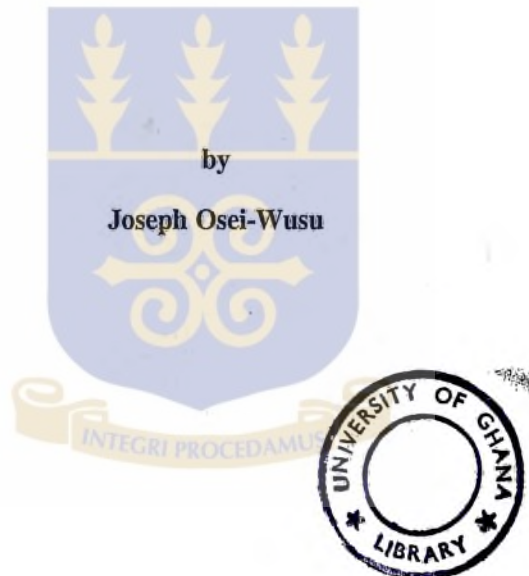


THE RELATIONSHIP BETWEEN NUTRIENT CONTENT OF LEAF SEGMENTS, RATES OF POTASSIUM, YIELD AND QUALITY OF PINEAPPLE (*ANANAS COMOSUS*) MERR L. VAR. SMOOTH CAYENNE IN THE COASTAL SAVANNAH ZONE OF GHANA



by

Joseph Osei-Wusu

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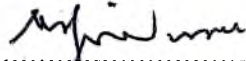
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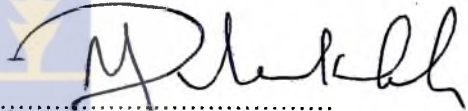
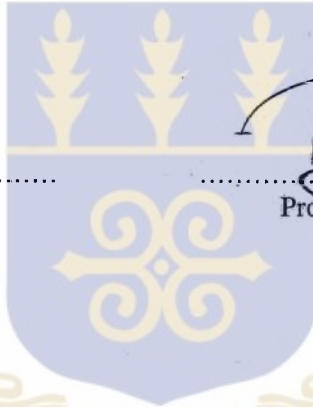
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DECLARATION

I hereby declare that the work presented in this thesis was carried out by myself and has never in part or in whole been presented to any other university for the award of a degree.



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II

DEDICATION

Dedicated to Clarice, Paa Kwasi and Maame Ekua



III

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I wish to record my appreciation and thankfulness to the Almighty God without whose help and strength this manuscript would not have materialised.

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IV

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V

ABSTRACT

Plant nutrition holds the key to increased and sustained yields and the production of good quality pineapple fruit. Potassium plays a vital role in obtaining higher yields and good quality fruit. A good knowledge about the nutrient status of the plant is important for the correction of nutrient deficiencies and/or imbalances which tend to influence yield and quality of the fruit.

This study was initiated to determine the appropriate leaf segment; viz. the non-chlorophyllous, chlorophyllous or the whole D-leaf to use for leaf analysis, and the effect of K on nutrient composition, growth, yield, and quality of pineapple.

Field trials were conducted at three locations (i.e. Agricultural Research Station, Pokuase, Silwood and Parrico Farms in the Aburi/Nsawam areas) in the Coastal Savannah Zone of Ghana. The main export variety of pineapple, the Smooth Cayenne was used.

Four rates of K, viz: 200, 300, 400 and 500 kg K/ha were used as main treatments. Leaf samples were taken at 8 months to study the growth of pineapple. A second sampling was carried out at 10 months to determine in addition to the above D-leaf N, P, K, Ca and Mg content. Mean fruit weight, titrable acidity and total soluble solids (T.S.S) of harvested fruits were also determined.

The contents of N, P, K, Ca and Mg ranged between 1.0 - 1.7 % for N, 0.1 - 0.3 % for P, 2.2 - 4.6 % for K, 0.3 - 0.8 % for Ca and 0.5 - 1.2 % for Mg. The values obtained reflected adequate amounts. Results of soil analyses showed similar adequate levels. Nutrient contents differed significantly in the various segments of the D-leaf.

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For N it was in the order whole D-leaf > chlorophyllous > non Chlorophyllous segment. For P, K, Ca, and Mg however, the non-chlorophyllous segment generally showed higher contents than the chlorophyllous or whole D-leaf. The non- chlorophyllous and whole D-leaf showed superiority over the chlorophyllous segment in the determination of nutrient content. Increasing K application influenced the leaf content of the other nutrient elements N, P, Ca and Mg. For N an increasing trend was observed whereas a decreasing trend was noted for P, Ca, and Mg. Potassium application significantly influenced dry matter content, mean fruit weight and acidity. The application of 500 kg K/ha caused significant yield increases over the 200 kg K/ha rate. No such yield differences were observed between 200, 300, and 400 kg/ha K rates. The application of between 200 - 300 kg K/ha was adequate for smooth cayenne fruit weighing between 1.6 - 1.8 kg (which satisfies the (European) export market) for the Pokuase and Silwood farms area. Significant correlations were observed between either leaf N, K or Mg with dry matter content, yield and acidity. These correlations were better in some segments than in others. N was better correlated with yield and acidity in the non-chlorophyllous segment whilst P correlated better in the whole leaf segment of the D-leaf. Potassium correlated equally with acidity in both the whole D-leaf and the non-chlorophyllous segment.

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CHAPTER ONE

INTRODUCTION

Pineapple (*Ananas comosus* (L) Merrill) is a crop native to the tropical Americas (Bartholomew and Malezieux, 1994). The cultivation of pineapple in Ghana was started in the 1930's. Since then production of the crop has been on the increase with trade shifting from local to commercial in the 1960's. Today, pineapple has become one of the most important non-traditional export crops with increasing potential on the international market. The volume of export of the crop increased more than 60% from about 8,000 metric tonnes in 1989 to 13,000 metric tonnes in 1993 (GEPC, 1993).

The crop grows in almost all the agro-ecological zones of Ghana, but by far the greatest concentration of farms is found in the Southern forest-Savannah ecological zone. Two main varieties of the crop, namely, the Sugarloaf and Smooth Cayenne are grown in Ghana with the latter being the main export variety. The Sugarloaf variety is grown mainly for the local market. In spite of the increasing volume of export of the crop (mainly the Smooth Cayenne variety) yields are low in Ghana - between 50-80 tonnes/ha compared with 80-100 tonnes/ha in the Cote d'Ivoire.

A survey conducted by the Pineapple Research team of the National Agricultural Research Project (NARP) in 1992 identified among others the lack of financial support, lack of proper disease and pest control methods, poor fruit quality and inadequate and improper methods of plant nutrition as the main causes for the low yields. For increased production, particularly for export, there is the need to pay attention to the above problems especially that of plant nutrition.

Pineapple has been shown to require large amounts of potassium and nitrogen for the growth and quality of the fruit. Phosphorus, even though needed, is not required in large amounts. Potassium has been shown to be an important nutrient with its greatest effect on yield and quality of pineapple (Dalldorf, 1975 ; Obiefuna et al., 1986). Studies by Abutiate and Eyeson (1973) established the importance of K for the Smooth Cayenne variety in the forest zone of Ghana but they failed to establish the upper limit. Even though plant response to K has been documented (Abutiate and Eyeson, 1973; Dalldorf, 1975; Obiefuna et al., 1986), there is a general agreement on lack of response to many crops in Ghana.

According to Ahenkorah (1970), Ghanaian soils particularly in the forest Savannah zone are well buffered against K depletion. One of the general methods of assessing the nutrient requirement of a crop is by visual observation of a growing crop. This method is usually confirmed with soil and/or foliar analysis. Soil chemical analysis has its limitations in that it does not portray the dynamics in the soil-root system hence a continuous check of the results of soil analysis by means of foliar diagnosis. Leaf analysis has been accepted as an important tool in modern soil fertility investigations (Subramanian et al., 1977). The nutritional status of the plant, as reflected by nutrient content, is an important component for assessing fertilizer requirements of a pineapple crop (Lacoeuilhe, 1971). Plant nutrient content is a valuable indicator since various components of yield and quality can be related to it. It is also of a special value in indicating any adjustment that may be needed to enable the expected yields to be achieved. Thus plant analysis is essentially a way of monitoring the correctness of the initial decisions on fertilizer requirement. Some of the uses which the method may be put to are in locating field

fertilizer experiments efficiently and in suggesting fertilizer practices (Ulrich, 1943) and in studying the effects of nutrient antagonisms (Martin-Prevel, 1961). The method has been used on many crops including pineapple with considerable success (Kanapathy, 1958; Tay et al., 1968; Ramirez and Tejera, 1983; Valez-Ramos et al., 1991). In Ghana, Godfrey-Sam-Aggrey (1970) used leaf analysis as an index in the nutrition of pineapple variety Sugarloaf cultivated in the forest zone.

The need for proper sampling techniques which take into account the choice of plant part as well as the stage of development of the plant has been stressed in assessing the relationship between plant composition and yield (Singh et al., 1977). Although it is generally agreed that for the diagnosis of nutrient concentration in pineapple, the D-leaf is the most ideal to sample (Bould et al., 1960; Smith, 1962), yet opinion is divided as to which portion of the leaf (i.e. the non-chlorophyllous, chlorophyllous or whole) is appropriate to give the best reflection of nutritional status in the plant.

Cooke (1949), Martin-Prevel (1961) and Sanford (1962) sampled from the basal non-chlorophyllous portion and fertilizer recommendations made on the basis of this analysis. Kanapathy (1958) sampled also from both the middle and tip portions of the chlorophyllous section of matured non-flowering and non-fruiting plants, analysed them and established critical nutrient levels for the pineapple. On the other hand, workers in the Institute of Research on Fruits and Agronomy in France (Martin-Prevel, 1959) concentrated on the use of the entire D-leaf for analysis. Even though different segments of the pineapple leaf have been used with varying results, no attempt has been made to compare the superiority of one segment over the other. The establishment of the appropriate leaf segment for

analysis to support the expanding pineapple industry in Ghana cannot be over-emphasized.

It was the objective of this study to :

1. determine which segment of the pineapple leaf viz.; non-chlorophyllous, chlorophyllous or whole leaf is suitable for analysis, and
2. to relate the nutrient content in the different leaf segments to:
 - (a) the different rates of K,
 - (b) yield and quality of fruit.

CHAPTER TWO

2.0. LITERATURE REVIEW.

This section is in three parts, the first part reviews the botany and physiology of the crop whilst the second part gives a review of the effect of environmental factors on yield and quality of the fruit. Part three gives a review on foliar diagnosis.

PART ONE

2.1. Botany and Physiology of Pineapple.

2.1.1. Anatomy and morphology of the pineapple plant.

The cultivated pineapple is a herbaceous, perennial, self-sterile monocotyledonous plant, a member of the bromeliaceae family (Dunsmore, 1957). This family includes a number of epiphytes. In the genus *Ananas*, there are three wild species, which are found in South America. No wild ancestral form of the cultivated pineapple *Ananas comosus* is known. It reproduces by successive vegetative propagation and under natural conditions, this takes place where the original plant grew. Presently, it is grown commercially over a wide range of latitudes, from about 30° N in the northern hemisphere to 33° 58' S in the southern hemisphere (Bartholomew and Kadzimin, 1977). There are many different species, all of which have adapted to growth in hot dry climates. Signs of this adaptation, which can be considered to be residual epiphytic characters are: stomata specially adapted to prevent water loss; optimum recovery from precipitation; absorption of water and mineral elements by leaves; and the relative fragility of root system (Py

et al., 1987). The adult plant can measure up to 1.20 metres in height and is roughly heart shaped with a diameter of 1.5 metres and a flattened base (Py *et al.*, 1987).

The plant comprises the following parts: the stem which forms the central axis of the plant and is completely concealed by the leaves; the leaves which are arranged in a spiral around the stem. Roots are adventitious, some of which are underground and some aerial (Py *et al.*, 1987). The leaves which number between 70 and 80, depending on the stage of growth, form a rosette with a 5/13 phyllotaxy. They are lanceolate in shape and are very elongated reaching a maximum length of more than 100 cm and a width of 7 cm. Leaf colour varies from pale yellow to dark bluish-green, depending on ecological, climatic and nutritional conditions. The spatial arrangement of the leaf system and internal leaf anatomy corresponds to adaptation to dry climate (Py, 1959). Where the leaves overlap the stem, a little reservoir is formed that catches rainfall, dew or sprayed fertilizer. An adult plant can thus hold more than 50 ml of liquid in its heart and leaf axilla (Py *et al.*, 1987). This fact is more significant since the solution trapped here can be absorbed either through the adventitious roots at the base of the old leaves, or directly through the epidermis of the non-chlorophyllous part of the leaf or both (Krauss, 1948; Marchal and Pinon, 1980). Water loss is limited by special adaptation of the leaf epidermis, trichomes and stomata (Krauss, 1948). The trichomes which appear in both the under and upper surface of the leaf play a major role in the absorption of the solutions that collect at the base of the leaves. It has been shown (Sakai and Sanford, 1980) that they possess the apparatus required for absorbing both water and aqueous nutrients.

The fruit is a syncarp formed by the fusion of the individual fruitlets produced by each flower. The number of individual fruitlets produced by any given variety is the principal factor that determines the weight of the fruit. Fruit weight can vary substantially. In the Smooth Cayenne cultivar, it can reach a maximum of 6 kg and 12 kg in other varieties (Py *et al.*, 1987).

The chemical composition of the fruit has been elucidated by Dull (1971) and Teisson (1977). Sugars and organic acids are indispensable for the organoleptic quality of the fruit. These two compounds are distributed very unevenly due to the heterogeneous structure of the fruit (Huet, 1958). Pineapple fruits do not contain starch. Free acidity represents approximately 70 % of total acidity. The juice is a buffered medium with pH normally between 3.7 and 3.9 (Huet, 1959). Amino acids comprise 0.33 % of fresh weight (Dull, 1971).

2.1.2. Taxonomy.

The taxonomy of the genus *Ananas* has been under review (Loison-Cabot, 1990; Dewald *et al.*, 1992) and it was recently proposed that the number of species be reduced (Loison-Cabot, 1992). The taxonomic distinction between *Ananas comosus* and other species of *Ananas* is the fruit length, although this criterion is highly dependent on the environment (Bartholomew and Malezieux, 1994). The pineapple of commercial value comes from five main groups (Py *et al.*, 1987) also called varieties (Samuels, 1970). These are the Smooth Cayenne, Queen, Spanish, Pernambuco, and Mordilonus-Perolera-Maipure groups (Bartholomew and Malezieux, 1994). Brown (1953) also gave the following groups: Smooth Cayenne or Kew; Singapore Spanish, Malacca Queen or Red Ceylon or Red Malacca. In

Ghana, the Sugarloaf variety is also cultivated. The most important of these groups is the Smooth Cayenne because of its almost universal use as a canning fruit and its wide use in the fresh fruit trade (Bartholomew and Malezieux, 1994).

2.1.3. Vegetative growth of pineapple.

The growth of pineapple can be divided into three stages: vegetative growth of the shoot that has been separated from the mother plant; growth of the fruit, crown and possibly of slips and growth of suckers (Py *et al.*, 1987). Suckers are the plantlets that arise from buds below the ground level, whilst slips are borne on the peduncle just below or on the base of the fruit. Crowns are formed on top of the fruit (Purseglove, 1987).

The growth curve for fresh and dry weight has a sigmoid trend (Py *et al.*, 1987). Before floral differentiation, plant growth comprises growth of the roots, stem and leaves. After floral differentiation, the growth of the fruit which is also sigmoid is added to that of the vegetative organs. Growth of the plant can vary considerably during this stage particularly after flowering. Production of dry matter per day ranges from 2 grams at four weeks to approximately 20 grams at 50 weeks (Sideris and Young, 1950). It has been estimated by Sanford (1971), that plant fresh weight can double every two months. Growth depends on a number of factors (e.g., climate, plant nutrition etc.) that are specific to the plant. The plant growth rate is linked to the weight of planting material (Gailard, 1969).

2.1.3.1. Growth of the leaves:

Until flower induction, the leaves represent 90% of the plant fresh weight excluding the roots (Py, 1959) and when the fruit is harvested, they still represent approximately 50%. Growth of the total leaf mass comprises: an increase in the number of living leaves of the plant and growth of individual leaves. When suckers are used as planting material, the rate at which leaves appear after planting increases regularly with the age of the plant (Lacoeuilhe, 1976).

Growth parameters of the leaf (length, width, fresh weight, and dry weight) react differently to external factors (Py, 1959). Allometric correlations depend on the conditions governing the observations and are thus not universal (Py *et al.*, 1987). Specific leaf weight can increase from 114 to 153 mg cm⁻² when night temperatures are reduced from 30 to 18 °C (Bartholomew and Kadzimin, 1977).

PART TWO

2.2. Environmental influences on the growth and quality of pineapple.

Environmental factors intervene either directly via the metabolism of the various vegetative organs or indirectly via fruit metabolism and have both quantitative (i.e. fruit weight, duration of development phase) and qualitative effects (Py *et al.*, 1987). During the formation of the fruit, the plant integrates both past and present influences of the physical environment. For example, the weight of the fruit is initially determined by the number of fruitlets differentiated during flowering and consequently depends on vegetative growth but conditions prevailing during fruit formation influence the increase in weight of individual fruitlets (Py *et al.*,

1987). Since high quality of the fruit is one of the main production objectives, the effects of the environment on fruit quality is especially significant.

Key factors of the abiotic and biotic environment which are known to influence fruit yield and quality are: climate and plant nutrition.

2.2.1. Effect of climate .

The main effects of climate have been that of temperature, moisture and altitude.

2.2.1.1. Effect of Temperature on growth and yield of pineapple.

Although there are few data on the growth and development of pineapple, temperature appears to be one of the most important environmental factors determining its distribution and productivity in the world (Bartholomew and Malezieux, 1994). Temperature affects the rate of growth, leaf production and character, dry matter, mineral absorption and length of growth cycle (Py *et al.*, 1987). The crop is reasonably productive in both hot and dry environments. In the hot regions, leaf and plant temperatures may reach values that would be considered extreme for conventional crops. Pineapple is also grown in the cool sub-tropics where freezing temperatures may occur (Bartholomew and Malezieux., 1994). The suitability of a particular region for the cultivation of the crop is generally a question of how closely temperatures approach those considered to be optimum (i.e. 30 °C maximum and 20 °C minimum) for the entire cycle (Nield and Boshell, 1976). At 15 °C, the plants undergo limited weight loss up to 30 °C after which growth increases less proportionally to temperature (Ravoof, 1973). In Hawaii, the

slower vegetative growth rate observed from December to April can mainly be linked to reduced temperature, especially that of the soil (Ekern, 1967). High night temperatures are deleterious to the crop and difference of at least 4 °C must be maintained between the day and night temperatures. The rate at which leaves appear is also influenced by temperature. The number of leaves that appear in one month is also linked to the mean temperature (Shiroma, 1972). The main effect of temperature is on the duration of the fruit forming stage which range from 150 - 300 days after forcing (Gailard, 1970; Dalldorf *et al.*, 1975). The speed at which the inflorescence develops decreases with very cold weather (Dalldorf *et al.*, 1975) and the fruit is less filled with prominent pointed fruitlets. On the other hand, those harvested during hot periods are well filled and have flat fruitlets (Collins, 1960). The amount of available light also exerts a marked effect on fruit weight (Sideris *et al.*, 1936).

2.2.1.2. Effect of temperature on fruit quality.

Temperature exerts a great influence on the quality of the fruit. Such components as eating quality, flesh colour and porosity, external appearance, and storage life are known to be affected by temperature (Bartholomew and Malezieux., 1994). Flavour, total soluble solids and titrable acidity are the main components of eating quality. The increase in concentration of sugars that occurs in the last week before harvest is reported to intensify with an increase in temperature (Chandler, 1958; Collins, 1960). Temperature is by far the most important factor in the determination of fruit acidity (Py *et al.*, 1987) which varies from 5 to 25 meq H⁺ / 100ml of juice. Fruits grown at high altitude where temperatures are low or during



cool seasons are more acid (Green, 1963; Py and Tisseau, 1965). The development of aroma increases with an increase in temperature (Haagin-Smit *et al.*, 1945; Silverstein, 1971), but decreases beyond 27 °C (Yow, 1959). Increasing temperature also influences translucence and fragility of the flesh (Py & Tisseau, 1965). The amount of available sunlight has a marked effect on quality of the fruit (Sideris *et al.*, 1936). In the Cote d'Ivoire, a reduction of up to 66% of available light from true flowering until harvest during the period of intense sunshine increased free acid from 6.3 to 15.5 meq % and ascorbic acid from 364 to 636 micro-millilitres (Combres, 1976).

2.2.1.3. Effect of moisture on growth and yield of pineapple.

The water requirement of pineapple far outweigh those of any other element. With adequate water supply, the crop can grow even in the drier regions. Though the crop can survive long dry periods (through its ability to retain water in the leaves), it is very sensitive to water deficit especially during the vegetative growth, flowering and fruiting periods (Doorenbos and Pruitt, 1979). The benefits of irrigation have been demonstrated in several countries (Medcalf, 1950; Py, 1965; Kuruvilla *et al.*, 1988). Chapman *et al.* (1983) reported that as watering frequency was reduced, D-leaf length and weight and whole plant weight reduced within four months of planting. Asoegwu (1987) found that plants receiving frequent irrigation treatments had their leaf area significantly increased compared to plants which received less watering. In Cote d'Ivoire, yield increases of 12 to 15 tons/ha were obtained with irrigation in both the northern area of the production zone (Combres, 1979) and in the more rainy south (Malezieux, 1992). In Guinea, growth of

unirrigated plants was delayed 3 to 3.5 months by the end of a 5-month dry season (Py, 1965).

