YIELD OF WILLIAMS HYBRID BANANA IN RELATION

TO FERTILITY, PLANT SIZE AND CLIMATE

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

MASTER OF SCIENCE

IN AGRONOMY & SOIL SCIENCE

AUGUST 1982

By

Robert A. Lower

Thesis Committee:

Peter P. Rotar, Chairman
Robert L. Fox
Duane P. Bartholomew
Paul C. Ekern
Samir A. El-Swaify

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy & Soil Science.

THESIS COMMITTEE

Peter P. Rotar
Chairman

Robert L. Fox

Samir A. El-Swaify

Duane P. Bartholomew

Paul C. Ekern

ACKNOWLEDGEMENTS

I appreciate the opportunity to have known, worked with and been helped during the past several years by many people. Professor Robert L. Fox, who had the courage and conviction to keep these banana studies on-going. Professor Fox gave me not only a job but the inspiration and encouragement to continue in this work. In a very real sense, this thesis would hot have been written had it not been for my respect and sense of indebtedness to him. Dr. Duane Bartholomew, who has been a continued source of material and moral support--a friend. Dr. Peter Rotar (PPR) who is one of the nicest, meanest people I've ever known. Dr. Rotar took over as my "daddy" after Dr. Fox went on leave and has pushed, pulled and carried me through what has been the toughest time in my life. Dr. Russel Yost - one of the best things to happen in this department in a long time. Russ would listen to even the most off-the-wall ideas and usually had a rational answer. Mrs. Ada Chu, who put up with me on my first job here and has had enough grace and patience since then to remain a friend and invaluable consultant. Thanks, also, to Ernest Okazaki and Roger Watanabe. Those two don't get half the credit they deserve. I hope it means something to them that they are respected and their help was most valuable. Oshiro and Nakatani - there is no way the banana field survey work could have been done without them. Oshiro deserves a long and happy retirement, but if there was any way I'd have him become 30 years old again so he could stay on the job. Nakatani's philosophy on things often helped me to look to the future and made me remember the "other guy" in the world. To Herbert Omizo and the "boys" at Waimanalo Farm - those guys are what makes it all possible for field research (as if they didn't already know it). Thanks especially to Koichi Kaneshiro and Felipe Epil for their sincere interest in our banana project and the commendable job they've done in recording data and caring for the plots. Thanks also to William, who I can never remember being in a bad mood. Jack and Blacky, thanks for the good stuff at lunch. George 1 and George 2, Felipe (even though he hates bananas), the late Charles "Charlie" Holmberg - hey, thanks for everything! Hideiki Okumura, who has a vision for the banana industry in Hawaii; I thank him for putting in the good word to get my initial support in this work. Harry Okumura, besides being about the best banana grower in the state he is a really nice person. Harry has his heart in what he does and to me that is the most important part of life. All the banana growers; the Fungs, Scott Chun, Howard Chaille, Stan Nakamura, the Chings, Larry Goebeldt, and the Shiromas - thank you all and good luck! Special thanks to extension agents Richard Yoshida and Fred Fujimoto for introducing me to the local growers and helping to set up the field survey. Al Martinez, thanks for cooperating with our banana disease "check-ups" and numerous consultations. Rolly Jones, who got me into computer graphics and loaned me his coffee cup. Extra special thanks to the whole staff at the U.H. Computing Center; they run a very professional service down there. In particular I owe a lot of gratitude to Helen and Ginger Carey, Rick Lenox, Jeff Blomberg, the operators (esp. Donald, Jerry and Vince) the receptionists and all the other super people at UHCC. Two of the best people on my list are Doris Victor and Alma Keene - it takes real special people to do what they do, and they really showed a lot of class and aloha in the midst of chaos.

Lastly, a very special debt of thanks goes to John (Jack) Troutwine, who did all the field work for the total nutrient uptake study. I wish Jack had stayed around to complete that project and take the credit he deserves.

As is always the case in these "acknowledgements" somebody who ought to get recognition is overlooked. If you're one of those please don't take it personally. Try to understand that this "banana thesis" has made my brain the consistency of overripe bananas! Well, thanks anyway, whomever you are.

P.S. Special thanks to Nita Perreira (Word Processing & Graphic Art) for the terrific manuscript.

ABSTRACT

Bananas (Musa asuminata cv. 'Williams Hybrid') were grown continuously for over seven years from an original planting under 48 levels of nitrogen and potassium fertilization (6N x 8K) in a continuous function design with eight replicated blocks. Total production of untrimmed bunches ranged from 33 mt/ha/yr (zero N, moderate K) to 101 mt/ha/yr (high N, high K) over all years. Response to N was observed each year, primarily due to increased numbers of pseudostems in high N treatments. Average bunch weight differences due to K were clear only after 4 years. Average bunch weight decreased over time in all treatments but increased numbers of bunches were harvested each year. Depressions in total yield which occurred in most treatments were due to production of smaller bunches resulting most likely from increased density, soil compaction and diseases. Bunch weight and components of yield were related to climate up to 8 months prior to harvest. Bunch weight was not closely correlated with concentration of N or K in the plant at harvest, but total uptake of N and K were related to the size of pseudostems. Bunch weight was closely related to the size of the pseudostem, as measured by height and girth at bunch emergence and to the size of the leaves sampled at harvest. Equations relating bunch weight to pseudostem measurements were modified by N and K fertilization status, climate and crop age. Reductions in bunch weight occurring relative to pseudostem size were determined to be due to reduced leaf area caused by poor nutrition, high density and diseases. A survey of commercial banana plantings showed that variations in pseudostem size of 3 cultivars was not closely related to levels of plant and soil

nutrients, probably because of widely varying irrigation, disease levels and other management practices.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

INTRODUCTION

When the Bluefield banana cultivar (Gros Michel) was devasted in Hawaii during the 1960's by Panama Wilt (Fusarium oxysporum, f. cubense) local merchants imported large quantities of Giant Cavendish varieties from Central and South America. Imports exceeded local production of quality fruit and with the increase in population the total banana market expanded significantly. Local growers recognizing the market potential for high quality fruit began planting the Williams Hybrid cultivar (introduced to Hawaii in 1954) as a substitute for the Bluefield banana. There was, however, little information available on the cultural requirements of Williams Hybrid. A fertility management study was established in 1971 at the University of Hawaii Experimental Farm at Waimanalo, on the island of Oahu. Objectives of that study (Warner, Fox and Prasomsook, 1972) were as follows:

1) Determine the amount and combination of nutrients, primarily nitrogen and potassium, needed to produce economically optimum yields and excellent bunch quality.

2) Relate banana yields to nutrient levels in the leaves so that growers producing this cultivar on other soil types would have target values for planning fertilizer programs.

3) Observe the effects of plant density on yield and other aspects of banana culture.

Results obtained were not clear, as some of the original management practices were dropped and some anticipated fertilizer responses were not obtained. In regards to the first objective, maximum yield was achieved by less than maximum fertilization; this was anticipated.

However, the specific amounts of fertilizer associated with maximum yields were not the same from year to year, making it difficult to interpret the fertilizer effects.

For the second objective it was intended that analysis of N and K in the leaves of bananas grown under a wide range of fertility levels would provide a management tool which could be calibrated for use in any other location. Several shortcomings became apparent: plant size characteristics were more influential in determining bunch yield than plant-nutrient concentration and bunch yield from plants which were comparable in size were heavily influenced by factors such as crop density and climate. Successful calibration of tissue analysis results depended on factors other than soil fertility and plant-nutrient characteristics. Development of "fertilization programs" tailored to individual growers needed more refinement than the simplified analysis of leaf nutrient concentration employed in the study.

The last objective was to evaluate the effects of plant density on yield and other aspects of banana culture. The way this objective was stated left it unclear whether the intention was to study the effect of plant density on other aspects of banana culture, or to study plant density in addition to studying other aspects of banana culture. Control of the plant density variable (as a design effect) was abandoned after the first year, but uncontrolled differences in density which developed between treatments and over time necessitated consideration of this factor as one of the "other aspects" of banana culture.

Objectives of this thesis were: 1) to determine total fruit yield of Williams Hybrid banana plants grown over a seven year period at widely varying combinations of nitrogen and potassium fertilizers; 2) to update results of the original study in which approximately four years' data had not been examined; 3) determine the effects of N and K fertilization on the components of total yield, particularly in relationship to crop age; 4) to determine the effect of climate on yield; 5) to develop a simple method of estimating the total N and K uptake of harvested plants; and 6) to survey commercial banana plantings on Oahu. The findings, it was hoped, would benefit banana growers by identifying the variation that exists in field practices, and determine the basis for future research work which can be of direct benefit to the Hawaii banana industry.

REVIEW OF LITERATURE

I. Banana yields in relation to N and K fertilization and other factors.

Introduction

One of the primary objectives of banana research in every country has been to meet the needs of commercial growers for information and management technology which will enable them to produce bananas more efficiently and profitably. There have been numerous attempts to recommend fertilization programs based directly on experimental work (Boland, 1975; Martin-Prével, 1962; Montagut and Martin-Prével, 1965; Ramaswamy et al., 1977; Sarma and Roy, 1972; Venkatesam et al., 1965; Weir, 1974a).

While recognizing limitations imposed on yield by climate and disease, researchers frequently rely on soil and leaf analysis to provide indices of fertility levels. Positive relationships between banana pseudostem size and/or yields and soil fertility, as measured by nutrient contents, pH and physical characteristics have been shown in several cases (Fernández-Caldas et al., 1977; Garcia, 1977; Garcia et al., 1977a; Garcia et al., 1979; Langenegger and Plessis, 1977; Walmsley et al., 1971). Many banana fertility studies have been concerned with foliar analysis methods and the development of nutrient critical percentages or ranges of nutrient concentration in various tissues. In many instances nutrient concentrations, usually N and K, have been shown to correlate positively with plant size and/or yield (Fernández-Caldas and Garcia, 1972; Fox et al., 1979; Garcia, 1977; Garcia et al., 1977a,b; Garcia et al., 1979; Hewitt and Osborne, 1962; Ho, 1969; Langenegger and Plessis, 1977; Randhawa et al., 1973).

Surveys of commercial banana plantings have shown positive correlations between plant appearance, general growth, yield and levels of soil and/or tissue nutrient levels (Cooil and Shoji, 1953; Fernández-Caldas and Garcia, 1972; Fernández-Caldas et al., 1977; Garcia, 1977; Garcia et al., 1977a,b; Garcia et al., 1979; Gonçalves and Cardoso, 1979; Meir, 1979).

No aspect of banana nutrition has been studied as much as N or K, a fact which emphasizes the importance of these two nutrients to the growth and yield of bananas. In a recent bibliography on the mineral nutrition of bananas (Lahav, 1980), of a total of 803 entries 145 were listed under the general heading "nitrogen" and another 148 entries under "potassium." Significant responses to N-K fertilization in every banana-growing locale have shown that bananas require large amounts of N and K (Simmonds, 1966; Twyford, 1967). Removal of both elements in harvested fruit can be considerable (Baillon et al., 1933; Martin-Prével, 1964; Simmonds, 1966; Twyford, 1967; Weir, 1974a,b).

Table 1 presents a brief survey of the literature showing the many studies involving various aspects of banana growth and development in relation to climate and fertilization.

Review of the Waimanalo experiment

The summary of yield and foliar analysis data through October, 1974 of the study by Warner and Fox (1977) indicated a close relationship between total yield and levels of nitrogen in the third youngest leaf at

TABLE 1

Examples of plant growth and bunch maturation periods of edible Musa spp. reported in the literature.

Growth Period*					
DPF	DFH	DPH	Cultivar	Associated Factors**	Reference
	95-118		Giant Cavendish	Temperature (-), humidity (+)	Arscott et al. (1965)
	100-250		?	Temperature (-)	Garcia (1977)
	105-240		?	Temperature (-)	Green and Kuhne (1975)
	137-151		Fairyman	K (-)	Ho (1967)
	90-125		Giant Cavendish	Temperature (-), humidity (-)	Hord and Spell (1962)
507-642			?	N sources (0), temperature (-)	Hussain and Jagirdar (1975)
	97-148		?	N sources (0)	" " "
	110-212		Dwarf Cavendish	Temperature (-)	Kuhne (1980)
	173-198		?	N (0), Manure (+)	Lahav (1973a)
	155-170		Williams	N, K, Manure (0)	Lahav (1977b)
		383-397	Robusta	Fungal disease (0)	Long (1973)
215-221			Giant Cavendish	S (-), N (-)	Marchal et al. (1972)
	101-119		" "	S (-), N (+)	" " "
	70-127		Gros Michel	Temperature (-)	Moreau (1965)
		312-405	Dwarf Cavendish	Sunlight (-)	Murray (1961)
	162-204		Dwarf Cavendish	N (0)	Plessis et al. (1977)
174-343			Williams	N (-), P (+), K (0)	Prasomsook (1973)
	80-147		"	N (+), P (-), K (0)	" "
		317-444	"	N (0), P (+), K (0)	" "
253-307		359-399	Dwarf Cavendish	K (+)	Ramaswamy et al. (1977)
	89-106		" "	K (-)	" " "
190-208			Giant Cavendish	K (-)	Rodríguez-Gómez (1980)
	92-109		Maricongo plantain	N-P-K (0), Mg (+)	Samuels et al. (1978)
		312-480	Dwarf Cavendish	N-P-K (-), Density (0)	Sarma and Roy (1972)
261-377			Valery	N-P-K (0)	Shand (1975)
	91-129		"	N-P-K (0)	" "
	127-165		Basrai	Soil/Foliar N (0)	Shawky et al. (1974)
271-445	98-117		Grand Nain	Temperature (-)	Stover (1979)
374-448		487-571	Harichhal	N (-)	Teaotia & Dubey (1971)
	86-136		"	N (0)	" " "
244-347			Poovan	N (-), P (0), K (0)	Venkatesam et al. (1965)
	112-116		"	N-P-K (0)	" " "

*DPF = days from planting to flower emergence; DFH = days from flower emergence to harvest; DPH = days from planting to harvest

**Symbols in parentheses refer to effect on growth period by an increase in the associated factor(s): 0 = no significant and/or consistent effect; - = significantly decreased growth period; + = significantly increased growth period; N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Mg = magnesium flower emergence. Yields increased from 30 Mt/ha/yr[1] when leaf N averaged 2.0% to over 100 Mt/ha/yr when leaf N exceeded 3.0%. The authors concluded that maximum yields were approached when leaf N was 2.8% but their data suggest that yield continued to increase up to N concentrations of at least 3.0%. In that same study, the level of K in the leaves, which ranged from 2.8 to 3.6%, was negatively correlated with total production: as Warner and Fox (1977) observed, "... a curious result for a crop which has the reputation of having a very high K requirement." Potassium in excess of 3.2% was associated with depressed yield but they concluded that those plants which had taken up luxury amounts of K were at the same time poorly supplied with nitrogen. High K levels probably were not the cause of poor yields.

Leaf K levels at all levels of applied N and K in the plant crop of this experiment were uniformly high, averaging 4.58% (Prasomsook, 1973). Thereafter, levels of leaf K declined and K often fell below the 3.2% target value, even in the highest K treatments (Warner et al., 1974a). Leaf N rapidly declined from plant-crop levels of 2.8-3.2% to around 2.5% at the highest N treatments (Warner and Fox, 1976). In the case of nitrogen, applications of urea resulted in increased leaf N percent usually within one month following fertilization. Leaf K levels were not very responsive to K applications, yield was poorly correlated with K application and there were no obvious visual symptoms of K deficiency through 1974 (Warner and Fox, 1977).

---

[1]Mt = metric ton (1 Mt/ha = 892 lbs./acre).

By 1976 in low K treatments symptoms of K-deficiency appeared, as evidenced by "premature yellowing" of the oldest leaves while still in an upright position on the pseudostem[2]. Increased yield at high levels of applied K was observed, but only when the nitrogen status of the plants was also high (Fox et al., 1978). During 1976 leaf K was as high as 3.5%, but only in plants with leaf N levels below 2.0% and yields at that level of N were less than 15 kg/bunch. When leaf N averaged 2.5% yields increased from 20 kg/bunch to over 30 kg/bunch as leaf K increased from 2.0 to 3.2% in response to K fertilization. It is important to recognize that high yields were obtained from plants having adequate N nutrition in spite of low leaf K levels. When N was deficient, although leaf K levels seldom fell below 2.5%, yields were greatly reduced.

One important aspect of the data being examined at that time (ca. 1976) was that leaf K levels of succeeding years were 20 to 40% lower than those observed in the first year while levels of soil K were 2 to 3 times greater than original K levels in some treatments as a result of massive K fertilization. Buildup of K in the soil surface was confirmed in 1977, as the following data indicate:[3]

depth, cm	meq K/100 g soil
0-10	3.34
10-20	0.83
20-40	0.28
40-60	0.20

---

[2] This symptom and its cause have been described by Hasselo (1961).

[3] Means of 8 replications at a constant K-fertilization level (K-7); unpublished data of the author.

Other soil samples taken in 1977 showed that exchangeable K was as high as 5.5 meq/100 g soil (0-15 cm depth) in the highest K treatments.[4]

Some of the results obtained since 1974 and certain aspects of banana culture related to this work have been discussed in recent publications (Fox et al., 1978; Lower and Fox, 1979; Fox and Lower, 1980).[5]

The need for long term N and K experiments.

Because of the potential to produce fruit from an original planting for 20 years or more (Simmonds, 1966), there is interest in observing long-term production under varying management levels. Usually, no more than four years of study are made before banana fertility experiments are terminated. Exceptions have been studies reported by Arscott (1970), Bhanghoo et al. (1962), Boland (1975), Lahav (1973a,b; 1977a), Lahav et al. (1981), Messing (1974), Plessis et al. (1977), Spurling and Spurling (1975a,b) and Turner and Barkus (1980a,b). In Hawaii, at least, where the usual practice is continuous, long-term production of intensively managed bananas, there is a need to work with similarly managed experimental plantings.

In practice continuous banana production usually results in yield decline. There are few clues to the specific cause(s) of age-related depressions in yield. Hasselo (1962) presented data from several experiments with Gros Michel banana which demonstrated varying degrees

---

[4] Unpublished data of Dr. Johnathan Braide and the author.

[5] Other published materials regarding the study not elsewhere cited in this thesis include Warner (1972) and Warner et al. (1973).

of yield decline. He attributed decreases in bunch weight to several factors: depletion of soil K, incidence of Sigatoka disease (Mycosphaerella musicola), climatic trends, overcrowding, and infestation by banana borers (Cosmopolites sordidus).

Recycling of K from subsurface depths to the soil surface with or without added K, may be associated with long-term yield decline if K is fixed(6) (as it may have been in this experiment; cf. above data). There is evidence that uptake of K by bananas is affected by soil physical and chemical characteristics (Lahav, 1973b; Weir and Miller, 1974). Potassium availability to bananas or other crops is a function of its concentration in the soil solution as well as its proportion to other soil cations and the total quantity of K in the soil (Barrow, 1980; Fernández-Caldas and Borges-Perez, 1971; Garcia, 1977; Garcia et al., 1979; Hagin et al., 1964).

Much of the nitrogen potentially available to a crop in a recently cleared field is in the soil organic matter fraction, and is usually concentrated in the upper few inches of soil. When the soil is cultivated large quantities of N may become available in a few weeks time. Apparently a newly planted crop of bananas can effectively utilize this native N source, as evidenced by the high yields of plant crops frequently observed. The following data illustrate examples of plant-crop yields from zero-N treatments in a few experiments:

---

[6] The term "K^+ fixation", as used in this thesis, has a subjective meaning: K^+ ions which are strongly sorbed by the soil and not readily available to the plant root or to standard exchange-type extractants.

Yield, Mt/ha	Cultivar	Source
11.7	Lacatan	Hewitt, 1955
10.5	"	"
7.6	"	"
15.6	Williams	Prasomsook, 1973
13.5	Dwarf Cavendish	Sarma and Roy, 1972
15.4	Valery	Shand, 1975

Because large quantities of N are removed from the field in each harvested crop the supply of native N will rapidly decrease, as will the yield of successive ratoons.

Tissue analysis in banana research

One of the original objectives of this study was to develop a method of tissue analysis which could be of practical use to growers as well as a research tool. The middle section of lamina from both sides of the third fully unfurled leaf of the dominant pseudostem in the mat (or from one which had just begun to flower) was chosen for sampling. Prasomsook (1973) states: "Hewitt (1955) and others consider this tissue to be the best indicator of plant nutrition...". This particular sampling method (or any other), however, had neither been firmly established nor widely accepted among banana researchers at that time (ca. 1972).

Studies on N-P-K factorial experiments with Robusta bananas in the Windward Islands were made by Twyford and Coulter (1964), with the aim of "finding a suitable leaf sampling technique... in an attempt to relate fertilizer treatment, nutrient uptake, soil nutrient status and yield." This ambitious project involved determination of N, K, Ca, Mg, and P under a wide variety of conditions: differences in leaf portion (both longitudinally and laterally), differences in leaf age (ordinal position of the leaf on the pseudostem), chronological and physiological age differences, sampling at different times of the day and for variable locations, soil types and fertilization levels.

Responses to nitrogen fertilizers were obtained in every trial, regardless of the level of leaf N obtained when no N was added. By contrast, increases in leaf K, although dramatic in several cases, seemed to occur only when the level of K in the control treatment was quite low to begin with. Of particular interest is their (Twyford and Coulter, 1964) finding that "N fertilizer always decreases leaf K and K fertilizer decreases leaf N ... [and] leaf N in a N-deficient plot is rather high if it is also K-deficient." They concluded "... that for estimation of limits of adequacy only leaf nutrient values from plots growing and yielding well, or for deficiency, from plots adequate in all but the nutrient under consideration [emphasis added], should be considered." This caution, while seemingly over-restrictive for the practicality desired of tissue analysis, seems warranted by the results they obtained.

Problems encountered by Twyford and Coulter (1964) included high plant-to-plant variability (they suggested always compositing samples from several plants), variable soil characteristics which may affect nutrient uptake rates and the nutrient balance associated with maximum growth, physiological abnormalities in plants severely limited by one or more growth factors, the possibility of using different sampling methods specific to a particular nutrient, and the possibility of nutrient ratios (e.g. N:P and internal K activity ratio) being more fundamental indices of plant nutrition than individual nutrient concentrations.

The foregoing discussion served to illustrate the general line of investigation which was developing at that time regarding the use of tissue analysis in banana research. Over the next decade many studies were made with bananas, each taking a slightly different approach to the problems of tissue analysis, and each resulting in slightly different conclusions about the method best suited to the objective.

Martin-Prével (1974) summarized the results of an international inquiry into the various methods of tissue sampling in use (ca. 1970), and later (Martin-Prével, 1977) detailed these methods and discussed the consequences of the different techniques. He reported that at least 15 leaf sampling methods were in use in 1975. The methods varied widely according to the stage of growth of the pseudostem, leaf position and portion of the leaf sampled. Among the significant effects on nutrient levels discussed were plant variety, age of plant, leaf age (ordinal position), leaf portion, geographical orientation, water, climate, parasitism, and interactions (between the above factors, between the above factors and nutrients within the plant, and between the nutrients themselves).

The situation had changed little since 1964, except that in 1975 there were at least 15 methods adding to the confusion! "Each team faces foreign publication as a treasure without keys or, worst [sic], tries to read ciphered messages with a false code." (Martin-Prével, 1977, from the English summary).

Some relief was offered by Turner and Barkus (1977) who reviewed the situation and concluded that plant age was less important than leaf position and seasonal effects. They suggested sampling a central portion of both halves of leaf number 3 in the mature, pre-flowering stage on plants at a single time of the year, rather than sampling only plants at a strictly defined growth stage on the (different) dates those plants would reach that stage of growth.

A comparison of 14 sampling methods, including sampling of pre- and post-flowering plants and three different leaf positions as well as several portions of some leaves, was carried out by Messing (1978) in a survey of 20 commercial plantations in the Windward Islands. In the case of N and K, which are the most commonly encountered yield-influencing variables it was concluded that "... the study confirms the discriminative value of the whole strips taken from the center of leaf III lamina as a single diagnostic tissue in bananas."

The problem of seasonal effects on nutrient levels was studied in Australia by Turner and Barkus (1980a) who grew Williams Hybrid bananas over several complete cycles in drainage lysmeters using a sand and gravel medium. Levels of K, Mg, and Mn were carefully controlled and monitored in the solution culture, and relationships between nutrient concentration in the leaves, nutrient concentration around the roots, and seasonal effects were evaluated. They concluded that leaf nutrient levels were strongly influenced not only by the concentration of nutrient in the medium but also by the mean daily evapotranspiration over the period of time required for the emergence of 6 successive leaves as well as the length of time itself.

They could account for between 73 and 91 percent of the variation in leaf nutrient levels by combining data for solution concentration, evapotranspiration and time in a prediction equation. They noted significant effects of internal K levels on the concentration of several elements as well as other nutrient interactions, and also observed differences in nutrient levels according to the age of the plants, the age of the crop, and the crop cycle. Although leaf 3 was used as the indicator tissue in their study, no attempt was made to show its relative superiority to any other possible sample.

In a more recent paper (Turner and Barkus, 1981) the problem of varietal effects on nutrient levels was addressed. Determinations of 13 elements in the dry matter of a portion from the center of the third leaf were made for 30 Musa spp. The plants were all grown simultaneously in the same location under a high level of fertilization. Leaf samples were taken 12 and 24 months after planting (plant crop and first ratoon). The largest differences in concentrations of elements occurred between species; less difference was observed between related varieties. There were also significant differences for most nutrients between the 1st and 2nd sampling. Among the Giant Cavendish group they found small differences between cultivars but concluded that "... detailed experimentation will be needed to establish the differences more precisely."

Although the preceding discussions have given some justification for the choice of sampling tissue, viz. a portion of both lamina halves of the middle part of leaf 3, it is also quite apparent that in the whole context of tissue analysis (e.g. the specific sampling method and the interpretation of results) there are still many more problems involved.

II. Banana bunch weight in relation to pseudostem size.

A number of reports illustrate the relationship between the weight of a banana bunch and the size of the pseudostem bearing the bunch. Ho (1967) reported correlation coefficients (r) greater than 0.98 for bunch weight vs. pseudostem girth and bunch weight vs. pseudostem height, with pseudostem measurements made at the shooting stage (correlations were not as high if pseudostem girth and height were measured at harvest). Fernández-Caldas and Garcia (1972) and Fernández-Caldas et al. (1977) reported highly significant correlations for pseudostem girth vs. bunch weight and pseudostem girth vs. number of hands per bunch (the principle yield component). Warner & Fox (1977) found a close relationship between pseudostem girth and bunch weight (r = 0.78) and between pseudostem girth and number of hands (r = 0.76). These correlations were higher than those of pseudostem height vs. bunch weight (r = 0.70) and height vs. number of hands (r = 0.69). In a study of three banana cultivars in Jamaica, high correlations were observed between pseudostem height and bunch weight (Walker, 1970). Pseudostem girth was not measured, but Walker cites the work of Hartman (1930) that girth increases in direct proportion to height. Others who have reported a close relationship between bunch weight and pseudostem circumference include Murray (1961) and Lossois (1963).

Hasselo (1962) attempted to demonstrate the utility of "... the circumference of the pseudostem as a growth index for the Gros Michel banana." He performed regression analyses of data covering several one-year periods taken from various experiments. In one experiment bunch weight declined over a three-year period relatively more than the decline in pseudostem girth (cf. Hasselo's Table 1). Hasselo attributed the reduction in bunch weight to depletion of soil potassium. Sigatoka disease (Mycosphaerella musicola) in another experiment was cited for the reduction of bunch weight relative to pseudostem girth.

Yield reduction was reflected not only in lower mean bunch weight and pseudostem girth but also in the mathematical relationship between bunch weight and girth, which gave smaller regression coefficients (a, in $y = ax + b$). Hasselo (1962) states "the magnitude of the regression coefficient might provide an indication of soil fertility in such a way that the larger this coefficient, the higher the fertility, or generally, the more favorable the environmental conditions."

Champion and Oliver (1961) studied root proliferation of plants in conjunction with pseudostem girth and the length of the three newest leaves. Both pseudostem girth and leaf length were closely correlated with root number, which increased from less than 10 to over 300 per plant during the vegetative cycle (few new roots developed after fruiting). The number of hands per bunch was closely correlated with both pseudostem girth and the number of roots per plant. Beugnon and Champion (1966) demonstrated that pseudostem girth increases at a constant rate over time and that girth is highly correlated with root number.

Murray (1961) studied shade and fertilizer relations in plant-crop bananas. Variations in bunch weight were not significantly related to either shade or fertilizer treatments, but the area of the third youngest leaf of all plants was closely related to bunch weight at each shade treatment. In Hawaii, bunch yield of plants was closely related to the number of healthy leaves per pseudostem remaining at harvest (Gabuin, 1969). Turner (1980) combined the total area of the 3rd, 4th, and 5th last leaves of plant crop bananas and found a very close correlation between leaf area and the number of fruits (fingers) per bunch.

Twyford and Walmsley (1973) showed a progressive increase of dry matter in all parts of the plant over the growth cycle. They concluded that bunch maturation proceeded at the expense of the other plant organs, which had net losses in dry matter. Bunch weights were proportional to the vegetative mass. Nutrient analyses of these same plants (Twyford and Walmsley, 1974a,b,) showed that total nutrient content, and especially potassium, rather than nutrient concentration alone was associated with final bunch weight because of "... the enormously varying sizes of the organs." Plant size played a dominant role in final yield. In Australia, Turner and Barkus (1980b), who were particularly interested in the total potassium supply as it affected both vegetative mass and final bunch weight, came to a similar conclusion.

The overall impression given by these studies is that the process of vegetative growth of bananas is one in which all of the various organs and interrelated functions progress simultaneously towards a single result: fruit production. Whereas many cultivated plants show a wide variability in yield components as a percentage of the whole plant mass, especially under varying nutritional and environmental regimes, the reproductive/vegetative ratio in banana is fairly constant. Consider nitrogen fertilization: in several species of crops, excess vegetative growth and reduction in fruit yield results from luxury uptake of N especially when it is applied throughout the growth period.

In banana, however, additional N fertilizer, if it results in greater vegetative mass, always seems to result in proportionately heavier bunches as well.

In recognition of the importance of plant size to the yield of bananas, Martin-Prével (1980) and R. L. Fox (1980) have proposed that leaf-blade sampling methods take this into account by varying the size of the sample portion in proportion to the size of the leaf. The weight of this sample times nutrient concentration(s) could provide an estimate of the total nutrient content of the plant. Such an estimate might reveal the nutritional status and yield potential of a plant more accurately than an assessment based on nutrient concentration alone.

METHODS AND MATERIALS

I. The Waimanalo experiment.

The original design of the experiment consisted of 6 nitrogen levels x 8 potassium levels x 2 phosphorus levels x 2 plant populations, giving 192 treatment combinations. Since no response to phosphorus was observed (Prasomsook, 1973) and leaf P concentration remained at adequate levels, no further P applications were made after the initial field preparation in 1971. Controls on plant population were discontinued after the first year of production.

Further specifications for the plot layouts and treatments are given in Warner et al. (1972) and Prasomsook (1973). A brief summary is presented here, with details provided where necessary for an understanding of the work reported in this thesis.

Sword suckers of Williams Hybrid bananas were planted in July, 1971, in 8 replicated blocks, with 48 plants per block on a 10' x 15' spacing giving 290 mats/acre (718 mats/ha). The plot layout is illustrated in Figure 1.

