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A great potential for increasing upland rice production exists in the savanna soils of Colombia. These vast areas are currently underutilized. However, they have good soil structure, flat topography, coupled with sufficient and well distributed rainfall, making savanna soils ideal for upland rice cropping system. The major constraints to upland rice production in these soils are their low fertility and lack of appropriate technology for their management. The basic concept is to alleviate or overcome soil constraints by planting rice cultivars to Al toxicity and low native fertility, and obtaining reasonable, but not necessarily the maximum yield obtained with lowland or paddy rice.

Upland rice production systems were evaluated in representative savanna soils of CRI La Libertad, Llanos Orientales, Colombia, during the rainy seasons of 1983 and 1984.

Cultivars such as Perola, Tox 1011-4-2, IAC 47, IAC 165, IRAT 101 and Makalioka 34 showed a high yield potential and good level of resistance against the prevalent pests and diseases. They also have thick and deep roots which make them suitable for upland rice culture

in savanna soils. They are tolerant to Al toxicity, and have good level of adaptation to acid-soil conditions.

A second component of a successful rice production technology was the determination of appropiate rates of P an Ca. Based on plant tissue analyses and in grain yield, a fertilization rate of 150 Kg Ca/ha using dolomite, and 60 Kg P_2O_5/ha as concentrate superphosphate, appears to be adequate for acceptable yield levels on savanna soils.

An additional component of the management system is to drill plant adapted rice cultivars in rows 15 cm apart, with a rate of seeding of 60 Kg/ha. Significantly higher yield was obtained with these cultural practices.

Through the integration of these management practices a productive upland rice production technology can be developed and the incorporation of savanna soils to food production is feasible.

Identification and Development of Cultural Practices for Upland Rice Production Systems for Savanna Soils of Colombia

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Typed by Mauro H. Ramirez S. for Dario Leal-M

In dedication to:

The memory of my mother and to
my father for his understanding
and moral support.

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INTRODUCTION

Rice, (*Oryza sativa* L.), is unique among cultivated crops being both aquatic and producing a reasonable yield under upland or dryland conditions.

Upland rice is grown on unbunded land that is neither irrigated nor submerged during the growing season and, therefore, depends on rainfall for moisture. Production systems for upland rice are loosely classified into several favored and unfavored catagories, depending largely on soil fertility and the amount of rainfall. Favored upland rice is grown in fertile alluvial soils with abundant and well distributed rainfall during the growing period. Unfavored upland rice, the predominant system found in Brazil, is planted in infertile, acid soils with low and erratic rainfall. A two to three week period without rainfall frequently occurs during the growing season. There are intermediate systems between these two agroecosystems, one is represented by savanna soils of Colombia where the soils are infertile, but the rainfall total and distribution are ideal for rice growth and yield.

Savanna soils are characterized by their low fertility and pH, high exchangeable aluminum and Al saturation. The soil constraints are chemical rather than physical. These acid, infertile zones are dominated by Oxisols and Ultisols. Only about 5% of the Oxisol-

Ultisol regions of Tropical America are estimated to be under continuous agricultural production (Buol and Sanchez, 1978; Sanchez and Cochrane, 1980). There is great interest in bringing these underutilized soils into production as they offer several advantages which make them ideal for mechanized agriculture: 1) abundant rainfall (2000-3500 mm per year), 2) good physical soil characteristics, 3) flat topography, 4) low commercial value and 5) large potential area. The acid subhumid tropics cover a total of about 300 million hectares of Tropical America (Sanchez and Cochrane, 1980). In the LLanos Orientales of Colombia, the potential upland rice growing area within the states of Meta, Arauca and Casanare is about two millions hectares (Owen and Sanchez, 1979). Part of this area is currently under extensive cattle grazing systems with no or little technology practiced and inherent low productivity. The bulk of the area remains in native savanna vegetation. No upland rice is grown on these savanna soils at this time.

Most food crops are insufficiently tolerant to acid soil constraints and require uneconomically high rates of lime and fertilizers to produce satisfactory yield. Crops that are generally more Al tolerant, such as cassava, rice, peanut and cowpea, could be grown in these acid soils if an appropriate technology for managing acid, infertile soils were available (Sanchez and Owen, 1982; Sanchez and Salinas, 1983; Leal, 1984). Rice is a staple food in the Colombian diet, and is the only one of these alternative crops for which there is a strong demand.

The main constraints to introduce upland rice cropping systems onto the savanna soils are:

1. Soil factors related to the low fertility status of these soils such as deficiency of macro and micronutrients, soil acidity, and aluminum (Al) toxicity.

2. Lack of improved rice cultivars to withstand Al toxicity and related soil acidity problems, and capable of being more efficiently at low fertility levels.

3. Lack of appropiate technology for managing acid, infertile soils.

Native vegetation would be replaced with one or two crops of rice to be followed by pasture establishment. Rice would open the land and finance the initiation of an intensive cattle production system. The low input strategy would exclude the use of lime or other costly soil amendments. The general objectives of this research are:

1. To identify and evaluate potential germplasm for upland rice production in savanna soils.

2. To measure phosphorus (P) and calcium (Ca) requirements of acid soil-tolerant upland rice cultivars grown under upland conditions in savanna soils.

3. To determine the optimum seeding rate for upland rice culture in acid soils.

4. To evaluate three methods of planting upland rice.

5. To estimate pest and disease problems in acid tolerant cultivars grown under upland conditions in savanna soils.

LITERATURE REVIEW

Oxisol- Ultisol regions of South America have two predominant types of native vegetation: savanna and forest. The savanna areas cover approximately 300 million hectares, with largest area being the Cerrado of Brazil with 180 million hectares, followed by the Llanos Orientales of Colombia and Llanos Occidentales of Venezuela. Forested areas are about 550 million hectares, and are primarily in the Amazon jungle (Sanchez, 1977).

The term savanna comes from the Caribbean and is a word of the Indian language (Pietri, 1973). It has been used to describe opened prairies, covered by herbaceous plants, with some shrubbery and widely spaced palm trees. This clearly says that savanna has an ecological meaning, but not a pedological one. The great diversity among soil types under savanna conditions makes it impossible to apply any common taxonomic criterion. According to Pietri (1973), eight out of ten major soil orders may be found in savanna. Those orders are: Aridisol, Alfisol, Inceptisol, Vertisol, Ultisol, Entisol, Oxisol and Mollisol.

Management practices under savanna conditions present many different problems which are related to the diversity of soils and soil conditions found in savanna soils. Spain (1973), defined as a good management practice one that makes it possible to conserve and improve the land, so that more food may be produced for the people. Such a system is employed in the Cerrado of Brazil, where low cost of pasture establishment was possible by using upland rice as precursor of pasture establishment. Upland rice was planted with low levels of lime and P; during the second or third crop Brachiaria decumbes or other grasses were oversown and after several months the area was ready for grazing (Kornelius et al, 1979).

Low-cost soil management technology is needed to utilize efficiently these vast areas. Recently, Sanchez and Salinas (1983), have proposed and defined a low input technology for managing acid soils of the tropics. A low input technology was defined as that technology required to produce approximately 80% of the maximum yield obtained with acid-tolerant plants with efficient use of soils and chemical inputs.

Key technology components must include: 1) the identification of suitable crop species and cultivars that can a) tolerate Al, b) extract P more effectively from Al and Fe compounds, and c) absorb Ca and P more efficiently in the presence of excess Al. 2) Also it is necessary to : a) determine the proper amount of P and Ca to satisfy plant demand, and b) identify adequate methods of planting with appropiate, seed density to improve plant utilization of natural resources.

Among annual crops, upland rice is the most promising with considerable genetic variability with regard to acid soil tolerance (IRRI, 1975; Howeler and Cadavid, 1978; IITA 1979, 1980; EMBRAPA, 1982; Martinez, 1983).

Upland rice depends on rain for its entire water requirements. Therefore, the amount of rainfall and its distribution are of paramount importance. Brown (1969), reported that 200 mm of monthly rainfall during the growing season is adequate for growing upland rice. When rainfall is adequate, rainfall distribution then becomes more important. For example, in the Philippines at Los Banos an area that receives 2000 mm of annual rainfall, the distribution of the rain has a major influence on yield (De Datta and Beachell, 1972). In Peru, using 18 dates of planting, Kawano et al (1972), showed that yields were closely related to rainfall pattern. An average monthly precipitation of about 200 mm was needed for producing over 4 tons/ha of rice under upland conditions in the Peruvian jungle .

In the Llanos Orientales of Colombia, where the rainfall pattern is unimodal, the bulk of the rain falls between April to November. Himat (1981), quoted by Owen (1982), on monthly rainfall at three locations of the Llanos Orientales of Colombia, reported for Villavicencio an annual rainfall of 3477 mm with 13 to 24 rainy days per month (average of 31 years); Puerto Lopez has an average annual rainfall of 2728 mm with 10-19 rainy days per month (average of 15 years), and Puerto Gaitan has 2285 mm per year with the number of days with rain ranged from 9 to 18 (average of 13 years). Therefore, the amount of rainfall and its distribution in the Llanos Orientales appear adequate for growing upland rice. The main constraints are lack of improved rice cultivars that can tolerance Al toxicity and related acidity problems, low fertility status of savanna soils and lack of appropiate technology related to the management of those soils (Sanchez and Salinas, 1983; Leal 1984).

Varietal aspects

No clear morphological differences separate tropical rice varieties into distinct upland and lowland types, instead the plant characteristics and growth features vary continuously between the groups. Any rice cultivar can be grown in either upland or flooded culture, but its growth and yield performance may differ markedly.

Years of selection have produced marked variability in the so-called upland cultivars; nevertheless, most of the traditional upland cultivars are medium-tall to tall, low to medium in tillering ability, long and droopy leaves, large well-excerted panicles and with deep, thick roots (Chang and Vergara, 1975; IITA, 1979). Drought resistance is associated with a high proportion of thick and long roots. Leaf characteristics such as moderate droopiness and folding when water stress occurs may also be associated with drought resistance (Chang et al, 1974). Yoshida and Hasegawa (1982),in studying the relationship between plant type and root growth of 1081 rice cultivars, found that the deep root score (deep root to shoot ratio) was negatively correlated with plant height. Tall cultivars tend to have deeper root system. The deep root score was positively correlated with tiller number, implying that low tillering cultivars tend to have deep root system. A negative association between plant height and number of tillers was observed. These results confirm the common observation that upland rice cultivars are usually tall, low tillering and deep rooted. Apparently tolerance to Al toxicity and deep rooting habit are associated. The upland cultivars tolerant to Al toxicity are usually deep rooted (IRRI, 1982).

Plant species differ widely in their tolerance to excess soluble or exchangeable Al, in both acid soils or nutrient solutions (Foy, 1974). Plant cultivars within species also differ widely in Al tolerance and their tolerance is under genetic control. Tolerance to Al toxicity in rice is recessive (Martinez, 1977), while it is dominant in both wheat and barley (Kerridge and Kronstad, 1968; Reid, 1976). Martinez (1977), indicated that in Monolaya and Bluebonnet 50 rice cultivars, two pair of recessive genes were involved in their tolerance. Recènt studies done in the Instituto Agronomico de Campinas, Brazil indicated that Al-tolerance in IAC 25, IAC 47, IAC 165 and IAC 1246 is due to several recessive genes (Martinez, 1983).

Crosses made at IRRI between Al-tolerant OS 4 and E 425 and Al-susceptible cultivars IR 8 and IR 22, were tested by Howeler and Cadavid (1976), and the relative root length (RRL) values measured. RRL-values obtained from the parents were 0.32 for IR 8, 0.42 for IR 22, 0.59 for OS 4, 0.68 for E 425, and 0.58 for OS 4/IR 8, 0.48 for E 425/IR 22 and 0.63 for E 425/IR 8. Thus, Al tolerance can be incorporated into high yielding cultivars that are presently very susceptible.

Differential Al-tolerance among plant species and cultivars has been associated with morphological, physiological and biochemical plant characteristics. Foy (1974) listed root morphology; Al uptake and translocation; Ca uptake and used; magnesium, potasium and silicon uptake, and P absorption and metabolism as all being responsible for differential response by species. Aluminum solubility and toxicity increase with low pH; therefore, the abilities of certain cultivars to prevent that pH of their root zone declines could explain higher Al tolerance on the basis of reduced Al solubility in the root zone. Conversely, the ability of certain Al-sensitive cultivars to reduce the pH of their root zone could cause yield reduction, because of increased Al solubility and toxicity (Foy et al, 1974).

Foy et al,(1964), reported than differential Al-tolerance of plant species in nutrient solution and in an acid soil was closely associated with the ability of plants to absorb and utilize P in the presence of excess Al.

Howeler and Cadavid (1976) found that the Al-tolerant cultivar Colombia 1 had a higher Al level in the roots and a lower level in the shoot than CICA 4 an Al-sensitive cultivar. This could indicate a better exclusion capacity of Colombia 1 resulting in a greater Al precipitation in or outside of the root and less Al translocation to the shoot. In relation with P and Ca, the same researchers found that P and Ca content in both roots and shoots were consistently higher in Colombia 1 than in CICA 4. Thus, the Al tolerant cultivar had higher levels of P and Ca, but lower levels of Al in the shoots than Al-sensitive cultivar. Studies conducted by Coronel (1980), using nutrient solution and acid soils showed that rice plant roots were more affected by Al than the shoot; the immediate effect of Al toxicity was root reduction.

Research done by Fageria and Barbosa (1979a), in acid soils of Brazil showed a differential response of rice cultivars to low P levels in the soil. The relative yield was used as a criterion for screening for P efficient cultivars. The rice cultivars Quatro meses and IAC 21 are reported as P efficient cultivars.

Based on some screenings done in P deficient soils in Brazil, rice cultivars where divided in two groups: Group 1 were efficient but low responsive cultivars to P. Those cultivars responded well to a low level of P applied (30 Kg P_2O_5/ha), but yield did not increase with further P applications. An example of this group is IAC 25. Group 2 were both efficient and high responsive cultivars to P applications. They yielded reasonably well at low P levels but they responded to increasing P rates. IAC 47 is an example of this group. Rice cultivars representing Group 2 are recommended for a high input technology (EMBRAPA, 1982).

Three techniques for distinguishing Al-tolerance in rice, using nutrient solutions were evaluated by Coronel (1980). The hematoxylin staining technique was considered impractical for screening Al tolerance in rice since visual detection of cultivar differences were not apparent. The regrowth method was not practical since extensive root measurements were involved. So far, the absolute root length technique is the most practical. In Brazil, Fageria and Barbosa (1979b), used root length reduction as a criterion of selection of Al-tolerant cultivars. This method measured the direct effect of Al, which is root reduction.

Nutritional aspects

Savanna soils of the Llanos Orientales of Colombia are characterized by low pH, high Al and Al saturation, and deficiency of some major and minor plant nutrients. Among the chemical constraints found, P and Ca are rather specific for the acid infertile soils of savanna.

In general, Al toxicity does not occur in soils above pH 5.5, but is common at lower pH values and is particularly severe below pH 5.0. Below pH 5.5, the solubility of Al increases sharply and more than half the cation exchange sites may be occupied by Al (Evans and Kamprath, 1970). The solubility of Al and the severity of resulting toxicity to plants are affected by many soil factors. Among them, Foy (1974) mentioned the soil pH, type of predominant clay mineral, concentration of other cations, total salt concentration, and organic matter content.

Four expressions used for identifying Al-toxic soils are: pH, exchangeable Al, percent Al saturation and soil solution Al (Kamprath, 1967, 1970, 1973; Foy, 1974; Jackson, 1967; IRRI, 1972). Liming recommendations for acid mineral soils based on the neutralization of exchangeable Al, which is based on the equation: meq Ca/100 g soil = 1.5 meq Al/100 gr, have been used since the mid-nineteen sixties (Kamprath, 1967, 1970). However, Evans and Kamprath (1970), Kamprath (1973) and Spain (1976), have demonstrated that crops and individual cultivars vary in their tolerance to Al, the degree of which may be expressed in terms of the percent Al saturation.

A modification of the formula proposed by Kamprath (1970),has been used by Sanchez (1981), based on the susceptibility of crop species to Al toxicity. Lime recommendations vary from highly susceptible crops like cotton, where: lime required (ton/ha) = 2.0 X Al meq/100 g soil, to highly resistant crops, such as the pastures *Melinis minutiflora*, *Panicum maximum* and *Brachiaria humidicola*, where lime recommendations are between 0-250 Kg/ha. It is necessary only to apply enough lime to decrease the Al saturation percentage to a level that does not affect production in susceptible crops or to provide Ca as a nutrient in highly resistant crops.

Many investigators have associated Al toxicity with reduced uptake of several nutrient elements by plants, particularly Ca and P. Usually root growth appears to be most affected by a severe influence of Al inhibiting cell division (Jackson, 1967). In the shoots, however the most common effect is most often due to lack of P, resulting from greatly impaired translocation. Excess Al may reduce the solubility of P in the growth medium and its uptake and utilization by plants (Foy, 1974).

The detrimental effects of high Al and low P are often difficult to separate in acid soils. Reviews by Salinas and Sanchez (1976), and Sanchez and Uehara (1980), indicate the possibility of a joint tolerance to high Al levels and low P levels. A faster translocation rate of P from the roots to the top of the plant seems to be the main factor accounting for these differences. Additional factors, such as Ca translocation, also affect Al tolerance. However, Reeve and Summer (1970), concluded that on eight Oxisols, Al toxicity, P deficiency and P fixation were primary, but independent, growth limiting factors. They attributed the beneficial effect of P fertilization to the elimination of Al toxicity and the resulting increase of plant absorption of P, rather than to increased P availability in the soil.

Phosphorus applications have been recommended by soil scientists to overcome P deficiency in acid soils. Responses to P by upland rice have been frequent in soils of the Campo Cerrado Brazil. Oliveira et al, (1965) found that maximum yield was obtained with 60 Kg P_2O_5/ha resulting in an increase of 48% over the check plot. Ponte et al (1980), determined a P response up to 120 Kg P_2O_5/ha. Morais and Macedo (1977) in experiments conducted in acid soils at four locations of Brazil, reported a variable P response. Phosphorus responses in grain yield varied from applications of 30 to 90 Kg P_2O_5/ha.

In savanna soils of Colombia, Sanchez and Leal (1978), using the cultivar IR 8, obtained from the average of two locations, a yield (1787 Kg/ha) almost double that of the check plot, when 75 Kg P_2O_5/ha were applied. Grain yield was relatively low due to the susceptibility of IR 8 to acid soil conditions. Comparing three P sources, triple superphosphate (TSP), basic slags and rock phosphates, Sanchez and Owen (1979), found that TSP and basic slags produced significantly higher peanut yield than rock phosphates in the first crop, but in the second crop, there were no significant differences among P sources.

Determining the effect of liming on P availability to plants has been the subject of numerous studies. Increases, decreases and no changes in P availability, as indicated by P concentration of plant tissue, have been reported by Amarasiri and Olsen (1973). Explanations for any one of these results have varied, primarily because of the numerous direct and indirect effects that lime additions can have on plant nutrition and physiology. Kunishi (1982), reported that at any given level of P, increasing levels of lime increased plant yield and plant uptake of Ca and P. On the other hand, Calvo et al, (1977), found a negative association between P concentration, based on tissue analysis, and lime rates applied.

It seems that Ca deficiency per se did not limit plant growth in acid soils, but did influence the toxic effect of Al (Kamprath, 1967; Jackson, 1967; Evans and Kamprath, 1970; Calvo et al, 1977). Evans and Kamprath, (1970) and Calvo et al (1977), found that the Ca concentration of the unlimed soils were adequate for plant growth. The poor growth observed on the unlimed soil was, therefore, not due to Ca deficiency, but to Al toxicity and the detrimental effect of Al on absorption and translocation of Ca. Jackson (1967), suggested that one of the differences in species sensitivity to high acidity is a difference in the ability to absorb Ca.

