cultivars without fertilizer are possibly due to the low phosphorus content in the soil (Table 3). Most of the cultivars in this experiment came from selections developed by EMBRAPA - Milho e Sorgo for acid soils, low fertility (mainly low phosphorus) and high aluminum saturation, but 60 kg ha^{-1} of P_2O_5 is usually applied to assure a reasonable level of available phosphorus (BAHIA FILHO et al., 1997). The cultivars coming from CIMMYT were selected in soils with levels of phosphorus of 10 mg kg^{-1} (SALAZAR et al., 1997; PANDEY et al., 1994).

Without fertilizer, the accumulation of total dry matter varied from 0.8 t ha^{-1} (CMS 28) to 1.6 t ha^{-1} (CMS 50), and, with fertilizer from 3.8 t ha^{-1} (CMS 28) to 5.7 t ha^{-1} (Pontinha) (Table 37). The high yields of total dry matter of the Pontinha cultivar are related to high leaf and stem yields, which consequently leads to a low harvest index (Table 38) and low grain yield (Figure 12). This cultivar, on the other hand, is preferred by the small farmers of the region for feeding chickens, because it has small grains, which do not have to be ground.

Table 37 - Grain, leaves, stem and total dry matter production of maize cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivar	Grain		Leaves		Stem		Total	
	NF	F	NF	F	NF	F	NF	F
	[t ha^{-1}]							
BR 5102	0.47	2.60	0.46	1.72	0.28	0.96	1.21	5.29
Saracura	0.46	2.43	0.52	1.57	0.30	0.89	1.28	4.89
CMS 50	0.45	2.68	0.68	1.72	0.47	1.01	1.60	5.42
CMS 39	0.37	2.40	0.69	1.78	0.36	1.13	1.42	5.31
CMS 473	0.34	2.06	0.47	1.31	0.24	0.78	1.05	4.16
CMS 453	0.34	2.29	0.42	1.05	0.22	0.57	0.98	3.91
CMS 04C	0.29	2.42	0.54	1.67	0.31	1.30	1.13	5.40
CMS 28	0.26	2.02	0.32	1.10	0.19	0.68	0.78	3.80
CMS 59	0.22	2.04	0.41	1.22	0.23	0.70	0.87	3.96
BR 106	0.17	2.20	0.43	1.37	0.21	0.86	0.81	4.43
Pontinha	0.14	1.99	0.80	2.32	0.45	1.42	1.39	5.73
Means	0.32	2.28	0.52	1.53	0.30	0.94	1.14	4.75
$LSD_{(P=0.05)}$	0.16	n.s.	0.22	0.59	0.14	0.38	0.41	1.06

n.s. = not significant

For the harvest index, plant height and ear height significant differences were observed, but not for 1000 grains weight. The plant height in non-fertilized plots varied from 96 cm (CMS 59) to 161 cm (Pontinha), in the fertilized plots from 164 cm (CMS 59) to 229 cm (Pontinha) (Table 38).

Table 38 - Harvest index, plant height, ear height and 1000 grain weight of maize cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivar	Harvest index		Plant height		Ear height		1000 grain	
	NF	F	NF	F	NF	F	NF	F
			[cm]		[cm]		[g]	
BR 5102	0.35	0.50	136	198	56	97	282	260
Saracura	0.36	0.50	128	185	52	93	264	232
CMS 50	0.28	0.51	127	206	53	103	279	231
CMS 39	0.25	0.46	129	202	53	102	259	251
CMS 473	0.33	0.50	120	183	40	87	261	244
CMS 453	0.34	0.58	114	171	42	82	268	275
CMS 04C	0.25	0.45	118	187	45	84	252	264
CMS 28	0.34	0.53	103	167	33	75	253	249
CMS 59	0.25	0.50	96	164	32	77	303	261
BR 106	0.21	0.49	119	186	45	86	225	246
Pontinha	0.10	0.36	161	229	88	148	260	249
Means	0.28	0.49	123	189	49	94	264	251
$LSD_{(P=0.05)}$	0.09	0.08	16.2	11.1	9.5	9.1	n.s.	n.s.

n.s. = not significant

The weight of 1000 grains varied from 225 g (BR 106) to 303 g (CMS 59) without fertilizer and from 231 g (CMS 50) to 275 g (CMS 453) with fertilizer, but no significant differences between cultivars were found. The harvest index was higher with fertilizer, varying from 0.36 (Pontinha) to 0.58 (CMS 453). Without fertilizer, the range was from 0.10 (Pontinha) to 0.36 (Saracura) (Table 38). A high harvest index is associated with a higher grain yield. According to FISHER AND PALMER (1984), PANDEY AND GARDNER (1992) and BOLAÑOS (1995) yield increases of tropical maize cultivars generally result from changes in the dry matter distribution and increase in the harvest index.

P uptake and P use efficiency

Phosphorus content in total dry matter and in grains, leaves and stems is presented in Table 39. Significant differences in the P content at both fertilizer levels were observed.

Table 39 - Phosphorus content in grains, leaves, stems and total biomass of maize cultivars tested in 1995 with mulch conditions with (F) and without (NF) fertilizer

Cultivar	Phosphorus content [kg ha^{-1}]							
	Grains		Leaves		Stems		Total	
	NF	F	NF	F	NF	F	NF	F
BR 5102	1.7	8.9	0.28	1.8	0.20	0.35	2.1	11.1
Saracura	1.7	9.3	0.35	1.0	0.19	0.40	2.2	10.7
CMS 50	1.6	9.0	0.51	1.9	0.27	0.42	2.4	11.3
CMS 39	1.4	8.6	0.43	1.5	0.19	0.54	2.1	10.6
CMS 473	1.2	7.5	0.30	1.1	0.16	0.29	1.7	8.8
CMS 453	1.2	7.6	0.28	1.1	0.12	0.27	1.6	8.9
CMS 04C	1.1	7.7	0.44	1.3	0.24	0.48	1.8	9.4
CMS 28	0.9	7.5	0.19	0.8	0.12	0.28	1.2	8.6
CMS 59	0.7	6.8	0.31	1.1	0.28	0.34	1.3	8.3
BR 106	0.5	6.7	0.28	0.9	0.18	0.30	1.0	7.8
Pontinha	0.9	11.2	0.84	2.3	0.32	0.58	2.0	14.1
Means	1.2	8.2	0.38	1.35	0.21	0.39	1.8	9.7
LSD$_{(P=0.05)}$	0.62	2.39	0.18	0.56	0.08	0.18	0.73	2.5

n.s. = not significant

Phosphorus uptake in the total biomass varied from 1.0 (BR106) to 2.4 kg P ha^{-1} (CMS 50) without fertilizer and from 7.8 (BR 106) to 14.1 kg P ha^{-1} (Pontinha) with fertilizer. Fertilization increased the total P uptake by of least 5 times compared to the unfertilized treatments (Table 39). With fertilizer, the local cultivar Pontinha accumulated the largest amount of phosphorus (14.1 kg P ha^{-1}), although it was statistically similar to the CMS 50 and BR 5102 cultivars. Without fertilizer, the cultivars CMS 50 (2.4 kg P ha^{-1}), Saracura (2.2 kg P ha^{-1}). Br 5102 (2.1 kg P ha^{-1}) and CMS 39 (2.1 kg P ha^{-1}) accumulated the largest amounts of phosphorus. In the south of Brazil, MODEL AND ANGHINONI (1992) observed a phosphorus accumulation in the aboveground maize in the order of 20 kg P ha^{-1} in a system with no-tillage and P-fertilizer application.