The soil, in the Kawaihapai series, has been taxonomically described by Ikawa et al. (1982) who place it in the fine, mixed, isohyperthermic family of Cumulic Haplustolls (cf. Soil Survey Staff, 1975). The description of the representative profile, taken from a location adjacent to the banana plot, is given in appendix Table 1, and the laboratory data (physical and chemical characteristics) are given in appendix Table 2. Exchangeable cations, pH, total N, nitrate-N after incubation (10 days at 30°C), and phosphorus in solution from the banana plot soil sampled prior to planting were as follows (source: Warner et

N_9K_0	N_9K_1	N_9K_3	N_9K_5	N_9K_7	N_9K_9	N_9K_{11}	N_9K_{13}
N_7K_0	N_7K_1	N_7K_3	N_7K_5	N_7K_7	N_7K_9	N_7K_{11}	N_7K_{13}
N_5K_0	N_5K_1	N_5K_3	N_5K_5	N_5K_7	N_5K_9	N_5K_{11}	N_5K_{13}
N_3K_0	N_3K_1	N_3K_3	N_3K_5	N_3K_7	N_3K_9	N_3K_{11}	N_3K_{13}
N_1K_0	N_1K_1	N_1K_3	N_1K_5	N_1K_7	N_1K_9	N_1K_{11}	N_1K_{13}
N_0K_0	N_0K_1	N_0K_3	N_0K_5	N_0K_7	N_0K_9	N_0K_{11}	N_0K_{13}
N_0K_{13}	N_0K_{11}	N_0K_9	N_0K_7	N_0K_5	N_0K_3	N_0K_1	N_0K_0
N_1K_{13}	N_1K_{11}	N_1K_9	N_1K_7	N_1K_5	N_1K_3	N_1K_1	N_1K_0
N_3K_{13}	N_3K_{11}	N_3K_9	N_3K_7	N_3K_5	N_3K_3	N_3K_1	N_3K_0
N_5K_{13}	N_5K_{11}	N_5K_9	N_5K_7	N_5K_5	N_5K_3	N_5K_1	N_5K_0
N_7K_{13}	N_7K_{11}	N_7K_9	N_7K_7	N_7K_5	N_7K_3	N_7K_1	N_7K_0
N_9K_{13}	N_9K_{11}	N_9K_9	N_9K_7	N_9K_5	N_9K_3	N_9K_1	N_9K_0

N_0K_{13}	N_0K_{11}	N_0K_9	N_0K_7	N_0K_5	N_0K_3	N_0K_1	N_0K_0
N_1K_{13}	N_1K_{11}	N_1K_9	N_1K_7	N_1K_5	N_1K_3	N_1K_1	N_1K_0
N_3K_{13}	N_3K_{11}	N_3K_9	N_3K_7	N_3K_5	N_3K_3	N_3K_1	N_3K_0
N_5K_{13}	N_5K_{11}	N_5K_9	N_5K_7	N_5K_5	N_5K_3	N_5K_1	N_5K_0
N_7K_{13}	N_7K_{11}	N_7K_9	N_7K_7	N_7K_5	N_7K_3	N_7K_1	N_7K_0
N_9K_{13}	N_9K_{11}	N_9K_9	N_9K_7	N_9K_5	N_9K_3	N_9K_1	N_9K_0
N_9K_0	N_9K_1	N_9K_3	N_9K_5	N_9K_7	N_9K_9	N_9K_{11}	N_9K_{13}
N_7K_0	N_7K_1	N_7K_3	N_7K_5	N_7K_7	N_7K_9	N_7K_{11}	N_7K_{13}
N_5K_0	N_5K_1	N_5K_3	N_5K_5	N_5K_7	N_5K_9	N_5K_{11}	N_5K_{13}
N_3K_0	N_3K_1	N_3K_3	N_3K_5	N_3K_7	N_3K_9	N_3K_{11}	N_3K_{13}
N_1K_0	N_1K_1	N_1K_3	N_1K_5	N_1K_7	N_1K_9	N_1K_{11}	N_1K_{13}
N_0K_0	N_0K_1	N_0K_3	N_0K_5	N_0K_7	N_0K_9	N_0K_{11}	N_0K_{13}

N_9K_0	N_9K_1	N_9K_3	N_9K_5	N_9K_7	N_9K_9	N_9K_{11}	N_9K_{13}
N_7K_0	N_7K_1	N_7K_3	N_7K_5	N_7K_7	N_7K_9	N_7K_{11}	N_7K_{13}
N_5K_0	N_5K_1	N_5K_3	N_5K_5	N_5K_7	N_5K_9	N_5K_{11}	N_5K_{13}
N_3K_0	N_3K_1	N_3K_3	N_3K_5	N_3K_7	N_3K_9	N_3K_{11}	N_3K_{13}
N_1K_0	N_1K_1	N_1K_3	N_1K_5	N_1K_7	N_1K_9	N_1K_{11}	N_1K_{13}
N_0K_0	N_0K_1	N_0K_3	N_0K_5	N_0K_7	N_0K_9	N_0K_{11}	N_0K_{13}
N_0K_{13}	N_0K_{11}	N_0K_9	N_0K_7	N_0K_5	N_0K_3	N_0K_1	N_0K_0
N_1K_{13}	N_1K_{11}	N_1K_9	N_1K_7	N_1K_5	N_1K_3	N_1K_1	N_1K_0
N_3K_{13}	N_3K_{11}	N_3K_9	N_3K_7	N_3K_5	N_3K_3	N_3K_1	N_3K_0
N_5K_{13}	N_5K_{11}	N_5K_9	N_5K_7	N_5K_5	N_5K_3	N_5K_1	N_5K_0
N_7K_{13}	N_7K_{11}	N_7K_9	N_7K_7	N_7K_5	N_7K_3	N_7K_1	N_7K_0
N_9K_{13}	N_9K_{11}	N_9K_9	N_9K_7	N_9K_5	N_9K_3	N_9K_1	N_9K_0

N_0K_{13}	N_0K_{11}	N_0K_9	N_0K_7	N_0K_5	N_0K_3	N_0K_1	N_0K_0
N_1K_{13}	N_1K_{11}	N_1K_9	N_1K_7	N_1K_5	N_1K_3	N_1K_1	N_1K_0
N_3K_{13}	N_3K_{11}	N_3K_9	N_3K_7	N_3K_5	N_3K_3	N_3K_1	N_3K_0
N_5K_{13}	N_5K_{11}	N_5K_9	N_5K_7	N_5K_5	N_5K_3	N_5K_1	N_5K_0
N_7K_{13}	N_7K_{11}	N_7K_9	N_7K_7	N_7K_5	N_7K_3	N_7K_1	N_7K_0
N_9K_{13}	N_9K_{11}	N_9K_9	N_9K_7	N_9K_5	N_9K_3	N_9K_1	N_9K_0
N_9K_0	N_9K_1	N_9K_3	N_9K_5	N_9K_7	N_9K_9	N_9K_{11}	N_9K_{13}
N_7K_0	N_7K_1	N_7K_3	N_7K_5	N_7K_7	N_7K_9	N_7K_{11}	N_7K_{13}
N_5K_0	N_5K_1	N_5K_3	N_5K_5	N_5K_7	N_5K_9	N_5K_{11}	N_5K_{13}
N_3K_0	N_3K_1	N_3K_3	N_3K_5	N_3K_7	N_3K_9	N_3K_{11}	N_3K_{13}
N_1K_0	N_1K_1	N_1K_3	N_1K_5	N_1K_7	N_1K_9	N_1K_{11}	N_1K_{13}
N_0K_0	N_0K_1	N_0K_3	N_0K_5	N_0K_7	N_0K_9	N_0K_{11}	N_0K_{13}

Fig. 1. Plot layout of the Williams Hybrid banana fertilization at the University of Hawaii Experimental Farm, Waimanalo, Oahu Island.

al., 1974b):

K	0.55 meq/100 g
Ca	24.0 "
Mg	25.2 "
Na	1.0 "
Total N	.107%
NO_3-N	4 ppm
P	0.05 ppm
pH	6.5

Note: P extractable by 0.5 M sodium bicarbonate (Olsen's Method), determined by the author in 1977, was less than 10 ppm.

The predominant mineral in the clay fraction is smectite, as determined by x-ray diffraction. The CEC of smectite is high and may also have the ability to fix K^+ and NH_4^+ ions within the clay lattices. Ions which are fixed in the clay may become slowly available to plants, but short-term release can be very small.

A laboratory study was conducted to assess the degree of K fixation against extraction with ammonium acetate. A solution of KCl in distilled water was added to soil samples (<2 mm fraction) collected in 1981 from the 0 to 30 cm depth of a high-N, zero-K treatment from plots which had been plowed and disced to a depth of 40 cm one year earlier. These samples were allowed to air dry 4 times, being resaturated with distilled water each time, over a 3 week period. Following the final drying the samples were shaken with ammonium acetate solution (1N, pH 7, 21:1 solution to soil ratio) for one hour and filtered without washing.

Results are presented in Table 2. The data show clearly that a significant percentage of K which is added to this soil may be retained (fixed) against recovery by ammonium acetate.

Nitrogen was applied in the form of granular urea spread by hand on the surface and immediately watered in by sprinkler irrigation. Potassium was applied as granular KCl in the same manner as the urea. The dates and amounts of N and K applied per mat through April, 1979, are given in Appendix Tables 3 and 4. Annual summaries of fertilization on a per hectare basis are given in Appendix Tables 5 and 6.

As described by Prasomsook (1973), the method of determining the timing of fertilization and the amounts of fertilizer applied was based on levels of N and K in the 3rd youngest leaf blades of pseudostems sampled at the time of bunch emergence (shooting). It is important to point out that the variations in the timing and amounts of fertilizer apparent from the records (Appendix Tables 3 and 4) are primarily because of the fluctuation of leaf N and K levels that were encountered by the researchers.

The following observations were recorded for every pseudostem:

bunch emergence stage:

- date of emergence
- height of pseudostem from ground to the "crook" of the fruit stalk (precision of ± 5 cm)
- girth of pseudostem at 30 cm above ground (precision of ± 1 cm)
- number of green leaves (this data recorded only since July, 1977)

TABLE 2

Recovery by ammonium acetate of K added in the laboratory to soil taken from a zero-K treatment of the Waimanalo banana experiment.

Treatment	K added	K extracted*	expected K** recovery	K not*** recovered	K not recovered / K added
	meq/100 g				%
1	0	0.25	0.25	-	-
2	1.02	1.14	1.25	0.11	11
3	2.05	1.97	2.30	0.33	16
4	3.08	2.59	3.33	0.74	24
5	4.10	3.41	4.35	0.94	23
6	5.13	4.14	5.38	1.24	24

*Mean of 2 replications.

**K added plus K extracted in treatment 1.

***Expected K recovery minus K extracted.

harvest stage:

- date of harvest (bunches cut when at full 3/4 grade; i.e. ridges on fruit only slightly angular but before any fruits began to yellow)
- bunch weight (including fruit stalk; flower bud was removed after bunch emergence; precision of ± 0.5 kg)
- number of hands per bunch (only full hands were counted)
- bunch length (between pedicels of 1st and last hands; precision of ± 1 cm)
- number of fingers on second hand (nearest to the pseudostem)
- length of the middle finger of the second hand (on the outer row of fingers, measured along the outside curve; precision ± 0.1 cm)
- girth of the middle finger of second hand (at widest point; precision ± 0.1 cm)
- number of green leaves

After bunches were harvested the pseudostems were trimmed to 1.5 m in height and allowed to rot in an upright position. All leaves and other pseudostem trash were allowed to decompose in the field near the mat from which they originated.

Weeds were controlled by sprays containing paraquat or amytryne with "Roundup" on an as-needed basis. Black leaf-streak disease (Mycosphaerella fijiensis), which was not a problem until 1974, was kept under some measure of control with sprays of C415 oil with Dithane M-45 (and malathion to control insect pests). This disease, however, has continued to be a serious problem.

Plots were irrigated once or twice weekly by sprinklers spaced 30 ft. apart on lines placed in every other row (20 ft. apart), and staggered in a hexagonal pattern. The sprinkler heads were of the rotating head type, placed about 0.5 m above ground. Although irrigation, augmented by natural rainfall, was programmed to always provide water at the rate of at least 1 acre-inch per week it was observed that some mats received less irrigation than others in parts of the field where large pseudostems blocked the jet of water.

Data analyses were performed with the aid of the Statistical Analysis System (SAS, 1979) software package at the University of Hawaii Computing Center. Most of the figures were drawn by a computer graphics device using FORTRAN programs written by the author.

II. Total analysis of nutrients in bunches and vegetative parts of harvested pseudostems.

Twenty-six pseudostems from the experimental plots previously described were selected on the basis of nitrogen and potassium fertilizer combinations. Two pseudostems from each of the 6 N levels at a constant K level (K-11), and two pseudostems from each of the other seven K levels at a constant N level (N-9) were sampled over a 5-week period (02/07/78-03/15/78).

From each leaf of each pseudostem, portions of leaf blade were removed from both sides of the midrib at the widest part of the leaf. The length of the leaf portions was measured to be exactly one-tenth of the length of the respective leaf. Preliminary study showed the weight of these samples to be highly correlated with the surface area and dry weight of the entire leaf. The petiole from each leaf was also separately removed, while the remaining leaf blades and midribs were combined and a composite subsample taken for nutrient analysis. After recording the fresh weight of the remaining pseudostem (cut at ground level) a subsample was obtained for moisture and nutrient determination. Fingers from the 1st, 5th, and last full hands of each bunch as well as the entire external fruit stalk were saved for analysis. Portions of the corm and roots were composited for nutrient analysis, but no estimate was made of the weight of under-ground portions.

Plant samples were analyzed for nitrogen using Kjeldahl digestion while P, K, Ca, Mg, S, Mn, Fe, Cu and Zn analyses were by X-ray florescence spectroscopy.

SUMMARY OF RESULTS

Yield of Williams Hybrid bananas over a seven year period at 6 nitrogen fertilization levels in combination with 8 potassium fertilization levels (48 N/K combinations) was studied. Averaging over all years the greatest difference in yield was between N treatments; significant response to K was observed only when N was well supplied, and large differences in yield between K treatments appeared only after several years, as did visual K-deficiency symptoms. Maximum average annual yield (field weight of whole bunches) was 101 Mt/ha/year as compared to 50 Mt/ha/year in the control treatment. Near-maximum yield, 90 Mt/ha/year, was obtained in the treatment which received an average of 391 kg N/ha/year and 629 kg K/ha/year. These amounts of N and K are comparable to the N/K fertilization routinely practiced by growers of Cavendish bananas in Hawaii.

Average bunch weight and the total number of bunches produced varied considerably among treatments and years. Average bunch weight reached a maximum in the second year of production and thereafter declined sharply in the third year and steadily declined through the 7th year, although the decline was relatively less when N and K were well supplied. The number of bunches harvested increased in each successive year (except in the 7th year, when storm damage reduced the numbers of harvestable bunches), and there was a positive effect of N on increasing the number harvested during each year (K had no effect).

Average minimum temperature, average maximum temperature and solar radiation were correlated with finger length, finger circumference, number of fingers, number of bunches and bunch weight. Bunch weights were highest in winter and lowest in summer. This pattern existed because of the direct effect of weather on critical growth events (which influence bunch size) that occur several months prior to harvest. There were very strong seasonal effects and nitrogen fertilizer effects on the length of time from bunch emergence to harvest: cool weather and high nitrogen were associated with delayed bunch maturation. Monthly harvest frequency was seasonably related, but not as much as bunch weight and in a nearly opposite pattern; e.g., fewer numbers of bunches were harvested in the winter. This resulted in a pattern of total monthly yield that was only slightly related to season.

Analysis of harvested pseudostems showed that bunch weights were most closely related to the weight of vegetative parts, particularly leaf-blade sections. There was little correlation between bunch weight and the concentration of N and K in any plant parts; nor were the total quantities of N and K closely related to bunch weight. The total amounts of N and K taken up by the whole plant, however, were in direct proportion to the weight of the plant; some variability was related to N and K fertilizer levels.

The relationship between bunch weight and the size of the pseudostem was examined using several mathematical models. One of these models is based on pseudostem volume, a function of pseudostem height times the square of pseudostem girth. Over all treatments, seasons, and years this model accounted for only 55% of the variation in bunch weight. When the data was categorized and analyzed separately for N, K, month or year, the prediction equations were more accurate. There were also correlations between the parameters of the prediction equation and the changes in average pseudostem size and bunch weight in the various categories.

The most influential effect on the bunch weight prediction model was crop age: between 78% and 90% of bunch weight variability was accounted for by the pseudostem volume model when data was categorized by years. Further inspection of the data revealed a close correlation between the reduction in bunch weight (relative to pseudostem size) and the number of leaves retained at harvest or at bunch emergence. There were nutritional, seasonal and age-related effects on leaf retention. The number of leaves or more probably, total leaf area during critical growth phases, was suggested to be the most direct cause of bunch weight variability.

RESULTS AND DISCUSSION

I. Yield and yield components of Williams Hybrid bananas in relation to N and K fertilization and climate.

Effects of N and K

Total yield responded most significantly to N fertilization, with the highest level of N producing the greatest yield of any N level (means of all K) in each year except the first (Fig. 2). The highest rate of K produced the highest yield of any K level (means of all N) from the second year on, but large yield differences between K-0 and other K treatments did not develop until the 4th or 5th year (Fig. 3). Total production for each N and K combination for each year are presented in Appendix Figures 1 through 7.

In the 7th year total production was reduced in all treatments. This was because of a reduction in bunch weight (Figs. 4 and 5) and also a reduction in the number of bunches harvested (Fig. 6). Reduction in yield was caused by poor weather conditions in that year. Excessive rainfall, and an increase in foliar diseases, during the 7th year was considerably higher than in previous years (Appendix Fig. 8) and a severe storm during February, 1979 caused substantial losses of fruit that would normally have been harvested during February, March and April. If it had not been for the storm damage in the 7th year, the trend towards high sustained yield in treatments well supplied with N and K (Figs. 2 and 3) suggested that production may have exceeded 100 Mt/ha[1] in the 7th year in those treatments.

---

[1] Mt = metric ton (1000 kg; 1 Mt/ha = 892 lbs/acre)

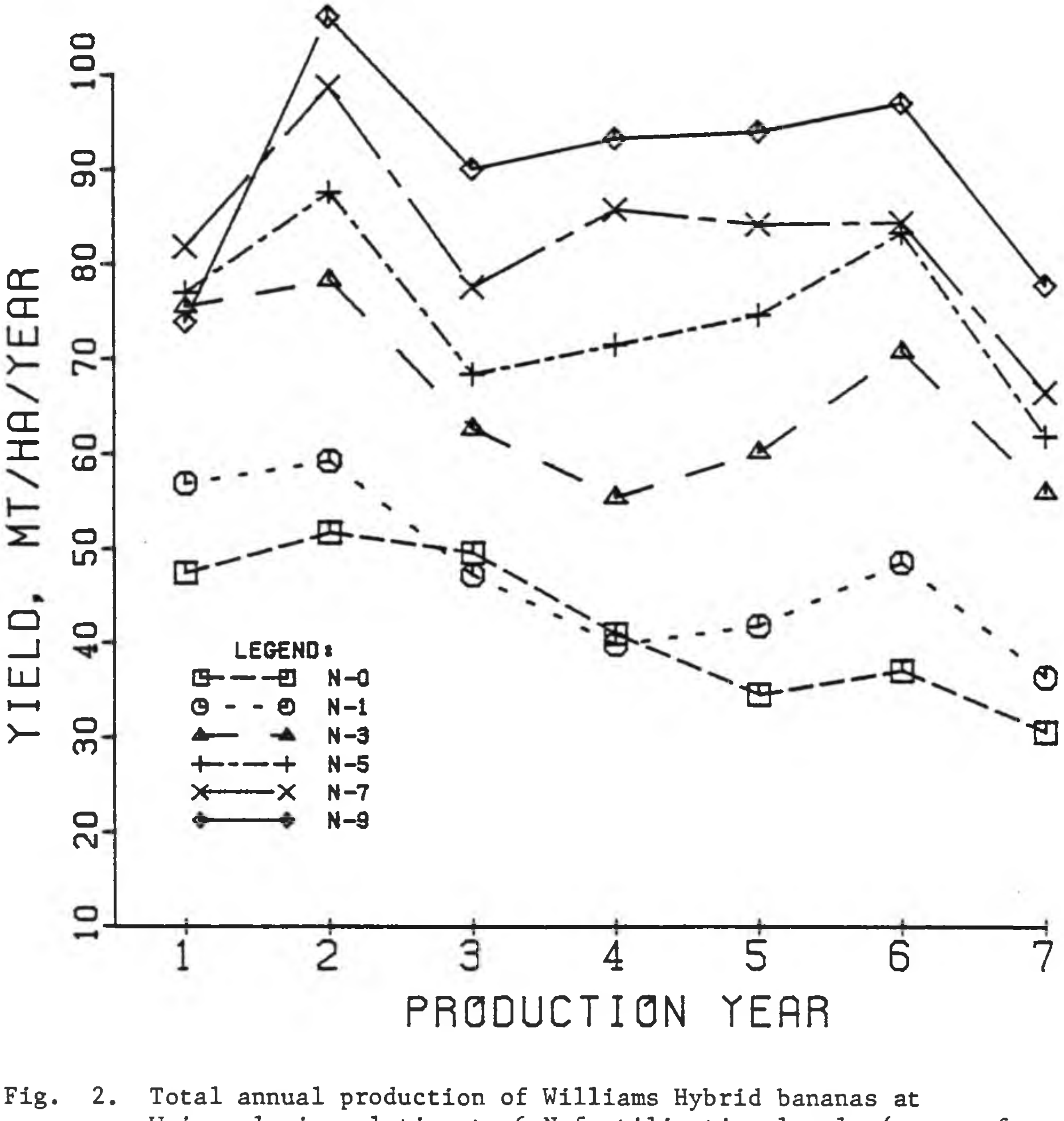


Fig. 2. Total annual production of Williams Hybrid bananas at Waimanalo in relation to 6 N fertilization levels (means of all K levels) during 1972 to 1979.

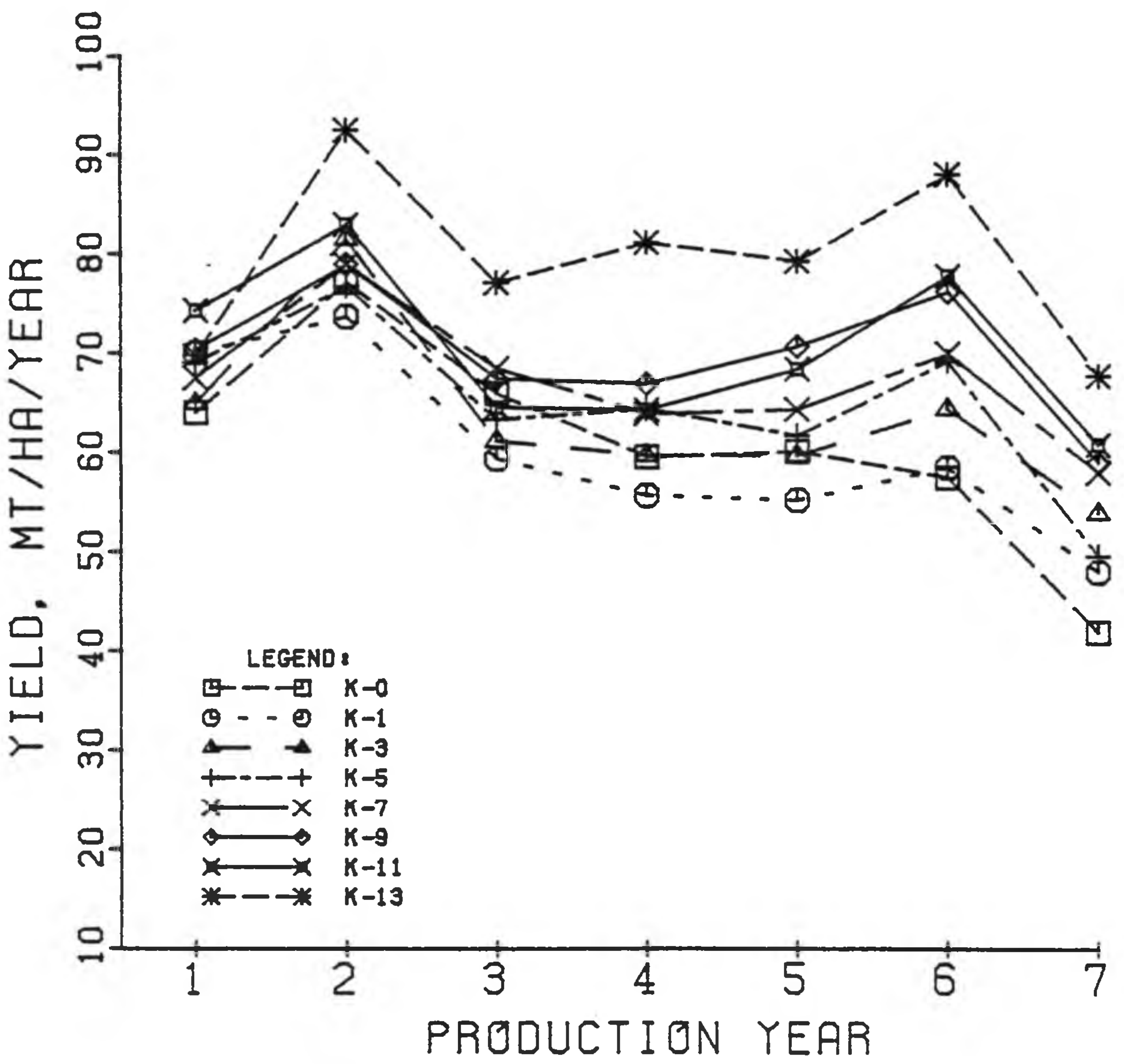


Fig. 3. Total annual production of Williams Hybrid bananas at Waimanalo in relation to 8 K fertilization levels (means of all N levels) during 1972 to 1979.

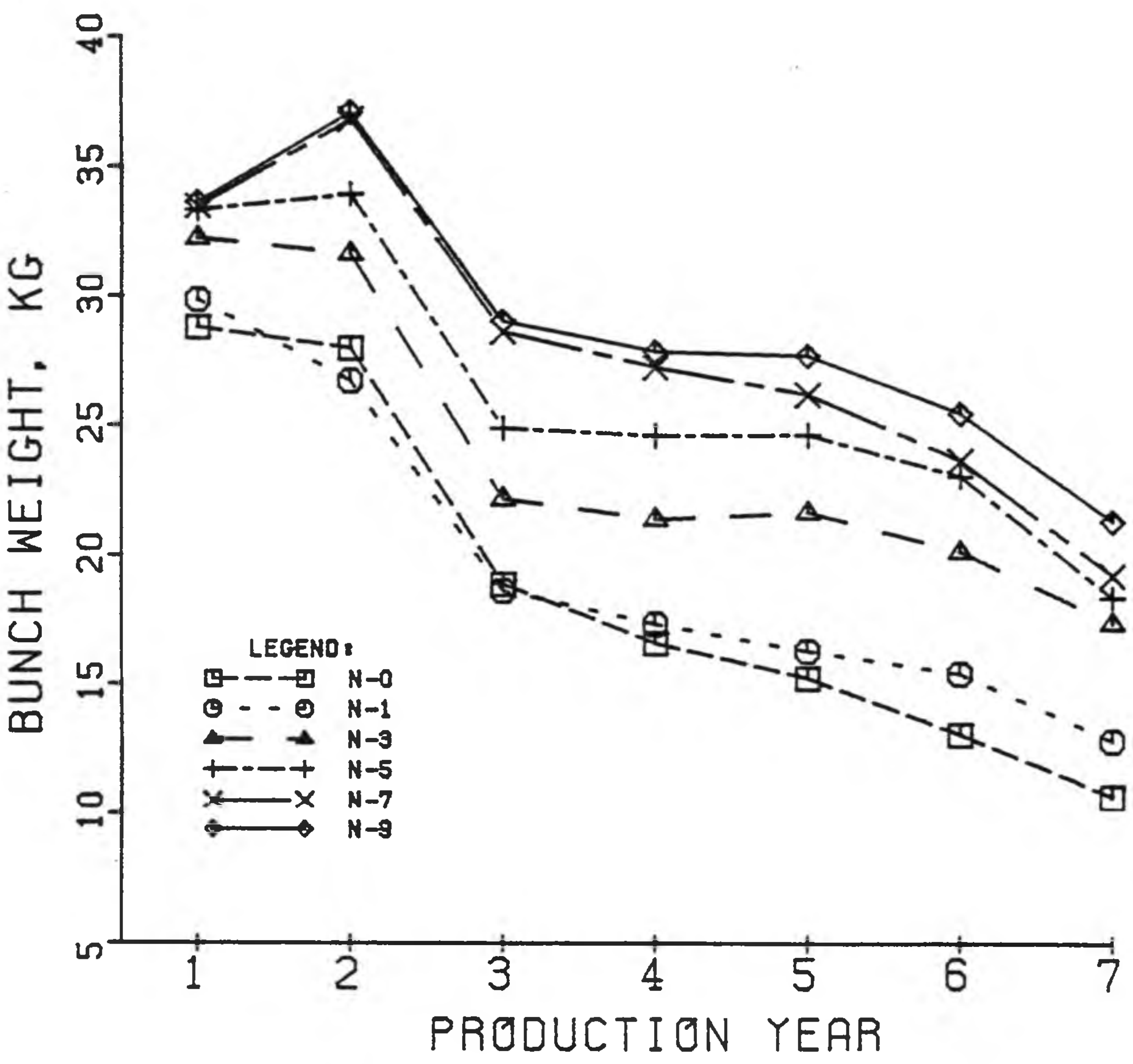


Fig. 4. Annual mean bunch weight of Williams Hybrid bananas at Waimanalo in relation to 6 N fertilization levels (means of all K levels) during 1972 to 1979.

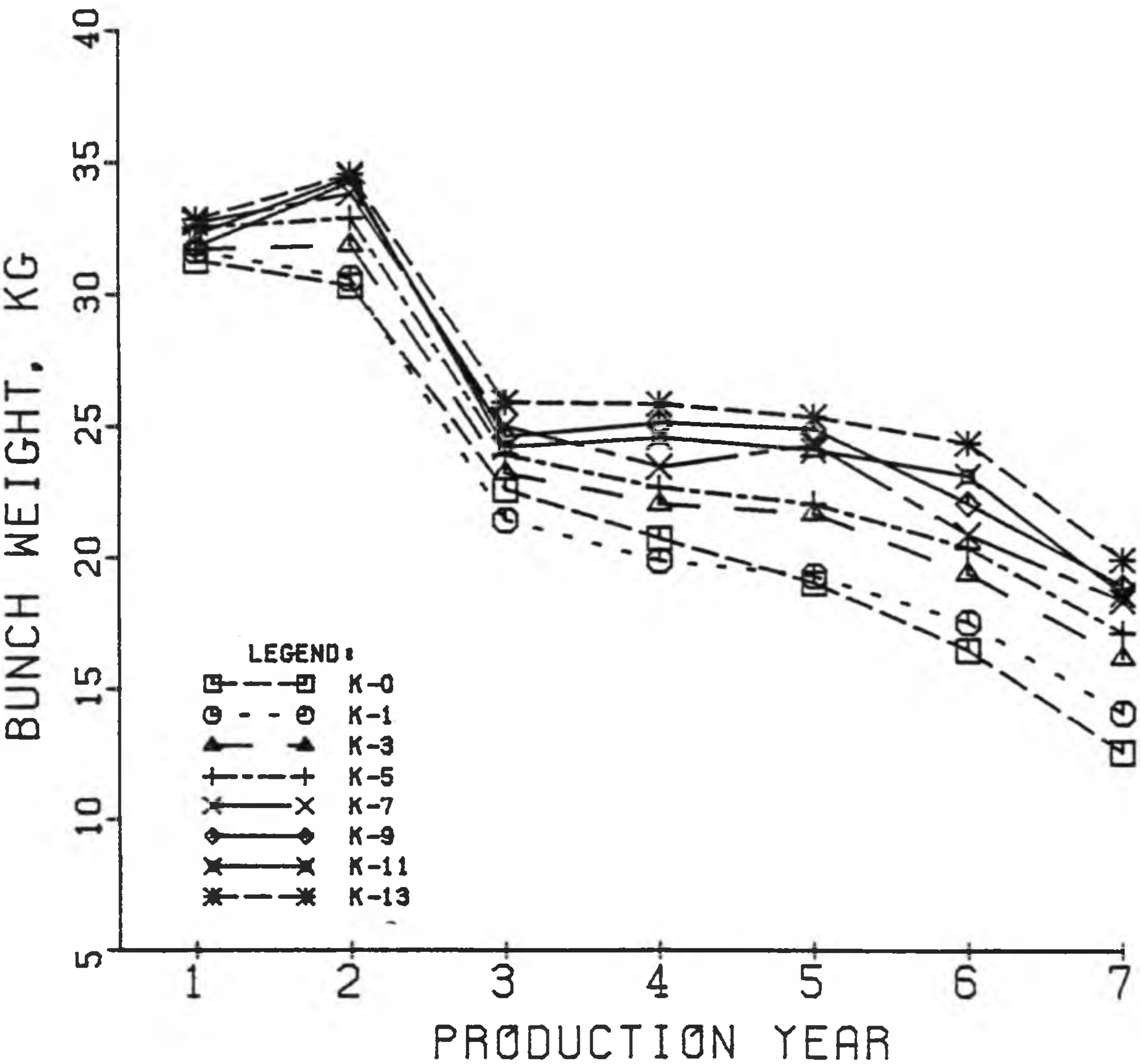


Fig. 5. Annual mean bunch weight of Williams Hybrid bananas at Waimanalo in relation to 8 K fertilization levels (means of all N levels) during 1972 to 1979.