Field experiments have shown that many tall, traditional rice cultivars from acid soils areas required only small lime applications, while most of the semidwarf cultivars required substantial quantities of lime to reach their yield potential. Yields of the semidwarf cultivars were essentially nil without lime (Spain et al, 1976; Howeler and Cadavid, 1976; Calvo et al, 1977). In Cerrado soils of Brazil, no lime response by upland rice cultivars was reported by Morais and Macedo (1977). A grain yield reduction due to lime application was reported by Ponte et al, (1980). They attributed the yield reduction to a possible Zn deficiency.

Field experiments conducted in savanna soils of the Llanos

Orientales, with increasing rates of lime applications, indicated that the main effect of lime was to neutralize the exchangeable Al and raise the pH. Calvo et al, (1977), found that 0.4 ton lime/ha provided Ca and Mg, as nutrients to the plants, without altering significantly pH or Al in the soil. With 4.0 ton lime/ha, 60% of the exchangeable Al was neutralized and the pH raised to 5.0. With 8.0 and 16.0 ton lime/ha, all the exchangeable Al was neutralized and pH increased to 5.5 and 6.0, respectively. The initial pH of the soil was 4.7. Similar results are reported by Howeler and Cadavid (1976), where 0.5 ton lime/ha slightly modified pH and exchangeable Al, but 6.0 tons lime/ha increased the pH of the soil from 4.3 to 5.3 and decreased the Al saturation from 80% to 20%.

Cultural practices

The interaction between the genotype and the enviroment determines the performance of a cultivar. Plant spacing and rate of seeding influence yield and cultivar performance since they affect water, nutrient and light availability. However, scarce information exists about cultural practices to maximize upland rice production in savanna soils.

Kawano et al, (1972), in studies done in acid Ultisols of the Peruvian jungle, found that a row spacing of 25 cm between rows produced higher yield than the traditional 50 cm. The row spacing of 25 cm was optimum for both traditional upland and improved semidwarf rice cultivars.

In another Peruvian experiment, two spacings of drilled rows 15 and 25 cm apart were compared with the conventional spacing of 50 cm. The conventional systems with rows spaced 50 cm, produced 1 ton/ha less than closer spacings. Closer spacing increased yields by about 40% (Sanchez, 1972).

Morais (1980), in Cerrado soils of Brazil, reported a significant difference in grain yield between two row spacings. Grain yield obtained was significantly higher when plants were sown in rows 40 cm apart, compared with those planted in rows 80 cm apart. Yield differences were due to a greater number of panicles per unit area. Results obtained by IITA (1981), indicate that an optimum planting density for upland rice is lower than that for irrigated lowland rice because of poor water holding capacity and low nutrient status of upland degraded soils.

Savanna soils of the LLanos Orientales offer great opportunity for increasing rice production in rainfed systems as they have several advantages such as favorable soil structure, plenty of well distributed rainfall and flat topography. The most limiting factors preventing widespread agricultural development in these soils are the inherent low native fertility and the lack of appropiate technology for their management.

The key basic concept of soil management technology for savanna soils is to alleviate or overcome certain soil constraints simply by using rice cultivars that are tolerant to them. Suitable rice cultivars, tolerant to Al toxicity and low levels of P and Ca, can be planted with low rates of fertilizers and still provide satisfactory yield. Adequate rate of seeding and sowing methods, for a better utilization of natural resources, are also essential components of a successful rice production technology for savanna soils.

MATERIALS AND METHODS

The research was conducted at the Regional Center for Research "La Libertad" (CRI La Libertad) of the Instituto Colombiano Agropecuario (ICA), Villavicencio, Llanos Orientales, Colombia, during the rainy seasons of 1983 and 1984.

CRI La Libertad, located at 336 meters above sea level, has an average annual rainfall of 2860 mm, and an average temperature of 25.4^{o}C with a maximum of 30.4^{o}C and a minimum of 21.4^{o}C. Precipitation has a monodal pattern with tha majority of the rain falling between April and November, followed by a pronounced dry season (Appendix Figure 1.)

Growing season 1983

Three experiments were conducted in representative savanna soils of CRI La Libertad, to provide data to develop a management system for upland rice production. A soil analysis of the experimental area is showed in Appendix Table 1. Soil samples were taken from 0-20 cm below soil surface. Soil pH was measured in a 1:1 soil to water ratio. Soil samples were extracted with 1N KCl to determine Ca, Mg, exchangeable acidity (Al, H) and micronutrients. Soils were extracted with 1N NH4Cl to determine K. Boron was measured with curcumin-oxalic acid color after extraction with hot water. Cations were measured with atomic absorption. Chemical analyses were done following CIAT's procedure (Salinas and Garcia, 1979).

Assessment of agronomic traits needed in upland rice cultivars for acid soils. Experiment 1.

A set of 58 cultivars was evaluated in this trial. Most of the introduced cultivars planted were tall, upland rice varieties, tolerant to Al toxicity and related acidity problems. A few semidwarf, improved irrigated varieties were included in the trial (Appendix Table 2).

Experimental plots consisted of eight rows. 30 cm apart and 5 meters in length. The experimental design was a randomized block, with four replications. Phosphorus (60 Kg P_2O_5/ha), potassiumm (40 Kg K_2O/ha) and calcium (150 Kg Ca/ha), were applied in rows just prior to planting. Fertilizer sources were concentrate superphosphate, potassium chloride and dolomite, respectively. The dolomite provided 50 Kg Mg/ha, in addition to calcium. Nitrogen (60 Kg N/ha as urea) was applied in equal fractions at tiller initiation, maximum tillering and panicle initiation.

Weeds, pests and diseases were chemically controlled as required and an optimum control level was maintained throughout the growing season.

The following data were recorded:

- Plant height (cm). From ground level to the tip of the tallest leaf or panicle based on the standard evaluation system for rice (CIAT, 1983). Data were taken at 30 and 60 days after germination and at harvest time.

- Root dry weight (g/m^2). Roots were taken from plants from selected border rows. Two samples, each 50 cm in length, were taken from each plot. Roots were washed, dried and weighed. Data were recorded at 30 days and at harvest.

- Biological yield (g/m^2). Dry matter production from a square meter was sampled at 30 days and at harvest.

- Root scale (1-6). A subjective scale was developed to characterize root development in upland soils. The scale, based on root thickness, length and number, is as follows:

Grade	Root morphology
1	Short, thin and few roots
2	Short, thin and many roots
3	Long, thin and many roots
4	Short, thick and few roots
5	Long, thick and few roots
6	Long, thick and many roots

- Aluminum toxicity scale (1-5). The rice cultivars exhibited differing degrees of susceptibility to Al toxicity and related acidity problems. To measure these differences, a scale was developed comprising incidence and severity of the problem. Ratings were made 60 days after germination.

Grade	Description
1	Healthy plants, normal leaves
2	Less than 10% of the plants showing a light chlorosis
3	10-25% chlorotic plants
4	25-50% chlorotic plants
5	More than 50% of plants chlorotic to severe yellowing

- Leaf calcium. Percent Ca based on leaf analysis. Plant samples were digested with nitric acid, then perchloric acid and brought to volume. Calcium was measured with atomic absorption, following CIAT's procedure. (Salinas and Garcia, 1979). Data were obtained 35 and 70 days after germination.

- Leaf phosphorus. Percent P concentration in leaves 35 and 70 days after germination. Phosphorus was determined colorimetrically using ammonium molybdate P color reaction (Salinas and Garcia, 1979).

- Leaf aluminum. Aluminum concentration in parts per million (ppm) in leaves 35 and 70 days after germination. Aluminum was determined by colorimetric procedure following CIAT's methodology. (Salinas and Garcia, 1979).

- Flowering date. Data were recorded in days, when 75% of the plants had flowered.

- Harvest. Time in days from germination to maturity.

- Tiller number. Two samples, 50 cm long, were taken from center rows at harvest, with data expressed as number of tillers per square meter.

- Panicle number. Effective tillers or panicles were counted at harvest from two samples, 50 cm long. Data are expresed as number of panicles per square meter.

- Grain number. Ten representative panicles were taken at random, the average number of filled grains per panicle was calculated.

- One thousand grain weight. A sample of 1000 dry grains was taken and weighed.

- Sterility. Percent unfilled grains at harvest from 10 randomly selected panicles.

- Grain to straw ratio. Grain weight over dry matter yield. Data were recorded at harvest, from two samples per plot, each being 50 cm long.

- Harvest index. Ratio of grain yield to total dry matter yield obtained from two samples per plot, each 50 cm long.

- Grain yield. Data were obtained from 4.8 square meters and expressed in Kg/ha of dry, clean rice.

Standard statistical procedures, including the analysis of variance and Tukey's test for multiple comparisons, were done for each one of the 25 plant characters measured. A t test was included to assess plant differences between upland rice cultivars. Simple correlation coefficients to measure the degree of association among yield components and a stepwise multiple regression analysis to explain grain yield and the possible contribution of the 25 plant characters measured, were also carried out.

Amendment of main nutritional disorders in savanna soils.

Experiment 2.

A split plot design with four rice cultivars as the main plots and nutrients as the subplots, with three replications was used. Rice cultivars tested were: IR 4568-225-3-2, IAC 165, Colombia 1 and CICA 4. Four levels of Ca and four levels of P were studied in a factorial arrangement of treatments.

Calcium levels were: 0, 75, 150 and 225 Kg Ca/ha and P levels: 0, 30, 60 and 90 Kg P_2O_5/ha. A uniform fertilization of 60 Kg N/ha and 40 Kg K_2O/ha was applied. Fertilizer sources were dolomite, concentrate superphosphate, urea and potassium chloride. Plants were protected against pests and diseases throughout the growing period. Individual plots consisted of eight rows, 30 centimeters apart and 5 meters in length. Data were recorded, as mentioned in Experiment 1.

Plant response to P and Ca was measured based on tissue analyses from leaf samples taken 35, 65, and 85 days after emergence and on the fertilizer effect for grain yield and the yield components. Plant tissue analyses and soil analyses were performed following CIAT's procedure (Salinas and Garcia, 1979).

An analysis of variance was conducted for each one of the plant variables measured. The F test was utilized to determine significant differences. Means values were compared using Duncan's multiple range test.

Cultivar performance in savanna soils with variation in sowing methods and seed density. Experiment 3.

A randomized block design with a factorial arrangement of treatments and three replications was utilized. Three rice cultivars: IR 4568-225-3-2, IAC 165 and Colombia 1 were planted under three different methods and four rates of seeding. Planting methods compared were: row spacings of 15 and 30 cm, and broadcast. Seeding rates evaluated were 60, 90, 120 and 150 Kg of seed per hectare.

Fertilizer rates and sources were 60 Kg N/ha, 60 Kg P_2O_5/ha, 40 Kg K_2O/ha and 150 Kg Ca/ha using urea, concentrate superphosphate, potassium chloride and dolomite, respectively. In addition to Ca, dolomite provided 50 Kg Mg/ha. Pest and diseases were controlled chemically and an optimum plant protection was maintained throughout the growing season. Data were taken following the procedures described in Experiment 1.

Analysis of variance was computed for each plant trait measured. Duncan's multiple range test was performed to compared mean values.

Growing season 1984

Integrated pest control management in selected upland rice cultivars for savanna soils. Experiment 4.

Data gathered in the preliminary screening nursery for upland rice cultivars were the main criteria for selecting a group of 25 cultivars for further evaluations. Field observations were based on the overall plant behavior as a measure of plant adaptation and on root morphology (thick and long roots). Grain yield was also a screening criterion and those rice cultivars that produced more than 3 tons/ha in the replicated trial were chosen. Most of the cultivars were tall, but some semidwarfs were included in the trial (Appendix Table 3).

Based on the results obtained in the experiments related to planting methods, rate of seeding, and the fertilizer trial, some modifications were introduced.

Seed were sowed in rows 15 cm apart. A uniform rate of seeding of 60 Kg seed per hectare was used. Plots consisted of 10 rows, 15 cm apart and 5 m in length. The harvest area was 8 rows, 4 meters long to avoid border effect. The fertilization used was: 60 Kg N/ha (urea), 60 Kg P_2O_5/ha (concentrate superphosphate), 40 Kg K_2O/ha (potassium chloride) and 150 Kg Ca/ha (dolomite).

A split plot design with four replication was used. Main plots were pest management: protected vs unprotected plants and the 25 rice cultivars were the subplots. In the protected plots, insects and diseases were chemically controlled. The main insect pests in the area were Sogatodes oryzicola, a planthopper that aside from causing sogata hopperburn damage, is the vector of the hoja blanca virus, and Diatrea sp, a stem borer. Among the rice diseases blast (Pyricularia oryzae), leaf scald (Rhynchosporium oryzae), grain discoloration which is associated with a number of fungi such as Helminthosporium orizae, Rhynchosporium oryzae, Nigrospora sp and Curvularia sp among others, and the hoja blanca virus, were the most prevalent in the field.

Three insecticide and four fungicide applications were necessary to maintain a satisfactory level of protection against insects and diseases in the protected plots. Unprotected plots were maintained without any chemical application.

The insecticides used were granular Carbofuran (20 pounds/ha) applied just after planting to prevent early damage by sogata, Lannate (0.45 Kg/ha) at tillering stage to protect against sogata, and Carbofuran (20 pounds/ha) just before heading to control stem borers.

Two foliage and two panicle sprays of fungicides were applied to protected against blast and grain diseases. At the tillering stage, Benlate (300 g/ha) was sprayed against blast and leaf scald. Two weeks later Bim (300 g/ha) was applied to control leaf blast. A mix of Bim (250 g/ha) + Duter (2 Kg/ha) was sprayed to control neck blast and grain diseases at early flowering. Two weecks after this application, Hinosan (1 liter/ha) + Dithane (4 pounds/ha) were mixed and applied to protect against a late infection of blast and grain discoloration. Since cultivars varied in flowering, fungicide sprays were timed to the proper development stage of the rice plants.

Upland rice production technology for savanna soils of Colombia. (Experiment 5).

A randomized block design with a factorial arrangement of treatment was used to compare four rice cultivars, two Ca levels and three P levels. Rice cultivars were IAC 165, Makalioka 34, Tox 95 and IR 4568-225-3-2. The first three cultivars are tall upland types and IR 4568-225-3-2 is semidwarf. They were chosen based on their adaptation to acid soil conditions and yield potential observed during the growing season of 1983.

Calcium rates were: 0 and 150 Kg Ca/ha. During the 1983 experiment a slight response to Ca applications was observed. Phosphorus rates were: 0, 60 and 120 Kg P_2O_5/ha. Nitrogen and potassium at rates of 60 Kg N/ha and 40 Kg K_2O/ha were applied uniformly to all plots. Plants were protected against pests and diseases as noted in Experiment 4 and satisfactory control was maintaned throughout the growing period.

Experimental plots consisted of 10 rows, separated by 15 cm, 5 m in length. An area of 4.8 square meters was used to determine grain yield.

RESULTS AND DISCUSSION

There are three main ways to increase food production in the tropics: increasing yields per unit area in regions presently cultivated, expanding irrigated lands, and opening new lands to cultivation. Increasing productivity in areas already under cultivation is the principal avenue for increasing food production. However, recent estimates by the Food and Agriculture Organization (FAO), as cited by Dudal (1980), suggest that food production should increase 60% in the next 20 years, to maintain the existing level of food per capita. He estimates that yield increases in areas under cultivation will not be enough, and an additional 200 million hectares must be incorporated into agriculture during the next two decades to accomplish this goal. The greatest potential for expanding the world's agriculture frontier is in the tropical rain forest and savanna regions dominated by acid, infertile soils, classified as Oxisols and Ultisols (Kellogg and Orvedal, 1969).

As suggested by Sanchez and Salinas (1983), research efforts in the tropics are now aimed toward a low input technology for managing infertile savanna soils which does not eliminate the use of fertilizers and amendments, but tries to maximize the efficiency of the inputs, through a series of cultural practices.

To this end, five experiments were carried out in representative savanna soils of the Llanos Orientales of Colombia. These included maximizing scarce inputs by planting and evaluating rice germplasm more tolerant to existing soil constraints combined with decrease in fertilizer rates to obtain reasonable, but not necessarily maximum yields, and some management practices to improve the utilization of natural soil resources by the rice crop.

This research was conducted during the rainy seasons of 1983 and 1984. In 1983 three studies were undertaken:

Assessment of agronomic traits needed in upland rice cultivars for acid soils. Experiment 1.

Amendment of main nutritional disorders in savanna soils. Experiment 2.

Cultivar performance in savanna soils with variation in sowing methods and seed density. Experiment 3.

The two experiments conducted in 1984, were:

Integrated pest control management in selected upland rice cultivars for savanna soils. Experiment 4.

Upland rice production technology for savanna soils of Colombia. Experiment 5.

Assessment of agronomic traits needed in upland rice cultivars for acid soils (Experiment 1)

Definition of the agronomic traits needed in upland rice cultivars for savanna soils was the objective of the first experiment.

A group of 58 rice cultivars from all over the world was planted in savanna soils of CRI La Libertad, during the rainy season of 1983. The soil analysis is in Appendix Table 1.

Plant type for irrigated lowland rice has been extensively studied. However, there is a notable lack of information on the growth habit of rice under upland conditions in savanna soils, where soil acidity and Al toxicity are the most limiting factors. Analysis of variance for each one of the plant characters was performed. Table 1 shows the traits, dates, means, range, standard deviation and the coefficient of variation of the 25 plant characters studied. There was a large variation in the plant characters measured due to the diverse genetic constitution of the rice cultivars evaluated.

Research on plant type for upland rice has indicated that for improving lodging resistance and yield potential, short to intermediate statured cultivars are superior to traditional, tall cultivars (IRRI, 1975; IITA, 1980). A height between 90-110 cm is suggested for upland rice in savanna soils.

A root scale based on root thickness, length and number was developed to characterize root development. A description of the scale is presented in the Materials and Methods section. Root scale ranged from 1.8 to 5.1 at harvest. A correlation between root scale and height was found at 30 days after emergence (0.643**), at 60 days (0.605**), and at harvest (0.516**). Leaf Al concentration at 35 days (-0.266*)and at 70 days (-0.262*), Al toxicity scale (-0.357**), numbers of tillers (-0.434**), number of panicles (-0.395**) and 1000 grain weight (0.564**) were also correlated. Upland cultivars are generally tall and have deeper and thicker roots compared to the paddy varieties. It appears that deep rooted cultivars generally have a larger proportion of thicker roots than shallow rooted cultivars.