On average, 82% and 66% of the total P uptake by the plants, were accumulated in the grains with and without fertilizer, respectively. With fertilizer the P content in grains varied from 6.7

(BR 106) to 11.2 kg P ha^{-1} (Pontinha) and without fertilizer from 0.5 (BR 106) to 1.7 kg P ha^{-1} (Saracura). Although Pontinha was known to be tolerant to low nutrient supply, in this study, it also seemed to be a cultivar which show a good response to fertilization.

The cultivars showed significant differences in the apparent P-recovery fraction. Of the 25 kg P ha^{-1} applied, 6.8 (BR 106) to 12.1 kg ha^{-1} (Pontinha) was recovered, which corresponds with 27.4 to 48.2% of applied P, respectively (Table 40). VAN REULER AND JANSSEN (1996), studying N, P and K in maize plants, observed that the recovery of applied phosphorus varied from 15.7 to 27.1% and the largest values were obtained at the lowest P level. Despite a larger capacity to recover the applied P (48.2%), the local cultivar Pontinha showed low P utilization efficiency (PUTE), i.e., yielded 142 kg of grains per kg P uptake (Table 40). P uptake efficiency (PUPE) varied from 0.31 (BR 106) to 0.56 (Pontinha) kg P in total biomass per kg of applied P. Despite the higher PUPE, Pontinha had the lowest grain yields.

Table 40 - Apparent recovery of P, P-uptake efficiency (PUPE), P-utilization efficiency (PUTE) and P-harvest index (PHI) of maize cultivars tested in 1995 under mulch conditions with (F) and without (NF) fertilizer

Cultivar	Apparent recovery		PUPE	PUTE [kg kg^{-1}]		PHI	
	[kg ha^{-1}]	[%]	[kg kg^{-1}]	NF	F	NF	F
BR 5102	8.9	35.7	0.44	199	235	0.72	0.80
Saracura	8.5	33.8	0.43	202	228	0.75	0.87
CMS 50	8.9	35.7	0.45	186	241	0.67	0.79
CMS 39	8.6	34.2	0.42	174	227	0.68	0.81
CMS 473	7.1	28.4	0.35	203	247	0.71	0.84
CMS 453	7.3	29.2	0.36	202	258	0.74	0.84
CMS 04C	7.7	30.6	0.38	155	259	0.60	0.81
CMS 28	7.4	29.5	0.34	210	235	0.74	0.87
CMS 59	7.0	27.9	0.33	170	248	0.52	0.81
BR 106	6.8	27.4	0.31	179	277	0.53	0.85
Pontinha	12.1	48.2	0.56	66	142	0.41	0.80
Means	8.2	32.8	0.40	177	236	0.64	0.83
LSD$_{(p=0.05)}$	2.6	10.4	0.10	33	37	0.12	0.06

PUTE and PHI are efficiency indicators for the utilization of P in the plant. At both fertilizer levels (Table 40) the improved cultivars were more efficient in converting absorbed P into grain yields (PUTE) than the local cultivar Pontinha. This fact was reflected in the high P content in grains and low grain yields in this cultivar. According to JANSSEN et al. (1990), the P utilization efficiency by the maize plant varies from 200 to 600 kg of grains per kg of absorbed P. In our study, the PUTE values were around the minimum reported by the authors. VAN REULER AND JANSSEN (1996) reported values of PUTE from 396 kg grains per kg P for maize planted in a non-burned area and of 614 kg in a burned area.

The P-harvest index (PHI), also known as phosphorus translocation efficiency to the grains (MOLL et al., 1982), was significantly different among the cultivars (Table 40). The values of PHI with fertilizer ranged from 0.79 (CM 50) to 0.87 (Saracura and CM 28) and without fertilizer from 0.41 (Pontinha) to 0.75 (Saracura).

In general, in this experiment, the yields of maize cultivars without fertilizer were not economically viable and not economic in the slash-and-mulch system. The maximum yield reached was 540 kg ha^{-1} for the BR 5102 cultivar. When fertilizer was used, the cultivars CMS 39, CMS 50, Saracura, CMS 04C and BR 5102 showed good performance in relation to yield, harvest index, PUTE and PUPE. In 1997, with fertilizer, the cultivars Cincalli 93 SA3, Cincalli 93 SA6, BR 5102 and CMS 04C reached yields superior to 2.3 t ha^{-1}. The improved maize cultivars, generally performed better as the local cultivar Pontinha, with the exception of the P acquisition (PUPE).

4.2.4 Cassava cultivars

The experiment was installed in the same area as the screening of the maize cultivars. The residual fertilizer effect was evaluated based on root yields and phosphorus uptake by the cassava plants.

Crop performance

The root yields varied from 16.7 t ha^{-1} (Tapioqueira) to 25.7 t ha^{-1} (Mameluca) with residual fertilizer, and from 12.4 t ha^{-1} (Tapioqueira) to 20.1 t ha^{-1} (Mameluca) without fertilizer (Figure 13). The lowest root yields were obtained with Tapioqueira, although statistically, the yields, differed only from Mameluca. The residual fertilizer had a significant effect on the production of cassava roots, increasing the yield by 23% compared to the treatments without fertilizer. The mean productivity of all cultivars was 19.6 t ha^{-1}, which is higher than the average yields of the Bragantina region (10 t ha^{-1}; IBGE, 1997).

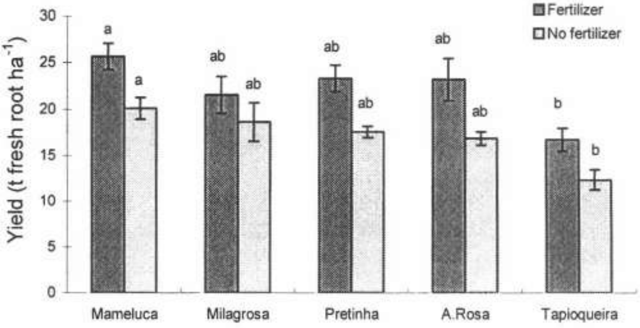

Figure 13 - Average fresh root yields of cassava cultivars tested in 1996 under mulch conditions with and without fertilizer.

Cultivars followed by the same letter(s) in each level of the fertilization are not significantly different at p=0.05 of the Tukey test. (Bars= SE; n = 4)

Selection of cassava cultivars in the different environments of Eastern Amazon has been undertaken by the various research institutes in the region. In the slash-and-burn system of the Transamazon-highway region, KATO et al. (1984) reported yields of 21 and 25 t ha^{-1} for Mameluca and Pretinha, respectively. CARDOSO (1989) obtained yields of 30 t ha^{-1} for cultivars in slash-and-burn systems with fertilization in northeastern Pará.