Soil water is the medium that contains all the mineral elements the plant uses (Py *et al.*, 1987). A satisfactory supply of water plays an important role in the filling and weight of the fruit (Su, 1961). Plants that have received comparable irrigation during the vegetative growth period and then from true flowering until harvest have their water requirements fulfilled at different rate. These plants also produce fruits with marked differences in weight even in periods with little water stress (Combres, 1980). Drought therefore affects filling and consequently the fruit weight.

2.2.1.3. Effect of moisture on fruit quality.

Water deficits at flowering has a less serious effect on fruit quality and may hasten fruiting and result in uniform ripening. A satisfactory supply of water while the fruit is developing increases the rate of photosynthesis and improves the mobility of sugars (Sideris and Krauss, 1933) as well as its concentration (Martin-Prevel *et al.*, 1961). The concentration of free acids increases with irrigation (Combres, 1976 & 1980). Fruits harvested during rainy season do not keep well (Collins, 1960). Too much water increases the fragility of the flesh (Green, 1963) and results in cellular lesions and also in the green ripe phenomenon (Ginsburg, 1953; Huet, 1953). Unlike the other fruits, a water deficit shortly before harvest does not increase the concentration of sugars (Linford and Magistad, 1933). On the contrary, if water stress is too severe it can have the opposite effect (Tisseau, 1963).

2.2.1.5. Effect of altitude on growth and yield of pineapple.

Altitude has its effects on leaf mass and fruit weight. Py et al. (1987) observed that between the altitudes of 50 and 380 metres, leaf mass at flower initiation increases two and a half times, all cultivation methods being identical. The average weight of fruits increased by 58 %. In higher altitude zones in the same region, growth is slower since temperatures are lower (Py *et al.*, 1987).

2.3. Effect of plant nutrition on yield and quality of pineapple

In common with other plants, the three nutrients required in the greatest quantity by the pineapple are Nitrogen (N), Phosphorus (P) and Potassium (K). When the soil is unable to supply these nutrients in sufficient quantities, there will be the need to make up the balance by the application of inorganic fertilizers. The effect of these nutrients have been investigated by many workers.

2.3.1. Effect of Nitrogen on yield of pineapple.

Nitrogen is required for vigorous growth and with favourable climatic conditions the potential growth and yield of pineapple is determined by the amount of nitrogen (Py *et al.*, 1987). Nightingale (1942) showed that N was by far the most limiting nutrient in pineapple production. Nitrogen applications resulted in significant increases in mean fruit weight (Tay *et al.*, 1968; Abutiata and Eyeson, 1973; Obiefuna *et al.*, 1986).

Lack of N delays crop harvest (Obiefuna *et al.*, 1986). Abutiata and Eyeson (1973) concluded from their studies with forest soils of Ghana that N requirement

for pineapple might not exceed 112 kg/ha as they found greater response to a low (112 kg/ha) than a high (448 kg/ha) N application. They also found that large doses of N (448 kgN/ha) produced more vegetative growth resulting in slightly lower fruitage and relatively higher amounts of hold-over plants.

2.3.2. Effect of N on fruit quality.

The main effect of N is on quality and total soluble solids (T.S.S.). Increasing N additions to soil has been found to reduce T.S.S. (Singh *et al.*, 1977) and free acids (Canon, 1958a; Dodson, 1968; Marchal *et al.*, 1980). This effect may be due partially to the dilution of K in the leaf resulting from increased growth of the plant (Marchal, 1973).

2.3.3. Effect of Phosphorus on yield of pineapple.

Phosphorus requirement by pineapple is small and has no influence on growth characters (Mustafa, 1984). It nevertheless increases the root system and physiological activity of the plant (Marchal, 1971). Samuels and Grandiaz-Diaz (1960) have established that there is a small but definite trend in all crops, sites or varieties to give a slightly lower yields with P fertilizers than with none. The trend observed was explained by Abutiata and Eyeson (1973) that if the initial level of P in the soil is adequate, further additions only depressed yields. The findings of other workers such as Obiefuna *et al.* (1986) supported the view of Samuels and Grandiaz-Diaz (1960). Nightingale (1942) observed that yields were increased or reduced when P was applied to the Smooth Cayenne pineapple already supplied with phosphates. Tay *et al.* (1968) observed characteristically insignificant response to P

additions. On the other hand, Mustafa (1989) observed that P application increased fruit length, breadth and yield for Kew pineapple. He, unlike the other workers, varied P rates.

2.3.4 Effect of P on quality of Pineapple.

Several studies have failed to show any improvement in the quality from the application of phosphorus. Mustafa (1989) found that T.S.S. and acidity decreased with P additions and that the negative response was a cubic function. Pan (1957) also observed poor quality when P fertilizer was added to Smooth Cayenne pineapple. Tay *et al.* (1968) and Tay (1972) found that P application reduced the sugar and acidity contents of the fruit.

2.3.5. Effect of Potassium on yield of pineapple.

Potassium is indispensable to plant life. It plays a significant role in the metabolic functioning of the plant, e.g. the opening of the stomata and the transfer of sugars and organic acids (Py *et al.*, 1987). High concentrations of potassium (K) are found in all the actively growing tissues where it is probably involved in the processes of elongation and cell division. Its presence also appears to be essential for the synthesis of carbohydrates, proteins and certain organic acids. It promotes the assimilation of carbon dioxide as well as the formation, condensation and transportation of sugars and the synthesis of proteins and fats. K is also known to promote hardening of the supporting tissues, which results in a stronger structure with greater resistance to lodging (Dalldorf, 1975; Mengel and Kirby, 1978; Obiefuna *et al.*, 1986). Nightingale (1942) was of the opinion that when

carbohydrates are high (in the leaf), which leads to a higher requirement for nitrate, additional potassium is necessary for the absorption of nitrates above that necessary for the functions that K performs.

The application of K has been found to significantly increase yield and mass of fruit (Canon, 1957; Su, 1958; Teaotia and Pandey, 1964). The response is especially remarkable in very low K soils (Tay *et al.*, 1968). Magistad (1934) stated that response to K is observed in soils with a level of exchangeable K in the neighbourhood of 0.5 meq/100 g and below. Where the soil exchangeable K is already high, further additions lowered yields (Kwong *et al.*, 1966). Su (1958 and 1959) found that where exchangeable K in the soil exceeded 5.1 meq/100 g K, there was lack of response to further additions of K. Lacoeuilhe (1978) in a study to investigate the effect of potassium on yield and quality found that beyond 4 gm K per plant, response to further additions of K was rather low. The optimum K level above which the plant no longer responds to additional K varies from place to place: for example, 78 ppm in Hawaii (Magistad, 1934); 70 ppm in Australia (Canon, 1957); 140 ppm in Taiwan (Su, 1969); and less than 1 meq/100 g in Martinique (Lacoeuilhe and Gicquiaux, 1971). The underlying factors accounting for the differences include the type and nature of parent material, the genesis of the soil, the soil type and environmental effects.

The critical concentration of K in the leaf at flower induction, above which fruit weight is unlikely to be increased has been determined as 2.7% (Py *et al.*, 1987). On the other hand the lack of response to K additions has been recorded in the literature. Briant and Tidbury (1942), in Zanzibar, observed decreased yields of pineapple to the application of sulphate of potash. A comparatively low fruit yield

obtained when high levels of K was used in combination with low levels of nitrogen was attributed to the inhibitive characteristics of K in the absorption of N (Butler, 1960; Obiefuna *et al.*, 1986).

2.3.6. Effect of sources of K on yield and quality of pineapple

The three principal sources of K reported in the literature are: chloride, sulphate and nitrate. Reports from South Africa indicate that of the three sources, potassium nitrate had the greatest effect on yield (Fisher, 1975). Most of the investigations on this topic reported in the literature compared the chloride and sulphate sources. The superiority of potassium sulphate (K_2SO_4) over potassium chloride (KCl) was shown by Samuels and Gandiaz-Diaz (1960). They found out that on a sandy clay soil, pineapple treated with potassium sulphate gave a higher yield per unit area and a higher mean fruit weight than plants treated with potassium chloride. This was confirmed by Su and Li (1963) in Taiwan and by Sanford (1968) in Hawaii. Su and Li (1963) also noted that the percentage of better quality fruits in the plant was raised by K_2SO_4 but was lowered by KCl. The main disadvantage of KCl is the adverse effects of the chloride anions which manifest in delayed ripening, reduced yields, fewer flesh sound fruits, increased root phytotoxicity, and reduced sugar percentages (Dalldorf and Langenegger, 1976; Laccouilhe, 1979; Dalldorf, 1983). On the other hand, Tay (1972) found no significant difference between the chloride and the sulphate sources of potassium.

2.3.7. Effect of K on quality of Pineapple.

Potassium appears to be the key element in the composition of the fruit (Py *et al.*, 1987). An increase in the concentration of K in the plant results in an improvement in the flavour and aroma of the fruit (Martin-Prevel *et al.*, 1961) and increases the firmness of the flesh (Py and Tisseau, 1965). It, however, results in less satisfactory colouring of the flesh which remains white but has a better shell colour (Py *et al.*, 1957; Teisson and Pinon, 1979). The most marked effect of K on the pineapple fruit is on the TSS and fruit acidity which increase with supplies of K to the plant (Tay *et al.*, 1968; Gailard, 1970; Marchal *et al.*, 1980). The increase in TSS can be attributed to an improvement in the transport of assimilable elements (Berniger, 1978) and in photosynthesis, due to its effect on the regulation of stomata. The supply of K effectively increases the concentration of saccharose in the pineapple leaf (Sideris and Young, 1954). The increase in acidity on the other hand may continue until the K concentration in the leaf has reached 5% of dry matter (Marchal, 1979; Teisson and Pinon, 1979). The effect of K on free acids is even more spectacular when the supply of K to the plant is unsatisfactory. Under this condition, a doubling of leaf K may be accompanied by an almost twofold increase in free acidity (Gailard, 1970). This same trend has been observed in citrus (Smith, 1966). Eaves and Luefe (1955) noted that fruit from apple trees receiving high rates of K contained a significantly higher acid content than fruits from control trees. The percentage acid in juice increased with the application of K up to 0.7 kg K/tree beyond which the acid content appeared inconsistent with consequent drop after the application of 1.4 kg K/tree.

Several studies in South Africa have shown that when K levels exceed 200 kg/ha, the sugar content may be reduced (Fisher, 1974 and 1975; Langenegger, 1976; Viljoen, 1980). Potassium has been found to have a beneficial effect on the storage properties of pineapple: it promotes fruit compactness and resistance to bruising, thus potentially prolonging shelf life (Jacob and Uexkull, 1963; Sanford, 1968; Chiang, 1969; and Teisson, 1980). In a study by Anderson (1951), the inclusion of K in the nutrient soil solutions reduced the incidence of root rot, *Phytophthora cinnamoni*. Potassium also renders the plants more resistant to various fungal diseases (for example mildew and rust) as well as insect infestation (Dalldorf, 1975; Mengel and Kirby, 1978). In short, a good supply of K enhances resistance to some known diseases of the pineapple plants.

2.3.8. Effect of Ca on yield and quality of Pineapple.

Even though calcium plays a vital role in the plant, amounts needed are small compared with N, P and K. The absorption of Ca by the plant is largely influenced by N and K. The nitrogen in the form of nitrate favours calcium absorption whilst the ammonium form hinders it (Sideris and Young, 1945). Increasing supplies of K causes a reduction in the supplies of Ca and vice versa (Sideris and Young, 1945). Few data are available on the calcium requirement of pineapple. According to Johnson (quoted by Py *et al.*, 1956) the maintenance of the N:CaO ratio at 1.33 is recommended. In most tropical soils, calcium is present in sufficient quantities, but in some countries it is advantageous to lime the soil at the rate of about 400 kg/ha before planting. According to Pennock (1944), liming increased the yield of pineapple on some soils but lowered it in others. In the latter

case, the pH of the soil after liming was raised to near pH 6 which is considered high for best growth of pineapple but may lead to yield decline (Py *et al.*, 1957). An excess of Ca may lead to chlorosis whilst a deficiency, according to Cibes and Samuels (1958) may affect the quality of the fruits due to the formation of blackish spots in the interior of the fruits.

2.3.9. Effect of magnesium on yield and quality of pineapple

Magnesium (Mg) is needed by all green plants as it is a constituent of chlorophyll. It also seems to play an important role in the transport of phosphate in the plant (Russell, 1973). As is the case for Ca, Mg absorption is influenced by the level and form of the N treatment and the level of K application (Sideris and Young, 1945).

Magnesium deficiency is not common in pineapple although it can be a limiting factor particularly in many sandy and strongly acid soils of the tropics and as reported, Cibes and Samuels (1958) found a yield reduction of 30% in plants grown minus magnesium. According to Hernandez-Medina (1961), Mg treated plants produced 34% more fruits per acre than untreated plots. The Mg treated plants were also more superior in fresh and dry weights than the control. On an acidic sandy clay soil, Hernandez-Medina (1964) also showed that Mg treated plants produced 2.7 tons per acre more fruits than the untreated plants. Higher yields were associated with the highest leaf Mg levels. Investigations carried out by Py *et al.* (1957) in Guinea found no significant differences in mean fruit weight between plants receiving Mg and those that had no Mg treatment. They, however, observed the tendency for higher fruit weight with Mg treatment.

2.3.10. Balanced Nutrition in pineapples

The importance of nutrient balance in both soil and plant has been emphasised (Bould *et al.*, 1960; Obiefuna *et al.*, 1986). The deficiency of a single nutrient may sometimes alter the absorptive capacity of the plant for various other elements. It is known that the application of P increases the uptake of K but the excess of P reduces the uptake of N. The uptake of N is reported to be dependent on the presence of K (Marchal *et al.*, 1970). Also the application of N or P alone can have a detrimental effect on growth of pineapple. It is therefore important not only to apply the three major elements, but more importantly to ensure that they are applied in the right proportions. The net interactive response of pineapple to a mixture of balanced levels of N, P, and K enhanced its yield. Fruit yield of pineapple was reduced in fertilizer mixtures containing low N, irrespective of the rates of any other nutrient component (Obiefuna *et al.*, 1986).

The balance of nutrients in the leaf is of prime significance. Of particular importance is the K/P ratio, which according to some authors should not exceed 12.0 (Kanapathy, 1958) for it is said that if too much P is added, the N intake is upset and the result is the reduction in yield of the fruit (Cooke, 1949). Su (1969) concluded that Mg dressing was beneficial if the level of exchangeable Mg was less than 70 ppm. It is seen that K modifies plant nutrition both quantitatively and qualitatively (i.e. total cations and ratio). Absorption of magnesium is most strongly affected by the antagonistic influence of K and in the primary instance Mg absorption depends on the availability of K (Lacoeuilhe and Gicquiaux, 1971).

Higher concentrations of K leads to a reduction in the absorption of Ca and Mg (Sideris and Young, 1945).

Significant effect of interactions between N x P, N x K and P x K on yield of Smooth Cayenne have been recorded by Pan (1957), Teatota and Pandey (1964) and Obiefuna et al. (1986). However, interactions appeared to have no significant effect on the yield and quality of the Singapore Spanish variety grown on peat soil. With the Selenger Green variety, Yap and Parbery (1961) noted that interactions have a significant effect on yield though not on quality. Yap and Parbery (1961) also found that at low P level increasing the N level resulted in the lowering of juice acidity but at the high P level juice acidity increased though not significantly. Low K was accompanied by an increased accumulation of Ca and Mg. However, the lack of K tended to cause increased Ca and Mg absorption, therefore Chapman and Brown (1942) concluded that there was some factor which operated to limit this absorption beyond a certain point. In regions of hot, wet climate which favour high yields and a short cycle, K nutrition and also K/N relations have to be carefully controlled in order to obtain fruits of satisfactory commercial quality (Py *et al.*, 1987). Gailard (1970) has emphasised the importance of maintaining the K/N ratio in pineapple leaves at about 1.5 for production of high yields and good quality fruits. Special care also needs to be taken to maintain the K/P ratio in the leaf at 12, in order to optimize yields and quality (Kanapathy, 1958). For high yields and good quality fruits the following parameters were set by Sumner and Angeles (1990):

Nutrient balance index = 0; Titrable acidity > 0.45%; TSS/TA < 25; and
TSS x TA > 4.5.

Although the amount of nutrient and other materials in plants are determined by the quantities available, the absorption of elements is not in proportions modified by certain characteristics of the plant (Thomas and Mack, 1939).

The effects of different amounts of K on Ca, Mg, and P have been shown by many workers (Bartholomew *et al.*, 1933; Sideris and Young, 1945). Bartholomew *et al.* (1933) observed that the P contents of tissues was higher in plants supplied with high rather than low K. They also found out that the abundant supply of K also increased the absorption of P whereas Wall (1939), observed the opposite trend. Results of Sideris and Young (1945) show antagonistic effects of K on Ca.

PART THREE

2.4. Foliar diagnosis

2.4.1. Concept

Foliar diagnosis (Leaf analysis) is defined as the chemical composition or state of the leaf with respect to the dominant nutritive element at the instant of sampling and taken from a predetermined and suitable position on the stalk (Thomas, 1937; Thomas and Mack, 1939).

In order to accomplish this objective effectively, the part of the leaf selected must be of a definite physiological age (i.e., taken from a definite position on the plant). Furthermore, it should be as uniform as possible; for example, leaf petioles should be separated from blades, and stems from leaves (Lagatu and Maume, 1934; Thomas, 1937). The experimental facts to which the method of foliar diagnosis (leaf analysis) is linked may briefly be summarised as follows: two morphologically homologous leaves of the same species and variety are the seat of identical



physiological processes when the medium (soil and meteorological factors) of the two is identical (Lagatu and Maume, 1932 and 1933). The composition of leaves of the same physiological age of plants grown on the same homogenous medium (soil and climate) and receiving different fertilizer treatments reflects these differences in the sense that whenever a fertilizer element (whether N, P or K) is effective, as determined by the response of the plant to that element, that response is always associated with the increase of that element in the dry foliage (Lagatu and Maume, 1932).

In foliar diagnosis, neither the processes of migration of elements into the leaf from the stem nor export from the leaf into the stem is under consideration but only the amount of the element present in the leaf at the moment of sampling. The composition as determined by periodic analysis of the leaves of the same physiological (metabolic) age taken from plants of the same species growing on the same homogenous medium but receiving different fertilizer treatments are related to their development (Vinet and Lemesle, 1930; Herschler, 1933). The foliar diagnosis for any given year or season then will consist of a sequence of chemical states (composition) as determined on different dates and at different periods during the growing season. The composition is based on the dry matter of the leaf without taking into consideration the weight of the dry material at each sampling time or the number of leaves sampled from each plant (Thomas, 1937). It is clear therefore that no physiological significance can be attributed to the foliar diagnosis of any one fertilizer treatment (plot) considered alone. The analysis of any particular element, considered independently of all other field data and of all other foliar diagnosis has no physiological significance (Thomas, 1937). The point of departure of the

method of foliar diagnosis from the methods of traditional agronomy (e.g. soil analysis) is that it utilizes as an analytical expression of plant performance not the soil nor the fertilizer applied, but the chemical condition of the leaf at different stages in its life cycle. The commonly used leaf for leaf analysis in pineapple is the D-leaf which is defined as the youngest fully developed leaf at any given time (Py and Lossois, 1962).

2.4.1. Development of Leaf Analysis procedures.

The first investigations on the use of the method of leaf analysis to assess nutrient status of pineapple were made by Nightingale (1942). His investigations were continued by a Hawaiian team comprising Sideris, Krauss, Young and Chun. The most notable result had been the definition of the crop log technique developed by Sanford (1962), which is used to varying extents in the majority of pineapple producing countries (Py *et al.*, 1987).

The approach to the use of the method for pineapple was rather different from the original concepts of foliar diagnosis introduced in France by Lagatu and Maume (1924). The concept of the Hawaiian team was essentially intended for temperate countries. In tropical climates where the crop is mainly grown, seasonal conditions are much less well differentiated. As such, differences between years and locations especially, the effect of altitude are of critical importance from an agronomic point of view. Nightingale's aim was to find indices that were independent of all these factors and applicable in any locality or season. The three main principles of his work were as follows: the concentration of an element is employed in relation to carbohydrate and nitrate reserves; nitrogen nutrition is first

considered in relation to nitrate and carbohydrate reserves and the deficiency of an essential element must not only be recognised, but most importantly of all it must be explained.

2.4.2. Leaf colour

Based on the above deductions, Nightingale (1942) and Sanford (1962) came out with a relationship between leaf colour, texture, and carbohydrate:protein ratio and defined values for the different colours as shown below:

<u>Index</u>	<u>Colour</u>	<u>Texture</u>	<u>Carbohydrate: protein ratio</u>
0	Yellow	Firm	Ill defined
1	Yellow/green	Firm	High
2	Olive green	Intermediate	Moderate
3	Dark green	Soft	Low

No analytical procedure was found which would satisfactorily measure the state of the carbohydrate reserves but there was a correlation between leaf colour and starch content. The optimum relationship between leaf colour, reflecting N status, and carbohydrate synthesis occurs at colour indices 1 & 2. This is influenced by temperature, solar radiation and carbon dioxide levels. K nutrition also affects leaf colour, since it is essential for the conversion of reducing sugars to sucrose and starch and for the transfer of protein N from the leaves to the stems (Sideris and Young, 1945). This relationship is also influenced by climatic conditions (Lacoeuilhe, 1978).

