PERFORMANCE OF MAIZE VARIETIES IN THREE TROPICAL SOIL FAMILIES AND THEIR RESPONSE TO N AND P FERTILIZATION

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

AGRONOMY AND SOIL SCIENCE

MAY 1981

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ACKNOWLEDGMENTS

I wish to express my sincere gratitude to the Benchmark Soils Project, Department of Agronomy and Soil Science at the University of Hawaii, for providing the study grant.

Grateful appreciation is also due the Soil Research Institute at Bogor, Indonesia, for allowing me to pursue my graduate program.

I am grateful to all personnel of the Project in Hawaii, Indonesia, and the Philippines, who generated the data used in this study.

Finally, sincerest gratitude is expressed to my wife, Nurmala, for her unfailing patience, devotion, and encouragement, and to my children, Prasetio, Setiowati, and Setianto, for their inspiration during the time that I carried out my studies away from them.

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1. INTRODUCTION

The Universities of Hawaii and Puerto Rico have established projects under contracts with the U.S. Agency for International Development to attempt to verify the transferability of agroproduction technology. The projects are frequently referred to as the Benchmark Soils Project. Transfer experiments have been conducted by the Project to test if soil management and crop production knowledge can be transferred among tropical and subtropical countries, using soil family taxa as defined in Soil Taxonomy as a basis for transfer. If this hypothesis is proven to be true, it will make possible the transference of sound management practices developed in one area to other areas with similar soils. This is essential for increasing crop production and carrying out wise land utilization (Beinroth et al., 1980).

Success in conducting transfer experiments depends, to some extent, on the correct choice of a maize variety that is used as the test crop. An adapted maize variety should be used in the transfer experiment to properly assess the yield potential of the environment and to avoid complete loss of the experiment from disease or insect attack or from poor growth due to other causes. The variety also must be responsive to the treatment variables being tested, nitrogen and phosphate fertilization. Therefore maize variety experiments are being conducted by the Project to select the required maize variety.

The objectives of this study were: (1) to evaluate the adaptation of several maize varieties to different conditions within the same soil family, (2) to determine response in yield and plant nutrients of several maize varieties to nitrogen and phosphate fertilization at different locations within the same soil family, and (3) to study the variation in yield and plant nutrient levels of several maize varieties grown on different soil families.

2. LITERATURE REVIEW

2.1 Factors Affecting Maize Adaptation

Maize growth as a measure of its adaptation to the environment may be expressed in terms of plant height, plant nutrient composition, or grain yields. Crop yield is the final product of growth, that is a product of both the genetic constitution of the crop and the environment. All of the factors included in these two components may not have been identified. Several factors, however, have been studied and shown to affect crop growth.

2.1.1 Genetics

The genotype of maize plays an important role in the quantity and quality of its growth and development. Maize varieties apparently vary considerably in their adaptation and responses to soil and/or environment, and in the nutrient composition of their tissue.

Adaptation is the property of a genotype which permits its survival under selection; and an adapted genotype or population is one which performs better than the standards under comparison (Simmonds, 1962). The term "adapted variety" has been used in the Project to mean a variety that will perform relatively well under the local agro-ecological conditions; in this case over the range of variation in environmental conditions within one soil family. The fact that a maize variety does better in one region than in another has been recognized for a long time and suggests that maize might be selected specifically for certain environmental conditions. A number of these studies are available in the literature and are reviewed in the following sections.

a. Variation in adaptation and response to P fertilization

The nutrient content of the soil has long been known to be a significant factor in determining the adaptability of a crop to a particular locality. Since the early 1920's differences in performance of maize varieties at different levels of fertility have been reported. Mooers (1921) suggested that the productivity of the soil was a highly important factor in determining the yields of maize varieties. A variety ranking high under poor-land conditions may be inferior under rich-land conditions. For example, he has demonstrated in his study that maize variety 'Neal Paymaster' outyielded 'Jellicorse' on the unmanured plots, while in manured plots 'Jellicorse' produced higher yields. Therefore the 'Jellicorse' variety was classified as a "rich-land" variety and 'Neal Paymaster' as a "poorland" variety (Mooers, 1933).

Smith (1934) noted that the better production of "poorland" varieties than "richland" varieties, when grown on poor soils, could not be accounted for by the differences in their relative maturity. He suggested that this seemed to be associated with a differential ability to produce under low nutrient supply. According to Mooers (1933), the results of a maize varietal trial are primarily applicable only to soil with similar productivity as that on which the trial was conducted. In order to furnish a comprehensive picture of the adaptability and relative standing of different varieties, varietal trials on soils of both high and low productivity are required. Moreover, he added that a fair comparison can be made only when each variety is spaced to produce approximately maximum yields.

Regional adaptation of maize varieties with respect to soil fertility levels has been reported by many workers since then, and most of the studies relate the adaptation of maize varieties to their responses to fertilization (Gooding and Kiesselbach, 1931; Stringfield and Salter, 1934; Lyness, 1936; Sayre, 1955).

More recently, many studies have been conducted on the differential response of maize varieties to fertilization. Vose (1963) divided varietal differences to mineral nutrition into two categories, yield response and nutrient uptake. He defined yield response as the ability of the plant to produce dry matter with the nutrients available, and also as the efficiency of the plant in utilizing the nutrients taken up by the plant. Nutrient uptake represents the total amount of nutrient taken up by the plant during the growth period and is indicated by the concentration or total content of the nutrient. He suggested that the difference in uptake may be due to differences in rooting pattern, or differences in absorption or translocation of nutrients.

An early study on the genetics of differential yield response in maize was done by Smith (1934). In his study, the effects of deficiencies of phosphorus and nitrogen on inbreds and hybrids, he found that if one parent of the hybrid was phosphate efficient, the hybrid was at least as good as the better parent (dominance of phosphate efficiency). Marked differences in the ratio of secondary branch roots to primary roots were found among inbred lines studied. A high ratio was found with the phosphate efficient lines and a low ratio with the phosphate inefficient lines. These differences were inherited and were the probable cause of the relative phosphate efficiency in the hybrids.

De Turk _et al_. (1933) reported that two crosses of maize, responsive and nonresponsive, differed in their response to phosphate fertilizers both in growth and yield. The nonresponsive cross contained a higher concentration of inorganic phosphorus during active vegetative growth, but the phosphorus gradually diminished and disappeared soon after pollination. They suggested that this cross possibly has a higher minimum requirement of phosphorus for maintenance of vegetative growth compared to the more responsive one.

Maize varieties varied in their capacities to extract soil phosphorus and metabolize it efficiently (Vose, 1963; Gorsline _et al_., 1964; Clark and Brown, 1974). Possible explanations for the differences between maize inbreds in absorption and accumulation of phosphorus may be differences in the abilities of the inbreds to change the pH of their root environments, especially in the presence of aluminum, and differences in the phosphatase activity of their roots (Clark and Brown, 1974).

Genetic control of phosphorus accumulation in maize inbreds and hybrids has been reported (De Turk _et al_., 1933; Smith, 1934; Lyness, 1936; Sayre, 1955; Gorsline _et al_., 1964; Baker _et al_., 1967 and 1970). This suggests that maize might be bred for adaptation to phosphate deficient soils. Since phosphorus deficiency is often the most important factor limiting the yield of maize in many tropical soils, a breeding program for the development of phosphorus efficient varieties would be a significant contribution to maize production.

Detailed studies on the efficiency in phosphate utilization by maize were carried out by Pulam (1978). He found that maize genotypes respond differently to phosphate fertilization. This differential response he measured in seedling dry weight, days to anthesis, grain yield, yield components, P concentration, and P uptake.

The terms, phosphorus-efficient and phosphorus-inefficient, were used by Clark and Brown (1974) to describe inbreds that accumulate large and small amounts of phosphorus, respectively. A mineral-efficient plant, Clark (1976) noted, is a plant that grows better, produces more dry matter, and develops fewer deficiency symptoms than another plant when grown at low levels of a mineral element. However he added that this definition may not necessarily mean that the mineral-efficient plant produces the highest amount of dry matter per unit element at high levels of nutrients, also mineral-efficient plants may have a greater ability to make mineral elements more available, to take up nutrients, and have a lower requirement for elements.

Differential efficiency of plants in uptake and use of mineral elements may be better understood if mineral requirements for plants were better understood and defined (Clark, 1976). He gave the example of Loneragan and colleagues who proposed three categories of the calcium (Ca) requirements of plants: (1) solution Ca requirement - minimum level of Ca in the growth medium required by the plant to attain maximum growth, (2) functional Ca requirement - minimum Ca concentration in the functional sites of the plant that sustain maximum growth rates, (3) critical Ca concentrations, those Ca concentrations actually present in plant organs at the time Ca becomes limiting to growth. A similar redefinition of phosphorus requirements for plants has been proposed by many workers (Fox et al., 1974; Gardner, 1977; Nishimoto et al., 1977).

The external phosphate (P) requirement which is defined as the concentration of P required in the soil solution to produce 95% of the maximum yield when other nutrients are adequate, has been suggested by Fox et al. (1974) as a better way to determine the P requirements of crops.

The external P requirements for specific crops are similar on different soil types. For example, Nishimoto et al. (1977) reported that the external P requirement for lettuce on both Typic Eutrandepts and Tropeptic Eutrustox was 0.30 ppm P. Similarly, the external P requirement for maize on Haplustolls, Eutrustox, Gibbsihumox, and Hydrandepts was reported to be the same at about 0.06 ppm P (Fox et al., 1974). However the external P requirement for some species are not always the same. Gardner (1977) reported 0.80 ppm P for head lettuce, a value considerably greater than the value of 0.30 ppm P reported by Nishimoto et al. (1977). The external P requirement for maize was reported to be 0.06 ppm P by Fox et al. (1974), 0.13 ppm P by Jones and Benson (1975), and 0.01 ppm P by Fox and Kang (1978). These differences in reported external P requirements may result from differences in cultivars or differences in environments.

External phosphate requirements of maize cultivars were evaluated by Pulam (1978), and he observed that cultivars with high yield have high external P requirements. However, this relationship was not strong because there was a cultivar which had high yield with a low external P requirement, and on the other hand there was a cultivar which had low yield with a high external P requirment. He suggested that it might be possible to select a maize cultivar with high yield and a low external P requirement. The external P requirements of maize cultivars varied in the range of 0.04 to 0.06 ppm P. However, to ensure good maize yield he suggested that the level of P in the adjusted solution should be equal or greater than 0.05 ppm P.

b. Variation in adaptation and response to N fertilization

Genetic variation in nitrogen uptake and its relation to the production of grain in maize have been reported (Hay *et al.*, 1953; Jung *et al.*, 1972; Beauchamp *et al.*, 1976; Chevalier and Schrader, 1977; Pollmer *et al.*, 1979). This variation suggests that there is a potential for genetic improvement of nitrogen uptake and utilization by maize.

Differences in response to N are recognized not only in the quantity of maize grain yield, but also in the quality of grain. For example, in studying the influence of a supplemental nitrogen treatment Deckard *et al.* (1973) concluded that regardless of the time of application, supplemental nitrogen significantly increased the percent of grain protein for all genotypes and the amount of grain protein per hectare for all but one hybrid. However the supplemental nitrogen treatments did not cause significant increases in grain yield within a given genotype. Pollmer *et al.* (1979) reported that their experimental hybrids, with high protein percentage and protein yield of grain, generally silked later than conventional hybrids, but were at least comparable in percent ear dry matter at maturity and grain yield. This indicated, they added, a high rate of ear dry matter production and drying of the high-protein hybrids. They hypothesized that a high-protein percentage and protein yield of mature grain may be due to intensive nitrogen uptake, a prolongation of the nitrogen uptake phase, and/or a high rate of nitrogen translocation. The relative importance of these factors may vary in different genotypes and environments.

c. Variation in N and P content of maize tissue

Nutrient composition in plant tissue has been used to help explain crop responses to fertilization and it has been noted that plant composition is a more sensitive indicator of response than is yield (Melsted et al., 1969). In a study conducted by Bennett et al. (1953), chemical soil analysis for available soil phosphorus using the method of Bray No. 1 did not distinguish between five experimental sites, but phosphorus content of the maize leaves appeared to differentiate between the sites.

Much work has been done on the relationships among fertilization, plant composition, and crop yield. The objectives of such studies usually include the establishment of critical nutrient concentrations. The critical value of a nutrient represents the nutrient concentration in plants below which a growth stress may be expected to occur (Melsted et al., 1969), or above which no further yield increase is expected (Voss et al., 1970). Plant composition, however, can vary without having any measurable or visible influence on crop growth and yield (Melsted et al., 1969). The critical concentration of a nutrient varied with variations in the concentrations of other nutrients (Dumenil, 1961), as well as with variations in climate and population density (Dumenil and Hanway, 1965). Even different varieties within a given species may have different critical concentrations (Dumenil and Hanway, 1965; Baker et al., 1966).

Maize plants differ in their ability to absorb nutrients and this is an inherited characteristic (Jones and Eck, 1973). Similarly, Barber et al. (1967) concluded that accumulation of nutrient elements is under genetic control. They found that ranking inbreds in order of accumulation of an element differed for each element. Hence, they suggested that different genes are controlling the systems involved in the accumulation of different elements. Differential uptake and accumulation of phosphorus among maize genotypes have been shown by Baker et al. (1964 and 1967), Bruetsch and Ester (1976), and Nielsen and Barber (1978).

Genetic differences in uptake and accumulation of nutrients, according to Jones and Eck (1973), should not invalidate the technique of relating nutrient concentration to plant growth. They suggest that, "...Soil type[1] is usually considered when making soil test interpretations. Accordingly, genotype may become a factor in the interpretation of plant analysis."

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[1]Soil type in this context, and anywhere else hereafter, is assumed to to refer to the lowest category of soil classification systems that have been used before Soil Taxonomy (Soil Survey Staff, 1975).

Attempts have been made to relate variations in mineral content of maize to differences in soil characteristics. DeLong et al. (1953) found significant differences in plant composition to be correlated with differences in soil types which received very similar management treatments. They reported that four soil types with relatively small differences in exchangeable cations produced corn plants which differed significantly in concentrations of leaf potassium and magnesium. They concluded that amounts of these elements in leaves were modified by the presence of free carbonate in the soil, and by seasonal and/or site influences. They noted that these results indicate that soil characteristics are dominant over the presumably leveling effects of uniform fertilizer applications, and over the effects of uniform cultural management.

2.1.2 Environmental factors

Environment is the aggregate of all external conditions and influences which affect crop life and development. Among the environmental factors that influence plant growth, the following are probably most important: soil, climate, and biotic factors.

a. Soil

Each crop has different soil requirements with respect to properties of the soil, such as temperature, moisture content, aeration, fertility level, and other specific properties (FAO, 1978). It seems logical, therefore, that variation in these properties influences crop growth and development. Although plant distribution and adaptation are controlled by climatic conditions, such as temperature, light, moisture, and air movement, soil factors may control the intensity of a crop grown in a particular area (Good as cited by Wilsie and Shaw, 1954). He noted that climatic factors will determine whether corn shall be a potential occupant of a given area, whereas soil factors will largely determine whether corn actually will be grown in the area and in what abundance.

The importance of soil factors in determining the adaptation of maize as postulated by Good has now been supported by additional research findings which show that soil temperature, soil moisture, soil aeration, and mineral nutrient content have significant effects on maize adaptation.

Soil temperature. Since during the early stages of growth the apical meristem of a crop such as maize is below or close to the soil surface, the temperature of the soil is more important than the air temperature. Small soil temperature changes can induce large changes in the early stages of growth of maize seedlings and rate of development at this early stage can be very crucial in latter stages of the crop.

It has been reported that soil temperature influences germination and emergence of maize (Blacklow, 1972a and 1972b; Cooper and Law, 1977; Milbourn and Carr, 1977), which in turn will affect subsequent growth and development of leaves (Arnold, 1969; Beauchamp and Lathwell, 1966; Hesketh et al., 1969; and Cooper and Law, 1977), tassel initiation (Coligado and Brown, 1975a), grain growth (Duncan et al., 1965), and the date of silking and maturity (Millbourn and Carr, 1977). Soil temperature, and to a lesser degree soil moisture, were shown to be the major factors causing lower yield of late planted maize in the highlands of Kenya (Cooper and Law, 1977). They reported that soil temperature and soil moisture status during the first 5 weeks post emergence, up to the 12th leaf stage where the apical meristem was still below ground level in this study, accounted for 81.6% of the variation in final grain yield. The yield variation produced by soil temperature differences in early growth were largely due to differences in number of potential grain sites initiated, and grains per plant at harvest. Moreover they added that leaf primordia initiation rate and final leaf number were also affected by soil temperature, that is warmer soils resulted in a greater initiation rate and more leaves per plant.

Knoll et al. (1964b) reported that a root zone temperature of 15°C for 15 days adversely affected dry matter production of maize compared to a constant temperature of 20°C, while a root zone temperature of 25°C for 12 days stimulated dry matter production compared to that of 20°C.

Soil temperature was also shown to influence nutrient uptake by Nielsen et al. (1961) who observed an increased phosphorus uptake and top and root yield of maize with increasing soil temperature. Similar results were reported by Knoll et al. (1964a) who also found higher phosphorus content in the plant.

An interesting finding is the work done by Ragland et al. (1965). They predicted from the regression equation for the relationship of ear growth rate and 5-cm soil temperature that grain growth would cease when the 24-hour average soil temperature at 5-cm dropped to 53°F.

The effect of temperature may also be modified by soil type. Mack et al. (1966) observed significant interactions between soil type, temperature, and phosphate fertilizer on the dry weights of the snap bean plant grown on five different soil types. The increase in dry weight as well as the increase in P content in the plant from increased temperature was not the same on different soil types.

Soil temperature also exerts its influence on plant growth indirectly through its effects on the soil microbial population. An increase or decrease in soil temperature may alter the activity of soil microorganisms. Since microbial activity is accompanied by a release of carbon dioxide, changes in soil temperature will also affect the composition of soil air. Changes in soil air will, in turn, affect the pH of the soil, and eventually all of these changes affect plant growth (Tisdale and Nelson, 1975).

Soil moisture. The growth of many plants is proportional to the amount of water present, for growth is restricted both at low and very high levels of soil moisture. Soil moisture is one of the most important factors influencing the growth and development of maize. Soil moisture depletion to the wilting percentage for periods of one or two days during the tasseling or pollination period resulted inasmuch as a 22% yield reduction, and moisture depletion for periods of 6 to 8 days gave a yield reduction of about 50% (Robins and Domingo, 1953). Dale and Shaw (1965) found that the number of days in the period from 6 weeks before to 3 weeks after silking on which maize was under no moisture stress was highly associated with yield.

In an irrigation study, Jenne et al. (1958) observed differences in dry matter production and the accumulation of nutrient elements due to differences in soil moisture supply during the growing season. Under conditions of decreasing soil moisture supply, P, dry matter, N, Mg, K and Ca accumulation by a mature corn plant were 40, 44, 50, 65, 71, and 93%, respectively, of the values obtained for the mature corn plant grown with adequate moisture throughout the growing season.

Soil structure and composition of soil air. Soil structure to a great extent determines the bulk density of a soil. Bertrand and Kohnke (1957) observed a marked reduction in both top and root growth of corn plants as a result of soil compaction which increased bulk density.

The rate of oxygen diffusion into the soil is reduced at high bulk density which affects root respiration. Under field conditions, if bulk density is not too high, oxygen diffusion into the soil is determined largely by the moisture content of the soil. Danielson and Russell (1957) reported that at low moisture tensions of 1/3 to 1/2 atm uptake of Rb^+ by corn seedlings continued to increase with increasing supply of oxygen up to 8 or 10% oxygen by volume; at higher moisture tensions of 1 atm or more, ion uptake increased only up to about 5% oxygen, possibly because of the limiting effect of the high moisture tension, much less oxygen was required for the maximum ion uptake.

Soil aeration is recognized as an important factor affecting the growth of maize. Generally low concentrations of O_2 in the soil atmosphere inhibit or retard maize growth (Gingrich and Russell, 1956). Maize seed was observed to germinate over a wide range of oxygen pressures, but further radicle elongation was inhibited by very low or very high partial O_2 pressures (0.0 and 150.0 cm Hg); maximum radicle growth occurred at a partial oxygen pressure of 20.0 cm Hg. The partial oxygen pressure in air at sea level is almost 16 cm Hg with correspondingly lower pressures at higher elevation (Unger and Danielson, 1964).

Soil acidity. It is known that there are substantial differences among crops in their tolerance to soil acidity. Differences in tolerance of varieties and species of important food and pasture crops to acid soil conditions in an Oxisol from Colombia were studied by Spain et al. (1975). They reported that cowpeas (*Vigna sinensis*) appeared to be the most tolerant food legume; black beans (*Phaseolus vulgaris* L.) were intermediate, while the non-black beans (also *Phaseolus vulgaris* L.) were the poorest. Very large differences in acid tolerance between cultivars of cassava were observed and foliar nutrient content was strongly influenced by liming, even at the lowest rates. In the case of upland rice, several local varieties responded to the first lime increment, but lodged with the higher lime rates. Many of the new semi-dwarf rice varieties gave marked response to lime and produced practically nothing in its absence under upland conditions.

Foy et al. (1969) found that different varieties of crops such as soybean, barley and wheat have a wide range of tolerance to high concentrations of Al in the soil solution. Soileau et al.

(1969) reported that increasing amounts of Al in soil solution were not only toxic, but also decreased the uptake of calcium by cotton.

Rhue and Grogan (1976) described a technique for screening corn for aluminum tolerance. Using this technique they found marked differences in Al tolerance among corn inbreds. Wide differences in height and vegetative top growth among inbred lines of corn have been reported by Lutz *et al*. (1971). They concluded that at low soil pH there were far more differences. Single crosses between acid-tolerant and acid-sensitive inbreds showed expected heterosis at the high pH levels, but at low pH, tolerance appeared to be dominant.

The differential response of corn inbreds to aluminum suggests the existence of genotypes with a wide range of tolerance to aluminum. It needs to be determined whether the tolerance of corn inbreds forms a continuum within this range of tolerance or whether corn inbreds, like wheat varieties, fall into a finite number of distinct tolerance classes (Rhue and Grogan, 1976).

b. Climate

Climate has a considerable effect on plant growth. Of the many climatic factors, probably temperature, light or radiant energy, and the composition of the atmosphere are the most important.

Temperature. Each crop has an optimum temperature range for growth. Temperature directly affects plant functions including photosynthesis, respiration or transpiration. Many environmental factors are closely related so that changes in one, such as air temperature affects others, such as soil temperature.

Temperature affects the availability and uptake of nutrients and in cooler areas a higher soil test level or rate of applied nutrients must be used to achieve plant concentrations of elements comparable to those found in warmer areas. Smith (1971) observed this relationship with potassium in alfalfa in both field and growth chamber studies. Jones (as cited by Uehara, 1978) reported that more phosphorus was needed to obtain 95% of maximum yield of lettuce as the soil temperature decreased.

There is interaction between temperature and light intensity on photosynthesis rate. Ormrod (1961) reported that if light was limiting, temperature had little effect on photosynthesis rate, but if carbon dioxide was limiting and light intensity was not, photosynthesis was increased by an increase in temperature.

Temperature variations in the tropics affect the growth and yield of corn plants. It was reported that corn grown at high altitudes developed slowly due to low temperature and this resulted in higher grain yields (Eberhart et al., 1973; Bhargave and Utkhede, 1978). On the other hand, Wilson et al. (1973) found that an increase in altitude resulted in a decrease in yields due to a decrease in the capacity of the grain to accumulate dry matter from the photosynthetic system. They noted that the changes in the demand of the grain could have been connected with the number of grains formed per plant with the early variety (N x K), but not with the late variety (SR52). According to Goldsworthy and Colegrove (1974) and Goldsworthy et al. (1974), the higher yields at high elevation were associated with better development of the grain sink capacity--more ears per unit area and more grains per ear--which were the result of the longer period of growth before flowering.

Radiant energy. Sunlight or radiant energy is a significant factor in plant growth and development and crop species differ in their response to light. It was reported that excessively high plant population did not produce higher yields because various factors, including light, became limiting and there was competition among plants for those factors. However, some corn hybrids were more shade-tolerant than others (Stinson and Moss, 1960).

Waggoner *et al*. (1963) studied the effect of light intensity on photosynthesis in four plant species and found that corn was the most responsive to increasing light intensities, followed by sunflower and tobacco, with dogwood the least responsive. Early *et al*. (1966) noted that reducing light to 70% of normal sunlight decreased kernel number per plant by 22% for the prolific hybrid Illinois 972A, but the kernel number of nonprolific hybrid WF9 x C103 was decreased only 4% under the same condition. The failure in the development of the second ear caused greater reduction of kernel number per plant for the prolific hybrid. Similar results were obtained in other studies (Early *et al*., 1967), and it was concluded that the kernel and ear initiation were directly dependent on the rate at which metabolites flow from the leaves.

The effect of light quality on the growth of alfalfa was studied by Nittler and Gibbs (1959). They reported that the growth of two alfalfa varieties was different when grown under light from different spectrums. If the light color changed from gold to blue, green or red, the stems of California common alfalfa grew faster than those of Ranger alfalfa.

Besides the quality and intensity of light, the duration of light is also important. Plant behavior in relation to daylength is termed photoperiodism. Many plants have been classified as short-day, long-day, and intermediate or day-neutral plants. Corn is classified as a short-day plant, that is, a plant that will flower only when the photoperiod is as short or shorter than some critical period of time. Knowledge of photoperiodism can lead to the development of better adapted varieties for specific areas.

Under long-day conditions, corn plants have been reported to have a longer period of vegetative growth, delayed silking and tasseling, with taller plant and ear heights and greater leaf number (Chaudhry, 1968; Hunter et al. 1974; Coligado and Brown, 1975b; Lee, 1978; Jong, 1980). Moreover, Lee (1978) observed that several yield components of corn were affected by extended daylength. Sensitive genotypes showed drastic yield reduction under extended daylength with decreased cob length, filled ear length, kernels per row and 100 kernel weight. The insensitive genotypes did not show differences in filled ear length, but their kernels per row and 100 kernel weight were also decreased. Row number in both genotypes was relatively unaffected by photoperiod. However, a yield increase due to longer daylength was also observed. Spencer (1974) reported that grain/stover ratios were decreased in sensitive cultivars, but not in photoperiod insensitive cultivars because the increased daylength increased both grain and stover yields.

The effects of seasonal change in climatic factors on yield components of corn were studied by Jong (1980). He observed that the days to maturity of the corn plants were mainly determined by temperature and the growth of the corn plants was a function of the solar radiation available before silking. Kernels per row, kernels per ear, cob length, filled ear length and grain yield followed the cyclical change in solar radiation, while floret number and row number were quite stable in seasonal environments. Average daily solar radiation during the third month of growth of the plants was found to be the most important, and it explained 65% of the variation in kernel number, ear length and grain yield. Similar results were obtained by Lee (1978). Furthermore Jong (1980) concluded that the small change of solar radiation under low solar radiation levels has a greater effect on kernel number, ear length and grain yield than under high solar radiation levels. The temperate inbreds were capable of high performance under favorable environments, while the tropical inbreds appeared to perform better under unfavorable conditions.

Composition of the atmosphere. The photosynthetic rate of plants is known to differ greatly. This is partly due to differences in environmental conditions such as light, temperature or availability of CO_2. However, individual species also show remarkable differences in rate photosynthesis due to differences in the pathway of CO_2 fixation. It is known, for example, that corn as a C-4 plant has a higher photosynthetic rate than soybean or pineapple which are C-3 and CAM plants, respectively.

The quality of the atmosphere surrounding the above-ground parts of plants may influence plant growth. Harper et al. (1973) reported an increase in the net production of photosynthate of cotton by about 35% when a CO_2 concentration of 450 to 500 ppm was maintained at three-fourths plant height. Other plants also have been reported to respond to increasing carbon dioxide concentrations. Wittwer and Robb (1964) reported responses to carbon dioxide enrichment of vegetable crops grown in a greenhouse. They found that there were differences in yield response among lettuce varieties. Differences in net photosynthesis among species in relation to CO_2 concentration were observed by Kesketh (1963). With increasing CO_2 concentration from 0 to 300 ppm, the net photosynthesis was the highest in maize, followed by sunflower and red clover, while the net photosynthesis of maple was the lowest. The net photosynthesis of oak was between that of maple and clover, while net photosynthesis of three other species, orchardgrass, castor bean, and tobacco, was identical with that of red clover.

c. Biotic

Many biotic factors can affect the adaptation of a crop. There are organisms that have beneficial effects but there are also many organisms that can limit crop growth and reduce crop yields, or even cause crop failure. In addition, there is competition among individual plants for growth factors such as light or plant nutrients.

Numerous organisms have been reported to have beneficial effects on crop growth. One of the most notable example is the association of symbiotic or non-symbiotic nitrogen fixing bacteria with plants. Different bacteria have been found to associate with different plant species (Dobereiner, 1961 and 1968), and variation between cultivars may exist. Recently symbiotic nitrogen fixation was found on maize (von Bulow and Dobereiner, 1975). Another important group of microorganisms is the fungi which infect roots of plants to form mycorrhizae and are implicated in the uptake of phosphorus and other elements such as zinc, sulphur, or potassium (Tinker, 1975). The presence of these microorganisms in a particular area obviously will affect the growth and adaptation of a crop.

Biotic factors which present a constant hazard to crop growth and pose a potential threat of reduced crop yields are plant diseases, insects, or other pests such as nematodes and weeds. Hence, the selection of adapted crop species or cultivar for a specific area should also be directed toward the development of cultivars which are resistant or "adapted" to the prevailing pests. It is known that the prevalence of plant diseases is related to soil characteristics as well as other environmental factors and the susceptibility of the crop.

The relationships between soil characteristics, plant nutrition, and diseases have been reported by many investigators. Generally, high nitrogen fertilization tends to increase the susceptibility of plants to disease, whereas phosphorus and potassium have the opposite effect. Nevertheless, the reverse pattern has been observed for each element (Walker, 1946; Taylor, 1954; Hooker et al., 1963). The severity of attack by certain vascular pathogens has been explained by nutrient imbalance of the host plant. The deficiency of a particular element sometimes results in a relative increase of other elements in the conductive tissue, which may increase the growth of vascular parasitic organisms. Conflicting cases may be found due to differences in the nutritional requirements of the various pathogens (Shear and Wingard, 1944; Taylor, 1954). Differences in susceptibility between inbred lines of corn with respect to leaf-blight caused by Helminthosporium maydis are well established (Taylor, 1954).

Soil characteristics and/or environmental conditions have significant effects on the growth of pathogens. Soil moisture, for example, has been reported to be one of the most important factors influencing the growth of pathogens in soil and the development of plant diseases caused by soil-borne microorganism (Craig, 1980). An interesting observation reported by the Benchmark Soils Project is that although downy mildew (Sclerospora maydis (Rac.) Buttler) is present on the Hydric Dystrandept sites in the Philippines and Indonesia and susceptible varieties were being grown, only minor incidence of the disease has occurred in the Philippines and Indonesia. Therefore, it has been suggested that the isothermic temperature regime is not favorable for the development and growth of the pathogen (Benchmark Soils Project, 1978).

d. Management

The adaptation of a crop to a specific area, mentioned in the preceding paragraph, is determined by the genotype of the crop and its interaction with many environmental factors. It is appropriate, therefore, to mention that changes in one of these factors will affect the adaptability of the crop. Screening crop varieties, such as screening maize for tolerance to acid or alkaline conditions (Rhue and

Grogan, 1976; Mortvedt, 1976), or for efficiency in the use of nutrients (Clark, 1976), has been used to select varieties that are more adapted to certain soil conditions.

Management factors can also affect the adaptation of a crop by altering, to a certain extent, the growing condition for the crop. Planting distance will influence the selection of the best adapted variety of maize, for example, since it is known that some varieties are more shade-tolerant than others (Stinson and Moss, 1960). The management of soil reaction by applying lime or sulfur has become a common practice to control many plant diseases (Walker, 1946). In addition, application of fertilizer can decrease the susceptibility of the crop to plant diseases and insecticides can reduce the insect population. These management practices will allow a crop variety to growth in a certain area where it would otherwise be impossible to grow it due to diseases.

2.2 Soil Family as an Integrator of the Agroenvironment

Since soils and climate are interrelated, both can be combined in one system of classification, as has been done in Soil Taxonomy. Therefore, Soil Taxonomy has the best potential as a basis for soil interpretation for identifying agricultural land and consequently for the transfer of agrotechnology (Beinroth *et al*., 1980). The soil family, the fifth category in Soil Taxonomy (Soil Survey Staff, 1975), has been used as the basis for agrotechnology transfer by the Project. Although knowledge transfer can be made at any categoric level of the taxonomic system, with increasingly more precise statements possible at lower levels, the soil family level has been chosen since the use of lower levels would be unrealistic in the process of international agrotechnology transfers (Beinroth et al., 1980).

The close interrelationships between crop adaptation and many physical characteristics of the environment, such as climatic factors and soil properties, specifically soil temperature, soil moisture regime, soil acidity, soil aeration, soil nutrient content, and others, have been discussed in the preceding paragraph. Some of these properties, on the other hand, are diagnostic and are used as criteria in classifying soil, specifically at the soil family level of Soil Taxonomy (Soil Survey Staff, 1975). It is quite possible therefore that the stratification of soils at the soil family level coincides with the stratification of maize variety adaptation; in other words some maize varieties might be better adapted to a certain soil family, while other varieties may be better suited to other soil families. It is too early, however, to draw such conclusions and more studies remain to be done.

2.3 Statistical Tests of Crop Adaptation

The adaptability of a crop is the ability of the crop to survive and reproduce in diverse environments. Crop yield is an important criterion in evaluating adaptability. The measure of yield commonly used in making cultivar recommendations is the average yield calculated from field trials. Much work has been done and various statistical methods have been developed to test the adaptability of crops. An excellent review on this matter has been given by Freeman (1973).

The most commonly used measure of adaptability is the regression technique which was originally proposed by Yates and Cochran in 1938 (as cited by Freeman, 1973) and later was used by Finlay and Wilkinson (1963). This measure uses the average yield of the cultivars at each site as an index of the site's productivity. This method was also used by Rowe and Andrew (1964) and Eberhart and Russell (1966).

Another type of procedure involves analysis of variance techniques. Sprague and Federer (1951) showed how variance components could be used to separate out the effects of genotypes, environments and their interaction by equating the observed mean squares in the analysis of variance to their expectations on the random model. The magnitude of the contribution of each environment to the total cultivar by environment interaction component was identified by Horner and Frey (1957), while Plaisted and Peterson (1958) utilized variance components directly, and intermediate between these two approaches is the regression procedure of Perkins and Jinks (1968).

Stratification of environments and evaluation of genotypes within regions of similar ecological conditions have been used to reduce the genotype x environment interaction. Allard and Bradshaw (1964) classified environmental factors into predictable and unpredictable. The first category includes all permanent characters of the environments, such as general features of the climate and soil, as well as those characteristics of the environment which fluctuate in a systematic manner, such as daylength. It also includes those aspects of the environment that are determined by man and can therefore be fixed more or less at will, such as planting date, sowing density, methods of harvest and other agronomic practices. The second category includes fluctuations in weather, such as temperature and amount and distribution of rainfall, and other factors such as established density of the crop.

Eberhard and Russell (1966) recommended the development of indices based on environmental factors such as rainfall, temperature and soil fertility. The differential responses of genotypes to these indices could be used to gain a clearer understanding of the cause of the genotype x environment interaction. According to Sprague and Eberhart (1977), when indices are not available to characterize the environments, the genotypes must be evaluated in a sufficiently large number of environments to estimate an average response. But if the key factors causing the genotype x environment interactions can be determined and appropriate indices can be developed, the response of genotype to these indices can be determined.

More recently, Nor and Cady (1979) proposed a multivariate regression methodology for providing an alternative environmental index not dependent on the cultivar responses. The beta response model, which was developed from a multivariate regression approach, was used as a quantitative measure of wide adaptability. The objective of this approach was to characterize a crop's adaptability to a range of environments as a specific relationship between the crop's yield in different environments, including measurable climatic and soil factors affecting crop yield.

3. MATERIALS AND METHODS

3.1 Source of Data

Data on grain yield and nutrient composition of maize leaves used in this study were from maize variety experiments conducted by the Benchmark Soils Project[2] during the period 1976 to 1980. These experiments were performed on three soil families in three countries, Hawaii, Indonesia, and the Philippines. The three soil families were the thixotropic, isothermic Hydric Dystrandept; the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox; and the clayey, kaolinitic, isohyperthermic Typic Paleudult. A total of 19 experiments were conducted and used in this study (Table 1). The range of soil characteristics of the experimental sites are presented in Appendix A1.

Applied management practices in conducting the experiments, such as land preparation, planting, weeding, and insect and disease control, were kept as uniform as possible. Experience reveal that downy mildew (Sclerospora maydis Rac Butter) is prevalent in the Typic Paleudult network, hence, fungicide was applied in experiments conducted in this network. Detailed instructions for conducting the experiments were provided by the Benchmark Office in Hawaii. Planting dates were selected by the Project Leader at each country based on environmental conditions at each site.

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[2]Benchmark Soils Project, Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii.

Table 1. Location, duration, and fertilization treatments of 19 maize variety experiments on three soil families in Hawaii, Indonesia, and the Philippines

Soil/ country/ site and block	Plant date	Harvest date	Season	Nitrogen Coded	Nitrogen Actual rate (kg N/ha)	Phosphate Coded	Phosphate Actual rate (kg/ P/ha)
Hydric Dystrandept							
HAWAII							
Iole-G-10	01/19/78	07/14/78	wet	-0.85	29	-0.85	6
				0	108	0	38
Iole-H-10	06/16/78	12/14/78	dry	-0.85	29	-0.85	18
				0	108	0	120
Iole-G-11	01/25/79	08/13/79	late-wet	-0.85	29	-0.85	6
				0	108	0	38
INDONESIA							
ITKA-0-10[a]	06/24/77	11/15/77	dry	-0.85	137	-0.85	0.02[b]
				0	746	0	0.05
ITKA-L-10	01/31/78	06/20/78	late-wet	-0.85	29	-0.85	9
				0.40	145	0.40	83
ITKA-N-20	12/12/78	05/09/79	wet	-0.85	29	-0.85	8
				0.85	186	0.40	101
ITKA-F-10	06/26/79	12/18/79	dry	-0.85	16	-0.85	16
				0.40	85	0.40	144
PHILIPPINES							
PUC-C-10[a]	06/03/76	09/20/76	dry	-0.85	79	-0.85	0
				0	525	0	288
PUC-L-10[a]	06/28/77	10/28/77	dry	-0.85	79	-0.85	0
				0	525	0	288
PUC-M-10	03/28/78	08/01/78	wet	-0.85	29	-0.85	18
				0	108	0	120
PUC-L-22	03/05/80	07/07/80	wet	-0.85	29	-0.85	18
				0	108	0	120

Table 1. (Continued) Location, duration, and fertilization treatments of 19 maize variety experiments on three soil families in Hawaii, Indonesia, and the Philippines

Soil/ country/ site and block	Plant date	Harvest date	Season	Nitrogen Coded	Nitrogen Actual rate (kg N/ha)	Phosphate Coded	Phosphate Actual rate (kg P/ha)
Tropeptic Eutrustox							
HAWAII							
Molokai-C-10	07/13/78	12/19/78	dry	-0.85	29	-0.85	11
				0	108	0	75
Molokai-D-10	02/01/79	08/01/79	late-wet	-0.85	27	-0.85	8
				0	95	0	56
Typic Paleudult							
INDONESIA							
Nakau-B-10	10/16/78	02/07/79	wet	-0.85	29	-0.85	11
				0.40	145	0.40	105
Nakau-E-10	02/28/79	06/12/79	early-dry	-0.85	29	-0.85	12
				0.85	145	0.85	109
Nakau-B-20	11/10/79	03/06/80	wet	-0.85	29	-0.85	8
				0	108	0	55
Nakau-E-20	05/29/80	09/16/80	dry	-0.85	29	-0.85	12
				0	145	0	109
PHILIPPINES							
Davao-G-10	06/21/79	10/03/79	late-wet	-0.85	29	-0.85	12
				0	108	0	82
Davao-B-13	12/05/79	03/19/80	dry	-0.85	29	-0.85	12
				0	108	0	82

[a]The treatment variables in this experiment were lime and P, instead of N and P.

[b]Concentration of P in soil solution (ppm).

3.2 Treatment Variables

3.2.1 Maize variety

Maize variety experiments were performed by the Project to identify the variety(ies) that are well adapted to a locality and responsive to N and P fertilizer application. A variety that is well adapted to the agroenvironment will be used in the transfer experiment of the Project to test the hypothesis of the transferability of agro-production technology. Selection of a well adapted variety is carried out to avoid complete loss of a transfer experiment from disease or insect attack for which the variety has no resistance or from poor growth due to other causes. Therefore, varieties tested in the variety experiments were those which were recommended by local research institutions.

For proper assessment of the yield potential of a variety at different locations, however, varieties grown in transfer experiments at other sites in the soil family network were also planted in the variety experiments in each country. This, hopefully, would allow identification of a single variety adapted to all sites within the network of a soil family, if it exists (Benchmark Soils Project, 1978). Due to plant quarantine restrictions, however, seed of varieties from Indonesia and the Philippines could not be introduced into Hawaii and thus evaluation of varieties from these countries under Hawaii conditions could not be done. The list of maize varieties tested in each soil family are presented in Table 2.

3.2.2 N and P differential

The other criterion used by the Project in selecting varieties for the transfer experiments is responsiveness to the

Table 2. Source and description of maize varieties tested in the variety experiments

No.	Name	Source and description[a]	No.	Name	Source and description[a]
1	H610	U. Hawaii, SX hybrid	20	Bastar Kuning	Indonesia, variety
2	H688	U. Hawaii, DX hybrid	21	Harapan	Indonesia, variety
3	H763	U. Hawaii, SX hybrid	22	Kodok	Indonesia, variety
4	H788	U. Hawaii, 3X hybrid	23	Metro	Indonesia, variety
5	Cargill 111	PAG Cargill	24	Wonosobo	Indonesia, variety
6	Phoenix 1110	Puerto Rico	25	DMR-5	Philippines, variety
7	X204A	Pioneer, DX hybrid	26	DMR Comp. 1	Philippines, variety
8	X304B	Pioneer, DX hybrid	27	DMR Comp. 2	Philippines, variety
9	X3046	Pioneer, DX hybrid	28	NK-T66	Philippines, DX hybrid
10	X036B	Pioneer, DX hybrid	29	Tiniguib	Philippines, variety
11	X4816	Pioneer, hybrid	30	UPCA-1	Philippines, variety
12	X4817	Pioneer, hybrid			
13	X5800	Pioneer, hybrid			
14	X5859	Pioneer, hybrid			
15	X6819	Pioneer, hybrid			
16	X6877	Pioneer, hybrid			
17	H6	Indonesia, variety			
18	H159	Indonesia, variety			
19	Arjuna	Indonsia, variety			

[a]SX, DX, and 3X indicate single cross, double cross, and three-way cross hybrid, respectively.

variables being tested, i.e., nitrogen (N) and phosphorus (P). Hence, varieties were screened in the variety experiments which also have fertilizer differentials (Benchmark Soils Project, 1978). The N and P treatments in variety experiments are discussed in the subsequent chapter.