Data reported by the International Institute of Tropical

Table 1. Traits, date and statistics measured in the preliminary screening of upland rice cultivars for acid soils. CRI La Libertad, Villavicencio, Llanos Orientales,Colombia, 1983. 1]

Variable	Date 2]	Mean	Range	Standard deviation	CV
Height (cm)	30 days	37.9	24.3- 56.0	7.23	7.7
Height (cm)	60 days	66.2	37.3- 96.5	14.06	5.9
Height (cm)	At harvest	89.1	57.3-116.0	16.26	6.2
Root dry weight (g/m2)	30 days	34.0	22.7- 50.3	11.17	19.3
Root dry weight (g/m2)	At harvest	72.7	31.3-155.3	15.87	21.8
Biological yield(g/m2)	30 days	119.0	86.0-158.7	20.47	12.7
Biological yield(g/m2)	At harvest	415.7	267.7-843.0	129.10	12.3
Root scale (1-6)	60 days	3.8	1.6 - 4.9	0.95	15.1
Root scale (1-6)	At harvest	3.6	1.8 - 5.1	1.12	20.6
Al toxicity scale (1-5)	60 days	2.5	1.4 - 4.6	0.86	21.2
Leaf calcium (%)	35 days	0.30	0.22- 0.43	0.07	13.7
Leaf phosphorus (%)	35 days	0.19	0.16- 0.26	0.03	12.7
Leaf aluminum (ppm)	35 days	31.5	7.5 -82.3	26.87	79.3
Leaf calcium (%)	70 days	0.32	0.22- 0.59	0.09	18.4
Leaf phosphorus (%)	70 days	0.15	0.13- 0.20	0.02	10.1
Leaf aluminum (ppm)	70 days	19.1	6.1 -85.8	25.20	123.7
Flowering (days)	Variable	89.3	59.0-132.8	15.74	2.1
Harvest (days)	Variable	115.7	82.8-160.8	15.31	2.7
Tillers (N/m2)	At harvest	306.7	159.3-587.7	90.60	12.1
Panicles (N/m2)	At harvest	270.0	153.3-522.7	83.37	12.2
Grains (N/panicle)	At harvest	56.7	14.2-104.1	17.50	16.1
1000 grain weight (g)	At harvest	29.0	16.0- 42.3	5.78	6.3
Sterility (%)	At harvest	21.1	11.1- 58.6	9.75	15.8
Grain/straw ratio (%)	At harvest	69.1	11.4- 99.1	22.32	15.1
Grain yield (tons/ha)	At harvest	2.54	0.71- 3.73	0.64	12.3

1] Data from 58 rice cultivars with 4 replications

2] Dates from seedling emergence

Agriculture (IITA) scientists on plant type under different ecologies, suggest no relationship between root dry weight and grain yield obtained in upland culture (IITA, 1980). Evaluation of root morphology by visual scoring based on the scale proposed, is simple and is related to good plant development in savanna soils. Selection based on this scale rather than the tedious process of root dry weight, is practicable. A non significant association was found between grain yield and root dry weight 30 days after rice emergence (0.058) and at harvest (0.086).

Among the yield components of the rice cultivars evaluated, panicle number ranged from 153.2 to 522.7 per square meter; number of grains per panicle ranged from 14.2 to 104.1; 1000 grain weight from 16.0 to 42.3 grams; percent sterility from 11.1 to 58.6%; grain to straw ratio ranged from 11.4 to 99.1% and grain yield ranged from 0.71 to 3.73 tons/ha with a mean value of 2.54 tons/ha. Variation in the plant traits is the result of the interaction between the wide range of genetic background of the cultivars and the environmental conditions such as climate, upland culture, soil acidity and fertility level.

Individual analysis of variance was done for the 25 plant characters. Coefficients of variation (CV) were low for most of the traits analyzed. Concentration of aluminum in the leaves had the highest CV, 79.3% and 123.7% at 35 and 70 days after planting, respectively; followed by root dry weight at both sampling days (17.3 and 21.8%, respectively). Other CV were intermediate to low, depending on the trait.

There were highly significant differences among rice cultivars for grain yield, showing a differential behavior due to different degrees of adaptation to soil acidity (Table 2). Average grain yield was 2544 kg/ha with a CV of 12.3%.

A stepwise regression analysis was carried out to explain the variation observed for grain yield using the 25 variables measured. The best regression analysis model and the contribution of those variables which were significantly differents are presented in Table 3. Grain to straw ratio, grains per panicle, tiller number, height at harvest, days to flowering, Al toxicity scale and P concentration based on leaf analysis done at 35 days, explained 78 percent of the variability associated with grain yield .

In order to characterize rice cultivars, two groups were formed among the 58 rice cultivars screened. In the upland rice group the main criterion for selection was the cultivar origin from rice areas of acid soils. Lowland rice cultivars were mainly improved varieties presently cultivated under irrigation. A t test was performed and highly significant differences were encountered for most of the traits compared (Table 4). In general, upland rice cultivars were taller, had higher biological yield, fewer tillers and panicles, more filled grains per panicle and higher 1000 grain weight than lowland rice cultivars. Upland rice cultivars matured earlier than lowland cultivars and presented less sterility. Roots were thicker and fewer in number for the upland group when compared to the lowland group. Grain yield was higher in the upland group.

Similar results have been obtained in investigations done in the

Table 2. Analysis of variance for grain yield of the preliminary screening of rice cultivars for upland rice culture in savanna soils. CRI La Libertad , Villavicencio, Llanos Orientales, Colombia. 1983.

Sources	df	MS	F
Replications	3	0.793	8.18**
Cultivars	57	1.624	16.74**
Error	171	0.097	
Total	231		

** : Significant at 1% level

Mean : 2544 Kg/Ha

CV : 12.3%

Table 3. Best step-wise regression analysis model for grain yield (tons/ha) of the preliminary screening of upland rice cultivars for acid soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1983.

Analysis of variance

Sources	df	MS	F
Regression	7	0.00000258	25.59**
Residual	50	0.00000010	
Total	57		

$R^2 = 0.78$

	B value	Standard error	F
Intercept	-0.00402583		
Leaf phosphorus	0.00470849	0.00239630	3.86*
Al toxicity scale	-0.00013887	0.00007111	3.81*
Flowering	0.00001840	0.00000415	19.67**
Height at harvest	0.00000809	0.00000371	4.76*
Tiller number	0.00001009	0.00000203	24.71**
Grains per panicle	0.00001667	0.00000365	20.83**
Grain /straw ratio	0.00259802	0.00027887	86.79**

* : Significant at 5% level

**: Significant at 1% level

Table 4. Mean values of 17 plant characters of two rice groups grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

	Rice groups		
Plant characters	Upland 1]	Lowland 2]	t test 3]
Height at 30 days (cm)	42.2	30.4	**
Height at 60 days (cm)	74.8	50.5	**
Height at harvest (cm)	101.5	72.9	**
Root dry weight at 30 days (g/m2)	32.3	37.0	*
Root dry weight at harvest (g/m2)	70.7	83.3	*
Biological yield at 30 days (g/m2)	124.3	109.0	**
Biological yield at harvest (g/m2)	450.3	395.3	**
Root scale at 60 days (1-6)	4.25	3.13	**
Root scale at harvest (1-6)	4.14	2.89	**
Al toxicity scale (1-5)	2.24	2.99	**
Leaf calcium at 35 days (%)	0.29	0.33	**
Leaf calcium at 70 days (%)	0.29	0.32	*
Leaf phosphorus at 35 days (%)	0.19	0.20	n.s
Leaf phosphorus at 70 days (%)	0.14	0.16	**
Flowering (days)	84.2	98.6	**
Harvest (days)	112.7	123.5	**
Tillers (N/m2)	295.0	359.0	**
Panicles (N/m2)	260.7	320.0	**
Grains (N/panicle)	68.3	52.1	**
1000 grain weight (g)	32.0	24.9	**
Sterility (%)	6.8	20.1	**
Harvest index (%)	42.8	41.1	*
Grain yield (tons/ha)	3.03	2.74	**

1] Average values of 15 upland rice cultivars.
2] Average values of 14 lowland rice cultivars
3] **: Significant at 0.01 level
*: Significant at 0.05 level
n.s : No significant

favored upland rice ecologies by IRRI and IITA (Internacional Rice Research Institute,1975, 1980; International Institute of Tropical Agriculture, 1979, 1980, 1981). Upland varieties usually have bold-shaped and thick grains that are high in 1000 grain weight, although some have slender grains (Chang and Vergara, 1975). A remarkable feature of upland cultivars is their ability to consistently produce completely fertile panicles of well-filled grains, even after mild drought (Jana and De Datta, 1971; Chang et al, 1974).

Tables 5 and 6 show plant tissue analysis of Ca and P in lowland and upland groups, respectively . Lowland cultivars had higher Ca and P content than upland rice cultivars, but both groups had P and Ca values above the critical nutrient concentration (those levels below which nutrient deficiencies and reduced crop production occur) reported in the literature for rice. Mikkelsen (1978), reported a P critical value of 0.08 % and an adequate value of 0.10-0.18 % for rice at the maximum tillering stage. These values were developed from data obtained in greenhouse and field experiments in California. No information about the critical value for Ca is presented by Mikkelsen (1978). Yoshida (1981), reported a critical concentration 0.10% for P and 0.15% for Ca. Similar values were presented by Howeler (1983). Highly significant differences were found in both Ca and P concentrations at both sampling dates in the two groups under study. Among the lowland varieties, higher Ca and P values were found for Metica 1 and Colombia 1. Metica 1, is an improved short stature irrigated variety released by ICA in 1980 for the Llanos Orientales of Colombia (Leal et al, 1980). Colombia 1 is tolerant to Al toxicity

Table 5. Tissue analyses of Ca and P in selected lowland rice cultivars grown in savanna soils under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

	Ca concentration (%)		P concentration (%)	
Cultivar	35 days	70 days	35 days	70 days
Bg 90-2	0.360	0.315	0.190	0.160
IRAT 122	0.290	0.260	0.193	0.155
P 2030 F4-235-1B-1B	0.275	0.290	0.215	0.168
IR 4568-225-3-2	0.303	0.398	0.208	0.163
IRAT 123	0.280	0.270	0.200	0.160
IR 6023-10-1-1	0.363	0.358	0.188	0.158
Metica 1	0.430	0.415	0.213	0.195
Camponi	0.300	0.268	0.190	0.155
CICA 8	0.278	0.260	0.173	0.135
Metica 2	0.408	0.388	0.188	0.173
CR 1113	0.333	0.293	0.195	0.148
Colombia 1	0.413	0.425	0.225	0.170
Kaohsiung 138	0.308	0.323	0.198	0.163
IR 4-2	0.275	0.263	0.200	0.153
Means	0.330	0.323	0.198	0.161
Tukey's values	0.103	0.146	0.060	0.039

Table 6. Tissue analyses of Ca and Pin selected upland rice cultivars grown in savanna soils under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983

	Ca concentration (%)		P concentration (%)	
Cultivar	35 days	70 days	35 days	70 days
Makalioka 34	0.258	0.215	0.208	0.143
Salumpikit	0.275	0.280	0.220	0.160
Tox 95	0.363	0.310	0.255	0.163
Khao maleuh	0.285	0.378	0.195	0.148
Tox 1369-18-1	0.318	0.313	0.173	0.150
IAC 47	0.268	0.223	0.165	0.125
IAC 25	0.275	0.277	0.180	0.143
Kinandang patone	0.265	0.300	0.188	0.153
MI 48	0.238	0.270	0.173	0.140
Quatro meses	0.290	0.308	0.163	0.133
Tox 1785-19-18	0.345	0.395	0.173	0.138
63-83	0.300	0.290	0.175	0.138
OS 6	0.265	0.263	0.168	0.138
Dourado	0.338	0.290	0.195	0.155
Monolaya	0.315	0.300	0.185	0.150
Means	0.293	0.294	0.188	0.145
Tukey's values	0.103	0.146	0.060	0.039

and related acidity problems (Howeler and Cadavid, 1976; Spain et al, 1976). Among the upland group, rice cultivars from IITA: Tox 95, Tox 1369-18-1 and Tox 1785-19-18 and a native variety from Colombia, Monolaya, showed higher Ca values based on plant tissue analysis. Highest P concentrations were found in Salumpikit an upland rice cultivar from the Philippines, and in Tox 95 from IITA.

There were significant differences among lowland rice cultivars in plant height and root dry weight at both sampling days, and biological yield at harvest time (Table 7). Similar results were found among upland rice cultivars (Table 8). Comparing both groups, upland cultivars were taller, matured earlier and had a higher biological yield than lowland cultivars. The lowland cultivars generally had a higher root dry weight value. These results are in agreement with those reported by IITA researchers in measurements done at three different growth stages, when comparing improved lowland and traditional upland cultivars (IITA, 1980). However, no differences were found in root dry weight in comparisons done between upland and lowland cultivars by Chang and Vergara (1975). Although upland cultivars had thicker and deeper roots than lowland cultivars, the latter had more roots per plant which explains the higher root dry weight values obtained. Studies done at IRRI, on varietal differences in various root characteristics among variety groups, found a positive association between root length and root thickness (0.982**). The deepest and thickest roots were found in the drought resistant, traditional dryland varieties. The semidwarfs (lowland cultivars) excelled in root number only (IRRI, 1982).

Table 7. Comparison of four agronomic characteristics of selected lowland rice cultivars grown in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Cultivar	Height (cm) 1]	Height (cm) 2]	Biological yield (g/m^2) 1]	Biological yield (g/m^2) 2]	Root dry weight (g/m^2) 1]	Root dry weight (g/m^2) 2]	Harvest (days)
Bg 90-2	30.3	69.3	121.7	378.3	42.7	82.0	123.5
IRAT 122	32.3	84.5	106.0	312.7	45.3	70.7	120.8
P 2030 F4-235-1B-1B	27.8	62.0	109.3	376.3	30.3	76.3	127.8
IR 4568-225-3-2	29.5	76.3	124.0	440.7	50.3	111.1	120.3
IRAT 123	33.3	79.5	98.7	317.7	32.0	73.0	121.3
IR 6023-10-1-1	33.5	90.0	99.7	408.0	37.7	88.0	120.3
Metica 1	26.8	70.8	95.0	350.0	37.3	61.0	127.3
Camponi	34.3	67.5	114.0	364.0	43.0	73.7	122.3
CICA 8	27.3	61.3	130.3	616.3	33.7	99.3	130.5
Metica 2	31.0	70.0	108.7	365.0	29.7	61.0	122.0
CR 1113	25.0	63.3	115.7	453.7	36.0	117.3	131.3
Colombia 1	34.8	87.0	102.3	367.7	40.0	60.3	116.5
Kaohsiung 138	34.3	80.3	96.0	295.0	28.0	57.0	111.5
IR 4-2	26.3	59.3	107.3	490.0	35.0	137.7	134.5
Means	30.4	72.9	109.2	395.4	37.2	83.5	123.6
Tukey's value	7.3	13.9	37.7	128.0	16.3	39.7	7.7

1] 30 days after rice emergence

2] At harvest

Table 8. Comparison of four agronomic characteristics of selected upland rice cultivars grown in an acid soil under upland condition. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

	Height (cm)		Biological yield (g/m^2)		Root dry weight (g/m^2)		Harvest (days)
	1]	2]	1]	2]	1]	2]	
Makalioka 34	30.3	102.5	109.7	843.0	39.0	141.0	134.0
Salumpikit	36.8	103.8	135.3	459.0	37.7	68.0	112.0
Tox 95	35.5	93.0	126.7	419.3	29.7	44.3	118.5
Khao maleuh	48.0	94.5	137.3	338.7	35.7	58.7	115.5
Tox 1369-18-1	45.8	96.8	115.3	402.0	27.7	50.3	110.0
IAC 47	45.5	105.0	134.3	449.3	28.3	61.3	103.5
IAC 25	51.0	114.3	133.7	449.0	32.0	56.3	107.3
Kinandang patone	39.3	103.8	136.0	445.3	33.3	63.0	110.8
MI 48	47.2	97.5	125.7	437.6	33.0	82.7	109.8
Quatro meses	46.3	101.0	125.7	546.3	36.7	80.0	107.5
Tox 1785-19-18	40.3	94.5	124.0	365.0	38.0	71.0	113.0
63-83	46.8	111.0	122.3	416.7	33.0	70.7	108.5
OS 6	37.0	105.0	114.3	412.3	24.0	76.3	113.8
Dourado	40.0	97.5	107.7	345.0	30.3	64.3	115.0
Monolaya	43.8	103.0	116.3	538.7	29.0	70.7	111.0
Means	42.2	101.5	115.9	457.8	32.5	70.6	112.7
Tukey's value	7.3	13.9	37.7	128.0	16.3	39.7	7.7

1] 30 days after rice emergence

2] At harvest

Growth duration was on the average 123.6 and 112.7 days for lowland and upland cultivars, respectively. In relation to growth duration, varieties with short growth duration may not produce high yields because of limited vegetative growth. Those of long growth duration may not be high yielding because of excessive vegetative growth. Approximately 120 days from seeding to maturity appears to be optimum for maximum yield in the tropics (Yoshida, 1981).

Further analyses were done on grain yield and the yield components. Significant differences were observed for all the traits in both cultivar groups (Tables 9 and 10). Comparisons made between upland and lowland cultivars showed that although lowland cultivars produced more panicles per unit area than upland cultivars, the panicle number recorded in upland cultivars was high. Experiments conducted at IRRI have shown that yield levels between 3.2 and 4.5 t/ha can be obtained under optimum upland conditions from rice cultivars producing from 200 to 305 panicles/sq.m (IRRI,1975). Upland rice cultivars produced more grains per panicle and higher 1000 grain weight than lowland cultivars, resulting in higher yield. Jennings et al (1979), explained that panicle characters do not strictly cause or determine yield as such traits simply permit yield to be divisible into their yield components. They pointed out that unlike the inflorescences of other cereals, rice panicles contribute little photosynthate to grain filling. Harvest index values, on the average, were high and similar for lowland and upland groups. Optimum harvest index values of about 0.3 have been reported for tall, upland rice cultivars; a value of 0.5 is reported for short, improved varieties

Table 9. Grain yield and yield components of selected lowland rice cultivars grown in savanna soils under upland rice conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Cultivar	Panicles (N/m^2)	Grains (N/panic)	1000 grain weight (g)	Harvest index(%)	Yield (Kg/ha)
Bg 90-2	266.0	64.0	28.3	46.9	3497
IRAT 122	274.3	47.4	29.0	50.2	3416
P 2030 F4-235-1B-1B	326.0	43.9	21.8	42.9	3100
IR 4568-225-3-2	291.0	56.0	26.9	39.0	3080
IRAT 123	225.0	55.9	30.1	45.2	2972
IR 6023-10-1-1	311.0	56.9	23.6	44.2	2939
Metica 1	346.7	45.2	22.7	45.1	2802
Camponi	261.7	46.3	28.4	40.9	2686
CICA 8	475.0	47.8	21.6	34.6	2625
Metica 2	390.0	34.9	25.1	35.0	2525
CR 1113	373.3	48.8	23.7	36.7	2330
Colombia 1	261.7	73.0	16.0	37.1	2220
Kaohsiung 138	194.3	70.7	24.3	42.1	2208
IR 4-2	486.0	38.1	27.0	36.0	1904
Means	320.1	52.1	25.0	41.1	2736
Tukey's value	91.3	19.9	3.5	9.5	782

Table 10. Grain yield and yield components of selected upland rice cultivars grown in savanna soils under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Cultivar	Panicles (N/m^2)	Grains (N/panic)	1000 grain weight(g)	Harvest index(%)	Yield (Kg/ha)
Makalioka 34	522.7	59.2	23.5	35.1	3729
Salumpikit	272.7	72.6	28.3	44.0	3464
Tox 95	268.3	71.9	30.0	42.8	3382
Khao maleuh	194.3	62.1	35.2	48.4	3251
Tox 1369-18-1	244.3	69.7	31.5	49.0	3154
IAC 47	302.7	68.5	35.5	45.2	3040
IAC 25	201.0	68.6	37.2	42.8	3029
Kinandang patone	297.7	79.5	27.3	40.8	2999
MI 48	207.7	104.1	24.1	41.0	2917
Quatro meses	232.7	56.2	33.0	42.3	2820
Tox 1785-19-18	230.0	59.4	32.5	45.9	2806
63-83	210.0	66.1	34.5	41.6	2795
OS-6	232.7	56.5	36.1	41.2	2763
Dourado	246.7	52.9	35.0	44.8	2750
Monolaya	246.7	77.0	35.1	37.5	2483
Means	260.7	68.3	32.0	42.8	3025
Tukey's value	86.3	25.9	4.7	7.7	1031

(Yoshida, 1981). Higher grain yields were obtained in the upland rice cultivars group due to their better tolerance to Al toxicity and related acidity problems.