2.4.3. Choice of plant part for leaf analysis

Unlike many plants, the development of pineapple varies greatly in the different tissues of the leaf, as well as in different leaves on the plant. Pineapple plants bear leaves simultaneously with stages of development ranging from embryonic to senescent (Cibes and Samuel, 1958). Although it is generally agreed that on the diagnosis for nutrient concentration or requirement the leaf is the most ideal tissue to sample for analysis (Bould *et al.*, 1960; Smith, 1962), opinion is divided as to which portion of the leaf to use for analysis. Sampling has also been done at different stages of growth of the plant.

Cooke (1949), Martin-Prevel (1961), Sanford (1962) and Godfrey-Sam-Aggrey (1970) sampled the basal non-chlorophyllous portion and fertilizer recommendations made on the basis of this analysis. Nightingale (1942) chose to analyse the median third of the basal, chlorophyll free portion of the D-leaf. From the physiological point of view, the non-chlorophyllous part of the leaf behaves like the petiole, i.e. a transit area between the leaves and other plant organs. The composition of the sample thus reflects the movement of elements within the plant and shows extreme sensitivity to the most mobile elements: nitrates, phosphorus and potassium. These migrations are sensitive to daily rhythms (Sideris *et al.*, 1948) and to quantitative and qualitative variations in the soil solution. The advantage of this particular sample is that the level of water is relatively constant which means results can be rapidly expressed on the basis of dry matter. The content of sugars in this sample is inversely related to growth and to nitrate N and K contents (Sideris and Young, 1951)

The chlorophyllous portions of the leaf is less sensitive to the above mentioned variations. It is the laboratory where the quantities of minerals present should allow optimum functioning in accordance with the climatic potential (Lagatu and Maume, 1930). In Malaya, Kanapathy (1958) took leaf samples from both the middle and tip sections of thirty fully matured non-flowering or non- fruiting plants, analysed them and established critical nutrient levels for the tip sections because it consistently showed less variation. Godfrey-Sam-Aggrey (1970) used both the middle and basal non chlorophyllous parts of the D leaf.

The use of the whole leaf for analysis has also been employed (Pan, 1957; Martin-Prevel, 1959), and appears to be more practical for two reasons : reserves of N available for plant growth can be assessed ; and total nutrition can be determined as critical concentrations are established. These considerations led the team at the Institute for Research into Fruits and Agronomy (IRFA, 1954) in France, to concentrate on the use of the entire D-leaf. Similar approach were initiated by the research groups in Puerto Rico (Samuels *et al.*, 1955) and in Taiwan and South Africa (Pan, 1957). Later the Hawaiian leaf base technique was adopted in many Pacific countries, but the IRFA, after several reassessments of the relative advantages of the two techniques concluded that whole leaf analysis was still the most preferable. The part of the leaf selected for analysis should reflect the general status of the plant with respect to the nutrient under consideration.

2.5. Nomenclature.

The nomenclature adopted for the different leaf sections by Sideris *et al.* (1936) was based on morphological characteristics and on chlorophyll distribution.

They were as follows:

- a. Basal non-chlorophyllous section - the white basal tissues of the leaf. This varies considerably in area and weight in the respective groups of leaves according to their stage of development.
- b. Transitional sub-chlorophyllous section - the transitional region between the chlorophyll-free base and the chlorophyllous tissue of the green blade proper.
- c. Lower chlorophyllous section - approximately the lower third of the green blade proper.
- d. Intermediate chlorophyllous section - approximately the middle third of the green blade proper.
- e. Terminal chlorophyllous section - approximately the terminal third of the green blade proper.

Later, Cibes and Samuel (1958) in Puerto Rico divided the leaf into sections as: basal non-chlorophyllous (white tissue), lower half of green leaf (bottom half) and terminal half of green leaf (top half). This nomenclature was similar to that used by Sideris *et al.* (1938) except that the former divided the green leaf blade into lower, intermediate and terminal sections.

2.6. Nutrient composition in pineapple leaf

Various workers (Pennock, 1944; Kanapathy, 1958; Su, 1969; Godfrey-Sam-Aggrey, 1970) have diagnosed nutrient problems in pineapple based on leaf

and soil analysis or a combination of both. The critical values or lower limits of sufficiency ranges used by these workers vary between 1.0 - 1.7% for N; 0.08 - 0.23% for P, and 1.8 - 4.20% for K. Although the D leaf nutrient content vary with age, climate, and variety, the generally accepted adequate values in Puerto Rico on dry weight basis are: N, 1.5 - 2% ; P, 0.12 - 0.15 ; K, 3 - 3.5% ; Ca , 0.2 - 0.30% ; and Mg, 0.2 - 0.25 (Valez Ramos *et al.*, 1991). Langenegger and Smith (1978) , using a data source comprising 39 observations developed norms for N, P, K as N, 1.5% ; P, 0.11% ; K, 2.76% . Angeles et al. (1989) using databank comprising 1185 observations of leaf nutrient concentrations and a field yield based on many years of pineapple growing experience of 60 tons/ha as the cut off between low and high yielding sub populations developed the following critical values N= 1.43% ; P= 0.25% and K=3.24%. The agreement among different sets of norms is good for N, whilst the values for P and K are slightly higher but within the range previously published by other workers.

The nutrient content of the different segments of the pineapple leaf is not the same. The literature contains inconsistent results on the comparison of nutrient levels in the various sections.

2.7. Factors influencing nutrient composition

The concentration of a nutrient in the plant as a whole or in any part of it is a function of soil, climate, plant variety, plant age (time), and management (Chapman, 1941; Ulrich, 1943; Valez-Ramos *et al.*, 1991), and the part of the plant analysed (Sideris and Young, 1950; Acquaye, 1964). According to Ahenkorah and Halm (1979), the effects of leaf age and light intensity tend to eclipse the nutritional

effects on leaf composition except when there exist marked deficiencies in the soil or in the growing media.

2.7.1. Effect of plant age on nutrient composition

Sideris and Young (1950) conducted extensive research on the effect of plant age on nutrient concentrations and arrived at the following conclusions:

Total nitrogen content in the non-chlorophyllous basal sections of the active D leaves of meristematic tissues until the period of floral differentiation generally decreased with advancing age. In the chlorophyllous distal sections of the active D leaves, total nitrogen remained almost at constant levels in the low nitrogen cultures, but increased in the high N cultures with advancing physiological and chronological age. The differences in the total nitrogen content of the tissues between the low and high N cultures were attributed to differences in rates of intake of N from the nutrient solution and formation of tissue matter exceeding those of N intake and the reverse in the high N cultures. The physical or chemical composition of the tissues in the chlorophyllous distal sections of the active D-leaf, did not undergo remarkable changes between the prefloral and postfloral stages.

Potassium concentrations in the non-chlorophyllous basal sections of the leaf generally decreased with advancing age of the plant. In the chlorophyllous distal sections however, the reverse trend was observed but in cultures with very low K in the nutrient solution a decrease was observed.

The concentration of calcium in both the non-chlorophyllous distal sections and chlorophyllous sections of the D-leaf generally increased with advancing age except in cultures with very low calcium in the nutrient solution. Valez-Ramos *et*

al. (1991) analysed nutrient contents of D-leaf at 4 and 8 months for N, P, K, Ca, and Mg, and observed decreases in N, P, K and Mg with advancing age. There was an increase in the Ca content. Nutrient content in particular those of N and K increased with increasing application of fertilizer (Valez-Ramos *et al.*, 1991).

2.7.2. Effect of time of sampling

It has been noted that, differences exist between leaf nutrient concentration and the time of sampling after fertilizer application. These observations vary with the type of nutrient applied. For the first application of fertilizer, leaf N values increased with increased N application to the soil when leaf samples were taken 3 months after the fertilizer was applied. However, when leaf samples of the first fertilizer application were taken 8 months after, the differences in leaf N disappeared, and all leaf N values tended to be the same despite the quantity of fertilizer applied (Samuels *et al.*, 1958). Leaf N, P, K, Ca, and Mg content have been found to decrease with age (Valez-Ramos *et al.*, 1991). Subramanian *et al.* (1977) found that leaf N, P, and K levels decreased from the 5th to the 8th month after planting but increased again at the 11th month. He attributed the fall in nutrient content at the 8th month to the vigorous growth during this period. Samuels *et al.* (1958) further found that leaf samples taken four months after the second of two fertilizer applications revealed differences in leaf N with increasing N applications. Leaf P values showed an increase with phosphate fertilizer application when leaf samples were taken 3 to 7 months thereafter. There were no increases in leaf P for leaf samples taken 4 months after the second fertilizer

application. After one application of fertilizer, leaf K values showed no appreciable increases with increased potash applications.

It appears that for sugarcane (Capo *et al.*, 1953) the best time for leaf sampling is about 3 to 4 months after fertilizing the plant (Samuels *et al.*, 1955).

2.8. Correlation between nutrient contents and yield parameters

Yields do not continue to increase indefinitely with increasing nutrient concentration in the plant, but do so only when the nutrient concentration is in the deficiency range. Within this range, an increase in the concentration of the nutrient will result in an increase in yield in comparison with the yield of plants with a lower nutrient concentration (Samuels *et al.*, 1958). Sideris and Young (1951) established that N content of the basal parts of older leaves of pineapple, devoid of chlorophyll had the best correlation with the N content of the nutrient medium whilst the K content of the medium was most reflected in the green parts of the D leaf.

Significant correlation in respect of leaf N was observed when sampling was done at 5 months but not at 8 or 11 months after planting. Maximum fruit yields (according to Kanapathy, 1958) were associated with 1.3% N but the sampling part in his case was the youngest fully grown leaf tips. Leaf N values for various applications showed a significant linear correlation with the relative yields of pineapple per acre. Also, there was a definite increase in leaf N and increasing yields with increasing application of N. The resultant equations obtained relating leaf N values with relative yields of pineapple were all highly significant. Although there were significant correlations between leaf N and yields for each individual fertilizer application, the leaf N values increased with each sampling after each application.

Since each successive fertilizer application meant that more N was being applied, increased leaf N values increased yield of fruits. On the other hand, Tay *et al.* (1968) observed no correlation between leaf N and yields, sugar or acid contents of fruits.

Leaf phosphorus values showed no significant relationship with pineapple yields (Samuels *et al.*, 1958; Tay *et al.*, 1968). However, significant correlations were observed in respect of leaf K and yields (Tay *et al.*, 1968; Subramanian *et al.*, 1977) with the correlation coefficient being slightly higher at 5 months than at the 8 or 11 months sampling period after planting.

In a much related work by Bartholomew *et al.* (1933), on K for different crops in soil, sand and solution cultures, the authors failed to establish any correlation between yields produced from the various treatments and the percentage of K in the plant. They observed that in some instances an increase in yield was accompanied by an increase in the percentage of K in the plant. However, whenever this condition was found, the increase in the percentage of K was usually several times as great as the increase in yields. In other cases, the yields from the K treatments were smaller than the control treatments and yet the percentage of K in the plant were considerably greater. It is therefore evident that the additional K in some cases was not probably needed for normal growth because it produced no increase in yields even in the presence of abundant supply of other elements. It is apparent that when the concentration of a given nutrient is above the critical range, then one of the many factors given in a plant nutrient equation would limit growth, and accordingly no correlation between the nutrient concentrations and yields should

be expected. Absorption of luxury amounts would equally disturb the correlations between yields and nutrient concentrations in the plant (Ulrich, 1943).

In summary, there is a divided opinion as to which segment of the D-leaf to use for analysis. Various workers therefore have used either the non-chlorophyllous, the chlorophyllous middle or tip portion or the entire leaf. However, the sensitiveness of these segments have not been compared. The effect of K on yield and quality has been studied by several workers with conflicting results. It is clear that both the biotic and abiotic environment play a significant role in determining the nutritional status, yield and quality of the pineapple.



CHAPTER THREE

3.0. MATERIALS AND METHODS.

3.1. Location of experimental sites :

The trials were located at three sites namely:

- a) Agricultural research station, Pokuase
- b) Silwood farms, Nsakyir, and
- c) Parrico farms, Oboadaka.



Silwood and Parrico farms are in the Aburi-Nsawam area. The Pokuase station is located in the dry area whilst that of Silwood and Parrico farms are in the wet Forest-Savannah transitional zone.

3.2. Cropping history of the sites.

The site at Pokuase had been cropped to maize, cassava and cowpea since 1952 while the plots at Silwood and Parrico had been under pineapple cultivation for not more than two cropping cycles.

3.3. Soils

Under the USDA Soil Taxonomy, the soils at Pokuase belong to the Ustalfs great group while those found at Parrico and Silwood farms belong to the Udalfs great group (Soil Survey Staff, 1987) and under the UNESCO/FAO classification of 1988 they belong to the class of Lixisols.

Representative soil samples were taken from the sites before land preparation. Sampling was from 0-15 cm which represented the zone in which most of the roots of

pineapple are found (Samson, 1980). The soil samples from each site were air dried, ground and passed through a 2 mm sieve and stored for laboratory analyses.

3.4. Chemical Analysis

3.4.1. Soil pH

Soil pH was measured in 1:2.5 soil-water suspension and in 1:2 soil-CaCl₂ (0.01M) suspension using a glass electrode-equipped pH meter, model MV 88 Pracitronic.

3.4.2. Organic Carbon

The wet oxidation method as described by Walkley and Black (1934) was used to determine organic carbon content of the soils. A 0.2 g soil sample was weighed into a 250 ml volumetric flask. Ten millilitre of potassium dichromate solution and 20 ml of concentrated Sulphuric acid were added and digestion allowed for 30 min. The dichromate remaining in solution was titrated against 0.2 N ammonium ferrous sulphate using barium diphenylamine as indicator.

3.4.3. Total Nitrogen

The total nitrogen content of the soils was determined using the modified Kjeldahl method (Bremner, 1965). Ten grams air dried soil were digested with 20 ml of concentrated sulphuric acid using selenium tablet as a catalyst. A 5 ml aliquot of the digest were then distilled with 5 ml of a 40 % sodium hydroxide solution and the distillate collected in 5 ml of 2 % boric acid solution. The distillate was then titrated with 0.01 N hydrochloric acid solution from green to reddish end point.

3.4.4. Available phosphorus

Available phosphorus in the soil was determined using a modified Murphy and Riley method by Watanabe and Olsen (1965). Two grams of air dried soil were weighed into a centrifuge tube and 40 ml of 0.5M sodium bicarbonate (pH 8.5) solution was added. The suspension was shaken for 30min. after which it was centrifuged at 3,000 revolutions per minute (rev/min.) for 10 min. The resulting suspension was then filtered and phosphorus was determined by the Molybdenum-blue method. All P determinations were read using the Philips UV-visible spectrophotometer at the wavelength of 712 nm.

3.4.5. Exchangeable cations

Exchangeable cations were extracted by saturation of the soil with 1.0 N ammonium acetate solution (pH 7.0) for 30 min., centrifuged and filtered. Potassium in the extract was determined using the “Jenway” flame photometer and magnesium and calcium by titration with 0.002 N EDTA solution (Moss, 1961).

3.4.6. Particle size analysis

The particle size distribution was determined by the conventional hydrometer method after dispersion in sodium hexametaphosphate solution (Day, 1965).

3.5. Experimental design

The field design used was Randomized Complete Block (RCBD). There were four replicates for each treatment at Pokuase and two for each of the treatments at

Silwood and Parrico. The low number of replicates at Silwood and Parrico was due to the limited land the farmer was willing to offer.

3.6. Size of plots and planting distance

Each micro-plot measured $(2.4 \times 6) \text{ m}^2 = 14.4 \text{ m}^2$. The double row system of planting was employed with a spacing of $(30 \times 30 \times 90)$ cm. There were 80 plants per micro-plot, thus giving a plant population of 55,000 plants per hectare.

3.7. Fertilizers used

3.7.1. Treatments.

Four levels of K were used as shown below:

K level 1 = 200 kg K_2O /ha.

K level 2 = 300 kg K_2O /ha.

K level 3 = 400 kg K_2O /ha.

K level 4 = 500 kg K_2O /ha.

Nitrogen (N) and Phosphorus (P) were applied at the rate of 110 and 50 kg/ha respectively.

The following were the sources of N and P fertilizers used :

1. P.....Single superphosphate (% $\text{P}_2\text{O}_5 = 18$).
2. NSulphate of ammonia (%N = 21).

The source of K was potassium nitrate which contained 46% K_2O and 13%N.



3.7.2. Fertilizer application

The fertilizers were applied in the basal axils of the older leaves in three split doses at 6 weeks, 16 and 32 weeks after planting (WAP) in the proportions shown below:

<u>Nutrient</u>	1st	2nd	3rd
	6 WAP	16 WAP	32 WAP
N	1/6	1/2	1/3
P	1	0	0
K	1/6	1/3	1/2

3.8. Cultural Practices

3.8.1. Land preparation

The land at Pokuase was prepared by mechanical means. It was ploughed and harrowed to obtain a good seedbed. The plots at Silwood and Parrico were, however, prepared manually by the slash and burn method.

3.8.2. Planting material selection, preparation and planting

Planting material (suckers) of uniform size, which weighed between 400-500 g were selected and treated against wilt disease by dipping in a solution containing 2% Dursban. The suckers were then left to dry for a day and planted at the experimental sites. Planting was started at Pokuase on 11 June, 1992 and was completed on the 28 June, 1992 at Silwood and Parrico.

3.9. Crop Management

3.9.1. Weed control

Weeds were controlled with the application of a mixture of Diuron and Bromacil (5-bromo-3-sec-butyl-6-methyluracil) in the ratio 1:1. Sixty grams of each chemical were mixed with 15 litres of water and applied at 4 weeks after planting. This was followed by two hand weedings just before the second and third fertilizer applications.

3.10. Flower induction

The plants were induced to flower at 10 months after planting with a mixture of water and calcium carbide. One kg of calcium carbide granules were reacted with 200 l of water in a sealed drum for about 10-15 min. The resultant saturated solution was decanted into a 15 l knapsack sprayer and about 50 ml solution was drenched into the heart of each plant. The whole process was repeated three days later in order to achieve a higher rate of flowering.

3.11. Leaf Analysis

3.11.1. Sampling , preparation and storage of leaf samples

The leaf samples used in this study were taken as the D-leaf from the various treatments. The D-leaf may be defined as the most recently fully expanded leaf that can be easily removed from the plant by a sharp sideways hand twist. A total of 10 leaves were harvested at random from the middle double rows (Lacoeuilhe,1981).

Sampling was carried out on two occasions, the first was on 1 March, 1993 (8 months after planting, MAP) and the second on 3 May, 1993 (10 MAP). Sampling on both occasions was carried out between the hours of 8 a.m. and 2 p.m.

The samples were collected in polythene bags, sent to the laboratory where they were immediately washed singly in 0.2 % Teepol (Mason, 1952/53), rinsed in two changes of tap water then in distilled water and finally mopped free of water.

The length of the D-leaf was measured for each of the 10 leaves and the mean length obtained. The leaf samples taken 8 MAP were chopped into small pieces and dried for the determination of dry matter content to study the growth of the pineapple.

Those sampled at 10 MAP were further separated into the white basal non-chlorophyllous segment and the green chlorophyllous segment. A third sample was collected which was treated as the whole D-leaf. The different sections were then cut into small pieces separately after which they were put in paper bags and weighed. The bagged samples were then dried in a hot air oven at 80 °C for four days. Dried samples were weighed in order to calculate percentage dry matter content. The dried samples collected at 10 MAP were then milled in a Wiley mill and stored in polythene bags to prevent absorption of moisture from the atmosphere.

3.11.2. Digestion of plant material

Digestion of the plant material was carried out using the wet oxidation method. A 0.5 g of dried ground plant tissue was placed into 150 ml digestion flask. Five millilitres (5 ml) of concentrated nitric acid was added to each flask and the contents heated on an electric sand bath set at low temperature. The resulting suspension was heated until the brown fumes ceased to escape. The digestion flasks were cooled and

5 ml of ternary mixture of acids in the ratio of 10 : 1 : 4 (HNO_3 : H_2SO_4 : HClO_3) was added to the contents of the flasks. The flasks were again heated, this time, at high temperature till the white fumes ceased to evolve and a clear solution or paste remained. The residue was then cooled and dissolved in about 20 ml of distilled water, filtered through a Whatman no. 42 filter paper into a 100 ml volumetric flask and made up to the volume. Suitable aliquots were withdrawn for the determination of P , K , Ca , and Mg.

3.12. Analytical methods

Chemical analyses were carried out on the samples collected at 10 MAP to determine Nitrogen, Phosphorus, Potassium , Calcium and Magnesium. The results are presented as a percentage of dry weights.

3.12.1. Determination of phosphorus in plant material

One millilitre (1 ml) aliquot of the clear filtrate was pipetted into a 50 ml volumetric flask. One drop of p-nitrophenol was added to the mixture followed by a few drops of NH_4OH which just turns the mixture yellow. Five millilitres (5 ml) of distilled water was added followed by 8 ml of ascorbic acid. The mixture was then topped up to the volume. The solution was shaken, allowed to stand for 15 min. after which the readings were taken using Philips UV-visible Spectrophotometer at the wavelength of 712 nm.

3.12.2. Determination of K in plant material

Potassium (K) in the aliquot was determined using the “Jenway” flame photometer.

3.12.3. Determination of Ca and Mg

Ca and Mg were determined on aliquots of the digest by complexometric titration method (Moss, 1961).