It should be mentioned that in the beginning of the Project the treatment variables were lime and P but lime was replaced with N in 1977 (Benchmark Soils Project, 1978).

3.3 Field Experimental Technique

A split-plot design, with fertilization treatments as the whole-plots and maize varieties as the sub-plots, was used in each experiment. All experiments were conducted in three replications, except the experiment at ITKA-N-20, Indonesia, in the wet season 1979 which was conducted in four replications. A different randomized layout was used for each experiment.

The fertilization treatments were factorial combinations of two levels of nitrogen and two levels of phosphorus, each at a low and an adequate level for each experimental site. The coded levels and the actual rates of N and P varied from site to site, and from season to season within the same site, as shown in Table 1. The coding and the rates of N and P followed the treatments used in the transfer experiments (Benchmark Soils Project, 1980).

With all other nutrients maintained at or near optimum by application of a basal fertilizer consisting of K, Mg, B, and Zn, it is expected that the NxP treatments will provide a measure of variety's requirement for and capacity to respond to applied nitrogen and phosphorus.

3.4 Methods of Data Analyses

3.4.1 Adaptation test

A regression technique developed by Finlay and Wilkinson (1963) was used to test the adaptation of maize varieties to a range of environmental conditions within one soil family. This approach has two major steps. First, for each variety a linear regression of the variety mean yield with a mean yield of all varieties (population mean yield) being considered in one data set is computed. The regression coefficient obtained indicate the adaptability of the variety. The second step in analyzing the behavior of the variety is achieved by plotting the regression coefficients (from the first step) of each variety against the variety mean yields over all environmental conditions of experiments being considered. The position of each variety in the plot indicates the class of adaptation and average yield performance of the variety (Figure 1).

Since the experiments were conducted in a split-plot design with four treatment combinations, as whole-plots, four new environmental conditions were created by the four fertilization treatments. Hence, each variety in one experiment is considered to have been tested under four environmental conditions. This increased the number of "population or site means" available for calculating regression from a small number of seasons or experiments.

The adaptation of each maize variety within each data set is evaluated using the first order linear regression model $\hat{y} = \beta_0 +$

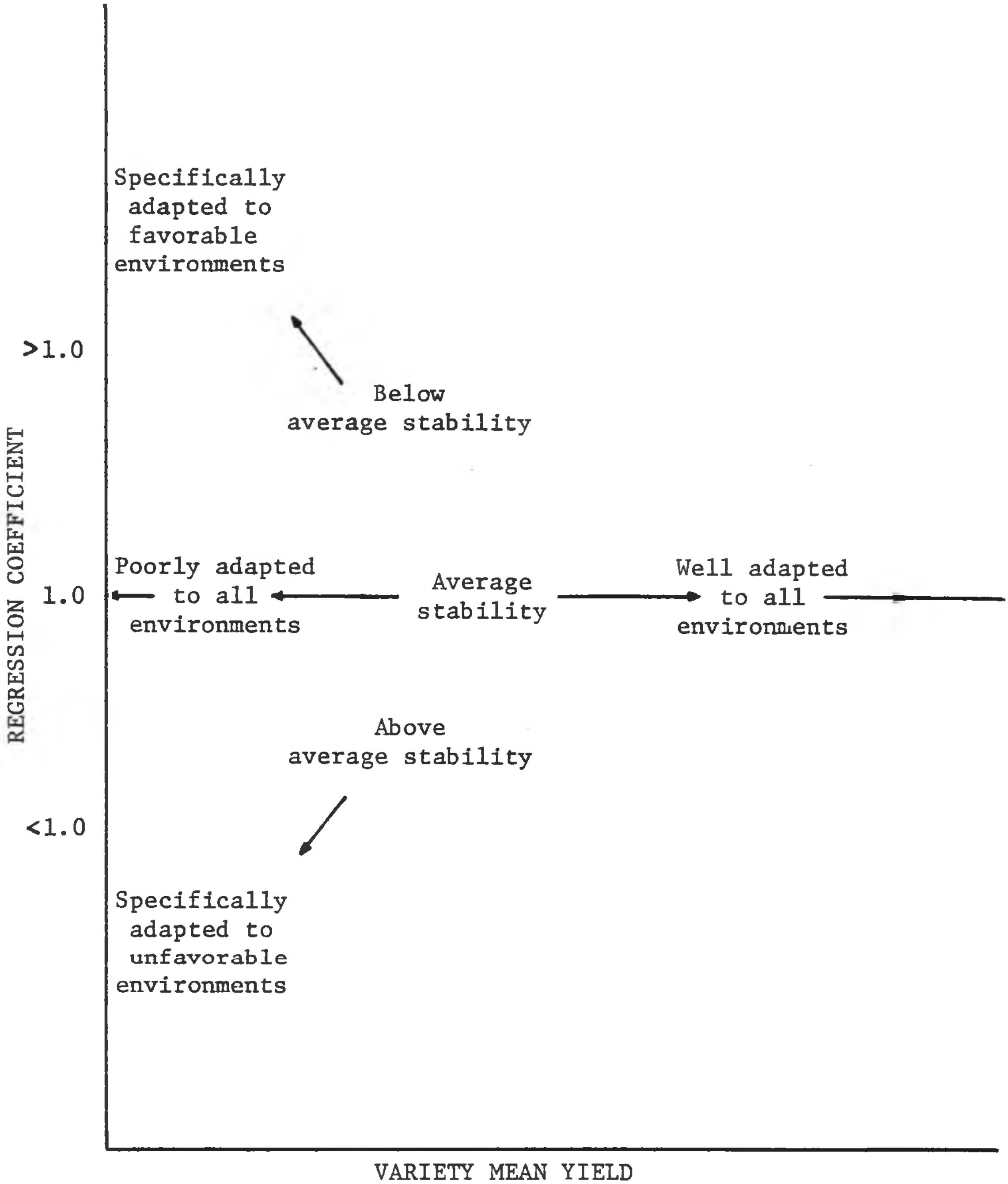


Figure 1. A generalized interpretation of variety adaptation as indicated by the variety regression coeffficients plotted against variety mean yields (After Finlay and Wilkinson, 1963).

β_1 x, where β_1 relates the individual variety mean yield (y) at each environmental (fertilization) condition to the mean yield of all varieties or the population being considered (x). Obviously this approach does not explain which factor, season or fertilization, had the greater influence on crop performance and what percentage of the variation in yields is accounted for by these factors. Hence, another regression model is employed to relate the yield of each variety to fertilization treatments and seasons. The same sets of data used in the evaluation of maize adaptation are used in the evaluation of effects of fertilizer and season.

The regression model for evaluating the effects of fertilizer and season is

$$\hat{Y} = \beta_0 + \beta_1 N + \beta_2 P + \beta_3 NP + \beta_4 S + \beta_5 NS + \beta_6 PS + \beta_7 NPS$$

where N and P are the coded values of the nitrogen and phosphate fertilization levels, and S is the coded value for season with +1 for wet season and -1 for dry season.

The stepwise procedure was used to perform the regression analysis, and two regression equations are presented for each variety. The first regression equation shows the most important variable that affects the yield of the variety and the amount of variation in the mean yield that it explains. The second regression equation includes all other variables that met the 10% significance level for inclusion in the model.

3.4.2 <u>Evaluation of responses to fertilization</u>

The objectives of maize variety experiments are the selection of a variety that is well adapted to a particular environment, and also selection of a variety that is responsive to the treatment variables being tested, nitrogen and phosphate fertilization.

A multiple comparison test of interaction (Harter, 1970) has been used to compare the responsiveness of varieties tested in the experiments. This approach, however, can not satisfactorily explain the differences in fertilization responses among varieties. Therefore, another approach, a test of contrasts (Duncan, 1975), has been used as a complementary test.

a. Multiple comparison test of interaction

The yield response of a maize variety to fertilization, e.g., nitrogen, is the difference between its mean yields under adequate and under low levels of nitrogen. This yield response is similar to an interaction element as defined by Harter (1970).

Given a split-plot design to test the effects of two factors, N and P, each at two levels--low and adequate--on several maize varieties, the following interactions are of interest. Let n be the number of varieties tested, and r be the number of replications (j = 1,2,...,r). The mean yield of the i-th variety (i = 2,...,n) for the low level of N and low level of P will be denoted by $V_{i.}N_1P_1$. These cell means can be tabulated as shown in Figure 2.

Five types of yield response can be expressed from the experiment, these are:

(1) Nitrogen response under low P, those of the form $V_{1.}(N_a-N_1)P_1$ representing the difference between the mean yields of a variety with adequate and low N, both under low P.

PHOSPHATE	NITROGEN: Low			NITROGEN: Adequate		
Low	$V_{ii}N_lP_l$	$V_{ii}N_lP_l$	$V_{ni}N_lP_l$	$V_{ii}N_aP_l$	-	$V_{ni}N_aP_l$
	$V_{ij}N_lP_l$	$V_{ij}N_lP_l$	$V_{nj}N_lP_l$	-	-	-
	$V_{ir}N_lP_l$	$V_{ir}N_lP_l$	$V_{nr}N_lP_l$	$V_{ir}N_aP_l$	-	$V_{nr}N_aP_l$
Adequate	$V_{ii}N_lP_a$	-	$V_{ni}N_lP_a$	$V_{ii}N_aP_a$		$V_{ni}N_aP_a$
	-	-	-	-	-	-
	$V_{ir}N_lP_a$	-	$V_{nr}N_lP_a$	$V_{ir}N_aP_a$	-	$V_{nr}N_aP_a$

Figure 2. Diagram illustrating the individual cells of a maize variety experiment. A number, n, of maize varieties, V, are fertilized with four treatment combinations of nitrogen, N, and phosphate, P, each with low, l, and adequate, a, levels, and replicated r times.

(2) Nitrogen response under adequate P, those of the form $V_{i.}(N_a-N_1)P_a$ representing the difference between the mean yields of a variety with adequate and low N, both under adequate P.

(3) Phosphate response under low N, those of the form $V_{i.}(P_a-P_1)N_1$ representing the difference between the mean yields of a variety with adequate and low P, both under low N.

(4) Phosphate response under adequate N, those of the form $V_{i.}(P_a-P_1)N_a$ representing the difference between the mean yields of a variety with adequate and low P, both under adequate N.

(5) Nitrogen x phosphate response, those of the form $V_{i.}N_aP_a$-$V_{i.}N_1P_1$ representing the difference between the mean yields of a variety with adequate NP and with low NP.

To compare responsiveness of two maize varieties a comparison is made of their two yield responses. For example, the difference in responsiveness between variety #1 and variety #2 in their response to N under low P is $V_1(N_a-N_1)P_1$ - $V_2(N_a-N_1)P_1$, and this difference is tested for significance.

To illustrate the method of calculation, nitrogen responses under low P of maize varieties planted on the Hydric Dystrandept at Iole-G-10 (Hawaii) in the wet season 1978 will be used as an example. Eight maize varieties were tested in this experiment. Yield responses of each variety were calculated as differences between the mean yields under adequate and low levels of nitrogen. The eight yield responses are listed in Table 3. This table is part of Table 22. Maize varieties in this table have been arranged so that their yield responses are in decreasing order from top to bottom.

Table 3. Mean yields and yield responses of maize varieties to N fertilization under low P level on the Hydric Dystrandept at Iole-G-10, Hawaii, in the wet season 1978. Test of interactions.

Maize variety	Mean yield (kg/ha)		Yield response* (kg/ha)
	Low N Low P	Adq. N Low P	
X5800	4297	6382	2085 a
X4816	4420	6250	1830 a
X304B	4145	5682	1537 a
X304C	5035	6400	1365 a
X4817	4858	5768	1110 a
H788	4038	4950	912 a
X304A	5104	5469	365 a
H610	4718	4852	134 a

*Yield responses are not significantly different at k ratio = 50 ($P < 0.10$), according to the Waller-Duncan k-ratio t test.

Degrees of freedom for the NxP interaction and for the error term (error b) of this experiment are 7 and 56, respectively; and the mean square for error is 607,354 (Analysis of variance, Appendix B1). The test was done at an error-weight ratio of k = 50, which is equivalent to a significance level of 10%.

Entering the Waller-Duncan (1972) Table A1 to get small sample $t_c(k,F,q,f)$ with simple linear interpolation between q = 6 and 10 and between f = 40 and 60 one will get t(50,1.2,7,56) = 2.42 and t(50,1.4,7,56) = 2.33. Interpolating linearly with respect to $a = (1/F)^{1/2}$ to get t_c at F = 1.36 at which $(1/F)^{1/2} = 0.857$ then gives

$$t_c = 2.42 - (2.42-2.33)(0.913-0.857)/(0.913-0.845) = 2.346$$

Since each interaction is the difference of two yield responses or two interaction elements, each with three replications, the standard error of interactions therefore is given by $s_i = (4 \times s^2/3)^{1/2}$ (Harter, 1970; Duncan, 1975). Hence, the standard error in this experiment is $s_i = (4 \times 607{,}354/3)^{1/2} = 899.89$, and LSD = $t_c \times s_i = (2.346)(899.89) = 2111$.

It should be noted that when the calculation was done with an electronic computer, this LSD was found to be 2153. This small difference between the two LSD's was due to interpolation and rounding error. Using the LSD calculated with the computer, there was no significant difference in the yield responses among the eight varieties shown in Table 3.

It is obvious in this example that using the test of interaction approach the differences in yield response among the varieties could not be demonstrated even though they range from 134 to 2085 kg/ha and the yield of variety X5800 increased almost 50%. Another approach, test of contrasts, therefore has been used to test the differences.

b. Test of contrasts

Differential yield responses of maize varieties to fertilization using the test of contrasts were evaluated by comparing their actual mean yields in pairs. The Waller-Duncan k-ratio t test (Duncan, 1975) was used to compare the mean yields of the same variety under different fertilization levels as well as the mean yields of different varieties under the same fertilization level.

Calculation of the t-value in the test of contrasts is the same as in the multiple comparison test of interaction, the only difference is in the calculation of standard error of the means. In the test of interaction, comparisons are made involving four mean yields and the standard error is calculated $s_i = (4 \times s^2/3)^{1/2}$. In the test of contrasts only two mean yields are being compared, therefore the standard error is calculated $s_d = (2 \times s^2/3)^{1/2}$.

Nitrogen responses of maize varieties tested at Iole-G-10 (Hawaii) in the wet season in 1978 will be used again to illustrate this method. The standard error of the means for this experiment, $s_d = (2 \times s^2/3)^{1/2} = (2 \times 607{,}354/3)^{1/2} = 636.32$. Hence, the LSD = $t_c \times s_d = 2.346 \times 636.32 = 1493$. Due to interpolation and rounding error this LSD is not the same as that calculated using the computer which is 1652.

Using the LSD obtained with the computer, obviously mean yields and responses of the maize varieties differed significantly (Table 4). While the test of interaction was not able to show differences in yield response among the varieties, the test of contrasts showed that two varieties, X5800 and 4816, responded significantly to N fertilization.

In this example, LSD tests have been conducted among all mean yields so that comparison can be made of all mean yields, either within the same N level or between different N levels of the same or different varieties. A similar method was used in all tests of contrasts, the results of which are presented in Tables 23 to 37.

Table 4. Mean yields and yield responses of maize varieties to N fertilization under low P on the Hydric Dystrandept at Iole-G-10, Hawaii, in the wet season 1978. Test of contrasts and test of interactions.

Maize variety	Mean yield (kg/ha)*		Yield response** (kg/ha)
	Low N Low P	Adq. N Low P	
X5800	4297 d	6382 a	2085 a
X4816	4420 cd	6250 ab	1830 a
X304B	4145 d	5682 abcd	1537 a
X304C	5035 abcd	6400 c	1365 a
X4817	4858 abcd	5968 abc	1110 a
H788	4038 d	4950 abcd	912 a
X304A	5104 abcd	5469 abcd	365 a
H610	4718 bcd	4852 abcd	134 a

*Test of contrasts: Means followed by the same letter are not significantly different at the k ratio = 50 ($P < 0.10$), according to the Waller-Duncan k-ratio t test.

**Test of interactions: Yield responses having the same letter are not significantly different at the k ratio = 50 ($P < 0.10$), according to the Waller-Duncan k-ratio t test.

4. RESULTS AND DISCUSSION

4.1 Adaptation of Maize Varieties to Three Soil Families

The adaptation of a maize variety to a certain locality can be evaluated by planting the variety in the particular location for several seasons. Other maize varieties should be planted with it in order to compare its yield potential and to evaluate it more completely. The data used in this study are derived from epxeriments designed to test specific varieties for adaptability to a particular soil family and therefore did not include all varieties used throughout the soil family network. No concerted effort was made to plant all of the same varieties every season and some varieties were planted only once.

The evaluation of adaptation, therefore, was carried out only for varieties that were planted for at least two seasons. Two approaches were used to group the varieties. The first was to include as many varieties as possible; and the second was to include as many seasons as possible, which, consequently, reduced the number of common varieties compared. The test was not performed if the number of common varieties available was less than three because a small number of common varieties, especially if they differed greatly, will not give good population mean yields. A good population mean yield was required as a measure of productivity of the experimental site.

The adaptation of the varieties within each data set was evaluated using two different standards, the population mean yield and the mean yield of a selected variety. Thirteen sets of data were formed from the 19 variety experiments. Maize varieties included in each data set and the corresponding location and season are presented in Tables 5, 6, and 7.

4.1.1 Hydric Dystrandept network

HAWAII

The two data sets from variety experiments on the Hydric Dystrandept site at Iole, Hawaii (Table 5), were evaluated on two bases. One was the population mean yield and the other was the mean yield of a standard variety, H610.

Adaptation test based on the population mean yield

The results of the adaptation tests of maize varieties in data sets 1 and 2 are presented in Figures 3 and 4, respectively.

All maize varieties exhibit similar slopes (Fig. 3a) and have regression coefficients which are not significantly different from 1.0 (Fig. 3b). In Figure 4a, however, the slopes of the three varieties do not appear similar, but were not shown to be significantly different from 1.0. Therefore, varieties in both sets of data are considered to have average stability.

Except for variety X304B, the Pioneer varieties, X304C, X4816 and X4817, consistently produced above average yields. Therefore varieties X304C, X4816, and X4817 can be described as having general adaptability, that is, varieties that are well adapted to all environments. Variety X304B and the Hawaiian varieties, H610, H688 and H788, on the other hand, consistently produced yields that were below the population mean yields (Figs. 3a and 4a). Their mean yields were significantly lower than those of the three Pioneer varieties mentioned earlier. The mean yield of H788 was the lowest and was significantly

Table 5. List of maize varieties tested in variety experiments on the Hydric Dystrandept at the Iole site and on the Tropeptic Eutrustox at the Molokai site in Hawaii

Maize variety	Hydric Dystrandept			Tropeptic Eutrustox	
	Iole-G-10 Wet 1978	Iole-H-10 Dry 1978	Iole-G-11 Late-wet 1979	Molokai-C-10 Dry 1978	Molokai-D-10 Late-wet 1979
H610	#$_1$	#$_{1,2}$	#$_2$	#$_1$	#$_1$
H688		#$_2$	#$_2$	#$_1$	#$_1$
H763			#		#
H788	#$_1$	#$_1$		#	
Phoenix 1110				#	
Cargill 111				#	
X304A	#				
X304B	#$_1$	#$_1$		#	
X304C	#$_1$	#$_{1,2}$	#$_2$	#$_1$	#$_1$
X306B		#		#	
X4816	#$_1$	#$_1$			#
X4817	#$_1$	#$_1$			
X5800	#				#
X5859			#		#
X6819			#		
X6874			#		
X6877			#		#

#The variety was planted in the experiment.

[1,2]Subscript numbers within one soil family refer to the number of the data set and indicate the varieties which were evaluated in each analysis.

Table 6. List of maize varieties tested in variety experiments on the Hydric Dystrandept at the ITKA site and on the Typic Paleudult at the Nakau site in Indonesia

Maize variety	Hydric Dystrandept				Typic Paleudult			
	ITKA-O-10 Dry 1977	ITKA-L-10 Late-wet 1978	ITKA-N-20 Wet 1979	ITKA-F-20 Dry 1979	Nakau-B-10 Dry 1979	Nakau-E-10 Early-dry 1979	Nakau-B-20 Dry 1980	Nakau-E-20 Dry 1980
H6	#$_{1,2,3}$	#$_{1,2,3,4}$	#$_{2,5}$	#$_{3,4,5}$	#		#$_{1}$	#$_{1}$
Bastar Kuning	#$_{1,2}$	#$_{1,2}$	#$_{2}$					
Harapan	#$_{1,2,3}$	#$_{1,2,3,4}$	#$_{2,5}$	#$_{3,4,5}$				
Bima	#$_{1}$	#$_{1}$						
Wonosobo			#$_{5}$	#$_{5}$			#	
DMR Comp. 2	#		#	#				
UPCA-1		#$_{4}$		#$_{4}$			#	
H610	#$_{1,3}$	#$_{1,3,4}$		#$_{3,4}$		#		#
Kodok					#		#$_{1}$	#$_{1}$
Metro					#	#		
H159					#	#		
DMR5			#			#	#	
X304C								#
Tiniguib				#			#$_{1}$	#$_{1}$
Arjuna								#

#The variety was planted in the experiment.

1 to 5 Subscript numbers within one soil family refer to the number of the data set and indicate the varieties which were evaluated in each analysis.

Table 7. List of maize varieties tested in variety experiments on the Hydric Dystrandept at the PUC site and on the Typic Paleudult at the Davao site in the Philippines

Maize variety	Hydric Dystrandept				Typic Paleudult	
	PUC-C-10 Dry 1976	PUC-L-10 Dry 1977	PUC-M-10 Wet 1978	PUC-L-22 Wet 1980	Davao-G-10 Late wet 1979	Davao-B-13 Dry 1980
UPCA-1	#$_{1,2}$	#$_{1}$	#$_{2,3}$	#$_{3}$	#$_{1}$	#$_{1}$
DMR Comp. 1	#$_{1}$	#$_{1}$			#	
DMR Comp. 2	#					
H610	#$_{1,2}$	#$_{1}$	#$_{2,3}$	#$_{3}$		#
H788	#$_{2}$		#$_{2}$			
X306B		#				
Bastar Kuning		#				
H6			#$_{3}$	#$_{3}$		#
Bima			#			
Tiniguib					#$_{1}$	#$_{1}$
NK-T66				#	#	
X304C				#	#$_{1}$	#$_{1}$

[#]The variety was planted in the experiment.

[1,2,3]Subscript numbers within one soil family refer to the number of the data set and indicate the varieties which were evaluated in each analysis.

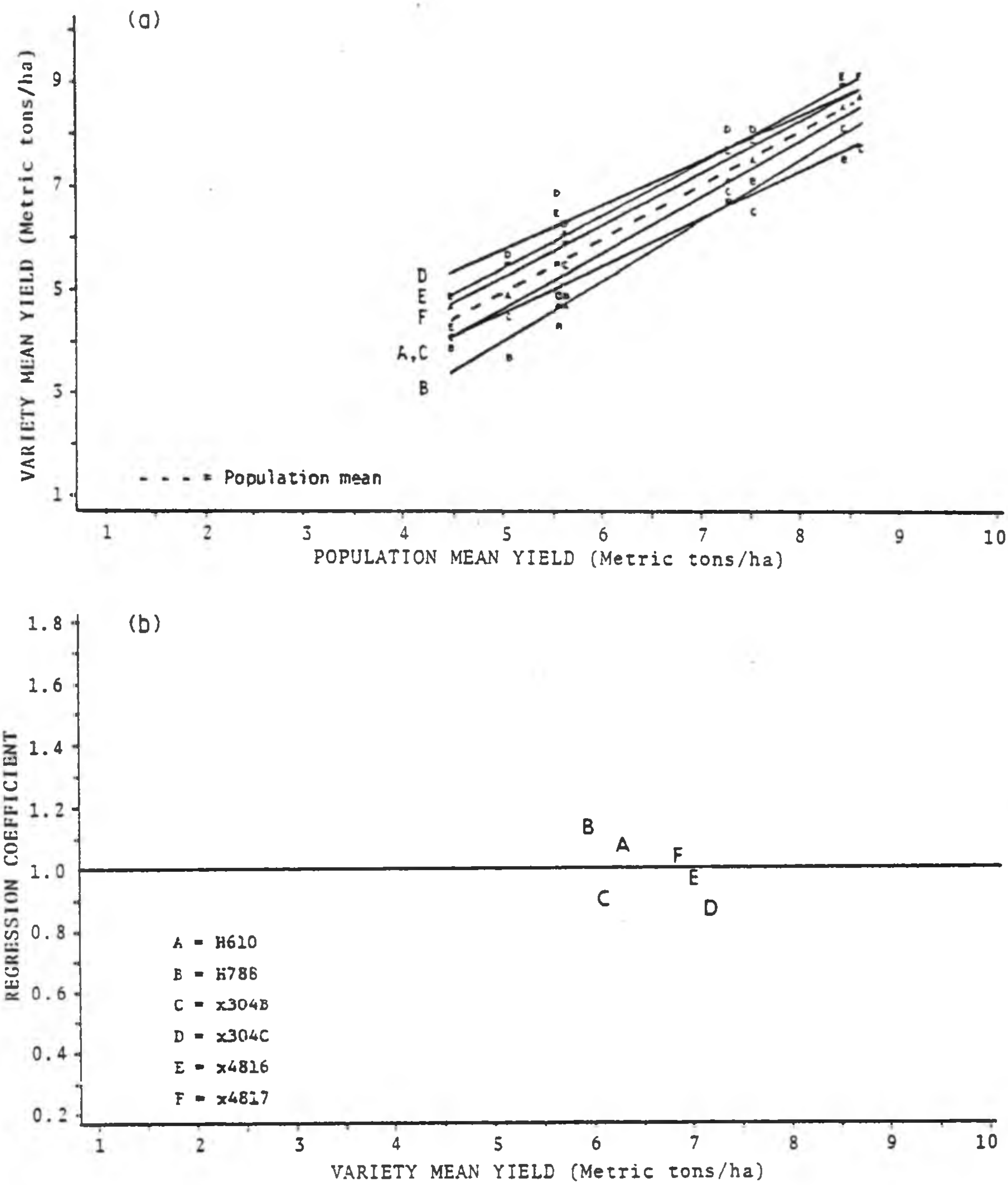
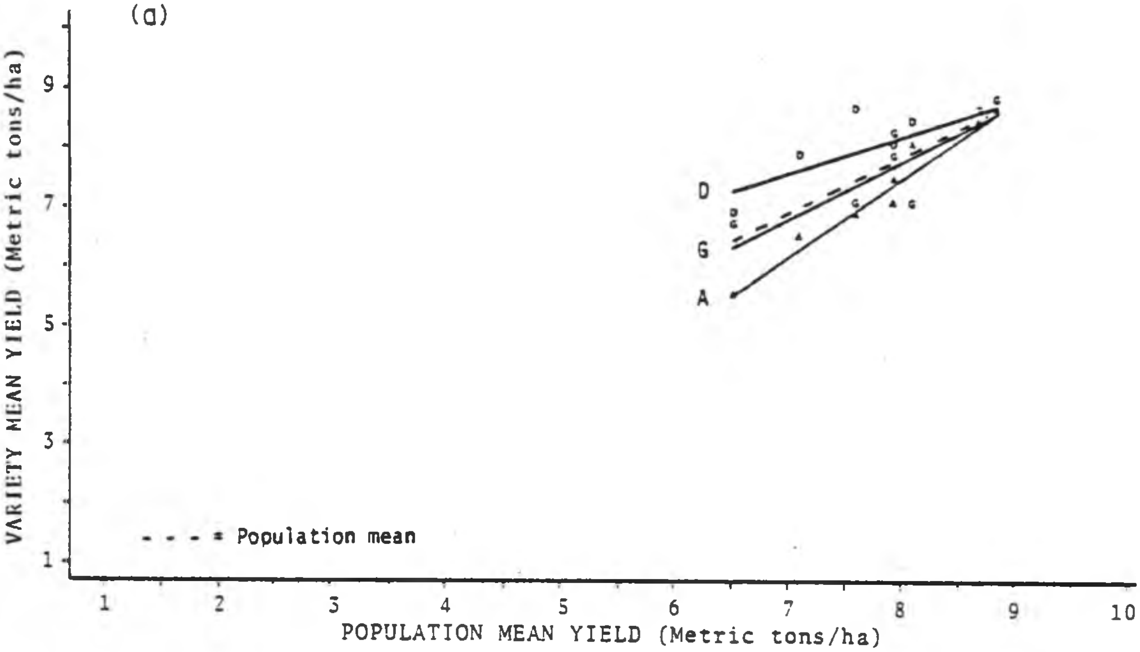


Figure 3a. The relationship between variety mean yields and the population mean yields.

3b. The relationship between the regression coefficient of each variety in Figure 3a and the respective variety mean yield.

Hydric Dystrandept, Iole, Hawaii. Data set 1 (wet 1978, dry 1978).



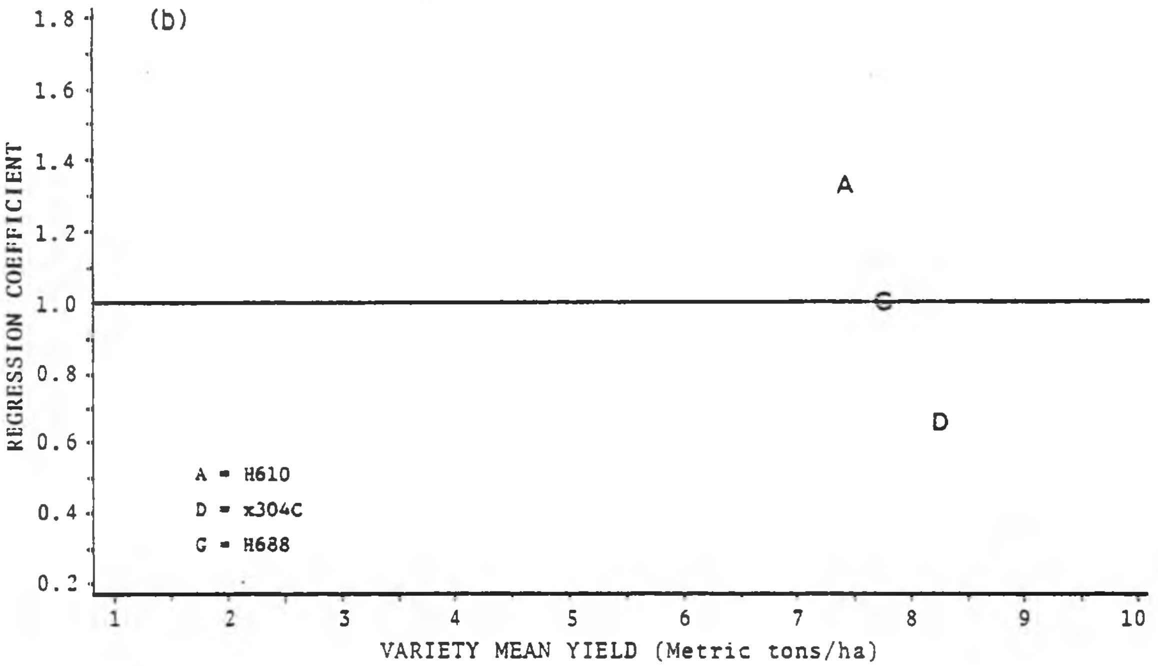


Figure 4a. The relationship between variety mean yields and the population mean yields.

4b. The relationship between the regression coefficient of each vareity in Figure 4a and the respective variety mean yield.

Hydric Dystrandept, Iole, Hawaii. Data set 2 (dry 1978, late-wet 1979).

lower than that of H610 (Appendix D1). Hence, H610, H688 and X304B can be described as having average adaptation, while H788 was poorly adapted to the environmental conditions of these experiments.

Adaptation test based on variety H610

When variety H610 was used as the standard, regression equations were calculated for the relationship between each variety and H610. The regression coefficient for each variety was then compared with the regression coefficient of H610 with itself which is 1.0 (Fig. 5 and Appendix D1).

It is apparent that the regression coefficients of all varieties, both in data sets 1 and 2, did not differ significantly from the regression coefficient of H610 indicating their stability was equal to that of H610. However, yields of variety H788 were significantly lower than yields of H610 (Appendix D1) indicating that H788 was less well adapted to the environmental conditions than H610. Yields of varieties X304B and H688 were equal to the yields of H610. This indicates that X304B and H688 were as well adapted as H610.

Varieties X304C, X4816, and X4817 had consistently higher yields than H610 suggesting that the three varieties were better adapted to the environment of these experiments than H610.

Effects of season and fertilization

Yield performances of maize varieties in various environmental conditions, consisting of combinations of seasons and NxP fertilization treatments, were evaluated in the preceding sections. The emphasis was on the evaluation of adaptation of the varieties to specific sites of a particular soil family. The response of the

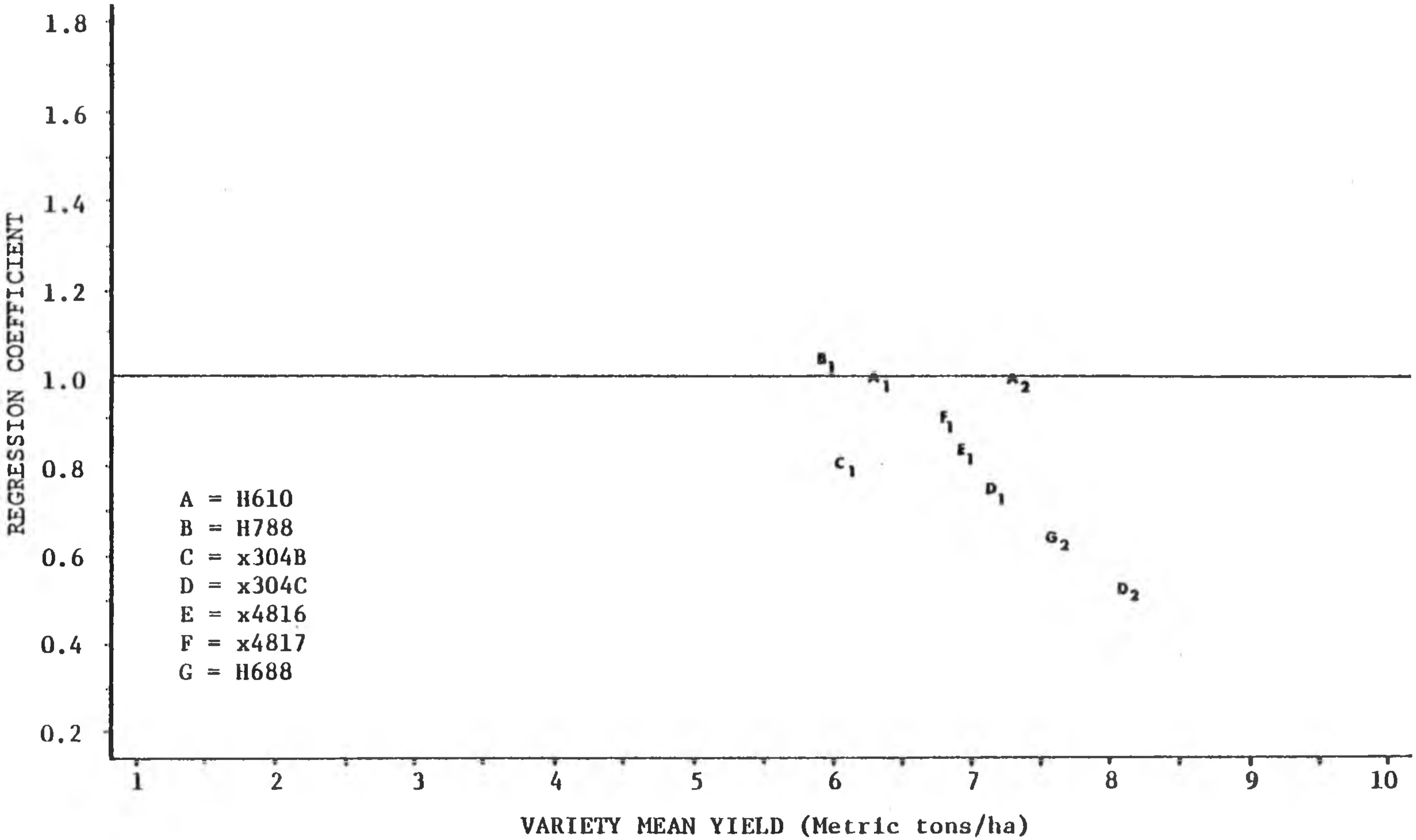


Figure 5. Relationships between regression coefficients (based on variety H610) and mean yields of individual varieties on the Hydric Dystrandept at Iole, Hawaii. Data sets 1 and 2 (indicated by subcripts).

varieties to season and fertilization are compared in the following section. A better understanding of the response of the varieties to environmental conditions is an important contribution in the evaluation of variety adaptation.

Two regression models were used to study the relationship between season and fertilization treatments as the independent variables and the yield of a maize variety as the dependent variable. The model I equation contains only the most important variable that was selected in the stepwise regression approach. The model II equation included all other variables that met the 10% significance level for inclusion in the model (cf. section 3.4.1).

Regression equations presented in Table 8 indicate that seasons were more important than the fertilization treatments in determining the variation in yields of all maize varieties tested in data set 1. About 60 to 80% of the variation in yields was accounted for by regression equation model I in which the single independent variable is season. The regression coefficients for season for Hawaiian varieties, H610 and H788, were slightly greater than those of Pioneer varieties, X304B, X304C, X4816, and X4817. This may indicate that the Hawaiian varieties were somewhat more sensitive to seasonal changes than the Pioneer varieties. However, the differences were not significant.

The second important variable that affected the yields of maize was nitrogen (N). With the regression equations of Model II the Pioneer varieties were more responsive to N than the Hawaiian varieties, with Pioneer variety X4816 being the most responsive and

Table 8. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the Iole site in Hawaii. Data set 1

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Six varieties, two seasons (wet 1978, dry 1978)				
H610	$\hat{y} = 6441 - 1572\ S$ (154)[a]	0.82	$\hat{y} = 6782 - 1912\ S + 801\ N - 802\ NS$ (171) (285) (285)	0.90
H788	$\hat{y} = 5959 - 1625\ S$ (199)	0.75	$\hat{y} = 6458 - 1625\ S + 1174\ N$ (172) (404)	0.82
X304B	$\hat{y} = 6126 - 1243\ S$ (204)	0.63	$\hat{y} = 6655 - 1243\ S + 1245\ N$ (175) (411)	0.74
X304C	$\hat{y} = 7234 - 1218\ S$ (209)	0.61	$\hat{y} = 7694 - 1218\ S + 1083\ N$ (189) (446)	0.69
X4816	$\hat{y} = 7093 - 1327\ S$ (190)	0.69	$\hat{y} = 7936 - 1176\ S + 1425\ N - 834\ NPS$ (146) (297) (404) $+ 558\ P$ (297)	0.88
X4817	$\hat{y} = 6886 - 1384\ S$ (193)	0.70	$\hat{y} = 7442 - 1384\ S + 1309\ N$ (156) (367)	0.81

[a]Figures in parentheses are the standard errors of regression coefficients.

Hawaiian variety H610 being the least responsive. No significant response to phosphate (P) application was observed, except with variety X4816. These results, however, should not be interpreted to mean that the varieties were not responsive to P fertilization since soil-P levels in the experimental sites were already high.

Data set 2, involving experiments during the dry season 1978 and the late wet season 1979 at Iole, Hawaii, exhibited different relationships between maize yields with seasons and fertilization (Table 9). Variety H688 was most affected by season which was followed by N fertilization just as shown by the Hawaiian varieties in data set 1.

In contrast, varieties H610 and X304C were affected only by N fertilization and not by season. However the regression equations explained very small amounts, 20 to 30%, of the variation in yields. No other variable considered significantly affected the yields of X304C, while H610 was affected by the PxS interaction and considerable improvement of R^2 occurred when this variable was included in the equation.

The inconsistent results obtained from data sets 1 and 2 emphasize the need for testing maize varieties for several seasons, to properly characterize their responses to seasonal changes. Therefore more information is needed to confirm the results in this study.

INDONESIA

Five data sets were grouped and evaluated from variety experiments on the Hydric Dystrandept at the ITKA site in Indonesia (Table 6). The adaptation tests within each data set were performed

Table 9. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the Iole site in Hawaii. Data set 2

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, two seasons (dry 1978, late-wet 1979)				
H610	$\hat{y}$ = 8141 + 1662 N (512)[a]	0.32	$\hat{y}$ = 8141 + 1662 N + 1123 PS (394) (278)	0.62
H688	$\hat{y}$ = 7746 - 796 S (126)	0.65	$\hat{y}$ = 8045 - 796 S + 702 N (111) (262)	0.74
X304C	$\hat{y}$ = 8726 + 1074 N (452)	0.20	-[b]	

[a]Figures in parentheses are the standard errors of regression coefficients.

[b]No other variable met the 10% significance level for inclusion in the model.

using two different standards. The first was based on the population mean yield and the second was based on the mean yield of variety H6.

Adaptation test based on the population mean yield

The results of adaptation tests for data sets 1 to 5 are presented in Figures 6 to 10. The corresponding regression coefficients and mean yields of each variety are given in Appendix D2.

Variety H6, an Indonesian variety, showed average stability in all data sets and is characterized by regression coefficients not significantly different from 1.0. This variety consistently produced above average yields. H6 therefore can be described as a well-adapted variety. Similar results were obtained with variety Harapan, also an Indonesian variety, except that it produced below-average yields in data set 2 and had a regression coefficient significantly greater than 1.0 in data set 4. However, its yields in data set 2 were not significantly different from the yields of the other varieties. Although its regression coefficient in data set 4 was nearly 1.0, it was found to be significantly different from 1.0 due to its small standard error of b_1. In general, therefore, variety Harapan can be described as being well adapted with average stability.