To measure possible relationships between grain yield and yield components, correlation coefficients were computed for lowland (Table 11) and upland (Table 12) rice cultivars.

For the lowland group grain yield was positive and significantly associated with harvest index (0.615**), sterility (0.450**) and 1000 grain weight (0.362**), and negative and significantly correlated with tiller number (-0.292*) and panicle number (-0.283*) as shown in Table 11.

Increasing harvest index and grain weight is recommended to increase grain yield, since grain weight is one of the yield components and harvest index is the ratio of dry grain yield over total dry weight. The associations between grain yield and sterility, tiller number and panicle number are related with the high tillering ability of semidwarf lowland cultivars which can be too high for upland culture in savanna soils, creating an imbalance between source and sink.

Table 12 shows the correlations between yield and yield components in the upland rice group. Grain yield gave positive and significant correlation values with number of tillers (0.433**) and number of panicles (0.460**), and a negative and significant relationship with 1000 grain weight (-0.279*). These associations were opposite to those found with lowland cultivars (Table 11). This is due to the lower tiller and panicle number of upland rice

Table 11. Correlation coefficients of grain yield and yield components of 14 lowland rice cultivars grown under upland conditions in acid soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

	Tillers	Panicles	Grain number	1000 grain weight	Sterility	Harvest index
Yield	-0.292*	-0.283*	0.154	0.362**	0.450**	0.615**
Tillers		0.968**	-0.517**	-0.146	0.217	-0.508**
Panicles			-0.456	-0.185	0.246	-0.482**
Grain number				-0.175	-0.442**	0.253
1000 grain weight					0.404**	0.520**
Sterility						0.198

N : 60

* : Significant at 5% level

** : Significant at 1% level

Table 12. Correlation coefficients of grain yield and yield components of 15 upland rice cultivars grown under upland conditions in acid soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

	Tillers	Panicles	Grain number	1000 grain weight	Sterility	Harvest index
Yield	0.433**	0.460**	0.076	-0.279*	0.067	0.164
Tillers		0.976**	-0.207	-0.451**	0.168	-0.402**
Panicles			-0.156	-0.494**	0.178	-0.386**
Grain number				-0.373**	0.038	0.066
1000 grain weight					-0.275*	0.286*
Sterility						0.013

N : 60

* : Significant at 5% level

** : Significant at 1% level

cultivars. Therefore one way to increase grain yield is to increase the numbers of tillers and panicles per unit area in upland cultivars. One thousand grain weight was negatively correlated with grain yield (-0.279*), tiller number (-0.451**), panicle number (-0.494**) and number of grains (-0.373**), which resulted from a compensatory association between some yield components.

It is possible that as grain yield is increased, several biological activities related to the sink-source relationship could result in indirect negative associations. This would cancel any further gain unless greater efficiency in the metabolism of the plant can be achieved. Another factor which can modify the expression of grain yield would be yield component compensation as is the case of the negative association between 1000 grain weight and the number of grains per panicle.

Amendment of main nutritional disorders in savanna soils (Experiment 2).

Savanna soils have relatively high organic matter content in the upper zone, a good clay loam structure, flat topography, with a climate featuring high temperature and adequate rainfall. They are potentially productive. The main limitations are chemical rather than physical. These soils have low fertility, low pH, high exchangeable Al and high Al saturation.

Phosphorus and Ca deficiencies seem to be more specific to these savanna soils and research was focused to solve these problems. Due to the high acidity of these soils and the cost of liming, field research was initiated with rice cultivars tolerant to Al toxicity and related acidity problems. Since Ca is a limiting factor in these soils, investigations were initiated to determine the proper amount of Ca as a fertilizer, not attempting to neutralize the exchangeable Al present in these soils. The idea is to develop a low cost technology based on the principle of adapting plants to acid soil infertility rather than eliminating these stresses by intensive use of lime and fertilizers.

In Table 13 , the chemical soil characteristics of the experimental area are presented. Soil samples were taken at a depth of 0-20 and 20-40 cm. Soil analyses were done following CIAT's procedure (Salinas and Garcia, 1979). The organic matter content is medium-high for tropical soils. Phosphorus content (Bray II), is extremely low. A soil survey done in savanna soils of Colombia, showed that out of 343 soil samples analyzed for P (Bray II), 43% of the samples had less than 5 ppm P (extremely low P content), 24% had between 5-10 ppm (very low), 9% of the soil samples had from 10-15 ppm (low P content) and 24% had more than 15 ppm, medium P content (Owen and Sanchez, 1980). Thus P deficiency is a limiting factor for crop production in savanna soils. The pH values ranged from 4.1 to 4.3, which are extremely acid. Slight variation was found in the Al content of the soil samples analyzed with the values being very high (3.0-3.2 meq Al/100 g soil). Owen (1982), noted that out of 343 savanna soil samples, 35% of them had more than 2 meq Al/100g soil which restricts savanna soils to Al tolerant crops. Calcium and

Table 13. Chemical soil analyses of the experimental area where the experiment related to amendment of main nutritional disorders in savanna soils was carried out. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983

Replication	Depth (cm)	% OM	ppm P Bray II	pH	----------meq/100 g soil----------				Al Sat(%)	B	Zn	Mn	Cu	Fe
					Al	Ca	Mg	K		----------ppm----------				
I	0-20	3.6	4.6	4.1	3.1	0.45	0.08	0.18	81.4	0.3	0.6	8.9	0.8	34.6
	20-40	3.3	4.3	4.2	3.1	0.39	0.06	0.15	83.8	0.2	0.5	7.2	0.7	31.6
II	0-20	3.7	4.6	4.1	3.1	0.37	0.07	0.17	83.6	0.3	0.5	9.5	0.7	40.4
	20-40	3.5	3.8	4.3	3.0	0.41	0.06	0.13	83.3	0.5	0.5	6.7	0.7	36.0
III	0-20	4.2	4.9	4.2	3.2	0.45	0.07	0.17	82.3	0.4	0.5	9.3	0.7	38.9
	20-40	3.3	3.4	4.3	3.0	0.51	0.05	0.14	81.1	0.4	0.5	6.0	0.7	31.4

magnesium levels were very low. According to Owen and Sanchez (1980), in a survey with 87 soil samples obtained from savanna soils of the Llanos Orientales of Colombia, 35% of the samples had less than 1.0 meq Ca/100g soil (very low) and 81% had less than 0.50 meq Mg/100 g soil (very low). The percent Al saturation was very high (81.1 to 83.8%).

Among the several micronutrients analyzed, zinc and copper seem to be deficient. A critical level of 1 ppm Zn and 1 ppm Cu, has been suggested for sensitive crops (Lopez, 1975). However by the missing element technique in greenhouse and field studies in acid soils of Brazil, only the treatment without zinc showed a significant reduction in grain yield of upland rice, with no beneficial effect from copper fertilization observed (Galrao et al, 1978). Randhawa et al (1978), report the following critical levels for deficiency of micronutrients in rice soils: boron 0.1-0.7 ppm; copper 0.2 ppm; iron 2.5-4.5 ppm; manganese 1.0 ppm; molybdenum 0.04-0.20 and zinc 0.5-0.8 ppm. The critical values reported in the literature vary according to the method of analysis and the digestion or extraction used (Yoshida et al, 1976).

Twenty five plant characters were recorded from seeding to maturity (Table 14). Plant height, root dry weight and biological yield were measured at 30, and 60 days after crop emergence and at harvest. Plant tissue analysis for Ca, P and Al were performed, following CIAT's methodology (Salinas and Garcia, 1979), from leaf samples taken 35, 65 and 85 days after rice emergence. Growth duration, grain yield and yield components were recorded at harvest

Table 14. Traits, dates and statistics measured on four rice cultivars grown in savanna soils with four rates of Ca and four rates of P. CRI La Libertad, Villavicencio Llanos Orientales, Colombia, 1983.

Traits	Dates 1]	Mean	Standard deviation	CV
Height (cm)	30 days	35.0	10.33	8.0
Height (cm)	60 days	60.0	20.35	7.3
Height (cm)	At harvest	77.5	18.34	4.8
Root dry weight (g/m2)	30 days	23.3	7.07	20.9
Root dry weight (g/m2)	60 days	77.0	25.57	18.6
Root dry weight (g/m2)	At harvest	81.0	31.5	24.3
Biological yield (g/m2)	30 days	94.7	31.17	18.9
Biological yield (g/m2)	60 days	368.3	115.7	16.6
Biological yield (g/m2)	At harvest	410.0	49.77	13.0
Leaf calcium (%)	35 days	0.29	0.06	14.2
Leaf calcium (%)	65 days	0.32	0.08	16.5
Leaf calcium (%)	85 days	0.43	0.25	23.1
Leaf phosphorus (%)	35 days	0.20	0.04	10.8
Leaf phosphorus (%)	65 days	0.19	0.03	8.5
Leaf phosphorus (%)	85 days	0.18	0.04	9.2
Leaf aluminum (ppm)	35 days	24.2	29.37	74.4
Leaf aluminum (ppm)	65 days	24.8	39.93	141.3
Leaf aluminum (ppm)	85 days	35.1	12.80	35.7
Harvest (days)	Variable	114.1	12.56	1.2
Tillers (N/m2)	At harvest	333.3	95.77	12.5
Panicles (N/m2)	At harvest	305.0	85.97	12.5
Grains (N/panicle)	At harvest	56.2	12.46	15.0
Sterility (%)	At harvest	10.7	3.37	21.6
1000 grain weight (g)	At harvest	25.2	7.25	4.4
Grain/straw ratio (%)	At harvest	71.9	9.25	10.4
Yield (tons/Ha)	At harvest	2.94	0.56	10.2

1] Dates from seedling emergence

time. Individual analysis of variance was computed for the 25 plant characters measured. The coefficients of variation were low for plant height, leaf P, harvest, 1000 grain weight and grain to straw ratio. Only Al content in plant tissue at the three sampling days gave a high CV value.

Analysis of variance for grain yield is in Table 15. Highly significant differences were found for cultivars, Ca, P and for the interaction Ca x cultivars. The most notable response was observed to P application. Other interactions were not significant. An overall mean of 2936 Kg/ha was obtained. The coefficients of variation were 18.6% and 10.2% for main plots and sub plots, respectively.

Correlation coefficients between grain yield and leaf analyses of Ca, P, and Al in Table 16, showed a significant association between grain yield and leaf Ca at panicle initiation (0.246**), and grain yield and leaf P at tillering stage (0.382**) and at maximum tillering (0.363**). No association was found between grain yield and leaf Al concentration in either growth stage of the rice plant . Rhue (1979), in a review article on the effect of Al on plant growth, concluded that correlations between Al concentration in the foliage of crop plants and toxicity are more the exception than the rule. He stated that toxic effects of Al may result from excess Al in the growth medium with little or no change in the Al concentration in the foliage. Furthermore, he pointed out that Al concentration in the foliage for most species appears to be a poor indicator of Al tolerance per se. In acid soils, the tolerance to high Al saturation has not been separated from low P tolerance. The limited evidence

Table 15. Grain yield analysis of variance of four rice cultivars grown in savanna soils with four rates of Ca and four rates of P. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1983.

Sources	df	MS	F
Replications	2	0.154	0.51
Cultivars	3	6.344	21.22**
Error a	6	0.299	
Calcium	3	0.451	5.02**
Phosphorus	3	5.562	62.00**
Calcium X cultivars	9	0.389	4.33**
Calcium X phosphorus	9	0.104	1.16
Phosphorus X cultivars	9	0.113	1.26
Cultivars X calcium X phosphorus	27	0.135	1.50
Error b	120	0.090	
Total	191		

** : Significant at 1% level

Mean : 2936 Kg/ha

CV a : 18.6 %

CV b : 10.2 %

Table 16. Correlation coefficients between grain yield and Ca, P and Al plant tissue analysis, at three different growth stages. Of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales,Colombia, 1983.

	Growth stage		
	Tillering	Maximum tillering	Panicle initiation
Grain Yield vs			
Calcium	-0.053	0.085	0.246**
Phosphorus	0.382**	0.363**	0.008
Aluminum	-0.133	-0.079	0.034

N : 192

** : Significant at 1% level.

suggests that both tolerances may occur together. Foy and Brown (1964), associated the differential Al tolerance of plant species with the ability of plants to absorb and utilize P in the presence of excess Al. Ikeda et al (1965), noted a correlation between acid soil tolerance and tolerance to low P level in wheat varieties.

Effect of P rates

There were no significant differences among rice cultivars in P concentration, based on leaf tissue analysis done from leaf samples taken 35 days after rice emergence (Table 17). But significant differences were found at 85 days after crop emergence. Colombia 1 and IR 4568-225-3-2 had significantly higher P concentration in the tissue than did CICA 4 and IAC 165. The low P concentration of IAC 165 at 85 days can be related with its short growth duration (95 days), and probably most of the P was already translocated to the grain. De Datta (1981), reported that N, P and S, which are components of proteins, are absorbed rapidly during vegetative growth and translocated from the vegetative organs to the grain after flowering. The P concentration in the rice leaves was generally higher at early growth stages and declined toward maturity. Similar P response has been reported in the literature (Yoshida, 1970; Mikkelsen, 1978; Yoshida, 1981; De Datta, 1981). Koyama et al (1973), cited by Yoshida (1981), reported clear varietal differences in the ability of rice cultivars to absorb soil P and express growth and yield on P deficient soils in Thailand. Similar differences in

Table 17. Leaf concentration of P in four rice cultivars grown in savanna soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

	P concentration (%)			
Cultivar	35 days	65 days	85 days	Means
IR 4568-225-3-2	0.208 a	0.191 b	0.195 ab	0.198
IAC 165	0.192 a	0.186 b	0.123 c	0.167
Colombia 1	0.207 a	0.186 b	0.207 a	0.200
CICA 4	0.204 a	0.204 a	0.190 b	0.199
Means	0.203	0.192	0.179	

1] Average of three replications x four P rates x four Ca rates. Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

relation to P were observed on a wide range of varieties by Ponnamperuma (1977).

There were significant responses in P concentration of the leaf tissue to increasing rates of P applications when analyzed at three different growth stages (Table 18). Mean P concentration values were 0.160, 0.185, 0.205 and 0.214 % for 0, 30 , 60 and 90 Kg P_2O_5/ha rates, respectively. Phosphorus concentration, based on tissue analysis was higher at the tillering stage (0.203 %) and declined thereafter.

The P rates applied did not influence Ca concentration of the rice plant in determinations done at 35, 65 and 85 days after emergence (Table 19). These results confirm the lack of a significant P x Ca interaction in the grain yield analysis of variance performed (Table 15). However, Kunishi (1982), reported a positive interaction between P and lime, and at any given level of additional P , increasing levels of lime increased plant yield and plant uptake of Ca and P.

For a better comparison of P and Ca rate effects on P concentration, four treatments were compared. These treatments were: plots with no application of P and Ca; the highest Ca rate with no P; the highest P rate with no Ca and the combination of the highest rates of both P and Ca (Table 20). There was no effect of different Ca levels on P concentration at any sampling dates. There were highly significant differences between the check plots and the application of P either alone or in combination with Ca, but no differences were detected when this highest P rate was applied either alone or in

Table 18. Effect of P rates on P concentration of rice cultivars grown in savanna soils under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

	P concentration (%)			
P_2O_5 (Kg/ha)	35 days	65 days	85 days	Means
0	0.160 d	0.166 d	0.155 d	0.160
30	0.192 c	0.187 c	0.175 c	0.185
60	0.222 b	0.203 b	0.189 b	0.205
90	0.237 a	0.210 a	0.196 a	0.214
Means	0.203	0.192	0.179	

1] Average of three replications x four cultivars x four Ca rates. Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 19. Effect of P rates on Ca concentration of rice cultivars grown in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

	Ca concentration (%)			
P_2O_5 (Kg/ha)	35 days	65 days	85 days	Means
0	0.272 b	0.298 b	0.415 a	0.328
30	0.284 ab	0.324 a	0.429 a	0.346
60	0.294 a	0.321 a	0.446 a	0.354
90	0.295 a	0.332 a	0.447 a	0.358
Means	0.286	0.319	0.434	

1] Average of three replications x four cultivars x four Ca rates. Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 20. Leaf P concentration of selected treatments, of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio Llanos Orientales, Colombia, 1983. 1]

Treatments		P concentration (%)			
P_2O_5	Ca				
Kg/ha		35 days	65 days	85 days	Means
0	0	0.157 a	0.163 a	0.163 a	0.161
0	225	0.154.a	0.170 a	0.150 a	0.158
90	0	0.240 b	0.203 b	0.193 b	0.212
90	225	0.226 b	0.217 b	0.192 b	0.212
Means		0.194	0.188	0.175	

1] Average of three replications x four rice cultivars.

Within a column, means followed by a common letter are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

combination with Ca .

The effect of P rates on grain yield and yield components were also analyzed (Table 21). Significant differences were found between zero P and the three rates of P applications in tiller number and panicle number, but no differences were found among P rates. An increase in the number of grains per panicle was observed with increasing P rates above 60 Kg P_2O_5/ha. The 1000 grain weight was not affected by the different P rates. Under most conditions, the 1000 grain weight of rice is a very stable varietal character (Yoshida, 1981).Grain yield increased with increasing rates of P application and significant differences were observed among all P rates. Phosphorus is involved in the supply and transfer of energy for all biochemical processes in the rice plant. Phosphorus is needed for tillering and encourages more active tillering (De Datta, 1981; Yoshida, 1981). A positive response to P applications was observed in relation to grain yield as expected, since the soil is very low in P content (Table 13). A consistent P response by upland rice is observed in the acid soils of Brazil. Oliveira et al (1965), reported an increase in grain yield of 48% , as compared to the no P control, when 60 Kg P_2O_5/ha were applied. Morais and Macedo (1978), in four experiments conducted in acid soils of Brazil, found a variable P response from 30 to 90 Kg P_2O_5/ha for grain yield. In acid soils of Colombia, Sanchez and Leal (1978), reported a positive P response up to 75 Kg P_2O_5/ha, with yields twice that of the zero P check plot.

Table 21. Effect of P rates on grain yield and yield components of rice cultivars grown in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

P_2O_5 (Kg/ha)	Tillers (N/m^2)	Panicles (N/m^2)	Grains (N/panic)	1000 grain weight (g)	Sterility (%)	Yield (Kg/ha)
0	318.0 b	293.3 b	48.2 c	25.0 a	11.5 a	2490 d
30	337.3 a	306.3 ab	54.8 b	25.2 a	10.5 b	2870 c
60	339.3 a	309.3 a	59.4 a	25.2 a	10.0 b	3107 b
90	338.7 a	311.3 a	62.3 a	25.3 a	10.9 ab	3275 a

1] Average of three replications x four cultivars x four Ca rates. Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Effect of Ca rates

The Ca concentration in leaf tissue analyses done at 35, 65 and 85 days after crop emergence can be found in Table 22. Based on the mean values (0.286, 0.319 and 0.434 %) Ca concentration increased with the growth stage of the rice plants and the highest Ca concentration was obtained at 85 days,the exception being CICA 4. De Datta (1981), found that K and Ca were absorbed at a rate almost parallel to dry matter production, but there was no marked translocation of these elements from vegetative organs to the grain during ripening. Angladette (1965), reported a steady Ca content along the vegetative growth phase. On the average higher Ca concentrations were obtained in IAC 165, a Brazilian cultivar developed for upland culture in acid soils, and in Colombia 1, a highly tolerant cultivar to acid soils. In this study the leaf Ca concentration in each of the four rice cultivars was higher than the critical nutrient level for Ca reported in the literature (Tanaka and Yoshida, 1970; Yoshida, 1981).