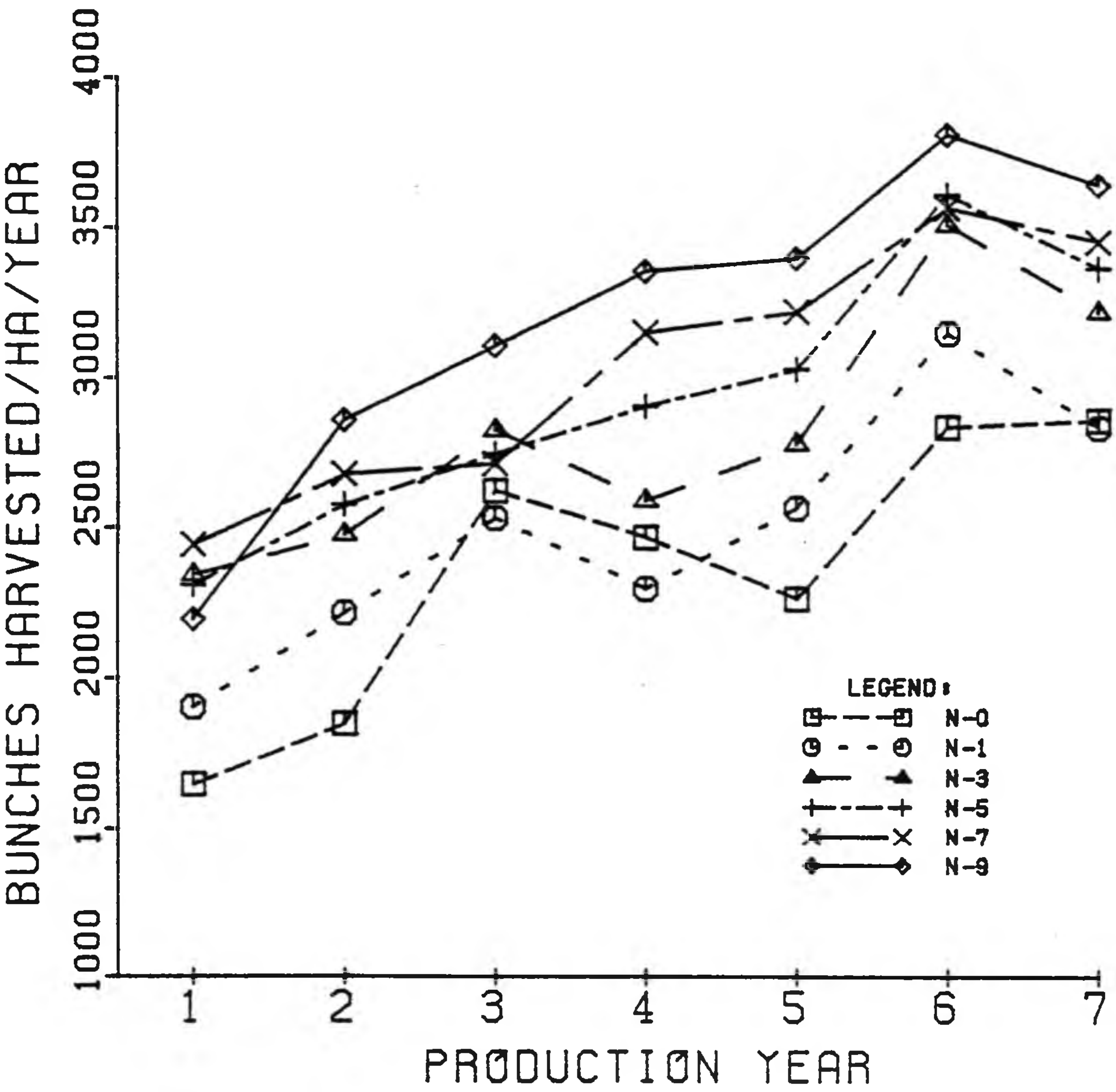


Fig. 6. Total annual numbers of bunches of Williams Hybrid bananas harvested at Waimanalo in relation to 6 N fertilization levels (means of all K levels) during 1972 to 1979.

The highest yields occurred in the 2nd year at all N and K levels. In the 1st year most of the production was from the plant crop, which had smaller bunches than those harvested during the 2nd year in the highest N and K treatments (Figs. 4 and 5). More important than bunch weight differences, however, were the increased numbers of bunches harvested from all N and K treatments in the 2nd year, particularly at high N levels (Fig. 6). The first year included the plant crop and only the 1st and 2nd ratoons of some mats, but during the 2nd year many ratoon bunches were produced in all treatments.

Yield in the 3rd year was reduced at all N and K levels because of a marked reduction in bunch weight (Figs. 4 and 5). This is believed to have been due to premature senescence and loss of leaves caused by an outbreak of Black Leaf-streak disease (*Mycosphaerella fijiensis*) which is favored by persistent wet weather. Rainfall data given in Appendix Figure 8 show that weather in the 3rd year was poor relative to the 2nd year. Aside from defoliation of the plants, poor weather conditions resulted in generally poor growth of the crop.

From the 3rd through the 7th years bunch weight continued to decline, although the decline was relatively less when N and K were well-supplied (Figs. 4 and 5). The continued decline in bunch weight may be related to a number of factors, including disease, fertility and crop density.

At the same time bunch weight was declining, the numbers of bunches produced continued to increase, especially when N was well-supplied (Fig. 6). Averaging over all years, the highest rate of N produced the greatest number of bunches at every K level (Fig. 7). Potassium had no consistent effect, except that greater numbers of bunches were harvested from both the control (K-0) and highest K level (K-13) relative to middle K treatments at the low N levels.

The reason for the general increase in the number of bunches produced from year to year (Fig. 6) was due to a lack of control over the number of suckers allowed to grow. While this may have resulted in greater total production in several treatments, the increased density contributed to reduction in bunch weight. Depending on the fertilizer treatment, there were increases in total production from the 3rd through the 6th year in those treatments where increased numbers of bunches counteracted decreased bunch weight; in some treatments bunch weights were so low that total production was also reduced.

Average production over all years (including the 7th) was 50 Mt/ha/year in the control (N-0,K-0) and 98 Mt/ha/year at the highest level of N and K (Fig. 8). Maximum yield, 101 Mt/ha/year, occurred in the N-9, K-11 treatment. Yields in the middle K treatments at the N-0 and N-1 levels were the poorest, with the least yield (33 Mt/ha/year) occurring at N-0,K-7. Nitrogen fertilization was clearly responsible for greater average annual yield at every level of K, and significant yield increases due to K occurred <u>only</u> when N was well-supplied (Fig. 8).

As mentioned previously, there were relatively few bunches harvested from the middle K treatments, particularly when N was low (Fig. 7). Average bunch weight was also relatively low in those treatments (Fig. 9). The apparent depression in yield in these low-N,

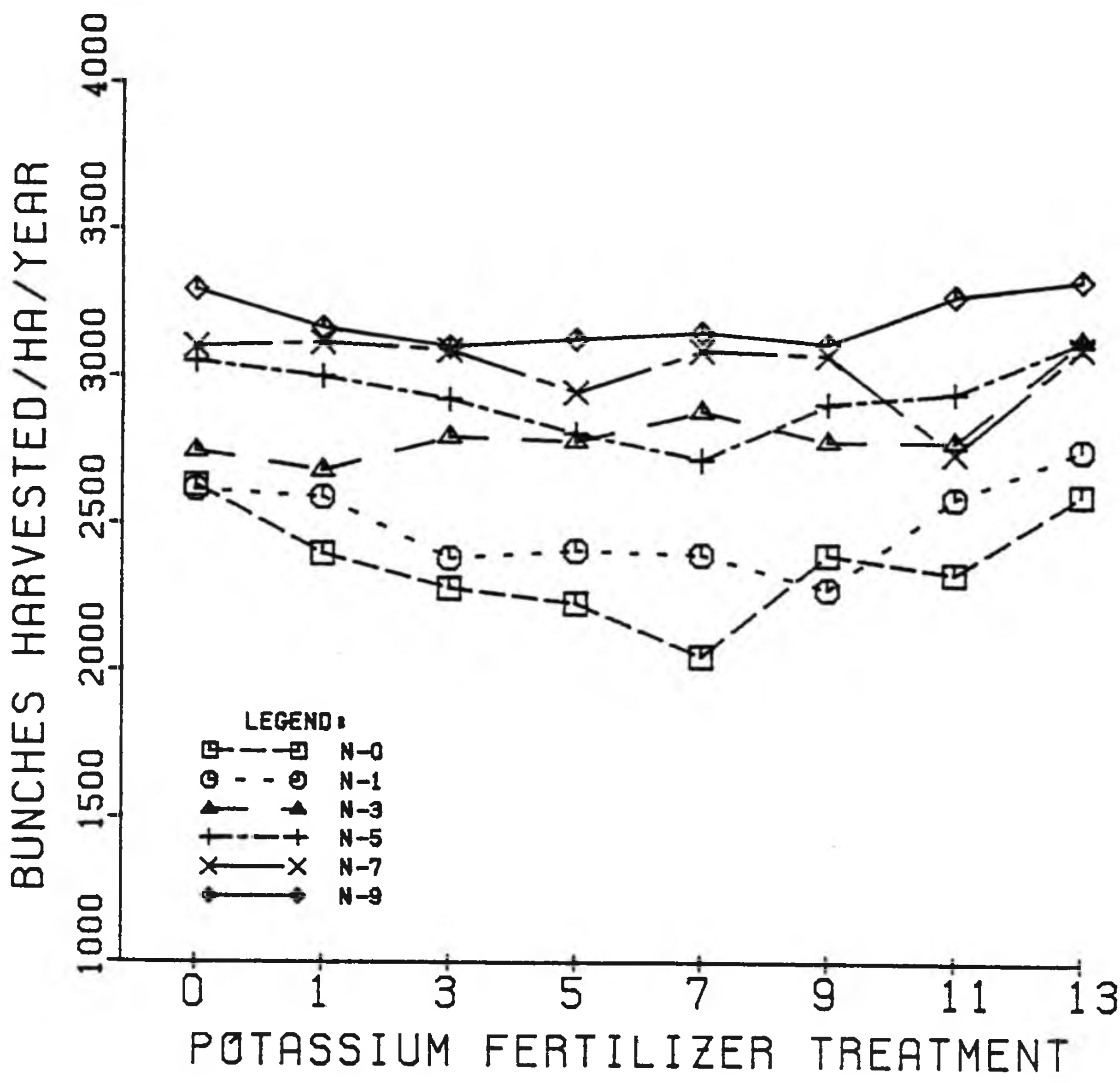


Fig. 7. Mean number of bunches of Williams Hybrid bananas harvested annually at Waimanalo in relation to 6 N x 8 K fertilization levels during 1972 to 1979.

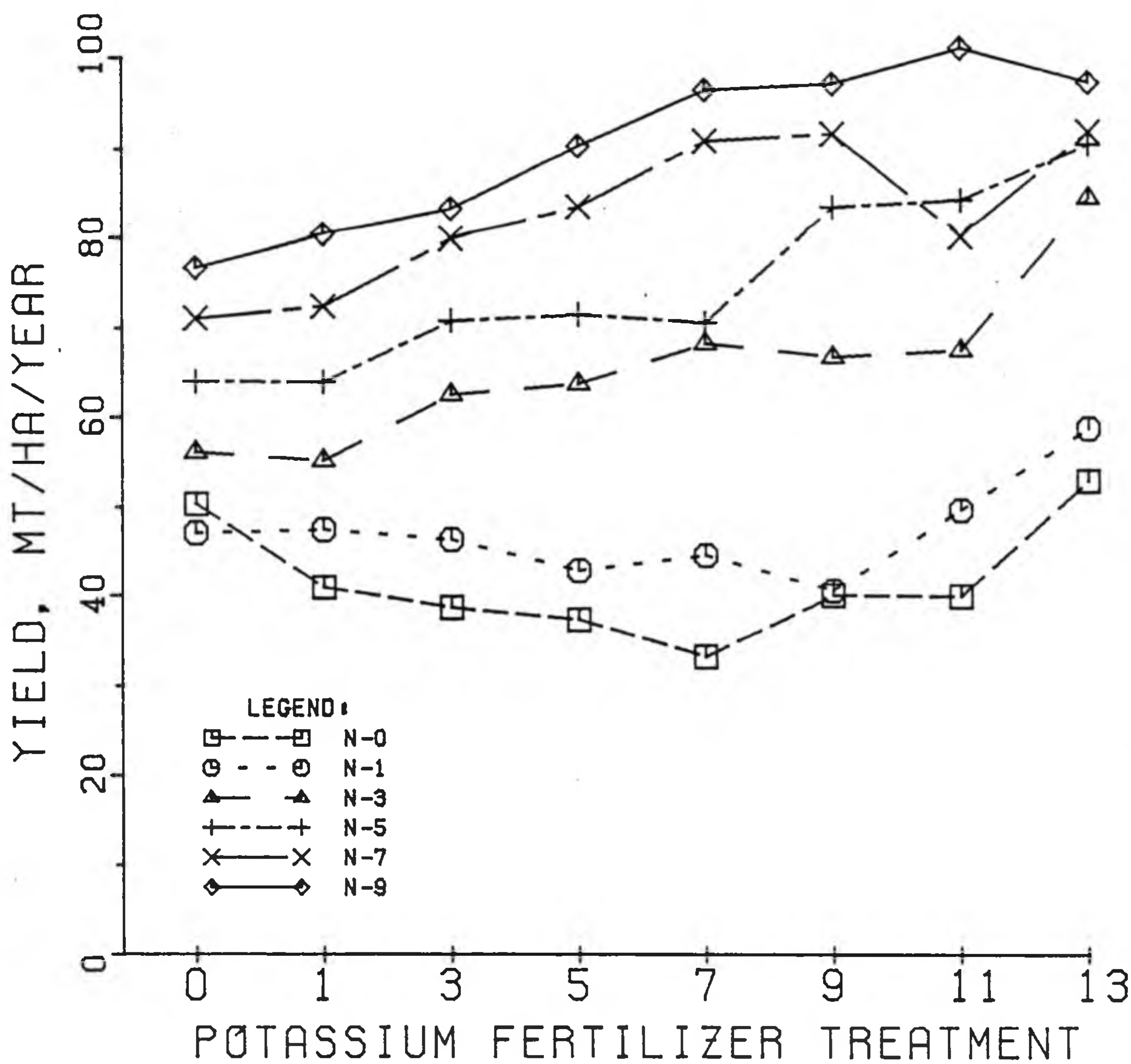


Fig. 8. Mean annual production of Williams Hybrid bananas at Waimanalo in relation to 6 N x 8 K fertilization levels during 1972 to 1979.

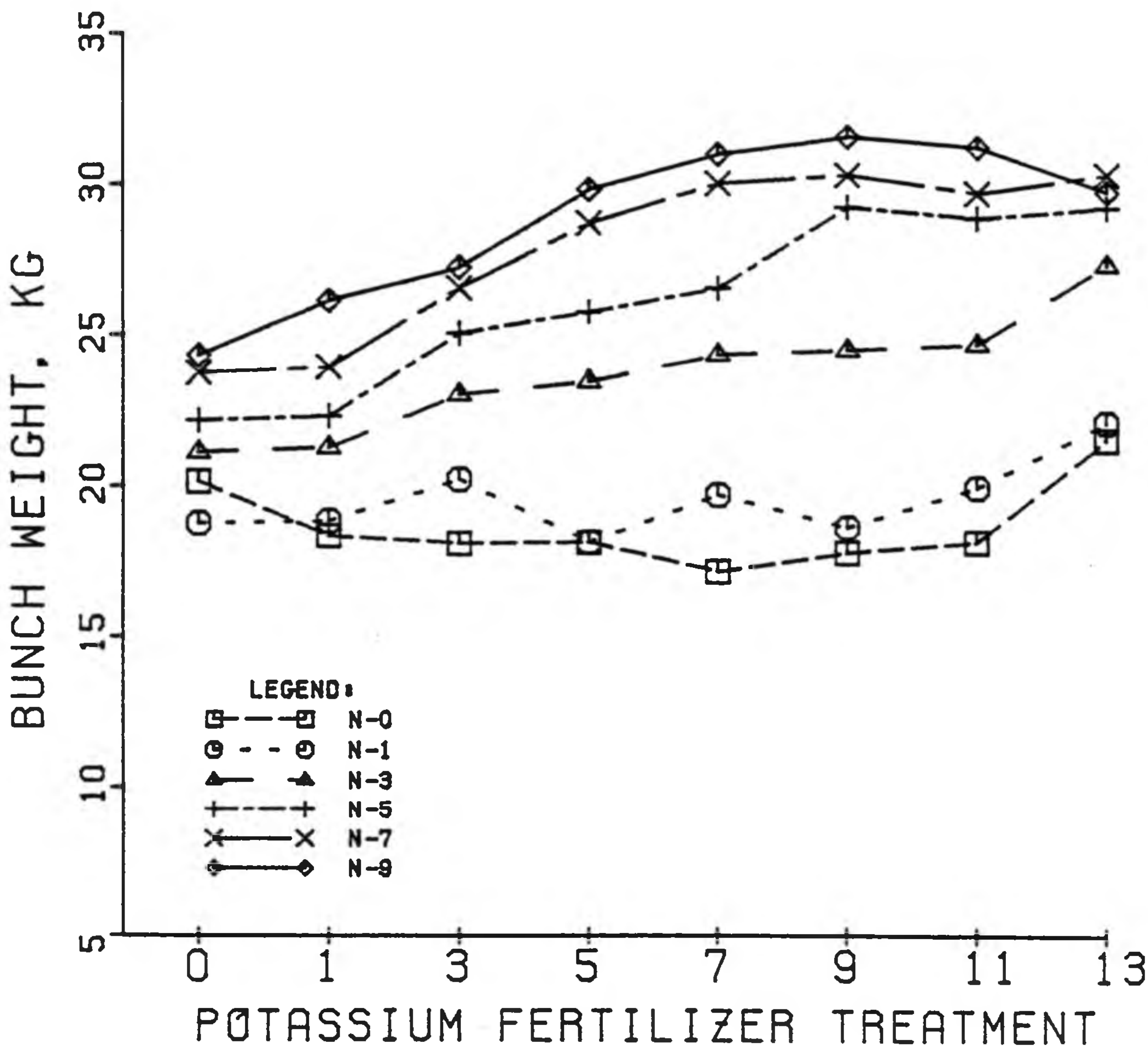


Fig. 9. Mean bunch weight of Williams Hybrid bananas at Waimanalo in relation to 6 N x 8 K fertilization levels during 1972 to 1979.

middle-K treatments may have been due to relatively increased production in the K-0 and K-13 treatments, rather than an actual negative effect of K in the middle treatments. It is probable that some mats were exposed to less competition than others, with the overall result being slightly greater yield from some treatments than would normally be expected (cf. plot layout, Fig. 1).

Near-maximum yield was obtained in the N-7,K-7 treatment (90 Mt/ha/year), from approximately 3000 bunches/ha/year (Fig. 7) averaging 30 kg/bunch (Fig. 9). The amounts of fertilizer applied in the N-7,K-7 treatment averaged 391 kg N/ha/year and 629 kg K/ha/year (cf. Appendix Tables 5 and 6). This is equivalent to 850 kg urea/ha/year and 1220 kg muriate of potash (KCl)/ha/year, or in terms of a mixed fertilizer containing 10% N this amounts to 3910 kg/ha/year of a 10-0-20 grade product.

The reader familiar with banana fertilization practices in Hawaii will recognize that similar formulations and annual application amounts are routinely used by many growers of Cavendish bananas. Hawaiian growers have, by their own experience and/or through the advice of extension agents and fertilizer sales-people, found these N:K ratios and amounts to be generally acceptable. However, while on the average these amounts of N and K resulted in optimum yield in this experiment, in the first 2 to 3 years the K requirement for near-maximum yield was significantly less than the long-term average.[(2)]

---

[2] Refer to Appendix Figures 1 through 7.

The native supply of K in the soil was sufficient for even the highest levels of production possible with heavy applications of N. The initial level of soil K, measured by extraction with ammonium acetate, was reported by Warner et al. (1974b) to be 0.55 meq K/100 g soil, or about 835 kg K/ha.[3] The amount of K estimated to have been taken up in the 1st year by the highest yielding zero-K treatment (N-7,K-0) was 537 kg K/ha.[4] After seven years of production the amount of K estimated to have been removed from the field in harvested fruit in the N-7,K-0 treatment was over 1,600 kg K/ha, nearly twice the amount assumed to have been originally present. There are two reasons for the apparent discrepancy: K from soil samples extracted only once with ammonium acetate underestimated the potentially available K and/or the plants were able to utilize K from depths greater than 30 cm. Both possibilities are likely. The reason why the extraction method might have underestimated K-availability is due to particular soil characteristics at this site, as discussed in the Materials and Methods section (cf. Table 2). Roots were present in soil cores taken to a depth of 60 cm, although the greatest numbers of roots were found between 10 and 30 cm.

Nitrogen was present in the soil in sufficient quantity to support the growth of bananas which yielded an average of 37.4 Mt/ha (N-0, mean of all K levels) in the last year. During 7 years of production the highest yielding zero-N treatment (N-0,K-13) was estimated to have

---

[3] Estimated for a depth of 30 cm, assuming uniform bulk soil density of 1.33 g/cm^3.

[4] See section II for the basis of computing this estimate.

removed 333 kg N/ha. Nitrogen taken up by the plants may have come from slowly available sources in the clay and organic matter, from ground water, irrigation water and from adjacent treatments where added N was leached and moved via ground water, or by occasional surface runoff.

Aspects of Potassium Fertilization

Determining when to fertilize and how much fertilizer to apply was based on analysis of N and K in the leaves. Because K in the leaves was found to be below the desired percentage (3.2%) on numerous occasions after the 1st year, frequent applications of K were made. During nearly eight years of fertilization over 9000 kg K/ha had been applied at the K-13 level, however, the difference in yield between K-0 and K-13 was relatively small, and the level of K in the leaves indicated that K was not being taken up in proportion to the amount of K applied to the soil. While it is now believed that the relatively small yield response to K as well as the age-related decline in bunch weight were primarily due to diseases and over-crowding, there is yet concern that the apparent K-deficiency at all K levels contributed to the yield problem.

Assuming that increased uptake of K might have resulted in improved yield, it is important to understand why so little fertilizer-K was utilized by the crop. There are basically two possible reasons: applied K did not reach the roots (or roots did not reach the K), or the plants were ineffective in taking up K that was adjacent to the roots.

A large percentage of the added K was held in the top few centimeters of soil. To best utilize this K the roots must have been active in this depth of soil. Generally, bananas have a large number of roots in the top 20 cm of soil, however, in our plots this was frequently not the case. Because the soil material consists of a heavy clay mixed with numerous small stones in the top 20 cm it had a tendency to become compacted, particularly during the dry season when the surface became dry between irrigations. Although no heavy equipment was used in the plots, several years of weekly foot traffic no doubt contributed to soil compaction.

In those treatments where heavy accumulation of K occurred after several years, at least some of the K applied in the most recent years would have exceeded the K-holding capacity of the soil and been leached to subsurface roots. Lahav (1973b) suggested massive initial K applications for bananas to overcome surface retention of K in a similar soil in Israel. In our plots poor growth conditions associated with the age of the crop may have precluded the efficient uptake of K from any depth in the soil in the latter years of the experiment. A check of roots in the top 30 cm of soil made in 1980 revealed that several parasitic nematode species were present in moderate to high levels and infestation by banana borers (*Cosmopolites sordidus*) was discovered in 1981. Because the original soil and planting material were free of pests it was likely that root damage reached high levels only after several years.

Most of the added K which was not removed in harvested fruit was still present in the soil. In August, 1977 extractable K in soil samples taken from each treatment was determined and estimates of total K to a depth of 30 cm were made, adjusted to a base level by subtracting the original soil K estimate (835 kg/ K/ha). These soil K estimates were compared to the difference (residual) between the amount of K added as fertilizer and the K estimated to have been removed in harvested fruit as of August, 1977. These data are shown in Figure 10 (data for K-1 and 3, 5 and 7, 9 and 11 were averaged). There was a deviation from the one-to-one correspondence (dashed line in Fig. 10) that would be expected if analysis of soil K entirely accounted for the estimated residual K. Assuming that the estimates are reasonably accurate, a logical explanation is offered for the deviation.

At the K-0 and K-1 levels the original extraction with ammonium acetate did not measure the actual amount of K which would eventually become available to the crop. At the highest K levels the K estimated to be left over from the fertilizer was about the same as the estimated soil K but some portion of the added K may have been leached from the depth to which the soil was analysed and/or was unextractable with ammonium acetate because of fixation in the clay (cf. Table 2).

Considering that it took over four years before any K deficiency was clearly evident at the K-0 level and that up to 1700 kg K/ha were removed by that time (Fig. 10), the amount of K present in this soil by the end of 1979 at the K-13 level (probably greater than 5000 kg K/ha) would be sufficient to support a high-yielding crop of bananas for up to 20 years.

This soil has an unusually high capacity to retain K, particularly in the clayey top-layer. In soils with a lesser K-holding capacity heavy applications of fertilizer might be largely wasted because of leaching. In our case the fertilizer was not utilized, as uptake of K and yields were limited for various reasons. The residual K built up in this soil can be assumed to be useful for many years to come, provided

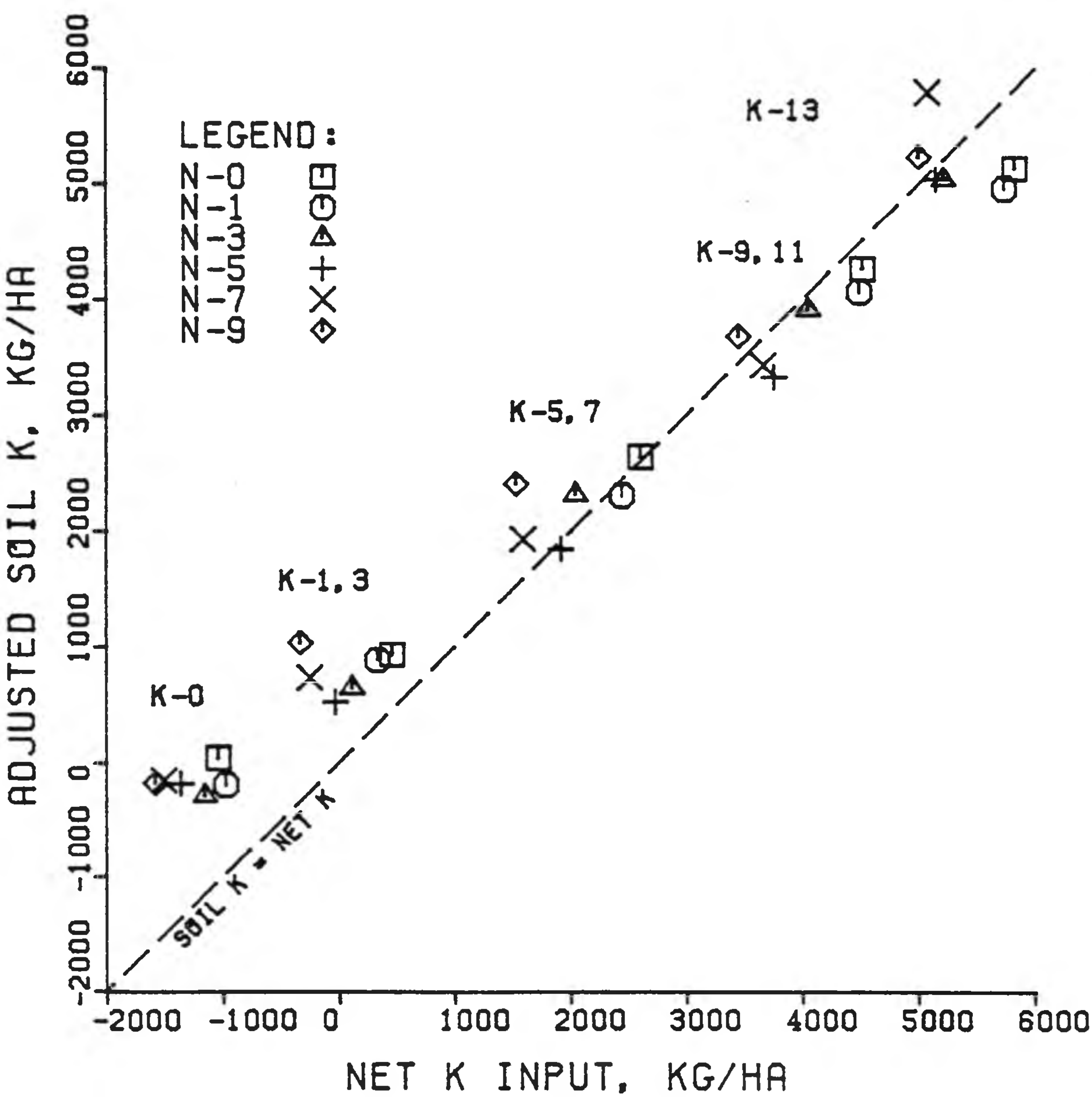


Fig. 10. Adjusted soil K (K measured in August, 1977 minus original 835 kg extractable K/ha) in relation to estimated residual K (K added as fertilizer minus estimated K removed in harvested fruit through August, 1977) in the Williams Hybrid banana experiment at Waimanalo.

that the adverse effects of factors responsible for reduced K uptake and yield can be eliminated.

Effect of climate on bunch weight.

Mean bunch weights at a high and low level of fertility were computed for each month of the seven-year period. The 'high' fertility level included all bunches from the N-5,7 and 9 treatments in combination with K-7,9,11 and 13 treatments and 'low' fertility included all other treatments. These data are illustrated in Figure 11.

Aside from the general decline of bunch weight over time at both fertility levels, which has already been shown, the interesting feature of these data are the distinct peaks corresponding to season, particularly at the high fertility level. Bunch weights were highest in the winter (Oct. to Jan.) and lowest in summer (May to Aug.). Apparently climate was the principal bunch weight-limiting factor in the first two years. By the 6th year the seasonal effect was diminished at the low fertility level, indicating that nutrition and/or other factors had become relatively more limiting to bunch weight than climate.

The relationship between climate and bunch yield was examined using a modelling technique known as cross-correlation analysis (Davis, 1973; Jenkins and Watts, 1968). This technique involves matching data pairs from two equally spaced data series (e.g. a chronological time sequence) and computing simple correlation coefficients. The data series are shifted relative to each other (while maintaining the sequence within each series) by constant increments and correlation coefficients for each new set of matched data pairs are computed. By this process the data series can be made to fall into or out of phase with each other if

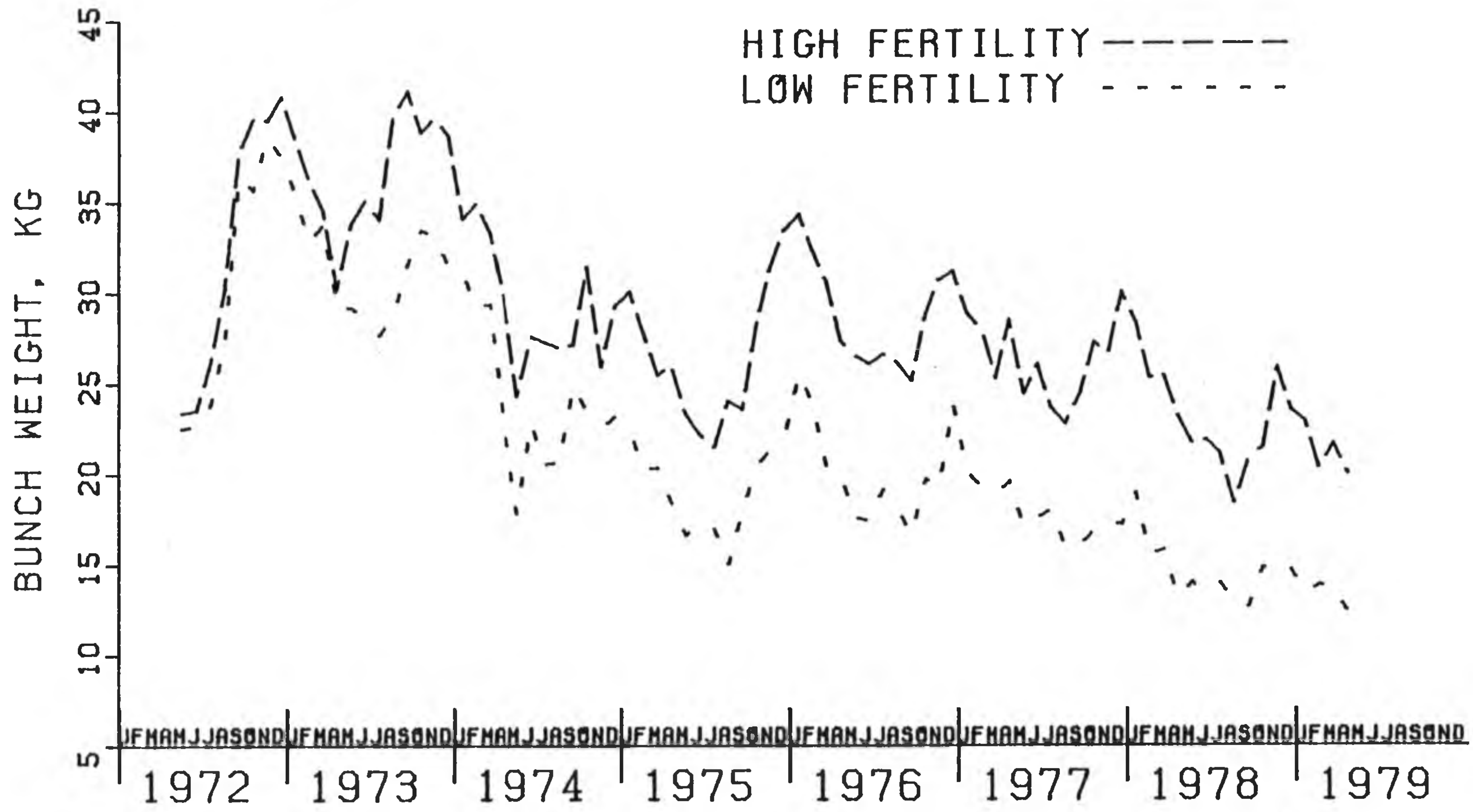


Fig. 11. Mean monthly bunch weights of Williams Hybrid bananas at Waimanalo for 'high' and 'low' fertility levels during May, 1972 to April, 1979 (high = N-5,7,9 with K-7,9,11,13; low = N-0,1,3 with K-0,1,3,5).

a phase exists. The shift which produces a high absolute value of the correlation coefficient may be thought of as a "critical" point in the relationship between the series, although there may not be any biological cause and effect between the factors. The technique is an easy way of evaluating similarities in the trends of cyclical data and can provide a basis for speculation on the actual cause and effect relationship.