The total dry matter yields (including roots, leaves and stem) are presented in Table 41. No significant differences were found between cultivars at both fertilizer levels. The dry matter yields ranged from 10.4 t ha^{-1} to 14.2 t ha^{-1} without fertilizer and from 13.3 t ha^{-1} to 19.8 t ha^{-1} with residual fertilizer (Table 41). The roots contributed 54% to the total dry matter.

Table 41 - Roots, leaves, stems and total dry matter yields of cassava cultivars tested in 1996 under mulch conditions with (F) and without (NF) fertilizer

Cultivars	Roots		Leaves		Stems		Total	
	NF	F	NF	F	NF	F	NF	F
					[t ha^{-1}]			
Mameluca	8.0	11.5	1.6	1.9	4.7	6.0	14.2	19.3
Milagrosa	6.7	8.7	1.0	1.2	2.7	3.5	10.4	13.3
Pretinha	6.9	10.1	0.9	1.2	4.0	5.3	11.8	16.6
Aipim Rosa	6.4	9.2	0.8	1.1	3.3	3.6	10.5	14.0
Tapioqueira	4.9	6.9	1.9	2.5	7.2	10.5	14.1	19.8
Means	6.6	9.3	1.2	1.6	4.4	5.8	12.2	16.6
$LSD_{(P=0.05)}$	2.1	2.5	0.7	0.9	1.8	3.0	3.1	5.1

n.s. = not significant

The dry matter of leaves and stems showed differences between the tested cultivars. Tapioqueira showed higher leaves and stem dry matter, but lower root yields. As a consequence, this cultivar has the smallest harvest index (0.35) (Table 42). In general, the harvest index ranged from 0.56 to 0.65 without and from 0.60 to 0.67 with residual fertilizer, suggesting that the cultivars have a potential for cropping under the conditions of slash-and-mulch. According to KAWANO (1982), the harvest index is the best indicator for the selection of cassava cultivars. Harvest index values higher than 0.60 are considered satisfactory for high yielding cultivars.

Harvest index and root yields are positively correlated in the fertilized ($r=0.42$, $p\leq0.05$) as well as in non-fertilized plots ($r=0.50$, $p\leq0.01$). In general, a high aboveground (stem and leaves) biomass is not desirable, because it decreases the root yield.

The number of roots per plant and the plant height showed significant differences between the cultivars (Table 42). With residual fertilizer the number of roots per plant ranged from 4 (Tapioqueira) to 8 (Mameluca), without fertilizer from 3 (Tapioqueira) to 5 (Mameluca and Milagrosa). Residual fertilizer, on average, increased the number of roots per plant by 33%. Residual fertilizer had no effect on the height of the cassava plant. Maximum heights were founded for the Tapioqueira, Pretinha and Mameluca cultivars.

Table 42 - Harvest index, number of roots per plant and plant height of cassava cultivars tested in 1996 under mulch conditions with (F) and without (NF) fertilizer

Cultivars	Harvest index		Roots		Plant height	
	NF	F	NF	F	NF	F
			[number plant^{-1}]		[m]	
Mameluca	0.56	0.60	5	8	2.7	2.7
Milagrosa	0.65	0.67	5	5	2.4	2.3
Pretinha	0.58	0.61	4	6	3.1	3.1
Aipim Rosa	0.62	0.67	4	6	2.5	2.4
Tapioqueira	0.35	0.35	3	4	3.1	3.0
Means	0.55	0.58	4	6	2.8	2.7
LSD$_{(P=0.05)}$	0.12	0.09	0.8	2.1	0.3	0.3

P uptake and P use efficiency

Phosphorus uptake in the total biomass varied from 10.9 to 14.5 kg ha^{-1} in plots with residual fertilizer and from 7.2 to 10.7 kg ha^{-1} in non-fertilized plots (Table 43), however, no significant difference between the cultivars were found in plot with fertilizer and significant difference in the plots without fertilizer.

Significant differences between cultivars were found for the P content of leaves and stems (Table 43). In general, residual fertilizer increased the P content by 24% in leaves and by 32% in stems compared to non-fertilized plots. In the leaves and stems the highest phosphorus content was largest for the cultivars Tapioqueira and Mameluca, regardless of the fertilizer levels. From the total of P absorbed by the plant, 58% was accumulated in the aboveground biomass (leaves: 27% and stem: 31%). PELLET et al. (1993) reported that total P uptake over time is affected by fertilizer levels, because all cultivars accumulated more P at high P levels (50 and 100 kg P ha^{-1}). HOWELER (1982) found in Colombia a maximum P accumulation of 24 - 37 kg ha^{-1} in the total biomass 10-12 months after planting

In contrast to the non-fertilized plots, in the residual fertilizer plots, the P content of the roots differed significantly between the cultivars (Table 43). P content of the roots varied from 2.3 (Tapioqueira) to 4.0 kg ha^{-1} (Mameluca and Aipim Rosa) without fertilizer and from 3.3 (Tapioqueira) to 6.5 kg ha^{-1} (Aipim Rosa) with residual fertilizer. In the roots the highest rates of P accumulation were found which corresponds with the results obtained by HOWELER (1982).

Table 43 - Phosphorus content in roots, leaves, stems and total dry matter of cassava cultivars tested in 1996 under mulch conditions with (F) and without (NF) fertilizer

Cultivars	P-content [kg ha^{-1}]							
	Roots		Leaves		Stems		Total	
	NF	F	NF	F	NF	F	NF	F
Mameluca	4.0	5.7	3.2	4.2	2.3	4.1	9.4	14.0
Milagrosa	3.5	5.3	2.2	3.0	1.5	2.6	7.2	10.9
Pretinha	3.2	5.0	2.1	3.1	2.3	3.2	7.6	11.3
Aipim Rosa	4.0	6.5	1.9	2.6	1.6	2.0	7.4	11.1
Tapioqueira	2.3	3.3	4.6	5.8	3.7	5.4	10.7	14.5
Means	3.4	5.2	2.8	3.7	2.3	3.4	8.5	12.3
LSD$_{(P=0.05)}$	n.s.	1.6	1.5	1.7	0.8	1.9	2.6	n.s.

n.s. = not significant

The cassava cultivars extracted around 0.52 kg of P per ton of dry roots without fertilizer, with the exception of Tapioqueira which only extracted 0.24 kg of P per ton of dry roots. With residual fertilizer, the cultivars extracted between 0.70 kg of P (Aipim Rosa) and 0.48 kg (Tapioqueira) per ton of harvested roots. Naturally, P extraction depends on the level of productivity as well as on the fertility of the soil (HOWELER, 1991). HOWELER (1982) reported for CIAT, Colombia, that per ton of cassava root 0.46 kg of P were extracted from the soil.

Cassava is adapted to acid and low-fertile soils, requiring little effort of land preparation. This ability has led to the assumption that cassava does not require a high level of soil fertility, nor responds to fertilization. But numerous results have shown that cassava extracts large amounts of nutrients from the soil, mainly nitrogen and potassium and small amounts of phosphorus (PERIM et al.,1983; PAULA et al., 1983). In spite of the phosphorus being the macronutrient with the smallest demand, it is the element that provides the most significant increases in cassava yields (PERIM et al., 1983; CORRÊA et al., 1981).