Increasing rates of Ca applications did not increase the Ca concentration in tissue analyses done at 35 and 65 days after emergence. However, at 85 days significant differences were found among treatments (Table 23). Calcium concentration increased with the growth of the rice plant and it was much higher at 85 days (0.434%) than either 65 days (0.319%) or 35 days (0.286%). None of these values were below the critical concentration level for Ca of 0.150%, reported by Tanaka and Yoshida (1970), for rice. Mean values for Ca concentration were 0.340, 0.355, 0.352 and 0.338% for 0, 75, 150 and

Table 22. Leaf concentration of Ca in four rice cultivars grown in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

	Ca concentration (%)			
Cultivar	35 days	65 days	85 days	Means
IR 4568-225-3-2	0.274 b	0.279 c	0.268 c	0.274
IAC 165	0.255 b	0.348 b	0.803 a	0.469
Colombia 1	0.358 a	0.399 a	0.424 b	0.394
CICA 4	0.259 b	0.250 c	0.243 c	0.251
Means	0.286	0.319	0.434	

1] Average of three replications x four P rates x four Ca rates. Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 23. Effect of Ca rates on Ca concentration of rice cultivars grown in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

Ca	Ca concentration (%)			
(Kg/ha)	35 days	65 days	85 days	Means
0	0.286 a	0.321 a	0.414 b	0.340
75	0.279 a	0.320 a	0.465 a	0.355
150	0.290 a	0.317 a	0.450 ab	0.352
225	0.289 a	0.316 a	0.409 b	0.338
Means	0.286	0.319	0.434	

1] Average of three replications x four cultivars x four P rates. Within a column, means with a letter in common are not significantly different in a accordance with Duncan's multiple range test, at the 0.05 probability level.

225 Kg Ca/ha applied, respectively.

Increasing Ca rates from 0 Kg Ca/ha to 150 Kg Ca/ha had a positive influence on P concentration in the early stages of growth of the rice plant, but there were no significant differences among treatments at 85 days after emergence (Table 24). Calcium rates apparently did not have any effect on P concentration in the foliage as the mean values were very similar.

When some selected treatments were compared for plant tissue Ca, as reported in Table 25, it was observed that Ca rates did not increase Ca concentration at any growth stage. These Ca concentration mean values were statistically similar. Phosphorus additions slightly increased Ca concentrations. However,the only significant difference was found with the treatment of 90 Kg P_2O_5 plus 0 Kg Ca/ha , in leaf analysis done in samples taken 65 days after rice emergence.

Table 26 shows the effect of Ca rates on grain yield and yield components. Small differences were observed for all traits analyzed as a consequence of the Ca treatments. This is in contrast with the marked P response previously noted (Table 21). There were no significant differences among Ca rates in the number of grains per panicle and 1000 grain weight. Differences were detected in tiller number, panicle number and percent sterility

In relation to grain yield and based on the statistical analysis presented in Table 15, it was observed that the F value for both cultivars and Ca were highly significant,as was their interaction. Therefore, the response to Ca applications is dependent on the cultivar. Figure 1 shows the differential response to Ca rates of the

Table 24. Effect of Ca rates on P concentration of rice cultivars grown in savanna soils under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

Ca (Kg/ha)	P concentration (%)			
	35 days	65 days	85 days	Means
0	0.202 b	0.185 c	0.180 a	0.189
75	0.199 b	0.190 bc	0.180 a	0.190
150	0.212 a	0.194 ab	0.177 a	0.194
225	0.198 b	0.197 a	0.179 a	0.191
Means	0.203	0.192	0.179	

1] Average of three replications x four cultivars x four P rates.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 25. Leaf Ca concentration of selected treatments of four rice cultivars grown under upland condition in savanna soils. CRI La Libertad, Villavicencio,Llanos Orientales, Colombia, 1983. 1]

Treatments		Ca concentration (%)			
P_2O_5	Ca				
Kg/ha		35 days	65 days	85 days	Means
0	0	0.269 a	0.288 a	0.376 a	0.311
0	225	0.274 a	0.278 a	0.408 a	0.320
90	0	0.294 a	0.348 b	0.450 a	0.364
90	225	0.303 a	0.328 ab	0.408 a	0.346
Means		0.285	0.310	0.410	

1] Average of three replications x four rice cultivars.

Within a column, means followed by a common letter are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 26. Effect of Ca rates on grain yield and yield components of rice cultivars grown in an acid soil under upland condition. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Ca (Kg/ha)	Tillers (N/m2)	Panicles (N/m2)	Grains (N/panic)	1000 grain weight (g)	Sterility (%)	Yield (Kg/ha)
0	319.3 b	292.7 b	55.5 a	25.1 a	11.2 a	2814 b
75	335.0 ab	307.7 ab	56.5 a	25.1 a	10.9 a	2941 ab
150	346.3 a	316.3 a	54.8 a	25.0 a	11.0 a	2937 ab
225	333.0 ab	302.7 ab	57.9 a	25.4 a	9.9 b	3051 a

1] Average of three replications x four cultivars x four P rates.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

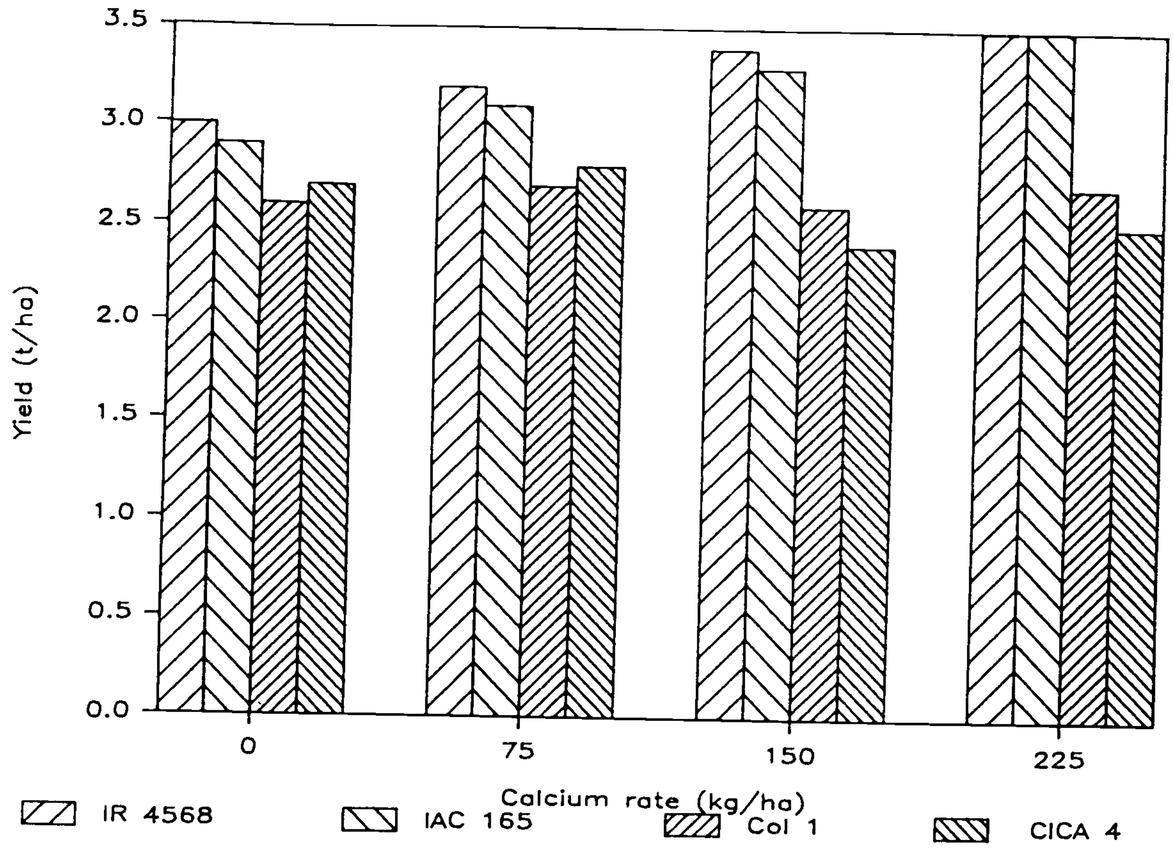

Figure 1. Effect of Ca rates on grain yield of four rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

four cultivars evaluated. This further indicates that IR4568-225-3-2 and IAC 165 have a similar response, with increases in yield up to 150 Kg Ca/ha. Colombia 1 did not show an apparent response to Ca applications and CICA 4 showed an erratic response. CICA 4 is highly susceptible to blast disease (Pyricularia oryzae), and although chemically controlled, better growth with high Ca applications likely favored blast incidence which could have reduced grain yield.

The slight response to Ca applications agrees with some findings reported in the literature. In Brazil, experiments conducted in four locations, characterized for their soil acidity, by Morais and Macedo (1978), did not show any response to lime rates of 2-5 tons/ha when IAC 1246, a tolerant variety to acid soils, was planted. Furthermore, Morais (1978), reported a detrimental effect in grain yield, when 3 tons lime/ha were applied to upland rice. Ponte et al (1980) found a negative interaction between lime and Zn. A reduction in grain yield with lime application was attributed to Zn deficiency. In savanna soils of Colombia, Howeler and Cadavid (1976) found that the Al-tolerant cultivars Bluebonnet 50 and Monolaya were relatively unresponsive to liming, while semi-dwarf cultivars showed a marked lime response. Spain et al (1976), reported that traditional upland rice varieties responded only to 0.4 tons lime/ha (80 Kg Ca/ha). Calvo et al (1977), recommended for tolerant crops like cowpea and some Al-tolerant rice cultivars an application of 0.5 tons lime/ha (100 Kg Ca/ha). Crops that are tolerant to soil acidity are also likely to be more efficient at recovering applied as well as existing plants nutrients than susceptible crops (Spain et al, 1976).

Nevertheless, both native and introduced plants in Oxisol savannas appear to do better in term of Ca and Mg than the low soil levels would infer.

Cultivar performance in savanna soils with variation in sowing methods and seed density (Experiment 3).

Cultural practices necessary for successful upland rice production have been studied less than those for lowland rice. No information is available on cultural practices for upland rice in savanna soils where the rice plant is subjected to the harmful effects of Al toxicity and low levels of nutrients. Methods of planting, row spacing and seeding rates can affect plant competition for light, water, nutrients and space.

The F values for the three factors under study: cultivars, planting methods and seeding rates, were highly significant, as were the interactions, planting methods x cultivars and planting methods x seeding rates (Table 27). This suggests that the yield of the individual cultivars depends of the method of planting and that the appropiate seeding rate will depend on the sowing method. The grain yield mean value obtained is this experiment was 3249 Kg/ha and a low coefficient of variatiation (7.9%) was found.

Effect of seeding rate

The effect of seeding rate on grain yield and yield components is

Table 27. Grain yield analysis of variance for grain yield of some cultural practices for upland rice production in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Sources	df	MS	F
Replications	2	0.532	8.12**
Methods	2	8.397	128.28**
Cultivars	2	9.581	146.36**
Seeding rate	3	0.590	9.01**
Methods x cultivars	4	0.910	13.90**
Methods x seeding rate	6	0.173	2.64*
Cultivars x seeding rate	6	0.106	1.62
Methods x cultivars x seeding rate	12	0.067	1.03
Error	70	0.065	
Total	107		

Mean : 3249 Kg/ha

CV : 7.9%

* : Significant at 5% level.

** : Significant at 1% level.

showed in Table 28. As a consequence of increasing seeding rates, the number of plants per unit area, tiller number and panicle number were consistently increased. Significant differences were found among the four seeding rates for these plant traits. There was a marked reduction in number of grains per panicle as seeding rates were increased from 60 to 120 Kg/ha, due to plant competition. A smaller difference was encountered between 120 and 150 Kg seed/ha. Significant differences were found between 60 Kg seed/ha and the other three seeding rates for grains per panicle, 1000 grain weight, grain to straw ratio and grain yield. The highest 1000 grain weight and grain to straw ratio were recorded when plants were sown at a rate of 60 Kg/ha. Grain yield was higher at a seeding rate of 60 Kg of seed per hectare. This value was significantly different for yield obtained when compared to the other three rates . No differences were observed among the other three rates of seeding evaluated. Grain yields obtained were 3458, 3226, 3202 and 3110 Kg/ha with 60, 90, 120 and 150 Kg seed/ha , respectively.

A significant interaction was found between seeding rates and planting methods; therefore the rate of seeding depended on the method of planting used in this experiment. These results are better visualized in Figure 2. Although an interaction exists between methods of planting and rate of seeding, it is clear that higher yields were obtained when plants were sown in rows 15 cm apart, regardless of seeding rate.

IITA researchers have indicated that an optimum planting density for upland rice should be lower than that for lowland rice because of

Table 28. Effect of seeding rate on grain yield and yield components of rice cultivars grown under upland conditions in an acid soil. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

Seeding Rate (Kg/ha)	Plants (N/m2)	Tillers (N/m2)	Panicles (N/m2)	Grains (N/panic)	1000 grain weight (g)	$\frac{\text{Grain}}{\text{straw}}$ (%)	Yield (Kg/ha)
60	277.5 d	423.8 d	384.1 d	59.6 a	28.7 a	71.9 a	3458 a
90	380.6 c	483.9 c	449.8 c	53.8 b	28.2 b	66.6 b	3226 b
120	461.3 b	520.6 b	478.8 b	49.0 c	27.9 b	64.0 b	3203 b
150	528.5 a	580.4 a	534.7 a	45.6 c	27.8 b	65.6 b	3110 b

1] Average of three replications x three cultivars x three planting methods.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

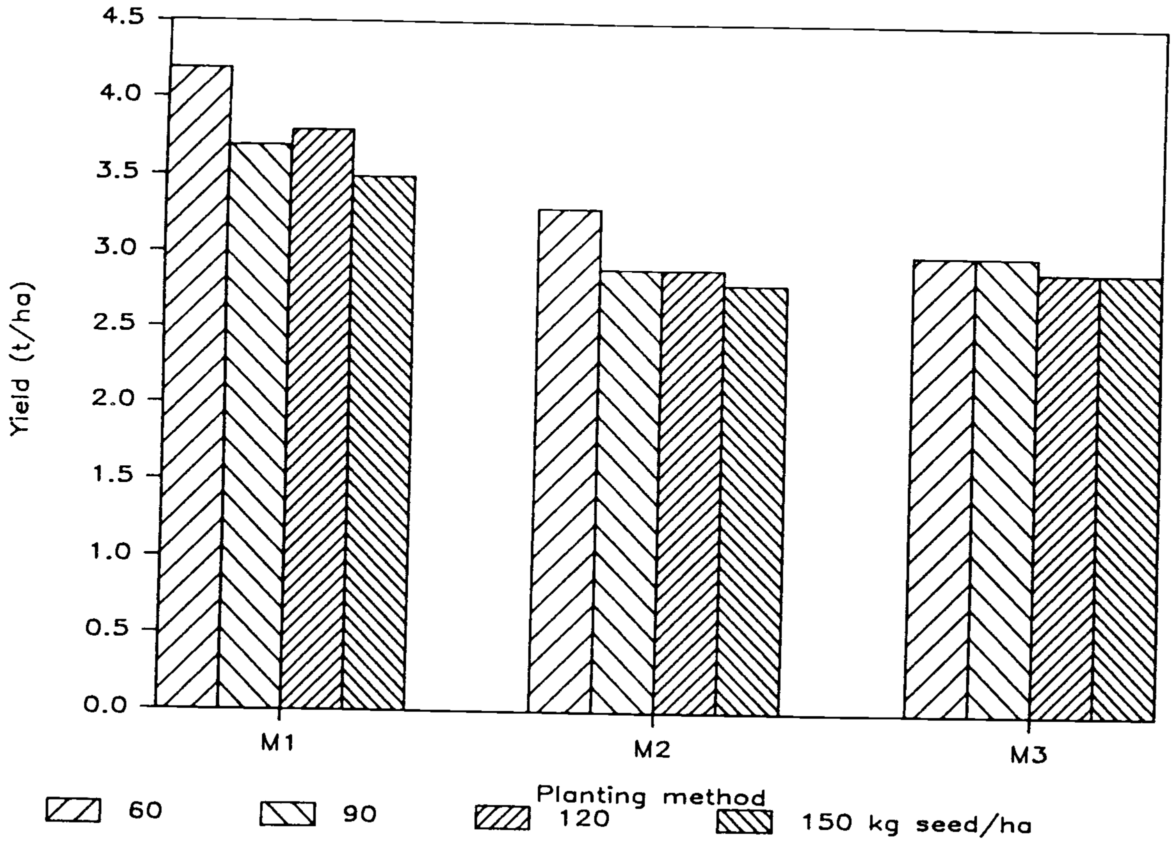

Figure 2. Effect of four seeding rates on grain yield of rice cultivars grown under three planting methods : Rows 15 cm apart (M1), Rows 30 cm apart (M2) and Broadcast (M3) in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia,1983.

poor water holding capacity and low nutrient status of degraded soils under tropical upland conditions (IITA, 1981). At IRRI, the highest grain yield was obtained at a seeding rate of 80 Kg/ha in single rows spaced 15 cm apart when two seeding rates (80 and 160 Kg seed/ha), three methods of planting and three row spacings were tested (IRRI, 1975). In another IRRI experiment, seed was sown at 15 cm row spacing and seeding rates varied from 25 to 150 Kg/ha at 25 Kg increments. The highest grain yield was obtained at a seeding rate of 75 Kg/ha (De Datta et al, 1974).

Effect of planting method.

Three methods of planting were evaluated. Sowing in rows 15 cm and 30 cm apart and the broadcast method used by Colombian rice growers. A comparison among these three sowing methods is presented in Table 29. Significant differences were observed for all traits analyzed, when the three planting methods were compared. Higher tiller number, panicle number and 1000 grain weight were recorded in the broadcast method, but a significant reduction in the number of grains and in the grain to straw ratio resulted in a lower grain yield compared with the planting method in rows 15 cm apart. The highest grain yield, 3806 Kg/ha, was obtained when seed was drilled at a 15 cm row spacing. This higher yield was due to a significant increase in number of tillers and panicles over the seeding method in rows 30 cm apart and to the higher number of grains per panicle, 1000 grain weight and grain to straw ratio over the broadcast method. De Datta

Table 29. Effect of method of planting on grain yield and yield components of rice cultivars grown under upland conditions in an acid soil. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. [1]

Planting method	Tillers (N/m2)	Panicles (N/m2)	Grains (N/panic)	1000 grain weight (g)	$\frac{\text{Grain}}{\text{straw}}$ (%)	Yield (Kg/ha)
Rows at 15 cm	535.1 b	496.7 b	53.2 a	27.8 b	66.3 b	3806 a
Rows at 30 cm	381.2 c	347.5 c	54.4 a	28.1 b	71.3 a	2995 b
Broadcast	590.2 a	541.4 a	48.5 b	28.6 a	63.5 c	2946 b

[1] Average of three replications x three cultivars x four seeding rates.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

and Ross (1975), reported that experiments in Sarawak, Malaysia and in Peru, indicated that closer spacing is highly desirable for upland rice production under shifting cultivation. In Peruvian experiments, closer spacing increased yield by an average of 1.7 tons/ha, 40% over the check plot (Sanchez, 1972).

A significant interaction was found in grain yield, between planting methods x cultivars (Table 27). Grain yield depended on the sowing methods, but higher yields were recorded at 15 cm row spacing as shown in Figure 3, regardless of the cultivar planted. Yield levels were 4042 kg/ha for IR 4568-225-3-2, 4459 Kg/ha for IAC 165 and 2918 Kg/ha for Colombia 1.