Data for bunch weight and climate (daily temperature extrema and solar radiation) were averaged for each week of the period from January, 1977 through April, 1979. Correlation coefficients for average bunch weight vs. average daily maximum temperature, average daily minimum temperature and average daily solar radiation were plotted corresponding to the week (prior to the week the bunch was harvested) in which the above climate data were obtained (Fig. 12).

In the week nearest to the date of harvest (week no. 1) little correlation existed between bunch weight and any climate variable--not a surprising result. When climate data for weeks 2 through 15 were compared with bunch weight the correlations steadily improved. Weather during the period 13 to 25 weeks prior to harvest was most highly correlated (positively) with bunch weight. Correlation coefficients for all three climatic variables were similar.

The cyclical nature of the data is obvious from this plot, and the fact that negative correlations (nearly significant at the .01 level) were obtained for the period 43 to 49 weeks prior to harvest probably reflects the fact that this period in time is exactly 6 months before the period from 17 to 23 weeks, when the highest positive correlations

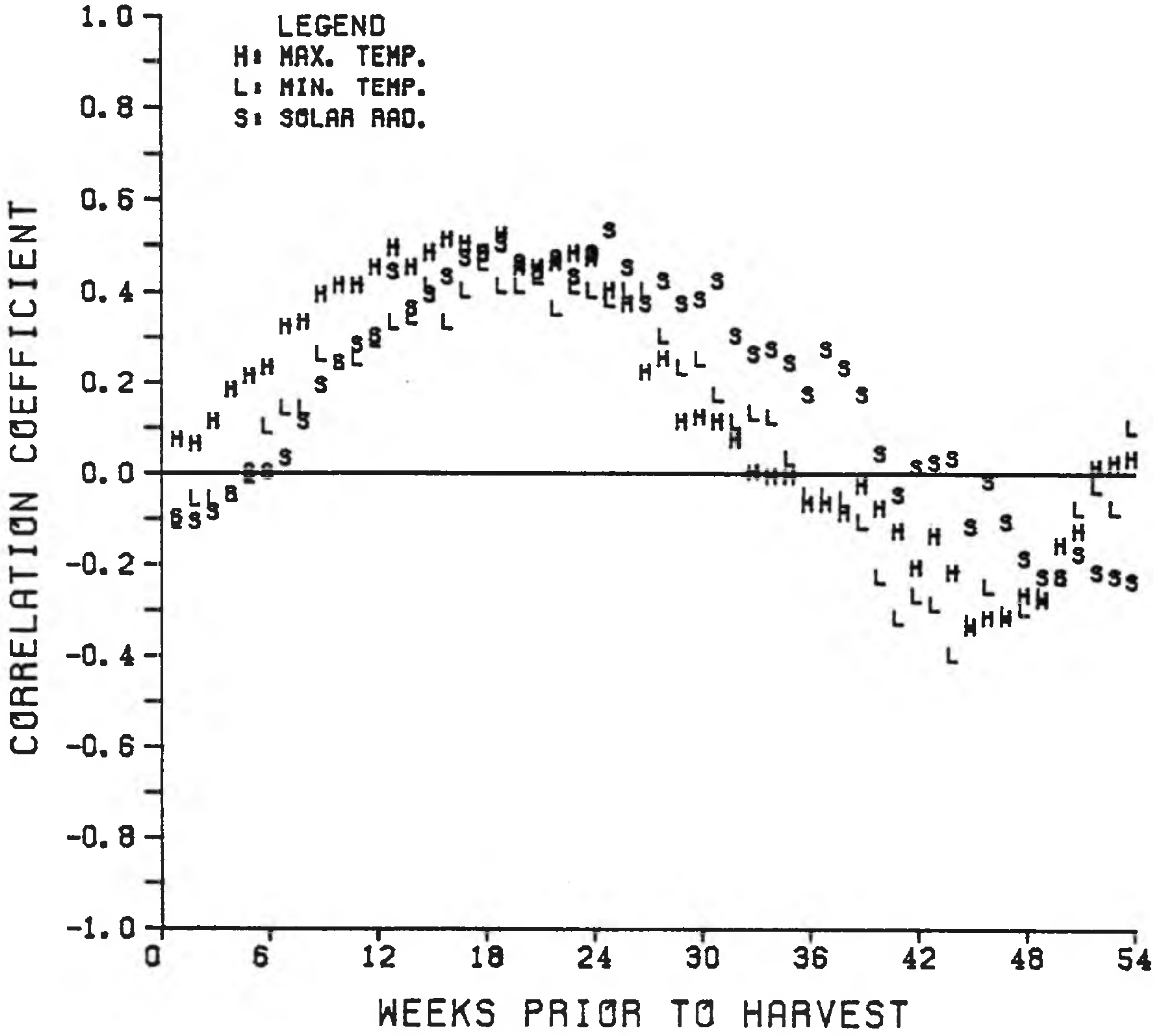


Fig. 12. Correlation coefficients for bunch weight of Williams Hybrid bananas vs. average daily maximum and minimum temperatures and solar radiation which occurred from 1 to 54 weeks prior to harvest.

were obtained. The plot of correlation coefficients also suggests a lagged relationship between temperature and solar radiation. Annual cycles of temperature and solar radiation at Waimanalo do not coincide: solar radiation is at a peak during June and July when the days are relatively long, whereas temperature maxima occur during August and September (Fig. 13). Cross-correlation analysis of average daily maximum temperature vs. average daily solar radiation showed that temperature was most highly correlated with solar radiation which occurred from 5 to 7 weeks earlier (Fig. 14). The lagged relationship between temperature and solar radiation may account for the time difference (about 6 weeks) between the peak in correlation coefficients for bunch weight vs. temperature and bunch weight vs. solar radiation (Fig. 12).

Bunch weight was well correlated with both temperature and solar radiation but at slightly different times. Because both temperature and solar radiation influence pseudostem growth and bunch size by direct physiochemical effects we cannot conclude from this analysis which factor is more "critical" to bunch weight.

Effects of N, K and climate on components of bunch weight.

The banana bunch consists of a fruit stalk bearing several hands, with each hand bearing several fingers. The average number of fingers which make up the hands, and the number of hands which will develop full-sized, "female" fingers are both fixed early in the chronological age of the pseudostem, during floral differentiation (Turner, 1970). The actual numbers of hands and fingers are determined by nutritional and climatic factors at that time. Final bunch weight is determined by

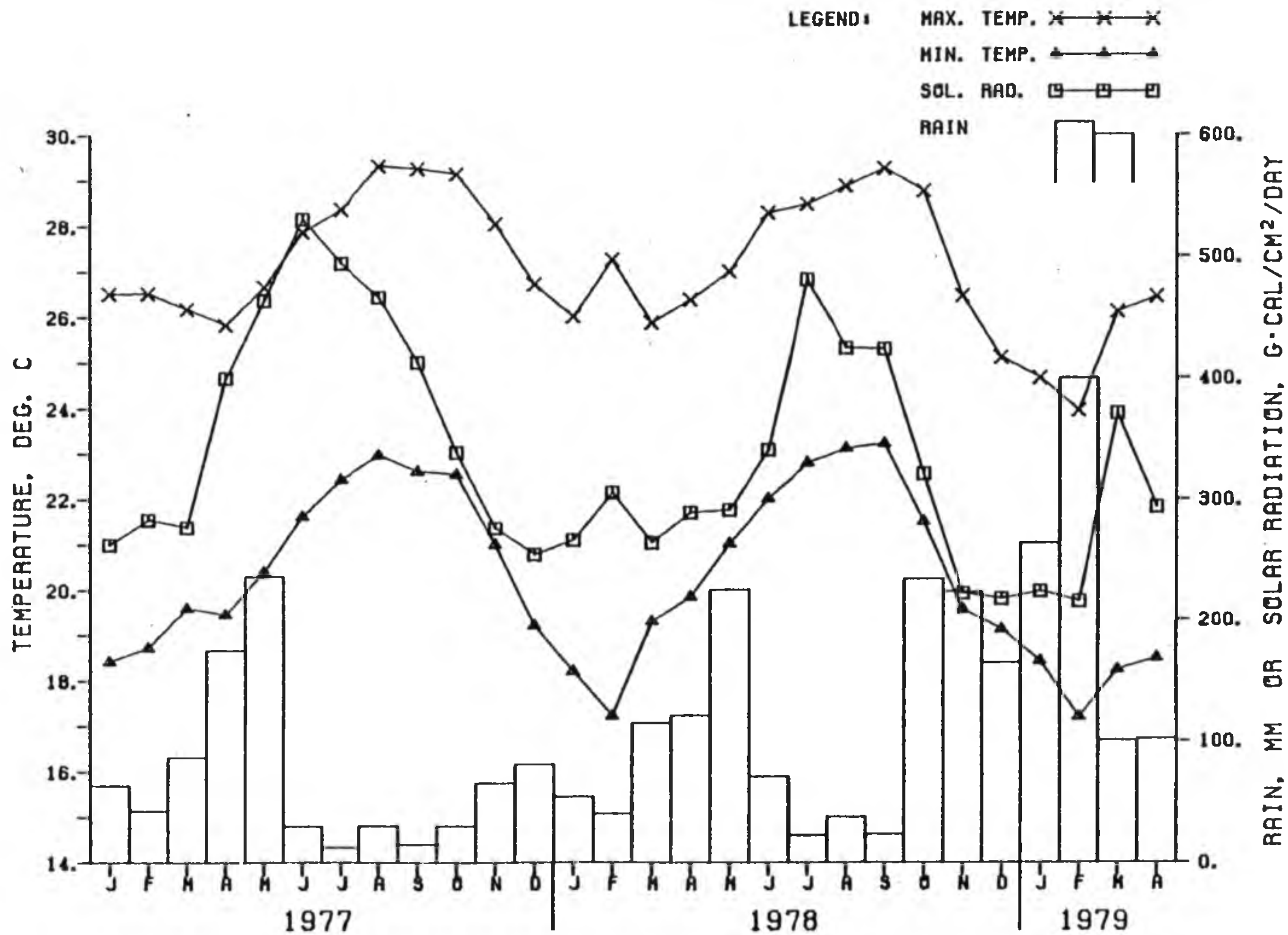


Fig. 13. Average daily minimum and maximum temperatures, solar radiation and total monthly rainfall at the Waimanalo Research Station during the period January, 1977 through April, 1979.

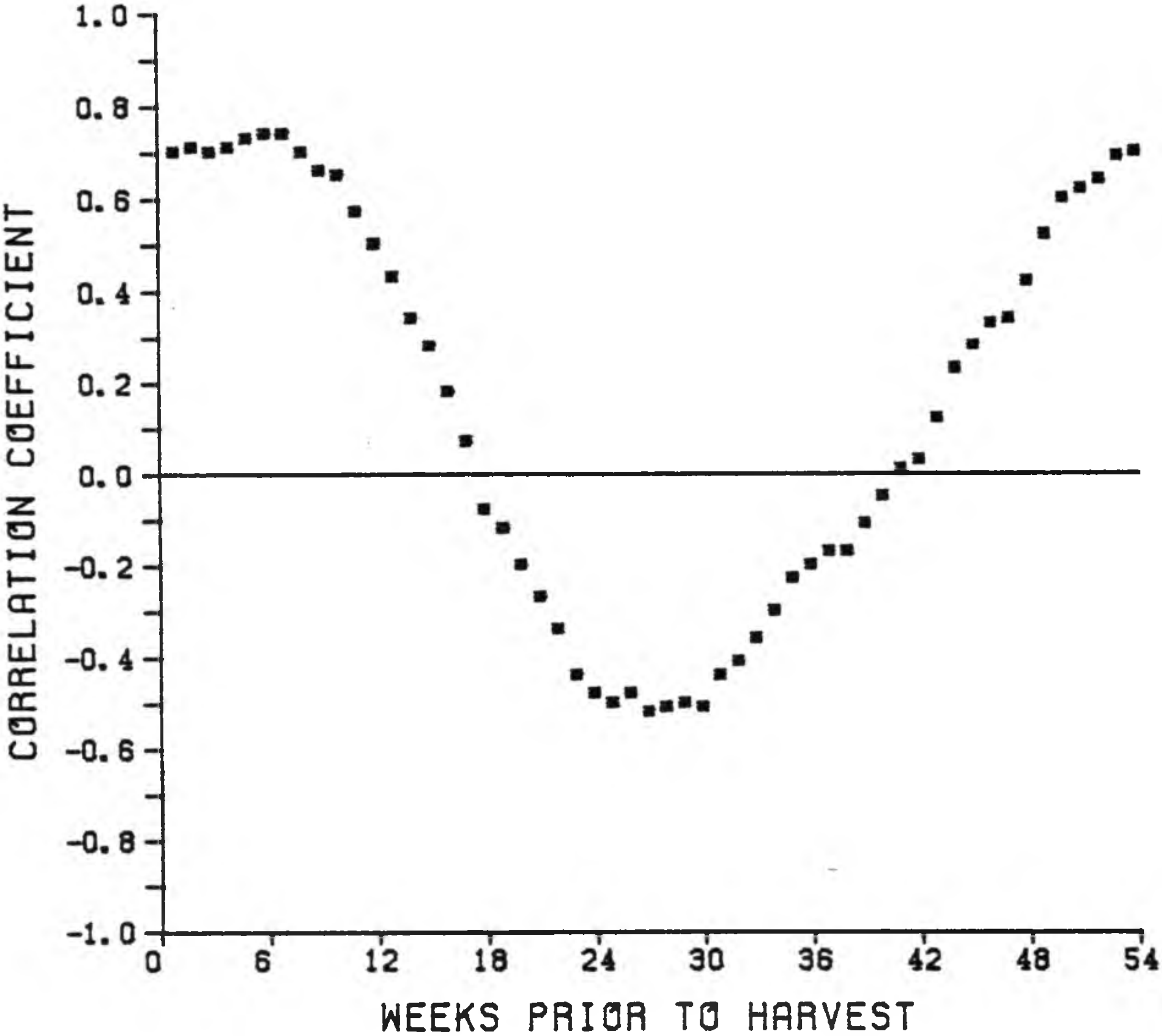


Fig. 14. Correlation coefficients for average daily maximum temperature vs. average daily solar radiation which occurred from 1 to 54 weeks earlier than the week in which temperature values were recorded.

the degree of 'filling', an increase in the size and mass of each finger due to translocation of carbohydrate from the pseudostem. As the following data indicate, a large percentage of the variation in bunch weight was explained by the number of hands, fingers, and the size of the fingers at harvest:

model	Correlation coefficient*
Bunch weight vs. no. of hands	0.88
" " " " " fingers**	0.79
" " " finger size***	0.75
" " " (hands x fingers x finger size)	0.92

* n=1309; data selected randomly from entire experiment

** number of fingers on the second hand

*** finger length x square of finger circumference

Because each bunch characteristic contributes significantly, either singly or interactively, to the determination of final bunch weight, it is of interest to evaluate the effects of N and K fertilization and climate on the components of bunch weight.

Since the number of hands alone accounted for 77% (r^2, from above) of the variation in bunch weight, we should expect that the number of hands per bunch would be correlated with the same nutritional and environmental factors that are responsible for overall plant growth and yield. With respect to N and K fertilization the number of hands per bunch was most significantly related to N. Table 3 shows the average hand count for all bunches in each N and K treatment over the entire experiment. The fewest number of hands, 6.9/bunch, occurred in the

TABLE 3

Mean number of hands per bunch of Williams Hybrid bananas in relation to 6 N x 8 K fertilization treatments during 1972 to 1979.

	K-0	K-1	K-3	K-5	K-7	K-9	K-11	K-13	$\bar{X}$
N-0	7.7	7.3	7.3	7.3	6.9	7.3	7.3	7.9	7.3
-1	7.5	7.5	7.8	7.4	7.5	7.3	7.7	8.2	7.6
-3	8.0	8.0	8.2	8.4	8.8	8.8	8.7	9.3	8.5
-5	8.2	8.3	8.9	9.0	8.9	9.6	9.6	9.8	9.0
-7	8.6	8.7	9.1	9.4	9.5	9.9	9.6	9.6	9.2
-9	8.7	8.8	7.3	9.5	9.7	9.9	10.0	9.8	9.4
$\bar{X}$	8.1	8.2	8.4	8.5	8.6	8.8	8.9	9.1	8.6

N-0,K-7 (lowest-yielding) treatment. The highest-yielding treatment, N-9,K-11, had bunches with the greatest number of hands, averaging 10.0/bunch. There was an average difference of 2.1 hands/bunch between N-0 and N-9 (means of all K) but a difference of only 1.0 hand/bunch between K-0 and K-13 (means of all N). As in the case of mean bunch weight and total yield, the benefit of adding either N or K was most pronounced when the level of the other nutrient was high.

The number of fingers on the second hand was influenced by N relatively much more than by K fertilization. On the average there were 4.7 more fingers/hand on bunches produced in N-9 treatments than in N-0, while only 1.2 more fingers/hand were produced in K-13 vs. K-0 treatments (Table 4). As with the number of hands/bunch and yield, the number of fingers/hand was least (13.9) in the N-0,K-7 treatment and greatest (20.4) in the N-9,K-11 treatment.

TABLE 4

Mean number of fingers on the second hand of Williams Hybrid bananas in relation to 6 N x 8 K fertilization treatments during 1972 to 1979.

	K-0	K-1	K-3	K-5	K-7	K-9	K-11	K-13	$\bar{X}$
N-0	15.6	14.5	14.6	14.6	13.9	14.5	14.5	15.2	14.5
-1	15.4	14.9	15.6	14.7	14.9	14.5	15.4	15.8	15.1
-3	15.8	16.3	16.2	16.7	17.1	17.1	17.0	17.8	16.8
-5	16.8	16.6	17.6	17.4	17.7	18.8	18.6	18.8	17.8
-7	17.3	18.0	18.5	18.4	19.4	19.4	19.1	18.8	18.3
-9	18.1	18.7	18.9	19.2	19.7	19.8	20.4	19.2	19.2
$\bar{X}$	16.5	16.6	16.9	16.9	17.3	17.4	17.5	17.7	17.1

Although fingers develop in length and girth to a limited degree while still sheathed in the pre-emerged flower bud, much of the increase in finger length, circumference and weight is achieved during the 3 to 5 months (before harvest) after the bunch has emerged from the pseudostem. Finger length at harvest was influenced relatively more by N than K, but the differences were much less pronounced than for number of hands/bunch or number of fingers/hand. The difference in finger length between N-0 and N-9 (means of all K) was 1.7 cm, whereas for K-0 vs. K-13 the difference was 1.3 cm (Table 5). The shortest fingers occurred in the N-0, K-9 treatment (17.5 cm) and the longest (20.2 cm) occurred in N-7, K-9/N-9, K-9/ and N-9,K-11 treatments. In general there was no added benefit of N above the N-5 level when K was well supplied and there was no added benefit of K above the K-9 level when N was well supplied.

Finger circumference at harvest was very little affected by N or K, but K was relatively more influential than N (Table 6). Overall there

TABLE 5

Mean finger length, cm, of the middle finger of the second hand of Williams Hybrid bananas in relation to 6 N x 8 K fertilization treatments during 1972 to 1979.

	K-0	K-1	K-3	K-5	K-7	K-9	K-11	K-13	$\bar{X}$
N-0	18.2	17.8	17.9	17.8	17.6	17.5	18.0	18.4	17.9
-1	17.7	18.0	18.3	18.3	18.1	18.2	18.6	18.9	18.3
-3	18.0	18.2	18.7	19.2	19.2	19.4	19.4	19.7	19.0
-5	18.0	18.4	19.0	19.5	19.5	19.8	20.1	20.1	19.3
-7	18.1	18.5	19.2	19.7	19.8	20.2	20.0	19.8	19.4
-9	18.7	19.0	19.4	19.9	20.1	20.2	20.2	19.7	19.6
$\bar{X}$	18.1	18.4	18.8	19.1	19.1	19.3	19.4	19.4	19.0

TABLE 6

Mean finger circumference, cm, of the middle finger of the second hand of Williams Hybrid bananas in relation to 6 N x 8 K fertilization treatments during 1972 to 1979.

	K-0	K-1	K-3	K-5	K-7	K-9	K-11	K-13	$\bar{X}$
N-0	13.0	12.9	13.0	12.8	12.9	12.8	12.8	12.9	12.9
-1	12.8	12.9	12.9	13.0	12.9	12.9	12.9	12.9	12.9
-3	12.9	12.8	12.9	13.1	13.0	13.0	13.0	13.8	13.0
-5	12.6	12.8	12.9	13.0	13.0	13.0	13.0	13.1	12.9
-7	12.6	12.8	12.9	13.0	12.9	13.0	13.0	13.0	12.9
-9	12.7	12.9	13.0	13.0	13.1	13.1	13.1	13.0	13.0
$\bar{X}$	12.7	12.8	12.9	13.0	12.9	13.0	13.0	13.0	12.9

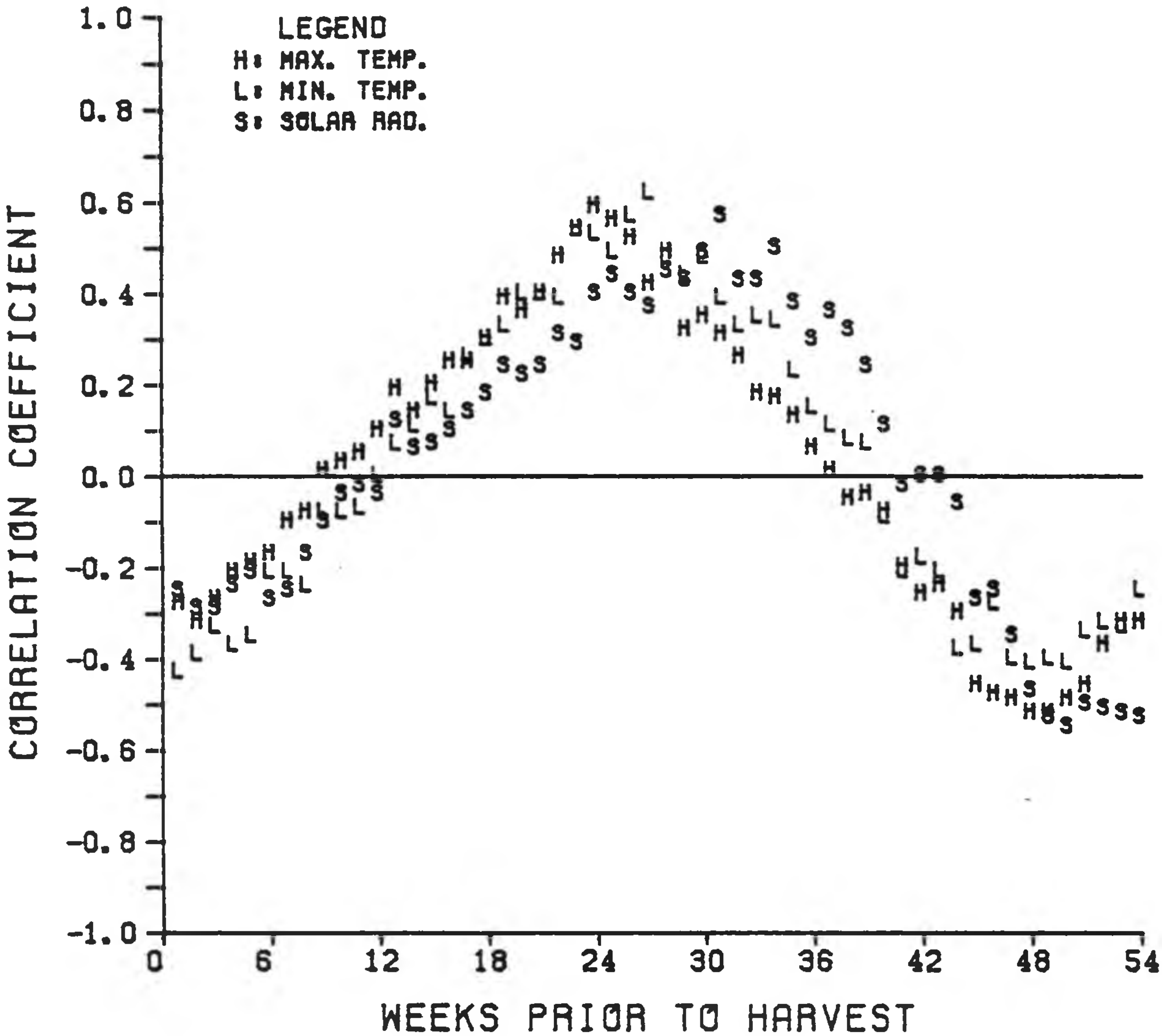


Fig. 15. Correlation coefficients for number of hands per bunch of Williams Hybrid bananas vs. average daily maximum and minimum temperature and solar radiation which occurred from 1 to 54 weeks prior to harvest.

was a positive response to N only through the N-3 level, and a positive response to K only through the K-5 level. Apparently the processes which determine fruit filling are very little affected by the N and K status of the plant, although large quantities of both nutrients are translocated to the developing bunch from the pseudostem, leaves and soil.

The effects of climate on bunch components--hands, fingers and finger size--were studied using the cross-correlation method previously described. Analysis was made of bunch components in order to assess the critical period for each component as well as the relative importance of temperature and solar radiation.

The critical period for the number of hands/bunch with respect to high or low temperature occurred from 23 to 28 weeks prior to harvest, and from 29 to 33 weeks prior to harvest with respect to solar radiation (Fig. 15). There was a closer correlation between number of hands and climate than between bunch weight and climate. The critical time shift relating climate to the number of hands per bunch was a few weeks earlier than the shift which gave the highest correlations between bunch weight and climate. Also, the correlation between climate and number of hands was high for only about 4 weeks, several weeks less than the time span over which climate was best correlated with bunch weight (approximately a 9 to 12 week period; compare Fig. 12 with Fig. 15).

The number of fingers on the second hand was also well correlated with temperature during the period 23 to 28 weeks before the harvest and with solar radiation during the period 29 to 33 weeks before harvest. In general, correlation coefficients for the number of fingers were not as high as those obtained for number of hands vs. climate (Fig. 16).

Finger length was well correlated with maximum temperature during the period 15 to 20 weeks before harvest and with solar radiation during 18 to 23 weeks prior to harvest (Fig. 17). When the bunch emerges from the pseudostem and flower bracts open to expose the hands the length of the fingers may be from 40 to 60% of their final length; therefore, it is reasonable that this component would correlate with weather which occurs after floral differentiation but several weeks before harvest.

Finger circumference at bunch emergence is only about 15 to 25% of that at harvest size. This yield component was best correlated with maximum temperature during the period 1 to 13 weeks prior to harvest, generally corresponding to the post-emergence bunch maturation period. Minimum temperature was slightly less correlated with finger circumference than maximum temperature. Correlation coefficients for solar radiation during the period 1 to 9 weeks prior to harvest were quite low (Fig. 18).

In summary, average bunch weight was positively correlated with temperature and solar radiation over a time span of about 9 to 12 weeks which began about 25 weeks before harvest. The components of bunch weight--number of hands and fingers, finger length and finger girth--were correlated with weather which occurred during the fruit development and filling period during 0 to 3 months before harvest (finger girth), 4 to 5 months before harvest (finger length), and from 6 to 7 months before harvest (hands and fingers). The time span of greatest positive correlation was relatively short for hands, fingers, and finger length but was longer in the case of finger girth. This summary statement is

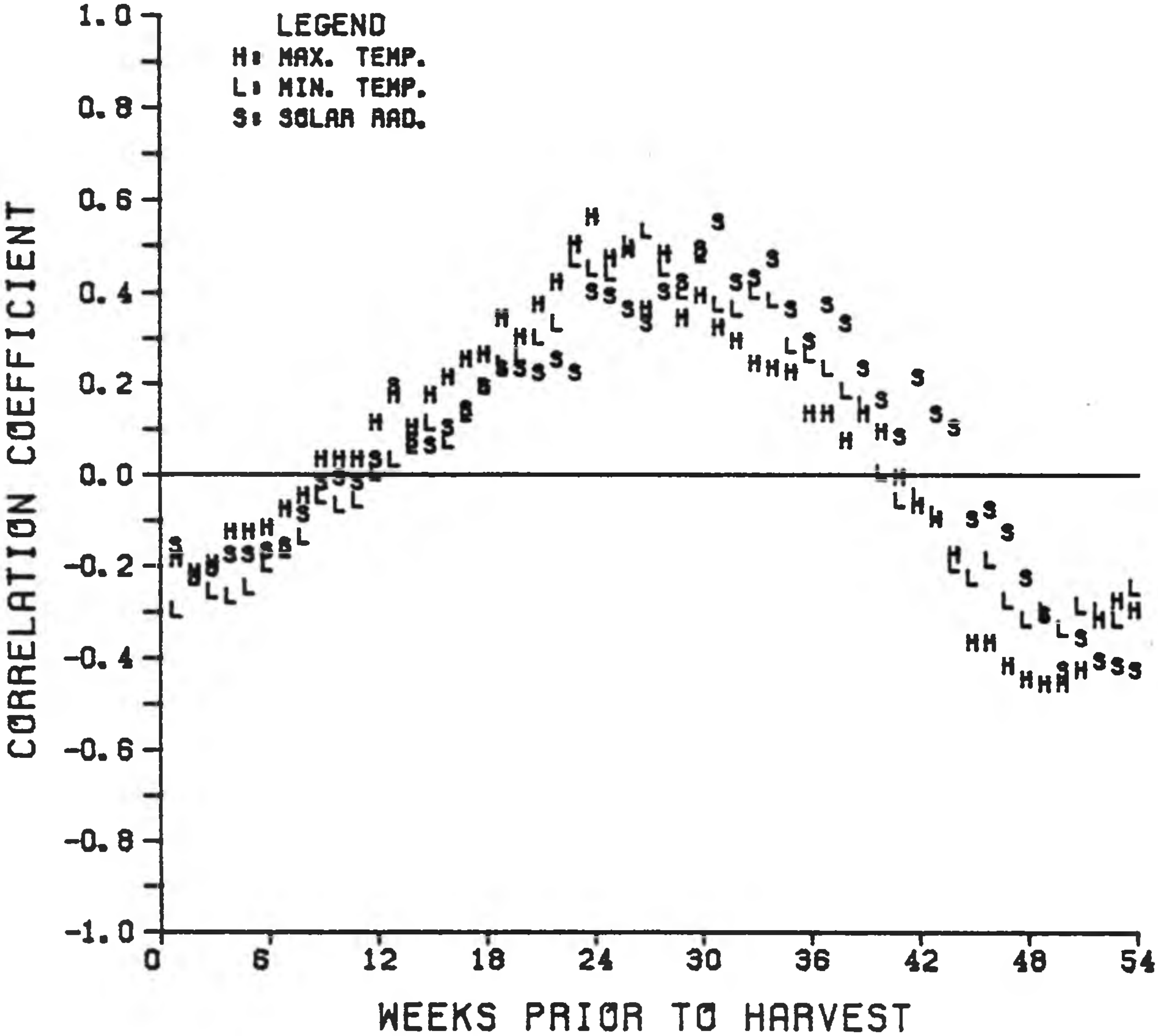


Fig. 16. Correlation coefficients for number of fingers on the second hand of Williams Hybrid bananas vs. average daily maximum and minimum temperature and solar radiation which occurred from 1 to 54 weeks prior to harvest.