The recovered fraction of P fertilizer was low and, due to high variability, no significant differences among the cultivars could be obtained. The P recovery ranged from 15 to 18 kg ha^{-1}, which is 4 to 5% of the applied P (Table 44). The low recovery values are due to the low availability of residual fertilizer.

Table 44 - Apparent recovery of P, P utilization efficiency (PUTE) and P harvest index (PHI) of cassava cultivars tested in 1996 under mulch conditions with (F) and without (NF) the residual fertilizers

Cultivars	Apparent recovery		PUTE		PHI	
			NF	F	NF	F
	[kg ha^{-1}]	[%]	[kg kg^{-1}]			
Mameluca	18	5	860	826	0.42	0.41
Milagrosa	15	4	948	832	0.49	0.49
Pretinha	15	4	908	898	0.42	0.45
Aipim Rosa	15	4	849	865	0.53	0.60
Tapioqueira	16	4	489	479	0.23	0.23
Means	16	4	811	780	0.42	0.44
LSD$_{(P=0.05)}$	n.s	n.s.	210	159	0.05	0.08

n.s. = not significant

With residual fertilizer, PUTE ranged from 479 to 898 kg of dry roots per kg of absorbed P and, without fertilizer, it varied from 489 to 948 kg. The cultivar Tapioqueira showed a low efficiency of 'converting' P uptake to root yield (Table 44). PUTE was lower when fertilizer was used, this corresponds with results reported by PELLET et al. (1993).

The P harvest index (PHI) in the residual fertilizer plots shows that 23% (Tapioqueira) to 60% (Aipim Rosa) and without fertilizer between 23% (Tapioqueira) and 53% (Aipim Rosa) of total biomass P were translocated to the roots (Table 44). The low PHI of the cultivar Tapioqueira is attributed to its large production of aerial biomass and low root production. Residual fertilizer did not influence the P harvest index.

With the exception of Tapioqueira, the tested cassava cultivars performed well in the slash-and-mulch system. Root production, harvest index, P harvest index and P uptake by Tapioqueira were low. The cultivars Mameluca, Pretinha, Aipim Rosa and Milagrosa showed a high potential for the use in the slash-and-mulch system. The Tapioqueira cultivar, however, remains attractive due to the fact that it is tolerant to the well-known disease called soft root-rot caused by *Phytophthora drechsleri* and *Phytophthora nicotiana* (CARDOSO, 1989; POLTRONIERI et al., 1993). In the Bragantina region this disease is spreading.

5 General Discussion and Conclusion

Land preparation

The main reasons why small farmers use the slash-and-burn system are the easiness of land preparation and the nutrient availability from the ashes. The beneficial effects to sustainability are, however, questionable, because of the negative effects of burning to the environment, such as the carbon dioxide and trace gas emissions (TINKER et al.,1996; KAUFFMANN et al., 1995; HÖLSCHER et al., 1997), the risks of accidental fires that destroy great areas of fallow vegetation (IPAN 1998a; IPAN 1998b), and nutrient losses from the ecosystem. MACKENSEN et al. (1996) reported that total element losses including volatilization, particle and leaching exports were somewhere between 30-47% of the initial P stock. In P deficient soils, these losses have to be avoided to maintain soil productivity.

Much research has been done on the effect of the quality of organic inputs on N release and availability. Little is known, however, about the quality with respect to P availability. In tropical regions, where high P-fixing soils are abundant and the soils have low P content, the management of phosphorus via organic inputs can be an alternative soil improvement. Phosphorus very often has been the great limiting factor for good crop yields. The quality of organic inputs could affect P availability through the P content or the C:P or N:P ratio of the material (SANCHEZ et al., 1989), the extent and activity of the soil microbial pool (HEDLEY et al., 1982), and the interaction between the organic material and the mineral soil (SANCHEZ et al., 1989).

Burning of the fallow vegetation significantly increased the pH of the soil, level inorganic phosphorus extractable with resin and organic phosphorus which is extractable with $NaHCO_3$. Without fertilizer, however, this increase during cultivation was only short-lived. Fertilization increased the P level in the soil as compared to no fertilization. Without fertilizer, the levels of inorganic P decreased with time to pre-burn levels and burning reduced the microbial biomass P and the plant available P. The differences in pH between the two study areas could be attributed to the quantity and composition of the deposited ash and the buffer capacity of the soil.

The inorganic P fractions (resin, $NaHCO_3$ and NaOH) of the soil of both sites were highly correlated with the bio-available phosphorus - determined in maize as extractor plant - and with the rice, cowpea and cassava yields as well as with the pH, showing the importance of this pool for plant growth and reflecting the short-term changes of plant available inorganic phosphorus. Similar results were obtained by BOWMAN AND COLE (1978), HEDLEY et al. (1982) and BECK AND SANCHEZ (1996). Organic phosphorus, NaOH-extractable, was the pool which showed the greater changes in burned and non-burned plots. The addition of crop residues contributed through its decomposition, to an increase in the level of organic P, extracted with NaOH. This pool seems to be important for all P dynamics. The fraction $NaHCO_3$-Po stayed stable during the whole period under observation.

Because of several social and economic reasons, slash-and-burn agriculture still dominates the land use of small farmers in the northeast of Pará, but alternatives that could reduce the nutrients losses caused by the burning, need to be introduced in the production system of the region. Whereas nitrogen could be supplied through biological fixation, other nutrients, especially P and K, need to be supplied by external sources. The use of mulch provides one of the viable sustainable alternatives for the slash-and-burn system. It may secure stability in production of the crops, but also assure long-term nutrient recycling (JUO AND MANU, 1996). The slash-and-mulch system has shown that a high crop productivity can be obtained with time and that the regeneration of the fallow vegetation and its functional biodiversity may not be as drastically affected as when burning was used to prepare the land (BAAR et al. 1997, DENICH AND KANASHIRO, 1995).

The overall nutrient uptake during the cropping sequence is shown in Table 45. With or without the use of fertilizers, phosphorus content appears not to be affected by fallow duration. Phosphorus application resulted in an increase of its absorption by the crops, however, no significant difference was observed with respect to the land preparation method. Apparent recovery of P was around 33% of the 47 kg ha^{-1} of applied P which suggests that P fixation is not a serious problem at the study area.

Table 45 - Total P uptake in a traditional cropping period (rice-cowpea-cassava) following a 4 and a 10 year fallow phase with and without fertilizer, and the apparent recovery of applied nutrients.