Other Indonesian varieties which were included in the test of adaptation were Bastar Kuning and Bima. Bastar Kuning yielded a regression coefficient significantly greater than 1.0 in data set 1, but not in data set 2. Since experiments included in data set 2 were the same experiments included data set 1 plus additional data from an experiment in the dry season 1979, more weight was put on data set 2 for evaluating the adaptation of Bastar Kuning. In data set 2,

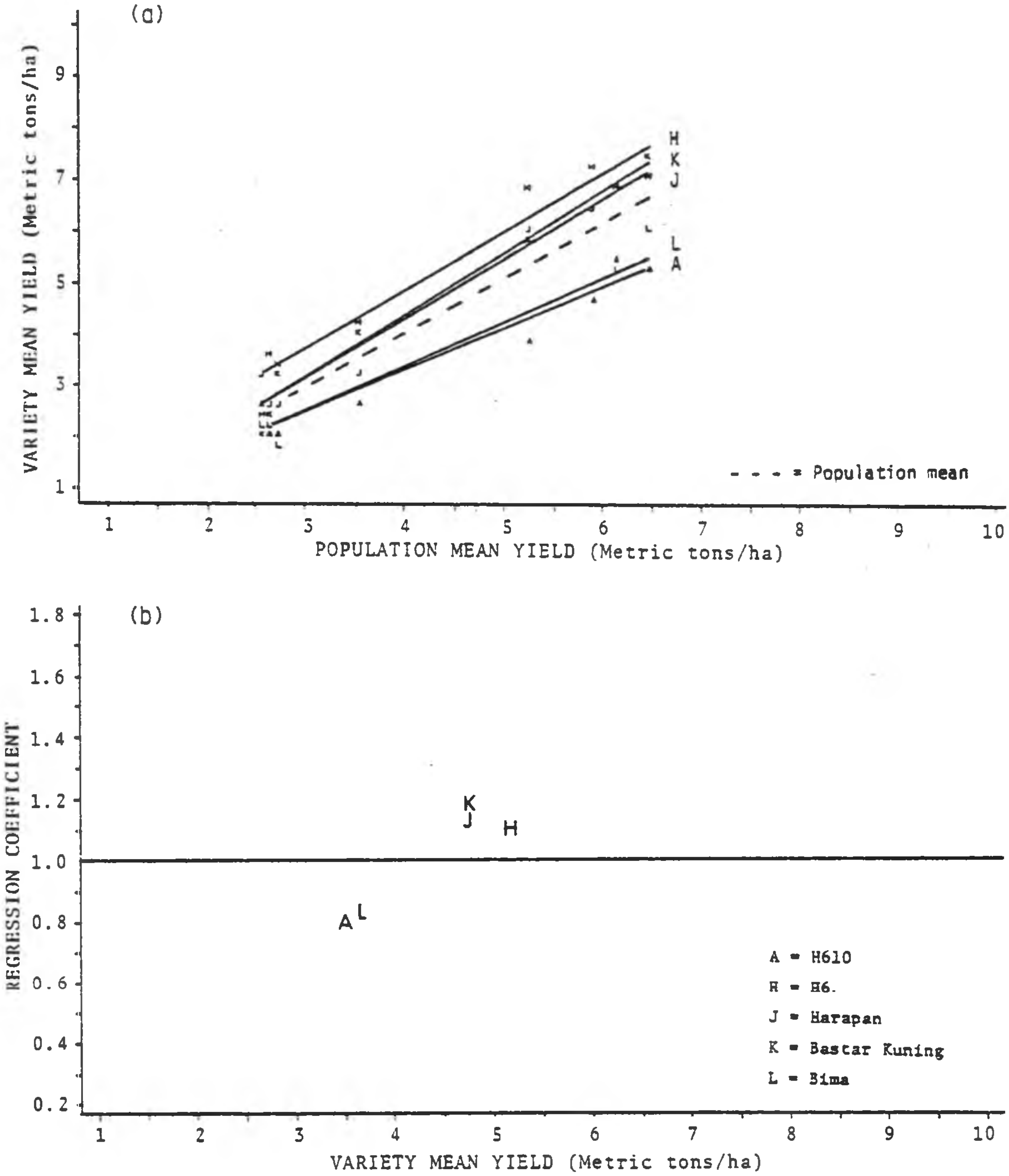


Figure 6a. The relationship between variety mean yields and the population mean yields.

6b. The relationship between the regression coefficient of each variety in Figure 6a and the respective variety mean yield.

Hydric Dystrandept, ITKA, Indonesia. Data set 1 (dry 1977, late-wet 1978).

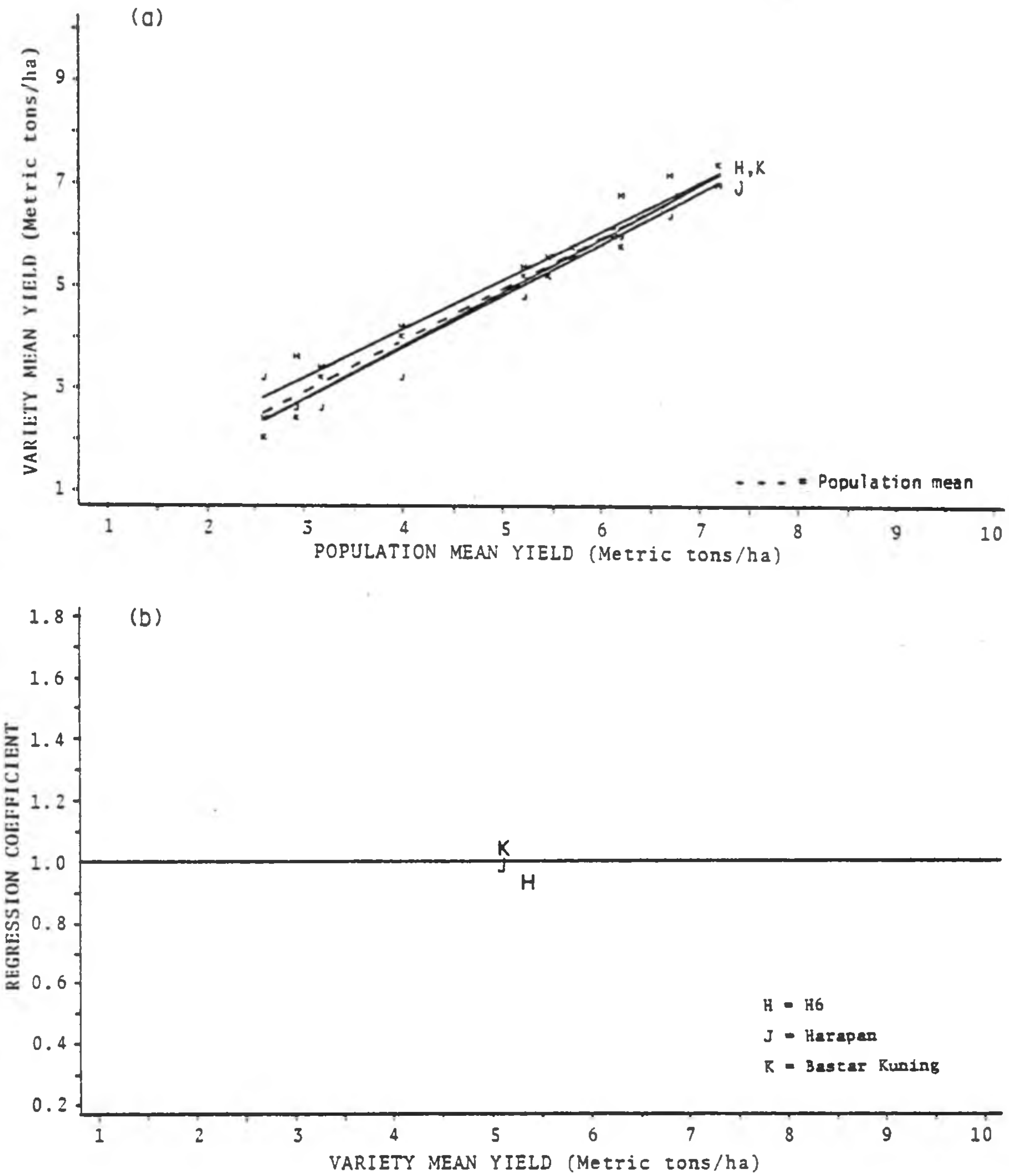


Figure 7a. The relationship between variety mean yields and the population mean yields.

7b. The relationship between the regression coefficient of each variety in Figure 7a and the respective variety mean yield.

Hydric Dystrandept, ITKA, Indonesia. Data set 2 (dry 1977, late-wet 1978, wet 1979).

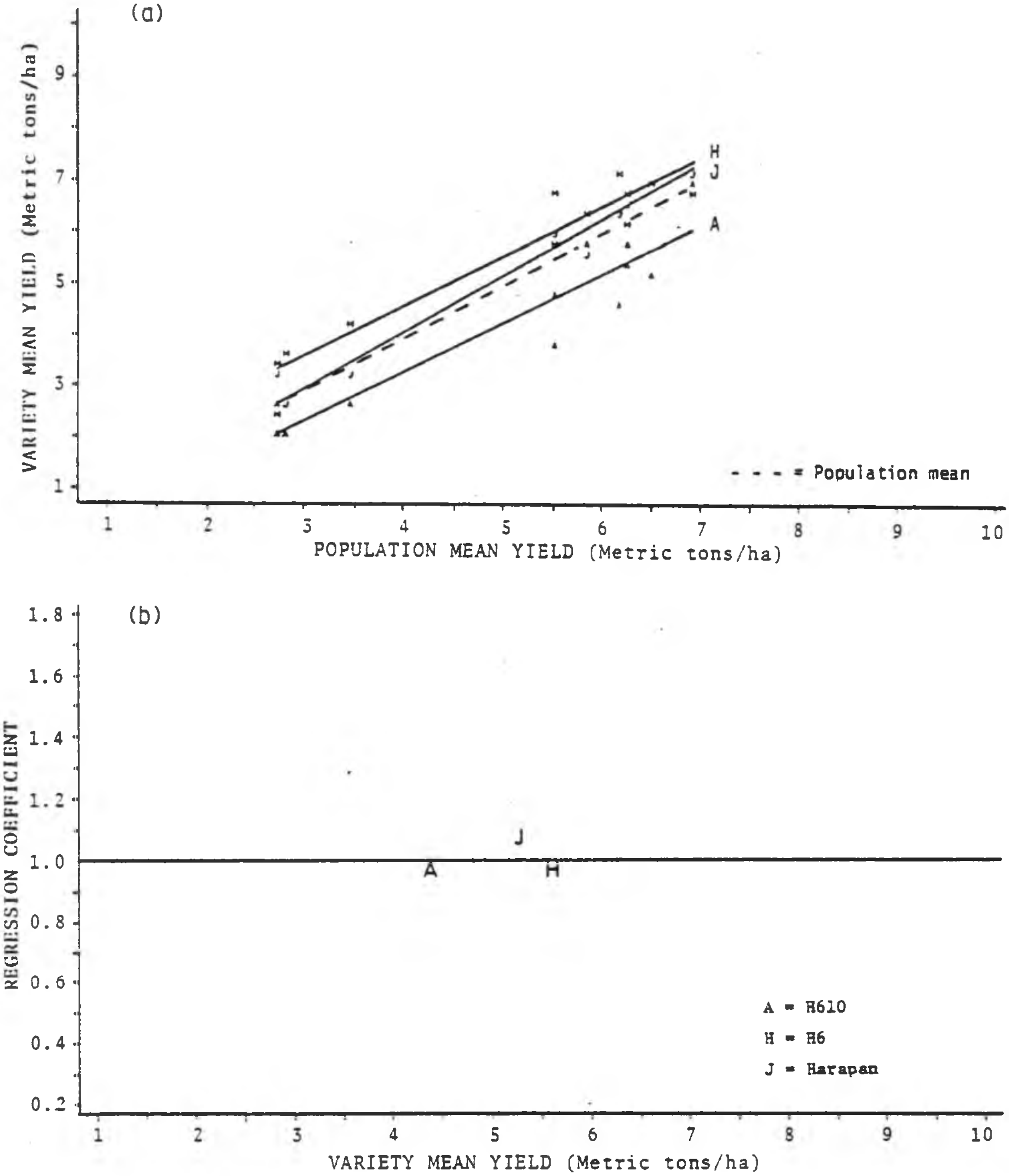


Figure 8a. The relationship between variety mean yields and the population mean yields.

8b. The relationship between the regression coefficient of each variety in Figure 8a and the respective variety mean yield.
Hydric Dystrandept, ITKA, Indonesia. Data set 3 (dry 1977, late-wet 1978, dry 1979).

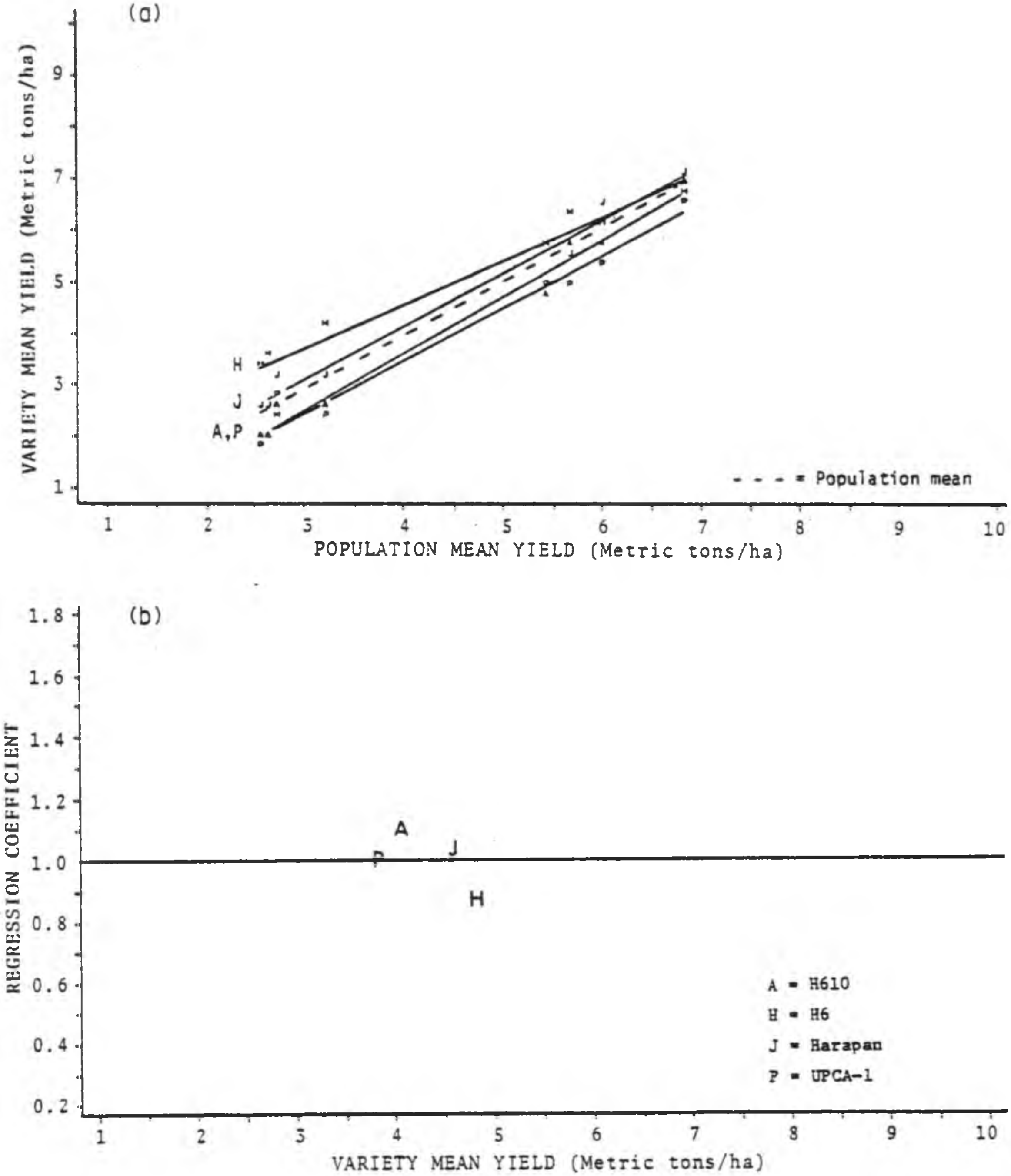


Figure 9a. The relationship between variety mean yields and the population mean yields.

9b. The relationship between the regression coefficient of each variety in Figure 9a and the respective variety mean yield.

Hydric Dystrandept, ITKA, Indonesia. Data set 4 (late-wet 1978, dry 1979).

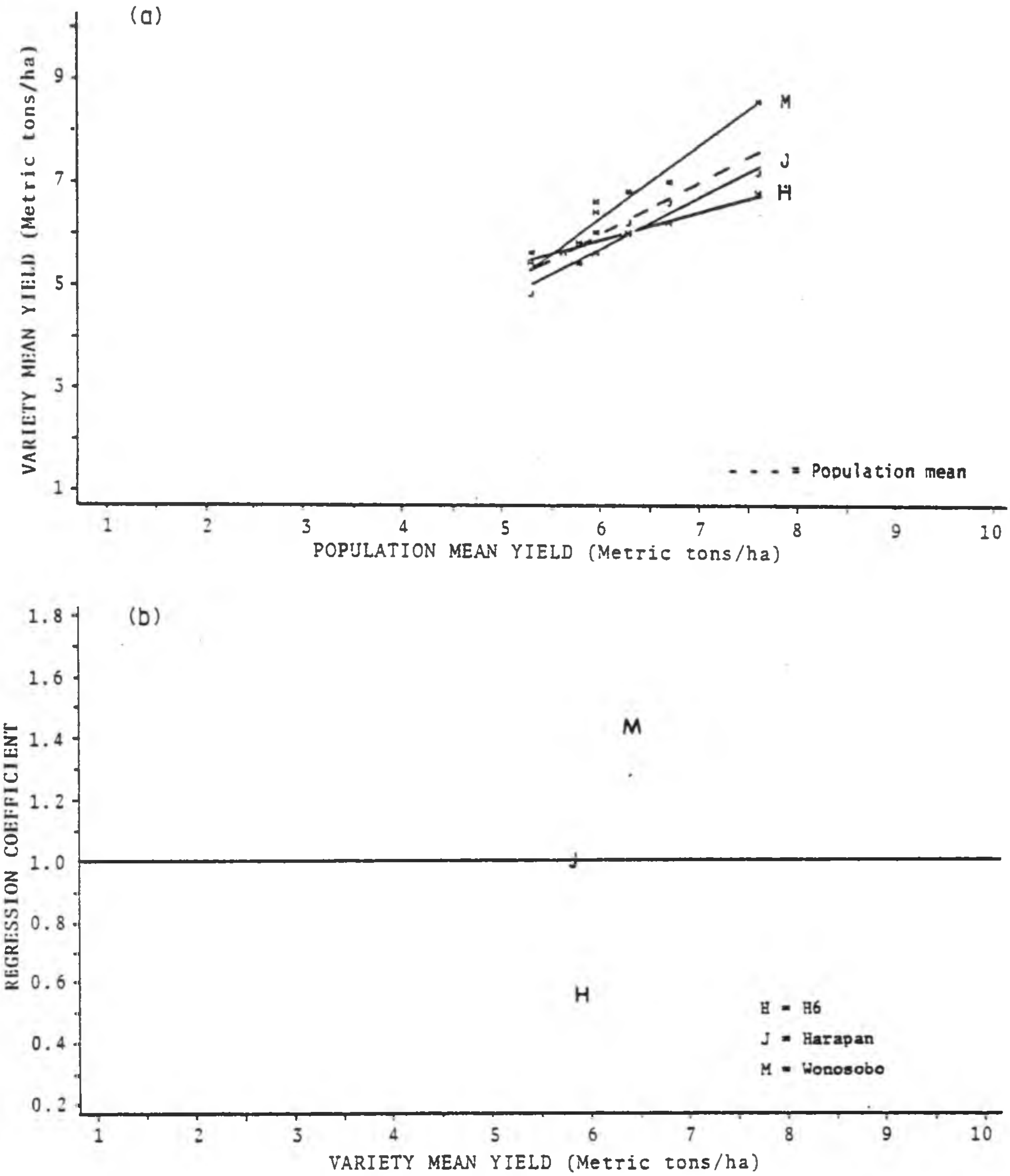


Figure 10a. The relationship between variety mean yields and the population mean yields.

10b. The relationship between the regression coefficient of each variety in Figure 10a and the respective variety mean yield.

Hydric Dystrandept, ITKA, Indonesia. Data set 5 (wet 1979, dry 1979).

although Bastar Kuning consistently produced below-average yields, they were not significantly lower than the yields of the other varieties. With average stability (b_1 = 1.0), therefore, Bastar Kuning can be described as having average adaptation.

Bima has a regression coefficient significantly less than 1.0 indicating that the variety was insensitive to changes in the environment or was specifically adapted to low-yielding environments.

The adaptation of H610, a Hawaiian variety, was evaluated in three data sets (1, 3, and 4). Its regression coefficient was not significantly different from 1.0 in either data sets 3 or 4, but it was significantly less than 1.0 in data set 1. Since data included in data sets 3 and 4 were the same data included in data set 1 plus additional data for the first two sets, the adaptation of H610 was evaluated on the basis of data sets 3 and 4. Therefore, H610 can be described as having average stability. Since its yields were consistently below the average yield and its mean yield was significantly lower than the mean yields of the other varieties, it can be considered that H610 was poorly adapted to the environments of the Hydric Dystrandept soil family at the ITKA site in Indonesia.

Variety UPCA-1, a Philippine variety, was also poorly adapted to the above environments which was characterized by a regression coefficient approximating 1.0 and yields consistently below the average for the population.

It should be mentioned that data set 5 was excluded from the evaluation of the adaptation of maize varieties because the results obtained from this set departed from the general trend. The regression equations, especially those for H6 and Harapan, accounted for small amounts of variation in yield. The cause of this deviation, however, was not clear.

Adaptation test based on variety H6

In the evaluation of the adaptation of maize varieties based on the population mean yield it was shown that variety H6, an Indonesian variety, was well adapted to environmental conditions within the network of the Hydric Dystrandept soil family in Indonesia. Considering the stability of this variety and the fact that it has been used in the transfer experiments, variety H6 was chosen as a standard for evaluating the adaptation of the other varieties.

The results presented in Figure 11 and Appendix D2 show that the regression coefficients of varieties Bastar Kuning and Harapan, both Indonesian varieties, were not significantly different from that of H6. This indicated that the stability of the two varieties was equal to that of H6. The yields of these varieties in most data sets were also not significantly different from the yields of H6. Bastar Kuning and Harapan, therefore, can be described as varieties that are as well adapted to the Hydric Dystrandept soil family as is variety H6.

Bima, also an Indonesian variety, produced significantly lower yields and was less sensitive to changes in the environment than the standard variety H6, as indicated by a regression coefficient significantly smaller than that of H6. Bima may be described as a variety that is specifically adapted to unfavorable environments. However it was included only in one data set and tentatively Bima was considered as a poorly adapted variety.

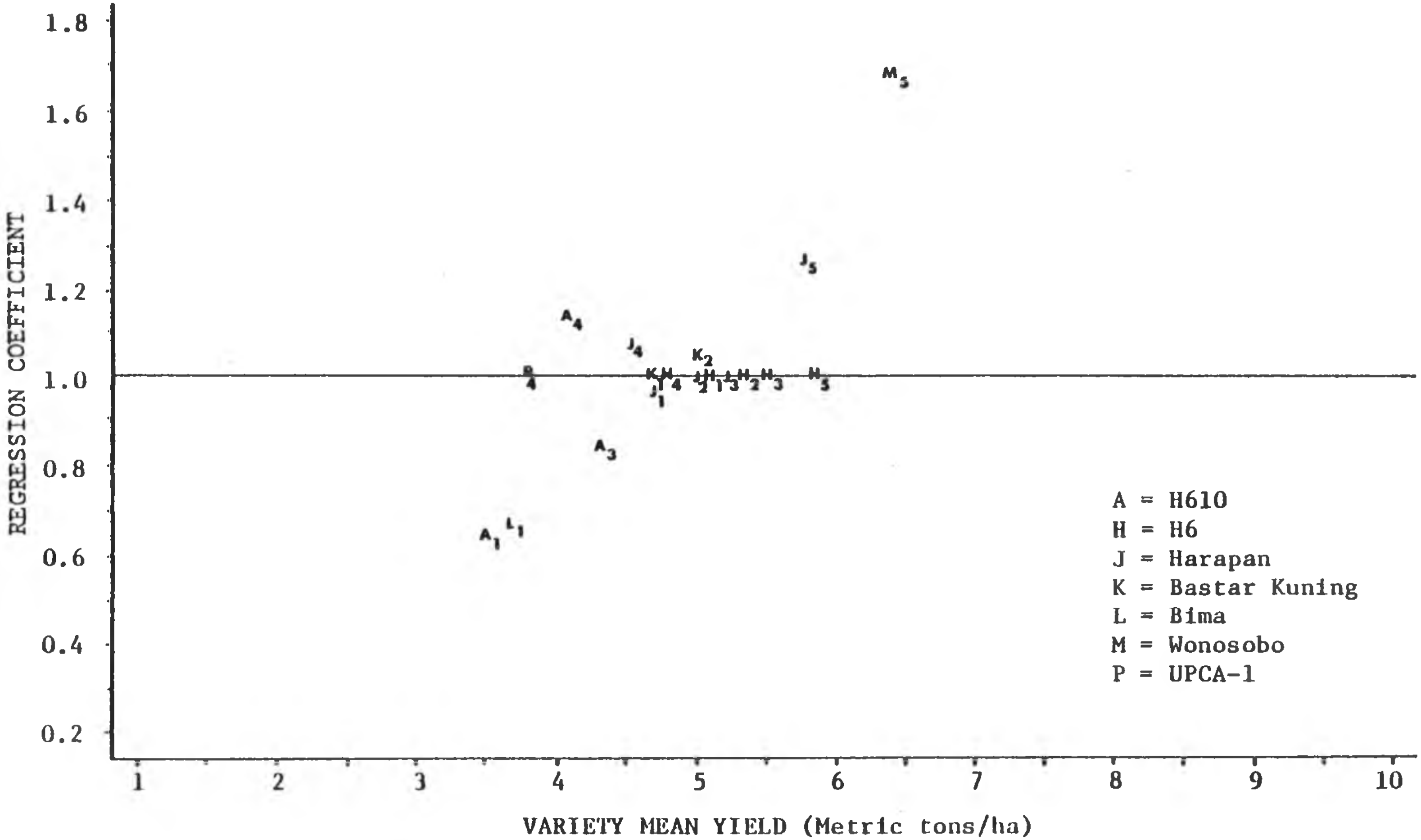


Figure 11. Relationships between regression coefficients (based on variety H6) and mean yields of individual varieties on the Hydric Dystrandept at ITKA, Indonesia. Data sets 1 to 5 (indicated by subcripts).

Varieties H610 and UPCA-1, have regression coefficients not significantly different from that of H6 (Fig. 11 and Appendix D2). These indicate that their stabilities were equal to variety H6. However, their yields were significantly lower than the yields of H6. Hence, H610 and UPCA-1 can be described as poorly adapted to the environmental conditions of the Hydric Dystrandept in Indonesia.

As in the test of adaptation based on the population mean yield, data set 5 was also excluded from the evaluation of the adaptation of maize varieties based on standard variety H6 due to the small coefficients of determination ($r^2 < 0.35$) in this data set.

Effects of season and fertilization

Because the experiment at ITKA-0-10 in the dry season 1977 had lime and P, while the other experiments had N and P as the fertilization variables, the full regression model (cf. section 3.4.1) which relates the yield of maize variety to season and fertilization was not valid for data sets that contained the experiment at ITKA-0-10. Therefore, for data sets 1, 2, and 3 only the effects of season were evaluated and the results are presented in Table 10. The effects of season and fertilization were evaluated in data sets 4 and 5 (Tables 11 and 12).

Season appeared to be the most important single variable that affected yields, as indicated by regression equations in Table 10 and model I regression equations in Tables 11 and 12. These regression equations, except those for data sets 2 and 5, explained 60 to 90% of the variation in yields. The low values of coefficients of determination (R^2) of regression equations in data sets 2 and 5, even

Table 10. Regression equations showing the effect of season on the yield of maize varieties grown on the Hydric Dystrandept at the ITKA site in Indonesia. Data sets 1, 2 and 3

Maize variety	Regression equation Model I	R^2
Data set 1 (dry 1977, late-wet 1978)		
H6	$\hat{y}$ = 5200 - 1767 S (179)[a]	0.82
Bastar Kuning	$\hat{y}$ = 4751 - 1816 S (191)	0.80
Harapan	$\hat{y}$ = 4731 - 1835 S (137)	0.89
Bima	$\hat{y}$ = 3642 - 1247 S (177)	0.69
H610	$\hat{y}$ = 3535 - 1247 S (179)	0.69
Data set 2 (dry 1977, late-wet 1978, wet 1979)		
H6	$\hat{y}$ = 5826 - 1141 S (211)	0.44
Bastar Kuning	$\hat{y}$ = 5511 - 1055 S (250)	0.32
Harapan	$\hat{y}$ = 5488 - 1077 S (238)	0.35
Data set 3 (dry 1977, late-wet 1978, dry 1979)		
H6	$\hat{y}$ = 5031 - 1598 S (164)	0.74
Harapan	$\hat{y}$ = 4667 - 1770 S (146)	0.80
H610	$\hat{y}$ = 3797 - 1509 S (188)	0.65

[a]Figures in parentheses are the standard errors of regression coefficients.

Table 11. Regression equations showing the effect of seasons and fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the ITKA site in Indonesia. Data set 4

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Four varieties, two seasons (late-wet 1978, dry 1979)				
H6	$\hat{y} = 4862 - 1429\ S$	0.70	$\hat{y} = 4982 - 1429\ S + 745\ N + 946\ NP$	0.79
	(201)[a]		(176) (297) (424)	
Harapan	$\hat{y} = 4603 - 1706\ S$	0.78	$\hat{y} = 4727 - 1706\ S + 551\ N$	0.81
	(192)		(181) (290)	
UPCA-1	$\hat{y} = 3863 - 1621\ S$	0.75	–[b]	
	(201)			
H610	$\hat{y} = 4059 - 1771\ S$	0.77	–	
	(208)			

[a] Figures in parentheses are the standard errors of regression coefficients.

[b] No other variable met the 10% significance level for inclusion in the model.

Table 12. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the ITKA site in Indonesia. Data set 5

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, two seasons (wet 1979, dry 1979)				
H6	$\hat{y}$ = 5958 − 333 S (151)[a]	0.16	–[b]	
Harapan	$\hat{y}$ = 5928 − 380 S (203)	0.12	$\hat{y}$ = 6034 − 486 S − 526 NS + 414 P (187) (238) (238)	0.34
Wonosobo	$\hat{y}$ = 6465 + 521 P (297)	0.11	$\hat{y}$ = 6725 + 593 P − 585 S − 914 NS (228) (183) (251) + 850 N (251)	0.54

[a] Figures in parentheses are the standard errors of regression coefficients.

[b] No other variable met the 10% significance level to be included in the model.

when fertilization variables were included in the model (Table 12, model II), indicated that there were other variables besides season and fertilization that affected yields. When data sets 1, 2, 3, and 5 were compared, it became clear that the experiment in the wet season 1979 (ITKA-N-10) had caused the poor relationships. However, the reasons were not clearly understood, and no serious insect or disease attack was reported.

Regression equations for model II in Table 11 show that N fertilization had significant effects on the yields of varieties H6 and Harapan, but not on the yields of varieties H610 and UPCA-1. In other words, varieties H6 and Harapan were more responsive to N fertilization than varieties H610 and UPCA-1. However in Table 12 variety H6 was not responsive to N while variety Harapan was responsive to N and the NP interaction.

PHILIPPINES

Three data sets were grouped and evaluated from variety experiments on the Hydric Dystrandept at PUC, the Philippines (Table 7). The adaptation of maize varieties was evaluated using two different standards, population mean yield and mean yield of variety UPCA-1.

Adaptation test based on the population mean yield

Figures 12 to 14 illustrate the adaptation of maize varieties tested in data sets 1 to 3, consecutively. The regression coefficient and mean yields of each variety are given in Appendix D3.

Data set 1 had poor relationships between the yields of individual varieties and the population mean yields. The resulting

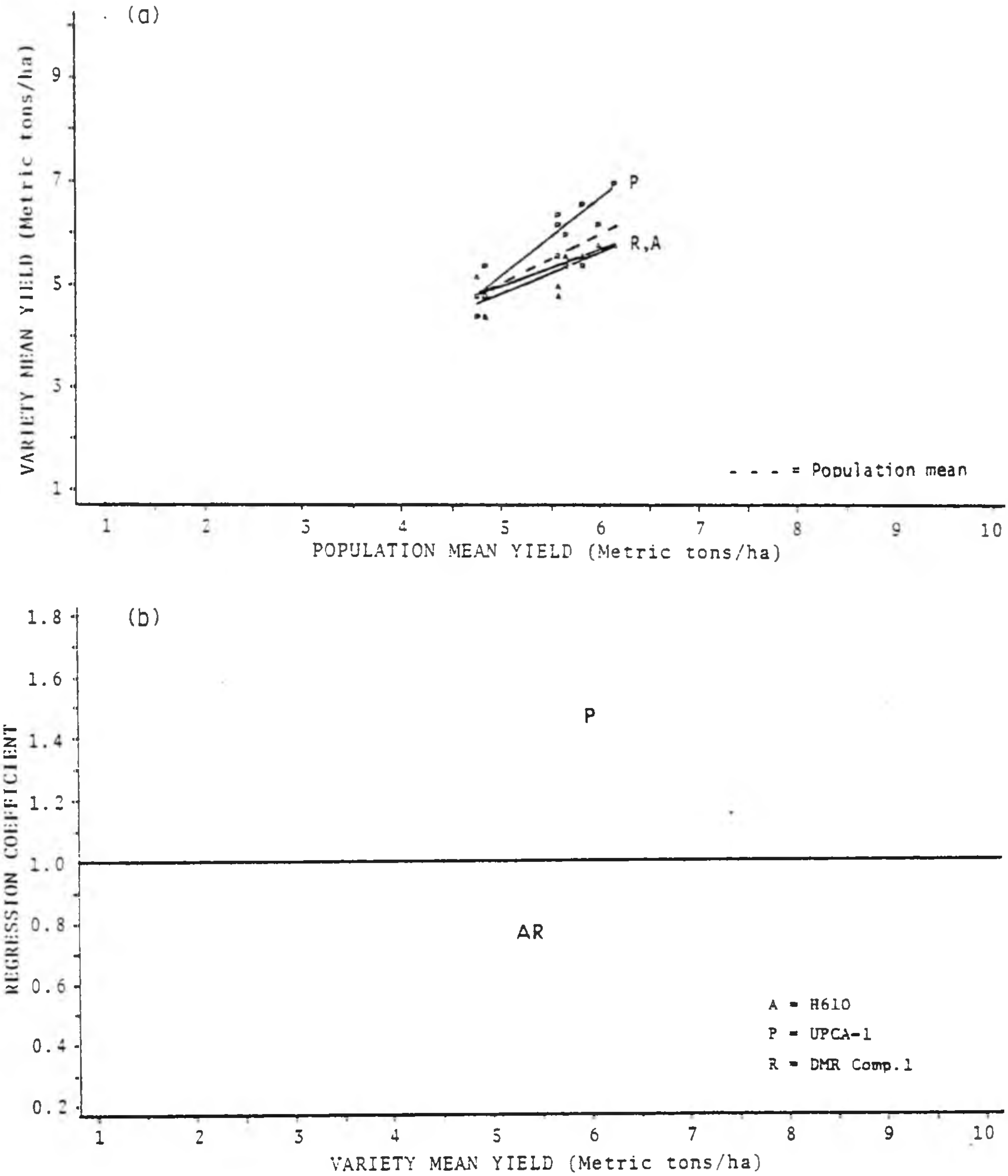


Figure 12a. The relationship between variety mean yields and the population mean yields.

12b. The relationship between the regression coefficient of each variety in Figure 12a and the respective variety mean yield.

Hydric Dystrandept, PUC, the Philippines. Data set 1 (dry 1976, dry 1977).

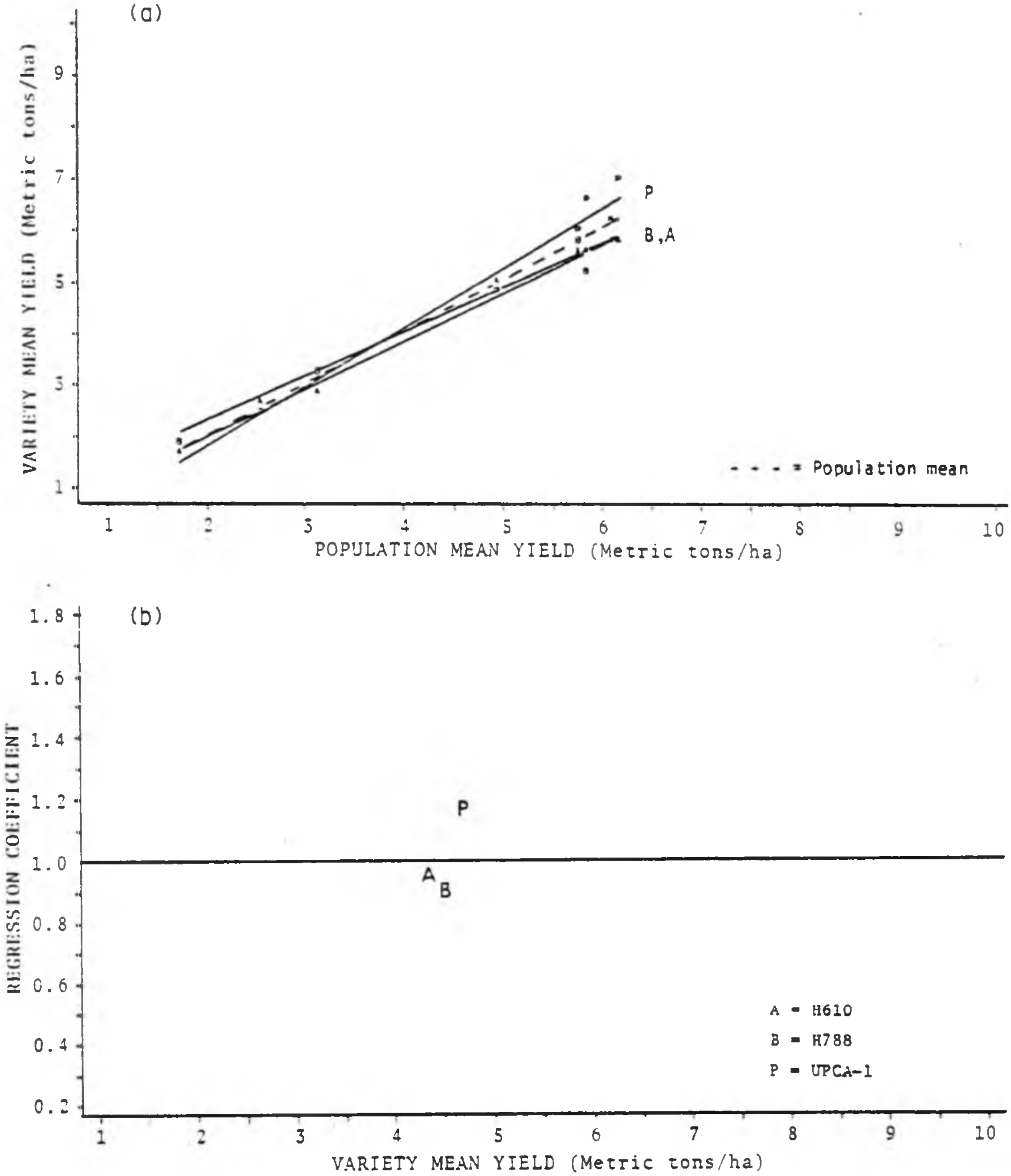


Figure 13a. The relationship between variety mean yields and the population mean yields.

13b. The relationship between the regression coefficient of each variety in Figure 13a and the respective variety mean yield.

Hydric Dystrandept, PUC, the Philippines. Data set 2 (dry 1976, wet 1979).

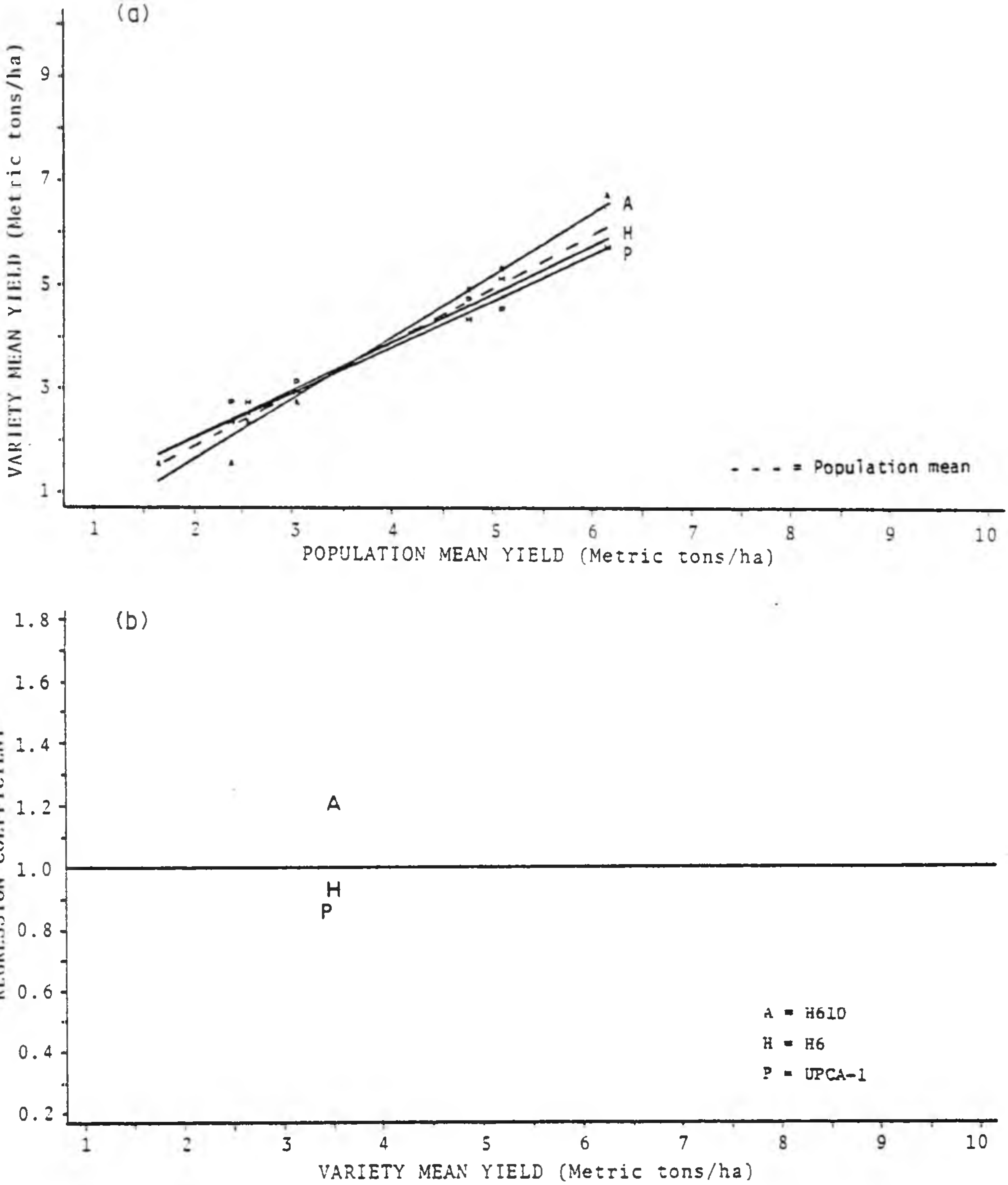


Figure 14a. The relationship between variety mean yields and the population mean yields.

14b. The relationship between the regression coefficient of each variety in Figure 14a and the respective variety mean yield.

Hydric Dystrandept, PUC, the Philippines. Data set 3 (wet 1978, wet 1980).

regression equation explained only a small proportion of the variation in yields, especially those for varieties DMR Comp. 1 and H610. The adaptation of the maize varieties, therefore, was characterized on the basis of data sets 2 and 3.