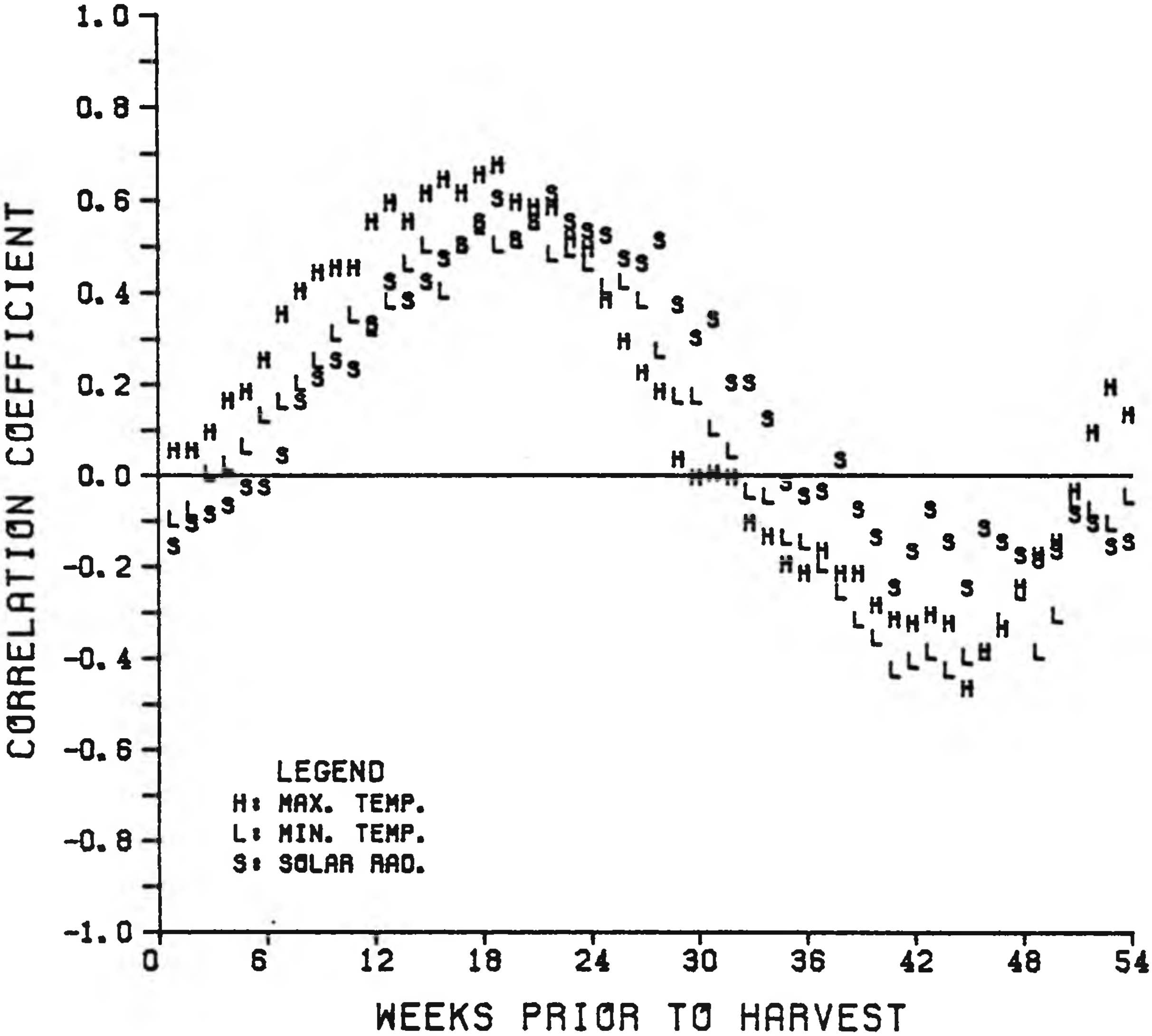


Fig. 17. Correlation coefficients for the length of the middle finger of the second hand of Williams Hybrid bananas vs. average daily maximum and minimum temperature and solar radiation which occurred from 1 to 54 weeks prior to harvest.

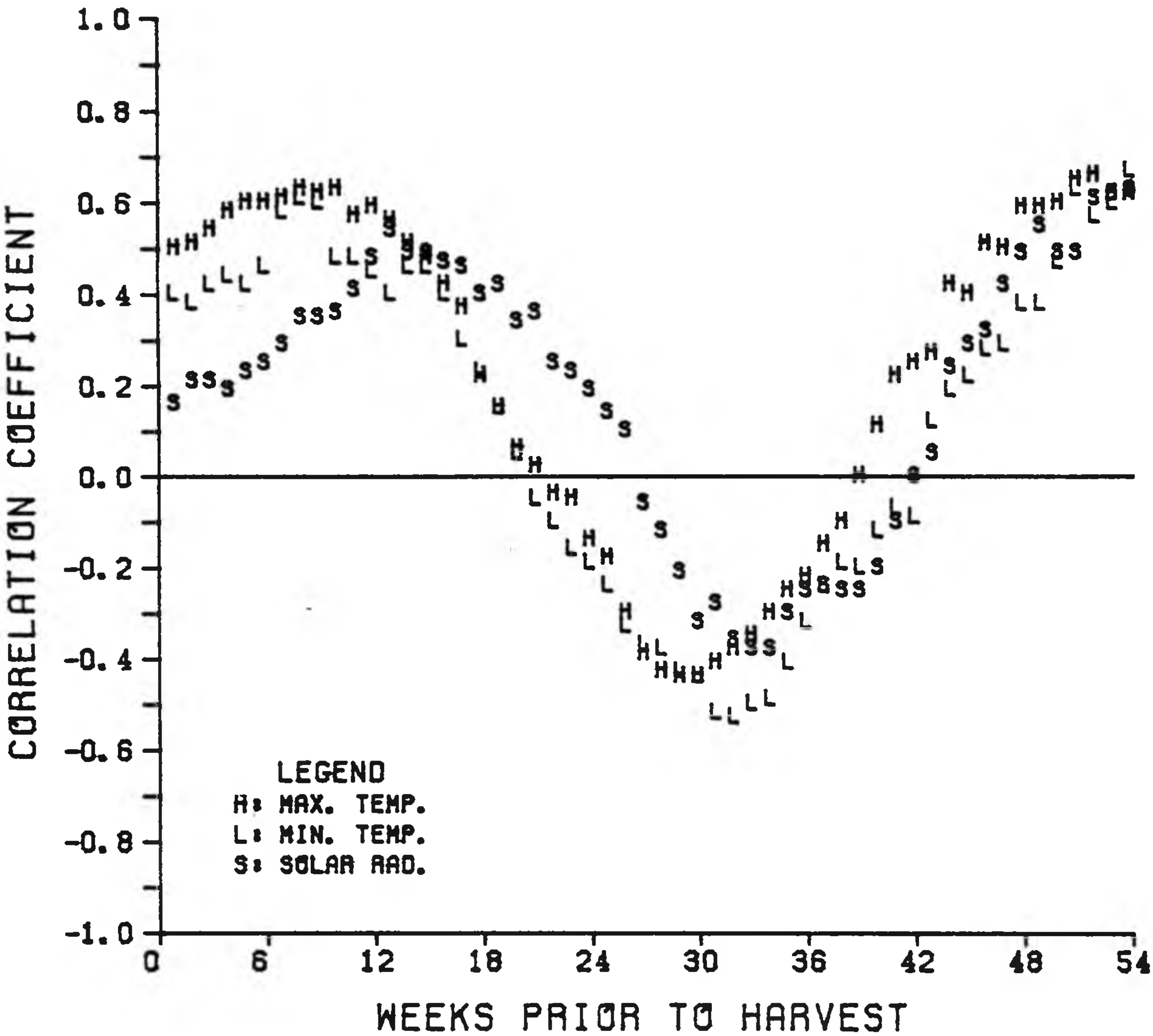


Fig. 18. Correlation coefficients for the circumference of the middle finger of the second hand of Williams Hybrid bananas vs. average daily maximum and minimum temperature and solar radiation which occurred from 1 to 54 weeks prior to harvest.

illustrated in Figures 19 and 20, for maximum temperature and solar radiation, respectively.

Final bunch weight is a biological synthesis of the number of hands, fingers, finger length and finger girth. Thus, the relationship between bunch weight and climate has a broad critical time span and has a relatively poor correlation with climate data for any particular week compared to the relationships between the individual bunch components and climate. Because the date of bunch emergence was not considered and we have no precise estimate of the developmental stage of the plants at any given week prior to harvest, the results must be considered as only general indicators of the possible cause and effect relationship between climate and bunch weight.

Seasonal variation in the number of bunches harvested per month and total monthly yield.

The total numbers of bunches harvested (all treatments combined) for each month of the seven-year period are illustrated in Figure 21. Seasonal variation is obvious, but the trend does not appear to be as closely related to climate as the variation in bunch weight. After the build-up of the crop during the first two years a harvest pattern developed which was characterized by numerous bunches being produced during the spring and summer and a relatively brief reduction in harvest frequency during the winter months.

There are at least two reasons for seasonal harvest frequency. As mentioned previously there were storms in some years, usually during Winter, which caused reductions in the numbers of bunches harvested because of blow-downs. Another reason is the temperature-related

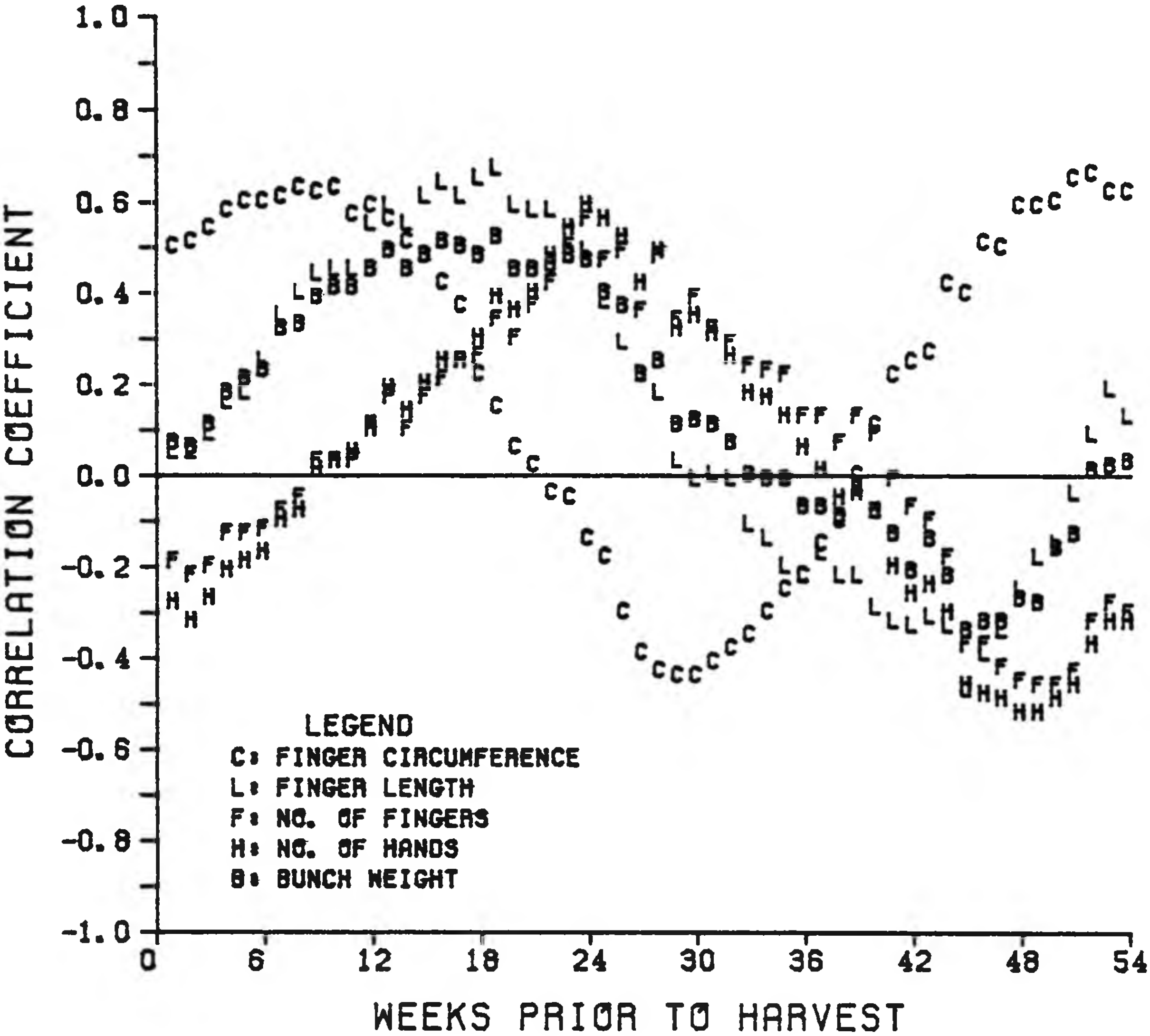


Fig. 19. Correlation coefficients for bunch weight, number of hands and fingers, and finger length and circumference of Williams Hybrid bananas vs. average daily maximum temperature which occurred from 1 to 54 weeks prior to harvest.

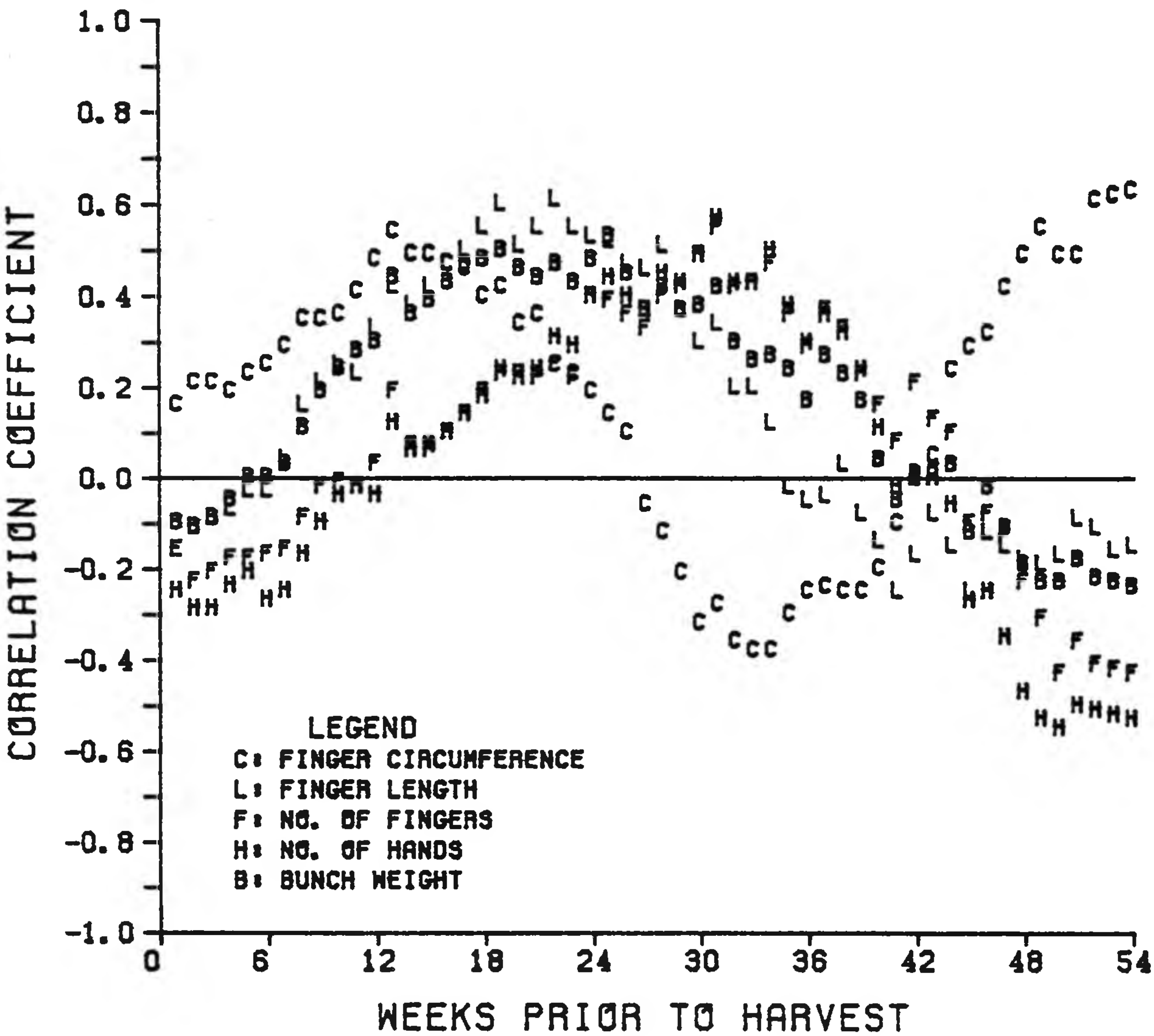


Fig. 20. Correlation coefficients for bunch weight, number of hands and fingers, and finger length and circumference of Williams Hybrid bananas vs. average daily solar radiation which occurred from 1 to 54 weeks prior to harvest.

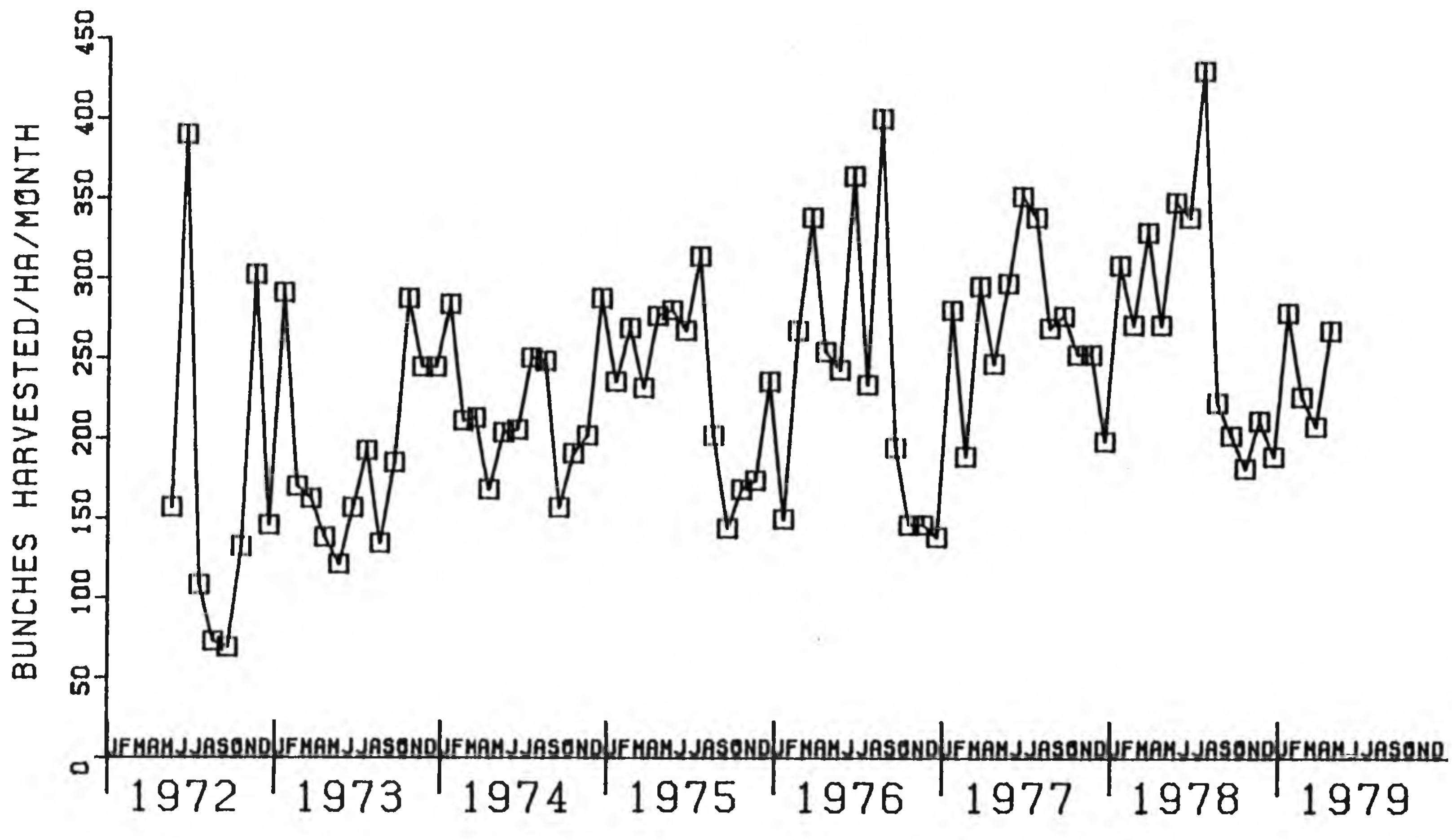


Fig. 21. Total number of bunches of Williams Hybrid bananas harvested monthly from the Waimanalo experiment during May, 1972 through April, 1979 (all treatments combined).

variation in bunch maturation rates. Bunches which emerge during late Fall and early Winter (October to December) require 4 to 5 months to mature and are harvested during Spring. Bunches emerging in Spring and Summer mature in only three months and are harvested in Summer and Fall. Relatively fewer bunches, emerging in late Summer or early Fall reach maturity in Winter.

The seasonality of harvest frequency was nearly opposite to the seasonal pattern of bunch weight (Fig. 11). These offsetting cycles resulted in a seasonal trend of total production which was less variable from season to season than either bunch weight or harvest frequency. Total yield (all treatments combined) for each month are illustrated in Figure 22. Seasonal yield peaks and depressions are evident, but the months in which they occurred were not always the same from year to year.

Effects of N, K and climate on the length of time required from bunch emergence to harvest.

An important factor influencing banana yield is the length of time to complete the growth cycle: plants which take less time to produce harvestable fruit will yield more over a given period than plants with a slow rate of growth, provided that the number of bunches harvested and average bunch weights are equal. In the event that certain management practices or climate cause an unusually extended growth period the fruit-loss risk factor may be important. The dangers of losses due to storms, theft and disease are all greater for plants having an extended growth period. These risks must be weighed against the possibility of a yield benefit accruing from management practices which also affect

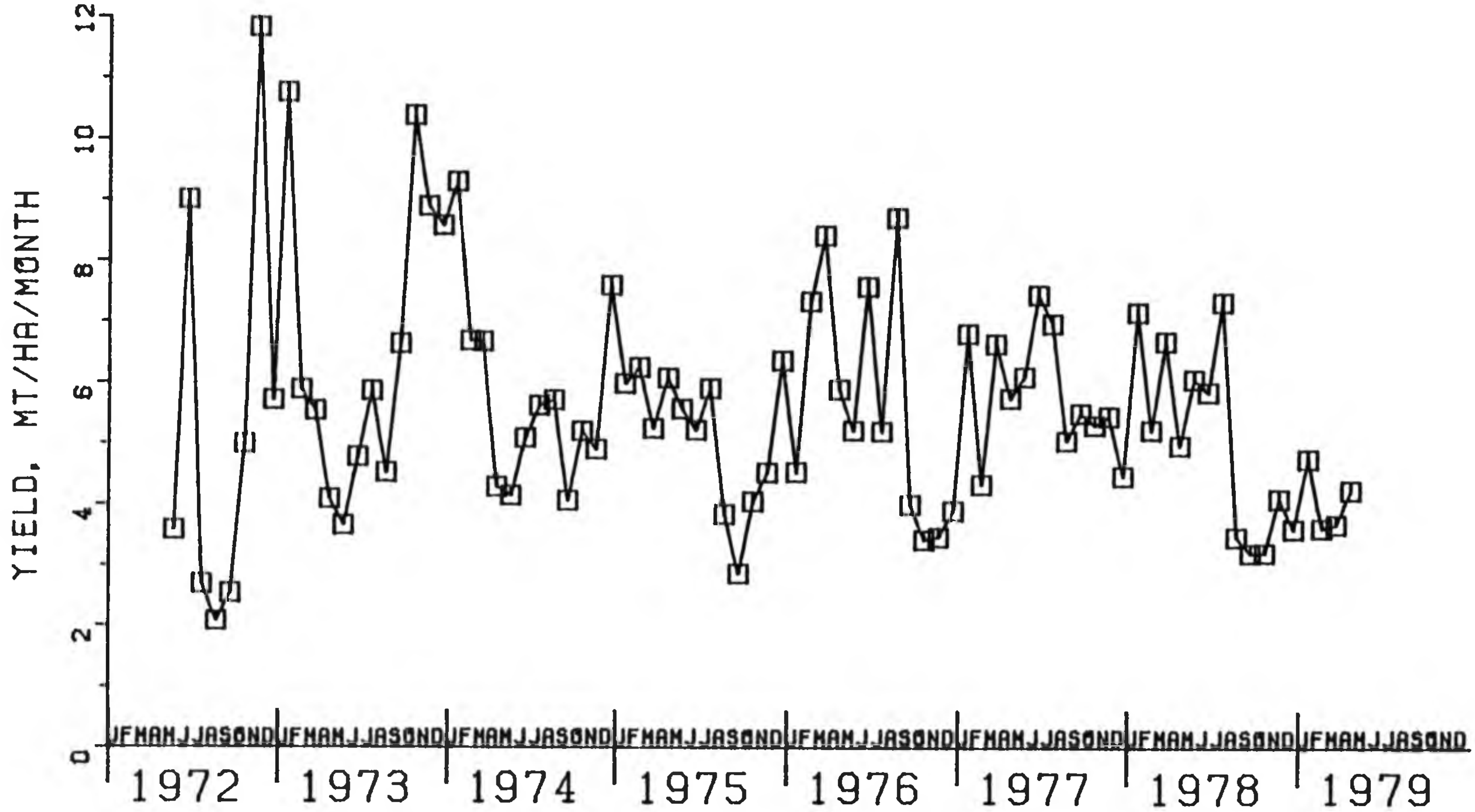


Fig. 22. Total monthly production of Williams Hybrid bananas harvested from the Waimanalo experiment during May, 1972 through April, 1979 (all treatments combined).

growth rate. For example, in the plant crop of this experiment it was found that the time from flowering to harvest in high N treatments was greater than in low N treatments (Prasomsook, 1973). The benefit from N, however, in terms of greater average bunch weight (equal numbers were harvested in each treatment) resulted in a total yield, expressed as pounds/acre/day, which was significantly higher in the high N treatments.

An indication of the variability of days-to-maturity observed in several studies and the factors associated with it were summarized in the Review of Literature (Table 1). Temperature was usually expressed or implied as the factor that most influenced all growth phases, having a positive relationship with the rate of maturity.

Results of cross-correlation analysis of our data support those findings. The average number of days from flower emergence to harvest was highly and negatively correlated with temperature, especially average daily minimum temperature, over the period from 3 to 11 weeks prior to harvest (Fig. 23). The absolute value of the correlation coefficient was even higher for the period from 30 to 35 weeks before harvest, but, as previously mentioned, this is probably an artifact introduced by the 6-month difference between the minimum and maximum annual temperature extrema.

Data for bunches produced from January, 1977 through April, 1979 were classified by calendar month x nitrogen treatment and calendar month x potassium treatment. Means were computed for the number of days to harvest for each sub-category and for the main effects. This data is presented in Tables 7 and 8. High nitrogen delayed maturity, but K had

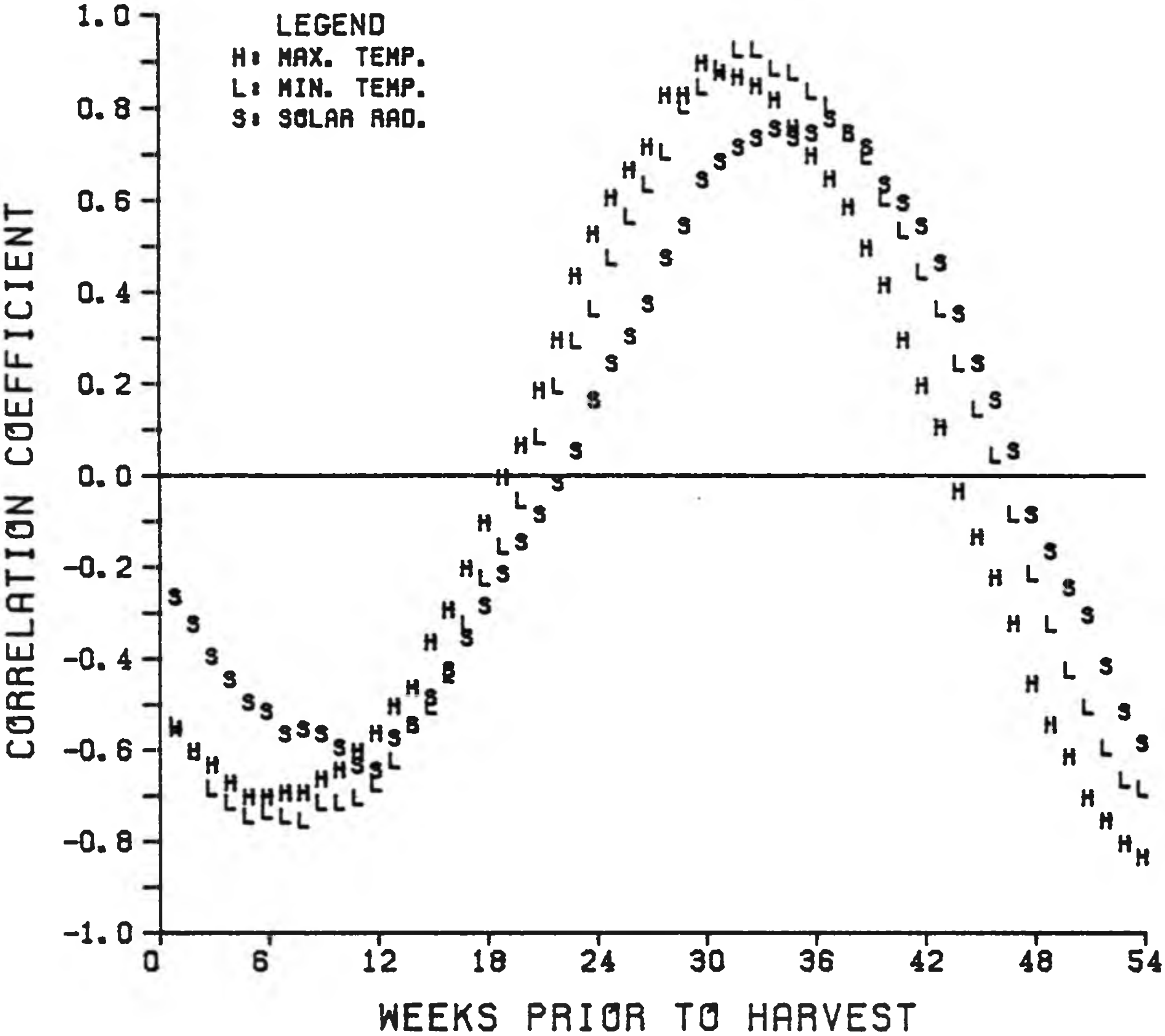


Fig. 23. Correlation coefficients for number of days from bunch emergence to harvest of Williams Hybrid bananas vs. average daily maximum and minimum temperature and solar radiation which occurred from 1 to 54 weeks prior to harvest.

TABLE 7

Mean days-to-maturity of Williams Hybrid banana bunches as influenced by 6 nitrogen levels; data arranged by calendar month in which the bunch emerged (for the period January, 1977 through April, 1979).

Nitrogen Level	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	X*
0	104	98	98	87	80	83	79	87	95	103	106	106	95 e (442)
1	108	106	101	89	85	81	84	93	99	106	112	110	99 d (477)
3	119	112	104	96	90	83	89	97	109	114	120	120	105 c (515)
5	122	113	109	100	90	90	98	103	115	119	124	126	110 b (544)
7	128	121	110	101	95	91	103	105	118	124	128	129	114 a (560)
9	127	122	113	101	95	98	102	109	120	123	129	130	116 a (589)
X*	118 (231)	113 (156)	106 (291)	96 (241)	90 (140)	87 (218)	93 (258)	101 (343)	110 (297)	116 (329)	121 (344)	122 (279)	107 (3127)
	b	c	e	g	i	i	h	f	d	b	a	a	

*Values in parentheses are number of observations for main effects means

Means not followed by same letter differ significantly at P = .01 level

TABLE 8

Mean days-to-maturity of Williams Hybrid banana bunches as influenced by 8 potassium levels; data arranged by calendar month in which the bunch emerged (for the period January, 1977 through April, 1979).

Potassium Level	Month												X*
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0	115	108	104	94	85	86	91	97	108	112	118	119	104 c (399)
1	114	111	108	94	89	83	94	99	113	115	117	121	106 b (394)
3	116	115	104	95	94	87	88	102	115	117	122	120	106 b (393)
5	119	117	109	94	89	87	90	103	113	117	120	122	108 ab (375)
7	118	107	105	100	90	87	94	102	109	120	126	123	108 ab (379)
9	114	110	108	93	86	90	97	105	110	121	121	123	109 a (378)
11	124	116	105	97	90	87	98	104	108	113	121	120	108 ab (393)
13	123	115	107	97	94	88	93	98	112	117	124	123	108 ab (416)
X*	118 (231)	113 (156)	106 (291)	96 (241)	90 (140)	87 (218)	93 (258)	101 (343)	110 (297)	116 (329)	121 (344)	122 (279)	107 (3127)
	b	c	e	g	i	i	h	f	d	b	a	a	

*Values in parentheses are number of observations for potassium level means; means not followed by same letter differ significantly at : = 0.01 level.

no effect. There was significant seasonal variation. The shortest average days-to-maturity was 79 days, occurring at the zero-N treatment for bunches which emerged in July. The longest average period was 130 days, for bunches at the highest N treatment which emerged in December.

The average minimum time required (mean of all fertilizer levels) during the year was 87 days for bunches emerging in June. Days-to-maturity reached a maximum average of 122 days in December. The range over N treatments (means of all months and K levels) was from 95 to 116 days, but K was associated with a range of only 5 days; 104 days at K-0 as compared with 109 days at the K-9 level. Similar effects were observed in the plant crop (Prasomsook, 1973).

Reports on the effect of N on the bunch maturation period do not indicate a consistent trend (cf. Table 1). One possibility is that in some experiments bunches matured during periods of different temperature. If so, there may have been climate-related variability which could have masked any nitrogen effect, but data presented in those reports was not detailed enough to confirm this.