Treatment	Total P uptake [kg ha^{-1}]	
	FV4y	FV10y
Burning	12.7	14.6
Mulching	12.4	10.0
Incorporation	11.4	9.0
Burning + NPK	29.3	29.2
Mulching + NPK	25.0	26.3
Incorporation + NPK	27.8	26.2
Aver. Nutr. Balance		
without NPK	-12	-11
with NPK	+20	+20
App. Recovery [kg ha^{-1}]	15	16
App. Recovery [%]	32	34

The use of fertilizers overcame the differences in yield due to fallow duration and land preparation, increasing rice and cowpea yields by 124 % and 565 %, respectively. The elimination of burning comes with a high price in terms of rice yield to the resource-poor farmer. The short-term benefits of burning in terms of harvested rice, when fertilizers are not affordable, are an obvious incentive for farmers to continue this practice. A promising perspective in changing the present undesirable scenario is associated with the fact that the fertilization of the first cereal crop, grown after slashing and burning, is increasing in popularity among the farmers of that region, as a way to cope with the need to shorten the fallow period due to population pressure. When burning is omitted, no yield reduction in rice and cowpea will be experienced by those farmers already used to applying fertilizers to these crops.

The economic analyses of the NPK fertilizer use are presented in the (Table 46). The results show that the fertilizer application duplicated the net return of the system in the first cultivation cycle, regardless of the age of the *capoeira*. When we analyzed each crop separately it was verified that only for the rice crop in FV10y the application of fertilization did not lead to an increase in the net return. In the second cropping cycle fertilizer contributed to an increase in the total net return – with a higher increase for FV10y - regardless of the crop and land preparation method. In general, with two cropping cycles the fertilization contributed to the increase of 2.3 times the net return, irrespective of the land preparation method and fallow vegetation duration.

Table 46 - Net return (US$) of the slash-and-burn and slash-and-mulch system, considering fertilizer costs.

	FV4y			FV10y		
	Market value	Fertilizer price	Net return	Market value	Fertilizer price	Net return
1995/96						
Rice						
Burning	176	-	176	259	-	259
Burning + NPK	318	98	219	353	98	255
Mulching + NPK	294	98	196	270	98	172
Cowpea						
Burning	86	-	86	86	-	86
Burning + NPK	457	68	389	428	68	360
Mulching + NPK	428	68	360	428	68	360
Cassava						
Burning	343	-	343	326	-	326
Burning + NPK	634	-	634	630	-	630
Mulching + NPK	605	-	605	563	-	563
Total (1)						
Burning			605			671
Burning + NPK			1242			1245
Mulching + NPK			1161			1095
1997/98						
Rice						
Burning	165	-	165	165	-	165
Burning + NPK	317	98	219	459	98	360
Mulching + NPK	376	98	278	423	98	325
Cowpea						
Burning	86	-	86	86	-	86
Burning + NPK	457	68	389	571	68	503
Mulching + NPK	571	68	503	657	68	589
Cassava						
Burning	238	-	238	214	-	214
Burning + NPK	517	-	517	609	-	609
Mulching + NPK	546	-	546	500	-	500
Total (2)						
Burning			489			465
Burning + NPK			1125			1472
Mulching + NPK			1327			1414
Total (1 + 2)						
Burning			1094			1136
Burning + NPK			2367			2717
Mulching + NPK			2488			2509

Price - rice=US$ 0.12 kg^{-1}, cowpea= US$ 0.29 kg^{-1}, cassava= US$ 21.00 t^{-1} fresh roots (official minimum prices) ; urea= US$ 0.29 kg^{-1}, triple superphosphate= US$ 0.39 kg^{-1}, potassium chloride= US$ 0.30 kg^{-1} (price in Belém)

The small farmers of northeastern Pará have a preference for the use of 4-year-old *capoeira* in their cropping systems (KATO et al., 1992). Based on the yields of rice, cowpea and cassava in our experiments, we can confirm that the use of those shorter followed areas (FV4y) has advantages. When the 10-year-old *capoeira* and a cropping period of 2 years (rice + cowpea + cassava) is used, the production cycle will take 12 years. With the use of a 4-year-old *capoeira,* however, two cropping cycles within the same period of time accompanied an overall grain production increase of, for example, 39% and 113% for rice, 241% and 200% for cowpea and 210% and 214% for cassava in the traditional (burned) system and the fertilized slash-and-mulch system, respectively. The consequences with regard to sustainability of shortening the fallow period can not be fully assessed here.

The implementation of two cropping cycles after the fallow period suggests a more intensive use of the land as expressed in the land use factor (R = [C*100] / [C + F]), where C represents the number of years of cultivation and F the number of fallow years (RUTHENBERG, 1980). When doubling the 2-year cropping period R was 50 % with 4 years of fallow, compared to 29 % with one cropping period and 10 years of fallow. Moreover, if we estimate the standardized yields of rice, cowpea and cassava [R * total of yields] as a measure of land productivity it is clear that shorter fallow periods are more advantageous (Table 47).

Table 47 – Standardized yields of rice, cowpea and cassava calculated as a function of land use factor [R] and crop yields of two cropping periods.

Treatment	Standardized yield [t ha^{-1}]					
	FV4y			**FV10y**		
	Rice	Cowpea	Cassava	Rice	Cowpea	Cassava
Burning	1.4	0.34	13.8	1.0	0.15	7.3
Mulching	1.2	0.41	17.6	0.6	0.06	7.5
Burning + NPK	2.7	1.60	27.5	2.0	1.00	16.9
Mulching + NPK	2.8	1.80	27.4	1.7	1.10	14.5

The practice of planting two crop cycles after a 4-year fallow period, not only show advantages in relation to yield, but also in reducing the amount of labor for the small farmer. Nevertheless, before this slash-and-mulch technology is transferred to the farmers, more investigations are needed to evaluate the long-term effects of this practice in terms of soil degradation and health as well as the vitality of the secondary vegetation as compared to the traditional system where fire is utilized in land preparation (BAAR et al., 1995; DENICH AND KANASHIRO, 1995).

Selection of crop cultivars

The land preparation methods and agricultural practices lad been modified to improve the traditional fallow system. To further complete the envisaged land use without the slash-and-burn system, improved rice, maize, cowpea and cassava cultivars had to be select; cultivars which are suitable for planting into large amounts of organic matter such as mulch and are and able to grow in the presence of this material with a high C:P ratio. It is likely that cultivars more adapted to the slash-and-mulch system are those tolerant to acid soils and low fertility.

From the screening for cultivars adapted to the slash-and-mulch system without the use of fertilizer only the rice cultivar CNA 7706 showed a satisfactory production level, with an increase of 39% over the local cultivar Ligeiro. So far it was not possible to identify, for either maize or cowpea, any cultivar able to offer satisfactory yields without using fertilizer. Rice, maize and cowpea cultivars may be tolerant to soil acidity, however, they are not tolerant to low P levels. During the previous selection of those cultivars by EMBRAPA and CIMMYT this characteristic has apparently not been considered, because P-deficiency is usually corrected in screening trials.

For cassava, all the tested cultivars did better than the average of the yields of the study region. The residual effect from the fertilizer applied in the previous crop increases cassava root yields. The good performance of cassava in slash-and-mulch system may be related to the ability of this species to grow in acid soils (HOWELER, 1991). Cassava is also known as a species more tolerant to high levels of aluminum and manganese, as well as low levels of calcium and potassium than many other species (REDDY, 1987). Due to the strong mycorrhizal infection under field conditions (HOWELER et al., 1987), this crop is able to sustain productivity by utilizing nutrients and water less accessible to other crops (KANG et al., 1980 cited by WICK, 1997).