UPCA-1, a Philippine variety, showed below-average stability in data set 2, with a regression coefficient significantly greater than 1.0; but it had average stability in data set 3, with a regression coefficient not significantly different from 1.0. Opposite results were obtained with H610, a Hawaiian variety. Therefore, it is difficult to generalize concerning the stability of these two varieties. Nevertheless, UPCA-1 produced higher yields in the dry season 1976 indicating this variety tended to be better adapted to favorable environments. More information is needed to clarify these results.

H788 and H6, a Hawaiian and an Indonesian variety, respectively, showed average stability. The average yields of these two varieties were equal to the average yield of the population. Hence, H788 and H6 can be described as having average adaptability.

Adaptation test based on variety UPCA-1

Figure 15 illustrates the adaptation of maize varieties relative to the adaptation of variety UPCA-1. The regression coefficients for each relationship are given in Appendix D3. Data set 1 in this test of adaptation also yielded small r^2 values, therefore this data set was excluded from the test.

Varieties H610 and H6, a Hawaiian and an Indonesian variety, respectively, are characterized by regression coefficients which are not significantly different from that of UPCA-1 and

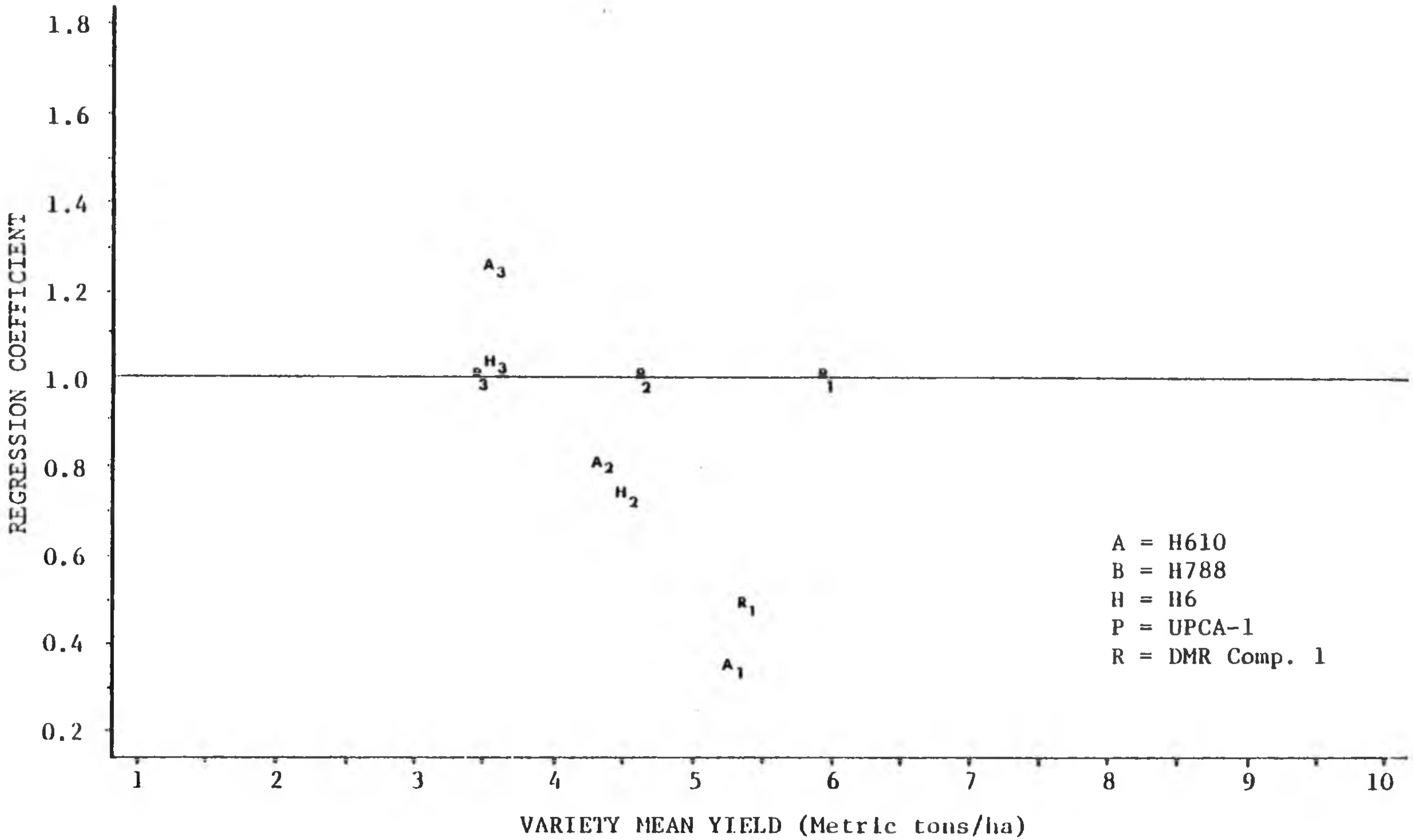


Figure 15. Relationships between regression coefficients (based on variety UPCA-1) and mean yields of individual varieties on the Hydric Dystrandept at PUC, the Philippines. Data set 1, 2, and 3 (indicated by subcripts).

therefore their stability is equal to that of UPCA-1. Variety H610 had significantly lower yield than UPCA-1 in data set 2, but their yields were equal in data set 3. Hence, no definite conclusion can be drawn about the adaptation of H610 without further tests. The yield of H6 did not differ significantly from that of UPCA-1; therefore the adaptation of H6 can be considered as being equal to that of UPCA-1.

Variety H788 had a regression coefficient significantly less than that of UPCA-1 which indicated that H788 was less sensitive to environmental changes than UPCA-1. However, the yield of H788 was significantly lower than that of UPCA-1 which indicates that H788 may be considered less well adapted to the environmental condition of the experiments than UPCA-1.

Effects of season and fertilization

Since the two experiments evaluated in data set 3 were both conducted in the wet season, the seasonal effect was not differentiated. Therefore, a regression model which only included treatment variables (cf. section 3.4.1), $\hat{y} = \beta_0 + \beta_1 N + \beta_2 P + \beta_3 N P$, was used. Similar consideration was given for data set 1, but the fertilization variables were lime x P, instead of NxP. On the other hand, the fertilization effect was not considered in data set 2 because different fertilization treatments were used in the two experiments evaluated in this data set, and the regression model became $\hat{y} = \beta_0 + \beta_1 S$.

Phosphate fertilization had a greater effect than N fertilization on the yields of UPCA-1 and DMR Comp. 1 in data set 1 (Table 13). But the coefficients of determination for these

Table 13. Regression equations showing the effects of liming and P fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the PUC site in the Philippines. Date set 1

Maize variety	Regression equation Model I[a]	R^2
Three varieties, two seasons (dry 1976, dry 1977)		
UPCA-1	$\hat{y} = 6469 + 1023\,P$ (450)[b]	0.19
DMR Comp. 1	$\hat{y} = 5710 + 774\,P$ (280)	0.26
H610	$\hat{y} =$ –[a]	

[a]No other variables met the 10% significance level for inclusion in the model.

[b]Figures in parentheses are the standard errors of regression coefficients.

relationships were very small ($r^2 < 0.26$) which indicated that the regression model did not fit the data very well. Moreover, the yield of H610 was not significantly affected by either N or P fertilization. These results suggest that other factors affected the yield of maize varieties in data set 1.

On the other hand, seasonal factors alone have explained 60 to 75% of the variation in yields of the three maize varieties in data set 2 (Table 14). Whereas in the case of data set 3, about 55% of the variation in yields of the varieties was accounted for by P fertilization (Table 15).

4.1.2 Tropeptic Eutrustox network

One data set was formed from maize variety experiments on the Tropeptic Eutrustox on Molokai, Hawaii (Table 5). The tests of adaptation were based on the population mean yield and the mean yield of variety H610.

Based on the population mean yield (Fig. 16 and Appendix D4), three varieties, H610, H688, and X304C, showed average stability which is characterized by regression coefficients not significantly different from 1.0. Variety X304C consistently produced above average yields; while H610 and H688 consistently produced below-average yields, but the yield levels were relatively high. Therefore, X304C can be described as being well adapted, and H610 and H688 as having average adaptation. It should be noted, however, that the regression equations which relate the yields of individual varieties to the population mean yield had relatively small coefficients of

Table 14. Regression equations showing the effects of season on the yield of maize varieties grown on the Hydric Dystrandept at the PUC site in the Philippines. Data set 2

Maize variety	Regression equation	R^2
Three varieties, two seasons (dry 1976, wet 1978)		
UPCA-1	$\hat{y} = 4698 - \underset{(224)^a}{1769}\ S$	0.74
H610	$\hat{y} = 4367 - \underset{(228)}{1355}\ S$	0.62
H788	$\hat{y} = 4460 - \underset{(223)}{1265}\ S$	0.59

[a]Figures in parentheses are the standard errors of regression coefficients.

Table 15. Regression equations showing the effects of N and P fertilization on the yield of maize varieties grown on the Hydric Dystrandept at the PUC site in the Philippines. Data set 3

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, 2 seasons (wet 1978, wet 1980)				
UPCA-1	$\hat{y} = 4544 + 2695\ P$ (508)[a]	0.56	$\hat{y} = 4942 + 2695\ P + 937\ N$ (478) (478)	0.63
H610	$\hat{y} = 4989 + 3452\ P$ (623)	0.58	$\hat{y} = 5655 + 3452\ P + 1568\ N$ (538) (538)	0.70
H6	$\hat{y} = 4647 + 2723\ P$	0.53	$\hat{y} = 5061 + 2723\ P + 976\ N$ (512) (512)	0.60

[a]Figures in parentheses are the standard errors of regression coefficients.

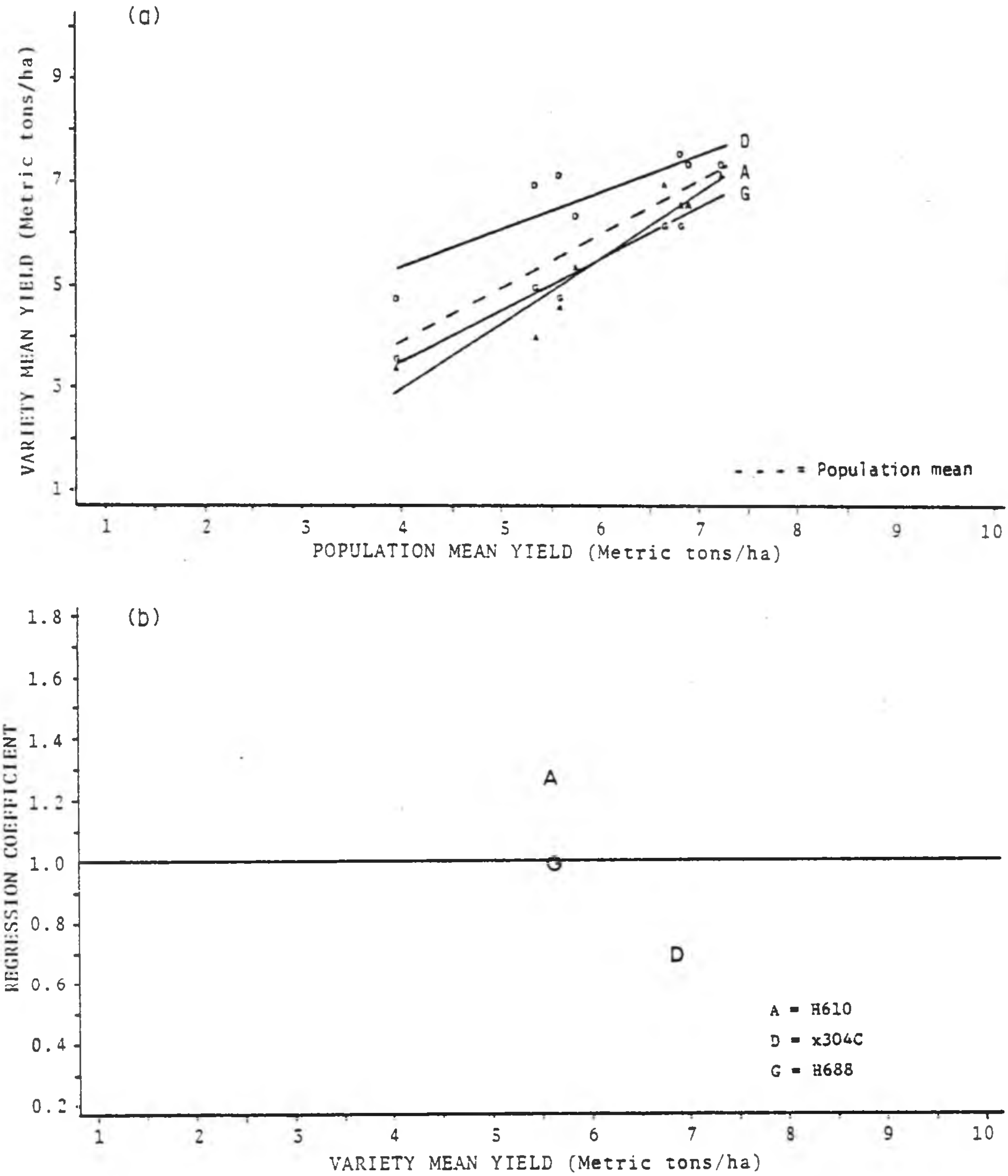


Figure 16a. The relationship between variety mean yields and the population mean yields.

16b. The relationship between the regression coefficient of each variety in Figure 16a and the respective variety mean yield.

Tropeptic Eutrustox, Molokai, Hawaii (dry 1978, dry 1979).

determination, particularly those for varieties X304C and H688. Hence, these results are not conclusive.

The adaptation of varieties H688 and X304C in relation to variety H610 was similar as indicated by the nonsignificant difference among their regression coefficients (Fig. 17 and Appendix D4). However, since yields of H688 were equal and yields of X304C were significantly higher than that of H610, variety H688 may be considered equally adapted while X304C may be considered better adapted to the environmental conditions of the experiments than H610.

The coefficients of determination for the relation between varieties H688 and X304C with H610 were small ($r^2 < 0.26$) as in the test based on the population mean. Hence, these results should also be considered tentative.

Season was the most important single variable that affected the yield of variety H610; while varieties H688 and X304C were more affected by the interactions of NP fertilization (Table 16). Considerable improvement in the value of R^2 was obtained for variety H610 by including N and P variables in regression model II. On the other hand, the R^2 value for variety H688 was not improved very much when the season variable was included in the model, and season had no significant effect on the yields of X304C. Thus it appears that there were other variables besides season and fertilization that had more significant effects on the yields of H688 and X304C.

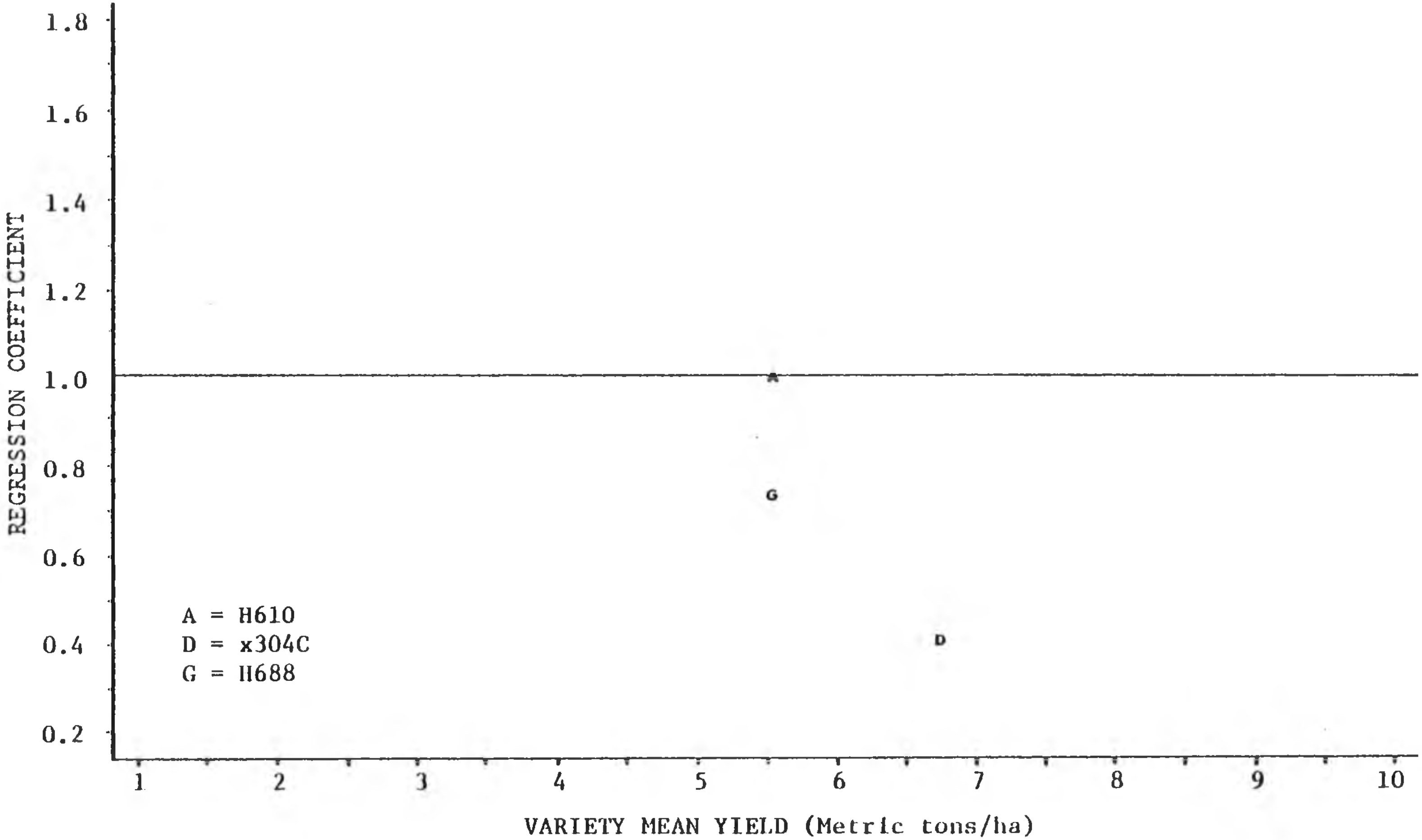


Figure 17. Relationships between regression coefficients (based on variety H610) and mean yields of individual varieties on the Tropeptic Eutrustox at Molokai, Hawaii (dry 1978, dry 1979).

Table 16. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Tropeptic Eutrustox at the Molokai site in Hawaii

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, two seasons (dry 1978, late-wet 1979)				
H610	$\hat{y} = 5619 - \underset{(296)^{a}}{976}\ S$	0.33	$\hat{y} = 6858 - \underset{(236)}{976}\ S + \underset{(556)}{1788}\ N + \underset{(557)}{1127}\ P$	0.61
H688	$\hat{y} = 5990 - \underset{(977)}{2045}\ NP$	0.17	$\hat{y} = 5990 - \underset{(909)}{2045}\ NP - \underset{(284)}{598}\ S$	0.31
X304C	$\hat{y} = 7283 - \underset{(843)}{2336}\ NP$	0.26	–[b]	

[a]Figures in parentheses are the standard errors of regression coefficients.

[b]No other variable met the 10% significance level for inclusion in the model.

4.1.3 Typic Paleudult network

INDONESIA

The data set from the Typic Paleudult site at Nakau, Indonesia (Table 6) was evaluated on two bases, population mean yield and the mean yield of a standard variety, H6.

Based on the population mean yield, the three varieties in the data set have regression coefficients which are not significantly different from 1.0 (Fig. 18 and Appendix D5). This indicates that the varieties have average stability. However, the yields of varieties H6 and Tiniguib were higher than the population mean, while the yield of Kodok was lower than the population mean. Hence, H6 and Tiniguib can be considered well adapted while Kodok had average adaptation to the environmental conditions in these experiments.

In the test of adaptation using H6 as the standard the regression coefficients for Kodok and Tiniguib are not significantly different from that of H6 (Fig. 19 and Appendix D5). The stability of these two varieties was therefore equal to that of H6. Yield of Kodok was significantly lower than that of H6, while yield of Tiniguib was equal to the yield of H6. Therefore Kodok may be considered less well adapted and Tiniguib as equally adapted to the environment as H6.

The relative effects of season and fertilization are presented in Table 17 and it is apparent that P fertilization was the most important single variable affecting the yields of all three varieties. The low coefficients of determination for H6 and Kodok ($R^2 < 0.35$) and the lack of significant effects of season or other

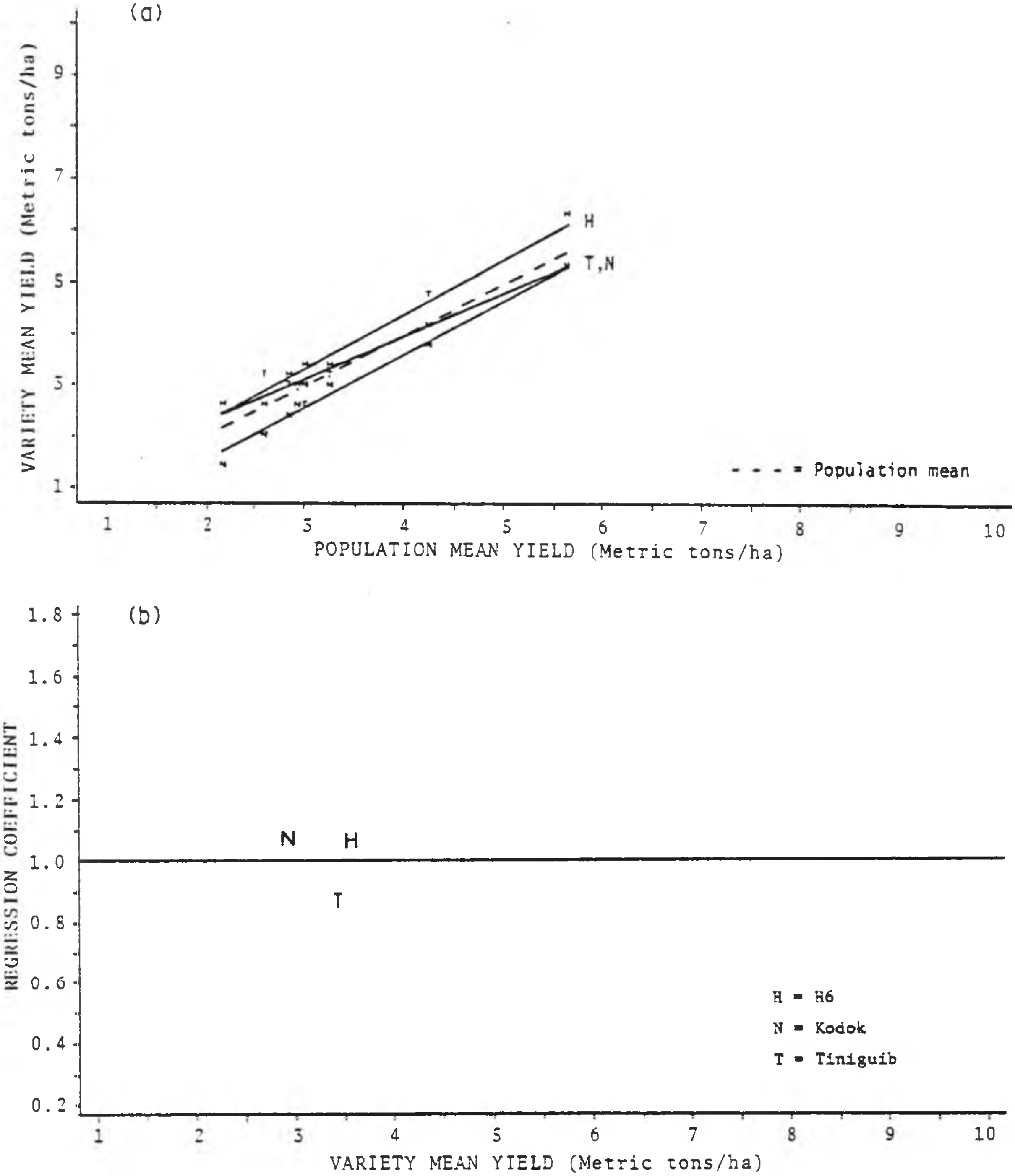


Figure 18a. The relationship between variety mean yields and the population mean yields.

18b. The relationship between the regression coefficient of each variety in Figure 18a and the respective variety mean yield.

Typic Paleudult, Nakau, Indonesia (wet 1980, dry 1980).

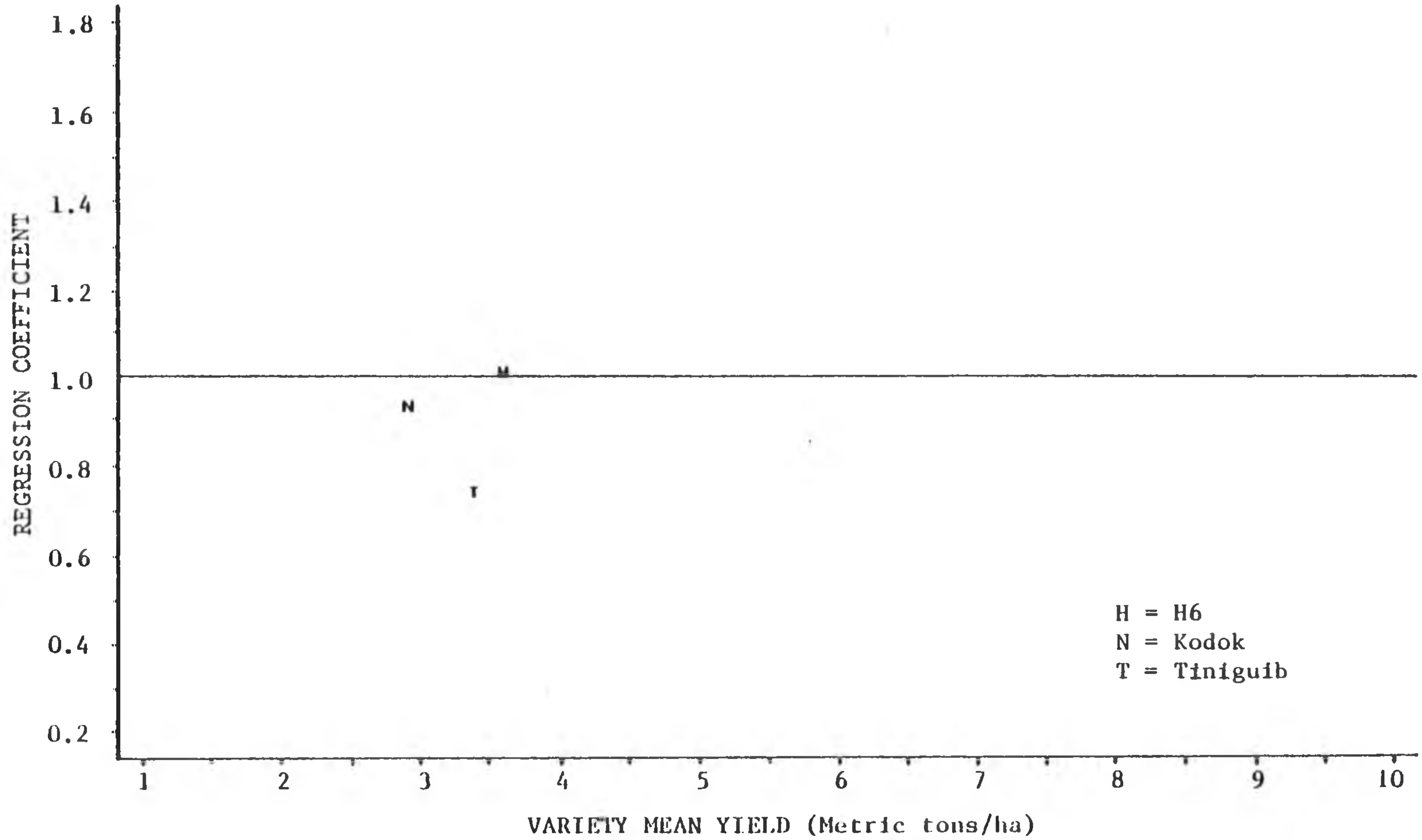


Figure 19. Relationships between regression coefficients (based on variety H6) and mean yields of individual varieties on the Typic Paleudult at Nakau, Indonesia (wet 1980, dry 1980).

Table 17. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Typic Paleudult at the Nakau site in Indonesia

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, two seasons (wet 1980, dry 1980)				
H6	$\hat{y} = 4244 + 1504\ P$ (508)[a]	0.23	–[b]	
Kodok	$\hat{y} = 3735 + 1841\ P$ (530)	0.35	–	
Tiniguib	$\hat{y} = 4085 + 1490\ P$	0.41	$\hat{y} = 4085 + 1744\ P + 934\ S + 1103\ PS + 598\ NP$ (236) (116) (193) (321)	0.87

[a]Figures in parentheses are the standard errors of regression coefficients.

[b]No other variable met the 10% significant level for inclusion in the model.

treatment variables indicates that although H6 and Kodok responded to P fertilization, other more important unknown factors affected their yields.

With variety Tiniguib, several variables other than P which were significant, namely S, PS, and NP (Table 17), were included in the regression model with a resultant increase in R^2 from 0.41 to 0.87. This indicates that the yield response of Tiniguib was due not only to P fertilization but also to the interaction of P with season and N fertilization.

PHILIPPINES

The data set from the Typic Paleudult site at Davao, the Philippines (Table 7), was evaluated based on the population mean yield and the mean yield of the standard variety, UPCA-1.

On the basis of the population mean yield, the regression coefficients of the three varieties were not significantly different from 1.0 (Fig. 20 and Appendix D6) which indicates the three varieties have average stability. However, X304C consistently produced higher yield while UPCA-1 and Tiniguib consistently produced lower yields than the population mean yield suggesting that X304C was well adapted and UPCA-1 and Tiniguib had average adaptation.

Based on the standard variety, UPCA-1, the regression coefficients of X304C and Tiniguib were not significantly different from that of UPCA-1 (Fig. 21 and Appendix D6). Yields of Tiniguib were equal to and yields of X304C were higher than those of UPCA-1. These relationships indicate that the stability of X304C and Tiniguib are equal to that of UPCA-1, but X304C was better adapted and Tiniguib was as well adapted as variety UPCA-1.

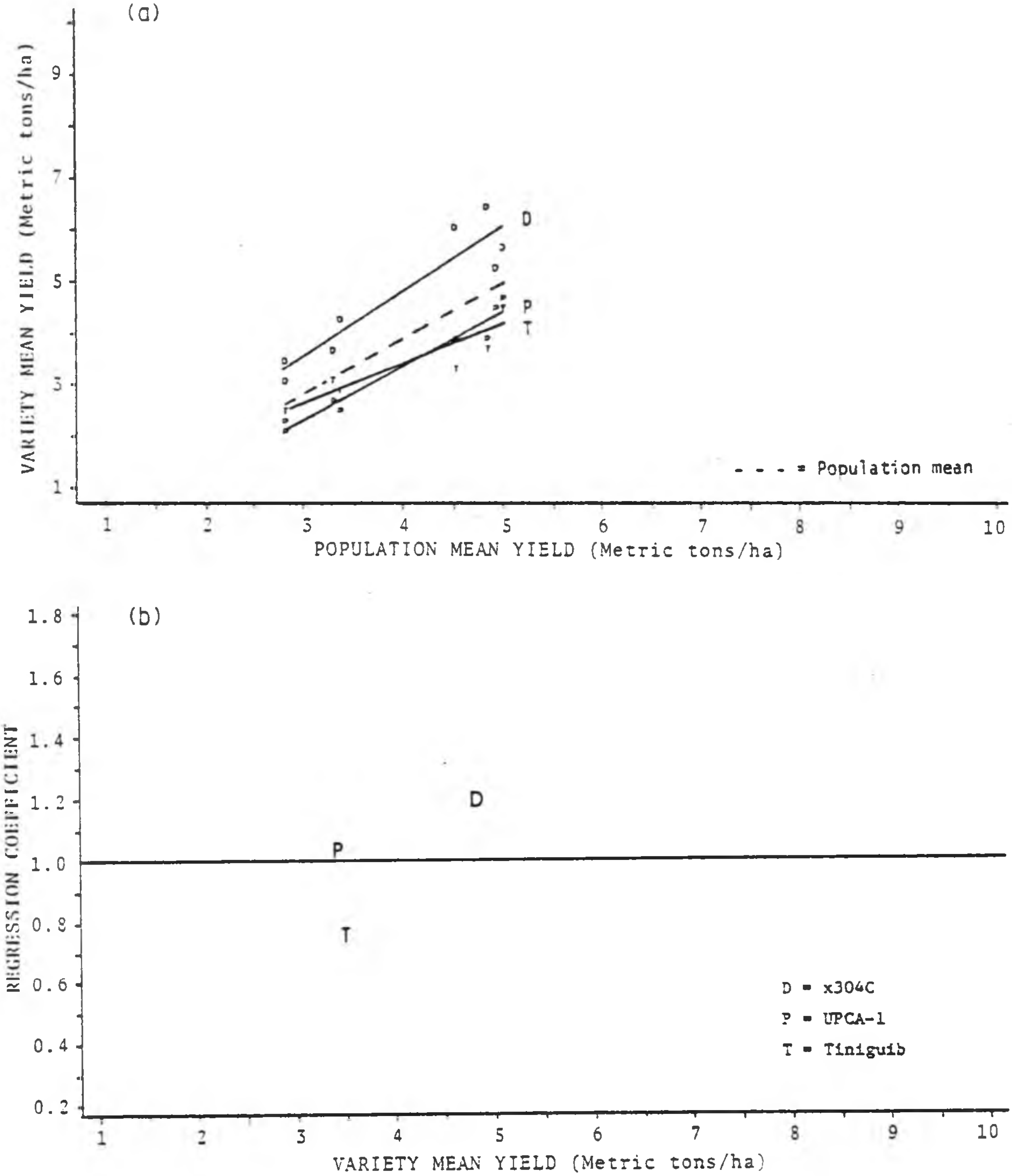


Figure 20a. The relationship between variety mean yields and the population mean yields.
20b. The relationship between the regression coefficient of each variety in Figure 20a and the respective variety mean yield.
Typic Paleudult, Davao, the Philippines (wet 1978, dry 1980).

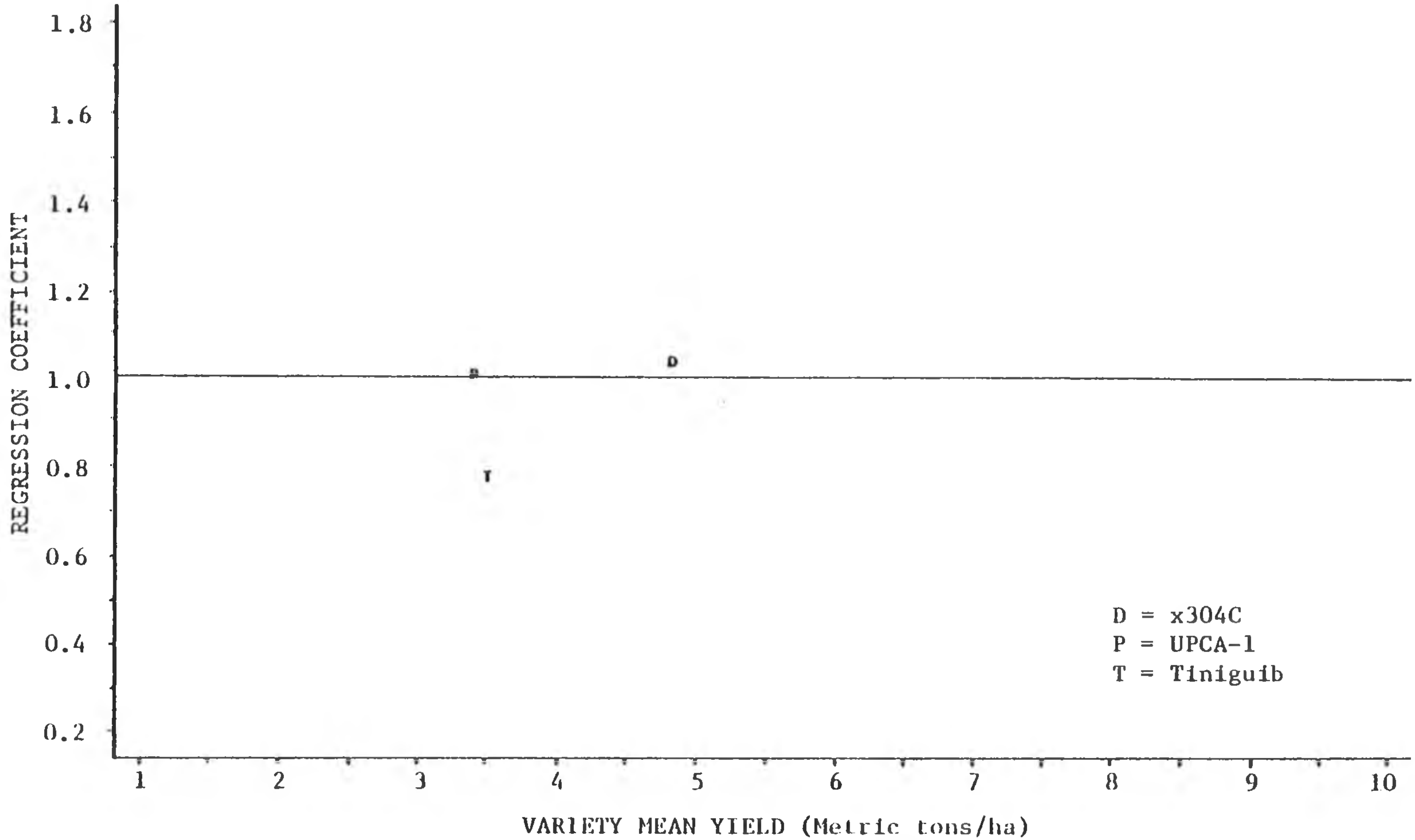


Figure 21. Relationships between regression coefficients (based on variety UPCA-1) and mean yields of individual varieties on the Typic Paleudult at Davao, the Philippines (wet 1978, dry 1980).

Nitrogen fertilization was found to be the most important single variable affecting the yield of all three maize varieties in this data set (Table 18). Regression model II indicated that in addition to N fertilization yields of these varieties were also affected significantly by season or the interaction of season with P fertilization.

4.1.4 Discussion

The adaptation of maize varieties to varying environmental conditions in three soil family networks was evaluated using the regression approach of Finlay and Wilkinson (1963). The first step in conducting this test was regressing the yield of individual varieties against the mean yield of a group of varieties (population mean yield). Since genotype response to complex agroenvironments involves diverse, simultaneous and separate responses to a number of environmental factors, an average performance of a group of varieties was considered as an effective and appropriate index of the site's productivity (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Breese, 1969; Moll and Stuber, 1974).

This environmental index, however, is not independent of the experimental varieties (Finlay and Wilkinson, 1963; Eberhart and Russell, 1969), and the most serious objection to this kind of index is that the yields of any one variety are, unavoidably, partially correlated with the environmental index against which they are being tested. In addition, the distribution of varieties about the mean yield will depend on the sample of varieties (Goldsworthy, 1974). Thus, it is very important that the number of varieties included in

Table 18. Regression equations showing the effects of season and fertilization on the yield of maize varieties grown on the Typic Paleudult at the Davao site in the Philippines

Maize variety	Regression equation Model I	R^2	Regression equation Model II	R^2
Three varieties, two seasons (wet 1978, dry 1980)				
UPCA-1	$\hat{y} = 4331 + 2179\ N$ (319)[a]	0.68	$\hat{y} = 4331 + 2179\ N + 391\ PS$ (303) (215)	0.72
Tiniguib	$\hat{y} = 4124 + 1511\ N$ (367)	0.44	$\hat{y} = 4124 + 1511\ N - 269\ S$ (349) (148)	0.51
X304C	$\hat{y} = 6006 + 2678\ N$	0.76	$\hat{y} = 6006 + 2678\ N + 446\ S$ (273) (134) $- 684\ NPS$ (371)	0.84

[a]Figures in parentheses are the standard errors of regression coefficients.

the experiment be large enough and the estimate of stability parameters be based on results from an adequate number of experiments representing the full range of possible environmental conditions (Hardwick and Wood, 1972; Goldsworthy, 1974).

Several other methods using physical factors such as climatic variables, an altitude index, soil fertility, and a drought index have been used as ways of estimating the environment (Dowker, 1963; Eberhart and Russell, 1966; Corsi and Shaw, 1971; Perkins, 1972; Eberhart et al., 1973; Sopher et al., 1973; Nor and Cady, 1979). However, to be able to use this approach the key factors causing the genotype x environment interactions should be determined so that appropriate and meaningful indices can be developed (Sprague and Eberhart, 1977).

Despite the deficiency of the regression approach, this method is commonly used and has been very fruitful (Rowe and Andrew, 1963; Eberhart and Russell, 1963; Freeman, 1973; Jong, 1980).

In this study the adaptation of maize varieties was evaluated using the regression approach and the population mean yield has been used as the measure of the environment. Regardless of the method being used, the limited number of maize varieties and number of experiments (seasons) involved in each data set have limited the assessment of the adaptation of the varieties. Had more common varieties been planted at each site from season to season, substantially more conclusive results could have been obtained. Moreover, if more common varieties were planted at different sites (countries) of the same soil family, it would have made possible the evaluation of maize adaptation to a particular soil family.

It might be noted at this point, however, that the objective of the Project in conducting the variety experiments was to select a maize variety (varieties) that is best/well adapted to the environment of a certain location. Maize varieties tested in the variety experiments were those varieties recommended by local institutions as well as varieties used in other transfer experiments in the soil family network. Thus when the selected variety was used in the transfer experiment it would allow assessment of the yield potential of the respective site and avoid complete loss of the transfer experiment from disease or insect attack.

In accordance with this perspective, the adaptation of maize varieties in this study was also evaluated or compared with a certain variety selected as a standard variety for specific conditions. The standard variety for each site is the variety that showed good performance and has been used extensively as the test variety in the transfer experiments.

However, with regard to the objective of conducting the transfer experiments--to test the transferability of agroproduction technology across different sites/countries of the same soil family--a dilemma is faced by the Project. If, at each site the best adapted local variety for that site is used, it might be possible, as shown in the latter parts of this thesis, that the response of the crop to the environment and treatment variables is not uniform across sites. As a result, the fact that different varieties have been used should be considered in comparing the results of transfer experiments.

The results of adaptation tests are summarized in Tables 19 and 20 for the tests based on the population mean yield and the mean yield of a standard variety, respectively. The tables show that certain varieties were adapted to certain environments, e.g., UPCA-1 was found to have average adaptation in the Philippines, both in the Hydric Dystrandept and the Typic Paleudult networks. But in the Hydric Dystrandept network in Indonesia, UPCA-1 did not perform very well. Similarly, H610, which could produce high yield in its original country, Hawaii, did not perform very well in Indonesia and the Philippines. Regional adaptation of maize varieties as found in this study has been recognized for a long time (Stringfield and Salter, 1934) and in some cases it was related to the fertility level of the soil, and the differential response among varieties was considered as a component of the adaptation complex (Mooers, 1922 and 1933; Smith, 1934). In other cases regional adaptation was related with climatic factors where, for example, tropical materials are unnecessarily tall and late in maturity when planted in a temperate area. On the other hand, much of the excellent Corn Belt germplasm matures too early in the tropics for maximal yields (Brewbaker, 1974).