3.12.4. Determination of Nitrogen

A 0.25 g of the milled sample was digested using 10 ml of concentrated Sulphuric acid and copper tablet as catalyst. Percentage nitrogen was determined from the digest using the Micro-Kjeldahl distillation Method as described in section 3.5.3.

3.13. Fruits

3.13.1. Harvesting of fruits

Fruits were harvested between the 5th and 6th month after flower induction. It was done sequentially at the one-third ripe stage and was completed after six weeks.

3.13.2. Determination of fruit weight

Ten fruits were harvested at random from each treatment and the mean fruit weight determined. Fruits were weighed with the crown.

3.13.3. Determination of fruit quality

Five fruits from each treatment plot were analyzed to determine titrable acidity and total soluble solids (brix). The fruit analyses were carried out by the Food Research Institute of the Council for Scientific and Industrial Research (CSIR).

3.14. Data analysis

Test of Analysis of Variance (ANOVA) was performed on the data collected. All data collected were analyzed separately for each of the three sites. Correlation analysis was performed between leaf nutrient content in the various segments of the leaf, and yield and quality parameters.



CHAPTER FOUR

4.0. RESULTS

4.1. Rainfall and temperature.

Mean monthly rainfall and temperature data for the period of the experiment (1992-1994) for Pokuase, Aburi and Nsawam (representing the area where the experiments were located) are presented in Figure 1 and Table 1 respectively.

Rainfall was generally higher in the Aburi and Nsawam areas (where Silwood and Parrico farms were located) than at Pokuase. Again rainfall amounts were better in 1993 than in 1992 (Fig. 1). In 1993, the highest amount of rainfall of 276 mm was recorded in the month of June at Aburi, whilst 170 mm was recorded at Pokuase.

The mean maximum and minimum temperatures during the period of the experiment ranged from 27 - 33 °C and 19 - 23 °C respectively (Table 1). The temperature at Aburi area, where Parrico farm is situated was generally cooler than at the other two sites.

4.2. Soil physical and chemical properties.

Some selected properties of the soils are shown in Table 2. Soil pH in 0.01 M CaCl₂ ranged from 5.1 to 5.9. The soils were low in organic carbon and total N. The exchangeable K of the soils was < 0.35 cmol (+) kg⁻¹, this value was lower than what Su (1958 and 1959) recorded as the threshold for lack of response to K addition. Generally, the available P at the sites was equally low. The texture of the soils was loamy sand.

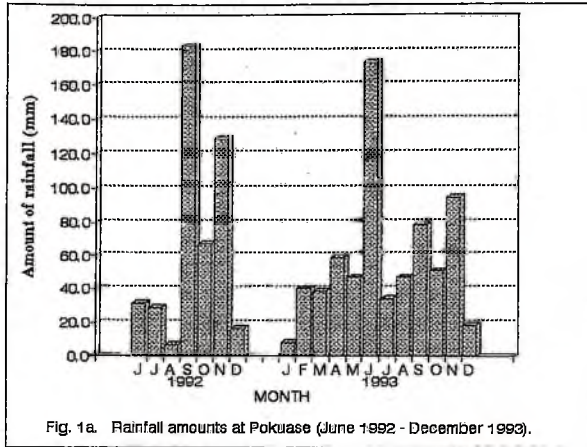


Fig. 1a. Rainfall amounts at Pokuase (June 1992 - December 1993).

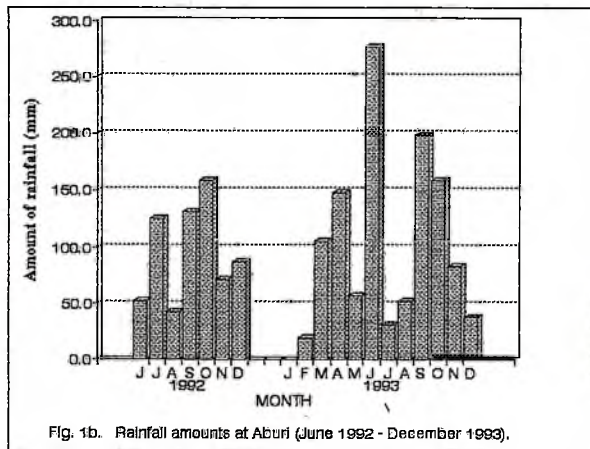


Fig. 1b. Rainfall amounts at Aburi (June 1992 - December 1993).

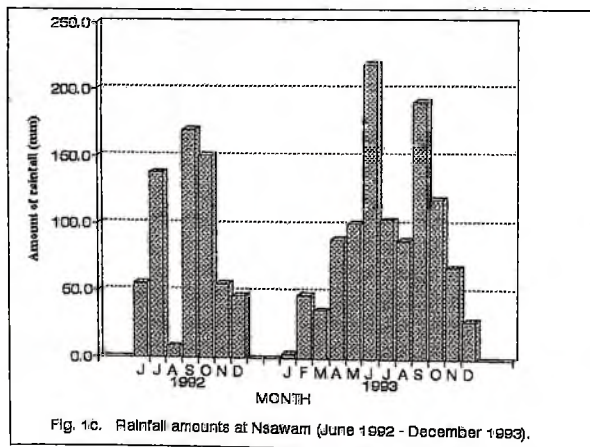


Fig. 1c. Rainfall amounts at Nsawam (June 1992 - December 1993).

Table 1. Mean annual temperature ($^{\circ}\text{C}$) data for Pokuase, Aburi and Nsawam (June, 1992 - December, 1993)

	<u>Pokuase</u>	<u>Aburi</u>	<u>Nsawam</u>
Minimum	21 - 23	19 - 21	20 - 22
Maximum	30 - 33	27 - 29	31 - 33

Source: Meteorological Services Department.

Table 2 Some physical and chemical properties of the soils from the three sites

	<u>Pokuase</u>	<u>Parrico</u>	<u>Silwood</u>
% Sand	81.0	79.5	79.9
% Silt	7.8	7.9	6.9
% Clay	11.2	12.6	13.1
pH			
1:2.5 soil : water	6.4	6.4	5.4
1:2 soil : 0.01M CaCl_2	5.7	5.9	5.1
Texture	Loamy sand	Loamy sand	Loamy sand
% Total organic carbon	0.60	0.81	0.64
% Total N	0.06	0.10	0.10
Exchangeable cations (cmol kg^{-1})			
Ca	4.35	7.54	7.24
Mg	2.47	3.65	3.42
K	0.23	0.35	0.32
Na	0.10	0.13	0.11
Available P (mg kg^{-1})	5.8	7.90	6.00

4.3. Effect of K on growth and yield

The influence of different rates of K on growth, yield and quality of pineapple at the three sites are shown in Figures 1(d) and Tables 3 - 5. There was a general but non-significant increase in the length of D-leaf with increasing K application at all sites (Tables 3 - 5, Fig.2). There were clear increases of not less than 7 % over the respective means at all sites between the length of the D-leaf at the lowest rate (i.e. 200 kg K/ha) and the highest (i.e. 500 kg K/ha). However, the differences were not clear cut between the 200 - 400 kg K/ha, particularly, at the second sampling (10 MAP). At Parrico, the differences in length of the D-leaf which was significant ($p = 0.01$) at the first sampling time (8 MAP) evened out two months later (at 10 MAP). Significant increases were observed in respect of dry matter content (Fig. 3) at both times of sampling (8 and 10 MAP). There were significant increases in dry matter between the lowest rate (200 kg K/ha) and the highest rate of 500 kg K/ha. The differences in dry matter between the application of 200 - 400 kg K/ha were statistically not significant. This trend which was amply demonstrated at the second sampling, was consistent at all sites and at the two sampling periods.

The lowest mean fruit weights of 1.45, 1.24 and 2.5 kg (Fig 1d) were obtained at Pokuase, Silwood and Parrico, respectively, at the lowest K rate of 200 kg/ha, while the corresponding highest mean fruit weights of 2.10, 2.25 and 2.90 kg, respectively were obtained at 500 kg/ha K. At Parrico, the 100 kg increase in K application from 400 to 500 kg/ha did not influence yield significantly. There was a clear and significant difference ($p = 0.05$) between mean fruit weights at the application of 200 kg K/ha and 500 kg K/ha at Pokuase and Silwood.

At Parrico, the increases in yield were not significantly different. Similar mean fruit weight values were obtained for 300 and 400 kg K/ha at Pokuase and Silwood.

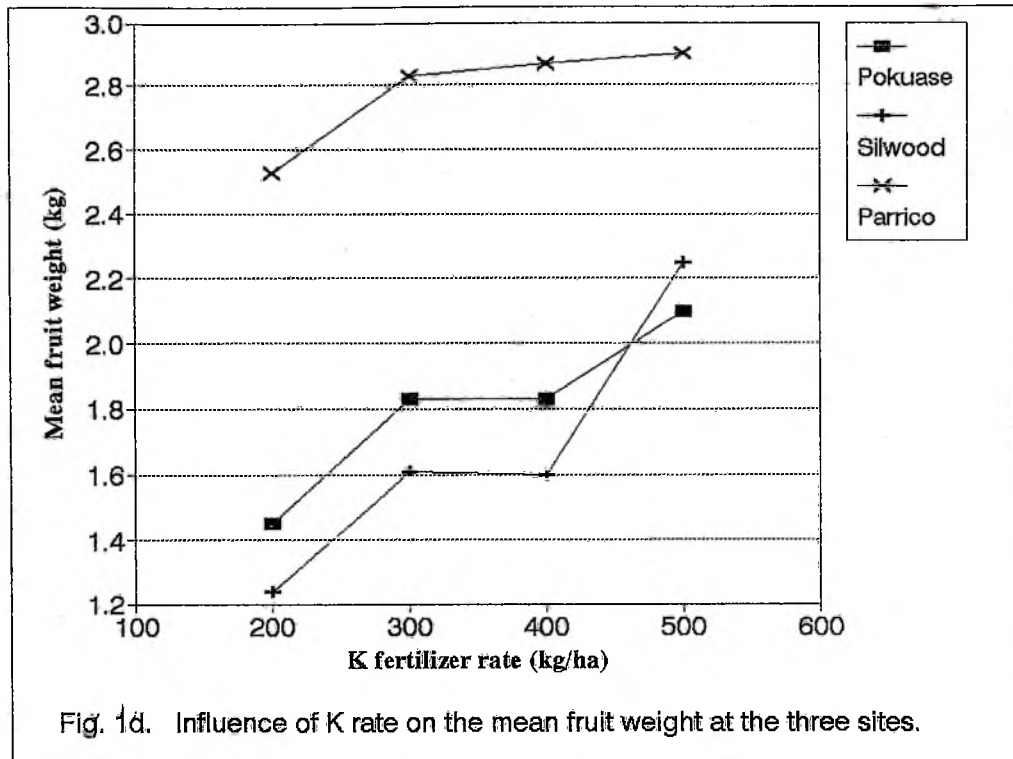


Table 3. Length and dry matter of D-leaf, yield and quality of pineapple from different K treatments at Pokuase

K RATE (kg/ha)	LENGTH OF D-LEAF (cm)		DRY MATTER (g)		MEAN FRUIT WEIGHT (kg)	ACIDITY mg citric acid/100 g fruit	T.S.S 10° Brix
	8 MAP	10 MAP	8 MAP	10 MAP			
200	71.77	73.30	5.19	5.32	1.45	0.57	17.99
300	74.24	74.19	6.01	6.53	1.83	0.53	17.85
400	75.38	78.88	6.24	6.85	1.83	0.53	18.06
500	77.03	79.98	6.40	6.74	2.10	0.54	18.00
MEAN	74.61	76.59	5.96	6.36	1.80	0.54	18.00
LSD	11.97	5.69	0.70*	0.55**	0.43*	0.09	0.34
CV (%)	10.03	4.64	7.59	5.41	14.93	10.79	3.75

Table 4. Length and dry matter of D-leaf, yield and quality of pineapple from different K treatments at Silwood

K RATE (kg ha)	LENGTH OF D-LEAF (cm)		DRY MATTER (g)		MEAN FRUIT WEIGHT (kg)	ACIDITY mg citric acid/100 g fruit	T.S.S 10° Brix
	8 MAP	10 MAP	8 MAP	10 MAP			
200	65.22	88.71	3.61	7.14	1.24	1.08	16.76
300	70.77	92.09	4.52	7.66	1.61	1.09	13.82
400	71.67	93.01	4.69	8.32	1.60	1.11	15.35
500	79.67	97.19	5.62	9.06	2.25	1.16	16.10
MEAN	71.83	92.75	4.61	8.04	1.67	1.11	15.51
LSD	10.26	5.77	0.64*	0.41**	0.56*	0.03*	3.79
CV (%)	4.49	1.96	4.34	0.87	10.51	1.27	7.69

Table 5. Length and dry matter of D-leaf, yield and quality of pineapple from different K treatments at Parrico

K RATE (kg /ha)	LENGTH OF D- LEAF (cm)		DRY MATTER (g)		MEAN FRUIT WEIGHT (kg)	ACIDITY mg citric acid/100 g fruit	T.S.S 10° Brix
	8 MAP	10 MAP	8 MAP	10 MAP			
200	72.73	91.44	5.79	8.30	2.53	0.80	18.24
300	77.42	92.55	6.69	8.70	2.82	0.79	17.73
400	79.78	96.22	6.89	9.60	2.87	0.88	16.45
500	79.86	98.19	7.18	10.50	2.90	1.00	15.30
MEAN	77.45	94.60	6.64	9.29	2.77	0.86	16.93
LSD	3.45**	5.23	1.68	1.05**	0.47	0.33	0.22
CV (%)	0.76	1.74	7.97	1.92	4.95	11.98	4.04

* Level of significance = 0.05

** Level of significance = 0.01.

Fig.2 Relationship between length of D-leaf and K-fertilizer rates at the three sites

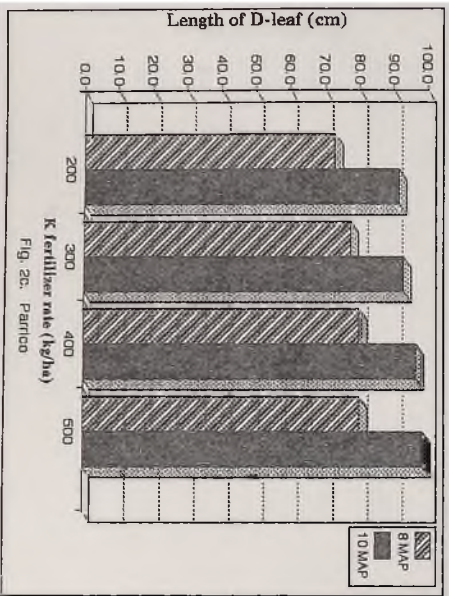
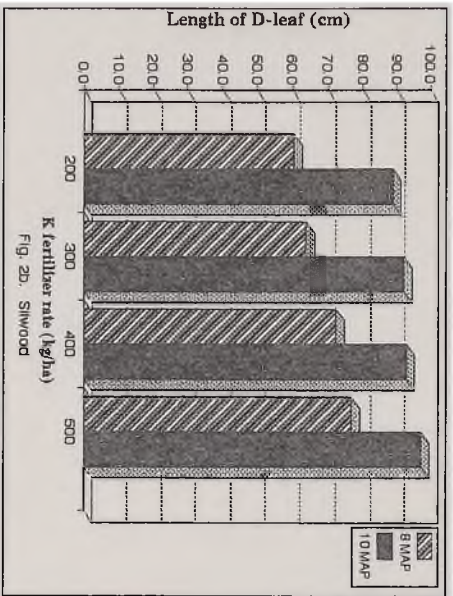
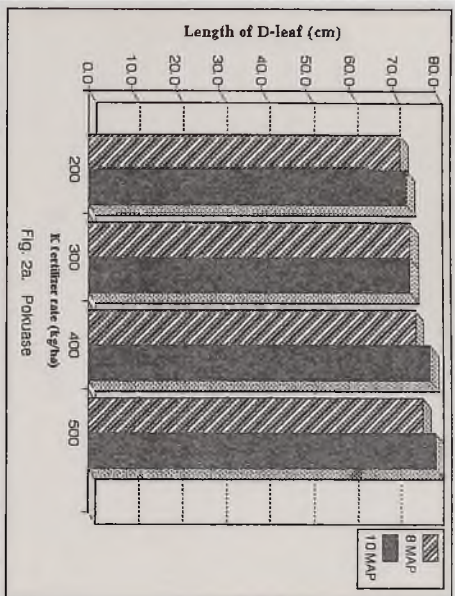
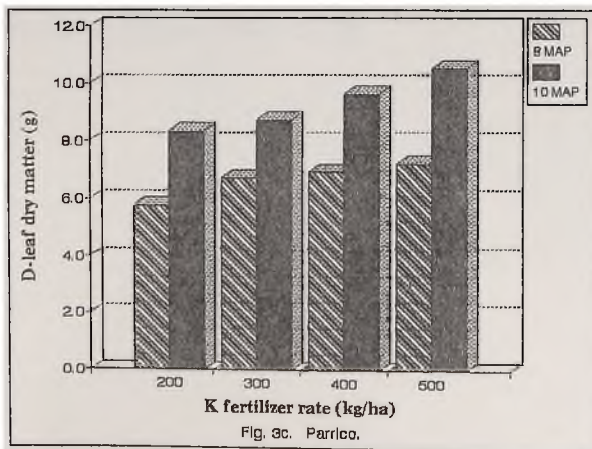
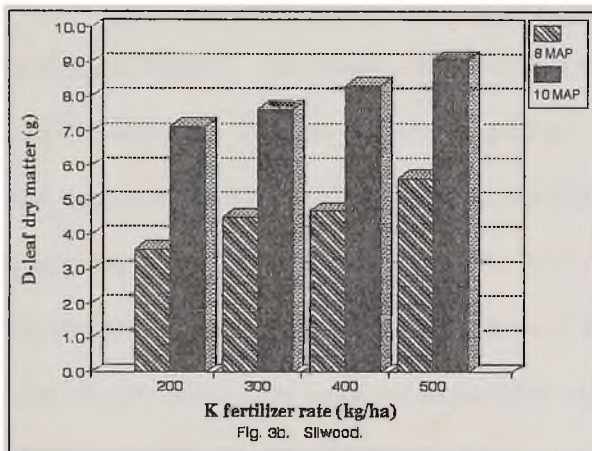
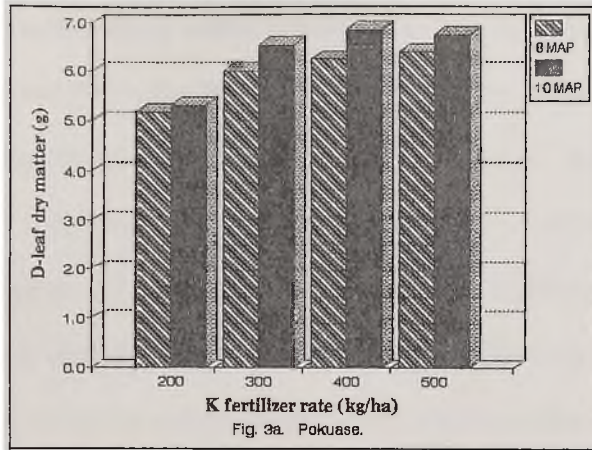


Fig. 3. Relationship between dry matter content of the D-leaf and K-fertilizer rates at the three sites



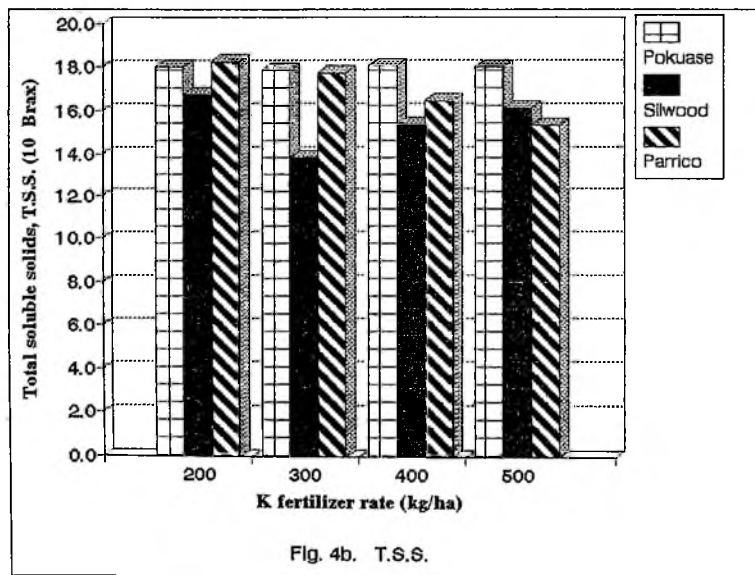
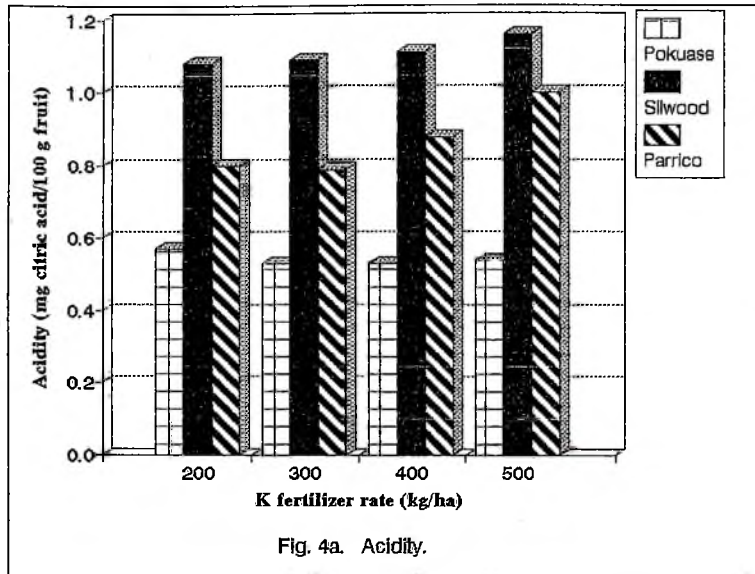
4.4. Effect of K on fruit quality

The quality of the fruit is expressed in terms of the acid and sugar contents.