We do not understand the specific role of N in affecting bunch maturation. It had been speculated that the apparent effect was due to the fact that many large pseudostems with large bunches were associated with increased N in this study: presumably large fruits would require a relatively long period to mature. All components of bunch weight (except finger girth) and pseudostem size were found to correlate positively (but not very significantly) with the number of days to harvest:

factor	correlation coefficient
pseudostem girth	0.24
pseudostem height	0.34
no. of hands	0.34
no. of fingers	0.31
finger length	0.22
finger girth	-0.12
bunch weight	0.29

However, when prediction of days-to-harvest was based on these factors, N level, and average daily minimum temperature in a stepwise regression procedure the N factor retained significance. Results of this analysis are summarized below:

F-ratio of parameter estimate

Factor *

FG	SG	F	FL	H	B	SH	N	T_L	R^2
								1962	.52
43								1994	.54
	272							2292	.59
		300						2165	.59
			374					2526	.61
				409				2298	.61
					528			2669	.63
						606		2664	.65
							1198	3102	.72
			130				859	3434	.74
			36			18	599	3439	.74
	48		64			65	513	3550	.75
	68		31		20	49	456	3609	.75
	65	9	26		29	48	467	3573	.75

* FG = finger girth, SG = pseudostem girth, F = no. of fingers, FL = finger length, H = no. of hands, B = bunch weight, SH = pseudostem height, N = nitrogen fertilizer level, T_L = avg. daily min. temperature

Inclusion of the various factors (after temperature) raised the accuracy of the estimate of days-to-harvest, but no pseudostem size or bunch component factor removed the strong influence of the N factor.

Although average monthly minimum temperature varied only 6° (17 to 23°C; Fig. 23) the rate of fruit filling following flower emergence was quite sensitive to this variation. Perumal and Adam (1968), who studied the effect of bagging the bunches on the rate of fruit maturation, found that bagged bunches matured 15 days earlier than unbagged bunches during winter and 8 days earlier in summer. They associated the effect of bagging with increased air temperatures within the bunch cover of only about 2°C greater [1 to 4°F in their paper] than in the open air near uncovered bunches.

In addition to the cross-correlation analysis discussed above, two prediction models were tried, based on regression of the bunch maturation period vs. the average daily temperature over the maturation period of each individual bunch. One, the so-called degree-days model, assumes an inverse relationship between days-to-maturity and temperature (Arnold, 1959). The critical parameter of this model is the base temperature (growth-limiting minimum). Calculated by the method of Arnold (1959) the base temperature of our data was estimated to be only 5°C, much lower than the 14°C assumed by Ganry and Sioussaram (1978), who tested a similar model.[(5)]

Although correlation between days-to-maturity and temperature using this model was highly significant, the method was less accurate than a

---

5 cf. also Ganry and Meyer (1975), who used a 14.5°C base temperature

simple linear model such as that used by Hord and Spell (1962). The linear relationship between days-to-maturity and temperature in our study resulted in correlation coefficients of -0.68 and -0.60 for average daily minimum and maximum temperatures, respectively, using data which included all fertilizer treatments. A separate set of data was used to test the regression estimates: a standard error of 11 days was obtained using minimum temperature in the model. This corresponds to a 90% confidence interval of about ± 3 weeks, which is not very precise if temperature forecasts, which are seldom accurate, are used to predict harvest dates.

The use of weekly temperature summaries (and perhaps daily values) during certain periods following bunch emergence, as was done in the cross-correlation analysis, may provide the best means of predicting harvest dates.

Summary

Total fruit production of Williams Hybrid bananas was significantly increased by fertilization with N and K, with near-maximum yield averaging 90 Mt/ha/year over a seven year period when N and K were applied at 391 kg/ha/year and 629 kg/ha/year, respectively, compared with 50 Mt/ha/year in the control. Response to N was much more evident than response to K, which did not clearly affect yield until the 4th or 5th year. Potassium was effective only when N was well supplied.

Variation in total yield between treatments and between years was due to variations in both average bunch weight and the number of bunches harvested. Differences in average bunch weight between treatments increased with the age of the crop, but there was an overall decrease in bunch weight in all treatments after the second year. Bunch numbers, however, increased in each successive year except the 7th year, when many bunches were lost during a severe storm. Nitrogen fertilization increased the numbers of bunches harvested over the control in any year, but potassium had no consistent effect. The age-related decline in bunch weight is attributable to increased crop density, diseases, soil compaction, and reduced soil fertility.

Climate affected bunch weight more strongly than it affected harvest frequency and total yield. Effects of temperature and solar radiation on bunch weight are attributable to their effects on the components of bunch weight: number of hands and fingers, finger length and finger girth. The time period most critical for the effect of weather on the number of hands per bunch and the number of fingers on the second hand was during 6 to 7 months before harvest, 4 to 5 months before harvest for finger length, and 0 to 3 months for finger girth (which was closely related to temperature). Nitrogen and potassium also affected bunch components, particularly the number of hands and fingers; finger length was relatively less responsive and neither N nor K had much effect on finger girth.

The number of days from bunch emergence to harvest was strongly affected by the average temperature during bunch maturation and the N fertilization level. Bunches emerging in December from the highest N treatment required 130 days to mature compared with only 79 days for bunches in the zero-N treatment which emerged in July. Potassium had very little effect on the bunch maturation rate.

II. Total N and K uptake and concentration of N and K in Williams Hybrid banana plants at the bunch harvest stage.

Results and Discussion

Plant size and yield data of 26 pseudostems harvested in their entirety are given in Table 9.[1] Total dry matter yields of the various tissues into which the plants were subdivided are given in Appendix Table 7, concentrations of K and N are detailed in Appendix Tables 8 and 9, respectively, and total K and N amounts are summarized in Appendix Table 10. Concentrations of P, Ca, Mg, S, Mn, Fe, Cu and Zn are given in Appendix Tables 11 through 18, and total amounts of the respective elements summarized in Appendix Tables 19 through 26.

Bunch weight was highly correlated with total vegetative dry weight (r=0.81), total dry weight of leaves (including petioles, r=0.76), and dry weight of the pseudostem (r=0.75). The correlation between bunch weight and the computed pseudostem volume (cf. Section III) was significantly higher (r=0.94) than that obtained for bunch weight vs. total vegetative dry weight. The reason for this may be that pseudostem volume (which is closely correlated with leaf size) more accurately represented the leaf area and photosynthetic activity of the plant during critical growth phases prior to bunch maturity than total vegetative weight at harvest, which is more representative of the leaf area only at that time. In any case, bunch weight was also highly correlated with the weight of the leaf sections of the 3rd (r=.96), 4th (r=.92), and 5th (r=.91) leaves (Table 10).

---

[1] Refer to Methods and Materials for a description of the method of sampling.

TABLE 9

Descriptive summary of 26 individual Williams Hybrid banana pseudostems at harvest; sampled from the Waimanalo experiment during March to April, 1979.

Plant Number	N Level	K Level	Bunch Wt., Kg	Pseudostem Height, Cm	Pseudostem Girth, Cm	Pseudostem* Volume, Dm^3	No. of Hands	No. of Leaves
1	9	11	39.0	330	84	61.8	12	4
2	9	3	38.1	320	83	58.5	11	7
3	7	11	37.2	-	-	-	-	10
4	9	13	34.5	310	82	55.3	11	7
5	9	7	33.6	280	76	42.9	12	9
6	9	9	29.1	280	77	44.0	10	9
7	9	13	29.1	285	78	46.0	10	6
8	9	11	28.1	305	76	46.7	10	7
9	9	3	28.1	270	68	33.1	10	8
10	9	9	27.2	285	76	43.7	10	5
11	5	11	27.2	305	77	48.0	11	6
12	9	5	26.8	290	72	39.9	9	5
13	3	11	26.3	275	74	39.9	10	7
14	9	1	25.4	255	72	35.1	20	7
15	9	5	25.4	270	66	31.2	9	4
16	3	11	24.5	260	74	37.8	9	7
17	5	11	23.6	290	73	41.0	11	7
18	9	0	21.8	245	69	30.9	9	10
19	7	11	21.8	260	64	28.2	10	7
20	9	0	20.0	300	64	32.6	8	3
21	9	1	19.1	250	67	29.8	8	8
22	1	11	13.6	225	64	24.4	6	3
23	1	11	12.7	220	57	19.0	7	5
24	9	7	11.8	270	56	22.5	7	8
25	0	11	10.9	205	63	21.6	6	4
26	0	11	10.0	200	59	18.5	6	4

*cf. Section III for the method of computing pseudostem volume.

TABLE 10

Correlation coefficients for bunch weight vs. dry weight, N concentration and K concentration in some tissues of individual Williams Hybrid banana pseudostems at harvest; sampled from the Waimanalo experiment during March to April, 1979.

tissue	n (1)	dry wt.	%N	%K
petiole # 1	26	.42*	.49**	.14
2	26	.38	.41*	-.26
3	27	.60**	.29	-.32
4	26	.48*	.35	-.31
5	24	.56**	.25	-.27
6	20	.39	.07	-.27
7	17	.50*	.01	.00
8	15	.54*	-.13	-.13
leaf # 1	26	.25	.22	.09
2	26	.72***	.41*	-.20
3	26	.96***	.34	-.37
4	26	.92***	.48*	-.15
5	24	.91***	.45*	-.27
6	20	.84***	-.10	-.46*
7	17	.89***	.10	-.27
8	15	.86***	-.36	.10
pseudostem	26	.75***	.26	-.08
total vegetative	26	.81***	.34	-.19
bunch	26	1.00 (2)	.40*	.003

(1) number of pseudostems

(2) 18 percent dry matter assumed for all bunches

* sig. at 0.05 level

** sig. at 0.01 level

*** sig. at 0.001 level

Correlations between bunch weight and nutrient concentrations in any of the various plant parts were uniformly low (Table 10). The highest correlation was between bunch weight and the nitrogen concentration in the petiole of leaf 1 (r=0.49). The lowest correlation was between bunch weight and the K concentration of the bunch (r=0.003) reflecting the fact that K concentration in the bunches was nearly constant (cf. Appendix Table 8).

The negative correlations between bunch weight and K concentration in most tissues reflects the negative correlation between N and K in those tissues. The apparent antagonism between N and K in banana plants is a well-recognized phenomenon. The ratio of N to K in certain tissues has been suggested as being more important to the nutritional status and yield of bananas as the absolute level of either nutrient (Martin-Prével and Montagut, 1966; Martin-Prével, 1969).

The estimates of N and K removals in harvested fruit used in Section I were drawn from the data discussed in this section. The range of N concentration in the bunch on a fresh weight basis was 0.082% to 0.172%, averaging 0.131%. Regression of bunch N concentration against the relative N fertilizer level was highly significant:

$$\% \text{ N in bunch} = 0.007 \times \text{N level} + .084, \; r = 0.90$$

Total plant N concentration (bunch included) was also well correlated with the fertilizer N level (r=0.88).

Potassium concentration in these bunches was relatively constant. The range in values (fresh weight basis) was from 0.28% to 0.40%, with a mean of 0.36%. The range of predicted bunch-K based on regression against K fertilizer levels was only 0.33% to 0.38%, at the K-0 and K-13 levels, respectively. Because of these results, a constant value of 0.36% K was assumed for all bunches produced in the this experiment for the purpose of estimating total K removals.

It is obvious from Table 10 that the sizes of the various plant parts were much more closely related to bunch weight than nutrient concentrations. Consideration of the total quantities of N and K in the plant parts did not provide better estimates of bunch weight; total N or total K in any plant part was less well correlated with bunch weight than was the weight of the respective sample.

Besides being closely correlated with bunch weight, samples such as the leaf sections from leaves 3 or 4 may also provide an index for total pseudostem weight (bunch included). Some of the highest correlations between weight or size measurements vs. total plant weight (pseudostem + bunch) were as follows:

factor	Correlation coefficient
bunch weight	0.97
bunch length	0.94
wt. of leaf #3 section	0.94
" " " #4 "	0.92
" " " #6 "	0.92
no. of hands/bunch	0.90
pseudostem volume	0.89

Correlation coefficients for several factors vs. N concentration in the plant (pseudostem + bunch) are presented below:

factor	Correlation coefficient
% N in bunch	0.97
" pseudostem	0.94
" fruit stalk	0.92
" petiole #4	0.88
" " #2	0.88
" " #3	0.87
" " #6	0.84

The best correlation between total N concentration and the N concentration in any leaf blade sample was for leaf 5 (r=0.80); correlation coefficients for total-N vs. leaf-N for leaves 3 and 4 were r=0.69 and r=0.70, respectively. Obviously, petioles were superior to leaf laminae for assessing total N concentration.

Petiole samples were also relatively better than leaf samples when total K concentration was considered. Correlation coefficients for several factors vs. total K concentration were as follows:

factor	Correlation coefficient
% K in pseudostem	0.96
" petiole #3	0.93
" " #5	0.92
" " #2	0.88
" " #4	0.84
" bunch	0.82
" leaf #2	0.61
" " #4	0.41
" " #3	0.33

If one wishes to estimate total N and K uptake, the above results indicate a problem: leaf blade samples were suitable for estimating total weight, but N or K concentration in those tissues were poor indicators of total N or K concentration, relative to the N or K concentration in petiole samples. The weight of petiole samples was not well correlated with total weight, as were the leaf sections. For example, the best single leaf or petiole sample to estimate total K content was the weight of the section of leaf 5, without any chemical analysis performed (r=.76). Estimation of total N content was better: the N content of leaf section 4 was highly correlated with total N content, with r = 0.91. The weight, however, of this leaf section was equally as well correlated (r=0.90) with total N content.

Because differences in total nutrient content between plants were relatively more closely related to differences in total weight than to differences in total nutrient concentration, the easiest measurements to obtain which may provide a good estimation of total nutrient content are those which estimate total weight. Any estimate of bunch weight would be useful because bunch weight is a large percentage of total weight. One approximation of bunch weight is the number of hands at harvest, which requires that we only count the hands and apply some linear coefficients to predict the weight of the bunch (or of the entire pseudostem). Measurements of bunch length, pseudostem height and pseudostem girth were highly correlated with total weight in this study, as previously shown.

The best estimates for total N and K contents require at least one tissue sample to be analysed for nutrient concentration.

Various petiole samples provided good indices of both total N concentration and total K concentration.

In the presentation of data below the following factors were considered:

number of hands/bunch

number of leaves/pseudostem

pseudostem height

pseudostem girth

computed pseudostem volume[2]

bunch length

% N and K in petiole #2

" " " #3

" " " #4

" " in oldest remaining petiole

Stepwise regression models were tested to evaluate the significance of the above factors in estimating total N uptake and total K uptake.[3] Four separate models were tested respectively using data for petiole 2, 3, 4, or for the oldest petiole. This was done because it was felt that for practical application, sampling and analysis of two or more separate petioles would not significantly enhance the results. Statistics for these regression models are summarized in Table 11. In none of the models tested for either N or K were the pseudostem height, pseudostem volume,

---

[2] cf. Section III for the method of computing pseudostem volume.

[3] Data for plant #3 was excluded due to missing value for pseudostem size.

TABLE 11

F-ratios of stepwise regression for models of total nitrogen and potassium uptake vs. several plant parameters of Williams Hybrid banana pseudostems at harvest.

	F-ratios of individual parameter estimates (1)											F-ratio of model (2)	R^2
	petiole #									pseudo-stem girth	bunch length		
	2		3		4		last		number of leaves				
	%N	%K	%N	%K	%N	%K	%N	%K					
Total											43**	43	.65
Nitrogen	29**										43**	63	.85
	25**								4*		43**	50	.88
			21**								47**	50	.82
					35**						59**	71	.86
					31**				5*		59**	58	.89
								15**			30**	42	.79
							9**	18**			34**	42	.86
										38**		38	.62
		22**								81**		47	.81
		41**								5*	13**	53	.88
Total				18**						75**		42	.75
Potassium				48**						3	21**	59	.89
						16**				73**		40	.78
						36**				4	15**	48	.87
								11**		64**		32	.74
								22**		5*	10**	34	.83

(1) * sig. at .05 level
** " " .01 "

(2) n=25 for all models; model F-ratios all sig. at .001 level

or number of hands/bunch parameters significant at the .05 level; therefore, these factors do not appear in the table.

The most significant single factor correlating with total N uptake was the length of the bunch (R^2=0.65). The best two-factor combination was bunch length and the N concentration in petiole 4 (R^2=0.86). The best 3-variable model included the number of leaves after bunch length and the N concentration in petiole 4 (R^2=0.89). The number of leaves, however, in this model was significant only at the .05 level.

In estimating total K content the best single factor was pseudostem girth (R^2=0.62) rather than bunch length. The best two-factor model included pseudostem girth and the K concentration of petiole 2 (R^2=.78). Bunch length was more significant than pseudostem girth when included with girth and the K concentration in petiole 4, and this model provided a good estimate of total K uptake (R^2=.87).

Based on these results, a suitable method to evaluate both the N and K content of harvested psuedostems would seem to be as follows: count the number of healthy leaves remaining at the harvest, measure the length of the bunch, measure pseudostem girth and remove the petiole of leaf 4 for determination of N and K concentration. The prediction equations were:

$$\text{Total N, g} = 116\ L + 2.4\ F + 63\ N - 49; \quad R^2 = 0.89$$

$$\text{Total K, g} = 280\ L + 236\ G + 27\ K - 212; \quad R^2 = 0.87$$

where L = bunch length, cm; F = number of leaves; G = pseudostem girth, cm; N = % N in petiole 4; and K = % K in petiole 4.

Summary

Bunch weights of Williams Hybrid bananas were closely related to the size of vegetative parts of the pseudostem, particularly the size of individual leaves. There was little correlation between bunch weight and the concentration of N or K in any plant part, nor was there a close relationship between bunch weight and the total quantity of N or K in those parts. Plants with large bunches took up total amounts of N and K in proportion to the size of the bunch and pseudostem. There were variations in total uptake according to the respective fertilization levels. The amount of N in bunches and vegetative parts was closely related to N fertilization, whereas the amount of K in the bunches was nearly constant. A method of sampling harvested plants which allows a simple, reasonably accurate means of estimating total N and K uptake was shown.

Total N and K contents of harvested plants did not give a better explanation of bunch weight than simply the dry weight of various plant parts. The idea that total nutrient content would explain yield variability ignores some basics of plant physiology: namely, that absolute amounts of N and K determine only basic limitations on growth and functioning. It is the rest of a plant's chemical composition--carbon, hydrogen and oxygen--which more directly determine ultimate yield. Nutrient concentrations in plants at certain critical growth stages (especially floral differentiation) would more directly influence subsequent growth and yield.

III. Bunch weight of Williams Hybrid banana in relation to pseudostem size.

Proposed Yield Model

A banana pseudostem is shaped approximately as a circular cone, the volume of which is given by $V = \pi r^2 h/3$, where r is the basal radius, and h is the height. In terms of basal circumference (girth, g) this formula becomes $V = g^2 h/12\pi$. Assuming that bunch weight is proportional to pseudostem weight, and that pseudostem weight is proportional to pseudostem volume, then bunch weight will be directly proportional to pseudostem volume (cf. Section II).

If bunch weight is related to pseudostem girth by an equation such as $y = ag^c + b$, the conic volume formula just stated is directly applicable: e.g., with $a = h/12\pi$, $b = 0$, and $c = 2$. However, in the slope term, pseudostem height (h), a variable, is in the numerator. Thus, if the pseudostem volume model is a truer approximation of bunch weight than either linear or quadratic models which are based only on pseudostem girth, then pseudostem height variation must not be ignored. Pseudostem height could be eliminated as a variable in the model by replacing it with a constant, estimable by pseudostem girth; e.g., $h = mg + n$, where m and n are empirical constants. The volume formula would then become a function only of pseudostem girth, $V = (mg^3 + ng^2)/12\pi$, with the second-order term dropping out if $n = 0$.(1) This suggests bunch weight might be linearly dependent on the cube of pseudostem girth.

[1] It will be seen later (Table 12, model number 13) that this term, n, was relatively small, and that the second-order term in the cubic model (Table 12, number 7) was non-significant.

The work reported in this section examined these and other yield models. Several models for bunch weight vs. pseudostem size (height, girth, or volume) and for pseudostem height vs. pseudostem girth using data selected randomly from the entire experiment (May, 1972 to April, 1979) were tested by linear regression. The results are summarized in Table 12. H.N. Hasselo's (1962) regression coefficient idea, presented in the Review of Literature, was examined with respect to various yield-influencing factors for which data were available.

Preliminary Results

There was some improvement over the 1st order model (1) if the pseudostem girth variable was squared (3) or cubed (4), suggesting that bunch weight did increase non-linearly in proportion to pseudostem girth. Pseudostem height was less well correlated with bunch weight than pseudostem girth; the linear (2) and log-log (10) models produced R^2's of 0.48 and 0.49, respectively.

Although pseudostem height was highly correlated with girth and the relationship between height and girth was essentially linear (models 13 and 14), there was enough independence of height from girth to significantly account for some of the residual variability of bunch weight (as a function only of girth): R^2 increased from 0.52 to 0.54 when pseudostem height was included with pseudostem girth in a 1st-order model (5) and increased to 0.55 if the square of pseudostem girth was also included (6). The log-log model of bunch weight vs. pseudostem girth (11) was also improved by the addition of the height variable (12).

The pseudostem volume model (9) predicted bunch weight more accurately than the pseudostem girth model (1) although the intercept term

TABLE 12

Regression equations for bunch weight vs. pseudostem height, girth, and volume and for pseudostem height vs. pseudostem girth of Williams Hybrid banana.

Model #	Dependent Variable	Model Regression Equation*	R^2**
1	Bunch wgt, kg	$= 0.80\ g - 30.3$	.52
2	"	$= 0.19\ h - 23.7$	.48
3	"	$= 0.0061\ g^2 - 4.4$	.53
4	"	$= 6.0 \times 10^{-5}\ g^3 + 4.5$	.53
5	"	$= 0.54\ g + 0.075\ h - 31.5$	.54
6	"	$= -1.0\ g + 0.012\ g^2 + 0.074\ h + 19.2$	.56
7***	"	$= 0.0012\ g^2 + 4.8 \times 10^{-5}\ g^3 + 2.7$	.53
8	"	$= -9.4\ g + 0.14\ g^2 - 6.8 \times 10^{-4}\ g^3 + 204$	.54
9	"	$= 607\ V + 4.2$	.55
10	"	$= 9.02 \times 10^{-5}\ h^{2.24}$	.49
11	"	$= 5.87 \times 10^{-4}\ g^{2.50}$	.52
12	"	$= 1.19 \times 10^{-4}\ g^{1.57} \times h^{1.00}$	.55
13	Pseudostem ht, cm	$= 3.6\ g + 15.0$	.74
14	"	$= 4.9\ g^{0.94}$	.74

*g = pseudostem girth (cm); h = pseudostem height (cm); V, $m^3 = g^2h/(12\pi \times 10^6)$
note: model numbers 10, 11, 12 and 14 are of the log-log form; i.e. log (dependent) = linear combination of log (independent).

**n = 3472 for all models; all parameter estimates very highly significant (p=.0001), with the exception of eqn. #7.

***g^2 parameter and intercept both non-significant at 0.1 level of the volume model (4.2 kg) was positive and highly significant. If the proposed model were correct, the intercept should have been equal to zero. There is at least one explanation for the non-zero intercept of the volume model. Because weight is biologically dependent on the mass of the entire plant (roots, pseudostem, leaves), the data is inadequate because some of the pseudostem (below 30 cm), the entire corm and root mass, and the leaves were not directly accounted for by the data used in the model. Also, the calculations did not take into account that at the point where height was measured the pseudostem girth was greater than zero; viz. the pseudostem is not pointed like a true cone, as was assumed by the model. Some plant parts that contribute to size and physiological functions vital to bunch production were excluded. This may be why positive bunch weights were predicted for (hypothetical) plants having zero volume, whereas in reality the intercept should occur at or below the origin (i.e. bunch weight should reduce to zero before plant size is reduced to zero).[2]

Modifying Effects of Nitrogen Fertilization

The set of data described above was sorted according to nitrogen fertilizer treatment (6 sub-sets). Three of the above models (1,9,13) were applied to the data of each sub-set. Results are summarized in Table 13.

While bunch weight, pseudostem girth, and pseudostem height all increased in response to nitrogen fertilization the regression

---

[2]The number (and size) of leaves will be considered later but no account was made for other parts of the pseudostem.

TABLE 13

Summary statistics and regression model coefficients for banana bunch weight in relation to pseudostem girth and volume and between pseudostem height and girth of Williams Hybrid banana at six levels of N fertilization.

Relative Nitrogen Rate	Variables*				Model: $Y = B_1G + B_o$			$Y = B_1V^{**} + B_o$			$H = B_1G + B_o$		
	n	G	H	Y	B_1	B_o	R^2	B_1	B_o	R^2	B_1	B_o	R^2
0	495	61.6	222	18.3	0.94	-39.8	.53	911	-3.0	.67	3.25	21.3	.70
1	517	63.0	234	19.3	0.70	-24.9	.39	699	1.4	.50	2.99	45.3	.65
3	578	67.1	255	23.6	0.68	-22.0	.40	551	6.1	.44	3.22	38.7	.72
5	596	68.8	267	26.0	0.79	-28.4	.47	576	5.8	.48	3.39	33.6	.74
7	626	70.1	272	27.5	0.79	-28.0	.50	562	6.7	.50	3.26	43.3	.73
9	660	70.3	270	28.3	0.74	-23.8	.45	510	9.6	.45	3.33	36.1	.68

*n = no. of bunches, G = mean pseudostem girth, cm, H = mean pseudostem height, cm, Y = mean bunch weight, kg

**$V = (G^2H)/12\pi \times 10^{-6}$

coefficient of the pseudostem girth model did not vary appreciably, nor did the intercept term show any consistent trend. While this does not lend support to Hasselo's idea that fertility status will affect the magnitude of the regression coefficient, at the same time it does not indicate the existence of a higher-order relationship between bunch weight and pseudostem weight or volume.

Assuming that the regression coefficient should have been related to N level, one reason that it was not may be that the range in mean pseudostem girth between N-0 and N-9 was small, being less than 9 cm. The coefficient of variation for pseudostem girth was about 12.5 percent at each nitrogen level, and thus there was considerable overlap of the range of values in each sub-set.

The regression parameters of the volume model did correspond to the trend in bunch weight. The correspondence was unexpected, as the slope decreased quite markedly (from 911 kg/m^3 to 510 kg/m^3) as mean bunch weight increased with increasing N. The intercept term correlated positively with the increase in mean bunch weight.

If there were no other criteria to go by, one might be willing to accept the simple, linear pseudostem girth model because its equation parameters were fairly constant over a range of nutritional levels, mean pseudostem sizes and bunch weights. However, a comparison of the coefficients of determination (R^2) between the models reveals that at the lowest N levels the pseudostem girth model was much less successful than the volume model in predicting bunch weight. Apparently, when plant volume is relatively small and/or when N is in short supply the height of the pseudostem is an important factor in the relationship between pseudostem size and bunch weight.

The relationship between pseudostem height and pseudostem girth was approximately the same regardless of nitrogen treatment, a result which was a little surprising considering the above results.

Modifying Effects of Potassium Fertilization

The original data sub-set was re-sorted according to potassium fertilizer treatments (8 levels) and reexamined using the same models as for the nitrogen sub-sets. The results are presented in Table 14.

The response to K in terms of bunch weight, pseudostem girth and pseudostem height was significant, but not as dramatic as the response to nitrogen (cf. Section I). The slope and intercept terms of the pseudostem girth model were practically invariant. The slope of the volume model decreased with increased bunch weight while the intercept increased.

The height vs. girth relationship was not as constant in the K sub-sets as it was in the case of nitrogen. There was some increase of the slope and decrease of the intercept through the K-5 level. The intercept term was non-significant from K3 to K11 (at K13, however, it was highly significant).

Modifying Effects of Climate

To evaluate seasonal climate effects the data was sorted by calendar month (12 sub-sets) and the same models were applied to each sub-set. Results are given in Table 18.

Mean pseudostem height, girth, and bunch weight were greatest in September through March, becoming depressed during the spring and summer

TABLE 14

Summary statistics and regression model coefficients for banana bunch weight in relation to pseudostem girth and volume and between pseudostem height and girth of Williams Hybrid banana at eight levels of K fertilization.

Potassium Rate	Variables*				Model: $Y = B_1G + B_o$			$Y = B_1V^{**} + B_o$			$H = B_1G + B_o$		
	n	G	H	Y	B_1	B_o	R^2	B_1	B_o	R^2	B_1	B_o	R^2
0	444	63.1	240	21.0	0.88	-34.6	.51	787	0.3	.57	3.10	44.7	.62
1	440	64.2	245	22.0	0.88	-34.5	.42	785	0.4	.51	3.40	26.7	.62
3	428	65.9	252	23.3	0.82	-31.2	.50	682	2.6	.55	3.54	18.1	.72
5	423	67.2	256	24.2	0.80	-29.7	.49	624	4.1	.54	3.84	-1.6	.75
7	417	68.4	260	25.1	0.80	-29.6	.50	590	5.1	.51	3.70	7.0	.75
9	425	69.1	262	25.8	0.81	-30.2	.53	583	5.4	.57	3.86	-5.3	.77
11	434	68.9	261	25.2	0.82	-31.2	.54	585	4.9	.56	3.66	9.0	.76
13	471	70.5	265	27.0	0.82	-30.5	.52	590	5.5	.54	3.38	26.6	.75

*n = no. of bunches, G = mean pseudostem girth, cm, H = mean pseudostem height, cm, Y = mean bunch weight, kg

**V, $m^3 = (G^2H)/12\pi \times 10^{-6}$

TABLE 15

Summary statistics and regression model coefficients for banana bunch weight in relation to pseudostem girth and volume and between pseudostem height and girth of Williams Hybrid banana by calendar months.

	Variables*				Model: $Y = B_1G + B_o$			Model: $Y = B_1V^{**} + B_o$			Model: $H = B_1G + B_o$		
Month	n	G	H	Y	B_1	B_o	R^2	B_1	B_o	R^2	B_1	B_o	R^2
Jan	327	69.6	270	27.4	0.98	-40.9	.54	663	3.5	.55	3.55	23.1	.68
Feb	284	67.6	262	24.4	0.93	-38.8	.54	710	1.0	.59	3.57	20.4	.65
Mar	312	69.2	267	24.7	0.93	-39.9	.61	643	2.2	.63	3.56	20.1	.70
Apr	293	67.3	256	21.8	0.79	-31.5	.59	580	3.3	.58	3.39	27.4	.70
May	313	64.9	243	20.9	0.54	-13.8	.38	458	7.7	.45	3.64	6.8	.78
Jun	379	63.5	236	22.0	0.48	-8.2	.31	416	10.7	.36	3.61	7.4	.82
Jul	330	65.2	242	21.2	0.73	-26.8	.51	605	3.8	.55	3.25	30.1	.74
Aug	253	64.8	243	22.0	0.77	-27.6	.52	638	3.8	.53	3.01	47.2	.73
Sep	205	67.0	251	24.6	1.05	-46.0	.63	780	0.1	.62	3.30	29.7	.75
Oct	242	69.0	263	27.2	1.02	-43.1	.63	687	3.2	.62	3.59	14.4	.76
Nov	270	69.0	265	28.1	0.99	-40.4	.57	674	4.6	.53	3.42	28.5	.69
Dec	264	70.1	270	28.0	0.92	-37.0	.53	652	4.2	.56	3.44	28.2	.65

*n = no. of bunches, G = mean pseudostem girth, cm, H = mean pseudostem height, cm, Y = mean bunch weight, kg

**V, $m^3 = (G^2H)/12\pi \times 10^{-6}$

(cf. Section I). In contrast to the non-effects of N and K, the parameters of the pseudostem girth model were correlated with this seasonal effect. The slope ranged from 0.48 to 0.79 kg/cm from April until August, but was from 0.92 to 1.05 kg/cm during the high yield season, thus corresponding to the trend in bunch weight. As in Hasselo's (1962) data, the intercept term had the opposite trend: intercepts were greatest when bunch weights were low and the slopes were flat.

The volume-model slope was positively correlated with bunch weight in contrast to the consistent negative relationship between slope and bunch weight in the nitrogen and potassium sub-set analyses. The volume-model intercepts were negatively correlated with the respective slope. The height vs. girth relationship throughout the year was about the same in any month. In contrast to the N and K sub-set analyses, the volume model was generally less accurate than the pseudostem girth model when applied to the monthly data sub-sets.

Modifying Effects of Crop Age

The data was sorted and analyzed by crop age (7 years; Table 19). The most significant feature of the crop age effect was that the accuracy of both models, as indicated by the R^2 value, was much higher than those obtained in the nitrogen, potassium, or seasonal sub-sets. This suggests that crop age has been more influential than N, K or season on bunch weight relative to pseudostem size, and is in agreement with the findings discussed in Section I.

The slope coefficient of the pseudostem girth model corresponded to fluctuations of mean pseudostem girth and height slightly more consistently than to the variation in mean bunch weight. For the 6th year data

TABLE 16

Summary statistics and regression model coefficients for banana bunch weight in relation to pseudostem girth and volume and between pseudostem height and girth of Williams Hybrid banana for seven consecutive years.