However, there was also a tendency for variety X304C, a Pioneer hybrid, to perform relatively well across the three soil families or the three countries. Due to limited data used in this study, however, the superiority of X304C remains to be confirmed with further tests.

Furthermore, it should be mentioned that the results from the Typic Paleudult networks were obtained with the application of

Table 19. Summary of the adaptation tests of maize varieties based on population mean yield

Soil/ country	Class of adaptation		
	Poorly adapted	Average adaptation	Well adapted
Hydric Dystrandept			
HAWAII	H788	H610, H688, X304B	X4816, X4817, X304C
INDONESIA	Bastar Kuning, UPCA-1, H610, Bima		H6, Harapan
PHILIPPINES	UPCA-1, H6, H610, H788	UPCA-1, H6, H610	
Tropeptic Eutrustox			
HAWAII		H610, H688	X304C
Typic Paleudult			
INDONESIA		Kodok	H6, Tiniguib
PHILIPPINES		UPCA-1, Tiniguib	X304C

Table 20. Summary of the adaptation tests of maize varieties based on the mean yield of a standard variety

Soil/ country	Standard variety	Class of adaptation (relative to the standard variety)		
		Less well adapted	Equally adapted	Better adapted
Hydric Dystrandept				
HAWAII	H610	H788	X304B, H688	X4816, X4817, X304C
INDONESIA	H6	UPCA-1, H610, Bima	Harapan, Bastar Kuning	
PHILIPPINES	UPCA-1	H788, H610, DMR Comp. 1	H610, H6	
Tropeptic Eutrustox				
HAWAII	H610		H688	X304C
Typic Paleudult				
INDONESIA	H6	Kodok	Tiniguib	
PHILIPPINES	UPCA-1		Tiniguib	X304C

fungicide Redomil to reduce the effect of downy mildew (Sclerospora maydis Rac. Butter) on the variety performance. Without Redomil a different result may be obtained.

4.2 Differential Response of Maize Varieties to N and P Fertilization

Analyses of variance for maize grain yields of the 19 variety experiments are given in Appendix B1 to B6. These analyses were summarized in Tables 21 and 22. The main effects of fertilizer were significant in 13 of the 19 experiments, including 1 experiment, i.e., Nakau-E-10 in the early dry season 1979, which is statistically significant at the 10% level.

The F tests of fertilizer effects partitioned into single degrees of freedom indicated that there were no significant phosphate effects in any of the three experiments on the Hydric Dystrandepts in Hawaii, and only two of the four experiments on the Hydric Dystrandepts in Indonesia showed significant phosphate effects. The smaller responses to phosphate application on the Hydric Dystrandepts in Hawaii and Indonesia were due to high residual phosphorus levels in the soils from the application of fertilizer and manure in the past (Benchmark Soils Project, 1978). The critical level of soil phosphorus has been set tentatively at 25 ppm P, determined with the modified Truog method (Benchmark Soils Project, 1980). Phosphorus levels of the Hydric Dystrandept soils on the experimental sites in Hawaii and Indonesia (Appendix A1) were far above the critical level.

Main effects of nitrogen were significant only in one of three experiments with nitrogen x phosphate fertilization treatments on the

Table 21. Summary of analyses of variance of 19 variety experiments showing the significance of F-values for the effects of fertilization

Soil/ country/ site & season	Combined effect of fertilizer	Effect of N	Effect of P	Effect of N x P
Hydric Dystrandept				
HAWAII				
Iole-G-10 wet 1978	ns	*	ns	ns
Iole-H-10 dry 1978	**	*	ns	ns
Iole-G-11 late-wet 1979	ns	*	ns	ns
INDONESIA				
ITKA-O-10 dry 1978[a]	**	ns	**	*
ITKA-L-10 late-wet 1978	ns	ns	ns	ns
ITKA-N-20 wet 1979	*	ns	**	ns
ITKA-F-10 dry 1979	**	**	ns	*
PHILIPPINES				
PUC-C-10 dry 1976[a]	ns	ns	+	ns
PUC-L-10 dry 1977[a]	*	ns	**	ns
PUC-M-10 wet 1978	**	**	**	*
PUC-L-22 wet 1980	**	ns	**	ns
Tropeptic Eutrustox				
HAWAII				
Molokai-C-10 dry 1978	ns	ns	ns	ns
Molokai-D-10 late-wet 1979	**	**	**	ns
Typic Paleudult				
INDONESIA				
Nakau-B-10 wet 1979	**	*	**	+
Nakau-E-10 early-dry 1979	+	+	ns	ns
Nakau-B-20 wet 1980	**	**	**	**
Nakau-E-20 dry 1980	ns	ns	+	ns
PHILIPPINES				
Davao-G-10 late-wet 1979	*	*	ns	ns
Davao-B-13 dry 1980	**	**	ns	ns
Number of experiments with significant effects	13	11	10	5
Total number of experiments	19	19	19	19

[a]The fertilization treatments in this experiment were lime by P, instead of N by P.

+, *, ** = significant at 10, 5, and 1% probability levels, respectively.

ns = not significant.

Table 22. Summary of analyses of variance of 19 variety experiments showing the F values and their significance for the interaction effects of fertilizer x variety

Soil/ country/ site & season	Combined effect of F x V[a]	Effect of		
		NxV	PxV	NxPxV
Hydric Dystrandept				
HAWAII				
Iole-G-10 wet 1978	1.06	1.36	1.52	0.29
Iole-H-10 dry 1978	0.91	0.92	1.11	0.70
Iole-G-11 late-wet 1978	0.74	0.69	0.74	0.78
INDONESIA				
ITKA-O-10 dry 1977[b]	0.62	0.18	1.45	0.24
ITKA-L-10 late-wet 1978	2.26*	3.63**	1.27	1.89
ITKA-N-20 wet 1979	0.75	1.01[c]	0.82	0.42
ITKA-F-10 dry 1979	0.90	1.13[c]	0.14	1.44
PHILIPPINES				
PUC-C-10 dry 1976[b]	0.84	0.11	0.23	2.18+
PUC-L-10 dry 1977[b]	1.60	1.23[c]	2.81*	0.77
PUC-M-10 wet 1978	0.97	0.92	1.31	0.69
PUC-L-22 wet 1980	3.50**	2.09	7.69**	1.20
Tropeptic Eutrustox				
HAWAII				
Molokai-C-10 dry 1978	0.64	0.86	0.64	0.41
Molokai-D-10 late-wet 1979	1.18	1.03	0.34	2.16+
Typic Paleudult				
INDONESIA				
Nakau-B-10 wet 1979	2.67*	1.17	4.22*	2.61+
Nakau-E-10 early-dry 1979	1.27	2.13	1.21[c]	0.48
Nakau-B-20 wet 1980	1.00	1.47	0.67	0.86
Nakau-E-20 dry 1980	0.80	0.33	1.57	0.51
PHILIPPINES				
Davao-G-10 late-wet 1979	2.16*	5.75**	0.08	0.64
Davao-B-13 dry 1980	0.57	0.57	0.20	0.94
Number of experiments with significant F-values and F-values > 1	7	10	10	6
Total number of experiments	19	19	19	19

[a]F and V refer to fertilizer and variety, respectively.

[b]The fertilization treatments in this experiment were lime by P, instead of N by P.

[c]F-value > 1.0 but it is not significant and no significant difference among mean yields or yield responses.

+, *, ** = significant at 10, 5, and 1% probability levels, respectively.

Hydric Dystrandept in Indonesia. The lack of response to nitrogen fertilization on this site was very likely due to the application of manure made in the past. Application of lime on the Hydric Dystrandepts at ITKA-block O in Indonesia and at PUC-blocks C and L in the Philippines did not significantly affect maize grain yields. These results are in agreement with previous results where it was concluded that the soils were able to supply adequate amounts of calcium for crops although the pH of the soil was relatively low, pH-H_2O ranged from 4.6 to 5.6 (Benchmark Soils Project, 1978).

The objective of this study was to identify the maize varieties that were most responsive to fertilization, or in other words, to determine the differential responses of maize varieties to fertilization. The significance of F values of main effects, therefore, are of less interest than those of the fertilizer x variety interaction effects.

The fertilizer x variety effects (Table 22), however, were significant only in 4 of the 19 experiments, indicating that only in those 4 experiments was there strong evidence of varietal differences in response to fertilization. Hence, the interaction effects were examined further by partitioning their sum of squares into sum of squares for the effects of N x Variety, P x Variety, and N x P x Variety and testing the resulting mean square with an F test. A summary of these analyses is presented in Table 22. These analyses revealed that the four significant fertilizer x variety effects were due to N x Variety effects at ITKA-L-10 and Davao-G-10, and due to P x Variety effects at PUC-L-22 and Nakau-B-10. In addition, a significant P x Variety effect was found at PUC-L-10, and significant (P < 0.10) N x P x Variety effects occurred at PUC-C-10, Molokai-D-10, and Nakau-B-10.

In an attempt to identify the most responsive varieties, mean separation tests were performed not only for those experiments with significant interaction effects, but also for experiments with F-values greater than 1.0 which indicated that all varieties did not respond in the same manner to fertilization. Mean yields and yield responses of maize varieties to fertilization in these experiments will be presented in the following discussion. The yields of maize varieties in experiments which had F-values less than 1.0 for their combined and partitioned interaction effects, i.e., Iole-G-11, Molokai-C-10, Nakau-B-20, and Davao-B-13 are given in Appendices C1 and C2.

4.2.1 Hydric Dystrandept network

HAWAII

Response to nitrogen

The effects of N fertilization were significant in all three experiments on the Hydric Dystrandept at the Iole site in Hawaii (Table 21). In two of the experiments, Iole-H-10 and Iole-G-11, the F values for the N x V interactions effects were less than 1 (Table 22). Thus, it may be said that the varieties tested in these two experiments responded similarly to N.

In the experiment at Iole-G-10 the F value for the N x V interaction effect was greater than 1 but was not significant (Table 22) which indicates that varieties tested in this experiment did not respond in the same manner to N fertilization. Evaluation of the differential response of the varieties to N fertilization was carried out with mean separation tests performed using the multiple comparison test of interaction (Harter, 1970). No significant difference in the yield response to N fertilization was found among the varieties under both low and adequate levels of P (Table 23).

The multiple comparison test of interaction was conducted using the Waller-Duncan Bayesian k-ratio t test. In this method the observed F value of the F-test statistic is actually used in calculating the critical t value for comparing two means. If the F value is large (3.0 or above, indicating strong evidence of differences), the test behaves like the ordinary least significant difference (LSD) procedure (Fisher's LSD or Duncan's multiple range test) with good power properties. But with a small F value its critical t value is increased and it will give a conservative, large LSD, making it more difficult to declare two treatments significantly different and thus decreasing the probability of Type I error (Waller and Duncan, 1965; Duncan, 1975; Chew, 1976). Moreover, a still larger LSD should be used in comparing two interaction elements because in calculating the standard error the error mean square is multiplied by 4 (not 2 as when comparing two means, cf. section 3.4.2), due to the fact that 4 mean yields are involved in the test of interactions (Harter, 1970; Duncan, 1975).

In view of the above remarks, it is obvious that the lack of significant differences in interactions or yield response to N fertilization among the varieties tested in the experiment at Iole-G-11

Table 23. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at Iole-G-10, Hawaii, wet season 1978

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to N		Response to P	
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Low P	Adq. P	Low N	Adq. N
X304C	5035	5724	6400	6907	1365 a	1183 a	689 ab	507 a
X4816	4420	5734	6250	6658	1830 a	924 a	1314 a	408 a
H610	4718	5022	4852	4886	134 a	-136 a	304 ab	34 a
X4817	4858	5535	5968	5648	1110 a	114 a	677 ab	-320 a
H788	4038	3885	4950	4463	912 a	578 a	-153 ab	-487 a
X304B	4145	4690	5682	5012	1537 a	324 a	545 ab	-668 a
X304A	5104	4288	5469	4702	365 a	414 a	-186 b	-767 a
X5800	4297	4335	6302	5308	2085 a	972 a	38 ab	-1074 a

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 1652; between P treatments under the same N level for the same or different varieties: 1571, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxPxV effect has an F value < 1.0.

(Table 23) was related to the small F value (F = 1.36) of the N x V effect (Table 22).

However, the yield response to N fertilization among the varieties varied considerably, for example under the low P level it varied from 134 kg/ha (variety H610) to 2085 kg/ha (variety X5800) (Table 23). This large differential yield response suggests that it may be possible to identify a responsive variety in the experiment. In addition, the fact that F > 1 indicates that at least one comparison of two mean yields must be significant. Therefore another test, the test of contrasts, was conducted to test all possible contrasts between the mean yields of the same variety under different N levels as well as between different varieties under the same N level. To have equal protection against making a Type I error (incorrectly declaring two means to be different), the same test procedure, namely the Waller-Duncan's Bayesian k-ratio t rule, was used (Duncan, 1975).

The test of contrasts (Table 23) showed that two Pioneer varieties, X5800 and X4816, gave significant yield increases with increased N fertilization under the low level of P. Under adequate P, however, none of the varieties responded significantly to N fertilization.

The test of contrasts (Table 23) also showed that with low P the yields of all varieties did not differ significantly with either the low or adequate rates of N. With adequate P under the low N treatment variety X304C produced a higher yield than H788, while under adequate N the yield of X304C was significantly higher than those of X304A, X304B, H610, and H788.

The above discussion shows that with the test of interaction, the yield responses of the varieties to N fertilization did not differ significantly with either the low or adequate P levels. The test of contrasts, however, indicates that two out of the eight varieties responded significantly to N fertilization under the low P level.

In the later parts of this section it will be shown that similar situations were encountered in comparing the yield responses of varieties to either N or P fertilization in most of the experiments evaluated in this study. In most cases no significant difference could be declared for the yield responses among the varieties even though their yield responses differed markedly. On the other hand, certain distinctions can be made using the test of contrasts. The author, therefore, has decided to use the test of contrasts to complement the test of interaction for selecting the more responsive varieties.

Response to phosphate

As already mentioned, there was no significant effect of phosphate (P) fertilization treatment in any experiment at the Iole site in Hawaii (Table 21). The P x V interaction effects at Iole-G-10 and Iole-H-10, however, had F values greater than 1.0 (Table 22).

At Iole-G-10, the yield response of variety X4816 to P fertilization under the low level of N was significantly higher than that of variety X304A. It should be noted that the yield of variety X4816 increased by 1314 kg/ha while the yield of X304A decreased by 186 kg/ha with the higher rate of P; however, neither change was statistically significant (Table 23). Therefore, in the absence of a significant response to phosphate, these findings must be considered preliminary.

The yield responses of maize varieties to P fertilization under the adequate N level at Iole-G-10 (Table 23), and under either the low or adequate N levels at Iole-H-10 (Table 24) did not differ significantly. The test of contrasts also indicated that the varieties did not respond significantly to increased P fertilization. This was not unexpected since no significant P effects were found in the analysis of variance. It is important to note, however, that the yields of more than half of the varieties decreased markedly with the higher level of P, especially at Iole-H-10, suggesting that the high rate of P created a nutrient imbalance.

INDONESIA

Response to nitrogen

The effect of the N x V interaction was significant in one of three experiments with the N x P fertilization treatment on the Hydric Dystrandept at the ITKA site in Indonesia, i.e., at ITKA-L-10 late-wet season 1978 (Table 22). With adequate P, the yield responses to N of varieties H6 and Bastar Kuning were significantly higher than those of Harapan, H610 and UPCA-1; and the yield response of Bima was significantly higher than that of UPCA-1. With low P, however, their yield responses to N did not differ significantly (Table 25). The test of contrasts showed that with adequate P three varieties H6, Bastar Kuning and Bima responded significantly to N fertilization; and with low P all varieties did not respond significantly to N

Table 24. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at Iole-H-10, Hawaii, dry season 1978

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to N		Response to P	
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Low P	Adq. P	Low N	Adq. N
X304B	6950	6602	7729	8106	779	1594	-348 a	467 a
X4816	7979	7814	8772	9113	793	1299	-165 a	341 a
X306B	7496	6617	8330	8619	834	2002	-879 a	288 a
H688	8084	8327	8916	8843	832	516	243 a	-73 a
X304C	8138	8200	8782	8688	644	488	62 a	-95 a
H610	7537	7127	8846	8542	1309	1415	-410 a	-304 a
X4817	7957	6970	9234	8918	1277	1948	-987 a	-316 a
H788	7119	6798	8806	7610	1687	812	-321 a	-1196 a

[a] Test of contrasts: BLSD (k = 50) for comparing mean yields between P treatments under the same N level for the same or different varieties: 1515, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV and the NxPxV effects have F values < 1.0.

Table 25. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at ITKA-L-10, Indonesia, late-wet season 1978

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Response to N		Response to P		Response to NP
					Low P	Adq. P	Low N	Adq. N	
Bastar Kuning	2384	2099	3202	4053	819 a	1954 a	-285 ab	850 a	1669 a
Bima	2270	2263	1878	3172	-392 a	909 ab	-7 ab	1294 a	902 a
Harapan	2514	3106	2672	3295	158 a	189 bc	592 a	623 a	781 a
H6	3653	2307	3491	4283	-162 a	1976 a	-1346 b	792 a	630 a
H610	2055	2561	1941	2596	-114 a	35 bc	507 a	655 a	542 a
UPCA-1	1994	2795	1785	2392	-209 a	-403 c	801 a	608 a	398 a

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same or different varieties: 862; between P treatments under the same N level for the same or different varieties: 1204; between the low NP and the adequate NP treatments for the same or different varieties: 1045, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test.

(Table 25). It is apparent that the multiple comparison tests of interaction and the test of contrasts support each other in this case, and suggest that with adequate P three varieties (H6, Bastar Kuning, and Bima) were more responsive to N than the other three varieties (Harapan, H610, and UPCA-1), but their responsiveness to N with low P did not differ significantly.

The effects of the N x V interaction were not significant in the experiments at ITKA-N-20 wet season 1979 and at ITKA-F-10 dry season 1979, but the F values were greater than 1.0 (Table 22). Therefore multiple comparison tests for interaction were carried out and the results supported those of the F tests with no significant difference found among the yield responses of the varieties to N fertilization (Tables 26 and 27). The tests of contrasts showed that all varieties in both experiments did not respond significantly to N fertilization under either the low or adequate level of P, except for variety Wonosobo in the experiment at ITKA-F-10 under adequate P (Table 27).

It should be noted that some varieties tested in ITKA-F-10 responded markedly to N fertilization. However, there was no consistent trend in the responsiveness of the varieties to N fertilization (Table 27). For example, variety X304C gave the highest yield increase of about 1500 kg/ha, followed by Wonosobo with a yield increase of about 1200 kg/ha due to N fertilization with low P, although both increases were not statistically significant. But under adequate P, the yield of X304C decreased by about 200 kg/ha with N fertilization,

Table 26. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at ITKA-N-10, Indonesia, wet season 1979

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to N		Response to P	
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Low P	Adq. P	Low N	Adq. N
Wonosobo	5665	6724	5512	6660	-153	-64	1059	1148
Harapan	5505	6183	4815	5689	-690	-494	678	874
DMR-5	5707	5832	5755	6606	47	774	125	851
Bastar Kuning	5230	6141	5252	5796	49	-345	911	544
H6	5541	5968	5470	5520	-71	-448	427	50

[a] Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 1367, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: The NxV effect has an F value < 1.0 but not significant and no significant difference between yield responses. The PxV effect has an F value < 1.0.

Table 27. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at ITKA-F-10, Indonesia, dry season 1979

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
					Response to N		Response to P		Response to NP
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Low P	Adq. P	Low N	Adq. N	
Wonosobo	5908	5449	7085	8681	1177	3232	-459	1596	2773 a
Harapan	5540	5873	6690	7132	1150	1259	333	442	1592 a
UPCA-1	5040	4945	5388	6560	348	1615	-95	1172	1520 a
H610	5759	4826	5814	6920	55	2094	-933	1106	1161 a
X304C	6383	7374	7818	7165	1435	-209	991	-653	782 a
H6	6302	5857	6192	6813	-110	956	-445	621	512 a

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same or different varieties: 2212; between the low NP and the adequate NP treatments for the same or different varieties: 2038, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV effect has an F value > 1.0 but not significant and no significant difference between yield responses. The PxV effect has an F value < 1.0.

and the yield of Wonosobo increased significantly by more than 3000 kg/ha with added N.

Instead of N x P, the fertilization treatments in the experiment at ITKA-O-10 dry season 1977 were lime x P and adequate N was applied to all plots. The application of lime had no significant effect, as discussed earlier, and there was no significant effect of the lime x variety interaction in this experiment (Table 28).

Response to phosphate

The effects of phosphate x variety (P x V) interactions were not significant in any of the four experiments conducted at the ITKA site in Indonesia, indicating that there was no strong evidence of differences in yield response among the varieties to P fertilization (Table 22). In two of these experiments, however, i.e., ITKA-O-10 dry season 1977 and ITKA-L-10 late-wet season 1977, the F values for the P x V interaction were greater than 1.0 (Table 22). This indicated that the varieties did not all respond to P fertilization in the same manner.

Based on multiple comparison tests of interaction, no significant differences in yield response among the varieties to P fertilization were observed at ITKA-L-10 with the adequate level of N (Table 25) or at ITKA-O-10 with either the low or adequate level of lime (Table 28). However at ITKA-L-10 with the low level of N, yield responses to P fertilization of three varieties, i.e., UPCA-1, Harapan and H610, were significantly different from that of variety H6 (Table 25). The test of contrasts showed that the three varieties did

Table 28. Mean yields and yield response of maize varieties to lime and P fertilization on the Hydric Dystrandept at ITKA-0-10, Indonesia, dry season 1977

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to L		Response to P	
	Low L Low P	Low L Adq. P	Adq. L Low P	Adq. L Adq. P	Low P	Adq. P	Low L	Adq. L
Bima	4635	5181	3821	5918	-814	737	546 a	2097 a
Bastar Kuning	6380	6875	5703	7305	-677	430	495 a	1602 a
H610	4867	5373	3864	5205	-1003	-168	687 a	1342 a
Harapan	6483	6726	5961	7095	-522	369	243 a	1133 a
DMR Comp. 2	5651	6008	5182	5923	-469	-85	357 a	741
H6	7258	6769	6762	7077	-496	308	-489 a	315 a

[a] L refers to lime.
Test of contrasts: BLSD (k = 50) for comparing mean yields between P treatments under the same lime level for the same or different varieties: 1428, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The LxV and the LxPxV effects have F values < 1.0.

not respond significantly to P fertilization but the yield of H6 decreased significantly due to increased P application (Table 25).

It is noteworthy that with low P fertilization variety H6 produced the highest yields in most of the experiments. Soil-P on the experimental sites was high, therefore H6 was probably able to take up sufficient P while the other varieties could not. These results indicate that H6 was more efficient than the other varieties in using phosphorus.

Response to N x P

The interaction effects of NxPxV were not significant in any of the experiments at ITKA, Indonesia. However, even though F values for the effects of NxPxV were greater than 1.0 for experiments at ITKA-L-10 and ITKA-F-10 (Table 22) no significant difference in yield response to NP fertilization was found among the varieties (Tables 25 and 27).

The test of contrasts indicated that most varieties did not respond significantly to increased NP fertilization, except variety Bastar Kuning at ITKA-L-10 (Table 25) and variety Wonosobo at ITKA-F-10 (Table 27).

PHILIPPINES

Response to nitrogen

One of the two experiments conducted at the PUC site in the Philippines with N and P as the fertilization treatments, i.e., experiment at PUC-L-22 in the wet season 1980, yielded an F value greater than 1.0 (Table 22). This indicated that there was a differential yield response to N fertilization among the varieties.

The multiple comparison tests of interaction showed that under the low level of P the yield response of variety H610 to N fertilization differed significantly from that of variety UPCA-1. However under adequate P their yield responses to N were not significantly different (Table 29). The significant difference in response to N under the low P level was due to the increase in yield of H610 along with the decrease in yield of UPCA-1. However, according to the test of contrasts, neither the increase or decrease in yield was significant. With adequate P, however, all varieties, except H6, responded significantly to increased N fertilization (Table 29).

In the other two experiments at PUC, lime and P were the fertilization treatments, and in the experiment at PUC-L-10 dry season 1977 an F value greater than 1.0 was obtained for the effect of lime x variety (Table 22). The yield responses of the varieties, however, did not differ significantly, and all of the varieties did not respond significantly to lime. On the other hand, it should be noted that the yields of varieties X306B and UPCA-1 under low P and varieties X306B and Bastar Kuning under adequate P decreased considerably due to lime application (Table 30).

Response to phosphate

The phosphate x variety (P x V) interactions were significant and highly significant at PUC-L-10 and PUC-L-22, respectively. At PUC-M-10 the effect of the P x V interaction was not significant, but its F value was greater than 1.0 (Table 22).

At PUC-M-10 all varieties responded significantly to P fertilization, either with low or adequate N; but their yield

Table 29. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at PUC-L-22, the Philippines, wet season 1980

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
	Low N	Low N	Adq. N	Adq. N	Response to N		Response to P		Response to NP
	Low P	Adq. P	Low P	Adq. P	Low P	Adq. P	Low N	Adq. N	
H610	1679	5331	2300	6816	621 a	1485 a	3652 a	4516 a	5137 a
X304C	2513	5475	2315	6782	-198 ab	1307 a	2962 a	4467 a	4269 ab
NK-T66	2526	4960	2951	6133	425 ab	1174 a	2433 bc	3182 b	3607 bc
H6	2460	5279	2802	5871	342 ab	592 a	2819 b	3069 b	3411 bc
UPCA-1	2780	4559	2383	5750	-397 b	1191 a	1779 c	3367 b	2970 c

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 807; between P treatments under the same N level for the same or different varieties: 549; between the low NP and the adequate NP treatments for the same or different varieties: 790, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test.

Table 30. Mean yields and yield responses of maize varieties to lime and P fertilization on the Hydric Dystrandept at PUC-L-10, the Philippines, dry season 1977

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to L		Response to P	
	Low L Low P	Low L Adq. P	Adq. L Low P	Adq. L Adq. P	Low P	Adq. P	Low L	Adq. L
UPCA-1	5362	6348	4425	6273	-937	-75	987 a	1848 a
X306B	3533	5471	2863	4366	-670	-1105	1938 a	1503 ab
DMR Comp. 1	4794	5567	4723	5641	-70	74	774 a	917 abc
H610	4443	4892	5162	4961	719	69	449 a	-201 bc
Bastar Kuning	1853	2495	2012	1478	159	-1017	642 a	-534 c

[a] L refers to lime.
Test of contrasts: BLSD (k = 50) for comparing mean yields between lime treatments under the same P level for the same or different varieties: 1594; between P treatments under the same lime level for the same or different varieties: 1246, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$). The lime x V effect has an F value < 1.0 but not significant and no significant difference between yield responses. The LxPxV effect has an F value < 1.0.

responses did not differ significantly (Table 31). Therefore the varieties can be said to respond similarly to P fertilization. However these results were not confirmed by the results of experiments at either PUC-L-10 or PUC-L-22. Furthermore, the results from these last two experiments did not agree with each other. Although varieties responded differently to P fertilization in these two experiments, their responsiveness was not consistent.

In the experiment at PUC-L-10 with low lime no significant difference in yield response to P fertilization was observed among the varieties, although one variety, X306B, did have a significant yield increase to added P (Table 30). With adequate lime, the yield response of variety UPCA-1 to P fertilization was significantly higher than that of varieties H610 and Bastar Kuning. Moreover, the yield response of varieties UPCA-1 and X306B was also significantly higher than that of variety Bastar Kuning. These differences were due to significant increases in the yields of varieties UPCA-1 and X306B, whereas the yields of H610 and Bastar Kuning decreased with increasing P fertilization although the decreases were not significant (Table 30).

In the experiment at PUC-L-22, on the other hand, differential responses to P fertilization were observed with both low and adequate N levels, and the yields of all varieties increased significantly with increasing P fertilization under the two N levels. The yield responses of varieties H610 and X304C were significantly higher than those of varieties NK-T66, H6, or UPCA-1, under both the low and the adequate levels of N (Table 29).

Table 31. Mean yields and yield responses of maize varieties to N and P fertilization on the Hydric Dystrandept at PUC-M-10, the Philippines wet season 1978

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
	Low N	Low N	Adq. N	Adq. N	Response to N		Response to P	
	Low P	Adq. P	Low P	Adq. P	Low P	Adq. P	Low N	Adq. N
H610	1656	2756	2853	5052	1107	2296	1120 a	2469 a
H788	1845	3248	2654	5031	809	1783	1403 a	2377 a
UPCA-1	1501	3161	2349	4704	848	1543	1660 a	2354 a
H6	1592	2969	2475	4467	883	1498	1377 a	1992 a
Bima	1607	2673	2569	4435	962	1762	1066 a	1866 a

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between P treatments under the same N level for the same or different varieties: 632, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV and the NxPxV have F values < 1.0.

It should be noted that under the low N and P rates variety UPCA-1 produced the highest yields in nearly all experiments, except PUC-M-10. This indicated that UPCA-1 was tolerant to low soil fertility conditions. However, its responsiveness to fertilization was not consistent.

Response to N x P

The effect of the N x P x V interaction at PUC-L-22 was not significant, but its F value was greater than 1.0 (Table 22). The multiple comparison tests of interaction showed that the yield response of variety H610 to NP fertilization was significantly higher than those of varieties NK-T66, H6 and UPCA-1. All of the varieties tested in this experiment, however, responded significantly to increasing NP fertilization (Table 29).

In the experiment at PUC-C-10 where the fertilization treatments were lime x P, the interaction effect of lime x P x V was significant at the 10% level (Table 22). The multiple comparison test of interaction, however, indicated no significant difference in yield responses among the varieties to lime x P fertilization. Also no significant yield increase was observed, according to the test of contrasts (Table 32).

4.2.2 Tropeptic Eutrustox network

Two experiments were conducted on the Tropeptic Eutrustox at Molokai, Hawaii. Only one of these experiments, Molokai-D-10, showed significant effects of fertilization and differential response to fertilization among the varieties (Tables 21 and 22). Therefore the results from this experiment are discussed in this section. The yield data from the other experiment, Molokai-C-10, are given in Appendix C1.

Response to nitrogen

The effect of the N x V interaction for experiment at Molokai-D-10 was not signifivant, but its F value was greater than 1.0

Table 32. Mean yields and yield responses of maize varieties to lime and P fertilization on the Hydric Dystrandept at PUC-C-10, the Philippines, dry season 1976

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
	Low L Low P	Low L Adq. P	Adq. L Low P	Adq. L Adq. P	Response to L		Response to P		Response to LP
					Low P	Adq. P	Low L	Adq. L	
DMR Comp. 2	5345	5513	5230	5996	-115	483	168	766	651 a
DMR Comp. 1	5369	5939	5325	5895	-44	120	370	570	526 a
H788	5717	5758	5210	6215	-507	457	41	1005	498 a
UPCA-1	6025	6968	6587	6289	562	-679	943	-298	264 a
H610	5594	5851	5662	5780	68	-71	257	118	186 a

[a] L refers to lime.
Test of contrasts: BLSD (k = 50) for comparing mean yields between the low LP and the adequate LP for the same or different varieties: 860, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The LxV and the PxV effects have F values < 1.0.

(Table 22). The multiple comparison tests for interaction showed that under the low P level the yield responses of the varieties to N fertilization did not differ significantly, while under the adequate level of P the yield response of variety H610 to N fertilization was was higher than that of variety X304C (Table 33).

However, the test of contrasts showed that under the low level of P the Pioneer varieties, X6877, X5859, X4816, X304C, and X5800, responded significantly to N fertilization, while the Hawaiian varieties, H763, H688, and H610, did not respond significantly to N fertilization although they also had increased yields with the higher level of N (Table 33). Furthermore, with the low N-low P treatment, the Pioneer varieties produced higher yields than the Hawaiian varieties although the differences were not significant. The difference in magnitude of the response to N of the Pioneer and Hawaiian varieties resulted in the yields of Pioneer varieties being significantly higher than the yields of Hawaiian varieties (Table 33).

The test of contrasts for mean yields of varieties tested at Molokai-D-10 with adequate P indicated that only one Pioneer variety, X6877, and two Hawaiian varieties, H610 and H763, responded significantly to increasing N fertilization. There were no consistent trends in the differences in yields among the two groups of varieties grown with adequate P (Table 33).

Response to Phosphate

The effect of the P x V interaction for the experiment at Molokai-D-10 was not significant and the F value was less than 1.0 (Table 22). Since the main effect of P fertilization was significant (Table 21), it can be concluded that all varieties tested in this experiment responded similarly to P fertilization (Table 33).

Table 33. Mean yields and yield responses of maize varieties to N and P fertilization on the Tropeptic Eutrustox at Molokai-D-10, Hawaii, wet season 1978

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
	Low N	Low N	Adq. N	Adq. N	Response to N		Response to P		Response
	Low P	Adq. P	Low P	Adq. P	Low P	Adq. P	Low N	Adq. N	to NP
X6877	4272	5628	7527	7972	3255 a	2344 ab	1356	445	3700 a
X4816	4053	5774	6703	7409	2650 a	1635 a	1721	706	3356 a
H610	3416	3923	4643	6592	1228 a	2669 a	507	1949	3177 a
X5859	4852	6872	7789	7922	2937 a	1050 ab	2020	133	3070 a
H688	3605	4849	4846	6650	1240 a	1662 ab	1244	1804	3045 a
H763	3306	3790	4955	6185	1647 a	2395 ab	484	1230	2879 a
X5800	4897	5795	6926	7527	1829 a	1732 ab	898	801	2629 a
X304C	4804	7024	7258	7407	2454 a	383 b	2220	149	2604 a

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 1766; between the low NP and the adequate NP treatments for the same or different varieties: 1284, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The PxV effect has an F value < 1.0.

Response to N x P

The effect of the N x P x V interaction for the experiment at Molokai-D-10 was significant (Table 22). However, based on the test of multiple comparisons for interaction, the yield responses of the varieties to NP fertilization were not significantly different. This result was verified by the test of contrasts of their mean yields which showed that all varieties responded significantly to NP fertilization (Table 33).

4.2.3 Typic Paleudult network

INDONESIA

Response to nitrogen

The effect of the N x V interaction was significant ($P < 0.10$) in one of four experiments on the Typic Paleudult at the Nakau site in Indonesia, i.e., the experiment at Nakau-E-10 in the early dry season 1979 (Table 22). The multiple comparison tests of interaction showed no significant difference in yield response among the varieties to N fertilization with the adequate P level. However, the test of contrasts showed that varieties Metro and H159 responded significantly to increased N application (Table 34).

With the low level of P, on the other hand, although no variety responded significantly to N fertilization, the yield response of variety H159 to N fertilization was significantly higher than that of variety H610. This significant difference apparently was due to considerable increase in the yield of variety H159, whereas the yield of variety H610 decreased with increasing N application (Table 34).

Table 34. Mean yields and yield responses of maize varieties to N and P fertilization on the Typic Paleudult at Nakau-E-10, Indonesia, early-dry season 1979

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
					Response to N		Response to P	
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P	Low P	Adq. N	Low N	Adq. N
DMR 5	5197	5403	4822	6700	-375 ab	1297 a	206	1878
H159	4223	5211	5261	6796	1038 a	1585 a	988	1535
H610	5333	5004	4487	5946	-846 b	942 a	-329	1459
Metro	5963	5212	6453	7497	440 ab	2285 a	-751	1094

[a] Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 1342; between P treatments under the same N level for the same or different varieties: 1540, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV effect has an F value > 1.0 but not significant and no significant difference between yield responses. The NxPxV effect has an F value < 1.0.

The experiment at Nakau-B-10 had an F value greater than 1.0 for the N x V interaction (Table 22). However the varieties did not differ significantly in their response to N at either low or adequate P. None of the varieties responded significantly to increased N fertilization under the low level of P. Under the adequate level of P two varieties, H159 and H6, responded significantly to N fertilization (Table 35).

Response to phosphate

The response to phosphate was similar among the tested varieties in three of the four experiments at Nakau, while in the experiment at Nakau-B-10 in the wet season 1979 the responses of the varieties to P fertilization differed significantly (Table 22). The multiple comparison tests of interaction showed that varieties H6 and Kodok had significantly greater response to P fertilization than variety Metro whose yield decreased with increasing P fertilization under the low level of N (Table 35).

However, with adequate N the pattern of response to P fertilization changed and yields of varieties H6 and H159 were significantly higher than those of varieties Metro and Kodok, with H6 being the most responsive and Kodok the least responsive (Table 35).

Although P x V effects in experiments at Nakau-E-10 in the early-dry season 1979 and at Nakau-E-20 in the dry season 1980 were not significant, their F values were greater than 1.0 (Table 22). However, the response to P fertilization did not differ significantly among varieties with either low or adequate N in both experiments. The response of individual varieties to P fertilization was not

Table 35. Mean yields and yield responses of maize varieties to N and P fertilization on the Typic Paleudult at Nakau-B-10, Indonesia, wet season 1979

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]				
	Low N	Low N	Adq. N	Adq. N	Response to N		Response to P		Response
	Low P	Adq. P	Low P	Adq. P	Low P	Adq. P	Low N	Adq. N	to NP
H6	2983	4984	3230	6800	247	1816	2001 a	3590 a	3819 a
H159	3598	4229	3858	7347	260	3118	631 ab	3489 a	3749 a
Kodok	4749	6157	6178	6686	1429	529	1408 a	508 b	1937 ab
Metro	5457	5033	4855	6385	-602	1352	-424 b	1530 b	927 b

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 1738; between P treatments under the same N level for the same or different varieties: 1283; between the low NP and the adequate NP treatments for the same or different varieties: 1429, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV effect has an F value > 1.0 but not significant and no significant difference between yield responses.

significant with low N at Nakau-E-10 (Table 34) and with either low or adequate N at Nakau-E-20 (Table 36). With adequate N at Nakau-E-10 yield of variety DMR-5 increased significantly with added P (Table 34).

Response to N x P

The effect of the N x P x V interaction was significant in one of four experiments on the Typic Paleudult at Nakau sites in Indonesia, i.e., at Nakau-B-10 in the wet season 1979 (Table 22).

The multiple comparison test of interaction showed that varieties H6 and H159 gave significantly higher response to NP fertilization than variety Metro while the test of contrasts showed that not only H6 and H195 but also variety Kodok responded significantly to NP fertilization (Table 35).

PHILIPPINES

Response to nitrogen

A significant N x P effect was observed in one of the two experiments on the Typic Paleudult at Davao, in the Philippines, i.e., at Davao-G-10 in the late-wet season 1979 (Table 22).

Based on the multiple comparison test of interaction, variety X304C was found to be the most responsive variety to N fertilization under both the low and adequate levels of P (Table 37). Variety UPCA-1 gave the second highest response, but its yield was not significantly higher than those of varieties Tiniguib and DMR Comp. 1 under the low level of P, and it was not significantly different from the yield responses of varieties Tiniguib, DMR Comp. 1 and NK-T66 under the adequate level of P.

Table 36. Mean yields and yield responses of maize varieties to N and P fertilization on the Typic Paleudult at Nakau-E-20, Indonesia, dry season 1980

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N	Response to N		Response to P	
					Low P	Adq. P	Low N	Adq. N
H610	3243	3700	3013	3787	-230	87	457 a	774 a
X304C	3643	4487	3554	4229	-89	-258	844 a	675 a
Tiniguib	2966	3281	2678	3021	-288	-260	315 a	343 a
Kodok	2328	3072	2923	2651	595	-421	744 a	-272 a
H6	3297	3329	3421	3034	124	-295	32 a	-387 a
Arjuna	3674	3659	3436	2993	-238	-666	-15 a	-443 a

[a] Test of contrasts: BLSD (k = 50) for comparing mean yields between P treatments under the same N level for the same or different varieties: 1085, according to the Waller-Duncan k-ratio t test.

[b] Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The NxV and the NxPxV have F values < 1.0.

Table 37. Mean yields and yield responses of maize varieties to N and P fertilization on the Typic Paleudult at Davao-G-10, The Philippines, late-wet season 1979

Maize variety	Mean yield (kg/ha)[a]				Yield response (kg/ha)[b]			
	Low N	Low N	Adq. N	Adq. N	Response to N		Response to P	
	Low P	Adq. P	Low P	Adq. P	Low P	Adq. P	Low N	Adq. N
NK-T66	1808	1939	2259	2415	450 c	476 c	131	156
UPCA-1	2219	2549	3927	3987	1708 b	1438 ab	330	60
DMR Comp. 1	2905	3107	3927	3617	1016 bc	510 b	202	-304
Tiniguib	2507	3069	3817	3456	1311 bc	387 b	562	-361
X304C	3624	4343	6686	6111	3062 a	1768 a	719	-575

[a]Test of contrasts: BLSD (k = 50) for comparing mean yields between N treatments under the same P level for the same or different varieties: 800, according to the Waller-Duncan k-ratio t test.

[b]Test of interactions: Yield responses within the same column followed by the same letter are not significantly different ($P < 0.10$), according to the Waller-Duncan k-ratio t test. The PxV and the NxPxV effects have F values < 1.0.

It should be noted, however, that based on the test of contrasts, all varieties except NK-T66, responded significantly to increased N fertilization under the low level of P, but with adequate P only varieties X304C and UPCA-1 responded significantly to N (Table 37). This generally supports the results of the multiple comparison test of interaction. Variety X304C produced the highest yields under all fertility conditions in this experiment.

The F value of the N x V interaction was less than 1.0 in the experiment at Davao-G-10 (Table 22). Since the effect of N fertilization was significant (Table 21), it can be said that all varieties tested in this experiment responded similarly to N fertilization. Yield data for this experiment are given in Appendix C2.

Response to phosphate

Neither experiments at the Davao site showed a significant effect of P fertilization (Table 21), and the effects of the P x V interactions were also not significant with F values less than 1.0 (Table 22). Therefore, the responsiveness to P fertilization of the varieties tested in these experiments could not be evaluated.

4.2.4 Discussion

Comparisons were made of the response to N and P fertilizer of many maize varieties in 19 field experiments conducted in three soil families in three countries. A majority of the varieties tended to respond to a similar degree. Some varieties, however, exhibited different capacities to respond to N or P fertilization. Not only did the yield response vary among the varieties, but the yield levels attained at either the low or adequate fertilization treatment were also different. The results are summarized in Table 38 where varieties with significant yield response are listed.

Varieties which were responsive to N fertilization under low P were not necessarily the ones that were responsive to N under adequate P. Similar results were obtained with regard to the responsiveness of varieties to P fertilization under low and adequate N. Likewise, maize varieties that responded significantly to N were not always the ones that responded significantly to P fertilization.

The differential responses of maize varieties to N or P fertilization observed in this study suggest that maize varieties can be selected specifically for their responsiveness to certain nutrients. These results support the findings of many other workers who reported differential response to N by varieties of maize (Hay et al., 1953; Zieserl and Hageman, 1962; Schrader et al., 1966; Jung et al., 1972; Beauchamp et al., 1976; Chevalier and Schrader, 1977; Pollmer et al., 1979), and also differential response to P fertilization (De Turk et al., 1933; Smith, 1934; Gorsline et al., 1964; Clark and Brown, 1974; Pulam, 1978).