Titration acidity values ranged between 0.53 - 0.57 at Pokuase, 1.08 - 1.16 at Silwood and 0.8 - 1.0 at Parrico (Tables 3 - 5). The ranges, which were generally close, were in the order Silwood > Parrico > Pokuase. Acidity generally tended to increase with increasing K application (Fig. 9a), this trend was shown to be significant ($p = 0.05$) at Silwood (Table 4a). The highest acidity values were associated with the 500 kg K/ha. At Silwood, acidity increased with increasing K application with the highest value of 1.16 occurring at rate of 500 kg K/ha and the lowest value of 1.08 was obtained at the rate of 200 kg K/ha. At Parrico, acidity increased with increasing K. The lowest acidity value of 0.8 was obtained at 200 kg K/ha and the highest of 1.0 at the rate of 500 kg K/ha.

The changes observed in the T.S.S with respect to different rates of K application tended to be specific with site (Fig. 4b). At Pokuase, the T.S.S was not affected by the different rates of K. The values for the K rates were essentially the same (about 18). At Silwood the trend was inconsistent whereas at Parrico, there was an apparent decrease after the 300 kg/ha application. None of the variations observed was significant (Tables 3 - 5).

Fig. 4. Relationship between Acidity, T.S.S and K-fertilizer rates at the three sites.



4.5. Nutrient contents of leaf segment

The nutrient composition of the non-chlorophyllous, chlorophyllous and whole D-leaf of the 10 MAP at the three sites are presented in Tables 6 - 8. A comparison of nutrient contents from the different leaf segments is also presented in Table 9.

4.5.1. Nitrogen.

Nitrogen content of the different leaf segments generally ranged between 1.0 - 1.7 % at Pokuase, Silwood and Parrico (Tables 6 - 8).

The whole D-leaf had the highest mean concentration of nitrogen followed by the chlorophyllous and the non-chlorophyllous segment in that order. However at Pokuase the N concentration in the non-chlorophyllous segment was higher than in either the whole D-leaf or the chlorophyllous segment and hence did not follow the above trend. Nonetheless, the analysis of variance (ANOVA) test run to compare the differences in nutrient contents from the different leaf segments, showed that the differences were significant (Table 9).

4.5.1.1. Changes in N contents with increasing K.

N contents in all the three segments of the D-leaf generally increased with increasing K application at all the three sites (Fig. 5a -5c). These increases were better reflected in the non-chlorophyllous segment of the D-leaf at each of the three sites (Tables 6 - 8). The N concentration was also significantly related to K rates in the whole D-leaf at Pokuase and Parrico. The highest amount of 1.7 % was

Table 6

Nutrient contents of D-leaf 10 months after planting from different rates of K at Pokuase

NON-CHLOROPHYLLOUS SECTION

K rate (kg/ha)	N	P	K %	Ca	Mg	K/P	K/N
200	1.10	0.31	2.52	0.80	0.54	8.52	2.33
300	1.23	0.32	2.60	0.92	0.55	8.25	2.13
400	1.27	0.30	2.71	0.79	0.48	9.22	2.16
500	1.30	0.28	2.80	0.60	0.46	10.07	2.16
Mean	1.22	0.30	2.66	0.78	0.51	9.02	2.19
LSD	0.11*	0.05	0.60	0.21***	0.24	2.84	0.60
CV(%)	5.52	10.75	14.07	11.62	29.95	19.69	17.07

CHLOROPHYLLOUS SECTION

K rate (kg/ha)	N	P	K %	Ca	Mg	K/P	K/N
200	1.00	0.13	2.20	0.43	0.65	17.37	2.24
300	1.05	0.13	2.25	0.44	0.52	17.64	2.15
400	1.05	0.12	2.30	0.43	0.55	18.89	2.23
500	1.14	0.12	2.36	0.42	0.48	20.14	2.07
Mean	1.06	0.12	2.28	0.43	0.55	18.48	2.17
LSD	0.22	0.02	0.13	0.50	0.13	2.03*	0.47
CV(%)	12.63	6.73	3.70	7.86	15.61	6.86	13.44

WHOLE LEAF SECTION

K rate (kg/ha)	N	P	K %	Ca	Mg	K/P	K/N
200	1.09	0.10	2.19	0.48	0.58	21.35	2.10
300	1.16	0.09	2.26	0.50	0.57	24.67	2.02
400	1.21	0.09	2.29	0.42	0.53	26.01	1.90
500	1.19	0.09	2.44	0.32	0.52	27.91	2.06
Mean	1.14	0.09	2.29	0.43	0.55	24.98	2.02
LSD	0.10**	0.02	0.15*	0.12*	0.27	8.77	0.14
CV(%)	3.87	16.96	4.22	18.94	19.25	21.95	4.44

* Level of significance = 0.05

** Level of significance = 0.01



Table 7 Nutrient contents of D-leaf 10 months after planting from different rates of K at Silwood

NON-CHLOROPHYLLOUS SECTION							
K rate (kg/ha)	N	P	K	Ca	Mg	K/P	K/N
	%						
200	1.15	0.15	3.80	0.48	1.12	26.24	3.31
300	1.22	0.13	4.10	0.48	0.96	31.54	3.36
400	1.27	0.12	4.50	0.48	0.76	37.50	3.56
500	1.46	0.12	4.60	0.48	0.77	38.33	3.14
Mean	1.28	0.13	4.25	0.48	0.90	33.40	3.34
LSD	0.06**	0.03*	0.41**	-	0.19**	5.86**	0.20*
CV(%)	1.01	2.75	1.66	-	3.42	3.01	1.91
CHLOROPHYLLOUS SECTION							
K rate (kg/ha)	N	P	K	Ca	Mg	K/P	K/N
	%						
200	1.22	0.12	3.00	0.48	1.01	24.79	2.47
300	1.28	0.12	3.35	0.48	0.91	27.92	2.62
400	1.39	0.10	3.85	0.48	0.81	38.50	2.78
500	1.50	0.10	4.05	0.48	0.77	40.50	2.70
Mean	1.35	0.11	3.56	0.48	0.88	32.93	2.64
LSD	0.06**	-	0.41**	-	0.10*	3.79**	0.14*
CV(%)	0.30	-	1.90	-	4.04	1.97	1.83
WHOLE LEAF SECTION							
K rate (kg/ha)	N	P	K	Ca	Mg	K/P	K/N
	%						
200	1.40	0.13	2.70	0.48	0.86	20.77	1.93
300	1.51	0.12	2.90	0.48	0.77	24.17	1.94
400	1.61	0.11	3.15	0.48	0.58	28.64	1.96
500	1.72	0.09	3.50	0.48	0.58	38.89	2.04
Mean	1.56	0.11	3.06	0.48	0.70	28.12	1.97
LSD	0.20	-	0.87	-	0.03	9.71*	0.63
CV(%)	4.10	-	8.92	-	-	10.85	10.00

* Level of significance = 0.05

** Level of significance = 0.01

Table 8 Nutrient contents of D-leaf 10 months after planting from different rates of K at Parrico

NON-CHLOROPHYLLOUS SECTION							
K rate (kg/ha)	N	P	K	Ca %	Mg	K/P	K/N
200	1.24	0.28	3.40	0.48	1.15	12.37	2.75
300	1.33	0.22	3.40	0.56	1.00	15.82	2.56
400	1.34	0.25	3.65	0.56	0.91	14.90	2.73
500	1.40	0.21	3.80	0.63	0.91	18.10	2.71
Mean	1.33	0.24	3.56	0.56	0.99	15.30	2.69
LSD	0.06**	0.06**	0.19**	0.30	0.36	2.03**	0.58
CV(%)	1.31	2.87	0.99	16.62	11.56	2.27	0.76

CHLOROPHYLLOUS SECTION							
K rate (kg/ha)	N	P	K	Ca %	Mg	K/P	K/N
200	1.33	0.12	3.30	0.48	0.77	27.50	2.49
300	1.37	0.12	3.60	0.48	0.78	30.00	2.65
400	1.37	0.14	3.60	0.48	0.58	25.90	2.65
500	1.44	0.11	3.35	0.48	0.58	30.46	2.34
Mean	1.37	0.12	3.46	0.48	0.68	28.46	2.53
LSD	0.35	0.06	0.60	0.03	0.06**	6.05	0.82
CV(%)	7.99	5.77	5.37	0.51	0.52	6.68	10.19

WHOLE LEAF SECTION							
K rate (kg/ha)	N	P	K	Ca %	Mg	K/P	K/N
200	1.23	0.15	2.70	0.56	0.82	18.64	2.20
300	1.33	0.10	3.15	0.56	0.58	31.50	2.38
400	1.65	0.10	3.35	0.48	0.58	33.50	2.04
500	1.62	0.15	3.20	0.48	0.58	22.75	1.98
Mean	1.46	0.12	3.10	0.52	0.64	22.60	2.15
LSD	0.25*	0.03	0.26**	0.20	0.10*	8.89*	0.46
CV(%)	5.11	15.63	1.32	12.56	5.52	10.51	6.73

* Level of significance = 0.05

** Level of significance = 0.01

Table 9. Comparison of nutrient contents from the different leaf segments at the three sites

	<u>Means of nutrient contents of leaf segments</u>		
	<u>Pokuase</u>	<u>Silwood</u> %N	<u>Parrico</u>
NC	1.22	1.28	1.33
C	1.06	1.35	1.37
WL	1.14	1.56	1.46
LSD	0.09**	0.10**	0.06*
CV (%)	8.09	4.44	5.06
%P			
NC	0.30	0.13	0.24
C	0.12	0.11	0.12
WL	0.09	0.11	0.12
LSD	0.01**	0.02**	0.02**
CV (%)	12.62	1.74	7.39
%K			
NC	2.66	4.25	3.56
C	2.28	3.56	3.46
WL	2.29	3.06	3.1
LSD	0.29**	0.26**	0.19**
CV (%)	9.97	4.69	3.57
%Ca			
NC	0.78	0.48	0.56
C	0.43	0.48	0.48
WL	0.43	0.48	0.52
LSD	0.08**	-	0.07**
CV (%)	13.69	-	12.56
%Mg			
NC	0.51	0.90	0.99
C	0.55	0.88	0.68
WL	0.55	0.70	0.64
LSD	0.08	0.05**	0.12**
CV (%)	20.78	4.08	10.00

* Level of significance = 0.05,

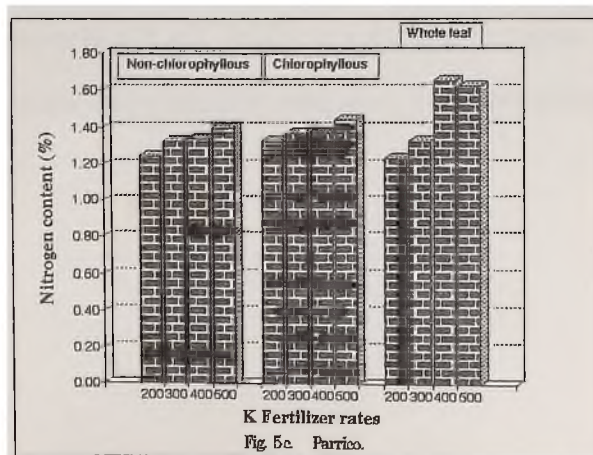
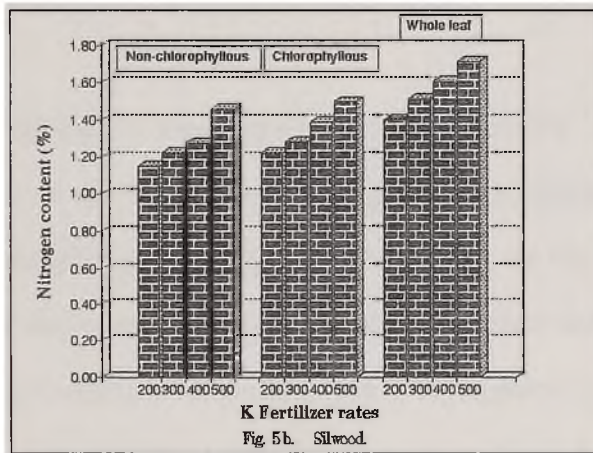
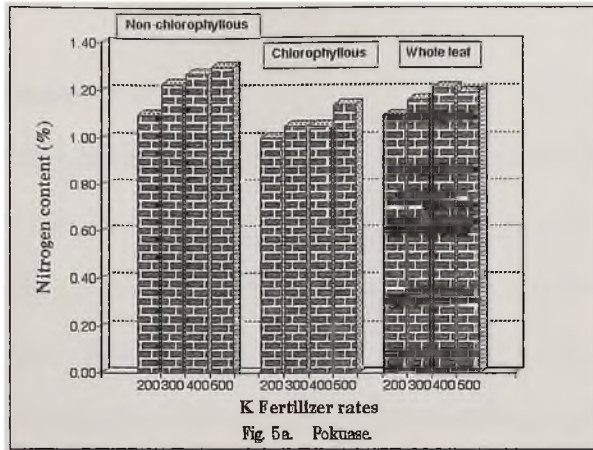
** Level of significance = 0.01.

NC = Non-Chlorophyllous segment of the D-leaf,

C = Chlorophyllous segment of the D-leaf,

WL = Whole leaf portion of the D-leaf.

Fig. 5. Relationship between N content of leaf segments and K-fertilizer rates at the three sites.



obtained in the whole D-leaf sampled from Silwood with the highest application of K fertilizer (500 kg/ha).

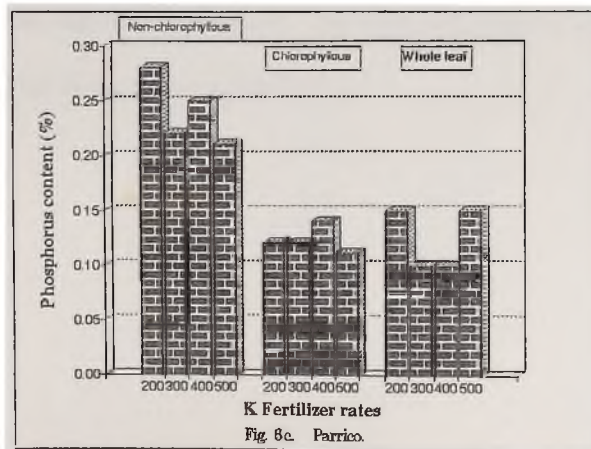
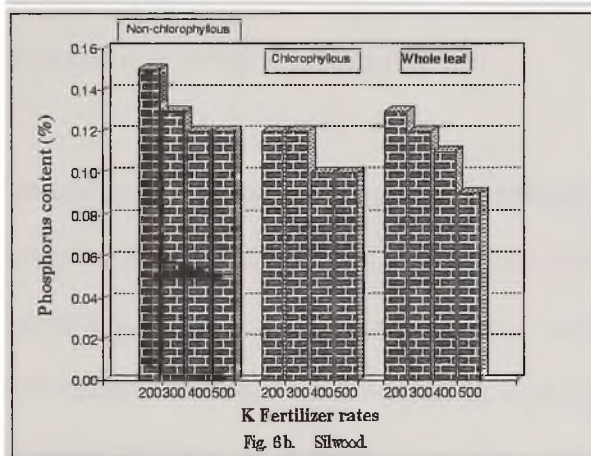
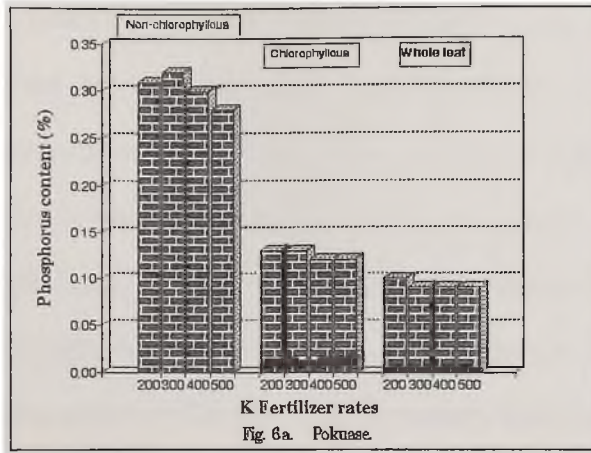
4.5.2. Phosphorus (P)

Phosphorus contents ranged from 0.1 - 0.3 % in the three leaf segments sampled at the three sites. As shown in Tables 6 - 8, the non-chlorophyllous leaf segment had significantly ($p < 0.01$) higher levels of P than either the chlorophyllous segment or whole D-leaf. This trend was consistent at all the three sites (Fig. 6). The values for the P concentration obtained with the chlorophyllous segment and whole D-leaf were very similar and generally not significantly different from each other.

4.5.2.1. Changes in P content with increasing rate of K

Increasing the rate of K application did not influence significantly the levels of P in the various leaf segments. The results (Tables 6 - 8 and Fig. 6), seem to indicate that, P content generally tended to reduce in all the three leaf segments with increasing K application at the three sites. This suggested trend is more discernible with the whole D-leaf at Silwood than with others. These decreases were however not significant ($p < 0.05$). It is to be noted that the highest P content was generally obtained at the lowest rate of K application, that is 200 kg/ha (Fig. 6).

Fig. 6. Relationship between P contents of leaf segments and K-fertilizer rates at the three sites.



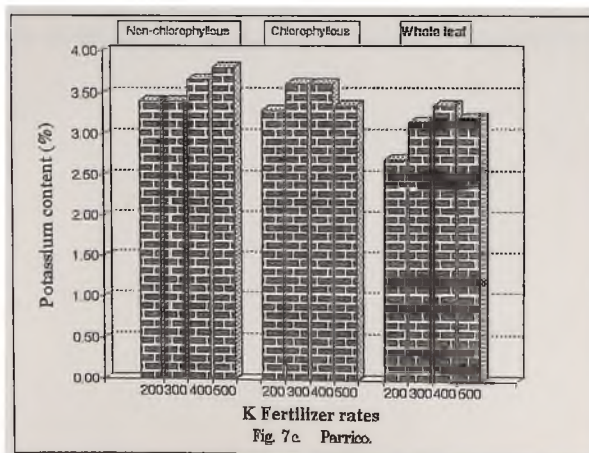
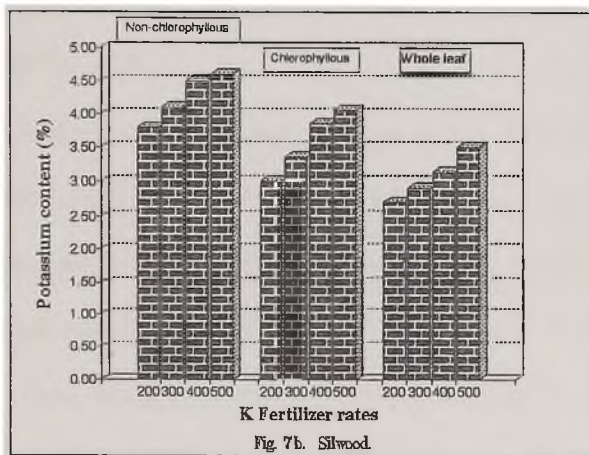
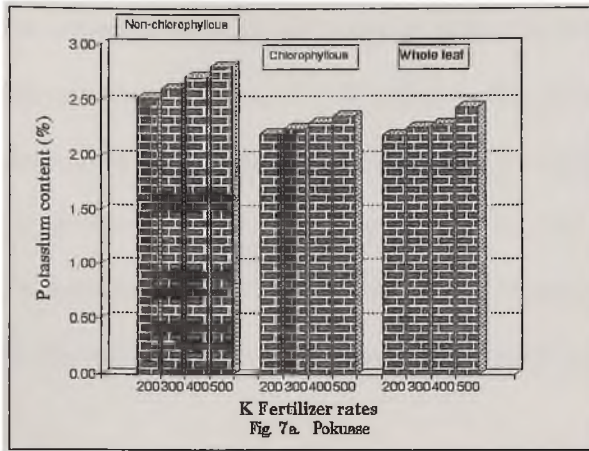
4.5.3. Potassium

Potassium contents, irrespective of leaf segments, ranged from 2.2 - 4.6 % at the three sites (Tables 6 - 8). The K content of the leaves sampled from Silwood was the highest and showed definite increase with increasing K application. Similarly, the K content in the various leaf segments was the least at Pokuase and indicated apparent increase with corresponding increase in the K application; the relative K contents in the leaf segments at the three sites being Silwood > Parrico > Pokuase. As could be seen from Tables 6 - 8, the content of K in the non-chlorophyllous segment of the D-leaf was consistently higher than the chlorophyllous and the whole D-leaf respectively. These differences in K contents among the segments were highly significant (Table 9).

4.5.3.1. Changes in K contents with increasing K application

The K content in the different leaf segments generally increased with increasing K application at the three sites (Table 6 - 8 and Fig. 7). The increases reflected more in the non-chlorophyllous segment of the D-leaf which were highly significant ($p < 0.01$) at Silwood and Parrico and followed by the whole D-leaf and the chlorophyllous segment in that order. The highest K contents in all cases was observed at the highest rate of 500 kg K/ha.