Production Year	Variables*				Model: $Y = B_1G + B_o$			$Y = B_1V^{**} + B_o$			$H = B_1G + B_o$		
	n	G	H	Y	B_1	B_o	R^2	B_1	B_o	R^2	B_1	B_o	R^2
1	254	60.4	221	31.4	0.80	-17.0	.87	720	14.6	.90	3.58	4.7	.89
2	418	70.0	269	34.6	1.06	-40.0	.73	704	9.3	.72	3.45	27.5	.64
3	469	67.3	262	27.1	0.96	-38.0	.77	730	3.0	.79	3.15	49.5	.68
4	502	65.6	256	22.2	0.82	-31.6	.75	643	2.4	.80	3.35	36.4	.71
5	509	67.6	254	23.5	0.90	-37.0	.81	669	2.0	.82	3.39	24.9	.73
6	531	69.1	256	22.1	0.95	-43.8	.81	663	-0.2	.84	3.63	4.9	.71
7	593	66.8	253	18.1	0.80	-35.6	.79	576	-0.0	.82	3.87	-6.1	.79

*n = no. of bunches, G = mean pseudostem girth, cm, H = mean pseudostem height, cm, Y = mean bunch weight, kg

**V, $m^3 = (G^2H)/12\pi \times 10^{-6}$

mean pseudostem girth and pseudostem height and the regression slope of the model were higher than for the 5th year, while mean bunch weight was lower. The increased slope was offset by an unusually low value of the respective intercept. This is contrary to Hasselo's (1962) results: in those data slope coefficients were more closely matched with mean bunch weight than with mean pseudostem girth.

With the exception of the 2nd year data, both of the volume model parameters generally corresponded to the trend in bunch weight.[3] In the first year, however, mean pseudostem girth and height were the lowest of the entire period, while bunch weight in that year was second only to the peak mean bunch weight in the 2nd year. It is not the slope which is unusually high for the first year data, but the intercept: e.g., large bunches were obtained regardless of pseudostem size.

The height-girth relationship over the period of the experiment did not change radically, but a trend towards increased slopes and non-significant intercepts occurred since the 3rd year.

Crop Age and Fertility Interactions

After sorting by years and N- or K-treatment (only the lowest and highest N and K levels will be discussed here), the data was further sorted by integral values of pseudostem girth. Means for bunch weight, number of hands per bunch, number of fingers per hand, finger size, pseudostem height and number of leaves at harvest were computed for the 1st year - low N, 1st year - high N, 1st year - low K, 1st year - high

---

[3] Recall that in the seasonal analysis the slope was positively correlated but the intercept was negatively correlated with bunch weight.

K, 6th year - low N, 6th year - high N, 6th year - low K and 6th year - high K subsets for each pseudostem girth category.

Mean bunch weights in the first and sixth years at high and low N are plotted against pseudostem girth in Figure 24. Even in the first year, when relatively large plants were being produced in the zero-N treatments (as a result of native fertility), there was a response to N in terms of bunch weight relative to pseudostem girth. However, the difference in bunch weight between high and low N vanishes at the larger pseudostem sizes, which suggests that small plants were preferentially benefitted by nitrogen fertilization. In the sixth year pseudostem size at the low N level was quite restricted, with maximum pseudostem girth seldom exceeding the pseudostem girth of average-sized plants at the high-N level. Plants having pseudostem girth in the 50-55 cm range in the first year were capable of producing bunches weighing 15-25 kg, but in the sixth year plants of that size produced bunches weighing only 7-9 kg.

Pseudostem height relative to pseudostem girth was very little affected by nitrogen in the first year, but by the sixth year there was apparently a strong positive influence of N (Fig. 25). This apparent response to N, however, resulted from N depletion in low N treatments rather than from a positive influence of added nitrogen. In the first year pseudostems having a 60-cm girth were about 220 cm in height at both high and low N. But in the sixth year pseudostems 60 cm in girth were only about 200 cm high at low N vs. 230 cm at high N. In any case, reduced pseudostem height at low N in the sixth year probably does not account for the reduced bunch weight in low N treatments, because bunch

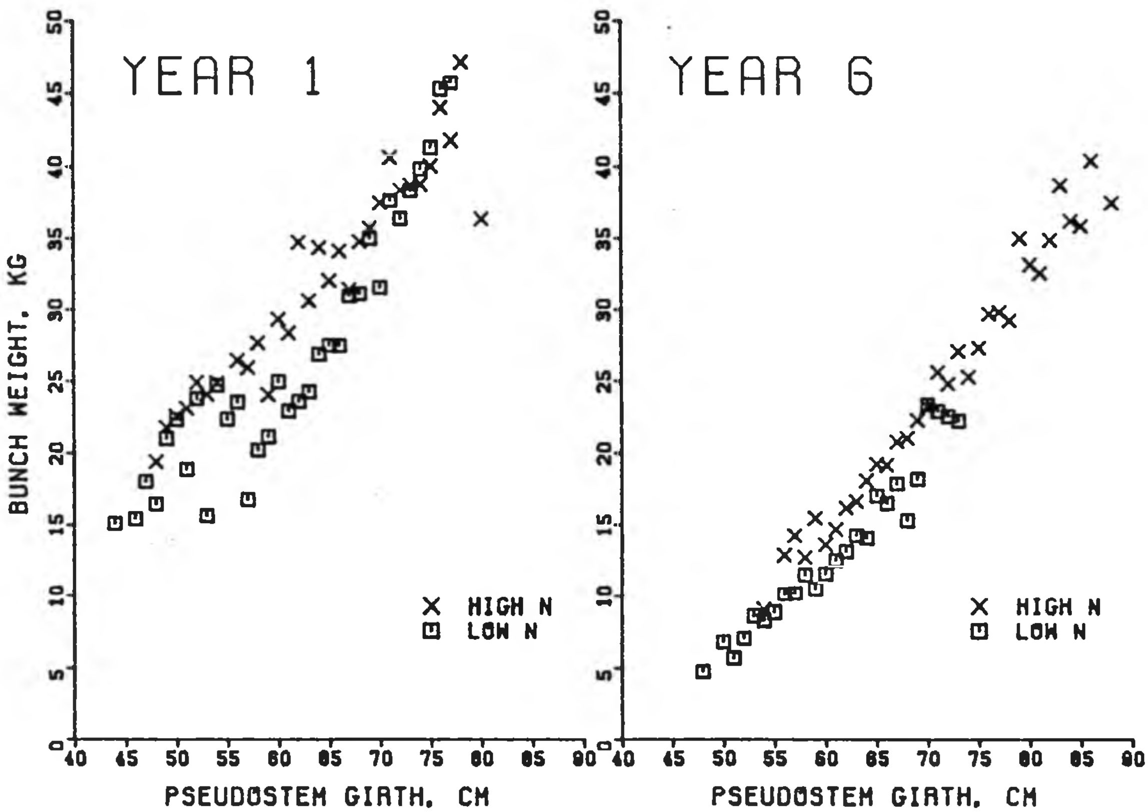


Fig. 24. Relationship between bunch weight and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

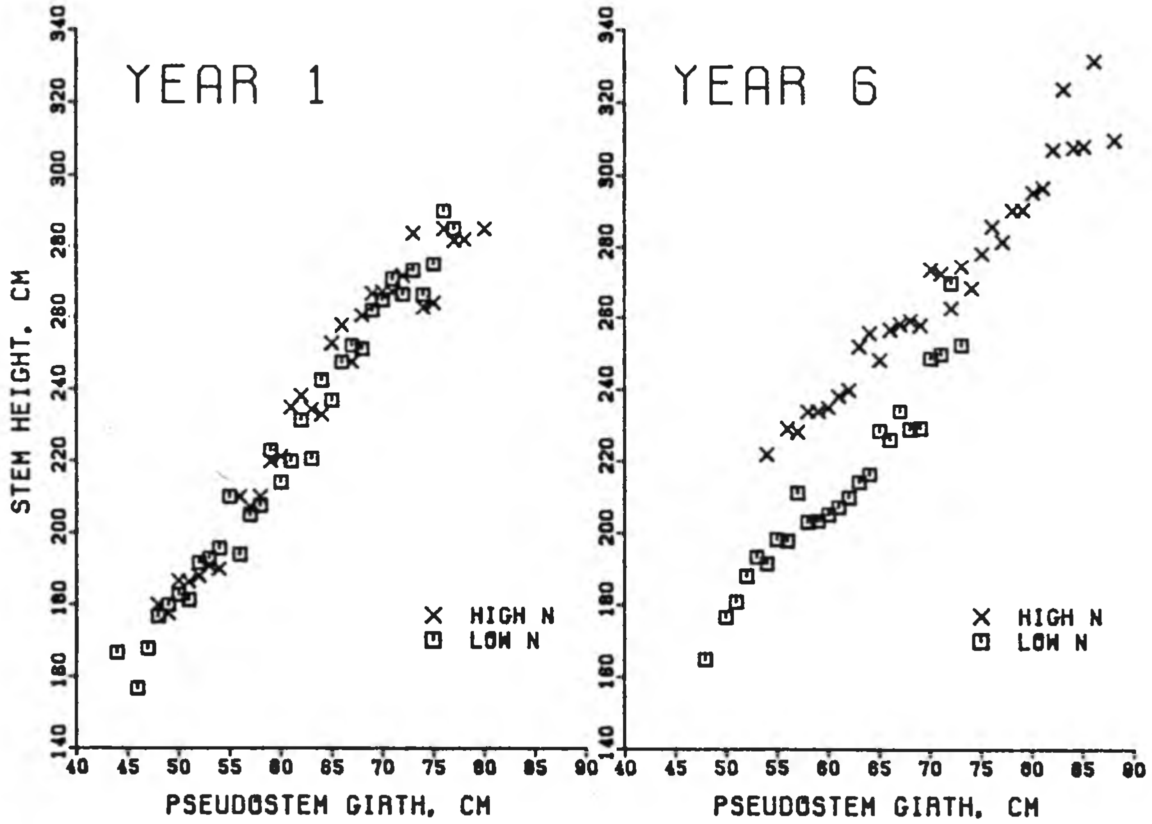


Fig. 25. Relationship between pseudostem height and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

weights in the high N treatments were also reduced from the first year (cf. Fig. 24).

Closely associated with bunch weight are the number of hands per bunch (Fig. 26) and number of fingers per hand (Fig. 27), both of which were reduced from the first year relatively more on smaller plants than large plants in the sixth year. The reason for the high variability in the number of fingers per hand in the first year is unknown. Mean finger size, while certainly related to pseudostem girth and bunch weight, was not affected by N status (Fig. 28). This point was also made in Section I (cf. Table 5 and 6).

The number of healthy leaves retained at harvest was somewhat greater on high-N plants vs. low-N plants in the first year (plant crop data not available), but not in the sixth year (Fig. 29). The most striking feature of the data in Figure 29 is that the number of leaves per plant drastically declined between the first and sixth year regardless of pseudostem size or N status.

Bunch weight in relation to pseudostem girth for low vs. high K is shown in Figure 30. As with nitrogen, in the first year bunch weight at both high and low K levels varied greatly. For a given pseudostem size bunch weight was not influenced by K in either the first or sixth years. Potassium had no effect on pseudostem height in either the first or sixth year (Fig. 31).

The number of hands per bunch was not influenced by K during the first year but in the sixth year high K seemed to exert a negative effect, especially if pseudostem girth was in the range from 55 to 65 cm (Fig. 32). By the sixth year there were fewer hands per bunch on

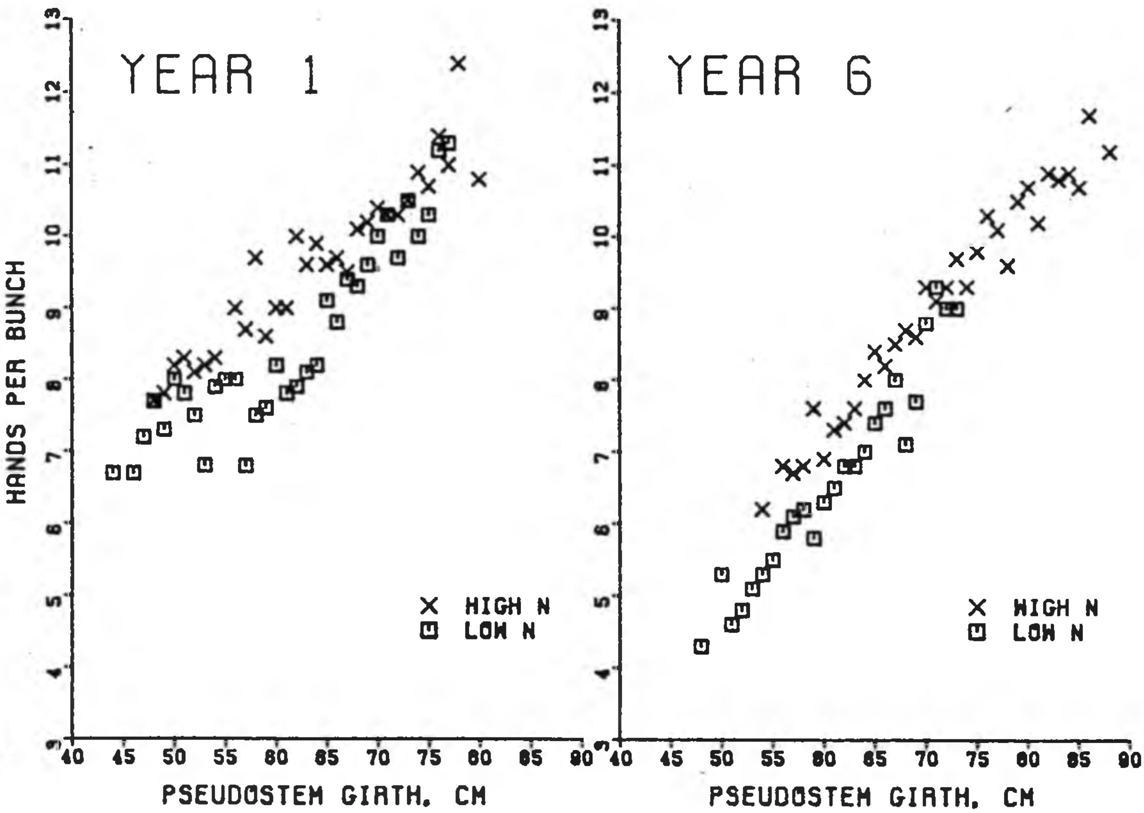


Fig. 26. Relationship between the number of hands per bunch and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

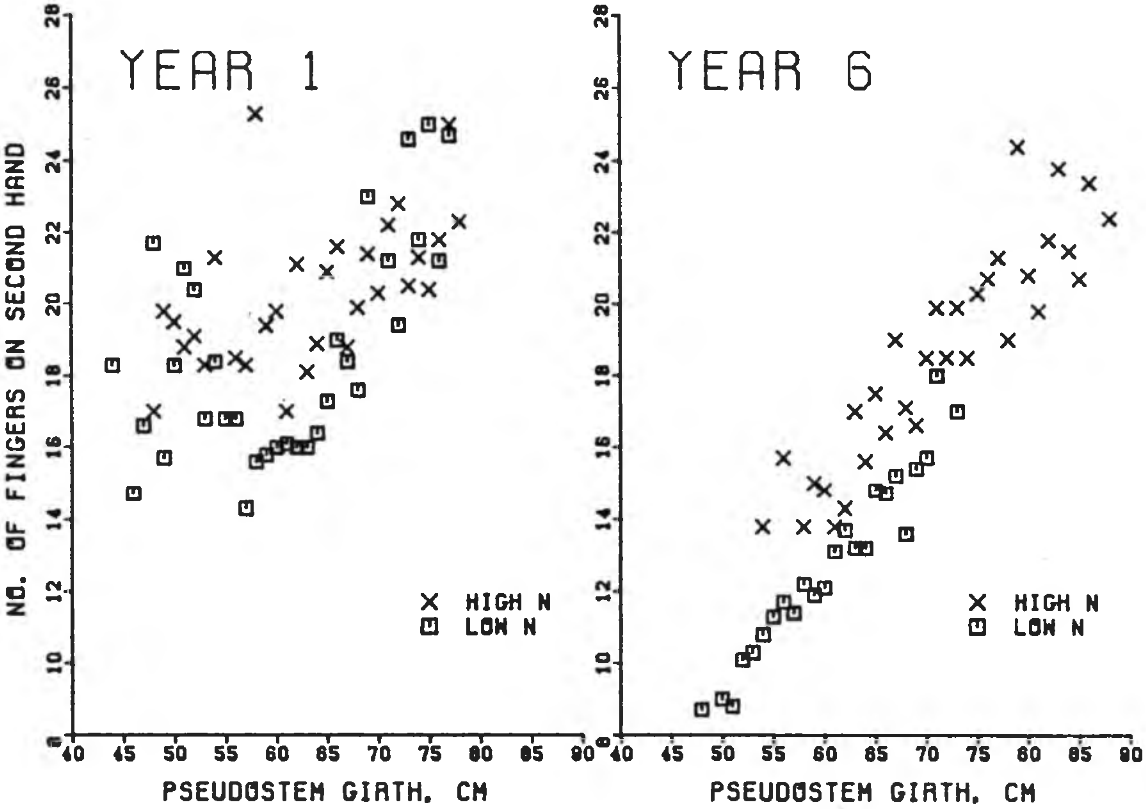


Fig. 27. Relationship between the number of fingers on the second hand and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

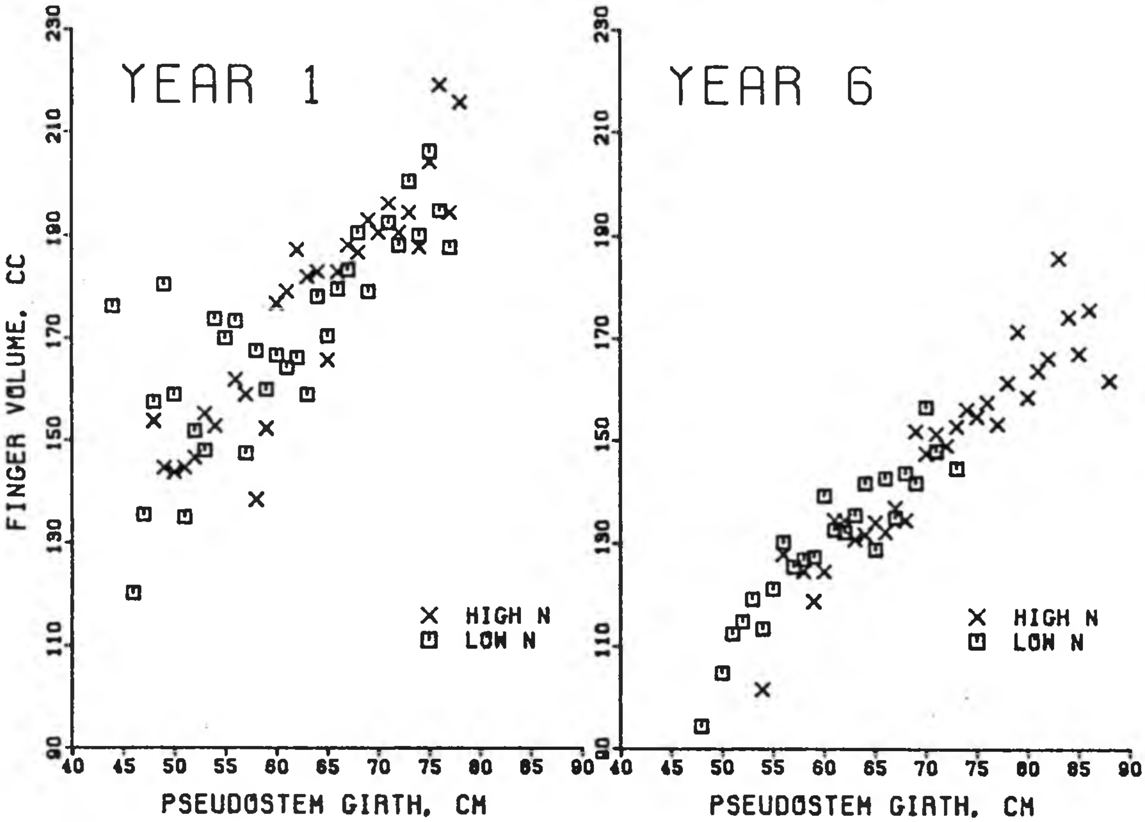


Fig. 28. Relationship between the volume of the middle finger of the second hand and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

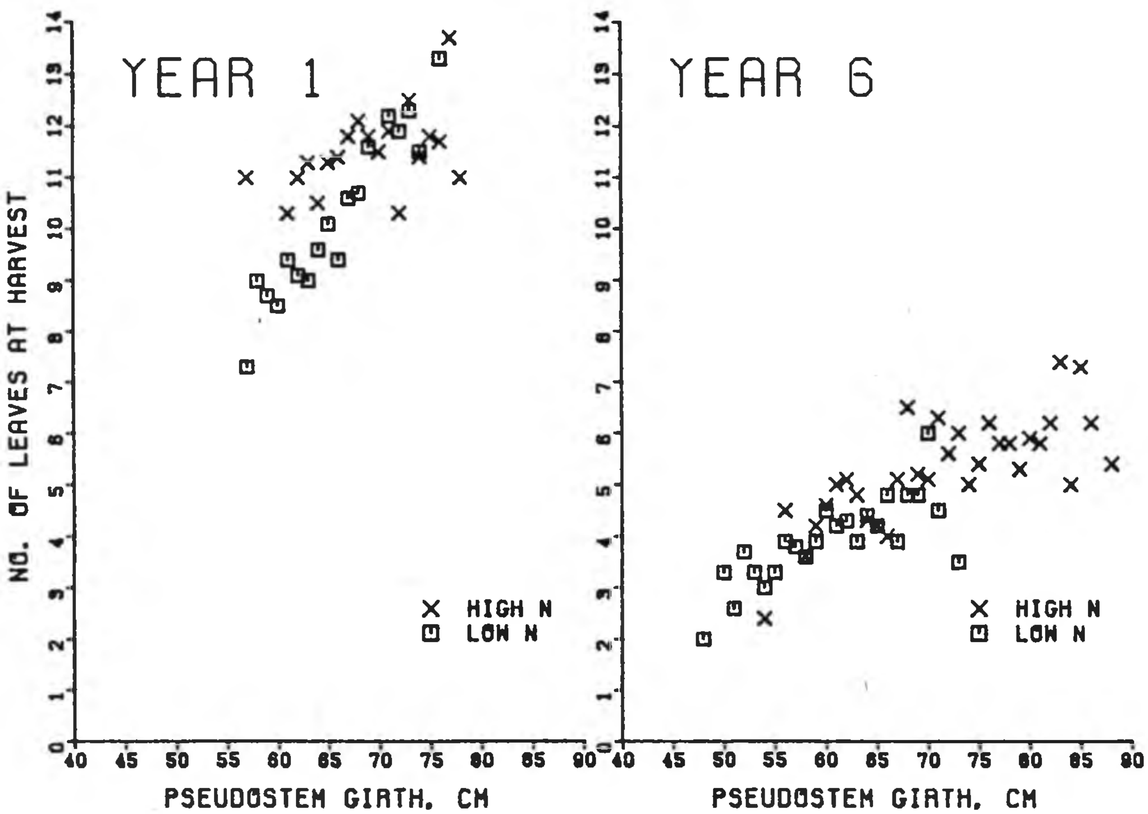


Fig. 29. Relationship between the number of leaves remaining at harvest and pseudostem girth of Williams Hybrid bananas at two N fertilization levels and two crop ages.

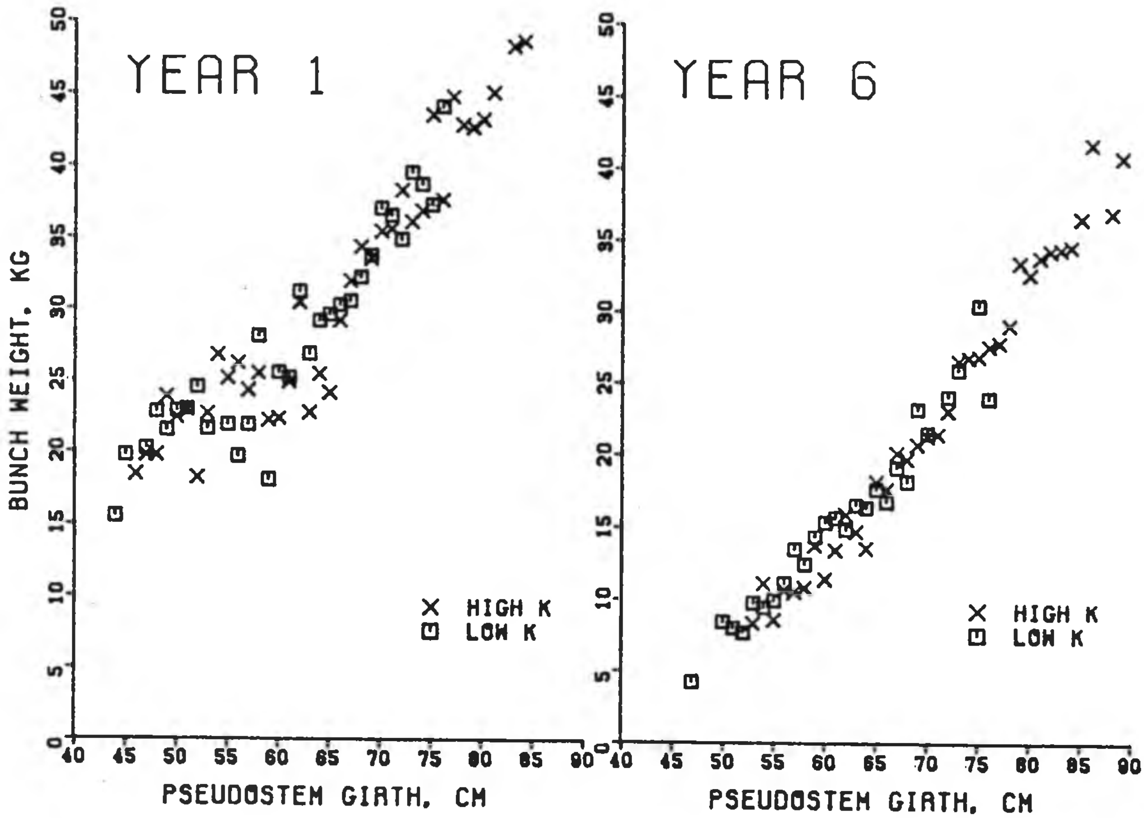


Fig. 30. Relationship between bunch weight and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

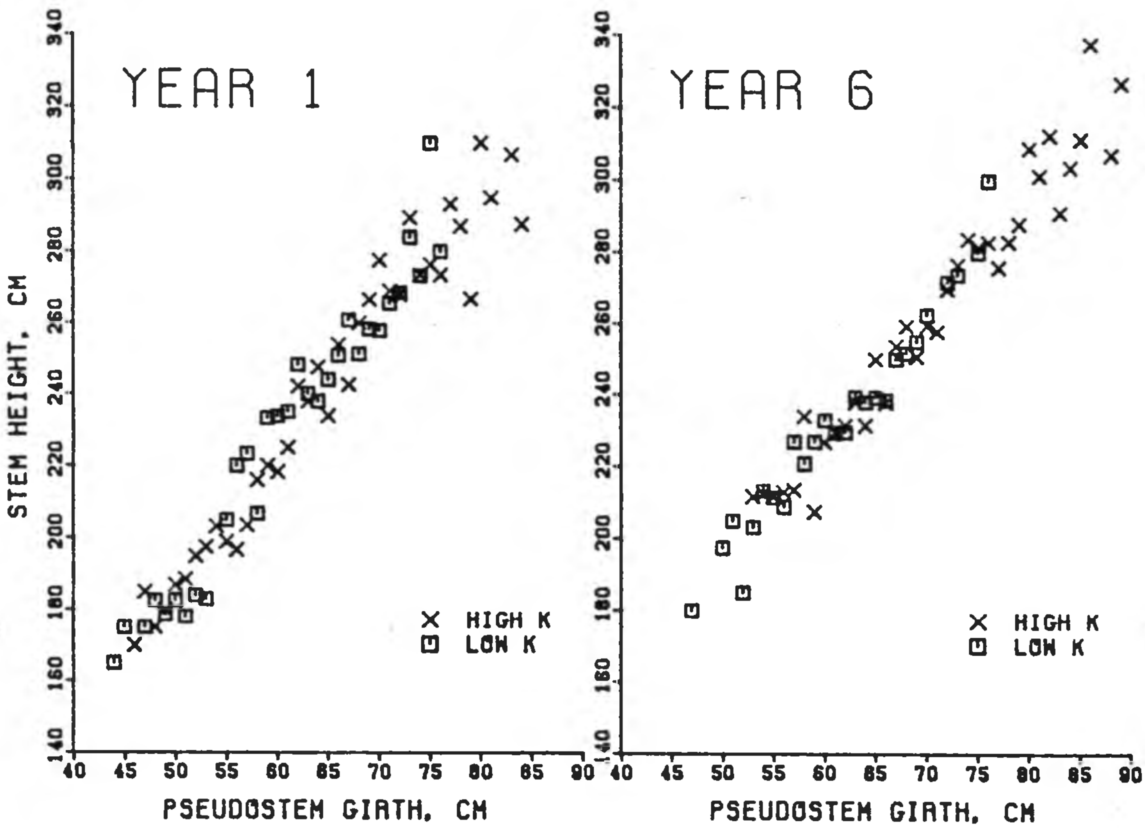


Fig. 31. Relationship between pseudostem height and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

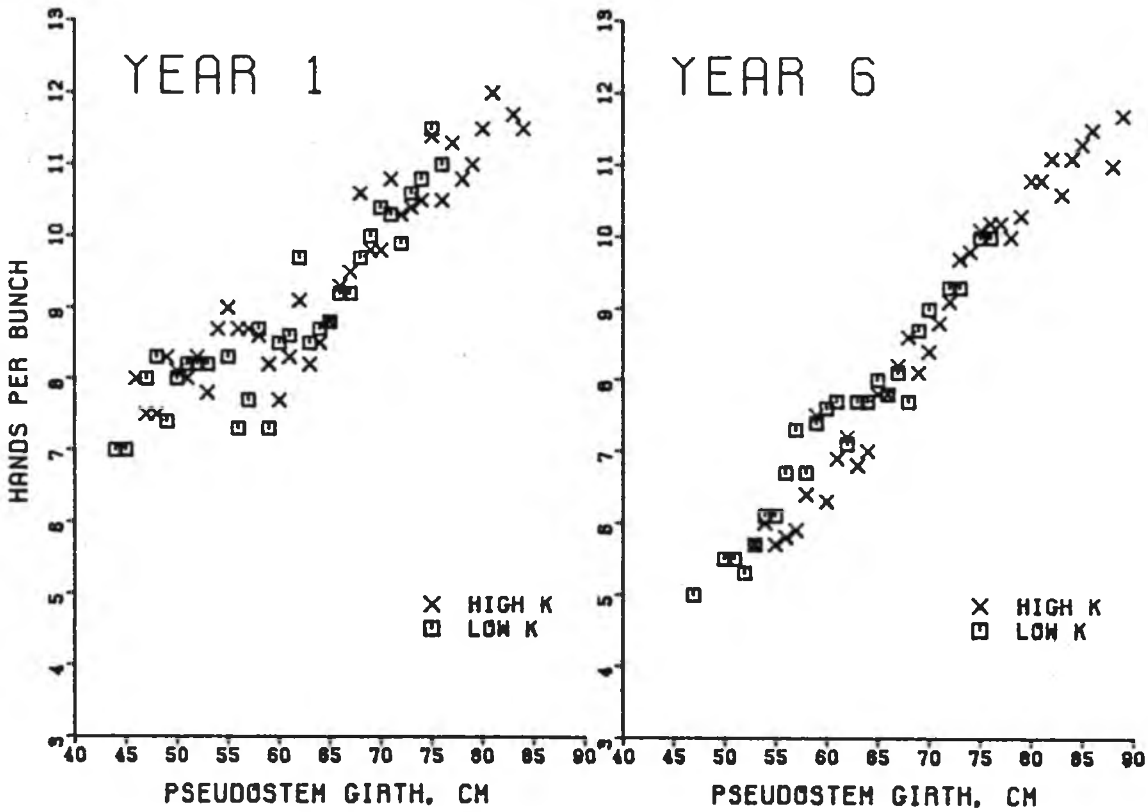


Fig. 32. Relationship between the number of hands per bunch and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

smaller plants regardless of K level, while large plants had nearly the same numbers of hands as large plants in the first year.

In the sixth year high K was also associated with slightly fewer fingers per hand (Fig. 33). As with the number of hands per bunch, the overall decrease in numbers of fingers per hand from the first to sixth years mainly occurred on smaller plants.

Mean finger size relative to pseudostem girth was not influenced by K in the first year but may have been increased by K in the sixth year (Fig. 34), certainly more so than by N (cf. Fig. 28; Tables 5 and 6). In contrast to the number of hands per bunch and number of fingers per hand, mean finger size at all pseudostem sizes declined after the first year.

Leaf counts were positively correlated with K status on small plants in the sixth year (Fig. 35). (Recall that neither leaf count nor finger size was strongly affected by N in the sixth year, cf. Figs. 28 and 29.) Since functional leaf area just prior to harvest is likely to have an immediate effect on individual finger size (as opposed to an effect on the number of hands per bunch or the number of fingers per hand, which are both fixed at shooting), this may explain why larger fingers were associated with high K. Regardless of the effect of K on leaf retention, the over-riding effect was that leaf counts decreased over 50 percent between the first year and sixth year, especially on small plants. This occurred at all N and K fertility levels.