One explanation offered for varietal differences in response to fertilization is the difference in their metabolic processes which affect the efficiency of nutrient utilization. It was reported that maize varieties and inbreds differed markedly in their nitrate reduction capacities (Zieserl and Hageman, 1962; Schrader et al., 1966). Nitrate reductase activity has been shown to have a significant positive correlation with grain protein and grain yield (Deckard et al., 1973). In the case of phosphate, Woolhouse

Table 38. Frequency of yield response of maize varieties to N and P fertilization in three countries: a. Hawaii

Maize variety	Hydric Dystrandept				Tropeptic Eutrustox			
	Response to N		Response to P		Response to N		Response to P	
	Low P	Adq. P	Low N	Adq. N	Low P	Adq. P	Low N	Adq. N
H610	0/3[a]	0/3	0/3	0/3	0/2	1/2	0/2	1/2
H688	0/2	0/2	0/2	0/2	0/2	0/2	0/2	1/2
H763	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1
H788	0/2	0/2	0/2	0/2	0/1	0/1	0/1	0/1
Phoenix 1110					0/1	0/1	0/1	0/1
Cargill 111					0/1	0/1	0/1	0/1
X304A	0/1	0/1	0/1	0/1				
X304B	0/2	0/2	0/2	0/2	0/1	0/1	0/1	0/1
X304C	0/3	0/3	0/3	0/3	1/2	0/2	1/2	0/2
X306B	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
X4816	1/1	0/1	0/1	0/1	1/1	0/1	1/1	0/1
X4817	0/2	0/2	0/2	0/2				
X5800	1/1	0/1	0/1	0/1	1/1	1/1	0/1	0/1
X5859	0/1	0/1	0/1	0/1	1/1	0/1	1/1	0/1
X6819	0/1	0/1	0/1	0/1				
X6874	0/1	0/1	0/1	0/1				
X6877	0/1	0/1	0/1	0/1	1/1	1/1	0/1	0/1

Table 38. (Continued) Frequency of yield response of maize varieties to N and P fertilization in three countries: b. Indonesia

Maize variety	Hydric Dystrandept				Typic Paleudult			
	Response to N		Response to P		Response to N		Response to P	
	Low P	Adq. P	Low N	Adq. N	Low P	Adq. P	Low N	Adq. N
H6	0/4[a]	1/4	0/4	0/4	0/3	2/3	2/3	2/3
Bastar Kuning	0/3	1/3	0/3	0/3				
Harapan	0/4	0/4	0/4	0/4				
Bima	0/2	1/2	0/2	2/2				
Wonosobo	0/2	1/2	0/2	0/2	0/1	1/1	1/1	0/1
DMR Comp. 2	0/3	0/3	0/3	0/3				
UPCA-1	0/2	0/2	0/2	0/2	0/1	0/1	0/1	0/1
H610	0/3	0/3	0/3	0/3	0/2	0/2	0/2	0/2
Kodok					0/3	1/3	1/3	1/3
Metro					0/2	1/2	0/2	1/2
H159					0/2	1/2	0/2	1/2
DMR-5	0/1	0/1	0/1	0/1	0/2	1/2	1/2	1/2
X304C					0/1	0/1	0/1	0/1
Tiniguib	0/1	0/1	0/1	0/1	0/2	1/2	1/2	1/2
Arjuna					0/1	0/1	0/1	0/1

Table 38. (Continued) Frequency of yield response of maize varieties to N and P fertilization in three countries: c. Philippines

Maize variety	Hydric Dystrandept				Typic Paleudult			
	Response to N		Response to P		Response to N		Response to P	
	Low P	Adq. P	Low N	Adq. N	Low P	Adq. P	Low N	Adq. N
UPCA-1	1/4[a]	2/4	2/4	3/4	2/2	2/2	0/2	0/2
DMR Comp. 1	0/2	0/2	0/2	0/2	1/1	0/1	0/1	0/1
DMR Comp. 2	0/1	0/1	0/1	0/1				
H610	1/4	2/4	2/4	2/4	1/1	1/1	0/1	0/1
H788	1/2	1/2	1/2	1/2				
X306B	0/1	0/1	1/1	1/1				
Bastar Kuning	0/1	0/1	0/1	0/1				
H6	1/2	1/2	1/2	1/2	1/1	1/1	0/1	0/1
Bima	1/1	1/1	1/1	1/1				
Tiniguib					2/2	1/2	0/2	0/2
NK-T66	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
X304C	0/1	1/1	1/1	1/1	2/2	2/2	0/2	0/2

[a]Upper figures are number of experiments in which the varieties responded significantly to fertilization; lower figures are total number of variety experiments considered.

(1969) suggested that adaptation of plants to P stress might be a result of high phosphatase activity in the roots, and Clark and Brown (1974) showed that phosphatase activity of two corn inbreds increased under P stress. Furthermore, the increase in phosphatase activity was greater in the inbred that was more efficient under P stress. The more efficient inbred also was able to lower the pH of the culture medium faster during growth than was the inefficient inbred, this may increase P availability. However, the causes of the differential responses of maize varieties to N and P in this study were not known.

Although extensive studies have been carried out, as cited above, and maize varieties are known to differ in their ability to respond to fertilization, it is not known, thus far, what specific types of maize are more responsive to fertilization. The present study was not able to differentiate among the various types of maize. This does raise the question of whether or not maize varieties can be classified according to their differential response to fertilization. Such a classification has been developed for rice by Yamada (1959) where it was shown that japonica varieties gave a striking response in grain yield to increasing fertilization. The indica varieties, on the other hand, were characterized as producing relatively higher yields without fertilizer, but did not respond to higher fertility levels.

Attempts to differentiate the maize varieties according to their response to N and P fertilization in the Hydric Dystrandept network in Hawaii and Indonesia have been overwhelmed by the high soil fertility status of the experimental sites. Nevertheless some varieties, as shown in Table 37, were found to respond significantly to N or P fertilization. The results of this study, however, may not properly represent the response of these varieties when they are planted in less fertile soils. Hence, results of this study are considered tentative and need to be confirmed with further tests.

Despite the lack of response to fertilization, some interesting trends were noted in experiments on the Hydric Dystrandept sites in Hawaii and Indonesia. In Hawaii, variety H688, a Hawaiian variety, in the dry season 1978 (Table 24) consistently produced higher yields than Pioneer variety X304B. Based on the average of all fertilization treatments, the yield of variety H688 was about 8.5 tons/ha, while the yield of X304B was about 7.4 tons/ha. Yields of these two varieties were significantly different with the low N-adequate P treatment which is in agreement with the findings of Azih (1978) who reported that variety H688 outyielded variety X304B by 700 kg and 200 kg/ha in two seasons at the Kohala Experimental Station on the Island of Hawaii.

However, it was also found in the present study that variety H788, another Hawaiian variety, produced lower yields than Pioneer varieties X304B, X304C, X4816, and X4817 in the wet season 1978 (Table 23). With the adequate P treatment yield of H788, 4.2 tons/ha, was significantly lower than those of X304C and X4816 which produced yields of about 6.3 tons/ha.

In the Hydric Dystrandept network in Indonesia, variety H6, an Indonesian variety, consistently produced high yields under low fertilization treatment in all experiments except that at ITKA-N-10 (Table 26). However only in one case H6 responded significantly to N fertilization (Table 38). It is not known whether the lack of response of H6 to fertilization is actually a characteristic of the variety or simply due to the high soil fertility level of experimental sites. The fact that H6 produced the highest yields may indicate that the variety has greater capacity to take up and/or utilize nutrients than other varieties.

In the Hydric Dystrandept network in the Philippines, variety UPCA-1, a Philippine variety, generally produced the highest yields, but it was not as consistent as was H6 in Indonesia. In some cases the introduced varieties (H610, H788, or X304C) outyielded variety UPCA-1.

In the Tropeptic Eutrustox network in Hawaii all of the Pioneer varieties (X6877, X5859, X4816, X304C, and X5800) tested in the experiment at Molokai-D-10 (Table 33) outyielded the Hawaiian varieties (H763, H688, and H610) in all fertilization treatments. Plant analysis data (cf. section 4.3.2) revealed that the N content of the ear leaves of the Pioneer varieties was higher than those of the Hawaiian varieties. This suggests that the Pioneer varieties are N-efficient varieties.

In Indonesia the yield of H6 at the Typic Paleudult site was not as good as its yield at the Hydric Dystrandept site. In many cases its yields were lower than the yields of other local variety Metro, or the introduced varieties H610 or X304C. Similarly, in the Philippines the performance of UPCA-1 at the Typic Paleudult site was not as good as its performance at the Hydric Dystrandept site. Its yields in certain experiments were lower than yields of the other

Philippine varieties Tiniguib or DMR Comp. 1, or the introduced variety X304C. It might be added that in both countries variety X304C tended to produce the highest yields.

4.3 Variability in the Performance of Maize Varieties Grown on the Same or Different Soil Families

4.3.1 Variation in growth and yield

VARIETY EXPERIMENT

The growth characteristics and the yields of maize variety H610 grown in variety experiments in three soil families in three countries are presented in Table 39. It is apparent that the same variety grew differently on the various sites, and during different seasons at the same site. Because inherent (unexplained) variation in yields of H610 in the experiment at ITKA-L-10 in Indonesia was exceptionally high (CV = 41.3%), this experiment was excluded from the evaluation.

Within the Hydric Dystrandept network, maize variety H610 grew fastest in the Philippines and was followed by Indonesia and Hawaii. Plant height at 30 days after emergence was only about 25 cm in Hawaii, while in the Philippines it was about 75 cm. In Hawaii, 50% tasseling was attained about 90 days after planting, while in the Philippines it took only about 60 days to reach this stage. However, at 100% tasseling the plants in Hawaii were taller than those in the Philippines. A longer growing period was needed by H610 grown in Hawaii as on the average it took about 190 days to reach maturity, while in the Philippines it took only about 120 days from planting to harvesting.

Table 39. Plant characters of maize variety H610 grown on three soil families

Soil/ country/ site & season	Plant height at 30 days					Days to 50% tasseling					Plant height at 100% tasseling					Days to harvest	Grain yield				
	1[a]	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean		1	2	3	4	Mean
	- - - - - cm - - - - -										- - - cm - - - - -						- - - - - kg/ha - - - - -				
Hydric Dystrandept																					
HAWAII																					
Iole-G-10 wet '78	27	29	27	27	28	100	99	101	100	100	206	199	201	204	203	188	4718	5022	4852	4886	4870
Iole-H-10 dry '78	-	-	-	-	-	72	72	70	70	71	202	219	230	235	222	181	7537	7127	8846	8542	8013
Iole-G-11 late-wet '78	27	28	25	28	27	93	91	91	93	92	192	199	210	211	203	200	5621	6626	6945	8229	6855
Mean	27	29	26	28	28	88	87	87	88	88	200	206	214	217	209	190	5959	6258	6881	7219	6579
INDONESIA																					
ITKA-O-10 dry '77[b]	-	-	-	-	-	100	100	100	100	100	-	-	-	-	-	145	4687	5373	3864	5205	4782
ITKA-F-10 dry '79	39	49	36	52	44	101	101	101	101	101	185	199	161	201	187	176	5759	4826	5814	6920	5830
Mean	39	49	36	52	44	101	101	101	101	101	185	199	161	201	187	161	5223	5100	4839	6063	5306
PHILIPPINES																					
PUC-C-10 dry '76[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	5594	5851	5662	5780	5722
PUC-L-10 dry '77[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	123	4443	4892	5162	4961	4864
PUC-M-10 wet '78	73	101	77	102	88	63	59	59	57	60	161	191	173	207	183	125	1656	2756	2583	5052	3012
PUC-L-22 wet '80	54	75	56	78	66	63	55	62	53	58	146	226	164	228	191	124	1679	5331	2300	6816	4031
Mean	64	88	67	90	77	63	57	61	55	59	154	209	169	218	187	121	3343	4708	3927	5652	4407
Soil family mean	44	56	44	57	51	85	82	84	82	83	182	205	190	214	198	157	4633	5311	5114	6266	5331
Tropeptic Eutrustox																					
HAWAII																					
Molokai-C-10 dry '78	81	95	87	91	91	66	64	64	64	65	-	-	-	-	-	159	5474	6625	7028	7253	6595
Molokai-D-10 late-wet '79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	180	3416	3923	4643	6592	4644
Soil family mean	81	95	87	91	91	66	64	64	64	65	-	-	-	-	-	170	4445	5274	5836	6923	5619
Typic Paleudult																					
INDONESIA																					
Nakau-E-10 early-dry '79	153	180	160	190	170	-	-	-	-	-	226	251	219	255	238	114	5333	5004	4487	5946	5193
Nakau-E-20 dry '80	-	-	-	-	-	64	64	64	64	64	-	-	-	-	-	111	3243	3700	3013	3787	3436
Mean	153	180	160	190	170	64	64	64	64	64	226	251	219	255	238	113	4288	4352	3750	4867	4315
PHILIPPINES																					
Davao-B-13 dry '80	104	106	98	93	101	53	51	52	52	52	205	205	210	212	208	105	2727	2645	5005	4383	3689
Soil family mean	129	143	129	141	136	59	58	58	59	58	216	228	215	233	223	109	3767	3783	4168	4705	4106

[a] 1, 2, 3, and 4 indicate fertilization treatments: low N-low N, low N-adq. P, adq. N-low P, and adq. N-adq. P, respectively.

[b] The treatment variables in this experiment were lime and P, instead of N and P.

The growth of variety H610 on the Hydric Dystrandept site in Indonesia was generally intermediate to that in Hawaii and the Philippines. Its height of about 50 cm at 30 days was greater than that in Hawaii, but less than that in the Philippines. The 50% tasseling stage was reached at about 100 days, a period which was longer than that needed in Hawaii and the Philippines, but its height at 100% tasseling was about 190 cm, which was about the same as that in the Philippines, but a little shorter than that in Hawaii.

The yields of H610 within the Hydric Dystrandept network varied considerably. Its variation due to season and/or location was much greater than the variation due to fertilization, except at PUC-M-10 and PUC-L-22, both in the Philippines. These results agree with those of the evaluation of responses of maize varieties to fertilization (cf. section 4.2). It has been shown that variety H610 did not respond significantly to either nitrogen or phosphate except at the two sites mentioned above, where H610 responded significantly to phosphate fertilization.

Figure 22 illustrates the variation (in percent) in yields of variety H610 in each block in a country, in terms of deviations from the soil family mean yield. When Figures 22a and 22b are compared, it is clear that the deviations from site to site were greater under low input (low N-low P treatment), -64.3 to 62.7%, than under high input (the adequate N-adequate P treatment), -22.0 to 31.3%.

The growth of variety H610 was fastest on the Typic Paleudult followed by the Tropeptic Eutrustox and the Hydric Dystrandept (Table 39). This is shown by the fact that plant height

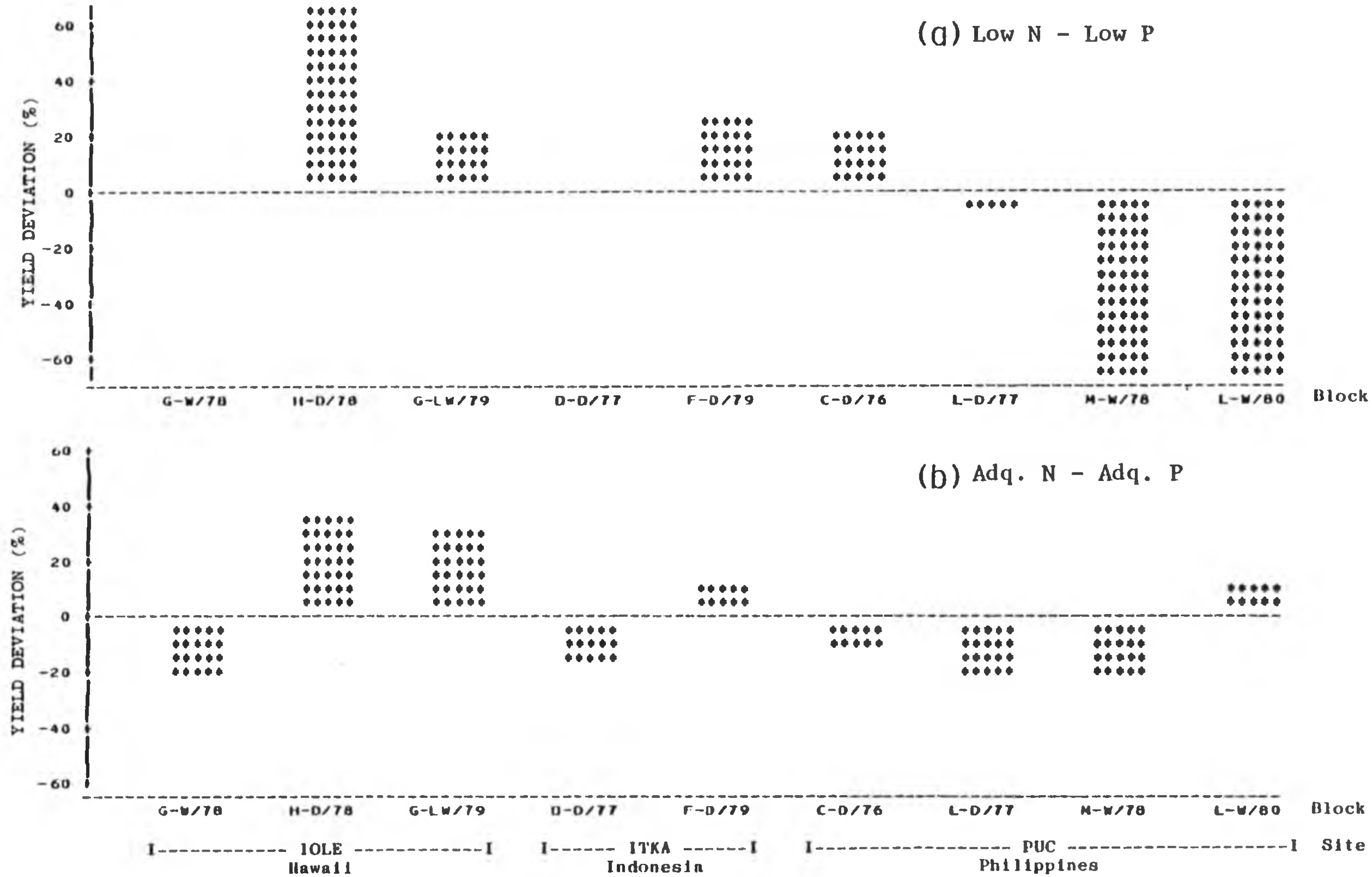


Figure 22. Deviation in the yield of maize variety H610 at individual locations from the mean yield of the soil family of the Hydric Dystrandepts.

was greatest at both 30 days and at 100% tasseling on the Typic Paleudult, and tasseling and harvest were also attained in the shortest growing periods on this soil family. This was particularly apparent in Indonesia where two soil families are compared within the same country.

It should be noted that higher yields were obtained at sites where plants grew more slowly and had a longer growing period in which to produce the grain. This was true both across countries within the same soil family and across soil families. Variety H610 grown on the Tropeptic Eutrustox produced 0.3 ton/ha more yield than when grown on the Hydric Dystrandept, and about 1.5 tons/ha greater yield than on the Typic Paleudult.

Variety H610 grown at sites that were responsive to P exhibited greater growth, higher yields, and shorter growing periods than on non-responsive sites, as might be expected. On the Hydric Dystrandept at the PUC site in the Philippines, variety H610 attained 50% tasseling about 6 days earlier and grew about 50 cm taller with adequate P fertilization. The effects of N fertilization were not as striking as the effects of P on these characteristics.

Within the Hydric Dystrandept network the correlation between plant height at 30 days after emergence and number of days to 50% tasseling was negative and significant (Table 40) indicating that the taller the plant at 30 days the sooner it would tassel. The correlation between plant height at 30 days and yield was also negative and significant, except under the adequate N-adequate P treatment (Table 40). This indicated that the taller the plant at 30 days the

Table 40. Correlation coefficients among several plant characters of maize variety H610

Soil/ Plant character	Plant character[a] H_{30}	H_t	D_t
Hydric Dystrandept			
Plant height			
30 days (H_{30})	--	0.05	-0.83**
100% tasseling (H_t)		--	-0.03
Days to 50% tasseling (D_t)			--
Grain yield			
low N-low P	-0.70**	0.81**	0.47*
low N-adq. P	-0.67**	0.50*	0.19
adq. N-low P	-0.68**	0.76**	0.26
adq. N-adq. P	-0.21	0.57**	-0.10
Mean	-0.35**	0.74**	0.17
Three soil families			
Plant height			
30 days (H_{30})	--	0.54**	-0.87**
100% tasseling (H_t)		--	-0.10
Days to 50% tasseling (D_t)			--
Grain yield			
low N-low P	-0.03	0.65**	0.47**
low N-adq. P	-0.25	0.31	0.34
adq. N-low P	-0.14	0.64**	0.19
adq. N-adq. P	-0.16	0.26	0.14
Mean	-0.09	0.56**	0.25**

[a] H_{30}, H_5, and D_t indicate plant height at 30 days, plant height at 100% tasseling, and number of days to 50% tasseling, respectively.

*, ** = significant at the 5 and 1% levels, respectively.

lower its yields, which is in agreement with the previous finding that plants which grew more slowly produced the highest yields. The correlation coefficient was not significant under adequate N-adequate P because plants in this treatment were tall and also produced high yields, particularly in the Philippines.

However, the relationships between plant height at tasseling and yield were all positive and correlation coefficients were larger than those for height at 30 days.

Across the three soil families, the correlation between plant height at 30 days and days to tasseling was negative and significant, but plant height at 30 days was not significantly correlated with yield. Positive and significant correlations were obtained between yield and number of days to 50% tasseling and plant height at 100% tasseling. This probably resulted from the differential inherent fertility of the sites used in this correlation. With low P application higher yields were obtained with plants grown on the Hydric Dystrandepts in Hawaii and Indonesia and also in the Typic Paleudult in the Philippines, where the plants were relatively tall and required a longer period to reach the tasseling stage. Native soil fertility was high in these three sites. The Philippines Hydric Dystrandept, in contrast, was very responsive to P and had very low native fertility. In addition, plant height was low and days to tasseling were shorter resulting in lower yields. However, this relationship did not hold when the high level of P was applied since the differential in inherent fertility was reduced by the P application.

Relationships between plant characters and several climatic factors were also studied. Plant characters were correlated with the daily average of climatic factors as well as with the cumulative solar radiation from planting until the respective plant characters were measured. In addition, yields were also correlated with the daily average of solar radiation during the period 4 weeks before and 4 weeks after tasseling. The resulting correlation coefficients are presented in Table 41.

In the Hydric Dystrandept network, the correlation between temperature, either maximum or minimum, with plant height at 30 days was positive and significant. This indicated that the higher the temperature during the first 30 days the taller the plants. On the other hand, the maximum temperature was negatively correlated with plant height at 100% tasseling and number of days to 50% tasseling, as well as with yields. This indicated that the plant attained 50% tasseling sooner on sites which had higher temperature (in Indonesia and the Philippines), but they were shorter and produced lower yields. The minimum temperature was significantly correlated only with number of days to 50% tasseling.

The correlation between solar radiation, either daily average or total radiation, with plant height at 30 days was positive and significant. Plant height at 30 days appears to be more affected by temperature than by solar radiation because the correlation coefficients of the former are larger than the latter. Daily average solar radiation was significantly correlated with plant height at 100%

Table 41. Correlation coefficients between plant characters of maize variety H610 and several climatic factors

Soil/ plant character	Temperature		Solar radiation			Relative humidity		Wind run
	Max.	Min.	Daily average	At tasseling [a]	Total [b]	Max.	Min.	
Hydric Dystrandept								
Plant height at 30 days								
low N-low P	0.91**	0.86**	0.77**	-	0.77**	0.45	-0.55*	-0.67**
low N-adq. P	0.98**	0.91**	0.84**	-	0.84**	0.46	-0.59*	-0.74**
adq. N-low P	0.93**	0.89**	0.81**	-	0.81**	0.45	-0.51	-0.65**
adq. N-adq. P	0.97**	0.89**	0.82**	-	0.82**	0.46	-0.63*	-0.77**
Mean	0.91**	0.85**	0.78**	-	0.78**	0.44**	-0.55**	-0.68**
Plant height at 100% tasseling								
low N-low P	-0.82**	-0.46	0.61**	-	0.71**	0.42	0.56*	0.66**
low N-adq. P	0.20	0.13	0.09	-	-0.25	0.34	-0.03	0.15
adq. N-low P	-0.57*	0.01	0.68**	-	0.40	0.26	0.77**	0.77**
adq. N-adq. P	0.15	0.35	0.19	-	-0.34	0.21	0.28	0.32
Mean	-0.32**	-0.04	0.39**	-	0.20	0.26*	0.40**	0.46**
Days to 50% tasseling								
low N-low P	-0.77**	-0.79**	0.19	-	0.85**	0.54*	-.21	0.10
low N-adq. P	-0.82**	-0.79**	0.20	-	0.85**	0.52*	-0.14	0.14
adq. N-low P	-0.76**	-0.80**	0.20	-	0.85**	0.57**	-0.22	0.11
adq. N-adq. P	-0.82**	-0.79**	0.23	-	0.87**	0.54*	-0.14	0.16
Mean	-0.89**	-0.84**	0.58**	-	0.93**	0.11	-0.50**	0.29**
Grain yield								
low N-low P	-0.61**	-0.32	0.09	0.23	0.40*	0.42*	0.14	0.52**
low N-adq. P	-0.52**	-0.27	0.28	0.36	0.40*	0.26	0.08	0.53**
adq. N-low P	-0.55**	-0.17	0.16	0.33	0.47*	0.46*	0.31	0.48*
adq. N-adq. P	-0.36	-0.20	0.30	0.49*	0.44*	0.11	-0.07	0.18
Mean	-0.49**	-0.22*	0.47**	0.31**	0.40*	0.31**	0.12	0.40**

Table 41. (Continued) Correlation coefficients between plant characters of maize variety H610 and several climatic factors

Soil/ plant character	Temperature		Solar radiation			Relative humidity		Wind run
	Max.	Min	Daily average	At tasseling[a]	Total[b]	Max.	Min.	
Three soil families								
Plant height at 30 days								
low N-low P	0.83**	0.89**	0.43*	-	0.43*	0.70**	-0.62**	-0.30
low N-adq. P	0.89**	0.90**	0.48**	-	0.49**	0.71**	-0.68**	-0.34
adq. N-low P	0.84**	0.90**	0.48**	-	0.48*	0.72**	-0.62**	-0.27
adq. N-adq. P	0.87**	0.85**	0.46*	-	0.46*	0.68**	-0.74**	-0.37
Mean	0.85**	0.87**	0.46**	-	0.46**	0.69**	-0.66	-0.32**
Plant height at 100% tasseling								
low N-low P	-0.02	0.11	0.10	-	0.16	0.45*	-0.13	0.18
low N-adq. P	0.48*	0.33	-0.19	-	-0.36	0.30	-0.55**	-0.21
adq. N-low P	-0.07	0.26	0.29	-	0.08	0.31	0.17	0.40*
adq. N-adq. P	0.45*	0.42*	-0.13	-	-0.40	0.21	-0.45*	-0.11
Mean	0.15	0.24*	0.04	-	-0.08	0.28	-0.17	0.10
Days to 50% tasseling								
low N-low P	-0.85**	-0.87**	0.29	-	0.88**	0.19	-0.04	0.35
low N-adq. P	-0.86**	-0.86**	0.28	-	0.87**	0.23	-0.04	0.35
adq. N-low P	-0.84**	-0.87**	0.28	-	0.87**	0.24	-0.06	0.34
adq. N-adq. P	-0.84**	-0.84**	0.29	-	0.88**	0.27	-0.04	0.34
Mean	-0.87**	-0.86**	0.56**	-	0.91**	-0.08	-0.03	0.46**
Grain yield								
low N-low P	-0.49**	-0.29	0.01	0.15	0.30	0.29	0.17	0.37*
low N-adq. P	-0.51**	-0.29	0.09	0.26	0.35*	0.21	0.30	0.49**
adq. N-low P	-0.48**	-0.13	0.17	0.30	0.42**	0.23	0.41**	0.49**
adq. N-adq. P	-0.47**	-0.26	0.28	0.46**	0.51**	-0.11	0.32*	0.42**
Mean	-0.46**	-0.23**	0.13	0.27**	0.37**	0.15	0.29**	0.41**

[a] Daily average of solar radiation during 4 weeks before and 4 weeks after 50% tasseling.

[b] Total solar radiation from planting until the respective plant characters were measured.

*, ** = significant at $P < 0.05$ and 0.01, respectively.

tasseling under the low P treatment. This probably resulted from the differential inherent fertility of the sites as mentioned earlier.

Unlike temperature, daily average solar radiation was not significantly correlated with days to 50% tasseling or with yields of any individual NP treatment. Total solar radiation, however, was positively and signficantly correlated with days to 50% tasseling (Table 41). This result is not unexpected because total solar radiation to tasseling is the product of days to tasseling times daily average solar radiation. The third to the seventh monthly average solar radiation were significantly correlated with yield, however the coefficients of correlation were low (Table 42).

Total solar radiation was significantly correlated with yields of all treatments. The positive correlation coefficients indicated that yields increased as the total amount of solar radiation received by the plant increased. In contrast, yields appeared to decrease as temperature increased. Maize yields appear to be affected by both temperature and solar radiation in that temperature affected the rate of growth of the plant and therefore the amount of solar radiation it could receive before the grain matures. For example, in Hawaii maximum and minimum temperature were cooler (24.1 and 17.4°C), the growth was slower (190 days to harvest) and the daily average solar radiation was higher (433 g cal/day) than in the Philippines where maximum and minimum temperature were 32.6 and 22.5°C, days to harvest were 121 and average daily solar radiation was 362 g cal/day. This combination of factors was probably responsible for the difference in yields between Hawaii and the Philippines, i.e., 6.6 versus 4.4 tons/ha, even at the high level of N and P.

Table 42. Correlation coefficients between plant characters of maize variety H610 and monthly average solar radiation

Soil/ plant character	Monthly average solar radiation						
	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Hydric Dystrandept							
Plant height at:							
30 days	0.50**						
100% tasseling	0.50	0.05	0.34**				
Days to 50% tasseling	-0.40**	-0.51**	0.14				
Grain yield	-0.17	-0.01	0.19*	0.55**	0.39**	0.44**	0.29**
Three soil families							
Plant height at:							
30 days	0.34**						
100% tasseling	0.10	<0.01	0.10				
Days to 50% tasseling	0.36**	0.25**	0.05				
Grain yield	0.04	0.14	0.19*	0.25**	0.36**	0.25**	0.27**

Wind run was significantly correlated with plant height at 30 days; however this relationship was possibly an artifact of the data from Hawaii relative to the data from Indonesia and the Philippines. The negative correlations were probably the result of the stronger wind in Hawaii where plant growth was slower due to the cooler temperature, as already mentioned. The positive and significant correlations between wind run and yield were probably also artifacts of the data since stronger wind occurred in Hawaii where higher yields were produced partly due to the longer growing period and higher amount of solar radiation received by the plant.

The relationships between climatic factors and plant characters of maize variety H610 grown on the three soil family networks were similar to those within the Hydric Dystrandept alone. A difference noted between the two groups of data was that the correlation coefficients for the relationship between maximum temperature and plant height at 100% tasseling were positive and significant under the adequate P treatments rather than with the low P treatments. This was probably due to plants growing taller with adequate P applications on sites which have higher temperature, namely Indonesia and the Philippines.

TRANSFER EXPERIMENT

Four transfer experiments, two from Hawaii and one each from Indonesia and the Philippines, were included in this study to obtain more information on the performance of the same variety grown on the same soil family. Variety H610 was planted to test the response to N and P fertilization on the Hydric Dystrandepts. The experiments were conducted using the 5^2 fractional factorial modification of Escobar (Benchmark Soils Project, 1979). The yield data are given in Appendix E.

The response of H610 to N fertilization under two fixed levels of P application are presented in Figure 23. Response to N was largest at the Iole and Halawa sites (Hawaii) followed by that at ITKA (Indonesia) and PUC (the Philippines). A significant response to P was obtained only at the PUC site in the Philippines. These differential responses are shown clearly by regression equations presented in Table 43 where P fertilization had a significant effect only at the PUC site in the Philippines. The variables included in this table were those whose F values met the 10% significance level for inclusion in the model.

On the average, the yield level in Indonesia was higher than that in either Hawaii or the Philippines, especially with low levels of fertilization. With increasing rates of fertilization the differences in yields between countries diminished, and with the highest levels of fertilization comparable yields were obtained in Hawaii and Indonesia. These results suggest that a yield level of about 8.5 tons/ha is the maximum yield attainable with variety H610 on this family of the Hydric Dystrandepts. A nutrient imbalance due to the excessive amount of P applied in the 0.85 P treatment at Iole may have accounted for its yield being lower than that in the -0.85 P treatment. Furthermore, the yield level in the Philippines was low even with the highest (0.85) rate of P; this probably indicated that the rate of applied fertilizer was not high enough.

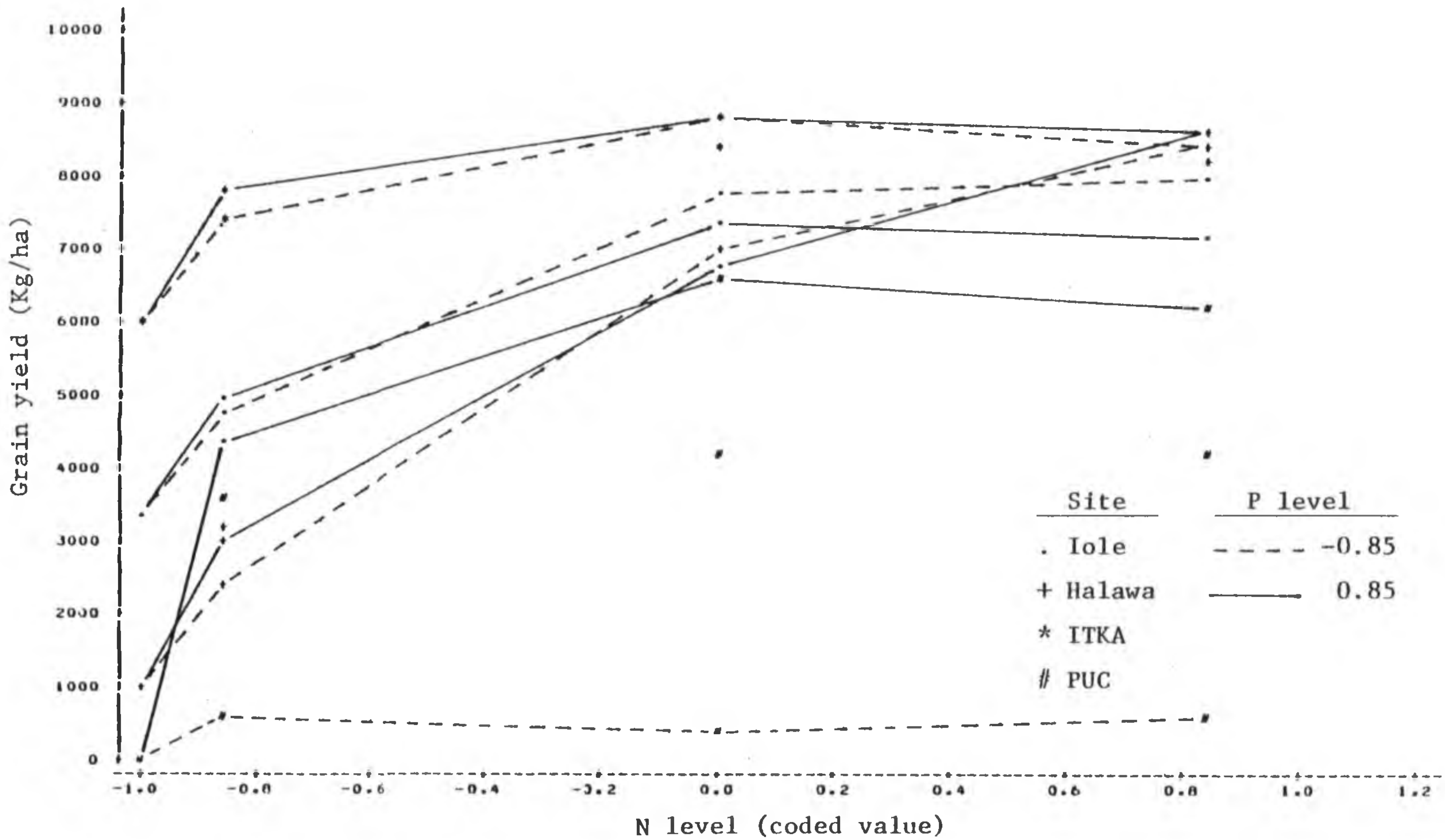


Figure 23. The effects of N fertilization on the yield of maize variety H610 under 2 P levels at 4 Hydric Dystrandept sites.

Table 43. Regression equations relating grain yields of maize variety H610 to N and P fertilization (reduced model with significant variables)[a] in transfer experiments on the Hydric Dystrandepts in Hawaii, Indonesia and the Philippines

Site and season	Regression equation[b]	R^2
Iole-E-11 dry 1979	$\hat{y} = 7320 + 1399.9\ N - 1679.1\ N^2$	0.49
	(280.8) (543.0)	
Halawa-B-22 dry 1979	$\hat{y} = 6938 + 3193.9\ N - 1802.4\ N^2$	0.92
	(158.2) (305.9)	
ITKA-K-13 dry 1979	$\hat{y} = 8419 + 434.6\ N - 600.2\ N^2$	0.30
	(135.8) (262.5)	
PUC-S-11 dry 1980	$\hat{y} = 4161 + 3068.5\ P - 430.5\ N - 1106.5\ P^2 - 541.2\ N^2 + 576.8\ NP$	0.92
	(161.4) (161.4) (319.6) (319.6) (243.3)	

[a]Variables maintained in the regression equation are those which met the 10% significance level for inclusion in the model.

[b]N and P are the treatment variables (coded value); figures in parentheses are the standard error of regression coefficients.

The coefficients of determination for the regression equations for the experiments at Halawa (Hawaii) and PUC (the Philippines) were very high (R^2 = 0.92). In contrast, it was very low for the experiments at Iole (Hawaii) and at ITKA (Indonesia), i.e., R^2 = 0.49 and 0.30, respectively (Table 43), indicating the regression model did not adequately fit the data. A small increase in R^2 resulted when the full regression model was considered (Table 44). These results suggest that further tests are needed to verify the response of variety H610 to N and P fertilization obtained in transfer experiments used in the present study.

4.3.2 Variation in nutrient content of maize

VARIETY EXPERIMENT

Samples of ear leaves taken at 50% tasseling from four variety experiments in Hawaii and Indonesia were analyzed. The nutrient concentrations are presented in Tables 45 to 48.

Nitrogen. On the Hydric Dystrandept site in Hawaii (Table 45), N contents for the low N-low P treatment were lower than those for the adequate N-adequate P treatment in all varieties. The N contents of some varieties were significantly different only in the low N-low P treatment. Two Pioneer hybrids, X5800 and X4816, had the lowest N concentration in this treatment while in the adequate N-adequate P treatment X5800 and X4817 had the lowest N concentrations.

At ITKA-0-10 in Indonesia the fertilizer variables were lime x P, and adequate nitrogen was applied to all plots. Nitrogen contents of all varieties, however, were below the critical nitrogen concentration (3.0% N) suggested by other workers (Melsted et al.,

Table 44. Regression equations relating grain yields of maize variety H610 to N and P fertilization (full model) in transfer experiments on the Hydric Dystrandepts in Hawaii, Indonesia and the Philippines

Site and season	Regression equation[a]	R^2
Iole-E-11 dry 1979	$\hat{y} = 7090 - 202.7\ P + 1399.9\ N + 708.0\ P^2 - 1831.6\ N^2 - 322.5\ NP$	0.57
	(282.0) (282.0) (558.4) (558.4) (425.0)	
Halawa-B-22 dry 1979	$\hat{y} = 6957 + 98.9\ P + 3193.9\ N - 64.0\ P^2 - 1788.6\ N^2 - 53.2\ NP$	0.93
	(164.0) (164.0) (324.9) (324.9) (247.1)	
ITKA-K-13 dry 1979	$\hat{y} = 8340 + 40.9\ P + 434.6\ N + 262.5\ P^2 - 656.8\ N^2 - 39.9\ NP$	0.32
	(139.7) (139.7) (276.6) (276.6) (210.5)	
PUC-S-11 dry 1979	$\hat{y} = 4161 + 3068.5\ P + 430.5\ N - 1106.5\ P^2 - 541.2\ N^2 + 576.8\ NP$	0.92
	(161.4) (161.4) (319.6) (319.6) (243.3)	

[a]N and P are the treatment variables (coded value); figures in parentheses are the standard errors of regression coefficients.

Table 45. Nutrient composition of maize varieties grown on the Hydric Dystrandept at Iole-G-10 in Hawaii in the wet season 1978

NP treatment/ variety	N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
	------ % ------						--- ppm -----				
Low N-Low P											
H610	2.82	0.25	1.60	0.52	0.28	0.19	193	25	123	15	271
H788	2.62	0.24	1.60	0.48	0.27	0.18	169	23	112	13	179
X4816	2.52	0.23	1.68	0.51	0.25	0.19	222	19	113	14	217
X4817	2.62	0.24	1.67	0.50	0.27	0.18	156	22	114	14	229
X5800	2.54	0.23	1.57	0.54	0.26	0.18	191	22	116	13	233
X304A	2.69	0.23	1.64	0.48	0.26	0.20	186	23	114	15	283
X304B	2.75	0.24	1.67	0.53	0.26	0.19	193	23	118	14	240
X304C	2.68	0.24	1.59	0.58	0.28	0.19	176	21	114	13	269
Adq. N-Adq. P											
H610	3.02	0.26	1.79	0.45	0.28	0.21	133	23	118	17	203
H788	3.04	0.26	1.75	0.48	0.25	0.21	133	19	120	16	211
X4816	3.10	0.27	1.72	0.52	0.22	0.20	156	14	130	17	175
X4817	2.87	0.26	1.78	0.51	0.26	0.20	125	22	119	17	195
X5800	2.79	0.25	1.79	0.45	0.25	0.18	239	27	123	16	242
X304A	2.96	0.26	1.71	0.49	0.27	0.19	187	25	117	16	163
X304B	2.99	0.27	1.82	0.51	0.26	0.21	133	20	115	17	181
X304C	3.06	0.26	1.71	0.54	0.29	0.20	176	24	114	16	184
$LSD^{a}_{.05}$ 1	0.26	0.02	0.14	0.07	0.06	0.03	109	11	10	1	66
$LSD^{a}_{.05}$ 2	0.29	0.02	0.23	0.08	0.07	0.03	105	18	11	3	66

[a] LSD-1 is for comparison of means within the same NP treatment.
LSD-2 is for comparison of means between different NP treatments.