Fig. 7. Relationship between K contents of leaf segments and K-fertilizer rates at the three sites.



4.5.4. Calcium and Magnesium

The content of Ca in the leaf segments ranged between 0.3 - 0.8 %, whilst that of Mg ranged between 0.6 - 1.2 % (Table 6 - 8). At Pokuase and Parrico, the non-chlorophyllous segment generally tended to have a significantly higher content of Ca than the chlorophyllous segment and the whole D-leaf. The concentration of Ca in the chlorophyllous segment and whole D-leaf were generally not different from each other (Table 9). Similar trends were observed in respect of Mg.

4.5.4.1. Changes in Ca and Mg content with increasing K application.

The Ca content for the various segments were essentially the same regardless of K rate at Silwood (Fig. 8b) and similarly true for the chlorophyllous D-leaf segment from Parrico (Fig. 8c). In the latter case, however, there was an increasing trend in the Ca content for the non-chlorophyllous segment with increasing K rates but a drop in the whole leaf beyond the 300 kg K/ha treatment at Parrico. These trends contrasted those observed for Mg at Silwood and Parrico (Figs. 9b and 9c and Tables 6-8). At Pokuase, there was an apparent decrease in Mg content in all the segments with respect to increasing K rates.

Fig. 8. Relationship between Ca contents of leaf segments and K-fertilizer rates at the three sites.

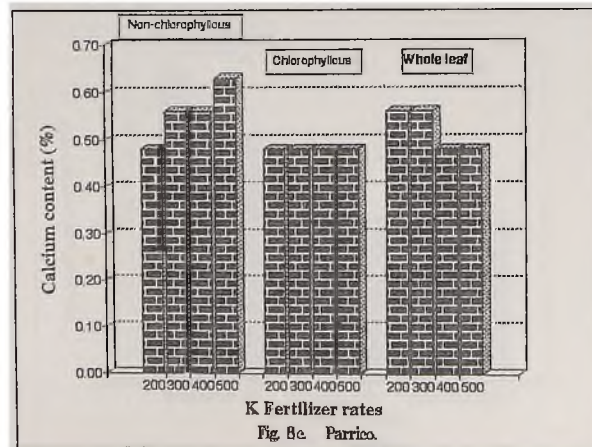
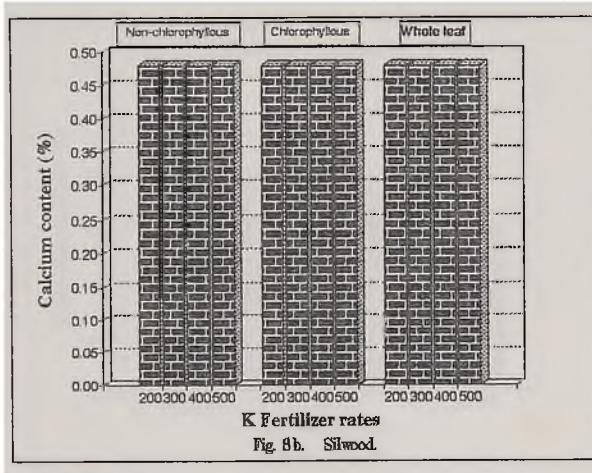
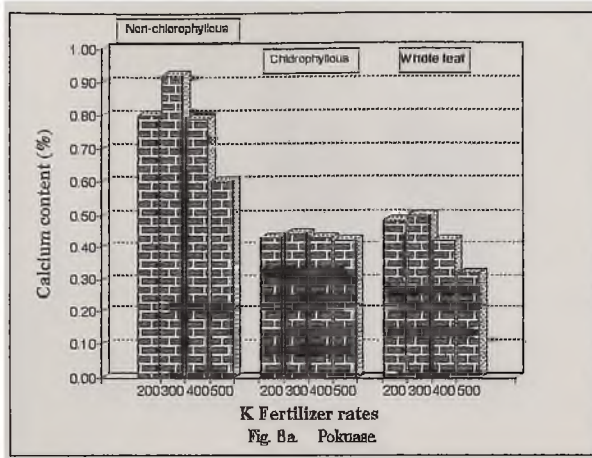
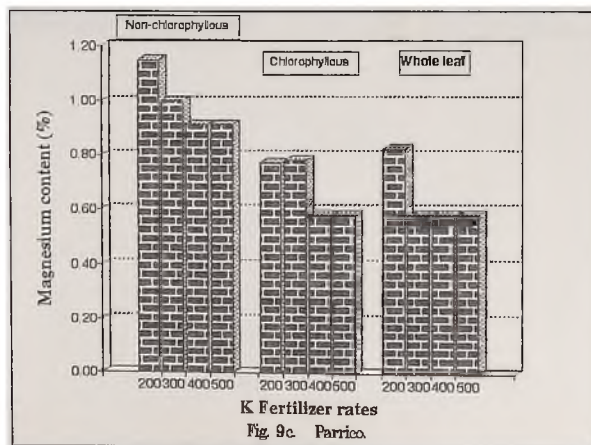
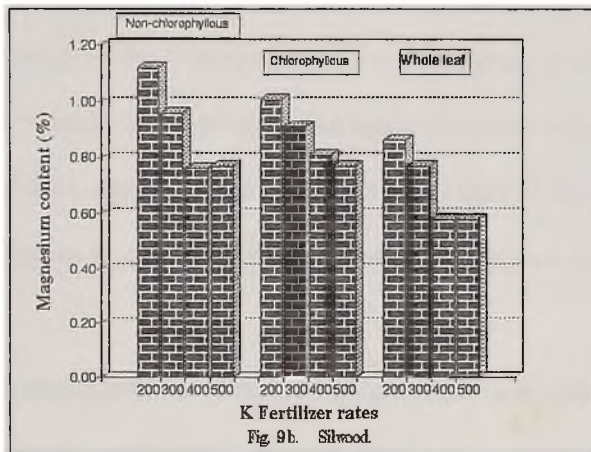
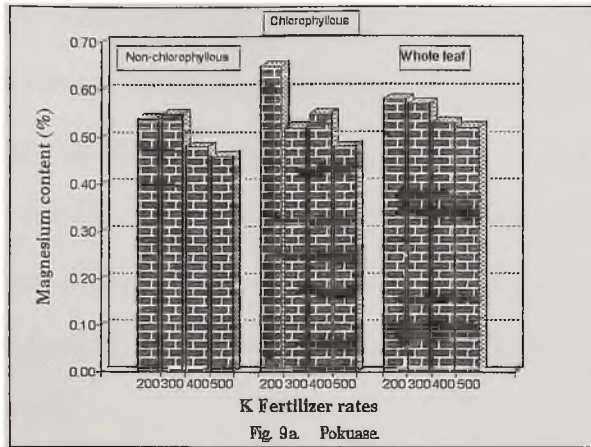


Fig. 9. Relationship between Mg contents of leaf segments and K-fertilizer rates at the three sites.



4.5.5. Effect of K/P and K/N ratios

The values of K: P obtained ranged between 8.0 - 27.0, 20.0 - 41.0 and 12.0 - 34.0 at Pokuase, Silwood and Parrico respectively (Tables 6 - 8). In respect of K:N ratios, values obtained ranged between 1.9 - 2.3 at Pokuase, 1.9 - 3.5 at Silwood, and 2.0 - 3.0 at Parrico. In the different segments of the D-leaf the ranges of K/P were generally in the order whole leaf > chlorophyllous > non-chlorophyllous. K/N ratios were in the order non-chlorophyllous > chlorophyllous > whole leaf.

K/P ratios generally increased with increasing K application at all sites and in all segments of the D-leaf (Tables 6 - 8). The increases were significant both in the non-chlorophyllous and whole leaf segments at Silwood and Parrico and in the chlorophyllous segment at Pokuase. K/N ratios showed similar trends of increases with increasing K application but these were generally not significant.

4.6. Relationship between nutrient content and yield and quality parameters

The correlation coefficients between nutrient composition and growth, yield and quality parameters of pineapple at the three sites are given in Tables 10 - 12.

Table 10. Correlation coefficient (r) between nutrient content of leaf segments and length of D-leaf, dry matter, yield, acidity and T.S.S 10 MAP at Pokuase

Parameter	LENGTH OF D-LEAF (cm)			DRY MATTER (kg)			MEAN FRUIT WEIGHT (kg)			ACIDITY			T.S.S		
	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL
N	0.859	0.806	0.850	0.972*	0.698	0.977**	0.959*	0.950*	0.831	-0.849	-0.483	-0.880	0.070	0.096	0.282
P	-0.871	0.985**	-0.658	-0.404	-0.712	-0.982**	0.652	-0.702	-0.879	0.077	0.457	0.968*	0.626	-0.715	0.113
K	0.972*	0.952*	0.863	0.819	0.816	0.699	0.921*	0.942	0.936*	-0.584	-0.585	-0.460	0.401	0.342	0.214
Ca	-0.748	-0.709	-0.901	-0.216	-0.121	-0.507	-0.533	-0.412	-0.751	-0.117	-0.216	0.196	-0.591	-0.689	-0.538
Mg	-0.978**	-0.681	-0.980**	-0.620	-0.978**	-0.786	-0.904	0.801	-0.826	0.328	0.801	0.538	-0.708	0.181	-0.573
K/P	0.923*	0.962*	0.904	0.514	0.684	0.912	0.725	0.856	0.980**	-0.200	-0.405	-0.740	0.609	0.485	0.197
K/N	-0.535	-0.484	-0.466	-0.943*	-0.505	-0.693	-0.832	-0.838	-0.283	0.976**	0.372	0.734	0.259	0.291	-0.347

* Level of significance = 0.05

** Level of significance = 0.01

Table 11. Correlation coefficient (r) between nutrient content of leaf segments and length of D-leaf, dry matter, yield, acidity and T.S.S 10 MAP at Silwood

Parameter	LENGTH OF D-LEAF (cm)			DRY MATTER (kg)			MEAN FRUIT WEIGHT (kg)			ACIDITY			T.S.S		
	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL
N	0.979**	0.964*	0.979**	0.968**	0.998**	0.997**	0.984**	0.926*	0.934*	0.994**	0.969*	0.944*	0.093	0.081	0.056
P	-0.863	-0.778	-0.985**	-0.879	-0.896	-0.992**	-0.768	-0.687	-0.968*	-0.728	-0.811	-0.987**	0.386	-0.199	-0.057
K	0.914*	0.932*	0.979**	0.964*	0.980**	0.998**	0.833	0.861	0.950*	0.861	0.894	0.987**	-0.102	-0.057	0.050
Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg	-0.858	-0.934*	-0.854	-0.917*	-0.970*	-0.932*	-0.757	-0.859	-0.757	-0.780	-0.871	-0.813	0.183	0.142	0.056
K/P	0.879	0.879	0.974**	0.945*	0.959*	0.980**	0.809	0.800	0.968*	0.826	0.875	0.997*	-0.166	0.064	0.126
K/N	-0.399	0.724	0.937*	-0.285	0.791	0.932*	-0.549	0.595	0.959*	-0.515	0.602	0.994**	-0.342	-0.330	0.230

* Level of significance = 0.05

** Level of significance = 0.01

Table 12. Correlation coefficient (r) between nutrient content of leaf segments and length of D-leaf, dry matter, yield, acidity and T.S.S 10 MAP at Parrico

Parameter	LENGTH OF D-LEAF (cm)			DRY MATTER (kg)			MEAN FRUIT WEIGHT (kg)			ACIDITY			T.S.S		
	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL	NC	C	WL
N	0.886	0.875	0.949*	0.910	0.927	0.904	0.945*	0.787	0.830	0.880	0.899	0.807	-0.904	-0.918*	-0.912
P	-0.593	-0.029	0.079	-0.655	-0.155	0.147	-0.838	-0.094	-0.442	-0.681	-0.293	0.387	0.642	0.134	-0.140
K	0.988**	0.033	0.729	0.983**	-0.029	0.686	0.701	0.552	0.957*	0.949*	-0.276	0.485	-0.986**	0.023	-0.691
Ca	0.871	-	-0.956*	0.908	-	-0.912	0.909	-	-0.714	0.901	-	-0.862	0.900	-	0.921*
Mg	-0.882	-0.950*	-0.670	-0.857	-0.906	-0.663	-0.977**	-0.688	-0.981**	-0.744	-0.863	-0.464	0.860	0.915*	0.661
K/P	0.786	0.143	0.187	0.840	0.264	0.119	0.872	0.284	0.651	0.859	0.285	-0.129	-0.829	-0.241	-0.126
K/N	0.261	-0.432	-0.838	0.211	-0.511	-0.806	-0.322	0.037	-0.368	0.195	-0.698	-0.868	-0.225	0.501	0.815

* Level of significance = 0.05

** Level of significance = 0.01.

4.6.1. Nitrogen

Nitrogen content in the non-chlorophyllous segment of the D-leaf correlated significantly with mean fruit weight at all the three sites (Tables 10 - 12). The highest correlation coefficient (r) of 0.984 was obtained at Silwood. The regression line relating leaf N and mean fruit weight was given by

$$B = 3.11a - 2.29, \quad r = 0.984^{**}.$$

where B = mean fruit weight, a = leaf N content. Significant relationship was also observed with dry matter content at Pokuase ($r = 0.972^*$) and Silwood ($r = 0.968^*$), and with the length of the D-leaf at Silwood ($r = 0.979^{**}$). In respect of the quality parameters (i.e. acidity and T.S.S.) however, no significant correlation was obtained between N in the non-chlorophyllous segment and acidity and T.S.S. at Pokuase and Parrico, except at Silwood where N correlated significantly with acidity ($r = 0.994^{**}$).

In the chlorophyllous segment, N correlated significantly with mean fruit weight at two (i.e. Pokuase and Silwood) of the three sites. The highest r value was obtained at Pokuase. The regression line relating leaf N and mean fruit weight was given by

$$Y = 4.35X - 2.81, \quad (r = 0.950^*).$$

where Y = mean fruit weight, X = leaf N content and $r = 0.950^*$. Significant correlations were observed between N and dry matter content ($r = 0.998^{**}$) and length of D-leaf ($r = 0.964^*$) at Silwood only. Significant correlations were found between leaf N and acidity at Silwood ($r = 0.969^*$) and with T.S.S. at Parrico ($r = -0.912^*$).

In the whole D-leaf, significant correlations were found between leaf N and mean fruit weight at only one (i.e. at Silwood) of the three sites of the experiment.

The regression line relating leaf N and mean fruit weight was given by

$$Q = 2.87S - 2.80, \quad (r = 0.997^{**})$$

where Q = mean fruit weight and S = leaf N content. Significant correlations were also found between leaf N and dry matter content at Pokuase ($r = 0.977^{**}$) and Silwood ($r = 0.997^{**}$), and between leaf N and length of the D-leaf at Parrico ($r = 0.949^{*}$) and Silwood ($r = 0.979^{**}$). The correlation between leaf N and length of the D-leaf at Pokuase was not significant. In respect of quality parameters, Leaf N correlated significantly with acidity at Silwood ($r = 0.944^{*}$).

4.6.2. Phosphorus (P)

There was a complete lack of significant correlation between P contents in the non-chlorophyllous segment of the D-leaf and mean fruit weight, dry matter and length of the D-leaf at the three sites (Tables 10 - 12). Correlations between the P content and the fruit quality parameters were also not significant.

A similar trend was observed between P values in the chlorophyllous segment and the yield and quality parameters. The only exception was a highly significant negative correlation ($r = 0.985^{**}$) between leaf P content and length of the D-leaf at Pokuase.

A relatively better correlation was found between leaf P content and some yield and quality parameters in the whole D-leaf. Significant negative correlations were found between leaf P content and dry matter content at Pokuase ($r = 0.982^{**}$) and Silwood (-0.992^{**}), and between leaf P content and mean fruit weight

at Silwood. The regression equation relating leaf P with mean fruit weight was given by

$$M = -23.83w + 4.36, \quad (r = -0.968^*)$$

where M = mean fruit weight and w = leaf P content.

With regards to quality parameters, a significant but negative correlation was found between leaf P content and acidity at Silwood ($r = -0.987^{**}$) and Pokuase ($r = 0.968^*$). No significant relationship was observed between the leaf P content and the TSS at any of the three sites.

4.6.3. Potassium (K)

In the non-chlorophyllous segment of the D-leaf, a significant correlation was observed between leaf K and mean fruit weight only at one (Pokuase) of the three sites of the experiment(Tables 10 -12). The regression line relating leaf K content and mean fruit weight was given by

$$B = 2.0c - 3.52, \quad (r = 0.921^*)$$

where B = mean fruit weight and c = leaf K content.

Significant correlation was observed between leaf K content and length of D-leaf at the three sites, with r values 0.972*, 0.914* and 0.988** for Pokuase, Silwood and Parrico, respectively. In respect of dry matter, a highly significant correlation ($r = 0.983^{**}$) and a significant correlation ($r = 0.964^*$) resulted at Parrico and Silwood, respectively. The correlation coefficient values of -0.584, 0.861 and 0.949 for Pokuase, Silwood and Parrico, respectively, was significant only at Parrico. K correlated significantly with T.S.S. at Parrico ($r = -0.986^{**}$) but not at Silwood nor Pokuase.

Similar trends as shown above were obtained in the chlorophyllous segment of the D-leaf at Pokuase and Silwood. Significant correlation ($r = 0.942^*$) was found between leaf K and mean fruit weight at Pokuase only. A significant correlation was found between leaf K content and length of D-leaf at Pokuase ($r = 0.952^*$) and Silwood ($r = 0.932^*$) and with dry matter at Silwood ($r = 0.980^{**}$). K, however, did not show any significant relationship with either acidity or T.S.S. at all the three sites.

The whole leaf section of the D-leaf showed a better correlation between K content and yield parameters. Significant correlation was observed between K and mean fruit weight at all the three sites. The highest value ($r = 0.957^{**}$) was obtained at Parrico. The regression equation relating leaf K(X) and mean fruit weight (Y) was given by

$$Y = 0.58X + 0.98.$$

The correlation coefficient values were 0.936, and 0.950 for Pokuase and Silwood respectively. Correlation of K content with length of D-leaf and dry matter were highly significant at Silwood with r values 0.979** and 0.998**, respectively. Except for the correlation between leaf K content and acidity at Silwood ($r = 0.987^{**}$) leaf K did not show any significant relationship with acidity or T.S.S.

4.6.4. Calcium (Ca) and Magnesium (Mg)

Leaf Ca content correlated poorly with yield or quality parameters at Pokuase and Silwood. Except for the significant correlations between leaf Ca content and length of the D-leaf ($r = -0.956^*$) and yield ($r = 0.921^*$) in the whole

D-leaf at Parrico, the correlations observed between leaf Ca content and the other yield and quality parameters were not significant.

The Mg content of the non-chlorophyllous segment of the D-leaf showed a highly significant correlation with length of the D-leaf at Pokuase ($r = -0.978^{**}$), with dry matter at Silwood ($r = -0.917^{*}$), with mean fruit weight at Parrico ($r = -0.977^{**}$) but not with quality parameters at any of the sites.

The chlorophyllous segment showed a much better correlation with yield and quality parameters. Significant correlations were found between leaf Mg content and dry matter ($r = -0.978^{**}$) at Pokuase, length of D-leaf ($r = -0.934^{*}$) and dry matter ($r = -0.970^{*}$) at Silwood and with length of D-leaf ($r = -0.950^{*}$) only at Parrico. At Parrico, a significant correlation was also found between leaf Mg content and TSS ($r = 0.915^{*}$).

In the whole leaf segment, significant correlations were found between leaf Mg content and length of the D-leaf at Pokuase ($r = 0.980^{**}$), with dry matter at Silwood ($r = -0.932^{*}$) and with mean fruit weight at Parrico ($r = -0.981^{**}$). Correlations found between leaf Mg content and acidity or T.S.S. were not significant.

4.6.5. K/P and K/N ratios

In the non-chlorophyllous segment, the only significant correlations between K/P ratio and growth parameters were length of D-leaf and dry matter at Pokuase ($r = 0.923^{*}$) and Silwood ($r = 0.945^{*}$), respectively. The correlations observed between leaf K/P ratio and quality parameters were not significant (Tables 10 - 12).

In the chlorophyllous segment, the same trend as in the non-chlorophyllous segment was observed.

The correlations with yield and quality parameters were better reflected in the whole leaf segment of the D-leaf. Significant correlations were found between leaf K/P ratio and yield and quality parameters (except T.S.S. at Silwood), and with yield at Pokuase. Significant relationships were found between K/P and length of the D- leaf ($r = 0.974^{**}$), dry matter ($r = 0.980^{**}$) and yield at both Silwood and Pokuase. A significant correlation was also found between leaf K/P and acidity ($r = 0.997^{*}$) only at Silwood. The correlation with T.S.S. was again not significant.

Leaf K/N ratio correlated significantly with dry matter ($r = -0.943^{*}$) and acidity ($r = 0.976^{*}$) in the non-chlorophyllous segment of the D-leaf at Pokuase only.

In the chlorophyllous segment, the correlations between K/N and yield or quality parameters at the three sites were not significant.

In the whole leaf segment, a much better correlation was recorded at Silwood. Like the K/P ratio, that of the K/N correlated significantly with length of the D-leaf ($r = 0.937^{*}$), dry matter ($r = 0.932^{*}$) mean fruit weight ($r = 0.959^{*}$) and acidity ($r = 0.994^{*}$) but not at Pokuase nor Parrico.