Significant differences were found among the rice cultivars planted for all traits measured (Table 30). IR 4568-225-3-2, a medium height cultivar from IRRI, produced more tillers and panicles, but it had fewer grains per panicle than the other two cultivars. Colombia 1, had more grains per panicle but a lower 1000 grain weight, resulting in less grain yield. The major contribution to the high yield obtained with IAC 165, was its considerably higher grain weight, 37.8 grams per 1000 seeds, compared with IR4568-225-3-2 (27.3 g) and Colombia 1 (19.3 g). However, grain yield produced by IAC 165 (3593 Kg/ha) was not significantly different from yield obtained with IR 4568-225-3-2 (3499 Kg/ha).

In areas with abundant and adequate distribution of rainfall, like the savanna region of the Llanos Orientales of Colombia, closer spacing can be used in combination with a moderate seed rate to achieve a better distribution of rice plants in the field , reduce

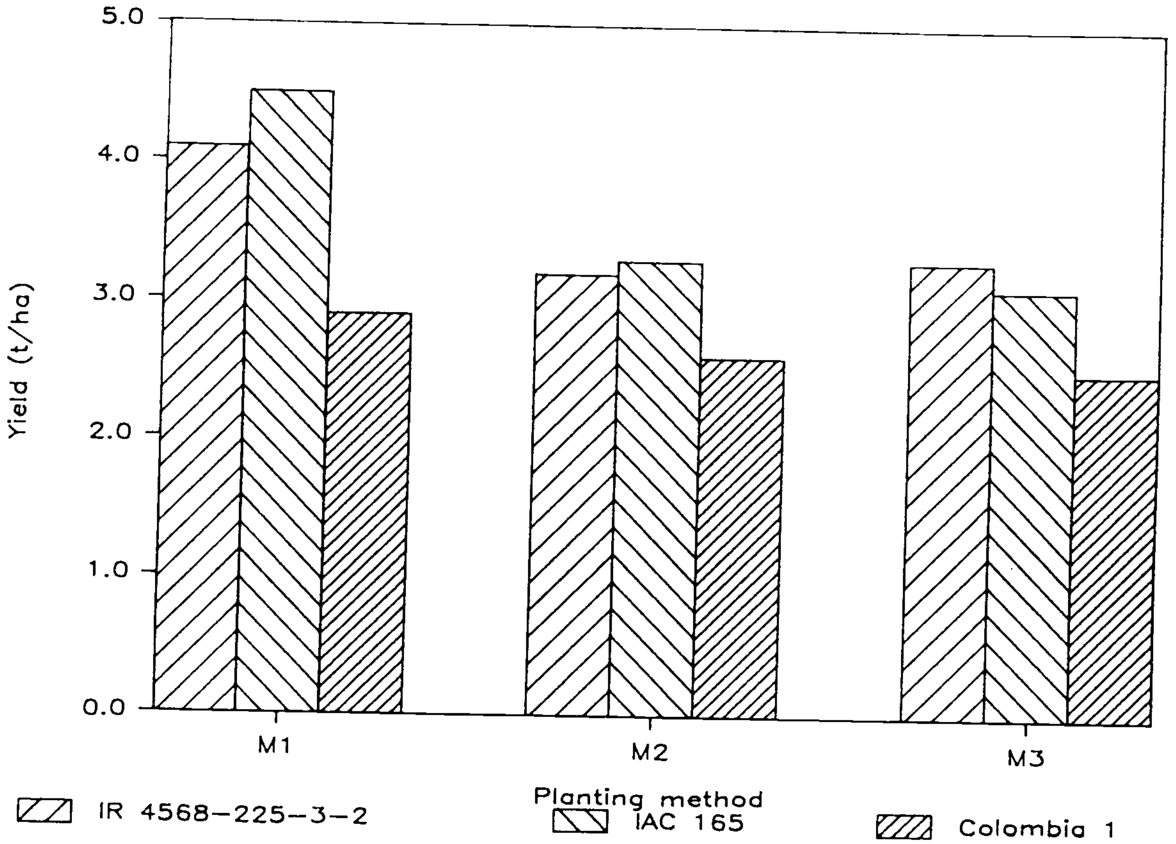

Figure 3. Effect of three methods of planting : Rows 15 cm apart (M1), Rows 30 cm apart (M2) and Broadcast (M3) on grain yield of three rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Table 30. Performance of rice cultivar performance in an acid soil under upland conditions. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983. 1]

Cultivars	Tillers (N/m2)	Panicles (N/m2)	Grains (N/panic)	1000 grain weight (g)	Yield (Kg/ha)
IAC 165	407.0 c	384.6 b	50.6 b	37.8 a	3593 a
IR 4568-225-3-2	573.0 a	510.8 a	46.1 c	27.3 b	3499 a
Colombia 1	526.0 b	490.1 a	59.3 a	19.3 c	2656 b

1] Average of three replications x four seeding rates x three planting methods.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

weed infestation and subsequently increase grain yield.

Integrated pest control management in selected upland rice cultivars for savanna soils (Experiment 4).

From the preliminary screening of 58 rice cultivars for savanna soils carried out in 1983, at CRI La Libertad (Appendix Table 2), twenty rice cultivars were selected for further evaluations (Appendix Table 3). The selection criteria were mainly grain yield, root morphology based on root thickness and length (grades 4 to 6), Al toxicity scale (grades 1 and 2) and growth in savanna soils. Five additional rice cultivars from the CIAT germplasm bank were included in this experiment based on their behavior in savanna soils. The objective was to observe acid-tolerant rice cultivars in relation to pest and disease incidence under natural infestation and to measure the effect of these constraints on selected agronomic characteristics and grain yield.

The main diseases observed were blast (*Pyricularia oryzae*), leaf scald (*Rhynchosporium oryzae*), grain discoloration caused by a fungal complex (*Helminthosporium oryzae*, *Rhynchosporium oryzae*, *Nigrospora* sp, *Curvularia* sp, among others) and the hoja blanca virus disease. Among the insect pests observed were the planthopper (*Sogatodes oryzicola*) and a stem borer (*Diatreae* sp).

An analysis of variance for grain yield is showed in Table 31. Highly significant differences were observed for pest management, cultivars and the interaction pest management x cultivars. The mean

Table 31. Grain yield analysis of variance of the experiment about integrated pest control management in selected upland rice cultivars for savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984

Sources	df	MS	F
Replication	3	79762.44	0.68
Pest management	1	26643540.44	228.41**
Error a	3	116650.38	
Cultivar	24	1336068.00	8.15**
Pest management x cultivar	24	973102.88	5.94**
Error b	144	163941.72	
Total	199		

Mean : 3520 Kg/ha

CV a : 9.7%

CV b : 11.5%

** : Significant at 1%

yield value was 3520 Kg/ha. The coefficients of variation were low, (9.7%) for main plots and (11.5%) for subplots.

The effect of the chemical control applied on the incidence of neck blast and grain discoloration is shown in Table 32. Significant differences were observed between protected and unprotected plots for all comparisons. Neck blast on the average was reduced from 21.0% in the unprotected plots to 5.4% in the protected plots. Less, but significant difference was observed for grain discoloration disease. Grain yield obtained averaged 3885 Kg/ha for protected cultivars and 3155 Kg/ha for unprotected cultivars. Significant differences were found between these two management practices.

Neck blast and grain discoloration incidence in the unprotected plots were high for most cultivars tested (Table 33). Blast incidence was severe and caused a high yield reduction in susceptible cultivars (Bg 90-2, Metica 1, MI-48 etc). A good level of resistance against blast under field conditions was observed for IAC 165, IAC 47, IR 4568-225-3-2, Perola, Tox 1011-4-2 and Tox 1369-18-1. Grain discoloration incidence ranged from 2.5% in IAC 165 to 74.5% in CR 156-5021-207 in the unprotected plots. Chemical control of grain discoloration was not as effective as for blast as can be noted by the high incidence observed in protected plots. Nevertheless, good sources of genetic resistance appear to be available. A low level of incidence was recorded in IAC 165, Ligerito, Perola, IAC 47, Khao lo x IR 8, Tox 1011-4-2, IAC 165, Tox 1369-18-1 and IRAT 101 .

When protected and unprotected plots are compared in relation to five agronomic characteristics, it was observed that number of

Table 32. Effect of chemical control on incidence of blast and grain discoloration diseases on rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1984. 1]

Pest management	Neck blast (%)	Grain discoloration (%)	Yield (Kg/ha)
Protected	5.4 b	8.3 b	3885 a
Unprotected	21.0 a	13.4 a	3155 b

1] Average of four replications x twenty five cultivars.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 33. Effect of pest control management on incidence of two diseases on 25 rice cultivars grown under upland condition in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984. [1]

Cultivar	Neck blast (%)		Grain discoloration (%)	
	Protected	Unprotected	Protected	Unprotected
Metica 1	6.5	46.5	18.8	33.3
MI-48	5.5	43.0	12.0	11.3
Bg 90-2	10.0	79.0	20.0	33.8
IRAT 122	9.0	30.8	6.5	7.5
IR 6023-10-1	5.0	35.0	5.5	8.5
P2030 F4-235-1B-1B	8.0	26.0	10.8	13.0
IR 4568-225-3-2	3.5	5.0	23.3	36.8
Makalioka 34	3.5	12.5	15.8	20.5
Salumpikit	4.8	29.8	11.3	16.3
Tox 1369-18-1	5.8	7.0	2.5	4.5
Ligerito	9.3	37.3	2.0	3.3
CR 156-5021-207	4.0	18.3	32.0	74.5
IRAT 101	6.5	10.5	2.8	5.0
Perola	3.0	5.5	2.0	3.3
IAC 47	2.8	4.3	1.8	3.3
C 424-2	5.5	32.8	9.5	10.3
IAC 165	2.3	3.8	2.5	2.5
TOX 1011-4-2	2.3	6.0	2.0	4.3
IAC 25	3.5	13.0	3.0	4.3
Bluebonnet 50	3.3	16.5	2.8	6.0
Tox 95	10.5	11.0	3.3	7.3
Khao Lo x IR 8	3.3	10.0	2.8	3.8
Monolaya	4.8	8.0	3.5	6.3
Miramono	6.0	19.3	6.8	9.8
Khao maleuh	5.8	14.0	4.3	5.8
Means	5.4	21.0	8.3	13.4
Tukey's value	11.02		9.23	

Average of four replications

tillers and day to harvest values did not change significantly, but differences were encountered for plant height and harvest index (Table 34). Neck blast affects grain filling, and reduces grain weight (Ou, 1972). In addition , grain discoloration affected the rice florets causing partial sterility and shrivelled grains, which contributed to the low harvest index percentage recorded in the unprotected plots.

There were no significant differences in the number of panicles, number of grains per panicle and number of grains per square meter, when both pest management systems (protected vs unprotected) were compared. Disease incidence reduced 1000 grain weight and increased percent sterility in the unprotected plots and therefore a significantly higher yield was obtained when plants were protected (Table 35).

Correlation coefficients among eight agronomic characters measured were obtained to observe possible associations (Table 36). The degree and magnitude of association varied for some traits as a consequence of the effectiveness of the chemical control. Grain yield was significantly correlated with grain discoloration (0.387**), harvest index (0.547**), panicle number (0.517**) and 1000 grain weight (-0.278**) in the protected plots. A negative, but significant interaction was found between yield and neck blast (-0.473**), and yield and sterility (-0.432**) in the unprotected plots. This shows the effectiveness of the chemical control against the neck blast disease and the deleterious effect the disease had on grain yield.

No significant association was found between neck blast and the other plant characteristics in the protected plants. Neck blast was

Table 34. Pest management effect on four agronomic characteristics of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984. 1]

Pest management	Height (cm)	Tillers (N/m2)	Harvest (days)	Harvest index %
Protected	102.9 a	330.6 a	118.7 a	48.8 a
Unprotected	100.1 b	343.8 a	118.5 a	43.1 b

1] Mean of four replications x twenty five cultivars.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 35. Pest management effect on grain yield and yield components of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984 1]

	Panicles	Grains		1000 grain	Sterility	Yield
Pest management	(N/m2)	(N/pan)	(N/m2)	weight(g)	(%)	(Kg/ha)
Protected	313.7 a	84.5 a	25056 a	30.8 a	13.5 b	3885 a
Unprotected	321.8 a	76.0 a	22446 a	29.3 b	19.1 a	3155 b

1] Mean of four replications x twenty five cultivars.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 36. Correlation coefficients among eight agronomic characters for protected and unprotected rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia1984

	Protected	Unprotected
Yield vs		
Neck blast	0.164	-0.473**
Grain discoloration	0.387**	-0.089
Harvest index	0.547**	0.657**
Panicle number	0.517**	0.030
1000 grain weight	-0.278**	0.324**
Grains per panicle	0.117	0.145
Sterility	0.190	-0.432**
Neck blast vs		
Grain discoloration	0.068	0.274**
Harvest index	0.122	-0.337**
Panicle number	0.162	0.337**
1000 grain weight	-0.154	-0.525**
Grains per panicle	-0.054	-0.243*
Sterility	0.148	0.572**
Grain discoloration vs		
Harvest index	0.240*	-0.086
Panicle number	0.730**	0.700**
1000 grain weight	0.490**	-0.465**
Grains per panicle	-0.122	-0.590**
Sterility	0.216*	0.456**
Harvest index vs		
Panicle number	0.219*	0.042
1000 grain weight	0.142	0.346**
Grains per panicle	0.017	0.177
Sterility	0.317**	-0.369**
Panicle number vs		
1000 grain weight	-0.490**	-0.470**
Grains per panicle	-0.210*	-0.676**
Sterility	0.241*	0.267**
1000 grain weight vs		
Grains per panicle	-0.139	0.217*
Sterility	-0.118	-0.234*
Grains per panicle vs		
Sterility	-0.088	-0.462**

N : 100
* : Significant at the 0.05 level
** : Significant at the 0.01 Level

significantly correlated with all the traits in the unprotected plots. It was significant and negatively correlated with harvest index (-0.337**), 1000 grain weight (-0.525**) and number of grains per panicle (-0.243*). A positive and significant association was found between neck blast and grain discoloration (0.274**), neck blast and panicle number (0.337**),and neck blast and percent sterility (0.572**).

Grain discoloration was significantly correlated with harvest index (0.240*), panicle number (0.730**), 1000 grain weight (-0.490**) and sterility (0.216*) in the protected plots and with panicle number (0.700**), 1000 grain weight (-0.465**), grains per panicle (-0.590**) and sterility (0.456**) in the unprotected plots. These results show that grain discoloration reduces grain weight and the number of grains per panicle, and increases sterility in the rice plant.

Some associations like grain yield and grain discoloration (0.387**), and harvest index and grain discoloration (0.240*) in the protected plots, could be due to the fact that most of the improved semidwarf cultivars like Metica 1, Bg 90-2, IR 4568-225-3-2 and CR 156-5021-207 yielded well because of the effective blast control. But since grain discoloration was not as effectively controlled and some degree of infestation was presented on these cultivars, positive correlations were obtained.

For grain yield an interaction between pest management and cultivars was observed, showing that the grain yield differed among cultivars depending on pest management (Table 31). In fact, the cultivars evaluated had different reactions to pest and diseases. In

Table 37, the grain yield obtained with the twenty five cultivars under the two management systems is compared. Rice cultivars are also ranked in Table 37, from the highest to the lowest for grain yield in protected plots. Grain yield on the average was higher (3885 Kg/ha), in the protected plots than in the unprotected ones (3155 Kg/ha). Most of the semidwarfs like Metica 1, MI-48, Bg 90-2, IRAT 122, IR 6023-10-1 and P 2030 F4-235-1B-1B yielded well when plots were protected against pests and disease. Fungicide control resulted in higher yield compared with the untreated plots where blast infestation was severe. The relative yield was calculated based on the ratio of grain yield obtained in the unprotected plots over the grain yield obtained from the protected plots x 100. There was a slight variation, or even a little increase in grain yield when yield from protected and unprotected plots were compared in Khao Maleuh, Tox 1011-4-2, Perola, Khao Lo x IR 8, Bluebonnet 50, IAC 47 IAC 25, IRAT 101 and IR 4568-225-3-2. However some had a low yield potential, even in protected plots, such as Khao Lo x IR 8 and Bluebonnet 50. Rice cultivars such as Perola, Tox 1011-4-2, IAC 165, IAC 47 and IRAT 101 have a good yield potential, thick and deep roots, good level of adaptation to savanna soils,and a good level of resistance against blast and grain discoloration diseases. But resistance to the sogata planthopper, to hoja blanca and to leaf scald should be incorporated into suitable cultivars to stabilize grain yield and to reduce the risk of epidemics.

Table 37. Effect of pest control management on grain yield of 25 rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984. 1]

Cultivar	Yield (Kg/ha)		Relative yield (%) 2]	Major biological constraint 3]
	Protected	Unprotected		
Metica 1	4782	3033	63.4	Bl, Gd.
MI 48	4703	3073	65.4	Bl.
Bg 90-2	4671	1853	39.7	Bl, Gd.
IRAT 122	4456	3433	77.0	Bl.
IR 6023-10-1	4430	2985	67.4	Bl, Ls.
P 2030 F4-235-1B	4271	3280	76.8	Bl, Ls.
IR 4568-225-3-2	4252	3854	90.4	Gd, Ls, Ph.
Makalioka 34	4212	3620	85.9	Gd, Ls.
Salumpikit	4192	3537	84.4	Bl.
Tox 1369-18-1	4180	3214	76.9	Ls, Sb, Ph.
Ligerito	4129	3098	75.0	Bl.
CR 156-5021-207	4041	3097	76.7	Bl, Gd.
IRAT 101	3920	3548	90.5	Ls, Ph.
Perola	3903	3922	100.5	Hb, Ph.
IAC 47	3834	3554	92.7	Hb, Ph.
C 424-2	3828	2930	76.5	Bl, Ls.
IAC 165	3669	3430	93.5	Hb, Sb.
Tox 1011-4-2	3526	3852	109.2	Ls, Ph.
IAC 25	3407	3140	92.2	Hb, Ph.
Bluebonnet 50	3295	3107	94.3	Bl, Ph.
Tox 95	3276	2610	79.7	Sb, Ls, Ph.
Khao Lo x IR 8	3257	3188	97.9	Ls.
Monolaya	3178	2369	74.5	Ls, Hb.
Miramono	3038	2112	69.5	Bl, Hb.
Khao maleuh	2660	3031	113.9	Ls.
Mean values	3865	3155	81.2	
Tukey's value	1066			

1] Mean of four replications.

2] $\frac{\text{Yield of unprotected plots}}{\text{Yield of protected plots}}$ X 100

3] Bl = Blast (*Pyricularia oryzae*).
Ls = Leaf scald (*Rhynchosporium oryzae*)
Gd = Grain discoloration (Several fungi).
Hb = Hoja blanca (Virus).
Ph = Planthopper (*Sogatodes oryzicola*)
Sb = Stem borer (*Diatrea sp*).

Upland rice production technology for savanna soils of Colombia. Experiment 5.