Table 46. Nutrient composition of maize varieties grown on the Hydric Dystrandept at ITKA-0-10 in Indonesia in the dry season 1977

LP treatment/ variety	N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
	- - - - - - %	- - - - - -					- - -	ppm	- - -		
Low L[a]-Low P											
H6	2.34	0.28	1.14	0.69	0.47	0.17	463	110	161	9	40
Harapan	2.29	0.25	0.99	0.73	0.63	0.17	387	143	135	7	40
Bima	2.31	0.28	1.05	0.74	0.51	0.18	370	123	149	8	53
Bastar Kuning	2.53	0.27	1.15	0.76	0.44	0.20	297	85	142	10	42
H610	2.23	0.30	1.18	0.89	0.48	0.20	532	110	176	10	55
DMR Comp. 2	2.53	0.26	1.01	0.81	0.49	0.19	411	92	152	9	50
Low L-Adq. P											
H6	2.29	0.28	1.01	0.74	0.51	0.15	440	121	156	7	37
Harapan	2.34	0.27	1.04	0.73	0.48	0.16	553	141	159	6	37
Bima	2.57	0.26	0.98	0.82	0.45	0.18	936	125	206	8	43
Bastar Kuning	2.51	0.27	1.03	0.82	0.54	0.19	668	123	168	8	42
H610	2.51	0.30	1.11	0.86	0.33	0.19	1031	98	258	10	52
DMR Comp. 2	2.42	0.28	0.99	0.83	0.41	0.16	528	107	175	8	50
Adq. L-Low P											
H6	2.67	0.28	1.08	0.68	0.48	0.17	337	101	151	9	42
Harapan	2.51	0.27	0.94	0.75	0.50	0.17	527	108	170	7	51
Bima	2.44	0.26	1.05	0.85	0.48	0.20	584	98	179	9	47
Bastar Kuning	2.44	0.27	1.11	0.85	0.49	0.21	463	89	166	9	44
H610	2.57	0.27	1.11	0.84	0.48	0.20	555	88	154	10	54
DMR Comp. 2	2.78	0.28	1.13	0.75	0.37	0.19	345	70	157	11	56
Adq. L-Adq. P											
H6	2.78	0.30	1.04	0.77	0.50	0.17	488	113	163	8	42
Harapan	2.44	0.29	0.94	0.83	0.56	0.17	501	130	156	6	44
Bima	2.70	0.28	1.06	0.77	0.42	0.19	643	97	196	9	41
Bastar Kuning	2.48	0.26	1.01	0.90	0.48	0.19	589	92	176	8	42
H610	2.71	0.30	1.14	0.88	0.45	0.18	579	80	176	8	40
DMR Comp. 2	2.78	0.28	1.09	0.81	0.45	0.19	605	95	191	9	43
$LSD^{b}_{.05}$ 1	0.39	0.01	0.21	0.12	0.12	0.02	201	31	31	2	9
2	0.45	0.03	0.28	0.13	0.23	0.04	217	31	34	3	10

[a]L refers to lime

[b]LSD-1 is for comparison of means within the same LP treatment.
LSD-2 is for comparison of means between different LP treatments.

Table 47. Nutrient composition of maize varieties grown on the Tropeptic Eutrustox at Molokai-C-10 in Hawaii in the dry season 1978

NP treatment/ variety	N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
	- - - - - -	-	%	- -	- - -		- - -		ppm	- - -	- -
Low N-Low P											
H610	1.79	0.19	1.67	0.43	0.21	0.11	188	84	145	7	27
H688	1.83	0.18	1.57	0.42	0.23	0.12	185	78	143	8	24
H788	1.86	0.17	1.30	0.45	0.23	0.10	159	92	137	7	23
X304B	2.13	0.19	1.35	0.42	0.23	0.12	149	104	130	7	28
X304C	2.16	0.20	1.35	0.52	0.26	0.12	266	125	142	7	30
X306B	1.85	0.18	1.33	0.38	0.21	0.11	186	97	145	8	26
Phoenix 1110	1.95	0.17	1.18	0.41	0.22	0.11	192	72	154	6	24
Cargill 111	2.19	0.19	1.20	0.42	0.24	0.11	206	90	175	6	24
Adq. N-Adq. P											
H610	2.36	0.23	1.79	0.48	0.21	0.15	285	84	147	11	30
H688	2.37	0.22	1.70	0.47	0.22	0.16	186	79	145	10	28
H788	2.33	0.22	1.57	0.46	0.22	0.14	182	92	152	9	28
X304B	2.41	0.23	1.46	0.45	0.21	0.13	232	104	150	9	37
X304C	2.39	0.23	1.50	0.53	0.26	0.14	196	117	140	9	32
X306B	2.24	0.21	1.44	0.41	0.23	0.13	182	107	138	8	26
Phoenix 1110	2.45	0.22	1.37	0.40	0.21	0.14	155	68	141	8	27
Cargill 111	2.38	0.22	1.35	0.41	0.20	0.13	172	81	155	8	36
$LSD^{a}_{.05}$ 1	0.22	0.02	0.13	0.04	0.03	0.01	75	13	25	1	9
2	0.44	0.08	0.46	0.06	0.10	0.03	137	16	31	3	11

[a]LSD-1 is for comparison of means within the same NP treatment.
LSD-2 is for comparison of means between different NP treatments.

Table 48. Nutrient composition of maize varieties grown on the Tropeptic Eutrustox at Molokai-D-10 in Hawaii in the late-wet season 1979

NP treatment/ variety	N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
	- - - - - -	- % -	- - - - -				- - - -		ppm - - - -		
Low N-Low P[a]											
H610	1.41	0.19	1.43	0.37	0.25	0.09	135	91	123	8	26
H688	1.60	0.17	1.29	0.39	0.28	0.11	137	102	152	7	27
H763	1.62	0.18	1.39	0.43	0.24	0.12	131	73	164	10	34
X5800	1.69	0.18	1.35	0.43	0.30	0.11	233	119	129	10	33
X4816	1.68	0.18	1.20	0.45	0.26	0.10	114	86	126	7	34
X6877	2.14	0.18	1.40	0.49	0.29	0.12	150	94	122	10	35
X304C	1.84	0.19	1.22	0.44	0.30	0.10	137	161	135	9	23
X5859	1.49	0.16	1.22	0.35	0.21	0.09	249	85	113	8	23
Low N-Adq. P[b]											
H610	2.35	0.23	1.35	0.46	0.27	0.13	157	94	124	9	33
H688	2.19	0.21	1.41	0.43	0.23	0.13	-[c]	84	152	10	33
H763	2.30	0.21	1.31	0.48	0.23	0.13	113	67	128	10	33
X5800	2.31	0.21	1.34	0.42	0.23	0.13	267	92	174	12	33
X4816	2.42	0.22	1.25	0.47	0.23	0.13	238	49	138	10	35
X6877	2.66	0.22	1.46	0.51	0.25	0.16	178	55	146	12	38
X304C	2.32	0.22	1.35	0.49	0.29	0.12	125	111	141	10	39
X5859	2.58	0.20	1.38	0.39	0.22	0.12	116	90	133	11	29
Adq. N-Low P[b]											
H610	1.71	0.20	1.54	0.42	0.28	0.10	190	100	144	8	31
H688	2.00	0.19	1.30	0.47	0.33	0.13	141	90	129	9	34
H763	1.64	0.19	1.42	0.47	0.29	0.11	126	91	111	7	28
X5800	1.75	0.16	1.35	0.39	0.22	0.10	-[c]	105	128	12	33
X4816	1.89	0.18	1.18	0.53	0.30	0.12	143	100	154	7	37
X6877	2.10	0.20	1.43	0.51	0.28	0.12	84	87	108	10	41
X304C	2.42	0.22	1.30	0.57	0.29	0.14	122	136	131	11	43
X5859	1.27	0.17	1.22	0.41	0.28	0.10	175	112	142	7	50
Adq. N-Adq. P[a]											
H610	2.34	0.26	1.59	0.47	0.25	0.14	147	93	129	12	42
H688	2.36	0.24	1.49	0.47	0.29	0.14	298	98	136	11	36
H673	2.38	0.24	1.44	0.48	0.25	0.14	137	79	138	11	34
X5800	2.54	0.25	1.48	0.48	0.27	0.15	152	108	129	14	44
X4816	2.58	0.24	1.33	0.56	0.26	0.15	137	73	138	11	42
X6877	2.64	0.24	1.39	0.54	0.23	0.16	145	72	144	12	43
X304C	2.36	0.23	1.45	0.47	0.28	0.13	161	114	135	10	38
X5859	2.51	0.22	1.37	0.44	0.24	0.13	199	96	132	11	34
LSD[a] .05 1	0.32	0.02	0.16	0.07	0.03	0.02	169	12	48	3	11
LSD .05 2	0.73	0.02	0.19	0.17	0.05	0.04	189	11	47	4	17

[a] Leaf samples from this treatment were taken from 2 replicates.
[b] Leaf samples from this treatment were taken from 1 replicate.
[c] Missing data.
[d] LSD-1 is for comparison of means within low N-low P and adq. N-adq. P treatments only.
LSD-2 is for comparison of means between low N-low P and adq. N-adq. P treatments only.

1965; Hanway and Dumenil, 1965; Escano, 1980) (Table 46). It should be noted, however, that N concentrations were generally higher in the adequate P treatments.

In the Tropeptic Eutrustox network (Tables 47 and 48), the N contents of all varieties were lower than the suggested critical concentrations, even with the adequate level of N. In Molokai-D-10 it appears that the Hawaiian varieties had lower yields as well as lower leaf N concentrations than the Pioneer varieties (Tables 33 and 48). Highest N contents were found in Pioneer variety X6877. Leaf N concentration appeared to be affected by level of P applied since leaf N increased with adequate P treatment even though the N application remained the same. Furthermore, the highest N levels were found in the adequate N-adequate P treatment. The N concentrations in two varieties, X6877 and X5859, did not increase with the higher rate of N in either the low or adequate P levels (Table 48). Similarly, N concentration of variety H610 did not increase with application of the higher rate of N with adequate P. It should be noted, however, that yields of varieties X6877 and X5859 increased significantly with increased N under the low P level, and yields of varieties X6877 and H610 increased significantly with increased N under the adequate P level.

Phosphorus. Leaf P concentrations for all varieties in the low P treatment at Iole-G-20 were about 0.24%. Application of the higher level of P increased P concentrations slightly to about 0.26% (Table 45). The P concentrations in both treatments are within the sufficiency range suggested by Gallo *et al*. (1968) and Melsted *et al*. (1969) which support the conclusion that the high level of native soil P prevented a yield response to P fertilization in this experiment.

On the Hydric Dystrandept site at ITKA-0-10 in Indonesia leaf P concentration of all varieties was about 0.27% under all fertilization treatments (Table 46). The application of the higher level of P did not significantly increase P concentration of varieties, and P concentrations in both P levels are within the suggested sufficiency range. These results support the previous findings that yields of most varieties in this experiment did not increase significantly with increased P treatment.

All varieties in both Tropeptic Eutrustox experiments, Molokai-C-10 and Molokai-D-10, had leaf P concentrations below the sufficiency range in the low P treatments (Table 47 and 48). Application of the adequate level of P increased leaf P concentrations slightly to levels a little below and at the published critical concentration in the low and adequate N treatments, respectively. As noted in the preceding paragraphs, the significant yield response to P fertilization at Molokai-D-10 (cf. section 4.2.2) was associated with increased N contents which were induced by application of the higher level of P. Similarly, leaf P concentration in this experiment increased with the higher rate of N even though the P application did not change.

Potassium, calcium, magnesium and sulfur. Blanket fertilizer application consisting of K, Mg, B, and Zn were applied in all variety experiments to maintain these nutrients at or near their optimum levels. However data in this study (Tables 45 to 48) show that K contents were low, particularly in experiments at ITKA-O-10 (Indonesia) and Molokai-D-10 (Hawaii) where K levels ranged from 0.95 to 1.50% in leaves of all varieties. This level was lower than 1.70%, the suggested sufficiency ranges of K (Loue, 1963; Hanway and Dumenil, 1965; Jones, 1967; Gallo et al., 1968; Melsted et al., 1969; Escano, 1980).

Considering varietal differences in nutrient content, it might be noted that variety H610 consistently had the highest leaf K content in all experiments except that at Iole-G-10. On the other hand, variety X4816 always exhibited the lowest leaf K concentration.

Calcium and magnesium contents of all varieties in all experiments were within the sufficiency ranges suggested by Jones (1967), Melsted et al. (1969) and Escano (1980). Exceptions were observed in the experiment at ITKA-O-10 in Indonesia where lime was applied as a treatment (Table 46). Here Ca contents of all varieties were above the suggested sufficiency range.

Leaf sulfur levels of all varieties in two experiments on the Hydric Dystrandept, Iole-G-10 and ITKA-O-10, were within the sufficiency range suggested by Escano (1980). In contrast, the sulfur contents of all varieties in experiments on the Tropeptic Eutrustox, Molokai-G-10 and Molokai-D-10, were below the suggested sufficiency range.

Aluminum, manganese, iron, copper, and zinc. The leaf aluminum, manganese, copper, and zinc levels were generally within the sufficiency ranges suggested by Jones (1967), Melsted et al.

(1969) and Escano (1980) except at ITKA-O-10 in Indonesia where aluminum levels were high and at Iole-G-10 in Hawaii where zinc levels were high.

TRANSFER EXPERIMENT

The nutrient content of the ear leaves of maize variety H610 taken from the transfer experiments at 50% tasseling are given in Appendix E. Earleaf samples were not taken from the experiment at PUC-S-11 in the Philippines. The relationships between N and P fertilization and the concentration of tissue N and P were studied using a quadratic regression model

$$\hat{y} = \beta_0 + \beta_1 N + \beta_2 N^2 + \beta_3 P + \beta_4 P^2 + \beta_5 NP$$

where $\hat{y}$ is the N or P concentration in the tissue, and N and P--in the linear, quadratic, and interaction terms--are the coded values of the fertilization treatments.

In Hawaii the N treatment had a major effect on tissue N and P (Table 49). This is not unexpected since native soil-P in the experimental sites was already high, which was supported by the fact that leaf P levels with all treatments were within the suggested sufficiency ranges (Appendix E). At Iole-E-11 the predicted maximum yield of about 7.6 tons/ha was attained with the application of the 0.42 coded rate of N which is equal to about 145 kg N/ha. The critical concentration of N associated with 95% of maximum yield, was about 2.80% (Fig. 24).

The same critical N concentration (2.88%) was found for the experiment at Halawa-B-22 (Fig. 25a). However a higher maximum yield (8.4 tons/ha) was predicted with the application of the 0.90

Table 49. Regression equations relating N and P fertilization treatments to N and P concentrations in the earleaf of maize variety H610 in three transfer experiments

Site/nutrient	Regression equation[a]	R^2
Iole-E-11, Hawaii		
N (%)	$\hat{y} = 2.75 + 0.31\ N - 0.13\ N^2$ (0.05)[b] (0.07)	0.58**
P (%)	$\hat{y} = 0.320 + 0.016\ N + 0.008\ P$ (0.003) (0.003)	0.42**
Halawa-B-22, Hawaii		
N (%)	$\hat{y} = 2.62 + 0.70\ N - 0.47\ N^2 + 0.24\ P^2$ (0.07) (0.14) (0.14)	0.76**
P (%)	$\hat{y} = 0.294 + 0.050\ N - 0.020\ N^2$ (0.004) (0.008)	0.80**
ITKA-K-13, Indonesia		
N (%)	$\hat{y} = 2.37 + 0.16\ N$ (0.08)	0.09+
P (%)	$\hat{y} = 0.236 + 0.011\ N + 0.017\ NP$ (0.006) (0.010)	0.15+

[a]Treatment variables maintained in the regression models are only those which met the 10% significance level.

[b]Figures in parentheses are the standard errors of regression coefficients.

+, ** = significant at the 10 and 1% level, respectively.

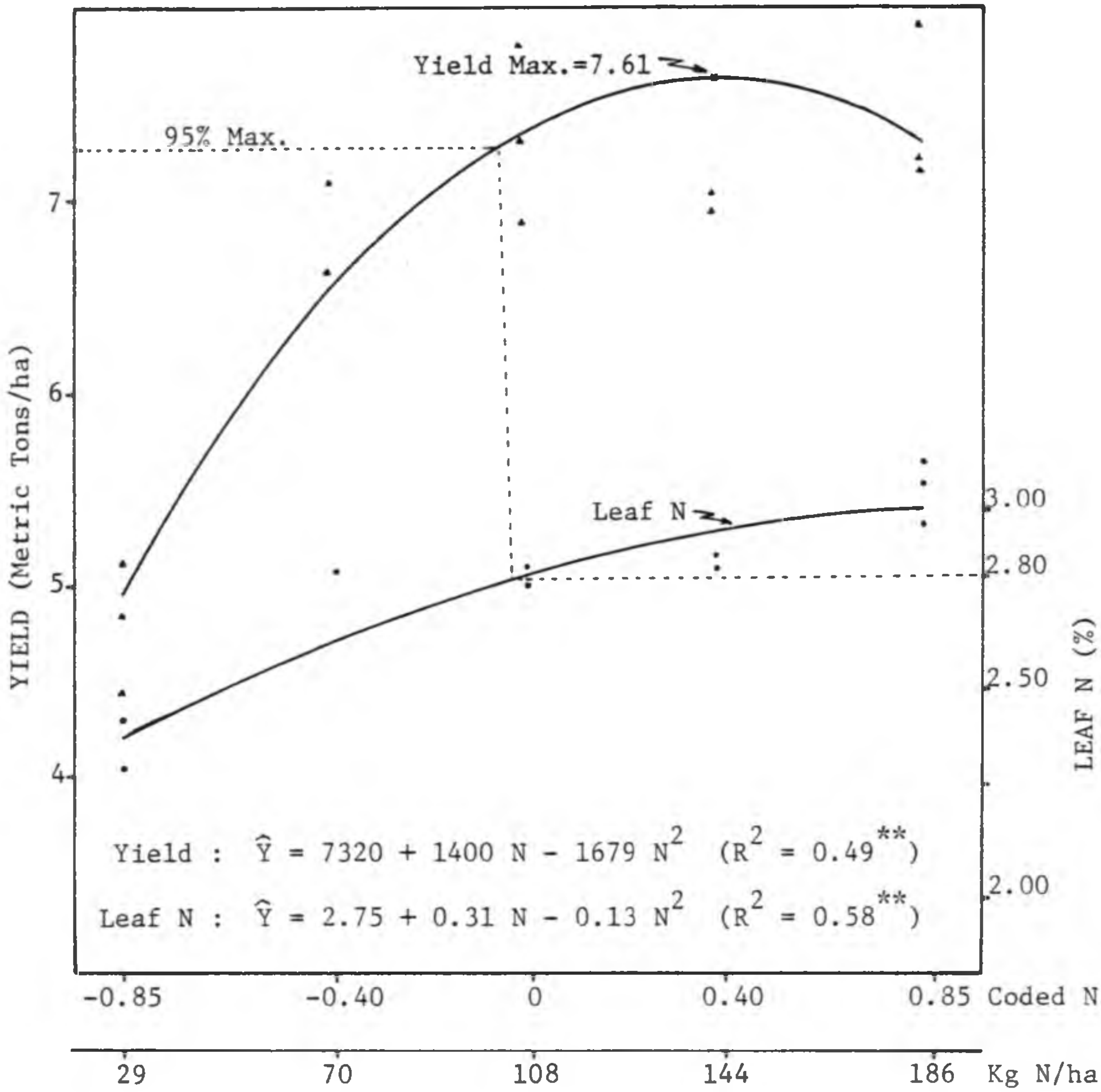


Figure 24. Relationships between N fertilization with grain yield and N concentration in the earleaf of maize variety H610 in the transfer experiment at Iole-E-11 in Hawaii.

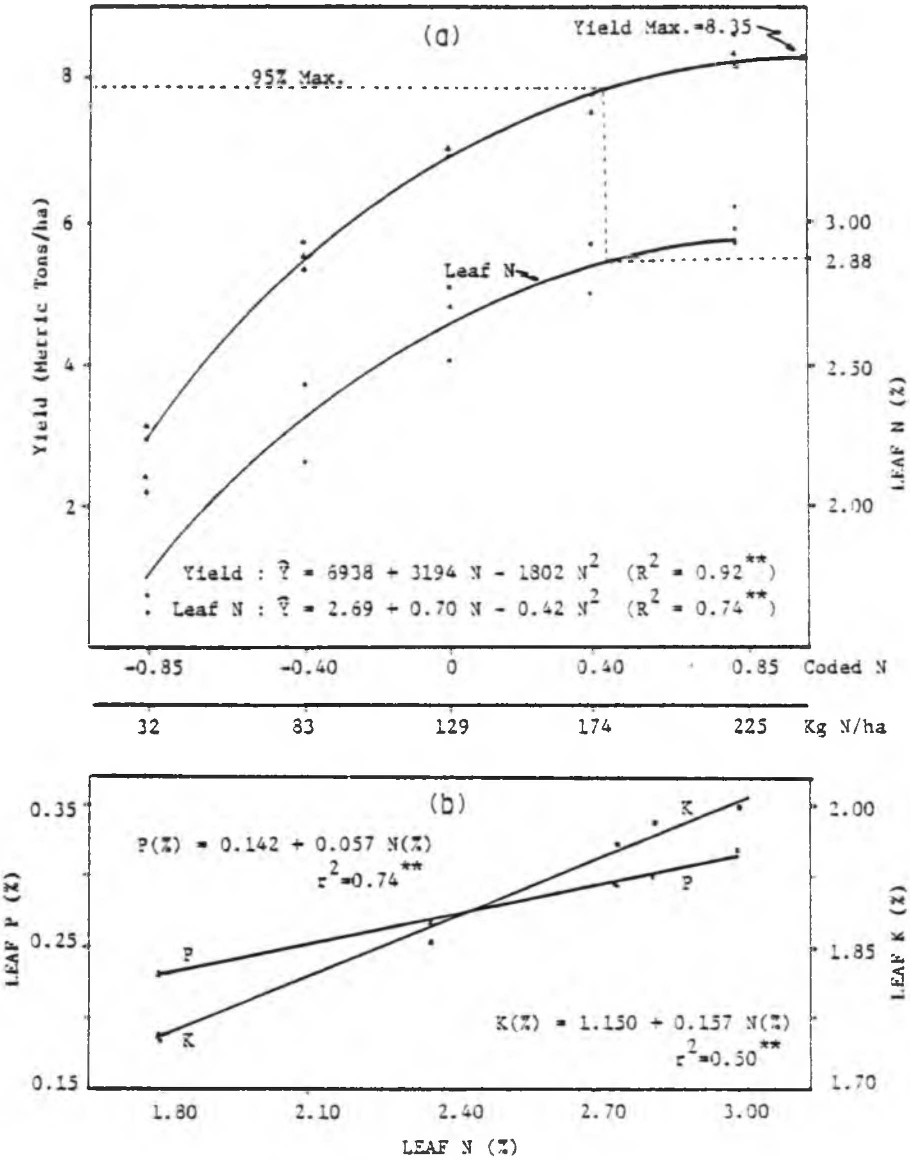


Figure 25a. Relationships between N fertilization with grain yield and N concentration in the earleaf of maize variety H610 in the transfer experiment at Halawa-B-22 in Hawaii.

25b. Relationships between N concentration with P and K concentration in the earleaf of maize variety H610 in the transfer experiment at Halawa-B-22 in Hawaii.

coded rate of N which is about 230 kg N/ha. It is evident that this N rate was beyond the range used in this experiment. It might be noted that both experiments in Hawaii were conducted at the same time, i.e., planted in June and harvested in November 1979. Slightly higher (20 kg N/ha) rates of nitrogen were used in the experiment at Halawa-B-22 (Appendix E).

Figure 25b shows the relationship between the concentration of tissue N with concentration of tissue P and K. It is apparent that increased N concentration in maize tissue was associated with linear increases in P and K concentrations. A highly significant correlation was also found between tissue N and P and K concentrations in the experiment at Halawa-B-22 (Appendix F2). In addition, tissue N was also positively correlated with concentrations of tissue Ca, S, Cu, and Zn. Since N and P were the fertilization variables and only the N treatment had significant effects, the above correlations suggest that concentrations of the other nutrients in the tissue were affected by applied N.

Similar relationships were found for experiments Iole-E-11 and ITKA-K-13 (Appendices F1 and F3, respectively). However in Indonesia the yield of maize variety H610 was not significantly correlated with concentrations of any of the nutrients in the earleaf. Although N and P concentrations in tissue were relatively low (Appendix E3), no definite response to N or P was observed (Table 48). The cause of these poor relationships, however, is not known. It might be noted, however, that concentrations of tissue K were about 1.55% which is somewhat lower than the reported sufficiency range for

K of 1.70 to 2.70% (Hanway and Dumenil, 1965; Gallo et al., 1968; Melsted et al., 1969; Escano, 1980). On the other hand, tissue concentrations of Al which in most cases were above 250 ppm were higher than the suggested sufficiency range of about 200 ppm (Jones, 1967; Escano, 1980). It should be mentioned that the yield level of about 8 tons/ha attained in this experiment was relatively high.

4.3.3 Discussion

Soil family. The sixth category in Soil Taxonomy, the soil family, groups soils within a subgroup having similar physical and chemical properties important to plant growth (Soil Survey Staff, 1975). Soils classified in the same soil family, therefore, should have nearly the same management requirements, a common response to cultural practices and similar potential for crop production. Based on this assumption, the transferability of agroproduction technology is now being investigated and indications are that the yield response of crops to a management practice, response to P, at different sites of the same soil family can be predicted with fairly good precision. The results of studies so far, clearly support the general validity of the transfer hypothesis (Benchmark Soils Project, 1978 and 1979; Beinroth et al., 1980).

In the present study, considerable variation in growth and yield of maize variety H610 grown at different locations of the same soil family were observed. The variations were greater under low than under high fertilization rates. In the Hydric Dystrandept network, for example, the yields of H610 in the variety experiments under the low N-low P treatment varied in the range of -64.3 to

62.7% of the soil family mean yield. Under the adequate N-adequate P treatment however, the variation was between -22.0 and 31.3%. Similar results were obtained in the transfer experiments where it was shown that differences in yields among several sites were greater under the low fertilization treatments than under the high treatments. This is understandable since the application of fertilizer eliminates one of the limitations of crop production and thus equalizes the potential productivity of the soils.

The fact that the yield of H610 varied considerably from site to site even on the same soil family, however, should not be surprising because soils at the experimental sites are not exactly the same, as they differ within the limits of characteristics of the soil family. It is well to remember in this context that although the soil family is quite narrowly defined, a considerable range is allowed in some characteristics, such as pH, base saturation or cation exchange capacity, that might be important to plant growth. Moreover, soils of the same soil family may also exhibit features of agronomic significance that are not used to identify soil taxa, such as solar radiation, temperature, and precipitation at a particular site and season which are unique to the site (Benchmark Soils Project, 1979; Beinroth _et al_., 1980).

The variations in the performance of variety H610 grown in the Hydric Dystrandept network were evaluated using transfer experiments and variety experiments. In the transfer experiments the yield level in Indonesia was considerably higher than that in either Hawaii or the Philippines, particularly under the low fertilization treatments. These results are inconsistent with the results of other transfer experiments reported by the Project earlier (Benchmark Soils Project, 1979). It was reported that the yield level in Hawaii was considerably higher than that in the Philippines, and the yield level in Indonesia was the lowest. These discrepancies might be due to the high soil-P level of the Indonesian site used in this study, where no phosphate response was obtained in the experiment. Whereas the experiments reported by the Project earlier were conducted at blocks which have lower soil-P levels, and where significant responses to phosphate were observed. Another possible reason may be the difference in maize varieties used in the two studies. The same variety, H610, was used in all sites in the present study; while different varieties were grown in the experiments reported by the Project: H610 in Hawaii, UPCA-1 in the Philippines, and H6 in Indonesia. It is possible that the genetic yield potential of these varieties is not the same A yield level of 8 tons/ha is rarely attained with the Indonesian varieties H6 and Harapan throughout the Project network in Indonesia. This yield level, however, was obtained when variety H610 was used in the transfer experiment at ITKA-E-11 in the dry season 1979 in Indonesia. In fact, the yield of 8 tons/ha is the common production level of H610 recorded in the Project network in Hawaii, where the variety originated.

In two variety experiments conducted in the dry season 1979 and in the late-wet season 1978 (Table 28 and 25, respectively), H610 never outyielded varieties H6 or Harapan on the Hydric Dystrandept sites in Indonesia. In the variety experiment in the dry season 1979, i.e., at ITKA-F-10, these three varieties had equal yield levels of about 7 tons/ha with the adequate N-adequate P treatment (Table 27). Apparently the dry season 1979 in Indonesia was a good season which enabled the three varieties to express their yield potentials. Yield level in this variety experiment was relatively high, but it was not as high as that in the transfer experiment mentioned earlier. This discrepancy was partly due to the lower rates of both N and P fertilizer applied in the variety experiment than in the transfer experiment (Table 1 and Appendix F3).

The results of this study suggest that the varieties planted in experiments must be considered when comparing yield levels among sites. Similarly, maize varieties should be considered in making yield predictions. Hence, if different varieties are used in transfer experiments, that is the best adapted local variety for a soil family within a country, the response of maize to treatment and environmental variables may not be uniform across countries because of differential variety responses.

Keeping in mind that differences in yield levels obtained in the three countries could be due to the fact that different varieties were used in the transfer experiments reported earlier, it was noted that the yield levels in Hawaii and the Philippines were higher than those in Indonesia due to higher amounts of solar radiation received in the first two countries (Benchmark Soils Project, 1979). The lower yields in the Philippines than in Hawaii, however, could not be accounted for only by the high minimum temperature that could cause greater use of photosynthate in respiration, since this difference probably is not significant. Apparently, as found in the present study, the higher temperature in the Philippines hastened growth rate of the plant and therefore resulted in a shorter period for accumulation of solar energy. This resulted in lower yields. There is further discussion of this in the succeeding paragraphs.

Weather. Temperature was found to be the most important climatic variable affecting growth of maize variety H610 in this study. It was better correlated with plant height at 30 days after emergence and at 100% tasseling, as well as with grain yield, than any other climatic variable. Plants grew more slowly at sites with lower temperature, they were also much shorter at 30 days after emergence, and tasseling and harvesting times were delayed, however yield levels were higher. The dominant role of temperature found in the present study confirmed similar results reported by Eberhart et al. (1973), Goldsworthy (1974), Goldsworthy and Colegrave (1974), Bhargave and Utkhede (1978), and Jong (1980).

The delayed tasseling has significance in the production of grain. As growth rate of the plants was delayed by the low temperature, more solar radiation was received by the plants. This increase in total solar radiation eventually resulted in a higher yield. The lower temperatures of the experimental sites in this study, however, were not only related to increasing altitudes as noted by Wilson et al. (1973) and Goldsworthy (1974), but were also related to the latitude of the sites. The temperature at the ITKA site in Indonesia, which is located at about 7° in the southern hemisphere at about 1250m above sea level, was warmer than that of the Iole site in Hawaii which is located at about 20° in the northern hemisphere at 545m elevation.

The highest temperature was recorded at the PUC site in the Philippines which is situated about 13°30' in the northern hemisphere at an elevation of about 300m above sea level.

Nutrient. The concentrations of leaf N and P differed among maize varieties in response to N and P fertilization. Since varieties in each experiment were grown on the same soil under identical management conditions, differences in their nutrient concentrations may indicate differences in the efficiency of their nutrient uptake. These results provided further evidence of differential N and P uptake by maize as was reported by several authors (Gorsline *et al*., 1964; Clark and Brown, 1974; Beauchamp *et al*., 1976; Pulam, 1978; Polmer *et al*., 1978). The causes of this differential uptake, however, were not revealed in this study, but differences in rooting systems or metabolism may account for this (Vose, 1963).

The existence of varieties that had higher nutrient concentration in their leaves under low fertility levels, such as varieties X6877 for N, H610 and H6 for P, and H610 for K, suggests that it should be possible to select maize varieties for specific soil conditions. This is important if maize is to be grown under low fertilizer input.

Another interesting observation with many maize varieties was the significant increase in leaf N concentration which was induced by application of P, but not by N. These increases were often associated with yield response. This evidence indicates that the effectiveness of N fertilization was reduced by the limited supply of P and demonstrated the importance of nutrient balance.

On the other hand, in certain transfer experiments tissue concentrations of P, K, and other nutrients increased significantly with increasing tissue N concentration as rate of N fertilization increased. Similar results were reported by Bennett et al. (1953) and Escano (1980). Bennett et al. (1953) suggested that the application of N gave rise to a more extensive root system and resulted in higher P content in the leaf.

Considering the importance of nutrient balance, it must be emphasized that earleaf K concentration was below the sufficiency range in most varieties in variety experiments from which tissue samples were analyzed in this study. Hence, variation in the concentration of N, P, and other nutrients reported for maize varieties in this thesis may not represent the normal variation in nutrient content. As a result, the differential yield responses may also not be representative because a deficiency of a single nutrient may affect the response of plants to other nutrients as well as affect the uptake of non-deficient nutrients (Watanabe et al., 1965). Similarly, nutrient imbalance may also have resulted from the high Al or Zn concentrations found in certain experiments which may have affected other responses.

From the transfer experiments in Hawaii a critical N level of 2.80-2.88% N was established. This value agrees well with those reported by other workers (Bennett et al., 1953; Viets et al., 1954; Dumenil, 1961; Voss et al., 1970; Escano, 1980).

5. SUMMARY AND CONCLUSIONS

The performance and response to N and P fertilization of several maize varieties were evaluated in 19 variety experiments and 4 transfer experiments conducted by the Benchmark Soils Project. The variety experiments were conducted on three tropical soil families and the transfer experiments were conducted on one soil family. Data from three countries for both types of experiments were evaluated in this study.

Varieties of maize performed differently at different locations either on the same soil family in different countries or in the same country on different soil families. There were varieties that tended to be better adapted to a specific locality such as varieties H610, H6, and UPCA-1 which generally performed well in their countries of origin, but poorly in other countries. In contrast, there was a variety, X304C, that exhibited a fairly wide range of adaptation and performed relatively well across different soil families in the same country as well as across different countries.

Maize varieties which were found to be well adapted (better than average adaptation) to the three soil family networks in the three countries were: (1) Hydric Dystrandept: Hawaii: X4816, X4817, and X304C; Indonesia: H6 and Harapan; The Philippines: none. (2) Tropeptic Eutrustox: Hawaii: X304C. (3) Typic Paleudult: Indonesia: H6 and Tiniguib; The Philippines: X304C.

Maize variety H610 which has been used extensively in transfer experiments in Hawaii was found to have average adaptation in both the Hydric Dystrandept and Tropeptic Eutrustox networks in Hawaii. In addition, variety H688 also had average adaptation in these two soil family networks, and variety X304B had average adaptation on the Hydric Dystrandept sites.

In the Philippines, no variety was found to be well adapted (above average adaptation) to the Hydric Dystrandept sites. Variety UPCA-1, a Philippine variety which has been used in the transfer experiments, did not perform consistently in this study. It had average adaptation in some conditions, but was poorly adapted in other conditions. Similar results were obtained with the introduced varieties, H6 from Indonesia and H610 from Hawaii.

Genotype-environment interactions appeared to be responsible for the variation in performance of maize grown at different locations or in different seasons. Therefore, not only the varieties planted, but also their interaction with the environment must be considered when comparing crop response to treatment variables and in making yield predictions.

The differential yield response of maize varieties to season and fertilization treatments generally appeared to be due to the effect of seasons rather than fertilization. However the seasonal effects were not consistently high throughout the three soil family networks. Some varieties in certain experiments showed greater response to fertilization than to seasonal changes.

Temperature was the most important climatic factor affecting the growth and yield of maize variety H610 grown at different locations. At sites which had lower temperature, plant growth was slower as indicated by shorter plants at 30 days after emergence, and delayed tasseling and harvesting times. However, since the plants grew slowly more solar radiation was received and resulted in higher yield.

Within the Hydric Dystrandept soil family network, the growth of maize variety H610 was the fastest in the Philippines, followed by growth in Indonesia and Hawaii. Plant height at 30 days after emergence was about 75 cm in the Philippines, while in Indonesia and Hawaii it was about 50 and 25 cm, respectively. In the Philippines, 50% tasseling was attained about 60 days after planting, but it took about 120 days from planting to harvesting in the Philippines, whereas in Indonesia and Hawaii it took 160 and 190 days, respectively. The yields of H610 in the three countries, however, were in the reverse order, i.e., 6.6, 5.3, and 4.4 tons/ha in Hawaii, Indonesia, and the Philippines, respectively.

Growth rates of variety H610 differed among the three soil families considered in this study; it was fastest in the Typic Paleudult network, intermediate in the Tropeptic Eutrustox network, and slowest in the Hydric Dystrandept network. However, the yield of variety H610 was the highest on the Tropeptic Eutrustox sites, followed by the yields on the Hydric Dystrandept and Typic Paleudult sites, i.e., 5.6, 5.3, and 4.1 tons/ha, respectively.

Maize varieties exhibited different capacities to respond to N and/or P fertilization. Not only did the yields under the low fertilization treatment vary among varieties, but increases in yield attained with the application of the higher level of fertilizer were also different. Varieties that were responsive to N under the low level of P were not necessarily those that were responsive to N with the adequate P level. Response of varieties to P fertilization with the low and adequate levels of N showed a similar pattern. Moreover, N responsive varieties were not always P responsive varieties.

N responsive varieties with adequate P in the three soil family networks were: (1) Hydric Dystrandept: Hawaii: none; Indonesia: H6, Bastar Kuning and Wonosobo; The Philippines: UPCA-1, NK-T66, H610, H788, X304C, H6, and Bima. (2) Tropeptic Eutrustox: Hawaii: H610, H763, X6877, and X5800. (3) Typic Paleudult: Indonesia: H159, H6, Metro, Kodok, Wonosobo, DMR-5, Tiniguib; The Philippines: UPCA-1, Tiniguib, H610, X304C, and H6.

P responsive varieties with adequate N were: (1) Hydric Dystrandept: Hawaii: none; Indonesia: Bima and Bastar Kuning; The Philippines: UPCA-1, NK-T66, H610, H788, X306B, X304C, H6, and Bima. (2) Tropeptic Eutrustox: Hawaii: H610 and H688. (3) Typic Paleudult: Indonesia: H6, H159, Metro, Kodok, DMR-5 and Tiniguib; The Philippines: none.

Maize varieties tested in the Hydric Dystrandept soil family network in Hawaii and Indonesia, and in the Typic Paleudult site in the Philippines, were not satisfactorily differentiated for responsiveness in this study. This was mainly due to high soil fertility levels of these experimental sites.

Significant variation in nutrient composition among maize varieties was observed, and varieties which were N-efficient (X6877), P-efficient (H610 and H6) and K-efficient (H610) were identified. These varieties were capable of maintaining consistently higher N, P, or K concentrations in their earleaf tissue under various fertility conditions. These varieties generally had higher yields and/or yield responses than other varieties. This suggests that there is a potential for genetic improvement of nutrient uptake and utilization by maize, and it may be possible to select maize varieties adapted to specific soil conditions.

Certain yield-nutrient relationships in maize were apparent in the data analyzed. In a P-responsive soil, N concentration in the earleaf tissue of many maize varieties increased significantly with application of P, but not with N application. These increases were associated with yield responses. The critical nitrogen concentration associated with 95% of maximum yield was found to be 2.80% for variety H610. In N-responsive soils, tissue concentrations of P and K as well as of many other nutrients increased significantly with the application of N, but not with application of P. Thus, the most deficient nutrient limited the uptake and response of plants to other nutrients.

APPENDICES

A - F

APPENDIX A

Soil Analysis and Weather Data

A1. Soil analysis data of the 19 experimental blocks

Soil/ country/ site & block	pH H2O 1:1	pH KCl 1:1	1N KCl Ext. Al	CEC	Extractable bases Ca	Mg	K	Na	Modified Truog P
			- - - - - - -meq/100g-						ppm
Hydric Dystrandept									
HAWAII									
Iole-G-10	-	-	-	-	-	-	-	-	-
Iole-H-10	5.09	4.81	0.36	42.46	1.23	0.86	0.40	0.34	75.6
Iole-G-11	5.30	5.12	0.17	36.23	5.05	1.57	0.59	0.13	59.4
INDONESIA									
ITKA-O-10	x	x	x	x	x	x	x	x	58.2
ITKA-L-10*	4.70	4.10	x	37.90	3.19	0.26	0.19	0.05	77.0
ITKA-N-20	4.94	4.48	x	45.17	5.91	0.89	0.04	0.01	62.3
ITKA-F-10	4.42	3.99	1.02	40.73	3.28	0.96	0.17	0.04	83.0
PHILIPPINES									
PUC-C-10*	5.66	4.74	0.26	54.10	1.57	0.66	0.31	0.11	13.0
PUC-L-10*	5.40	4.60	0.33	43.60	2.57	1.27	0.13	0.06	15.0
PUC-M-10	4.80	4.20	1.13	45.90	1.18	1.02	0.15	0.03	11.0
PUC-L-20	-	-	-	-	-	-	-	-	-
Tropeptic Eutrustox									
HAWAII									
Molokai-C-10	5.40	5.22	0.10	18.22	2.30	1.14	0.84	0.72	18.5
Molokai-D-10	5.32	5.01	0.10	17.87	2.38	1.44	1.62	0.21	21.6
Typic Paleudult									
INDONESIA									
Nakau-B-10	5.15	4.95	0.21	18.72	1.95	0.96	0.64	0.08	3.1
Nakau-E-10	4.50	3.70	0.51	12.95	4.87	1.88	0.56	0.04	6.0
Nakau-B-20	-	-	-	-	-	-	-	-	-
Nakau-E-20	-	-	-	-	-	-	-	-	-
PHILIPPINES									
Davao-G-10	5.44	4.91	0.01	20.52	8.48	2.98	1.53	0.04	22.6
Davao-B-13*	5.16	4.67	0.06	10.17	3.30	1.78	2.41	0.01	11.7

-Soil sample was not taken.

[x]Not analyzed.

*Soil sample obtained from adjacent block.