The most important factor for good yields under slash-and-mulch conditions, however, may have been the completion of the nutrient immobilization phase of mulch decomposition by the time cassava was planted.

Conclusions

The fire-free land preparation appears to be a viable technology for the nutrient poor soils of the Eastern Amazon region if fertilizers are applied to compensate for the loss of the fertilizing effect of the ashes from burning and the microbial immobilization of nutrients during the decomposition of the mulch layer. If fertilizer is applied high grain yields of rice, maize and cowpea as well as cassava roots are achieved.

The highest grain yields of rice and cowpea in the slash-and-mulch system were obtained when the cropping period was extended, indicating the long-term beneficial effects of mulch in the improvement of chemical soil properties.

Shorter fallow periods are more attractive to the slash-and-mulch system as they generate higher yields per unit area due to the higher cropping frequency. The thinner trunks are also easier to handle in land preparation and could possibly be slashed and chopped by machines (DENICH AND LÜCKE, 1998).

An improved rice cultivar (CNA 7706) was found to achieve economic yields without fertilization and yielded noticeably more than the locally most-widespread cultivars. Maize and cowpea cultivars, currently available in Amazon region seem poorly suited to soils of low P fertility due to the immobilization of soil P by the degrading biomass and thus require fertilization under mulch conditions

The tuber yields of all cassava cultivars were satisfactory under slash-and-mulch conditions, with and without fertilization, and showed a great capacity to take advantage of residual nutrients from a previous cropping. As the last crop in the slash-and-mulch system it escapes the negative immobilization effects of mulch decomposition so that no specific breeding targets are needed for this crop.

The phosphorus available in the soil for plants increased as a result of the burning of the fallow vegetation biomass and, as a result of fertilizer application. This is reflected in high grain yields of rice and cowpea. In the plots with fire-free land preparation, P availability was dependent on the mulch decomposition, leading to an increase in production only in the second cropping period.

6. Summary

Shifting cultivation is the most important agricultural land-use system in the Amazon region and the slash-and-burn practice is the traditional method for land preparation used by small farmers. During slash and burning, however, high amounts of nutrients are lost through volatilization. This fact, exacerbate by reduced fallow time, decreases the total nutrient stock of fallow systems and compromises the system's sustainability.

The objectives of this study were: 1) to evaluate the effects of fire-free land preparation on crop performance and phosphorus dynamics; 2) to evaluate the importance of the use of chemical fertilizer in systems without the use of fire and 3) to select rice, maize, cowpea and cassava cultivars suitable for mulch systems.

The studies were conducted in the community of Cumaru in the municipality of Igarapé Açu (Pará, Brazil) on two neighboring sites with 4-year-old (FV4y) and 10-year-old fallow vegetation (FV10y). Three treatments for land preparation were tested with and without fertilizer. The treatments were: 1) burning ± NPK fertilization; 2) mulching ± NPK fertilization; 3) incorporation of the fallow vegetation biomass into the soil ± NPK fertilization. Rice was planted followed by cowpea and cassava in two consecutive cropping periods. Yield characteristics of the crops as well as the phosphorus dynamics in the soil and uptake by the crops were evaluated. Furthermore, screening experiments were set up to evaluate the yield characteristics of a total of 8 rice, 18 maize, 21 cowpea and 5 cassava cultivars under mulch conditions with and without fertilizer application.

The land preparation experiment revealed that without fertilization, burning significantly increased the grain yields of rice in the first cropping period compared to cropping without burning. This result was most likely due to the slow release of nutrients from the mulch or the incorporated plant material, possibly acerbated by nutrient immobilization, especially P. In the second cropping period, no differences in rice yield were detected in the FV10y due to increased yields in the non-burned and non-fertilized treatment. Compared with the first cropping period, with burning the rice grain yields showed an overall reduction of 7 in FV4y and 36% in FV10y in the second cropping period. The opposite effect may be noticed in systems without the use of fire; an increase in yields of 117% and 233%, respectively, in the

second cropping period compared to the first one could be observed. The yield increases in the second cropping period may be related to the liberation of nutrients through the decomposition of mulch. The use of fertilizers significantly increased the rice grain yields in the two cropping periods in both areas and erased the land preparation effect seen without the use of fertilizers.

The cowpea yields without fertilizer were around 0.3 t ha^{-1} in the burned treatments. When the field was not burned the yields were around 0.20 t ha^{-1} in FV4y but cowpea did not produce at all in FV10y. With fertilization, cowpea grain yields were around 1.5 t ha^{-1}, regardless of the length of the fallow period and land preparation method. In the second cropping period the greatest response in grain yield in relation to the first period were in the plots with mulch (with and without fertilizer).

In the first cropping period cassava tuber yields were not influenced by land preparation, but residual fertilizer of the previously fertilized rice and cowpea crop doubled the yields. In the second period, without residual fertilizer, tuber yields decreased in the burned plots by 30% and 34% in FV4y and FV10y, respectively. With residual fertilizer such a reduction was observed only in FV4y. In the non-burned treatments tuber yields were higher in FV4y than in FV10y.

The total phosphorus uptake of the aboveground rice biomass in the first cropping period was 44 % higher in FV10y than in FV4y, which is in line with an increase of 52 % in total rice biomass due to an improved nutrient supply in FV10y after burning. Given the fact that the P stock in the fallow vegetation of FV4y and FV10y were the same (9 kg ha^{-1}), the uptake of P by rice has been soil derived rather than ash derived. In spite of the higher plant absorption observed in the burned treatments, the P utilization efficiency was higher in the treatments that were not burned.

In non-burned and non-fertilized plots the total P content of the cowpea pods was reduced by 50 % in FV4y, compared to fertilized treatments. In FV10y this comparison cannot be made because cowpea did not yield without fertilizer. P uptake was not affected by the land preparation method when fertilizer was applied.

The total amount of P absorbed by cassava was similar in FV4y and FV10y. Residual fertilizer of the previous rice and cowpea crop increased P uptake of cassava by 37% and 42% in FV4y and FV10y, respectively, in relation to the plants without residual fertilizer.

The burning of the fallow vegetation significantly increased the pH of the soil as well as inorganic phosphorus (Pi) extractable with resin, and organic phosphorus (Po),, extractable with $NaHCO_3$-, but without fertilizer application this increase, during cultivation, was only short-lived. Fertilization increased the P level in the soil. Without fertilizer, the levels of inorganic P decreased with time to pre-burn levels within 8 months. The dynamics of resin-Pi and $NaHCO_3$-Pi levels were synchronized with the dynamics of the less available NaOH-Pi fraction. The $NaHCO_3$-Po pool was not affected by land preparation methods nor by the fertilizer treatment at either site. Regardless of the land preparation method, seasonal changes were observed in this fraction. The addition of crop residues contributed through its decomposition to an increase in the NaOH-Po level. This pool seems to be important for all P dynamics. NaOH-Po was the fraction that showed the highest short-term increments as compared to other fractions. An increase in NaOH-Po was concomitant with a decrease in resin- and NaOH-Pi. The NaOH-Po seemed to be an indicator of the soil P and fertility status.