CHAPTER FIVE

5.0. DISCUSSION

5.1. Nutrient contents of leaf segments

The respective ranges of nutrient contents (N, P, K, Ca and Mg) obtained in this work (i.e. N = 1.0 - 1.7%, P = 0.1 - 0.30, K = 2.2 - 4.6%) are in agreement with the critical limits of sufficiency values quoted by Su (1969), Godfrey-Sam-Aggrey (1970), Marchal *et al.* (1971) and Valez-Ramos *et al.* (1991). Also the range of values for Ca (0.3 - 0.8%) and Mg (0.5 - 0.6%) compared favourably with data reported by Mustafa (1989), Ramirez and Tejera (1989) and Angeles (1991). This supports the fact that the N, P, and K contents in the leaf sampled just before flower induction were adequate for normal pineapple production.

From the three sites, the contents of N, K, and Ca in the D-leaf were in the order Parrico > Silwood > Pokuase. This followed the same trend for the respective soil nutrients (Table 2) thus suggesting similarity in trends of both sources.

5.1.2. Nutrient contents in the different leaf segments.

In the different leaf segments, P, K, Ca and Mg contents were generally higher in the non-chlorophyllous than the chlorophyllous or the whole D-leaf. Cibes and Samuel (1958) concluded that in the D-group leaves of the sucker there was the tendency for the white tissues (non-chlorophyllous segment) to have as much as, or more of the element than did the green leaf -- either bottom or top half. They observed the opposite trend in older leaves. N content was in the order

chlorophyllous > whole leaf > non-chlorophyllous segment. This trend is consistent with the data of Kanapathy (1958) who analysed the basal non-chlorophyllous, the middle and tip portions of the D-leaf (but not the whole leaf segment) and found N concentration to be higher in the non-chlorophyllous than either the middle or tip portions of the leaf.

5.1.3. Changes in nutrient contents with increasing K application

The general increase in N and K observed with increasing K application is expected as the uptake of N is known to be influenced by K (Marchal *et al.*, 1970). K application significantly increased N and K contents in the D-leaf. K appeared to influence negatively the absorption of P. This was exemplified by the general decrease in P content with increasing K application which was significant at Silwood and Parrico (in the non-chlorophyllous segment of the leaf). This seemingly suggests antagonistic effect between K and P. Mustafa (1989) also found K content in the D-leaf to decrease with increasing P application.

The significant decrease in Mg and to some extent in Ca with increasing K application suggests antagonistic effects between K and either Ca or Mg. Sideris and Young (1950) were the first to report antagonistic effect between K and Ca and Mg in pineapple. Results from this work, tend to corroborate such antagonistic trend (i.e. presence of K modifies Mg and Ca content in the D-leaf) and hence underscores the importance of nutrient balance in pineapple.

5.1.4. Relationship between leaf nutrient content and yield and quality parameters.

The N, P, Ca and Mg contents of the D-leaf have all been shown to correlate significantly with some yield and quality parameters. The extent of the relationship, however, depends on the segment of the leaf chosen for analysis.

The relationship between N content in the D-leaf with yield parameters of all the three sites were strongly demonstrated in the non-chlorophyllous segment. Seven out of the nine correlations ran between N content and yield parameters were significant. This represented about 77% as against 55% and 44% in the whole D-leaf and chlorophyllous segments respectively. With respect to quality parameters, there were virtually no differences in the choice of leaf segment. Subramanian *et al.* (1977) made similar observations between N and yield when they used the middle third of the basal (non-chlorophyllous) D-leaf.

The correlations between leaf P content and yield or quality parameters were not significant in the non-chlorophyllous and chlorophyllous segments of the D-leaf. The comparatively better correlation in the whole leaf segment (44% significant with yield parameters) makes it a more preferable segment for leaf P studies. In general, the poor relationship between leaf P and yield or quality parameters obtained in this study agrees with the findings of other workers. For example, Subramanian *et al.* (1977) and Tay *et al.* (1968) found no significant correlation between leaf P and yield. The absence of significant correlation between leaf P and yield may be due to the fact that P application was not varied, as was in this study, and the variable factors did not influence the levels of P significantly. In a study on the effect of phosphorus application on fruit yield and leaf nutrient content,

Mustafa (1989), found P to relate positively and significantly to yield and acidity and T.S.S.

The K content of the whole D-leaf at the three sites correlated significantly with yield. The use of the whole leaf or the non-chlorophyllous segment is suggested for K studies. Subramanian *et al.* (1977) and Tay *et al.* (1968) found the degree of relationship between leaf K and yield to be high.

5.2. Effect of K on yield

The application of K led to an increased absorption of N and resulted in general increases in the length of the D-leaf and dry matter content, which was significant at all the sites. This led to correspondingly significant increases in mean fruit weight at all the sites. Significant differences in fruit weight were realised with the highest K doses (500 kg/ha). However results from this work suggest that the application 200 - 300kg K/ha, would be adequate for the required commercially exportable fruit weight of 1.6 - 1.8 kg at Pokuase and Silwood areas. But at Aburi area, i.e. at Parrico, this same fruit weight may be obtained by reducing the K rates. This is because at Parrico, the higher mean fruit weights recorded may be attributed to the relatively nutrient rich soil coupled with a relatively higher and more evenly distributed rainfall pattern at Parrico during the period of the experiment. In all the three sites higher application of K (i.e. > 500 kg K/ha) would increase fruit weight to 2 kg which is the local consumer's preference. The increase in fruit weight with the application of K has been reported by Su (1958), Tay *et al.* (1968), and Obiefuna *et al.* (1986). Magistad (1934) concluded that on soils with a level of 0.5 m.e. K per 100g and below, pineapple

would respond to additions of K. Response to K addition was expected since the K levels in the three sites ranged from 0.23 - 0.35 cmol kg⁻¹ (Table 2) and were below the adequate level quoted by Magistad (1934).

5.3. Effect of K on fruit quality

The range of values obtained for acidity are comparable to those obtained by Kanapathy (1958) and Mustafa (1989). There was a general increase in acidity with increasing K application. This was significant at Silwood (Fig. 4a). Acidity values were in the order Silwood > Parrico > Pokuase. The comparatively low pH values of the soil at Silwood may partly explain this trend.

The statistically non significant changes observed in the T.S.S with increasing K application agree with the results of Kanapathy (1958) and Valez-Ramos *et al.* (1991). On the contrary, some workers have found T.S.S. to increase significantly with increasing K application. The variations in findings may be due largely to environmental differences. Linford and Magistad (1933) stated that a water deficit shortly before harvest affects the concentration of sugars in the fruit. The period just before harvest in December 1993 was marked by drought. This might have affected the T.S.S. of the fruits. On the desirable levels of T.S.S., the consensus is that it should be greater than 12 - 13 % (Sumner and Angeles, 1990). The values obtained in this study (13.8 - 18.2 %) were, however, greater than those quoted above.

The ratios K:P and K:N have been found to be very important in determining the yield and quality of the fruit (Kanapathy, 1958; Gailard, 1970; Angeles *et al.*, 1989). Several workers have cited various ratios that should be

maintained in the leaf for good quality fruit. These include K:P ratio of 12 and 14 for the bases and tips of young leaves respectively (Kanapathy, 1958). Angeles *et al.* (1989) and Langenegger and Smith (1978) quoted values of 13.9 and 25.5 respectively. The values obtained in the non-chlorophyllous segment at Parrico and Pokuase are in agreement with those of the above workers. The values at Silwood, even though were on the high side corroborate with the findings of Langenegger and Smith (1978). The ranges of K:P in the chlorophyllous segment and whole leaf were generally higher than those in the non-chlorophyllous segment and deviated more from the ranges quoted above. It appeared that the non-chlorophyllous segment had an advantage in providing more consistent values over the whole leaf and the chlorophyllous segments in its use to study the K:P ratios.

Values of K:N ratios cited in the literature include 1.9 - 2.3 (Angeles *et al.*, 1989), 1.7 (Langenegger and Smith, 1978) and 1.5 (Gailard, 1970). The range of values obtained for the whole leaf had an advantage over the other segments as it gave the most consistent and further showed closest ranges comparable to those recommended by others quoted above.

CHAPTER SIX

6.0. SUMMARY AND CONCLUSION

6.1. Summary

The pineapple industry in Ghana is growing at a very fast rate. All efforts therefore need to be made to sustain this growth and to increase the yields and quality of fruit produced for the export market. The problem of inadequate and improper plant nutrition requires priority attention, as plant nutrition holds the key to increased and sustained yields and the production of, good quality fruit. The role played by potassium in obtaining higher yields and good quality fruit cannot be over-emphasised.

There is the need to know the nutrient status of the plant to correct any nutrient deficiencies and/or imbalances which influence yield and quality of the fruit.

This study was therefore initiated to determine which segment of the leaf namely the non-chlorophyllous, chlorophyllous or whole D-leaf should be used in leaf analysis. It was also to determine the effect of K on yield and quality of pineapple fruit.

Three field trials were conducted at the Agricultural Research Station, Pokuase; Silwood Farms and Parrico Farms at the Aburi/Nsawam area. Four levels of K, viz.; 200, 300, 400, and 500 kg K/ha were used as main treatments. Leaf sampling was carried out at 8 months after planting for D-leaf length and dry matter determination. At 10 months after planting, the second sampling was carried out to determine in addition to the above parameters, N, P, K, Ca and Mg content of the leaf. Mean fruit weight, titrable acidity and total soluble solids (T.S.S.) were also determined after fruits were harvested.

The following were the main findings drawn from the studies:

The contents of N, P, K, Ca, and Mg of the D-leaf for the three sites ranged between 1.0 - 1.7 %; 0.1 - 0.3 %; 2.2 - 4.6 %; 0.3 - 0.8 % and 0.5 - 1.2 %, respectively. The range of values obtained reflect adequate amounts.

Nutrient contents differed significantly in the various segments of the D-leaf. For N, this was in the order whole D-leaf > chlorophyllous > non-chlorophyllous segment but for P, K, Ca, and Mg the non-chlorophyllous segment generally showed higher contents than the chlorophyllous or whole leaf segment. However, the differences in nutrient contents between the chlorophyllous and whole D-leaf were generally not significant. The non-chlorophyllous segment and whole D-leaf showed superiority over the chlorophyllous segment in the determination of nutrient content.

Potassium application influenced the leaf content of the other nutrient elements N, P, Ca and Mg. The influence of increasing K rate on N was positive whilst it was negative on P, Ca and Mg. Potassium application significantly influenced dry matter content, mean fruit weight and acidity. The application of 500 kg K/ha caused significant yield increase over the 200 kg K/ha dose. No such yield differences were observed between 200, 300 and 400 kg K/ha rates.

Significant correlations were observed between leaf N, K and Mg with dry matter content, yield and acidity. These correlations were better in some segments than others. Nitrogen was better correlated with yield and acidity in the non-chlorophyllous segment of the D-leaf whilst P correlated better in the whole leaf segment. With both yield and acidity, it was observed that there exist highly significant correlation with the N content of the non-chlorophyllous segment of the

D-leaf, whilst P in the whole leaf and K in both the whole leaf and non-chlorophyllous segments gave equally high levels of correlation.

6.2. Conclusion

The kind of nutrient under study would determine which segment of the leaf to use for analysis. The use of the non-chlorophyllous segment of the D-leaf is recommended for the determination of N and K, whilst the whole D-leaf is recommended for P and K determinations.

The application of between 200 - 300 kg K/ha is recommended for the Pokuase and Silwood farm areas if Smooth Cayenne fruit weighing between 1.6 - 1.8 kg is required to meet export demands and about 500 kg K/ha is recommended if fruit weighing more than 2 kg is required.

6.3. Suggested further work

Further work is required in the Aburi area (where Parrico farm is located) to determine the rate of K (which may probably be less than 200 kg K/ha for fruit that would meet the demand of the export (European) market (i.e. fruit between 1.6 - 1.8 kg). Trials with variable P-rates should also be initiated to investigate the relationship between the appropriate leaf P content and suitable pineapple production in the coastal Savannah ecotone of Ghana.



REFERENCES

- Abutiate, W. S. and Eyeson, K. K. 1973. The response of pineapples (*Ananas comosus* L merr.) var. Smooth Cayenne to Nitrogen, Phosphorus and Potassium in the forest zone of Ghana. *Ghana Jour. Agric. Sci.* 6: 155 - 159.
- Acquaye, D. K. 1964. Foliar analysis as a diagnostic technique in cocoa nutrition. I-Sampling procedure and analytical methods. *Jour. Sci. Fd. Agric.* 15: 855 - 863.
- Ahenkorah, Y. 1970. Potassium supplying power of soils cropped to cacao. *Soil Sci.* 109: 127 -135.
- Ahenkorah, Y. and Halm, B. J. 1979. Foliar analysis as a diagnostic technique in cocoa nutrition: III Standard curves and observations. 7th International Cocoa Research Conference, Douala, Cameroun. Nov. 4 -12. pp 177 - 182.
- Anderson, E. J. 1951. Effect of nutrient salt concentrations on infection of pineapple roots by *Phytophthora cinamoni*, *Phytopath* 41: 2.
- Angeles, D. E., Sumner, M. E. and Barbour, N. W. 1989. Preliminary N, P, and K DRIS norms for pineapple. *Hort Sci.* (in press).
- Asoegwu, S. N. 1987. Effect of irrigation and nitrogen on the growth and yield of pineapples (*Ananas comosus*) cv Smooth Cayenne. *Fruits* 42: No. 9.
- Bartholomew, D. P. and Kadzimin, S. B. 1977. Pineapple p.113-156. In Parlo de T. Alvin and T.T, Kozlowski (ed). *Ecophysiology of Tropical Crops*. Academic Press Inc. New York, San Francisco.
- Bartholomew, D. P. and Malezieux, E. P. 1994. Pineapple. Pp 243 -291. In B.

REFERENCES

- Abutiate, W. S. and Eyeson, K. K. 1973. The response of pineapples (*Ananas comosus* L merr.) var. Smooth Cayenne to Nitrogen, Phosphorus and Potassium in the forest zone of Ghana. *Ghana Jour. Agric. Sci.* 6: 155 - 159.
- Acquaye, D. K. 1964. Foliar analysis as a diagnostic technique in cocoa nutrition. I-Sampling procedure and analytical methods. *Jour. Sci. Fd. Agric.* 15: 855 - 863.
- Ahenkorah, Y. 1970. Potassium supplying power of soils cropped to cacao. *Soil Sci.* 109: 127 -135.
- Ahenkorah, Y. and Halm, B. J. 1979. Foliar analysis as a diagnostic technique in cocoa nutrition: III Standard curves and observations. 7th International Cocoa Research Conference, Douala, Cameroun. Nov. 4 -12. pp 177 - 182.
- Anderson, E. J. 1951. Effect of nutrient salt concentrations on infection of pineapple roots by *Phytophthora cinamoni*, *Phytopath* 41: 2.
- Angeles, D. E., Sumner, M. E. and Barbour, N. W. 1989. Preliminary N, P, and K DRIS norms for pineapple. *Hort Sci.* (in press).
- Asoegwu, S. N. 1987. Effect of irrigation and nitrogen on the growth and yield of pineapples (*Ananas comosus*) cv Smooth Cayenne. *Fruits* 42: No. 9.
- Bartholomew, D. P. and Kadzimin, S. B. 1977. Pineapple p.113-156. In Parlo de T. Alvin and T.T, Kozlowski (ed). *Ecophysiology of Tropical Crops*. Academic Press Inc. New York, San Francisco.
- Bartholomew, D. P. and Malezieux, E. P. 1994. Pineapple. Pp 243 -291. In B.

- Schaffer and P. Anderson (ed). Handbook of Environmental Physiology of Fruit Crops, Vol.I. Subtropical and Tropical Crops. CRC Press, Inc., Boca (in press).
- Bartholomew, R. P., Watts, V. M. and Janssen, G. 1933. The Effect of variations in the nutrient media upon the N, P, and K content on plants with special reference to the tomato. Agric. Exp. Sta., Univ. of Arkansas Bull. pp. 288.
- Beringer, H. 1978. Le potassium, ses fonctions dans la metabolisme de la plante et son action sur le rendement. Colloque potassium in soils and crops, New Delhi.
- Bould, C. and Bradfield, E. G. and Clarke, G. M. 1960. Leaf analysis as a guide to the nutrition of fruit crops. I - General principles, Sampling Techniques and analytical Methods. Jour. Sci. Fd. and Agric. 11: 229.
- Bremner, J. M. 1965. Total Nitrogen. In : C.A. Black (ed.), Methods of Soil Analysis, Part II. Amer. Soc. Agron. 9: 1149 - 1176.
- Briant, A. K. and Tidbury, G. E. 1942. Pineapple experiments in Zanzibar. E. Africa Agric. Jour. 8: 80 - 84
- Brown, F. B. 1953. Pineapple varieties and selection in Malaya. Malayan Agric. Jour. 36: 237 - 246.
- Butler, A. F. 1960. Fertilizer experiments with 'Gros Michel' banana. Trop. Agric. Trin. 37:31 - 50.
- Canon, R. C. 1957. Pineapple fertilizer investigations in South Eastern Queensland. Qd. Jour. Agric Sci. 14, 93 - 110.

- Capo, B. G., Samuels, G. and Bonnet, J. A. 1953. Why foliar diagnosis. Sugar
15 (12) 48 - 51.
- Chandler, W. H. 1958. Evergreen Orchards. Ed. London: Henry Kempton.
- Chapman, G. W. 1941. Leaf analysis and plant nutrition. Soil Sci. 52 : 63 - 81.
- Chapman, H. D. and Brown, S. M. 1942. Potash relation to citrus nutrition.
Soil science 55: 87 -99.
- Chapman, K. R., Glennie, J. D., and Paxton, B. 1983. Effect of five watering
frequencies on growth and yield of various plant parts of container grown
Queensland Cayenne pineapples. Queensland Jour. Agric. Anim. Sci.
40:75.
- Chiang, W. N. 1969. Recommendations on the nutritional management of
pineapple in Taiwan. Potash Review (27) 18.
- Cibes, H. and Samuels, G. 1958. Mineral deficiency symptoms displayed by Red
Spanish pineapple plants grown under controlled conditions. Technical paper
No. 25, Agric. Exp. Sta. Univ. of Puerto Rico, Rio Pedras.
- Collins, J. L. 1960. The pineapple, botany, cultivation and utilization. Leonard
Hill Ltd. London, p.294.
- Combres, J. C. 1976. Irrigation de l'ananas en cote-d'Ivoire. Reunion
Annuelle IRFA, doc. Interne No. 24.
- Combres, J. C. 1979. Adaptation de l'ananas a'la sercheresse. Reunion annuelle
IRFA, doc. Interne No. 56.
- Combres, J. C. 1980. Essai ETM - AN.CI.EXT. 528. Doc. Interne IRFA.
- Cooke, F. C. 1949. The pineapple industry of the Hawaiian islands. Bull.
No.32, General series, Dept. of Agric., Fed. of Malaya.

- Dalldorf, D. 1975. Potassium Nitrate on Pineapple. Pineapple Research Station Report, South Africa. pp. 15-25.
- Dalldorf, D. 1983. Pineapple Report. Pineapple Research Station, South Africa.
- Dalldorf, D. B., Keetch, D. P. and Webster, G. 1975. Pineapples: Forecasting of harvesting time in the Eastern Cape. Inf. Bull. Citrus and Subtrop. Fruit Res. Inst. 39: 5.
- Dalldorf, D.B. and Langenegger, W. 1976. The influence of Potassium on yield, fruit quality and plant growth of Smooth Cayenne pineapples. Gewasprodutsie Crop Production 5: 135 - 137.
- Day, P. R. 1965. Particle fractionation and particle size analysis. In: C. A. Black (ed.) Methods of Soil analysis, Part 1. Am. Soc. of Agron., Madison, Wisconsin.
- Dewald, M.G., Moore, G. A. and Serman, W. B. 1992. Isozymes in Ananas (Pineapple): Genetics and usefulness in taxonomy, Jour. Am. Soc. Hort. Sci. 117: 491.
- Dodson, P. G. C. 1968. Effects of spacing and Hormone treatment on pineapple in Swaziland. Exp. Agric. 14: 103 - 115.
- Dorenbos, J. and Pruitt, K. 1979. Yield response to water. F.A.O. Irrigation and Drainage paper No. 33: p. 119.
- Dull, C. G. 1971. The pineapple genera. In the biochemistry of fruits and their products. A. C. Hulme Ed. Press. New York, London. 11: 303 - 324.
- Dunsmore, J. G. 1957. The pineapple in Malaya. Malayan Agric. Jour. 40: 159.
- Eaves, C. A. and Luefe, J. S. 1955. The influence of orchard nutrition upon the acidity relationships in apples. Jour. Hort. Sci. 30: 86 - 96.