A2. Weather data from 19 variety experiments on three soil families

Soil/ country/ site & block	Temperature		Average solar radiation		Total solar radi-ation	Monthly average solar radiation							Relative humidity		Cumulative rainfall	Wind run
	Max	Min	Tass.[a]	Crop[b]		1	2	3	4	5	6	7	Max	Min		
	- - °C - -		- g cal/day -		kg cal	- - - - - - - g cal/day - - - - - -							- - % - -		mm	km/hr
Hydric Dystrandept																
HAWAII																
Iole-G-10 wet	23.8	16.9	512	445	83.7	353	435	385	534	486	503	361	95.3	63.1	690	15.5
Iole-H-10 dry '78	24.8	18.6	489	410	74.2	453	393	476	476	391	291	x[c]	97.1	68.0	278	15.8
Iole-G-11 late-wet '79	23.7	16.6	505	418	88.6	234	422	412	533	457	429	443	97.3	62.7	515	14.0
INDONESIA																
ITKA-O-10 dry '77	24.6	12.0	404	397	57.6	383	386	398	392	399	481		95.3	46.3	x	x
ITKA-L-10 late-wet '78	26.0	16.4	368	353	51.5	501	448	305	379	353	274		98.7	59.5	534	4.9
ITKA-N-10 wet '79	25.5	16.1	363	312	46.2	307	409	327	213	314	286		95.4	57.9	456	5.4
ITKA-F-10 dry '79	26.1	15.1	398	353	62.1	349	353	366	428	275	357		97.6	51.0	800	5.3
PHILIPPINES																
PUC-C-10 dry '76	32.1	24.1	331	326	35.9	x	345	328	321	360			99.8	72.8	418	10.5
PUC-L-10 dry '77	31.5	23.4	321	323	39.7	303	369	284	309	401			99.0	78.2	673	7.0
PUC-M-10 wet '78	34.5	23.6	392	373	46.6	455	443	392	373	287			95.6	64.3	x	6.7
PUC-L-20 wet '80	31.9	20.5	423	391	48.9	392	443	412	320	x			95.6	55.8	900	6.0
Tropeptic Eutrustox																
HAWAII																
Molokai-C-10 dry '78	29.2	22.0	513	487	77.4	584	572	550	441	346	373		97.4	74.2	116	23.1
Molokai-D-10 late-wet '79	27.2	18.8	588	534	96.1	335	515	557	593	629	606		89.9	68.1	311	18.0
Typic Paleudult																
INDONESIA																
Nakau-B-10 wet '79	34.2	24.6	388	404	61.1	402	434	371	804				92.0	39.0	232	4.4
Nakau-E-10 early-dry '79	35.8	23.0	386	393	44.8	412	395	376	364				97.0	33.0	492	3.1
Nakau-B 20 wet '80	32.3	21.2	391	384	44.9	419	381	406	396				92.6	36.5	1137	4.2
Nakau-E-20 dry '80	34.6	21.3	395	391	43.4	378	382	409	406				98.4	30.8	548	3.4
PHILIPPINES																
Davao-G-10 late-wet '79	36.0	23.7	440	443	50.9	439	407	430	494				98.9	57.6	1053	4.6
Davao-B-13 dry '79	34.4	23.8	375	401	42.1	380	365	386	508				97.6	51.9	445	6.0

[a] Daily average solar radiation during 4 weeks before and after tasseling.

[b] Daily average solar radiation during the whole crop period.

[c] Missing data.

APPENDIX B

Analyses of Variance

of Variety Experiments

B1. Analyses of variance of maize grain yields for three variety experiments on the Hydric Dystrandept at Iole, Hawaii

Source of variation	d.f.	Mean squares		
		Iole-G-10 Wet 1978	Iole-H-10 Dry 1978	Iole-G-11 Late-wet 1979
Replication	2	8,657,981*	666,488	590,777
Fertilizer (F)	3	6,650,604	10,713,277**	10,600,768
N	1	17,635,347*	31,158,488**	30,184,051**
P	1	5,104	841,501	1,618,243
NxP	1	2,311,363	139,843	9
Error (a)	6	2,178,691	310,930	4,202,222
Variety (V)	7	3,667,421**	2,318,240**	4,830,377**
FxV	21	643,079	390,468	632,116
NxV	7	826,343	394,060	591,622
PxV	7	924,950	477,826	635,727
NxPxV	7	177,946	299,518	669,000
Error (b)	56	607,354	429,877	856,469
Total	95			
CV (a)		28.56	6.93	27.45
(b)		15.08	8.14	12.39

*, ** = significant at the 5 and 1% levels, respectively.

B2. Analyses of variance of maize grain yields for four variety experiments on the Hydric Dystrandept at ITKA, Indonesia

Source of variation	d.f.	Mean squares			
		ITKA-0-10[b] Dry 1977	ITKA-L-10 Late-wet 1978	ITKA-N-20 Wet 1979	ITKA-F-10 Dry 1979
Replication	2(3)[a]	22,217	2,848,608	2,896,008*	2,901,323*
Fertilizer (F)	3(3)	4,841,222**	2,887,681	3,119,013*	8,606,589
N	1(1)	610,884	2,832,200	390,042	21,139,086**
P	1(1)	10,278,578**	3,230,882	8,955,234**	1,688,816
NxP	1(1)	3,634,208*	2,599,960	11,767	2,991,866*
Error (a)	6(9)	579,694	969,941	701,315	465,692
Variety (V)	5(4)	10,414,754**	2,650,137**	1,115,421+	4,563,586**
FxV	15(12)	316,285	745,405*	387,152	929,150
NxV	5(4)	90,158	1,196,330**	522,913	1,162,939
PxV	5(4)	738,185	417,844	423,523	146,420
NxPxV	5(4)	120,513	622,040	215,019	1,478,091
Error (b)	40(48)	508,018	329,457	515,307	1,029,637
Total	71(79)				
CV (a)		12.88	36.50	14.50	10.81
(b)		12.06	21.27	12.43	16.07

[a]Degrees of freedom in parentheses are degrees of freedom for ITKA-N-20.

[b]Treatment variables in this experiment were lime (L) and P, instead of N and P.

+, *, ** = significant at the 10, 5, and 1% levels, respectively.

B3. Analyses of variance of maize grain yields for three variety experiments on the Hydric Dystrandept at PUC, the Philippines

Source of variation	d.f.	Mean squares			
		PUC-C-10[a] Dry 1976	PUC-L-10[a] Dry 1977	PUC-M-10 Wet 1978	PUC-L-22 Wet 1980
Replication	2	102,341	3,205,320*	9,498,769**	486,306
Fertilizer (F)	3	787,576	3,949,010*	25,454,399**	55,361,819**
N	1	14,384	1,221,797	26,586,727**	6,420,319
P	1	2,326,570+	10,388,353**	46,802,534**	155,980,351**
NxP	1	21,774	236,882	2,973,936*	18,466,739
Error (a)	6	412,734	514,207	494,372	3,077.790
Variety (V)	4	1,745,794**	24,964,537**	254,467*	264,746
FxV	12	206,476	956,196	94,714	564,211**
NxV	4	27,159	732,119	89,363	218,381
PxV	4	56,658	1,678,697*	127,700	1,240,862**
NxPxV	4	535,610+	457,774	67,080	233,389
Error (b)	32	245,706	596,589	97,157	161,282
Total	59				
CV (a)		11.07	16.55	23.70	42.96
(b)		7.50	11.53	10.51	9.84

[a]Treatment variables in this experiment were lime (L) and P, instead of N and P.

+, *, ** = significant at 10, 5, and 1% levels, respectively.

B4. Analyses of variance of maize grain yields for two variety experiments on the Tropeptic Eutrustox at Molokai, Hawaii

Source of variation	d.f.	Mean squares: Mol-C-10 Dry 1978	Mean squares: Mol-D-10 Late-wet 1979
Replication	2	3,296,174	14,753,731*
Fertilizer (F)	3	7,627,826	40,515,020**
N	1	10,473,549	90,751,760**
P	1	11,685,219	29,727,117*
NxP	1	724,711	1,066,184
Error (a)	6	2,102,756	2,247,345
Variety (V)	7	1,526,919**	9,952,173**
FxV	21	303,393	649,165
NxV	7	410,368	568,021
PxV	7	302,540	189,159
NxPxV	7	197,271	1,190,315+
Error (b)	56	476,390	550,185
Total	95		
CV (a)		22.43	25.91
(b)		10.67	12.82

+, *, ** = significant at the 10, 5, and 1% levels, respectively.

B5. Analyses of variance of maize grain yields for four variety experiments on the Typic Paleudult at Nakau, Indonesia

Source of variation	d.f.	Mean squares			
		Nakau-B-10 Wet 1979	Nakau-E-10 Early-dry 1979	Nakau-B-20 Wet 1980	Nakau-E-20 Dry 1980
Replication	2(2)[a]	531,010	1,496,050	177,203	821,643
Fertilizer (F)	3(3)	16,126,632**	6,981,335+	4,475,180**	667,502
N	1(1)	12,450,144*	7,596,230+	6,721,000**	469,481
P	1(1)	30,299,052**	6,927,401	114,498,800**	1,176,578+
NxP	1(1)	5,630,700+	6,420,376	13,035,618**	356,449
Error (a)	6(6)	1,079,289	1,962,429	864,754	229,315
Variety (V)	3(5)	5,140,537**	2,678,094*	1,842,739*	2,175,877*
FxV	9(15)	1,975,330*	752,628	406,608	249,128
NxV	3(5)	866,263	1,258,821+	595,101	103,556
PxV	3(5)	3,123,482*	715,290	274,054	486,796
NxPxV	3(5)	1,936,246+	283,715	349,048	157,032
Error (b)	24(40)	740,555	590,550	406,068	310,491
Total	47(71)				
CV (a)		20.14	25.06	23.73	14.47
(b)		16.68	13.74	20.33	16.84

[a]Degrees of freedom in parentheses are degrees of freedom for Nakau-B-20 wet 1980 and Nakau-E-20 dry 1980.

+, *, ** = significant at the 10, 5, 1% levels, respectively.

B6. Analyses of variance of maize grain yields for two variety experiments on the Typic Paleudult at Davao, the Philippines

Source variation	d.f.	Mean squares	
		Davao-G-10 Late-wet 1979	Davao-B-13 Dry 1980
Replication	2	1,207,640	2,539,276*
Fertilizer (F)	3	7,835,178*	21,600,636**
N	1	22,058,407*	63,538,692**
P	1	126,960	695,957
NxP	1	1,320,167	567,259
Error (a)	6	1,630,534	267,118
Variety (V)	4	14,916,506**	2,360,820**
FxV	12	694,964*	137,855
NxV	4	1,853,731**	137,946
PxV	4	25,636	47,598
PxPxV	4	205,525	228,020
Error (b)	32	322,209	242,011
Total	59		
CV (a)		37.41	13.61
(b)		16.63	12.95

*, ** = significant at the 5 and 1% levels, respectively.

APPENDIX C

Yield Data of the Variety Experiments
with No Significant Varietal Differences
in Response to N or P

C1. Mean yields (kg/ha) of varieties in maize variety experiments at Iole-G-11 and at Molokai-C-10 in Hawaii

Maize variety	Fertilization treatment				Maize variety	Fertilization treatment			
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P		Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P
Iole-G-11 wet 1979					Molokai-C-10 late-wet 1979				
H610	5621	6626	6945	8229	H610	5474	6625	7028	7253
H688	6875	6506	7157	7263	H688	5420	6214	6106	7137
H763	6671	6425	8036	7553	H788	5833	6203	7352	7098
X304C	6913	8002	8767	8668	X304C	6386	7658	6955	7395
X4816	6846	7586	9094	8968	X304B	5631	6927	6318	7070
X5859	7960	7987	8109	8994	X306B	5810	6493	6709	7128
X6819	5820	6299	7476	7127	Phoenix 1110	5351	6037	5421	6658
X6877	7515	6863	7604	8469	Cargill 111	5698	6417	6390	6733

C2. Mean yields (kg/ha) of varieties in maize variety experiments at Nakau-B-20 in Indonesia and at Davao-B-13 in the Philippines

Maize variety	Fertilization treatment				Maize variety	Fertilization treatment			
	Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P		Low N Low P	Low N Adq. P	Adq. N Low P	Adq. N Adq. P
Nakau-B-20 wet 1980					Davao-B-13 dry 1980				
Tiniguib	3102	4724	2526	5313	UPCA-1	2777	2372	4699	4710
Kodok	2071	3877	1359	5339	Tiniguib	3178	1603	4663	4558
H6	2562	4249	2584	6364	H6	2469	1963	4368	4653
DMR-5	2946	5133	2818	5973	H610	2724	2645	5005	4383
Wonosobo	2893	4798	3015	6105	X304C	3720	3234	5451	5777

APPENDIX D

The 90% Confidence Limits for Regression Coefficients (b_1), Coefficients of Determination (r^2), and Mean Yields of Individual Varieties in the Tests of Adaptation

D1. Hydric Dystrandept at Iole in Hawaii

Data set	Maize variety	Population mean $b_1 \pm t$ (s.e.b_1)	Population mean r^2	Standard variety (H610) $b_1 \pm t$ (s.e.b_1)	Standard variety (H610) r^2	Mean yield* (kg/ha)
1	Six varieties, two seasons (wet 1978, dry 1978)					
	H610	1.083 ± 0.158	0.87	1.000 ± 0.115	0.91	6440 b
	H788	1.141 ± 0.191	0.83	1.025 ± 0.178	0.82	5960 c
	X304B	0.905 ± 0.196	0.74	0.788 ± 0.195	0.69	6130 bc
	X304C	0.868 ± 0.215	0.69	0.743 ± 0.214	0.62	7230 a
	X4816	0.982 ± 0.156	0.84	0.840 ± 0.176	0.75	7090 a
	X4817	1.021 ± 0.158	0.85	0.915 ± 0.149	0.83	6890 a
2	Three varieties, two seasons (dry 1978, late-wet 1979)					
	H610	1.326 ± 0.381	0.62	1.000 ± 0.261	0.66	7430 b
	H688	1.005 ± 0.326	0.56	0.640 ± 0.272	0.42	7750 b
	X304C	0.669 ± 0.438	0.24	0.485 ± 0.320	0.23	8270 a

*Means within the same data set followed by the same letter are not significantly different ($P < 0.10$).

D2. Hydric Dystrandept at ITKA in Indonesia

Data set	Maize variety	Population mean $b_1 \pm t$ (s.e.b_1)	r^2	Standard variety (H6) $b \pm t$ (s.e.b_1)	r^2	Mean yield* (kg/ha)
1	Five varieties, two seasons (dry 1977, late-wet 1978)					
	H6	1.084 ± 0.180	0.83	1.000 ± 0.129	0.89	5200 a
	Bastar Kuning	1.169 ± 0.144	0.90	1.014 ± 0.153	0.85	4750 b
	Harapan	1.127 ± 0.132	0.91	0.958 ± 0.160	0.83	4730 b
	Bima	0.830 ± 0.139	0.83	0.683 ± 0.161	0.71	3640 c
	H610	0.790 ± 0.168	0.75	0.647 ± 0.182	0.63	3540 c
2	Three varieties, three seasons (dry 1977, late-wet 1978, wet 1979)					
	H6	0.947 ± 0.130	0.80	1.000 ± 0.121	0.84	5370 a
	Bastar Kuning	1.045 ± 0.128	0.83	1.039 ± 0.154	0.77	5090 a
	Harapan	1.008 ± 0.130	0.82	0.986 ± 0.162	0.74	5060 a
3	Three varieties, three seasons (dry 1977, late-wet 1978, dry 1979)					
	H6	0.965 ± 0.157	0.76	1.000 ± 0.129	0.83	5560 a
	Harapan	1.083 ± 0.135	0.84	1.012 ± 0.168	0.75	5260 a
	H610	0.953 ± 0.164	0.74	0.819 ± 0.212	0.56	4300 b
4	Four varieties, two seasons (late-wet 1978, dry 1979)					
	H6	0.864 ± 0.194	0.73	1.000 ± 0.180	0.81	4860 a
	Harapan	1.044 ± 0.015	0.83	1.065 ± 0.244	0.72	4600 a
	UPCA-1	0.998 ± 0.179	0.81	1.120 ± 0.252	0.73	4060 b
	H610	1.094 ± 0.179	0.84	0.995 ± 0.299	0.66	3860 b
5	Three varieties, two seasons (wet 1979, dry 1979)					
	H6	0.572 ± 0.384	0.20	1.000 ± 0.560	0.26	5910 b
	Harapan	0.988 ± 0.454	0.35	1.271 ± 0.742	0.25	5870 b
	Wonosobo	1.440 ± 0.415	0.58	1.698 ± 0.781	0.35	6410 a

*Means within the same data set followed by the same letter are not significantly different ($P < 0.10$).

D3. Hydric Dystrandept at PUC in the Philippines

Data set	Maize variety	Population mean $b_1 \pm t$ (s.e.b_1)	Population mean r^2	Standard variety (UPCA-1) $b_1 \pm$ (s.e.b_1)	Standard variety (UPCA-1) r^2	Mean yield* (kg/ha)
1	Three varieties, two seasons (dry 1976, dry 1977)					
	UPCA-1	1.470 ± 0.555	0.49	1.000 ± 0.325	0.56	6030 a
	DMR Comp. 1	0.772 ± 0.414	0.32	0.452 ± 0.480	0.27	5380 b
	H610	0.758 ± 0.556	0.20	0.321 ± 0.561	0.09	5290 b
2	Three varieties, two seasons (dry 1976, wet 1978)					
	UPCA-1	1.153 ± 0.141	0.90	1.000 ± 0.110	0.92	4700 a
	H610	0.952 ± 0.134	0.87	0.805 ± 0.127	0.83	4370 b
	H788	0.895 ± 0.136	0.85	0.749 ± 0.133	0.81	4460 b
3	Three varieties, two seasons (wet 1978, wet 1980)					
	UPCA-1	0.883 ± 0.179	0.77	1.000 ± 0.189	0.79	3400 a
	H610	1.184 ± 0.165	0.87	1.283 ± 0.218	0.82	3520 a
	H6	0.932 ± 0.170	0.80	1.022 ± 0.384	0.77	3490 a

*Means within the same data set followed by the same letter are not significantly different ($P < 0.10$).

D4. Tropeptic Eutrustox at Molokai in Hawaii

Maize variety	Population mean		Standard variety (H610)		Mean yield* (kg/ha)
	$b_1 \pm t$ (s.e.b_1)	r^2	$b_1 \pm t$ (s.e.b_1)	r^2	
Three varieties, two seasons (dry 1978, dry 1979)					
H610	1.283 ± 0.378	0.61	1.000 ± 0.259	0.67	5620 b
H688	1.015 ± 0.417	0.44	0.722 ± 0.321	0.40	5620 b
X304C	0.702 ± 0.441	0.25	0.410 ± 0.349	0.16	6860 a

D5. Typic Paleudult at Nakau in Indonesia

Maize variety	Population mean		Standard variety (H6)		Mean yield* (kg/ha)
	$b_1 \pm t$ (s.e.b_1)	r^2	$b_1 \pm t$ (s.e.b_1)	r^2	
Three varieties, two seasons (wet 1980, dry 1980)					
H6	1.077 ± 0.235	0.74	1.000 ± 0.203	0.77	3610 a
Kodok	1.064 ± 0.240	0.72	0.941 ± 0.234	0.68	2950 b
Tiniguib	0.858 ± 0.144	0.83	0.734 ± 0.163	0.73	3450 a

D6. Typic Paleudult at Davao in the Philippines

Mean variety	Population mean		Standard variety (UPCA-1)		Mean yield* (kg/ha)
	$b_1 \pm t$ (s.e.b_1)	r^2	$b_1 \pm t$ (s.e.b_1)	r^2	
Three varieties, two seasons (wet 1979, dry 1980)					
UPCA-1	1.023 ± 0.235	0.72	1.000 ± 0.209	0.75	3400 b
Tiniguib	0.762 ± 0.263	0.53	0.751 ± 0.240	0.57	3480 b
X304C	1.215 ± 0.259	0.75	1.046 ± 0.309	0.61	4870 a

*Means followed by the same letter are not significantly different ($P < 0.10$).

APPENDIX E

Fertilization Treatment, Mean Yield, and Leaf Nutrient Composition in Transfer Experiments

E1. Data from transfer experiment with variety H610 at Iole-E-11 in Hawaii

Treat-ment No.	Coded value		Actual rate		Mean yield	Earleaf composition										
	N	P	N	P		N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
			kg/ha		kg/ha	- - - - - - - - - %					- - - - - - - - -	- - -	ppm	- - - - -		
1	-0.85	-0.85	29	21	4794	2.37	0.30	1.80	0.38	0.25	0.17	168	73	123	15	41
2	0.85	-0.85	186	21	7956	3.06	0.33	1.90	0.44	0.27	0.21	154	47	107	18	54
3	-0.85	0.85	29	262	5079	2.61	0.23	1.71	0.43	0.26	0.18	150	41	104	14	41
4	0.85	0.85	186	262	7176	2.90	0.34	1.90	0.43	0.27	0.21	124	42	110	18	50
5	-0.40	-0.40	70	85	7157	2.77	0.31	1.91	0.43	0.27	0.20	136	43	109	16	46
6	0.40	-0.40	144	85	7081	2.83	0.32	1.87	0.41	0.26	0.21	128	42	108	18	47
7	-0.40	0.40	70	199	6638	2.77	0.33	1.85	0.44	0.27	0.20	141	37	106	16	47
8	0.40	0.40	144	199	6957	2.82	0.32	1.80	0.42	0.27	0.20	186	41	110	18	47
9	0	0	108	142	6875	2.77	0.33	1.79	0.45	0.26	0.20	134	42	112	18	54
10	0	-0.85	108	21	7823	2.79	0.31	1.87	0.44	0.26	0.20	149	39	107	17	43
11	0	0.85	108	262	7439	2.76	0.32	1.73	0.46	0.27	0.20	126	44	109	16	43
12	-0.85	0	29	142	4389	2.25	0.29	1.85	0.38	0.25	0.15	145	48	102	14	39
13	0.85	0	186	142	7209	3.02	0.33	1.82	0.45	0.28	0.22	139	42	109	18	47
14	-1.00	-1.00	0	0	2909	1.97	0.27	1.53	0.44	0.20	0.14	210	100	113	11	39
15	-1.00	-1.00	0	0	3494	2.06	0.28	1.76	0.41	0.27	0.16	163	79	106	13	39
				$LSD^{a}_{.05}$	1213	0.29	0.02	0.16	0.06	0.03	0.02	49	16	10	1	5

[a]The LSD's are for comparing means within the first 13 treatments.

E2. Data from transfer experiment with variety H610 at Halawa-B-22 in Hawaii

Treatment No.	Coded value N	Coded value P	Actual rate N	Actual rate P[a]	Mean yield	Earleaf composition N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
			kg/ha		kg/ha	%						ppm				
1	-0.85	-0.85	32	192	2401	1.64	0.23	1.76	0.25	0.29	0.12	199	51	102	11	35
2	0.85	-0.85	225	192	8373	2.96	0.31	1.97	0.37	0.28	0.22	171	35	113	18	62
3	-0.85	0.85	32	578	2992	2.02	0.24	1.71	0.28	0.24	0.11	165	50	104	11	38
4	0.85	0.85	225	578	8629	3.06	0.32	1.99	0.44	0.28	0.22	151	33	113	18	66
5	-0.40	-0.40	83	420	5766	2.22	0.26	1.87	0.32	0.28	0.16	174	45	111	14	48
6	0.40	-0.40	174	420	7455	2.91	0.32	1.96	0.37	0.26	0.21	160	29	114	17	65
7	-0.40	0.40	83	520	5339	2.47	0.27	1.82	0.37	0.28	0.16	293	44	106	13	46
8	0.40	0.40	174	520	7815	2.72	0.31	2.00	0.38	0.26	0.20	150	34	114	17	62
9	0	0	129	493	7027	2.51	0.29	1.95	0.35	0.27	0.18	161	39	108	15	55
10	0	-0.85	129	192	7099	2.88	0.30	1.99	0.35	0.28	0.20	181	35	111	16	55
11	0	0.85	129	578	6863	2.82	0.29	1.92	0.40	0.28	0.18	203	38	110	15	52
12	-0.85	0	32	493	3172	1.68	0.24	1.78	0.27	0.26	0.11	276	60	103	12	36
13	0.85	0	225	493	8298	2.98	0.33	2.06	0.36	0.26	0.21	147	33	113	17	65
14	-1.00	-1.00	0	0	778	1.43	0.25	1.38	0.34	0.21	0.09	300	31	116	9	27
15	-1.00	-1.00	0	0	1004	1.18	0.20	1.63	0.20	0.27	0.09	247	49	106	9	29
				$LSD^{b}_{.05}$	889	0.49	0.03	0.11	0.05	0.03	0.02	126	9	6	1	7

[a] Applied to the second crop before this experiment.
[b] The LSD's are for comparing means within the first 13 treatments.

E3. Data from transfer experiment with variety H610 at ITKA-K-13 in Indonesia

Treat-ment No.	Coded value N	Coded value P	Actual rate N	Actual rate P[a]	Mean yield	Earleaf composition N	P	K	Ca	Mg	S	Al	Mn	Fe	Cu	Zn
			kg/ha		kg/ha	%						ppm				
1	-0.85	-0.85	29	86	7482	2.41	0.23	1.51	0.52	0.11	0.15	181	138	124	9	49
2	0.85	-0.85	186	86	8236	2.28	0.23	1.50	0.46	0.13	0.14	280	128	133	8	43
3	-0.85	0.85	29	1009	7723	2.17	0.21	1.54	0.49	0.12	0.15	273	176	143	8	44
4	0.85	0.85	186	1009	8427	2.68	0.27	1.55	0.53	0.15	0.17	270	109	150	11	57
5	-0.40	-0.40	71	464	7922	2.08	0.22	1.51	0.47	0.12	0.13	248	117	138	8	37
6	0.40	-0.40	144	464	8450	2.66	0.25	1.59	0.48	0.13	0.16	211	110	139	10	48
7	-0.40	0.40	71	834	7981	2.45	0.24	1.50	0.50	0.11	0.14	238	120	137	9	48
8	0.40	0.40	144	834	8185	2.53	0.23	1.45	0.51	0.14	0.16	261	117	151	9	44
9	0	0	108	683	8305	2.38	0.24	1.55	0.52	0.12	0.16	323	126	157	10	53
10	0	-0.85	108	86	8817	2.30	0.24	1.59	0.51	0.14	0.16	258	127	145	11	53
11	0	0.85	108	1009	8721	2.28	0.24	1.58	0.50	0.12	0.14	278	152	132	8	45
12	-0.85	0	29	683	7734	2.22	0.23	1.52	0.53	0.13	0.15	255	116	139	8	44
13	0.85	0	186	683	8476	2.45	0.24	1.50	0.49	0.13	0.16	380	120	151	10	49
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-1.00	-1.00	0	0	6015	1.97	0.20	1.52	0.40	0.13	0.13	412	177	126	8	44
16	-1.00	0	0	683	4571	1.63	0.17	1.37	0.37	0.11	0.10	220	183	130	5	35
				$LSD^{b}_{.05}$	904	0.50	0.04	0.14	0.08	0.03	0.02	146	58	32	2	13

[a] Applied to the third crop before this experiment.

[b] The LSD's are for comparing means within the first 13 treatments.

E4. Data from transfer experiment with variety H610 at PUC-S-11 in the Philippines

Treatment No.	Coded value		Actual rate		Mean yield
	N	P	N	P	
			kg/ha		kg/ha
1	-0.85	-0.85	29	15	539
2	0.85	-0.85	186	15	583
3	-0.85	0.85	29	186	4466
4	0.85	0.85	186	186	6103
5	-0.40	-0.40	71	60	2632
6	0.40	-0.40	144	60	2451
7	-0.40	0.40	71	141	4855
8	0.40	0.40	144	141	5378
9	0	0	107	101	4123
10	0	-0.85	107	15	442
11	0	0.85	107	186	6530
13	0.85	0	186	101	4234
14	-1.00	-1.00	0	0	41
16	-1.00	0	0	101	2819
17	Complete control		0	0	437
			$LSD^{a}_{.05}$		990

[a]The LSD is for comparing means within the first 13 treatments.

APPENDIX F

Correlation Matrices for the Relationships between Fertilization Treatments, Yield, and Leaf Nutrient Composition of Transfer Experiments

F1. Transfer experiment with variety H610 on the Hydric Dystrandept at Iole-E-11 in Hawaii

	YIELD	N	P	K	CA	MG	S	AL	MN	FE	CU	ZN
NCODF	0.59410[a]	0.71288	0.57497	0.21517	0.31934	0.32539	0.74743	-0.09854	-0.24784	-0.05477	0.80006	0.59670
	0.0001	0.0001	0.0001	0.1883	0.0475	0.0432	0.0001	0.5506	0.1282	0.7405	0.0001	0.0001
NCODFSQ	-0.36852	-0.15585	-0.09632	0.02497	-0.25630	-0.06092	-0.26986	0.08371	0.28913	0.03149	-0.23364	-0.10549
	0.0210	0.3434	0.5597	0.8801	0.1145	0.7126	0.0966	0.6124	0.0742	0.8491	0.1523	0.5227
PCODF	-0.08604	0.02106	0.29977	-0.28427	0.21954	0.10610	0.00934	-0.14539	-0.30982	-0.22980	-0.13986	-0.06575
	0.6025	0.8988	0.0637	0.0795	0.1793	0.5203	0.9550	0.3772	0.0558	0.1593	0.3958	0.6909
PCODFSQ	0.06882	0.03357	-0.02767	-0.07720	0.05302	-0.02139	-0.00881	0.03594	0.19895	0.15463	-0.13429	-0.09481
	0.6772	0.8392	0.8672	0.6404	0.7486	0.8972	0.9576	0.8283	0.2247	0.3473	0.4150	0.5659
NPCODF	-0.09081	-0.21131	-0.17525	0.09873	-0.19585	-0.15074	-0.02761	-0.00200	0.31029	0.45999	-0.02581	-0.11190
	0.5825	0.1966	0.2859	0.5498	0.2321	0.3597	0.8675	0.9903	0.0545	0.0032	0.8761	0.4976
N	0.69732	1.00000	0.67195	0.02758	0.46601	0.31794	0.73138	-0.08714	-0.34593	-0.08479	0.61290	0.45842
	0.0001	0.0000	0.0001	0.8676	0.0028	0.0486	0.0001	0.5979	0.0310	0.6078	0.0001	0.0033
P	0.29050	0.67195	1.00000	0.10870	0.49461	0.31608	0.74305	-0.23393	-0.54351	-0.19673	0.63128	0.58913
	0.0728	0.0001	0.0000	0.5101	0.0014	0.0500	0.0001	0.1518	0.0004	0.2300	0.0001	0.0001
K	-0.13996	0.02758	0.10870	1.00000	-0.29748	-0.11704	0.13836	0.18214	-0.13936	-0.15987	0.39495	0.37728
	0.3954	0.8676	0.5101	0.0000	0.0659	0.4780	0.4009	0.2671	0.3975	0.3310	0.0128	0.0179
CA	0.32779	0.46601	0.49463	-0.29748	1.00000	0.54064	0.60216	-0.26468	-0.39706	0.03556	0.37902	0.31350
	0.0416	0.0028	0.0014	0.0659	0.0000	0.0004	0.0001	0.1035	0.0123	0.8298	0.0173	0.0620
MG	0.31615	0.31794	0.31608	-0.11704	0.54064	1.00000	0.48559	-0.04510	-0.17912	0.03374	0.34960	0.22823
	0.0499	0.0486	0.0500	0.4780	0.0004	0.0000	0.0017	0.7852	0.2753	0.8384	0.0291	0.1623
S	0.40498	0.73138	0.74305	0.13836	0.60216	0.48559	1.00000	-0.09881	-0.45762	0.14187	0.88035	0.59000
	0.0105	0.0001	0.0001	0.4009	0.0001	0.0017	0.0000	0.5495	0.0034	0.3890	0.0001	0.0001
AL	-0.20539	-0.08714	-0.23393	0.18214	-0.26468	-0.04510	-0.09881	1.00000	0.27016	0.10627	-0.02312	-0.01936
	0.2047	0.5979	0.1518	0.2671	0.1035	0.7852	0.5495	0.0000	0.0962	0.5196	0.8889	0.9069
MN	-0.06309	-0.34593	-0.54351	-0.13936	-0.39706	-0.17912	-0.45762	0.27016	1.00000	0.47507	-0.39602	-0.13678
	0.7028	0.0310	0.0004	0.3975	0.0123	0.2753	0.0034	0.0962	0.0000	0.0022	0.0126	0.4064
FE	-0.20439	-0.08479	-0.19673	-0.15987	0.03556	0.03374	0.14187	0.10627	0.47507	1.00000	0.10229	0.12358
	0.2108	0.6078	0.2300	0.3310	0.8298	0.8384	0.3890	0.5196	0.0022	0.0000	0.5355	0.4535
CU	0.32929	0.61290	0.63128	0.39495	0.37902	0.34960	0.88035	-0.02312	-0.39602	0.10229	1.00000	0.76256
	0.0413	0.0001	0.0001	0.0128	0.0173	0.0291	0.0001	0.8889	0.0126	0.5355	0.0000	0.0001
ZN	0.23130	0.45842	0.58913	0.37728	0.31350	0.22823	0.59000	-0.01936	-0.13678	0.12358	0.76256	1.00000
	0.1566	0.0033	0.0001	0.0179	0.0520	0.1623	0.0001	0.9069	0.4064	0.4535	0.0001	0.0000

[a] The upper figure is the correlation coefficient for the relationship between the two variables indicated; the lower figure is the probability of obtaining the correlation coefficient due to chance.

F2. Transfer experiment with variety H610 on the Hydric Dystrandept at Halawa-B-22 in Hawaii

	YIELD	N	P	K	CA	MG	S	AL	MN	FE	CU	ZN
NCODE	0.92313[a] 0.0001	0.92135 0.0001	0.87519 0.0001	0.81829 0.0001	0.75323 0.0001	0.04472 0.7869	0.92768 0.0001	-0.34847 0.0297	-0.71830 0.0001	0.61347 0.0001	0.93543 0.0001	0.92058 0.0001
NCODESQ	-0.26940 0.0972	-0.25606 0.1144	-0.18482 0.2600	-0.23738 0.1456	-0.29788 0.0655	-0.07162 0.6643	-0.25108 0.1231	-0.01612 0.9224	0.27322 0.0924	-0.19725 0.2287	-0.18785 0.2521	-0.17804 0.2782
PCODE	0.02858 0.8629	0.08929 0.5888	0.07027 0.6708	-0.09432 0.5679	0.32844 0.0412	-0.21242 0.1942	-0.08609 0.6023	0.02607 0.8748	0.01395 0.9328	-0.02048 0.9015	-0.09777 0.5538	0.00308 0.9851
PCODESQ	-0.06714 0.6847	0.03402 0.6111	-0.06932 0.6750	-0.14343 0.3837	0.08235 0.6182	0.13664 0.4068	0.03360 0.8391	-0.10590 0.5211	-0.03961 0.8108	-0.04204 0.7994	0.02051 0.9014	-0.08176 0.6207
NPCODE	-0.01020 0.9509	-0.09790 0.5532	0.02149 0.8967	0.09627 0.5599	0.09439 0.5676	0.27955 0.0848	-0.02092 0.8994	-0.02686 0.8711	0.00138 0.9934	-0.02192 0.8946	-0.01005 0.9516	0.01932 0.9070
N	0.83406 0.0001	1.00000 0.0000	0.85865 0.0001	0.70458 0.0001	0.80704 0.0001	0.00659 0.9682	0.89973 0.0001	-0.23410 0.1515	-0.78158 0.0001	0.55399 0.0003	0.85845 0.0001	0.84517 0.0001
P	0.86540 0.0001	0.85865 0.0001	1.00000 0.0000	0.83042 0.0001	0.77450 0.0001	-0.11395 0.4897	0.91252 0.0001	-0.22472 0.1690	-0.81058 0.0001	0.56247 0.0002	0.87925 0.0001	0.91561 0.0001
K	0.79886 0.0001	0.70458 0.0001	0.83042 0.0001	1.00000 0.0000	0.53933 0.0004	-0.07842 0.6351	0.84750 0.0001	-0.38041 0.0169	-0.74705 0.0001	0.57806 0.0001	0.85347 0.0001	0.79088 0.0001
CA	0.83739 0.0001	0.80704 0.0001	0.77450 0.0001	0.53933 0.0004	1.00000 0.0000	0.24406 0.1343	0.80545 0.0001	-0.13603 0.4090	-0.56262 0.0002	0.53707 0.0004	0.75862 0.0001	0.77014 0.0001
MG	0.11195 0.4974	0.00659 0.9682	-0.11395 0.4897	-0.07842 0.6351	0.24406 0.1343	1.00000 0.0000	0.09750 0.5549	0.11966 0.4681	0.31296 0.0524	0.21925 0.1799	0.04608 0.7806	0.04069 0.8057
S	0.92615 0.0001	0.89973 0.0001	0.91252 0.0001	0.84750 0.0001	0.80545 0.0001	0.09750 0.5549	1.00000 0.0000	-0.32242 0.0453	-0.81026 0.0001	0.67722 0.0001	0.97519 0.0001	0.93804 0.0001
AL	-0.33251 0.0186	-0.23410 0.1515	-0.22472 0.1690	-0.38041 0.0169	-0.13603 0.4090	0.11966 0.4681	-0.32242 0.0453	1.00000 0.0000	0.42944 0.0064	-0.21325 0.1924	-0.37964 0.0171	-0.30409 0.0598
MN	-0.69450 0.0001	-0.78158 0.0001	-0.81058 0.0001	-0.74705 0.0001	-0.56262 0.0002	0.31296 0.0524	-0.81026 0.0001	0.42944 0.0064	1.00000 0.0000	-0.45339 0.0037	-0.80058 0.0001	-0.76666 0.0001
FE	0.60680 0.0001	0.55399 0.0003	0.56247 0.0002	0.57806 0.0001	0.53707 0.0004	0.21925 0.1799	0.67722 0.0001	-0.21325 0.1924	-0.45339 0.0037	1.00000 0.0000	0.63883 0.0001	0.63038 0.0001
CU	0.92258 0.0001	0.85845 0.0001	0.87925 0.0001	0.85347 0.0001	0.75862 0.0001	0.04608 0.7806	0.97519 0.0001	-0.37964 0.0171	-0.80058 0.0001	0.63883 0.0001	1.00000 0.0000	0.92848 0.0001
ZN	0.39463 0.0001	0.84517 0.0001	0.91561 0.0001	0.79088 0.0001	0.77014 0.0001	0.04069 0.8057	0.93904 0.0001	-0.30409 0.0598	-0.76666 0.0001	0.63038 0.0001	0.92849 0.0001	1.00000 0.0000

[a]The upper figure is the correlation coefficient for the relationship between the two variables indicated; the lower figure is the probability of obtaining the correlation coefficient due to chance.

F3. Transfer experiment with variety H610 on the Hydric Dystrandept at ITKA-K-13 in Indonesia

	YIELD	N	P	K	CA	MG	S	AL	MN	FE	CU	ZN
NCODE	0.44616[a] 0.0044	0.30089 0.0627	0.28281 0.0811	-0.01917 0.9078	-0.08733 0.5970	0.44707 0.0043	0.25420 0.1184	0.23074 0.1576	-0.25167 0.1222	0.18590 0.2572	0.31467 0.0511	0.19694 0.2295
NCODESQ	-0.31866 0.0480	-0.00001 1.0000	-0.05530 0.7381	-0.16112 0.3271	0.01463 0.9296	0.12330 0.4546	0.10834 0.5115	0.03621 0.8268	0.06333 0.7017	-0.07324 0.6577	-0.09705 0.5567	0.00492 0.9763
PCODE	0.04199 0.7996	0.07888 0.6331	0.04086 0.8049	0.00998 0.9519	0.08265 0.6169	0.03781 0.8192	0.09210 0.5771	0.13115 0.4261	0.15506 0.3459	0.15012 0.3617	-0.09319 0.5726	0.06556 0.6917
PCODESQ	0.06427 0.6975	-0.04871 0.7684	-0.01053 0.9493	0.15439 0.3480	-0.02895 0.8611	-0.00099 0.9952	0.03972 0.8103	-0.13945 0.3972	0.29192 0.0714	-0.19070 0.2449	0.07203 0.6630	0.10980 0.5058
NPCODE	-0.02721 0.8694	0.22603 0.1665	0.26768 0.0995	0.00081 0.9961	0.28964 0.0737	0.15327 0.3516	0.27640 0.0885	-0.12355 0.4537	-0.22486 0.1687	0.00539 0.9740	0.24906 0.1263	0.24421 0.1341
N	0.17528 0.2858	1.00000 0.0000	0.69248 0.0001	0.17190 0.2954	0.40147 0.0113	0.44311 0.0047	0.63988 0.0001	0.19304 0.2390	-0.54599 0.0003	0.34604 0.0309	0.55157 0.0003	0.44368 0.0047
P	0.12589 0.4451	0.69248 0.0001	1.00000 0.0000	0.33203 0.0389	0.60416 0.0001	0.55004 0.0003	0.73508 0.0001	0.39343 0.0132	-0.66914 0.0001	0.48998 0.0015	0.62397 0.0001	0.52331 0.0006
K	-0.01181 0.9431	0.17190 0.2954	0.33203 0.0389	1.00000 0.0000	-0.10269 0.5339	0.13644 0.4075	0.14024 0.3945	0.10911 0.5085	0.00632 0.9695	0.20151 0.2186	0.44943 0.0041	0.42949 0.0064
CA	0.03557 0.8298	0.40147 0.0113	0.60416 0.0001	-0.10269 0.5339	1.00000 0.0000	0.42710 0.0067	0.75457 0.0001	0.16490 0.3158	-0.38446 0.0157	0.30716 0.0572	0.42817 0.0065	0.50265 0.0011
MG	0.07744 0.6394	0.44311 0.0047	0.55004 0.0003	0.13644 0.4075	0.42710 0.0067	1.00000 0.0000	0.50988 0.0009	0.16860 0.3049	-0.50331 0.0011	0.24124 0.1390	0.58884 0.0001	0.28461 0.0791
S	0.09342 0.5841	0.63988 0.0001	0.73508 0.0001	0.14024 0.3945	0.75457 0.0001	0.50988 0.0009	1.00000 0.0000	0.30318 0.0606	-0.34588 0.0310	0.47012 0.0025	0.72960 0.0001	0.75330 0.0001
AL	0.16267 0.3224	0.19304 0.2390	0.39343 0.0132	0.10911 0.5085	0.16490 0.3158	0.16860 0.3049	0.30318 0.0606	1.00000 0.0000	-0.09417 0.5685	0.79085 0.0001	0.05347 0.7465	0.26791 0.0992
MN	-0.11873 0.4716	-0.54599 0.0003	-0.66914 0.0001	0.00632 0.9695	-0.38446 0.0157	-0.50331 0.0011	-0.34588 0.0310	-0.09417 0.5685	1.00000 0.0000	-0.09030 0.5846	-0.36867 0.0209	0.00395 0.9810
FE	0.17442 0.2883	0.34604 0.0309	0.48998 0.0015	0.20151 0.2186	0.30716 0.0572	0.24124 0.1390	0.47012 0.0025	0.79085 0.0001	-0.09030 0.5846	1.00000 0.0000	0.20064 0.2207	0.49832 0.0012
CU	0.06798 0.6809	0.55157 0.0003	0.62397 0.0001	0.44943 0.0041	0.42817 0.0065	0.58884 0.0001	0.72960 0.0001	0.05347 0.7465	-0.36867 0.0209	0.20064 0.2207	1.00000 0.0000	0.69220 0.0001
ZN	0.03613 0.8271	0.44368 0.0047	0.52331 0.0006	0.42949 0.0064	0.50265 0.0011	0.28461 0.0791	0.75330 0.0001	0.26791 0.0992	0.00395 0.9810	0.49832 0.0012	0.69220 0.0001	1.00000 0.0000

[a]The upper figure is the correlation coefficient for the relationship between the two variables indicated; the lower figure is the probability of obtaining the correlation coefficient due to chance.

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