The inorganic P fractions (resin-, $NaHCO_3$- and NaOH-) of the soil of both sites were highly correlated with the available P determined in maize used as extractor plant in bioassay tests and with the rice, cowpea and cassava yields grown in the field.

The plant bioassay P extracted from the soil by the test plant and the microbial biomass P were reduced by burning when fertilizer was not applied. With fertilization, the differences between the available P levels of the burned and the non-burned plots were greater at FV10y than at FV4y.

From the screening of cultivars suitable for the slash-and-mulch system without fertilizer use, only the rice cultivar CNA 7706 showed with a satisfactory production level (39% over the local cultivar Ligeiro). It was not possible to identify any cultivar for either maize or cowpea able to offer satisfactory yields without the use of fertilizer. With fertilizer, the newly introduced rice cultivars yielded between 2.2 t ha^{-1} to 3.0 t ha^{-1}, with cultivars Progresso, Xingú and Araguaia standing out. The best yielding maize cultivars were Cincalli 93 SA3, Cincalli 93 SA6, BR 5102, CMS 04C, CMS 39, CMS 50 and Saracura (2 to 3 t ha^{-1}). The

cowpea cultivars produced only when fertilizer was used. The best performance showed TE 86-80-86F and TE 86-80-3G, with yields around 1.4 t ha^{-1}.

Cassava tuber yields were increased by the residual effect from the fertilizer applied in the previous screening experiment (maize). The cultivars Mameluca, Pretinha, Aipim Rosa and Milagrosa seem suitable for slash-and-mulch systems.

The fire-free land preparation appears to be a viable technology for the nutrient-poor soils of the Eastern Amazon Region if fertilizers are applied to compensate for the loss of the fertilizing effect of the ashes from burning and the microbial immobilization of nutrients during the decomposition of the mulch layer. The availability of P was dependent on the decomposition of plant material (mulch or incorporated plant material), reflecting an increase in the production during the second cropping period. The results suggest that P was the limiting element to crop production.

7 Zusammenfassung

Die Feldumlagewirtschaft ist das vorherrschende Landnutzungssystem im Amazonasgebiet. Die Brandrodung stellt dabei die traditionell von Kleinbauern praktizierte Methode der Flächenvorbereitung dar. Bei der Brandrodung gehen jedoch große Mengen an Nährstoffen durch Volatisierung verloren. Zusammen mit verkürzten Brachephasen führt dies zu einer Abnahme der Nährstoffvorräte der Böden und damit auch der Nachhaltigkeit des Landnutzungssystems.

Die Zielsetzungen der vorliegende Studie waren: 1) die Auswirkungen nicht-brennender Flächenvorbereitung auf die landwirtschaftliche Produktion und die Phosphordynamik zu untersuchen; 2) die Bedeutung von mineralischem Dünger in Systemen ohne Brandrodung zu ermitteln und 3) für Mulchsysteme geeignete Sorten von Reis, Mais, Augenbohne (*Vigna unguiculata*) und Maniok (*Manihot esculenta*) zu finden.

Die Untersuchungen wurden in der Gemeinde Cumaru im Munizip Igarapé Açu (Pará, Brasilien) auf zwei benachbarten Flächen mit 4 Jahre alter (FV4y) und 10 Jahre alter (FV10y) Brachevegetation durchgeführt. Drei Arten der Flächenvorbereitung wurden jeweils mit und ohne mineralischem Dünger untersucht. Die Behandlungen waren: 1) Brennen ± NPK-Düngung; 2) Mulchen ± NPK-Düngung; 3) Einarbeitung der Biomasse der Brachevegetation in den Boden ± NPK-Düngung. In zwei aufeinanderfolgenden Anbauphasen wurde Reis gefolgt von Augenbohnen und Maniok angebaut. Untersucht wurden Ertragsparameter, die Phosphordynamik im Boden und die Aufnahme von Phosphor durch die Kulturpflanzen. Darüberhinaus wurde die Ertragsleistung von insgesamt 8 Reis-, 18 Mais-, 21 Augenbohnen- und 5 Manioksorten auf gemulchten Flächen sowohl mit als auch ohne Einsatz von Mineraldünger verglichen.

Der Versuch zur Flächenvorbereitung ergab, daß ohne Düngung die Reiserträge in der ersten Anbauphase auf gebrannten Flächen signifikant höher waren als auf gemulchten. Dies beruhte höchstwahrscheinlich auf der langsamen Freisetzung von Nährstoffen aus dem Mulch oder dem eingearbeiteten Pflanzenmaterial, möglicherweise verstärkt durch ein Immobilisierung von Nährstoffen, insbesondere P. In der zweiten Anbauphase waren in der Fläche FV10y aufgrund von Ertragszunahmen in der Behandlung ohne Brennen keine Unterschiede mehr zwischen den Reiserträgen auf gebrannten und gemulchten Flächen zu erkennen. Auf den gebrannten Flächen war der Reisertrag in der zweiten Anbauphase auf den Flächen FV4y bzw. FV10y um 7 bzw. 36% gegenüber der ersten Anbauphase verringert. In den Varianten ohne Brennen wurden dagegen Ertragssteigerungen gegenüber der ersten Anbauphase von 117 beziehungsweise 233% erzielt. Die Ertragssteigerungen in der zweiten Anbauphase könnten mit der Freisetzung von Nährstoffen beim Mulchabbau zusammenhängen. In beiden Anbauphasen und auf beiden Flächen wurde der Reisertrag durch die mineralische Düngung signifikant gesteigert, so daß die Auswirkungen der Flächenvorbereitung überdeckt wurden.

Ohne Düngung lagen die Erträge der Augenbohnen auf den gebrannten Flächen bei etwa 0,3 t ha^{-1}. Mit Mulchen wurde in der Fläche FV4y ein Ertrag von ca. 0,20 t ha^{-1} erzielt, während es in der Fläche FV10y zu einem totalen Ertragsausfall kam. Mit Düngung betrugen die Bohnenerträge unabhängig von der Länge der Brachephase und der Art der Flächenvorbereitung etwa 1,5 t ha^{-1}. Die größten Ertragssteigerungen in der zweiten gegenüber der ersten Anbauphase traten in den gemulchten Parzellen auf (mit und ohne Dünger).

Beim Maniok wurden die Knollenerträge in der ersten Anbauphase nicht durch die Art der Flächenvorbereitung beeinflußt, die Erträge wurden jedoch durch die Residualwirkung des zu Reis und Bohnen applizierten Düngers verdoppelt. Ohne Düngung der vorherigen Kulturen nahmen die Knollenerträge in der zweiten Anbauphase um 30% bei FV4y und 34% bei FV10y ab. Auf zuvor gedüngten Flächen war eine solche Ertragsminderung nur in der Fläche FV4y zu beobachten. In den Behandlungen ohne Brennen waren die Knollenerträge bei FV4y höher als bei FV10y.