- Ekern, P.C. Soil moisture and soil temperature with the use of black vapor barrier mulch and their influence on pineapple (*Ananas comosus* (L.) Merr.) growth in Hawaii. *Soil Sci. Soc. Amer. Proc.*, 31(2):270-275.
- Fisher, J. 1974. Suggested guide to the use of KNO_3 in crop production. In: Report of South African Research Station.
- Fisher, J. 1975. Potassium application to pineapples. Field Report of South African Research Station.
- Gailard, J. P. 1969. Influence de la date de plantation et du poids des rejets sur la croissance des ananas au Cameroun. *Fruits* 24 (2): 75 - 87.
- Gailard, J. P. 1970. Recherche d'un equilibre K/N dans la production de l'ananas frais au Cameroun. *Fruits*, 25 (1): 11 - 24.
- Ghana Export Promotion Council (G.E.P.C). Annual Report.
- Ginsburg, L. 1953. Cold storage tests to determine shipping temperatures for pineapple. *Farming in South Africa*, 28: 85-91.
- Godfrey-Sam-Aggrey, W. 1970. Foliar analysis as a guide to N, P, K, nutrition of pineapples in the forest zone of Ghana. *Exptl. Agric.* 6:327 - 333.
- Green, G. C. 1963. The pineapple plant. In *The effect of weather and climate upon the keeping of fruit*. Tech. World Meteo. Org. Geneva, 53 p, 136 - 180.
- Haagin Smit , A. L., Kirchner, J. G., Prater, A. N. and Clara, L. 1945. Chemical studies of pineapple. I. The volatile flavor and odor constituents of pineapple. *Jour. Amer. Chem. Soc.*, 67: 1646 - 1650.
- Hernandez-Medina, E. 1961. Pineapple response to magnesium in Puerto Rico. *Proc. Amer. Soc. Hort. Sci. (Caribbean Region)* 5: 70 - 75.

- Hernandez-Medina, E. 1964. Magnesium, an important nutrient in pineapple production in a Bayamon sandy clay. Jour. Agric. Univ. P. R. 48 (1):7-24.
- Herschler, A. 1933. Analysen von Rebblättern zur zertstellung des Nahrstoffbeddurfnisses des bodens und zur Erkennung von Ernahrungstorungen. Arb. Biol. Reichsanstalt Landrund Forstw. (Berlin - Dahlem) 20: 633 - 666.
- Huet, R. 1953. Contribution a l'etude du ô jauneø de l'anas en Guinee. Fruits, 8 (11): 544 - 546.
- Huet, R. 1958. La composition chimique de l'anas. Fruits, 13 (5): 183 - 197.
- Huet, R. 1959. A propos du dosage de l'acidite du jus d'anas. Fruits, 14 (2): 83-85.
- Institute of Research into Fruits and Agronomy (IRFA). 1954. Annual Report, France.
- Jacob, A and Uexkull, H.V. 1963. Fertilizer Use - Nutrition and manuring of tropical crops. Pineapple, 3rd ed., Hannover, pp. 391 - 405.
- Kanapathy, K. 1958. Leaf analysis in relation to yield and quality of pineapples. Malay. Agric. Jour. 41:18 - 26.
- Krauss, B. H. 1948. Anatomy of the vegetative organs of the pineapple, *Ananas comosus* (L) Merr. I. Introduction, organography, the stem and the lateral branch or axillary buds. Bot. Gaz., 110 (2): 159 - 217. The leaf. Bot. Gaz. 110(3): 333 - 404.
- Kuruvilla, V., Pillai, G. R., Jose, M., Santhakumari, G., and Gopi, S. 1988. Effect of irrigation and mulching on the growth and yield of pineapple (*Ananas comosus* (L.). Agric. Res. Jour. Kerala, 26: 85.

- Kwong, K. H., Chin, Y. M. and Li, S.K. 1966. Field experiments on the Potassium requirement of pineapple in the Taitung district. Rep. Taiwan Sugar Expt. Sta. (41): 109 - 128.
- Lacoeuilhe, J.J. 1971. L'azote et la croissance de l'ananas. *Fruits*, 26(1): 37-44.
- Lacoeuilhe, J.J. 1976. Contribution des feuilles vivantes pendant la periode de fructification a la croissance et au developement du fruit. Reunion Annuelle IRFA, doc. Interne, No. 10.
- Lacoeuilhe, J. J. 1978. La Fumure N-K de l'ananas en Cote-d'Ivoire. *Fruits*, 3 (5): 341 - 348.
- Lacoeuilhe, J.J. 1979. N-K manuring of the pineapple in the Ivory Coast. *Potash Review*, 27 (89): 3.
- Lacoeuilhe, J.J. 1981. Documents IRFA non publies
- Lacoeuilhe, J. J. and Gicquiaux, Y. 1971. La nutrition en cations de l'ananas a la Martinique. *Fruits*, 26 (5): 353.
- Lagatu, H. and Maume, L. 1924. Etude par l'analyse periodique de feuilles, de l'influence des engraisde chaux, de magnesie et de potasse sur le vigne. C. R. Acad. Sci., Paris, 179: 932 - 934.
- Lagatu, H. and Maume, L. 1930. Le diagnostic foliare de la pomme de terre. *Ann Ecole Agric., Montpellier*, 20: 219 - 281.
- Lagatu, H. and Maume, L. 1932. Le dignostic foliare de la pomme de terre. *Ann. Ecole Nat. Agric., Montpellier*. Deuxieme memoire.
- Lagatu, H. and Maume, L. 1933. Composition comparee chez la vigne, de fueilles homologues prises respectivement sur des sop. 263 273.
- Langenegger, W. 1976. Pineapple fertilizer trial. *Citrus and Sub Tropical fruit*

Research Institute, South Africa.

- Langengger, W and Smith, B. L. 1978. An evaluation of the DRIS system as applied to pineapple leaf analysis. In Fergusson, A.R., Bieleski, R.L and Ferguson, I. B. (Ed), Proc. 8th Intl., colloq. plant analyses and fertilizer problems, Auckland, New Zealand, pp. 263-273.
- Linford, M.B. and Magistad, O. C. 1933. Fruit quality studies. III. Soil moisture as a factor in limiting the development and quality of pineapple. *Fruits*, 3 (4):196 - 206.
- Loison-Cabot, C. 1990. State of botanical, cytogenetic and biological knowledge on pineapple reproduction. *Fruits*, 45: 347.
- Loison-Cabot, C. 1992. Origin, phylogeny and evolution of pineapple species. *Fruits*, 47: 25.
- Magistad, O. C. 1934. Relation between Replaceable Potassium and field response to Potash in Hawaiian soils. *Soil Sci.* 37: 99.
- Malezieux, E. 1992. Effet d'une irrigation localisee et d'une couverture de polythylene sur la croissance et le rendement de l'ananas en Basse Cote d'Ivoire. *Compte rendu d'Essai, doc. Interne IRFA.*
- Marchal, J. 1971. Le phosphore chez l'ananas. *Fruits*, 26(3): 189-206.
- Marchal, J. 1973. Analyse foliare des essais dose d'azote. *Reunion Annuelle IRFA, doc. Interne, No. 173.*
- Marchal, J. 1979. Chlorure et sulfate de potasse en culture d'ananas - Relation entre la composition minerale et les rendement qualitatifs. *Reunion Annuelle IRFA, doc. Interne, No. 134.*

- Marchal, J. 1980. Arriere effects du chaulage en culture d'ananas (var. Cayenne Lisse) sur un sol ferrallitique de Cote d'Ivoire. *Fruits*, 35 (12):,301-308.
- Marchal, J. and Pinon, A. 1980. Nutrition azotee de l'ananas. Etude des voies d'absorption de l'azote par la technique de la dilution isotopic. *Fruits*, 35 (1): 29 - 38.
- Marchal, J., Martin-Prevel, P., Lacoeyllhe, J.J. and Lossois, P. 1970. Recherche d'un equilibre K/N dans la production de l'ananas frais au Cameroun. II. Analyses foliaires. *Fruits*, 25 (2): 87 - 95.
- Marchal, J., Pinon, A., and Teisson C. 1980. Effects de la forme de l'engrais potassique sur la qualite' de l'ananas. Seminaire 1.1. P. sur le potassium, Abidjan, 21-22/10/80.
- Martin-Prevel, P. 1959a. Echantillonnage de l'ananas en vue du diagnostic foliare, Nutrition, minerale et engrais (Abidjan), I.R.F.A, Paris.
- Martin-Prevel, P. 1959b. Apercu sur les relations croissance nutrition minerale chez l'ananas. *Fruits*, 14: 101 122.
- Martin-Prevel, P. 1961. Ca. and Mg in the nutrition of pineapples in Guinea. III Effect on fruit quality. *Fruits d'outre merr.* 16: 111 - 180.
- Martin-Prevel, P., Huet, R. Haendler, L. and Dugain, F. 1961. Potassium, Calcium et Magnesium dans la nutrition de l'ananas en Guinee. *Fruits*, 16(2): 49 - 56; 16 (3): 113 - 123.
- Mason, A.C. 1952 and 1953. The estimation of P,K, Ca, Mg, Fe, and Nitrogen in plant material. Rep. E. Malling Res. Station p. 104.
- Medcalf, J. C. 1950. Hawaiian Pineapple Co.'s irrigation studies on Lanai.

- Abstract of monthly seminar summary, private document, Pineapple Research Institute of Hawaii, Honolulu.
- Mengel, K. and Kirby, E. A. 1978. Principles of plant nutrition. I. P. I. Berne, Switzerland, pp. 367 - 390.
- Moss, P. 1961. Limits of interference by iron, manganese, aluminium and phosphate in the EDTA determination of calcium in the presence of magnesium using cal-red as indicator. Jour. Sci. Fd. Agric., 12: 30 - 34.
- Mustafa, M. M. 1984. Annual Report. Indian Inst. Hort. Res., Bangalore.
- Mustafa, M. M. 1989. Effect of Phosphorus on fruit yield, quality and leaf nutrient content of Kew pineapple. Fruits, 44 No. 5.
- Nield, R. E. and Boshell, F. 1976. An agroclimatic procedure and survey of the pineapple production potential of Columbia. Agric. Meteorol., 17: 81.
- Nightingale, C. T. 1942. Nitrate and carbohydrate reserves in relation to nitrogen nutrition of pineapples. Bot. Gaz., 103: 405 - 456.
- Obiefuna, J. C., Majumder, P.K. and Ucheagwu, A. C. 1986. Fertilizer rates for increased pineapple production in the tropical ferralitic soils of South Western Nigeria.
- Pan, K. Y. 1957. Research on the three essential fertilizers for pineapples. Jour. Agric. Asso. China, 19: 111 - 129.
- Pennock, W. 1944. Field response of Red Spanish pineapple to N,Ca,Fe and soil pH. Fruits, 20 (7): 315 - 329.
- Purseglove, J.W. 1987. Tropical Crops, monocotyledons.
- Py, C. 1959. Etude, dans les conditions ecologiques de la Guinee, de l'action du

- pois du rejet a la plantation et de la date de plantation sur la croissance, le development foliaire et la nutrition de l'ananas. Document IRFA non publie.
- Py, C. 1965. Approches pour combler le deficit en eau, principal facteur limitant de la culture de l'ananas en Guinee. *Fruits*, 20(7): 315-329.
- Py, C., Haendler, H., Huet, R. and Silvy, A. 1956. Manuring of pineapple in Guinea. *Fruits*, 11(1): 5 - 20.
- Py, C., Lacoeyille, J. J. and Teisson, C. 1987. *The pineapple: Cultivation and Uses*. Maisonneuve and Larose, Paris, 568p.
- Py, C and Lossois, P. 1962. Previsions de recolte en culture d'ananas. II. Etude de correlations. *Fruits*, 17(2), 75-87.
- Py, C and Tisseau, M.A. 1965. *L'ananas, Techniques agricoles et productions Tropicales*. G.P. Maisonneuve et Larose, Paris
- Py, C., Tisseau, M. A., Oury, B., and Ahmaoh, F. 1957. *La culture de l'ananas en Guinee*. Manuel du planteur, Ed. IRFA, 331p.
- Ramirez, C. T. and Tejera, E. G. 1989. Spacing, N and K on yield and quality of Cabezona pineapple. *Jour. Agric., Univ. Puerto Rico*. Vol. 67:1 - 10.
- Ravoof, A. A. 1973. Effects of root temperatures and nitrogen carriers on nutrient uptake, growth and composition of pineapple plants. Ph.D. Dissertation. Univ. Hawaii Library, Honolulu.
- Russell, E.W. 1973. *Soil conditions and plant growth*. 10th ed. pp 45 - 46.
- Sakai, W. S. and Sanford, W. G. 1980. Ultrastructure of the water absorbing trichomes of pineapple (*Ananas comosus*). *Ann. Jour. Bot.*, 46:, 7 - 11.
- Samson, J.A. 1980. Tropical fruits. Pp 162-171. *Tropical Agricultural Series*,

Longman, London.

- Samuels, G. 1970. Pineapple cultivars. Proc. Trop. Region Am. Soc. Hortic. Sci., 14: 13.
- Samuels, G., Alers, S.A. and Jackson, G. C. 1958. Influence of fertilizers on yields of pineapples on a Cato clay. Jour. Agric. Univ. Puerto Rico, 42: 12 - 26.
- Samuels, G and Gandiaz-Diaz, H. 1960. A comparison of the yield and nutritional requirement of the Red Spanish and Smooth Cayenne pineapple. Proc. Carrib. Am. Soc. Hort. Sci. 4: 41 - 47.
- Samuels, G., Landran, P. and Alers, S.A. 1956. Influence of phosphate fertilizers on pineapple yields. Jour. Agric. Univ. Puerto Rico, 40(4): 218 - 223.
- Samuels, G., Landrau, P. and Olivencia, R. 1955. Response of pineapple to the application of fertilizers. Jour. Agric. Univ. Puerto Rico, 39: 1 - 11.
- Sanford, W. G. 1962. Pineapple crop log concept and development. Better Crops Plant Food, 46: 32.
- Sanford, W. G. 1968. Potassium builds pineapple quality. Better crops with plant food, pp. 13.
- Sanford, W. D. 1971. Personal communication. Cited by Py et al. (1987).
- Shiroma, M. 1972. Air temperature in Okinawa and vegetative growth of pineapples. Sci. Bull., College Agric. Univ. of the Ryukyus, 19: 363 - 377.
- Sideris, C. P. and Young, H. Y. 1950. Growth of *Ananas comosus* (L) Merr. at different levels of mineral nutrition under greenhouse and field conditions.

- 1: Plant and fruit weights and absorption of nitrate and potassium at different growth intervals. *Plant physiol.*, 25: 594 - 616.
- Sideris, C. P. and Kraus, B. H. 1933. Physiological studies on the factors influencing the quality of pineapple fruits. I. Physico-chemical variations in the tissues of ripe pineapples. *Pineapple Quarterly*, 3: 82 - 114.
- Sideris, C. P. , Krauss, B. H. and Young, H.Y. 1936. Effects of light intensity on the time of fruit harvest, yield and quality of pineapple. *Pineapple quarterly*, 6: 56 - 66.
- Sideris, C.P.; Krauss, B.H., and Young, H.Y. 1938. Assimilation of ammonium and Nitrate by Pineapple plants grown in nutrient solutions and its effects on nitrogenous and carbohydrate constituents. *Plant Physiol.*, 13: 489-527.
- Sideris, C. P. and Young, H. Y. 1945. Effects of different amounts of potassium on growth and ash constituents of *Ananas comosus* (L.) Merr. *Plant physiol.*, 20: 609 - 630.
- Sideris, C. P. and Young, H. Y. 1954. Effects of chlorides on the metabolism of pineapple. *Ann. Jour. Bot.*, 41: 847 - 854.
- Sideris, C. P. and Young, H.Y. 1950. Growth of *Ananas comosus* (L.) Merr. at different levels of mineral nutrition under greenhouse and field conditions. II. Chemical composition of the tissues at different growth intervals. *Plant Physiol.*, 26: 456 - 474.
- Sideris, C. P. and Young, H.Y. 1951. Growth of *Ananas comosus* at different levels of mineral nutrition under greenhouse and field conditions. II. Chemical composition of the tissues at different growth intervals. *Plant Physiol.*, 26: 456 - 474.

- Sideris, C. P., Young, H. Y., and Chun, H. Q. 1948. Diurnal changes and growth rate associated with ascorbic acid, titrable acidity, carbohydrate and nitrogenous fractions in levels of *Ananas comosus* (L.) Merr. *Plant Physiol.*, 23: 38 - 68.
- Silverstein, R. M. 1971. The pineapple flavor, in Hulme, *Biochemistry of fruits and their products*. II. Academic Press, New York. 325 - 331.
- Singh, H.P., Dass, H.C., Ganapathy, K.M. and Subramanian T.R. 1977. Nitrogen requirement of pineapple under irrigated and rainfed conditions. *Ind. Jour. of Hort.*, 34 (4): 377 - 384.
- Smith, P. F. 1962. Mineral analysis of plant tissues. *Annu. Rev. Plant Physiol.*, 13: 81 - 108.
- Smith, P. I. 1966. Citrus nutrition. In: N.F. Childers ed., *Temperate to Tropical fruit nutrition*, pp. 174 - 207. Hort. Publications, New Brunswick, N.J.
- Soil Survey Staff. 1987. Keys to soil taxonomy. Soil management support services, monograph No. 6. (3 edn). Cornell University.
- Su, N. R. 1959a. Response of Pineapple to Potash in Taiwan. *Soils and Fertilizers*, 29 - 38.
- Su, N. R. 1959b. Response of pineapple to the application of Potassium chloride. *Soils and Fertil.*, 22 (2): 152.
- Su, N. R. 1961. Potassium requirements of formosan pineapple soils. *Soils and Fertilizers*. Taiwan, pp. 60 - 73.
- Su, N. R. 1969. Recommendations on the nutritional management of pineapple in Taiwan. *Potash Review*, 27: 1 - 8.

- Su, N. R. 1969. Research on fertilization of pineapples in Taiwan and some associated cultural problems. Soc. Soil Fert. Techn. Taiwan, publication No. 1, 185p.
- Su, N. R. and Li, C. Y. 1963. Comparison of two Potassium salts as regards their effects on yield and quality of pineapple fruits. Jour. Agric. Ass. of China, 39, 31 - 42.
- Su, N.R. 1958. The response of pineapples to the application of Potassium chloride, I. Plant crop. Jour. Agric. Ass. China, 22: 27.
- Subramanian, T. R., Srinivasa, H. K., Murthy, K. L. and Melanta, K. R. 1977. Studies on Nutrition of pineapple: Leaf N, P, K, status as influenced by sources of Nitrogen and Potassium and their inter-relationship in pineapple. Ind. Jour. Hort. 34: 335 - 341.
- Sumner, M. E. and Angeles, D.E. 1990. Communication in Soil Sci. Plant Anal., 21: 13 - 16, 1431 - 1436.
- Tay, T. H. , Wee, Y. C. and Chong, W. S. 1968. The nutritional requirement of pineapple on a peat soil in Malaya. I. Effect of nitrogen, phosphorus and potassium on yield, sugar and acid content of the fruit. Malay. Agric. Jour. 46: 458 - 468.
- Tay, T. H. 1972. Comparative study of different types of fertilizers as sources of N, P, and K in pineapple cultivation. Trop. Agric. (Trinidad) 49: No.1, pp. 51 - 59.
- Teaotia, S. S. And Pandey, I. C. 1964. A manural trial on pineapples (*Ananas comosus* (L.) merr. Var. Giant Kew) I. Effect of N, P, and K on yield , flowering and growth. Kanpur Agric. Coll. Jour. 24: 27.

- Teisson, C. 1977. Le brunissement interne de l'ananas. These Doctorat Etat, Abidjan, p. 183.
- Teisson, C. 1980. Inorganic nutrition and internal browning of pineapple. Potash Review 27 (94): 1 - 8.
- Teisson, C and Pinon, A. 1979. Utilization du chlorure du potasse en culture d'ananas. Reunion Annuelle, IRFA, doc. Interne, No. 102.
- Thomas, W and Mack, W.B. 1939. A foliar diagnosis study of the effect of three nitrogen carriers on the nutrition of Zea mays. Jour. Agric. Res. 59: 303 - 313.
- Thomas, W. 1930. The conception of balance with respect to the absorption of N, P, and K by plants and the influence of the level of nutrition. Science N.S. 72: 425 - 427.
- Thomas, W. 1937. Foliar diagnosis: Principles and practice. Plant Physiol. 12: 571 - 599.
- Tisseau, R. 1963. Variations de l'acidite et de l'extrait sec des jus frais d'ananas en basse Cote-d'Ivoire au cours de la campagne de production 1962 - 1963. Reunion Annuelle IRFA, doc. Interne, No. 3.
- Ulrich, A. 1943. Plant analysis as a diagnostic procedure. Soil Sci. Vol. 55: 101 -112.
- Valez-Ramos, A., Marquez, P. and Cha de Baez, C. 1991. Effect of N and K levels and planting density on pineapple fruit yield and quality. Jour. Agric., Univ. Puerto Rico. Vol. 75: 319 - 328.
- Viljoen, B. 1980. Cheaper potassium for pines. Farmers weekly, p. 38, June 11 edition.

- Vinet, M. E. and Lemesle, M. M. 1930. Essais sur les engrais appliques a la vigne. Bull. Mens Soc. Ind. et Agric. Angers, 101: 81 - 97.
- Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for the determination of soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29 - 38.
- Wall, M. E. 1939. Effects of varying amounts of K on nitrogenous, carbohydrate and mineral metabolism in the tomato plant. Soil Sci. 47: 143 - 161.
- Watanabe, F. S. and Olsen, S. R. 1965. Test of Ascorbic acid method in the determination of P in water and sodium bicarbonate extracts. Soil Sci. Soc. Amer. Proc. 29: 677 - 678.
- Yap, L. K. and Parbery, D.B. 1961. A 33 factorial Trial on pineapples (*Ananas comosus* (L.) Merr. var. Selangor Green) at the South Malayan Growers Simpang Rengam Estate, Part I (Unpublished).
- Yow, Y. L. 1959. The time of maturity for the summer crop of pineapple in relation to climatic and cultural conditions. Jour. Agric. Ass. of China. (27): 282 - 285.