Based on the information gathered in the experiments conducted in 1983, a factorial experiment with four rice acid-tolerant cultivars, two rates of Ca and three rates of P was carried out in savanna soils of CRI La Libertad during the rainy season of 1984. A soil analysis of the experimental area is presented in Table 38. Soil samples for chemical analysis were taken from 0-20 and 20-40 cm, below soil surface. Chemical analyses shown in Table 38 are quite similar to those presented in Appendix Table 1 and in Table 13, showing the experimental area to be fairly uniform for the nutrients measured . Deficiencies in P (4.3 ppm Bray II), Ca (0.24 meq/100 g soil), Mg (0.12 meq/100 g soil) and K (0.15 meq/100 g soil) are evident. The pH was very acid (4.0), Al content was very high (3.6 meq/100 g soil) and the percentage Al saturation was also very high (87.6%). The concentration of the micronutrients Zn (0.9 ppm), Mn (15.3 ppm), Cu (0.60 ppm) and Fe (34.6 ppm) was above the critical deficient levels in rice soils, as reported by Randhawa et al (1978). Possible Fe or Mn toxicity was also examined. Tanaka et al (1966), found that the critical Fe concentration in the soil solution varies with the pH, and it is about 100 ppm at pH 3.7 and 300 ppm or higher at pH 5.0, therefore Fe toxicity did not appear to be a limiting factor in this study. Tanaka and Navasero (1966), reported that in culture solution a concentration higher than 10 ppm Mn could be toxic, but they further explained that rice roots have a high degree of Mn excluding power,

Table 38. Chemical soil analyses of the area where the experiment related to upland rice production technology for savanna soils was conducted. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

Depth	% OM	ppm P Bray II	pH	meq/100 g soil				Al Sat(%)	Zn	Mn	Cu	Fe
				Al	Ca	Mg	K		ppm			
0-20	3.9	4.3	4.0	3.6	0.24	0.12	0.15	87.6	0.9	15.3	0.60	34.6
20-40	3.0	3.1	4.0	3.3	0.21	0.09	0.09	89.4	0.8	12.7	0.52	28.8

and that rice plants can tolerate high levels of Mn. Also a high level of Fe may counteract an excessive Mn uptake. No visual symptoms of Mn toxicity were observed and it seems that Mn levels found in this soil did not affect the rice cultivars evaluated.

An analysis of variance for grain yield is provided in Table 39. A significant F value was found for cultivars, Ca and P, with no significant interactions being observed. A higher F value was found for P when compared with either Ca or rice cultivars. A general yield mean of 3519 Kg/ha was obtained and the coefficient of variation was low (13.6%).

Effect of P rates

Tissue analyses for P concentration were carried out at 15, 30, 45 and 60 days after emergence. There was a significant increase in P concentration in plant tissue as P rates of application were increased (Table 40). Significant differences were encountered among P rates at any given date of sampling. On the average, P concentration varied across sampling dates from 0.142% with no application of P to 0.215% with 60 Kg P_2O_5/ha and to 0.241% when a rate of 120 Kg P_2O_5/ha were applied to the rice crop. Phosphorus concentration was also higher at the early stage of growth.

The effect of the three rates of P fertilizer on Ca concentration is showed in Table 41. Calcium concentration in rice leaves was increased as P rates of application were increased, but significant differences were found only up to 60 Kg P_2O_5/ha,with the exception of

Table 39. Analysis of variance for grain yield of the experiment related to upland rice production technology for savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

Sources	df	MS	F
Replications	3	223622.95	0.97
Cultivars	3	3236315.10	14.03 **
Calcium	1	5545451.34	24.05 **
Phosphorus	2	26455433.04	114.72 **
Cultivars x calcium	3	508183.20	2.20
Cultivars x phosphorus	6	480090.28	2.08
Calcium x phosphorus	2	22809.50	0.10
Cultivars x Ca x P	6	306504.85	1.33
Error	69	230613.38	
Total	95		

Mean: 3519 Kg/ha

CV : 13.6%

** : Significant at 1% level.

Table 40. Effect of P rates on P concentration of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio,Llanos Orientales, Colombia, 1984.

	P concentration (%) 1]				
P_2O_5	15	30	45	60	Means
(Kg/ha)	Dare 2]				
0	0.153 c	0.175 c	0.120 c	0.120 c	0.142
60	0.282 b	0.243 b	0.167 b	0.170 b	0.215
120	0.325 a	0.272 a	0.176 a	0.191 a	0.241
Means	0.253	0.230	0.154	0.160	

1] Mean of four replications x four cultivars x two Ca rates.

2] Dare : Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test at the 0.05 probability level.

Table 41. Effect of P rates on Ca concentration of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1984.

	Ca concentration (%) 1]				
P_2O_5	15	30	45	60	Means
(Kg/ha)	Dare 2]				
0	0.141 b	0.157 b	0.147 c	0.136 b	0.145
60	0.183 a	0.182 a	0.205 b	0.182 a	0.188
120	0.185 a	0.190 a	0.228 a	0.189 a	0.198
Means	0.169	0.176	0.193	0.169	

1] Mean of four replications x four cultivars x two Ca rates.

2] Dare : Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

the 45 day sample, where significant differences was also noted between 60 and 120 Kg P_2O_5/ha. Tissue Ca increased, on the average, until 45 days after rice emergence and then a slight decrease in Ca concentration was recorded. Calcium concentrations were higher in all treatments than the 0.15% critical level found by Tanaka and Yoshida (1970), for rice. Calcium concentration values were lower than those found in 1983, Experiment 2. This can be attributed to either the different set of cultivars, differences in sampling days between the two years or to the lower Ca meq/100 g soil content of the soil, since these experiments were carried out in different fields in 1983 and 1984.

Phosphorus response on four agronomic characters is presented in Table 42. There was a significant response in plant height at 30 days and at harvest, as P rates were increased. Phosphorus rates, also influenced the number of tillers per square meter with significant differences encountered between P rates. The mean values for number of tillers per sq.m. were 330.2, 374.2 and 396.4, with 0, 60 and 120 Kg P_2O_5/ha, respectively. It was observed that plants with zero application of P matured later than those in which P was applied. Furthermore, due to P application, the harvest index percentage was increased, but no significant differences were found by increasing P_2O_5 rates from 60 to 120 Kg/ha.

Data on the effect of P rates on grain yield and the yield components are presented in Table 43. The number of panicles increased as P rates were increased, but significant differences were found only between zero P and either 60 or 120 Kg P_2O_5/ha rates.

Table 42. Effect of P rates on some agronomic characteristics of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984 1]

P_2O_5 (Kg/ha)	Height (cm) 30 days	Height (cm) at harvest	Tillers (N/m2)	Harvest (days)	Harvest index (%)
0	30.6 c	88.8 c	330.2 c	126.0 a	42.3 b
60	42.1 b	99.3 b	374.2 b	121.9 b	45.3 a
120	44.2 a	102.4 a	396.4 a	121.3 b	45.5 a

1] Mean of four replications x four cultivars x two Ca rates.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 43. Effect of P rates on grain yield and yield components of rice grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1984. 1]

P_2O_5 (Kg/ha)	Panicles (N/m2)	Grains (N/panicle)	Grains (N/m2)	1000 Grain weight (g)	Sterility (%)	Yield (Kg/ha)
0	321.3 b	55.6 c	17088 c	30.7 a	15.2 a	2482 c
60	361.2 a	68.4 b	23910 b	30.4 a	13.9 a	3897 b
120	376.4 a	73.6 a	27038 a	30.4 a	14.4 a	4179 a

1] Mean of four replications x four cultivars x two Ca rates.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Number of grains per panicle and number of grains per square meter were significantly increased due to a positive P response. Neither 1000 grain weight nor percent sterility were affected by P applications. Yield increase was much higher from 0 to 60 Kg P_2O_5/ha (1415 Kg/ha), than from 60 to 120 Kg P_2O_5/ha (282 Kg ha); however, significant differences were found among the three P rates. Yields obtained were 2482 Kg/ha, 3897 kg/ha and 4179 Kg/ha with 0, 60 and 120 Kg P_2O_5/ha, respectively.

Effect of Ca rates

The effect of Ca application on the concentration of Ca in rice tissue at four sampling dates is showed in Table 44. There was a significant increase in the Ca concentration in the tissue due to Ca fertilizer. Differences were observed when the two levels of calcium (0 and 150 Kg Ca/ha) were compared at all sampling dates. Mean values for tissue Ca were 0.154 and 0.200% corresponding to 0 and 150 Kg Ca/ha. Calcium level in the zero treatment is similar to the critical level of 0.150% reported for Ca (Tanaka and Yoshida, 1970; Yoshida 1981).

Calcium rate did not affect the P concentration in samples taken at 15, 30, 45 and 60 days after emergence. No significant differences were found in P concentration between the two Ca levels at any given sampling dates (Table 45).

Application of Ca did significantly increase plant height, at 30 days and at harvest (Table 46). The number of tillers and the growth

Table 44. Effect of Ca rates on Ca concentration of rice cultivars grown under upland conditions in savanna soil. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984

Ca	Ca concentration (%) 1]				
(Kg/ha)	15	30	45	60	Means
	Dare 2]				
0	0.146 b	0.158 b	0.166 b	0.146 b	0.154
150	0.193 a	0.195 a	0.221 a	0.192 a	0.200
Means	0.169	0.176	0.193	0.169	

1] Mean of four replications x four cultivars x three P rates.

2] Dare : Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 45. Effect of Ca rates on P concentration of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984.

	P concentration (%) 1]				
Ca	15	30	45	60	Means
(Kg/ha)	Dare 2]				
0	0.255a	0.225a	0.156a	0.161a	0.199
150	0.252a	0.235a	0.153a	0.159a	0.200
Means	0.253	0.230	0.154	0.160	

1] Mean of four replications x four cultivars x three P rates.

2] Dare : Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 46. Effect of Ca rates on four agronomic characteristics of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984 1]

Ca	Height (cm)		Tillers	Harvest	Harvest index
(Kg/ha)	30 days	at harvest	(N/m2)	(days)	(%)
0	37.5b	94.6b	361.8a	123.3a	43.3b
150	40.4a	99.1a	372.1a	122.8a	45.4a

1] Mean of four replications x four cultivars x three P rates.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

duration were not affected by the Ca application. But, increasing Ca rate from 0 to 150 Kg Ca/ha slightly but significantly increased harvest index. Harvest index values were 43.3% and 45.4% with 0 and 150 Kg Ca/ha, respectively.

When the yield components are considered, no significant differences were observed for panicle number, 1000 grain weight, and percent sterility (Table 47). But, a significant response to Ca application was recorded in the number of grains per panicle, number of grains per square meter and grain yield. A grain yield of 3279 Kg/ha was obtained with no application of Ca while 3760 Kg/ha resulted when a rate of 150 Kg Ca/ha was applied.

Cultivar performance

Leaf tissue analysis for P was performed at 15, 30, 45 and 60 days after emergence for cultivars IAC 165, Makalioka 34, Tox 95 and IR 4568-225-3-2 (Table 48). Although, average P concentration was quite similar for all four cultivars, significant differences were encountered at different sampling dates. Phosphorus concentration in leaf tissue was higher at early stages of growth and tended to stabilize. Similar P pattern have been reported by Yoshida (1981) and Howeler (1983). Based on the mean values, it was observed that higher P concentrations were generally found in Tox 95, followed by IR 4568-225-3-2, with all P concentrations being higher than the critical P level reported by Tanaka and Yoshida (1970) and by Mikkelsen (1978).

Table 49, gives the tissue Ca concentration values for the four

Table 47. Effect of Ca rates on grain yield and yield components of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984. 1]

Ca	Panicles	Grains		1000 Grain	Sterility	Yield
(Kg/ha)	(N/m2)	N/panicle)	(N/m2)	weigth(g)	(%)	(Kg/ha)
0	348.1a	62.0b	20866b	30.3a	15.1a	3279b
150	357.8a	69.7a	24492a	30.7a	13.9a	3760a

1] Mean of four replications x four cultivars x three P rates.

Means with a letter in common are not significantly different in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 48. Leaf concentration of P in four rice cultivars grown under upland conditions in savanna. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984

	P concentration (%) 1]				
Cultivar	15	30	45	60	Means
	Dare 2]				
IAC 165	0.241 b	0.215 b	0.155 ab	0.164 a	0.193
Makalioka 34	0.240 b	0.240 a	0.148 b	0.152 b	0.195
Tox 95	0.282 a	0.236 a	0.159 a	0.156 b	0.208
IR 4568-225-3-2	0.250 b	0.229 ab	0.155 ab	0.169 a	0.201
Means	0.253	0.230	0.154	0.160	

1] Mean of four replications x two Ca rates x three P rates.

2] Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 49. Leaf concentration of Ca in four rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1984.

	Ca concentration (%) 1]				
Cultivar	15	30	45	60	Means
	Dare 2]				
IAC 165	0.160 b	0.155 b	0.179 c	0.134 c	0.157
Makalioka 34	0.162 b	0.163 b	0.164 c	0.160 b	0.162
Tox 95	0.191 a	0.191 a	0.234 a	0.195 a	0.203
IR 4568-225-3-2	0.164 b	0.196 a	0.197 b	0.188 a	0.186
Means	0.169	0.176	0.193	0.169	

1]Mean of four replications x two Ca rates x three P rates.

2] Days after rice emergence.

Within a column, means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0,05 probability level.

rice cultivars. There was no consistent pattern of Ca concentration over dates. A higher Ca level was found in Tox 95 compared with the other three rice cultivars. The mean Ca concentrations were 0.157 % for IAC 165, 0.162 % for Makalioka 34, 0.186 % for IR 4568-225-3-2 and 0.203 % for Tox 95. The critical Ca level for deficiency is 0.150 % (Tanaka and Yoshida, 1970).

Four agronomic characteristics of the cultivars under evaluation are presented in Table 50. Significant differences were found among the cultivars for plant height, number of tillers per square meter, growth duration and harvest index. IAC 165, Makalioka 34 and Tox 95 are tall cultivars and IR 4568-225-3-2 is a semidwarf cultivar. IAC 165 and IR 4568-225-3-2 have a high tillering capacity while Tox 95 and IAC 165 are low. Based on growth duration, IAC 165 is an early cultivar, Tox 95 and IR 4568-225-3-2 are intermediate and Makalioka 34 is late. Harvest index values were significantly different among cultivars with 52.4 % for IAC 165, 46.6 % for Tox 95, 44.0 % for IR 4568-225-3-2 and 34.3 % for Makalioka 34. The low harvest index value encountered in Makalioka 34 is attributed to the excessive vegetative growth of this cultivar.

Significant differences were found among rice cultivars for grain yield and its components (Table 51). Panicle number was high for IR 4568-225-3-2 (467.5 panicles/sq. m) and Makalioka 34 (413.9 panicles/sq. m), and intermediate for Tox 95 and IAC 165. These latter two cultivars had a higher number of grains per panicle (75.3 for IAC 165 and 71.2 for Tox 95) . Significant differences were found among cultivars in 1000 grain weight. The highest grain weight was 38.7 g

Table 50. Four agronomic characteristics of four rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984 1]

	Height (cm)		Tillers	Harvest	Harvest
Cultivar	30 days	at harvest	(N/m2)	(days)	index (%)
IAC 165	48.8 a	110.5 a	265.8 c	98.3 d	52.4 a
Makalioka 34	36.2 c	104.8 b	426.2 b	137.4 a	34.3 d
Tox 95	38.4 b	96.9 c	284.4 c	126.0 c	46.6 b
IR 4568-225-3-2	32.4 d	75.2 d	491.3 a	130.6 b	44.0 c

1] Mean of four replications x two Ca rates x three P rates.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

Table 51. Grain yield and yield components of four rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984. 1]

	Panicles	Grains		1000 grain	Sterility	Yield
Cultivar	(N/m2)	(N/pan)	(N/m2)	weight(g)	(%)	(Kg/ha)
IAC 165	258.0 c	75.3 a	19711 c	38.7 a	12.7 c	3758 a
Makalioka 34	413.9 b	65.5 b	27421 a	25.0 d	15.0 b	3556 a
Tox 95	272.4 c	71.2 a	19554 c	30.4 b	12.0 c	2989 b
IR 4568-225-3-2	467.5 a	51.4 c	24030 b	27.9 c	18.3 a	3775 a

1] Mean of four replications x two Ca rates x three P rates.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

for IAC 165 and the lowest 25.0 g for Makalioka 34. Although significant differences were encountered among cultivars in percent sterility, most of the values are within the normal spikelet sterility range of 10 to 15% reported by Jennings et al (1979). Grain yields were high and significantly different being higher for IR 4568-225-3-2, IAC 165 and Makalioka 34 in contrast to Tox 95. These grain yields are regarded as high in terms of the low fertility status of the soils and the low input technology applied.

A further characterization of grain yield was performed and a regression model using grain yield as the dependent variable and the yield components, tiller number, panicle number, grains per panicle, percent sterility and 1000 grain weight as independent variables. The best regression analysis model for grain yield of IAC 165 is showed in Table 52. The yield component, grains per panicle explained 80% of the variability in grain yield.

When the same grain yield analysis was performed on Makalioka 34, it was observed that number of tillers (b= 9.86) and grains per panicle (b= 30.07) contributed to 59 % of the grain yield variability (Table 53).

The best regression analysis model for grain yield obtained with Tox 95 is showed in Table 54. In this rice cultivar, the grains per panicle and number of tillers per square meter explained 72 % of the variability in grain yield.

In the case of IR 4568-225-3-2, the number of tillers, grains per panicle and 1000 grain weight accounted for 56 % of the grain yield variability (Table 55).

Table 52. Best regression analysis model for grain yield of IAC 165, using yield components (tillers, panicles, grains per panicle, sterility and 1000 grain weight) as independent variables. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

Analysis of variance

Sources	df	MS	F
Regression	1	18915423.087	89.46**
Residual	22	211449.494	
Total	23		

$R^2 = 0.80$

	B value	Standard error	F
Intercept	-1209.95		
Grains per panicle	65.95	6.97	89.46**

** : Significant at 1% level

Table 53. Best regression analysis model for grain yield of Makalioka 34, using yield components (tiller, panicles, grains per panicle, sterility and 1000 grain weight) as independent variables. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

Analysis of variance

Sources	df	MS	F
Regression	2	6974330.138	14.83**
Residual	21	470307.937	
Total	23		

$R^2 = 0.59$

	B value	Standard error	F
Intercept	-2617.31		
Tillers	9.86	3.99	6.11*
Grains per panicle	30.07	13.96	4.64*

* : Significant at 5% level

** : Significant at 1% level

Table 54. Best regression analysis model for grain yield of Tox 95, using yield components (tillers, panicles, grains per panicle, sterility and 1000 grain weight) as independent variables. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia 1984.

Analysis of variance			
Sources	df	MS	F
Regression	2	4449950.446	27.27**
Residual	21	163209.545	
Total	23		
		$R^2 = 0.72$	
	B value	Standard error	F
Intercept	-1399.56		
Tillers	5.31	1.86	8.14**
Grains per panicle	40.46	6.65	37.07**

** : Significant at 1% level.

Table 55. Best regression analysis model for grain yield of IR 4568-225-3-2, using yield components (tillers, panicles, grains per panicle, sterility and 1000 grain weight) as independent variables. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

Analysis of variance

Sources	df	MS	F
Regression	3	4068575.38	8.65**
Residual	20	470189.09	
Total	23		

$R^2 = 0.56$

	B value	Standard error	F
Intercep	-8738.66		
Tillers	4.73	2.32	4.18*
Grains per panicle	26.92	12.21	4.86*
1000 grain weight	315.22	101.25	9.69**

* : Significant at 5% level.

** : Significant at 1% level.

The correlation coefficients between grain yield and yield components for cultivar IAC 165 are showed in Table 56. Grain yield was positive and significantly correlated with tiller number (0.611**), panicle number (0.653**), number of grains per panicle (0.896**), number of grains per square meter (0.880**) and harvest index (0.544**). The significant association of grain yield with these yield components explains in part the high grain yield of 3758 kg/ha produced by IAC 165 under upland conditions in savanna soils. Harvest index was other factor correlated with most of the traits. Harvest index was positively associated with grain yield (0.544**), tiller number (0.409*), panicle number (0.450*), grains per panicle (0.473*) and grains per square meter (0.505*). As expected, there was a high positive association between grains per panicle and grains per square meter (0.925**).