Die Gesamtakkumulation von Phosphor in der oberirdischen Biomasse von Reis lag in der ersten Anbauphase in der Fläche FV10y um 44% höher in FV4y. Das stimmt gut mit der Gesamtbiomasse überein, die in der Fläche FV10y 52% höher ausfiel und auf eine bessere Nährstoffversorgung nach dem Brennen in der Fläche FV10y schließen läßt. Da der Phosphorvorrat in der Brachevegetation von FV4y und FV10y mit 9 kg ha^{-1} gleich groß war, stammt die erhöhte Phosphoraufnahme durch Reis eher aus dem Boden als aus der Asche. Trotz der erhöhten Absorption durch die Pflanzen in den Behandlungen ohne Brennen war die Effizienz der P-Ausnutzung bei den Behandlungen ohne Brennen höher.

Auf den nicht gebrannten und nicht gedüngten Flächen war der Gesamtphosphorgehalt der Bohnenhülsen in der Fläche FV4y im Vergleich zur gedüngten Behandlung um 50% reduziert.

In der Fläche FV10y kann dieser Vergleich nicht angestellt werden, weil die Augenbohnen hier ohne Dünger überhaupt keinen Ertrag brachte. Mit Düngung war die Aufnahme von P nicht von der Art der Flächenvorbereitung beeinflußt.

Die Gesamtmenge aufgenommenen Phosphors durch Maniok war in den Flächen FV4y und FV10y ähnlich. Die Residualwirkung des zu Reis und Augenbohnen applizierten Düngers erhöhte die Phosphoraufnahme von Maniok um 37% in FV4y und um 42% in FV10y im Vergleich zu den Pflanzen auf zuvor nicht gedüngten Böden.

Das Brennen der Brachevegetation führte zu einer signifikanten Erhöhung sowohl des pH-Wertes des Bodens als auch der Gehalte an mit Austauscherharz extrahierbarem anorganischen Phosphor (Pi) und an mit $NaHCO_3$- extrahierbarem organischen Phosphor (Po), wobei dieser Anstieg während der Kulturphase ohne Düngung nur kurzzeitig war. Düngung erhöhte den P-Gehalt des Bodens im Vergleich zu den Flächen ohne Düngung. Ohne Düngung nahmen die Gehalte an anorganischem P innerhalb von 8 Monaten auf die Werte vor der Brandrodung ab. Die Dynamik des mit Austauscherharz und mit $NaHCO_3$- extrahierbaren Pi waren mit der weniger verfügbaren NaOH-Pi Fraktion synchronisiert. Der $NaHCO_3$-Po Vorrat wurde auf keiner der Flächen von der Art der Flächenvorbereitung oder von der Düngung beeinflußt. Unabhängig von der Art der Flächenvorbereitung wurden in dieser Fraktion jahreszeitliche Schwankungen beobachtet. Der Abbau von Ernterückständen trug zu einem Anstieg des NaOH-Po Gehaltes bei. Diese Fraktion scheint für alle Phosphordynamiken von Bedeutung zu sein. NaOH-Po war die Fraktion mit den höchsten kurzfristigen Zunahmen im Vergleich zu den anderen Fraktionen. Ein Anstieg des NaOH-Po ging einher mit einer Abnahme der Gehalte an Austauscherharz- und NaOH-Pi. Somit scheint NaOH-Po ein Indikator für den Phosphorgehalt des Bodens und die Bodenfruchtbarkeit zu sein.

Die anorganischen P-Fraktionen (Austauscherharz-, $NaHCO_3$- und NaOH-) in den Böden beider Flächen (FV4y und FV10y) waren in hohem Maße korreliert mit dem verfügbaren Phosphor, der in Biotests mit Mais als Extraktionspflanze sowie bei Reis, Augenbohnen und Maniok im Feld ermittelt wurde.

Die von der Testpflanze im Biotest aus dem Boden aufgenommene Phosphormenge und der P-Gehalt in der mikrobiellen Biomasse waren bei der Behandlung mit Brennen vermindert, wenn kein Dünger appliziert wurde. Mit Düngung waren die Unterschiede bezüglich der

Gehalte an verfügbarem P zwischen gebrannten und nicht gebrannten Flächen in FV10y größer als in FV4y.

Aus der Sortenprüfung für ein Mulchsystem ohne Düngung ging lediglich die Reissorte CNA 7706 mit einem zufriedenstellenden Produktionsniveau (39% höherer Ertrag als die lokale Sorte Ligeiro) als geeignet hervor. Keine der Mais- oder Bohnensorten erbrachte ohne den Einsatz von Dünger einen zufriedenstellenden Ertrag. Mit Düngung produzierten die neuen Reissorten zwischen 2,2 und 3,0 t ha^{-1}, wobei die Sorten Progresso, Xingu und Araguaia besonders hervortraten. Die Maissorten mit den höchsten Erträgen (2 bis 3 t ha^{-1}) waren Cincalli 93 SA3, Cincalli 93 SA6, BR 5102, CMS 04C, CMS 39, CMS 50 und Saracura. Die Augenbohnensorten brachten nur bei Düngung einen Ertrag. Die Sorten TE 86-80-86F und TE 86-80-3G zeigten mit Erträgen von ca. 1,4 t ha^{-1} die beste Leistung.

Der Ertrag von Maniokknollen wurde durch die Residualwirkung des zuvor zu Mais applizierten Düngers erhöht. Die Sorten Mameluca, Pretinha, Aipim Rosa und Milagrosa erwiesen sich als geeignet für Mulchsysteme.

Die Flächenvorbereitung ohne Brennen erscheint als eine sinnvolle Methode für die nährstoffarmen Böden im östlichen Amazonasgebiet, wenn mineralischer Dünger als Ausgleich für den fehlenden Düngungseffekt der Asche beim Brennen sowie für die mikrobielle Immobilisierung von Nährstoffen beim Mulchabbau appliziert wird. Die Verfügbarkeit von P hing vom Abbau des Pflanzenmaterials (als Mulch oder eingearbeitet) ab, was sich in einem Anstieg der Produktion in der zweiten Anbauphase widerspiegelte. Die Ergebnisse legen nahe, daß Phosphor das für die Kulturpflanzen limitierend Element war.

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Curriculum Vitae

Personal data

Name:	Maria do Socorro Andrade Kato
Date of Birth:	June 21, 1955
Place of Birth:	Capanema-Para, Brazil
Civil Status:	Married and 2 children
Address:	Av. Conselheiro Furtado, 1911/702 66.040 – 100 Belém-Pará, Brazil

Professional Experience

Since 1979	Research at Brazilian Agricultural Research Center-EMBRAPA, in Belém-Pa, Brazil

Education

1962 – 1971	Primary School in Capitão-Poço-Pará-Brazil
1972 – 1974	Grammar School in Belém-Pará-Brazil
1975 - 1978	Faculdade de Ciencias Agrarias do Pará, graduate studies in agronomy
1985 – 1987	Escola Superior de Agricultura de Lavras, Minas Gerais-Br. M. Sc. in agronomy
Jan.1995-Nov. 1998	Post-graduate studies at the Institute of Agriculture in the Tropics, Faculty of Agriculture, University of Göttingen, Germany.

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