In Makalioka 34, similar results were observed (Table 57). Grain yield was significantly correlated with tiller number (0.703**), panicle number (0.620**), grains per panicle (0.682**), grains per square meter (0.732**) and harvest index (0.599*). In turn, harvest index values were positively associated with grain yield (0.599**), tiller number (0.619**), panicle number (0.638**), grains per panicle (0.505*) and grains per square meter (0.633**). Grain yield obtained with Makalioka 34 was 3556 Kg/ha.

Correlation coefficients among yield components for Tox 95 are in Table 58. Yield was associated with tiller number (0.481*), panicle number (0.529**), grains per panicle (0.784**) and grains/sq.m (0.809**). Harvest index was associated with number of tillers

Table 56. Correlation coefficients of grain yield and yield components of IAC 165 grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

	Tillers	Panicles	Grains/panicle	Grains/sq.m	1000 grain weight	Sterility	Harvest index
Yield	0.611**	0.653**	0.896**	0.880**	-0.201	0.095	0.544**
Tillers		0.978**	0.578**	0.832**	-0.103	-0.054	0.409*
Panicles			0.604**	0.855**	-0.209	-0.039	0.450*
Grains/panicle				0.925**	-0.138	-0.012	0.473*
Grains/sq.m					-0.173	-0.036	0.505*
1000 grain weight						-0.232	-0.204
Sterility							0.176

N : 24

* : Significant at 5% level.

** : Significant at 1% level.

Table 57. Correlation coefficients of grain yield and yield components of Makalioka 34 grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

	Tillers	Panicles	Grains/panicle	Grains/sq.m	1000 grain weight	Sterility	Harvest index
Yield	0.703**	0.620**	0.682**	0.732**	-0.053	-0.148	0.599**
Tillers		0.953**	0.639**	0.818**	-0.069	-0.155	0.619**
Panicles			0.557*	0.785**	-0.078	-0.187	0.638**
Grains/panicle				0.948**	-0.128	-0.034	0.505*
Grains/sq.m					-0.151	-0.073	0.633**
1000 grain weight						-0.352	-0.080
Sterility							0.074

N : 24

* : Significant at 5% level.

** : Significant at 1% level.

Table 58. Correlation coefficients of grain yield and yield components of Tox 95 grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

	Tillers	Panicles	Grains / panicle	Grains / sq.m	1000 grain weight	Sterility	Harvest index
Yield	0.481*	0.529**	0.784**	0.809**	0.104	0.103	0.140
Tillers		0.934**	0.203	0.683**	-0.433*	0.046	0.542**
Panicles			0.306	0.795**	-0.383	-0.006	0.467*
Grains/panicle				0.817**	0.084	-0.040	0.349
Grains/sq.m					-0.171	-0.017	-0.054
1000 grain weight						0.119	0.678**
Sterility							-0.004

N : 24

* : Significant at 5% level.

** : Significant at 1% level.

(0.542**), number of panicles (0.467*) and 1000 grain weight (0.678**). Fewer positive associations were found with this cultivar, when compared with either IAC 165 or Makalioka 34.

These three cultivars are tall and all showed similar trends and degrees of association, with some variation in magnitude. On the other hand, with IR 4568-225-3-2, a semidwarf cultivar, differences in sign and magnitude of the different characters were observed (Table 59). Grain yield was positive and significantly associated with number of grains per panicle (0.545**), number of grains per square meter (0.551**), 1000 grain weight (0.592**) and harvest index (0.785**). No significant association was found between grain yield and number of tillers or number of panicles. A negative and significant association was found between sterility and number of grains per panicle (-0.718**) and number of grains per square meter (-0.628**). Harvest index was associated with grain yield (0.785**), grains per panicle (0.475*), grains/sq m (0.452*) and 1000 grain weight (0.575**). The high number of positive associations between grain yield and yield components, and between harvest index and other yield components contributed to the yield of 3775 Kg/ha obtained with IR 4568-225-3-2.

Some general observations can be made based on the six treatments resulting from the combination of the two Ca rates x three P rates studied (Table 60). Significant differences were found among treatments for panicle number. An increase in the number of panicles was obtained due to P application either alone or in combination with Ca. No response was observed due to Ca application alone. A similar

Table 59. Correlation coefficients of grain yield and yield components of IR 4568-225-3-2 grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1984.

	Tillers	Panicles	Grains/panicle	Grains/sq.m	1000 grain weight	Sterility	Harvest index
Yield	0.258	0.170	0.545**	0.551**	0.592**	-0.296	0.785**
Tillers		0.962**	0.035	0.484*	-0.117	-0.109	0.174
Panicles			-0.013	0.461*	-0.146	-0.007	0.072
Grains/panicle				0.878**	0.367	-0.718*	0.475*
Grains/sq.m					0.268	-0.628*	0.452*
1000 grain weight						-0.125	0.575**
Sterility							-0.125

N : 24

* : Significant at 5% level.

** : Significant at 1% level.

Table 60. Effect of two rates of Ca and three rates of P on grain yield and yield components of rice cultivars grown under upland conditions in savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales,Colombia,1984 1]

Ca	P_2O_5	Panicles	Grains		1000 grain	Yield	Increment
(Kg/ha)		(N/m2)	(N/panicle)	(N/m2)	weight(g)	(Kg/ha)	over check
0	0	320.4 b	52.4 c	16040 c	30.1 a	2223 e	0
0	60	348.2 ab	62.7 b	20876 b	30.4 a	3645 c	1422
0	120	375.8 a	70.9 a	25681 a	30.4 a	3969 bc	1746
150	0	322.1 b	58.7 bc	18136 bc	31.3 a	2741 d	518
150	60	374.1 a	74.2 a	26945 a	30.5 a	4150 ab	1927
150	120	377.1 a	76.2 a	28396 a	30.4 a	4388 a	2165

1]Mean of four replications x four cultivars.

Means with a letter in common are not significantly different, in accordance with Duncan's multiple range test, at the 0.05 probability level.

response was encountered in grains per panicle and number of grains per square meter. No significant differences were found in these traits between the check plot and where 150 Kg Ca/ha was applied alone. Significant differences were observed, however, between the check plots and where P was applied. One thousand grain weight was not affected by the fertilizers applied and no significant differences were found among treatments.

Large differences were observed for grain yield obtained due to the treatments. An increment of 518 Kg/ha over the check plot was obtained when Ca at a rate of 150 Kg/ha was added. When P was added the increments were even higher. An increase in grain yield of 1422 Kg/ha was produced, when 60 Kg P_2O_5/ha was applied. Furthermore, yield was increased by 1746 Kg/ha with 120 Kg P_2O_5/ha. Phosphorus response was greater than the response to Ca. Similar results were found in the experiment conducted in 1983 in savanna soils. When P and Ca were applied together a higher increase in grain yield was obtained. Although the maximum yield of 4388 Kg/ha was produced with 150 Kg Ca/ha plus 120 Kg P_2O_5/ha, this yield was not significantly different from the yield of 4150 Kg/ha obtained with a fertilization rate of 150 Kg Ca/ha plus 60 Kg P_2O_5/ha.

The previous sections have discussed the essential components for upland rice production on the acid, infertile savanna soils of the Llanos Orientales of Colombia.

The first basic concept for a successful technology for these soils is the identification and utilization of rice cultivars to overcome Al toxicity and related acidity problems, and capable of utilizing more efficiently the low fertility level of savanna soils. Resistance against the prevalent pest and diseases in the area, is also essential for a productive upland rice technology . Rice cultivars such as Perola, Tox 1011-4-2, IRAT 101, IAC 47, IAC 165, Makalioka 34 and IR 4568-225-3-2 showed a high yield potential, good level of adaptation to savanna soils and acceptable level of resistance to most of the diseases.

A second component of the rice production system for savanna soils is the determination of the proper amount of Ca an P as essential plant nutrients. The idea is to develop a low cost technology based on the principle of plant adaptation to acid soils infertility rather than application of costly soil amendments. Based on two years data, a fertilization of 150 Kg Ca/ha using dolomite as a Ca source, and 60 Kg P_2O_5/ha as concentrate superphosphate, can be recomended as part of the production system package.

A third component of the management system is to drill plant adapted rice cultivars at closer spacings with a moderate seeding rate. A significant yield increase was obtained when rice was drilled in rows 15 centimeters apart with a seed density of 60 Kg/ha.

Through the integration of these management practices, an upland rice production technology appears feasible for savanna soils, permitting the utilization of these vast areas for food production.

SUMMARY AND CONCLUSIONS

In order to develop an upland rice production system, five field experiments were conducted in representative savanna soils of CRI La Libertad, Villavicencio, Llanos Orientales of Colombia.

Three experiments were undertaken in 1983. These involved 1) an screening of rice cultivars for upland conditions in savanna soils, 2) an assessment of Ca and P requirements for acid-tolerant cultivars and 3) an evaluation of suitable rice cultivars under three methods of planting and four seed densities. Experiments carried out in 1984 involved, 1) effect of pest and disease incidence on selected upland rice cultivars and 2) a production technology package for upland rice in savanna soils.

In the first experiment a set of 58 rice cultivars was evaluated. Differences were found among cultivars for all 25 traits measured. A root scale based on root thickness, length and number was developed to characterize root development. The root scale was correlated with plant height, Al concentration in plant tissue, Al toxicity scale, tiller number, panicle number and 1000 grain weight. It appears that selection based on the proposed root scale would be suitable for identifying adapted upland cultivars. Differences for most traits measured were encountered when upland and lowland cultivars were compared under upland conditions. In general upland cultivars were taller, had fewer tillers and panicles, and a higher biological yield than lowland cultivars. Their roots were thicker, deeper and fewer in number. They also had higher 1000 grain weight, more grains per panicle and less sterility.

In the upland cultivars grain yield was positively correlated with tiller number and panicle number, and negatively associated with 1000 grain weight. For the lowland group, grain yield was positively associated with harvest index, sterility and 1000 grain weight. Negative correlations were observed with tiller number and panicle number. As grain yield is increased through selection, it is possible that several biological activities related to the sink-source relationship could result in indirect negative association. Another factor which can modified the expression of grain yield may result from a compensatory association between some yield components. The yield potential was found to be high, with 13 cultivars out of 58 tested (22.4 %), yielding more than 3.0 tons/ha. Overall mean yield was 2.5 tons/ha for this experiment.

In the second experiment, fertilizer applications were measured for P and Ca concentrations based on plant tissue analyses and their subsequent response on grain yield and the yield components. Increasing P rates increase P concentration in plant tissue analyses . However, P rates applied did not influence Ca concentration. Differences were found between zero P and the three P rates in tiller number and panicle number but no differences were found between P rates for these traits. Grains per panicle were increased with increasing P rates above 60 Kg P_2O_5/ha. Differences were also observed among P rates for grain yield.

Increasing rates of Ca applications did not increase the Ca concentration in tissue measured at 35 and 65 days. However, at 85 days significant differences were found. None of the values observed were below the critical Ca concentration level reported for rice. Calcium rates apparently did not have any effect on P concentrations in plant tissue. Small differences were observed on grain yield and yield components as a consequence of Ca treatments. This is in contrast to the marked P response for the same traits. A significant interaction between cultivars and Ca was also noted.

To measure the effect of seeding methods and rates on grain yield and yield components, a third experiment was conducted. Differences were found between 60 Kg seed per hectare and the other three rates. The higher grain yield with 60 Kg seed/ha was the result of a higher number of grains per panicle, 1000 grain weight and grain to straw ratio values. When the three planting methods were compared differences were observed for grain yield and the yield components. The highest yield was obtained by drilling rice at a row spacing of 15 cm.

When the two pest managements (protected vs unprotected) were compared with 25 acid-tolerant rice cultivars disease incidence reduced harvest index, 1000 grain weight, grain yield and increased percent sterility in the unprotected plots. Rice cultivars such as Perola, Tox 1011-4-2, IAC 47, IAC 165, IRAT 101 and Makalioka 34 combine high yield potential, good adaptation to acid soil conditions and resistance to pests and diseases.

A production package which included a row spacing at 15 cm, a seed rate of 60 Kg seed/ha and the comparison of two Ca rates and three P rates was tested. Cultivar performance was evaluated based on tissue analyses for P and Ca. Grain yield and yield components analyses were also performed.

There was an increase in P concentration in the tissue as P rates of application were increased. Plant height, number of tillers, grains per panicle, number of grains per square meter and grain yield increased with P rates. Differences were observed in tissue Ca at all sampling dates. Calcium rates did not affect the P concentration in samples taken at four growth stages. Calcium application increased plant height, harvest index, grains per panicle, grains per square meter and grain yield.

Based on two years data a productive upland rice farming system can be visualized for savanna soils. The higher experimental plot yields consistently exceeded 3.5 tons/ha. A package of practices would include the use of acid-soil tolerant cultivars with good levels of resistance against the prevalent pests and diseases in the area, and a moderate fertilization with 60 Kg P_2O_5/ha and 150 Kg Ca/ha. Planting should be done in rows 15 cm apart with a low rate of 60 Kg seed/ha for a better distribution of plants in the field and subsequently an increase in grain yield.

Continuing research should focus on breeding cultivars that combine acceptable grain quality with overall adaptation to the savanna ecology, and on other potentially limiting minor elements. The production system must be evaluated on farms with concurrent economic analysis of its profitability.

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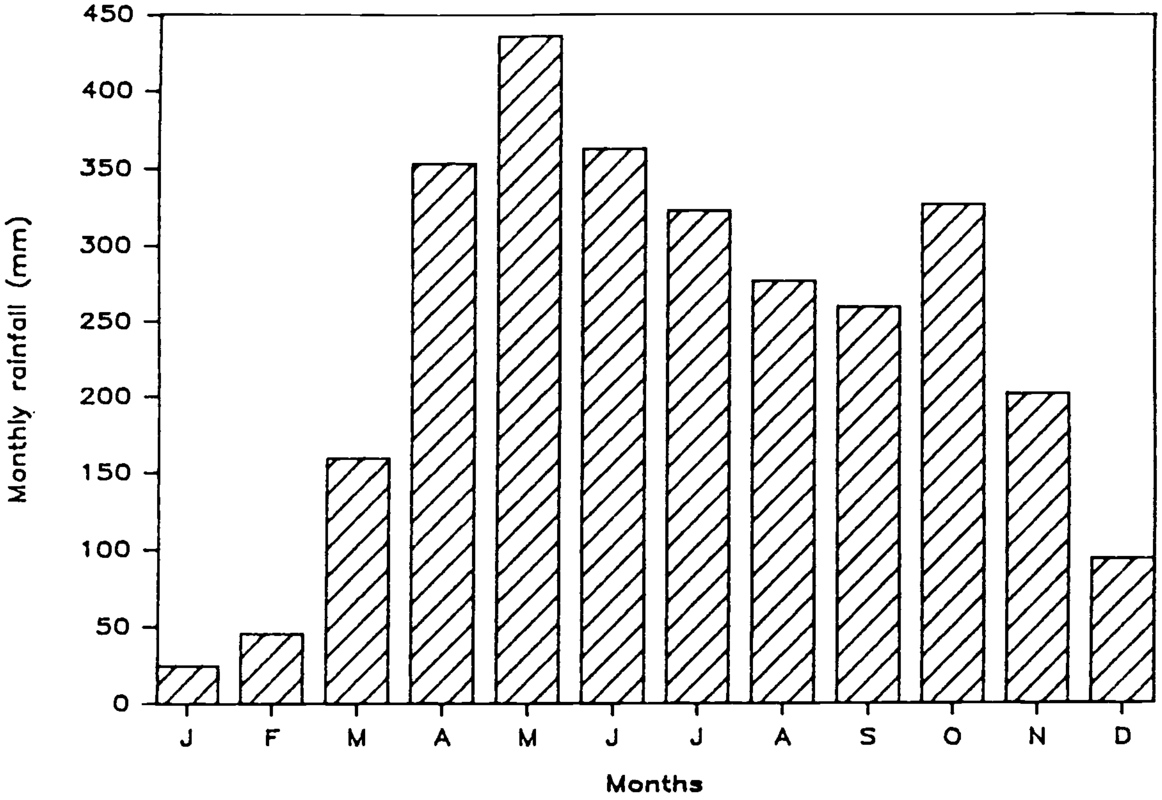
APPENDICES



Appendix Figure 1. Average monthly rainfall for the 14 year period (1970-1983) at CRI La Libertad, Villavicencio,Llanos Orientales, Colombia.

Appendix Table 1. Chemical analysis of a representative savanna soil. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

%	ppm P		meq/100 g of soil				Al	B	Zn	Mn	Cu	Fe
OM	Bray	pH	Al	Ca	Mg	K	sat.(%)	ppm				
3.7	4.6	4.1	3.1	0.37	0.07	0.17	83.6	0.32	0.50	9.5	0.72	40.4

Appendix Table 2. Genetic material sown in the preliminary screening of upland rice cultivars for savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia, 1983.

Cultivars	Origin	Cultivars	Origin
IRAT 10	Ivory Coast	Khao dawk mali 105	Thailand
IRAT 13	Ivory Coast	Nam sa gui 19	Thailand
IRAT 101	Ivory Coast	Khao maleuh	Thailand
IRAT 112	Ivory Coast	Sein ta lay	Burma
IRAT 122	Ivory Coast	Bg 90-2	Srilanka
IRAT 123	Ivory Coast	Bluebonnet 50	USA
IRAT 126	Ivory Coast	CR 1113	Costa Rica
IRAT 127	Ivory Coast	Peru X	Peru
Tox 95	Nigeria	Ceysvoni	Surinam
Tox 1010-45-1-1	Nigeria	Camponi	Surinam
Tox 1369-18-1	Nigeria	Tupuripa	Surinam
Tox 1785-19-18	Nigeria	IAC 25	Brazil
Tox 718-1-23	Nigeria	IAC 47	Brazil
OS 6 mutant	Nigeria	IAC 1246	Brazil
OS 6	Zaire	IAC 5544	Brazil
Moroberekan	Guinea	Quatro meses	Brazil
63-83	Senegal	Zebu	Brazil
Suakoko	Liberia	Paga divida	Brazil
Makalioka 34	Madagascar	Filipinas	Brazil
IR 4-2	Philippines	Batatais	Brazil
IR 4568-225-3-2	Philippines	Dourado	Brazil
IR 6023-10-1-1	Philippines	P 2030 F4-235-1B-1B	Colombia
Upl R1-3 (C424-2)	Philippines	CICA 8	Colombia
Kinandang patone	Philippines	Metica 1	Colombia
Salumpikit	Philippines	Metica 2	Colombia
MI 48	Philippines	Colombia 1	Colombia
Chianung 242	Taiwan	Ligerito	Colombia
Taichung 186	Taiwan	Miramono	Colombia
Kaohsiung 138	Taiwan	Monolaya	Colombia

Appendix Table 3. Selected upland rice cultivars evaluated in the experiment on pest control management on savanna soils. CRI La Libertad, Villavicencio, Llanos Orientales, Colombia. 1984.

Cultivar	Plant type	Cultivar	Plant type
Metica 1	Semidwarf	Perola	Tall
MI 48	Tall	IAC 47	Tall
Bg 90-2	Semidwarf	C 424-2	Intermedium
IRAT 122	Intermedium	IAC 165	Tall
IR 6023-10-1	Intermedium	Tox 1011-4-2	Tall
P 2030 F4-235-1B-1B	Semidwarf	IAC 125	Tall
IR 4568-225-3-2	Semidwarf	Bluebonnet 50	Tall
Makalioka 34	Tall	Tox 95	Tall
Salumpikit	Tall	Khao Lo x IR 8	Tall
Tox 1369-18-1	Tall	Monolaya	Tall
Ligerito	Tall	Miramono	Tall
CR 156-5021-207	Semidwarf	Khao maleuh	Intermedium
IRAT 101	Intermedium		