General Age-Related Factors Influencing Leaf Count and Bunch Weight

The number of leaves per pseudostem at harvest (monthly means of all fertilizer treatments; plant crop data not available) over the

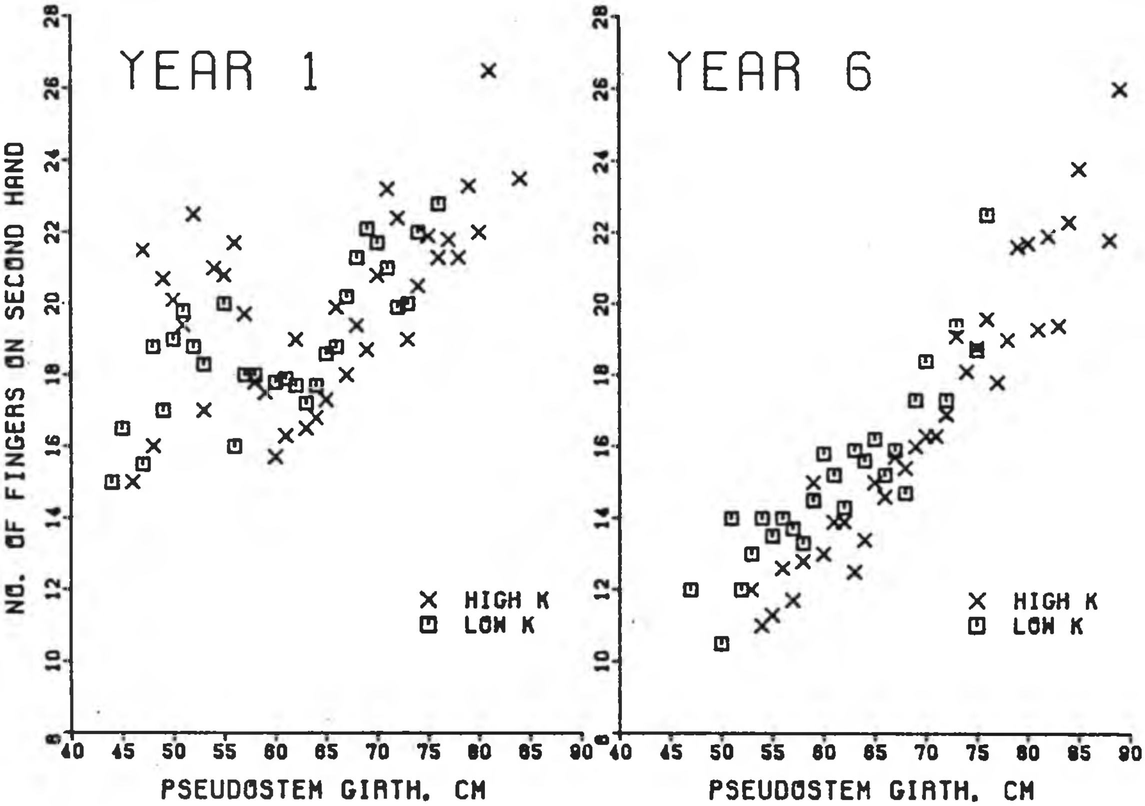


Fig. 33. Relationship between the number of fingers on the second hand and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

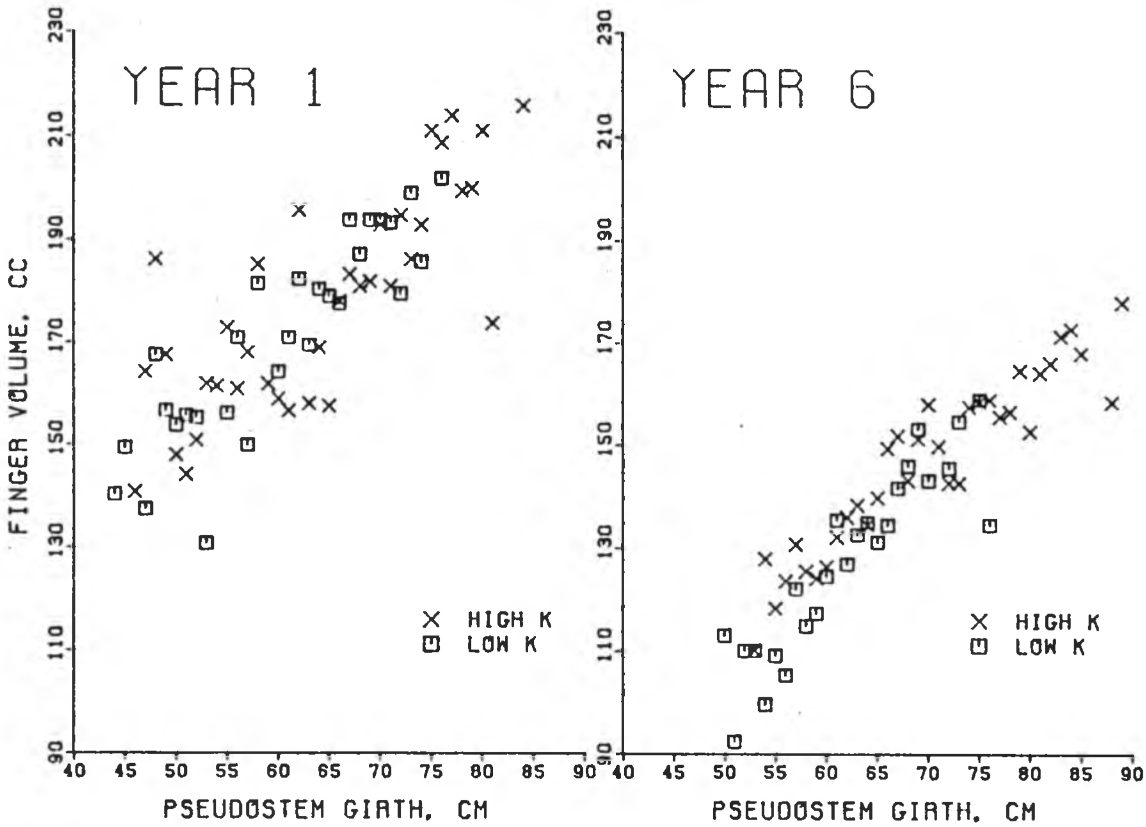


Fig. 34. Relationship between the volume of the middle finger of the second hand and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

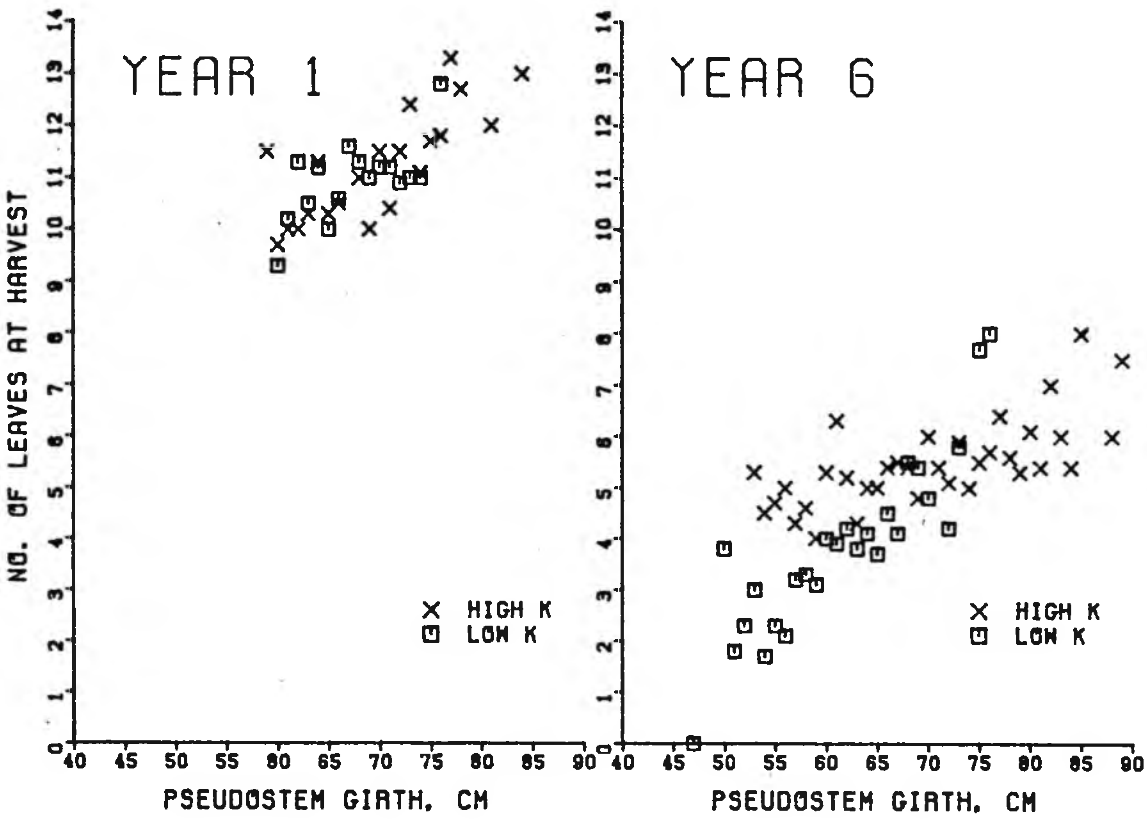


Fig. 35. Relationship between the number of leaves remaining at harvest and pseudostem girth of Williams Hybrid bananas at two K fertilization levels and two crop ages.

7-year period are shown in Figure 36. Besides a steady decline from 12 leaves per pseudostem at a rate of 2.7 leaves per year, there were sharp fluctuations corresponding to season. A drastic defoliation which began after November 1974 was associated with the outbreak of Black-leaf Streak disease (Mycosphaerella fijiensis). After that time spraying and field sanitation were instituted; nevertheless the disease and defoliation continued.

The reason for the initial decline of leaf count and its continued decline may be related to the effect of this disease or other stress factors associated with high crop density. Figure 6 showed that crop density increased steadily, especially at high N rates after the first year. High density leads to shading of lower leaves and this in itself may directly contribute to bunch weight decline. We cannot say that density per se caused the premature leaf senescence evident in Figure 36. It is likely that the combined effects of shading, disease severity and persistence, and increased nutritional and moisture stress due to higher density all contributed to defoliation and general decline in bunch weight.

Walker, 1973; Costas, 1968; Sarma and Roy, 1972; Spurling and Spurling, 1975a and others have shown that high crop densities usually result in reduced bunch weight. It is unclear whether reductions in bunch weight in those studies occurred because of a general reduction in plant size or because smaller fruits were produced on relatively large plants (as in the present case), or both. One would expect high density to reduce available light, and thus retard fruit enlargement, either by direct shading or indirectly because of disease-related reductions in

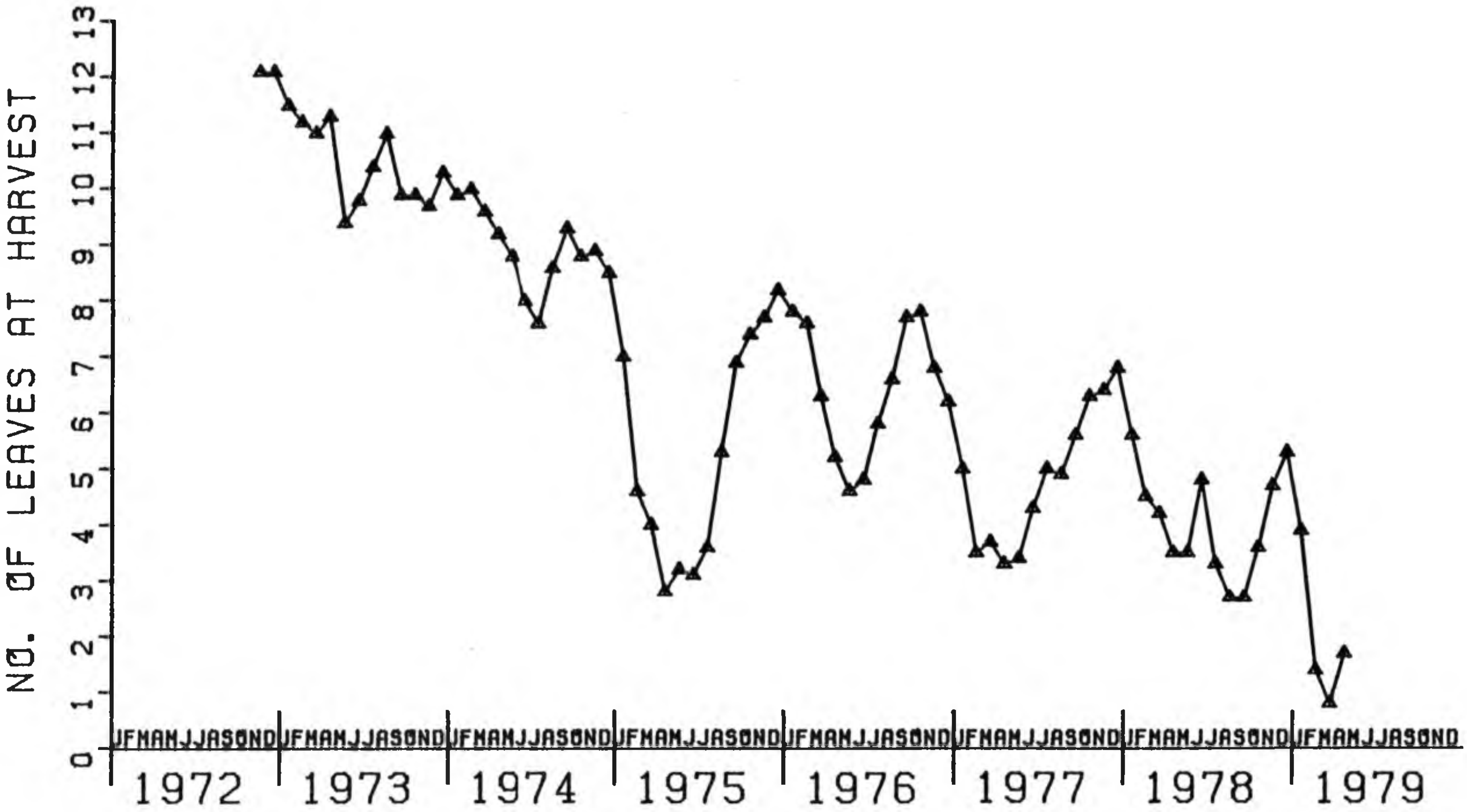


Fig. 36. Number of leaves remaining at harvest on Williams Hybrid bananas at Waimanalo during the period September, 1972 through April, 1979 (monthly means of all treatments).

leaf numbers and/or effective leaf function. High density also limits aerial CO_2 exchange, a factor which has not been studied in banana plantings, and when the root environment becomes crowded, soil water and nutrients may become limiting (Hardy, 1974).

In a study of Williams Hybrid bananas in Australia, Turner (1971) found that removal of up to all but 3 or 4 leaves on the date of bunch emergence had no significant effect on bunch weight. Thus, reductions in finger size were not severe. But Turner did not report on long-term effects of repeated defoliation of fruit-bearing pseudostems on the yield of successive ratoons. It is probable that such defoliation would eventually result in reduction of the number of hands and fingers on successive ratoon bunches.

Figure 37 shows that average pseudostem girth and height remained fairly constant over the entire seven years, while bunch weight clearly declined. If leaf area reductions were responsible for bunch weight decline, why didn't the pseudostems also become smaller over time? We are not certain why, but it seems likely that the vegetative growth of each pseudostem is to some extent independent of the status of the mat. If a newly developing pseudostem has access to water, light and nutrients, it is capable of achieving a size limited mainly by those factors. Vegetative growth is only slightly reduced if there is a lack of nutritive carbohydrate from the common root system of the mat.

The reproductive phase of the plant, which is initiated several months prior to shooting, puts added stress on already limited resources and sets in motion a chain of events: a chain of events which cannot often be overcome by the current growth of the pseudostem or of the mat.

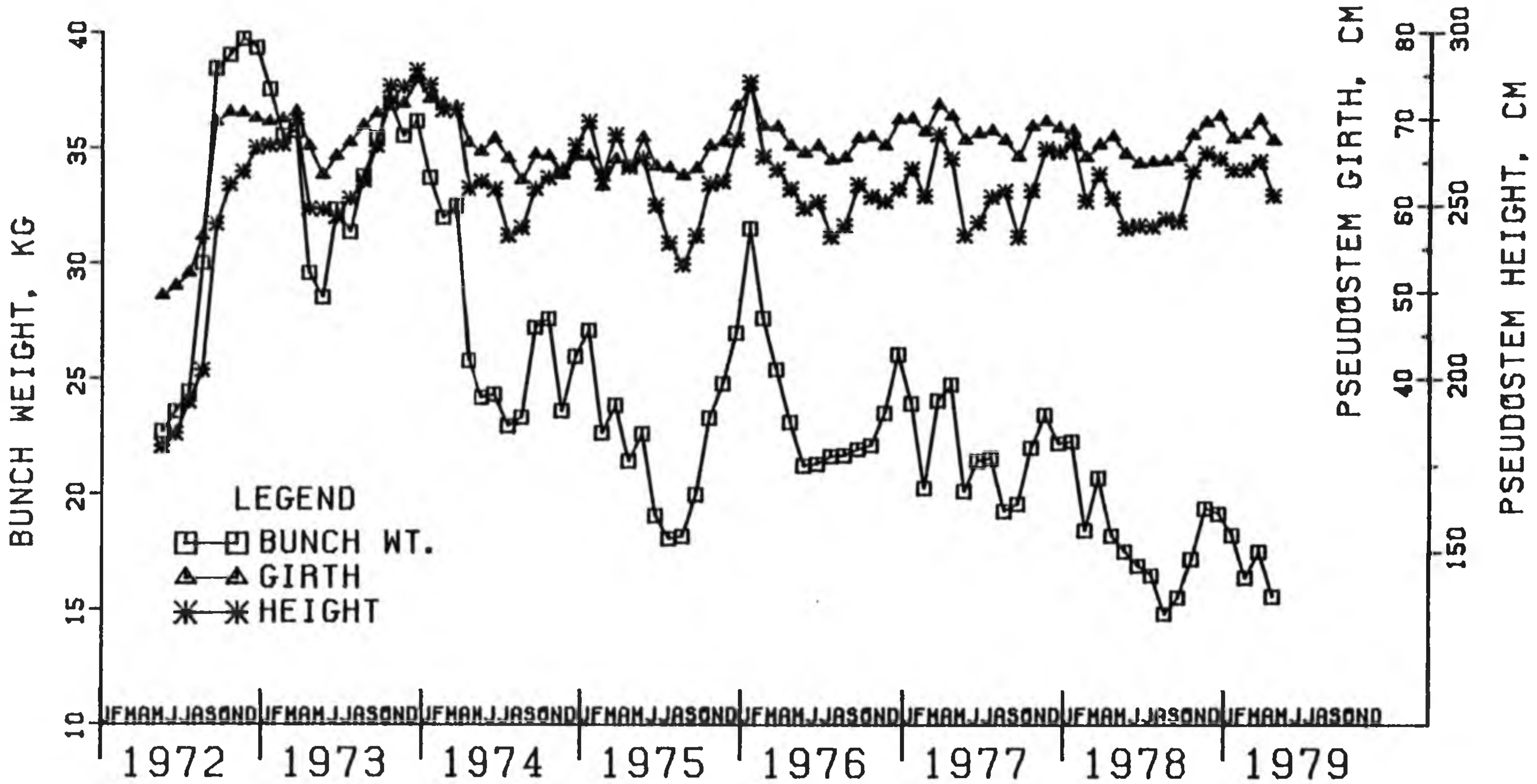


Fig. 37. Bunch weight, pseudostem height and pseudostem girth of Williams Hybrid bananas at Waimanalo during the period May, 1972 through April, 1979 (monthly means of all treatments).

Thus, while vigorous in appearance, a pseudostem may be under borderline stress which is evidenced later by reduced hand and finger count, and still later by defoliation and reduced finger size. Perhaps this is why plant crop bunches are often small relative to the first few ratoon bunches. The plant crop pseudostem, although not in competition with other pseudostems in the mat, is dependent on itself for carbohydrate production. Ratoon pseudostems, besides producing their own carbohydrate, may also take advantage of carbohydrate from older pseudostems and the corm, and are thus able to produce unusually large bunches.[4] After the mat was produced 5 to 10 bunches, density or other age-related effects may combine to reduce bunch weight although each pseudostem still has the potential to achieve a relatively large size.

Because N and K inputs were fairly constant the age-related reduction in leaf count is not explained solely as a fertility effect, although leaf retention was closely correlated with pseudostem size, which in turn was related to K and N status. The results presented in Section II showed also that individual leaf area is highly correlated with pseudostem weight. Thus, both N and K affect leaf area during bunch maturation at least and presumably over the entire life of the pseudostem.

Defoliation and reduced bunch weight, insofar as these are caused by nutrient stress, would have occurred at a gradually increasing rate over time in those mats where nutrient export was not balanced by fertilizer input. Cumulative yield can be used as a variable to

---

4 Bunches weighing in excess of 60 kg were produced in several mats which received high N and K during the second year of production.

differentiate between treatments which had differing rates of N and K inputs and removals. If bunch weight vs. pseudostem size reductions would have been caused by different rates of nutrient depletion, then cumulative yield may indicate the effect.

The following calculations illustrate how cumulative yield variation contributed to the pseudostem volume model, with and without time as a factor.

Model	R^2
Bunch weight (kg) = 671 V + 1.5	.63
= 743 V - 0.022 S + 6.7	.79
= 648 V - 0.20 T + 12.9	.86
= 641 V - 0.22 T + 0.002 S + 13.2	.86

V = pseudostem volume, m^3

S = yield sum, kg/mat after T months

T = chronological month (month 1 = Jan., 1972)

It would appear from this that cumulative yield, despite varying greatly between some treatments, did little more than describe the general time process. Note that in the last equation the parameter estimate of the yield factor is positive: but the estimate was not significant at the 5% level, whereas both the pseudostem volume and time parameters were highly significant. If there was any effect on bunch weight by fertility levels which changed over time (because of nutrient removals from prior cumulative production) it was not very sensitive.

Climate Effects on Leaf Retention

Figure 36 showed that leaf retention was seasonally related. The following statistics summarize the results of a stepwise regression which evaluated the importance of solar radiation and rainfall in addition to pseudostem size and fertilization levels on the number of leaves retained at harvest: (R^2 of full model was 0.32)

Factor	Sign	F-ratio
Pseudostem volume	+	169.6
N level	+	3.1^{ns}
K level	+	20.2
R2-4	-	149.2
R5-7	-	196.6
S1-3	+	150.5
S4-6	+	54.2

where R2-4 = cumulative rainfall during the 2nd, 3rd, and 4th months prior to harvest

R5-7 = cumulative rainfall during the 5th, 6th and 7th months prior to harvest

S1-3 = cumulative solar radiation 1, 2 and 3 months prior to harvest

S4-5 = cumulative solar radiation 4, 5 and 6 months prior to harvest

F-ratios sig. at 0.0001 level, except N-factor (not sig. at .05)

It is not surprising that leaf counts were negatively correlated with rainfall. Persistent wet weather favors Black Leaf-streak disease (Mycosphaerella fijiensis). In a study on Kauai Island (Gabuin, 1969) this disease affected the number of healthy leaves, to which bunch weight was highly correlated.

In Section I it was shown that bunch weight and the components of bunch size were correlated with temperature and solar radiation. Rainfall data were not included in those analyses because preliminary study showed that weekly rainfall summaries were too highly variable from week to week and from year to year to show any consistently well-correlated relationship with bunch weight. Nevertheless it may be inferred that rainfall patterns and totals would have some relationship to bunch weight--perhaps due to leaf area reductions.

The number of leaves, at least at harvest, exhibited an age-related decline that cannot be entirely explained by seasonal effects (although rain-related disease effects which reduce leaf counts may carry over into the dry season). The suggestion here is that reduction of effective leaf area, due to any primary cause, will be the most direct cause of reduction in bunch weight. The next logical step is inclusion of some leaf area modification effect to the bunch weight vs. pseudostem volume model.

Modifications of the Pseudostem Volume Model

After regressing bunch weight on pseudostem volume, an additional 17 percent of the variation in bunch weight was accounted for by the number of leaves at harvest:

Model	R^2
Bunch weight, kg = 671 V + 1.5	.63
= 562 V + 1.36 L - 3.4	.80
= 607 V + 0.56 L - 0.15 T + 17.4	.85

V = pseudostem volume, m^3
L = number of leaves at harvest
T = chronological time, months (month 1 = Jan., 1972)

The general decrease of bunch weight with time was not entirely explained by leaf-count reductions; time in the model was still significant, contributing an additional 5% to the explanation of bunch weight variability (last equation above).

The data recorded from August 1977 through April 1979 were examined separately to include the number of leaves at flower emergence in addition to the number of leaves at harvest, pseudostem size, and the N and K status in the pseudostem volume model. Results of stepwise regression involving the above factors plus pseudostem size x leaves interactions, which estimate total leaf area, are given in Table 17.

Those data show that bunch weight can be predicted very accurately by using pseudostem volume and the number of leaves at flower emergence. The reason why the number of leaves at harvest was much less influential than the number of leaves at flower emergence is probably because defoliation occurred rapidly just prior to harvest: many plants retained no leaves at harvest, but bunches were still reasonably large as a result of prior functioning leaves. The number of leaves at shooting is more closely related to the leaf area of the pseudostem during floral differentiation; a time when leaf area may influence the number of hands and fingers. This reasoning is in agreement with the climate effects discussed in Section I and also provides further interpretation of those results. A portion of the seasonal variability in bunch weight attributable to weather conditions could be a direct result of climate effects on leaf area.

We cannot exclude the independent effects of climate on yield. Comparison of the leaf-count data in Figure 36 with the bunch weight

TABLE 17

Coefficients of determination (R^2) obtained by stepwise regression models for bunch weight of Williams Hybrid banana in relation to pseudostem volume, leaf retention and nutrition factors.

Factors in model**							
K	LH	N	LS	V	V x LH	V x LS	R^2
*							0.09
	*						.21
		*					.24
			*				.44
					*		.57
				*			.80
						*	.82
	*			*			.83
			*	*			.83
			*	*		*	.83
	*		*	*			.85
*	*	*	*	*	*	*	.86

**K = K fert. level; LH = no. leaves harvest; N = N fert. level; LS = no. leaves shooting; V = pseudostem volume.

data in Figure 11 shows that relatively little seasonal variation occurred in leaf counts during the first two years of production while definite seasonal effects on bunch weight were observed during that period.

It is reasonable to expect that statistical interaction effects would also arise from a true physiochemical interaction between leaf function and solar radiation and probably also temperature. Perhaps such interrelationships would account for the relative absence of a seasonal effect in the latter years of the experiment, particularly at the low fertility level (Fig. 11).

It was suggested earlier in this section that the pseudostem height factor in the pseudostem volume model was important primarily at low N levels. The behavior of the model across K levels was similar to that across N levels, but variation in the parameters was much less pronounced than across N. We also have the following observations: in the first year neither N nor K affected pseudostem height relative to pseudostem girth; and leaf counts were relatively less on small plants in low N treatments (K had no effect). Hands per bunch, fingers per hand and bunch weight were also relatively less on small, low-N plants (K had no effect). In the sixth year N strongly affected pseudostem height but had little effect on hands, fingers and bunch weight--N did not affect leaf count. Slightly greater leaf counts were observed on small, low-K plants but there was no significant K effect on pseudostem height, hands, fingers or bunch weight.

From these observations, and under the assumption that leaf area most directly influences bunch weight, the following may be concluded:

the apparent effect of pseudostem height in the volume model at low N is because of the difference in the relationship between leaf count and pseudostem girth at high vs. low N. In the first year leaf count vs. pseudostem girth was steeply sloped at low N (Fig. 29), analogous to the behavior of the pseudostem volume model. Because height had a close linear relationship to girth in the first year (Table 16) pseudostem height had essentially the same effect in the model as if bunch weight were modelled using pseudostem girth raised to a power greater than 2 (cf. introduction to this section). Although by the sixth year the N effect on leaf count had disappeared and there was instead an N effect on pseudostem height, because only small plants were produced at the low N level the result was basically the same; small plants had few leaves, the pseudostem height vs. girth relationship was steeply sloped and, therefore, pseudostem height weighed heavily in the volume model when N was in low supply.

By a reverse argument it can be explained why height would be less important when N was well-supplied and the plants were relatively large. The effects of N on any factors were small compared to the effects of increasing pseudostem girth, provided the pseudostems were above the middle-sized range.

Recall that the seasonal effect was quite different with respect to the model parameters than the N or K effects. When girth was large the relationship between bunch weight and pseudostem girth was steeply sloped. A seasonal effect on leaf counts and climate-leaves interactions were obviously involved. Despite retention of fewer leaves at harvest during late Winter and Spring, the leaf area at flower emergence and before that time will exert an influence during the growth periods when weather and leaf function have the most critical effects. In the case of winter-harvested pseudostems this period is during the summer, when many leaves are retained and the weather is good.

In the crop-age effect the differences in the parameters of the pseudostem volume model from year to year can also be explained on the basis of leaf retention. The crop-age effect probably involves a combination of factors common to the fertility and seasonal effects. The effect of the reduction in leaf count over time is analogous to the effect of seasonal variation of leaf count on the bunch weight vs. pseudostem size relationship. The effects of N and K, as manifested directly or indirectly via the pseudostem girth effect on leaf retention, are involved in the crop-age effect because of a separation between the true fertility status of the treatments developing over time. It should be cautioned, however, that the age-effect analysis may have been biased due to a greater proportion of high-N data after the first year (cf. Fig. 6). There may also be other effects involved which are not directly a result of leaf count reductions; i.e. plant density and diseases, both of which were related to the age of the crop. Recall that the time factor was still significant in the pseudostem volume model after leaf retention was included.

Summary

Banana bunch weight was very closely related to the size of the pseudostem, particularly pseudostem girth. The mathematical relationship may be best described by a higher order power of pseudostem girth: bunch weight was more closely correlated with the square or the cube of pseudostem girth than with pseudostem girth. The product of pseudostem height times the square of pseudostem height (an estimate of pseudostem volume) was significantly better correlated with bunch weight than any power of pseudostem girth alone.

Several factors which influenced bunch weight--N and K fertilization, climate and crop age--were found to alter the mathematical parameters describing the bunch weight/stem size relationship. The most influential factor was crop age: from 72 to 90% of bunch weight variability was explained by the pseudostem volume model if data was analysed for each of the seven years separately, compared to only 55% when the data was combined.

Subsets of the data by fertility level and crop age revealed interaction effects and led to the conclusion that leaf area variability due to fertility, climate and especially crop age was the single most important factor modifying the behavior of the pseudostem volume model: an additional 17% of bunch weight variation was accounted for by the number of leaves retained at harvest after regressing bunch weight on pseudostem volume. The product of pseudostem volume times leaf count (an estimate of total leaf area) was closely correlated with bunch weight. The accuracy of the model was significantly greater when the number of leaves at bunch emergence was substituted for the number of leaves at harvest. Despite the large contribution of leaf count to the prediction equation there was still a significant time effect.

Insofar as demonstrating the validity of H. N. Hasselo's (1962)idea (that the relationship between bunch weight and pseudostem girth indicates general growth conditions), the regression coefficient for bunch weight vs. pseudostem girth did not indicate average yield differences due to N or K nutrition. There was some sensitivity of the regression coefficient to seasonal and age-related reductions in bunch weight relative to pseudostem girth.

GENERAL REMARKS

While it is clear that both N and K fertilization increased banana yields, the specific relationships among fertilization and crop density, average bunch weight and total yield cannot be clearly determined. This is unfortunate because knowledge of this relationship would allow an optimization formula enabling the grower to adjust harvest frequency up or down so that average bunch weight and bunch numbers provide the most economical system.

There are a number of factors entering into this "optimization formula," including the minimum allowable bunch size (to preserve fruit quality standards) and possibly a maximum bunch size, too, if harvesting and handling considerations are involved. Given a constant bunch size, manipulation of harvest frequency (and perhaps initial planting density) will be influenced by variable labor and material costs which would no doubt increase with increasing harvest frequency. Studies of variable planting densities, within-mat harvest frequency and fertilization levels are needed to help resolve the yield formula and allow for an economic analysis.

In regards to K fertilization the best approach may be to measure the potentially available soil K prior to planting bananas, and supply the projected deficit by incorporating a large initial application of K during pre-plant cultivation. If a soil is similar in K-holding capacity the Waimanalo soil (a property easily evaluated in the laboratory) then the amount of K required may be initially high but will have a long-term residual effect. If the K-holding capacity is low, large applications should be avoided; but in such a soil K applied to the surface at a later date will not have difficulty reaching subsurface roots. Further studies should be done to develop a suitable soil-K test system for bananas which will evaluate three parameters: initial K-availability and response index (expected yield response if K is added), retention and residual supply characteristics and the penetrability factor for surface-applied K. Tissue analysis would be useful to monitor the effectiveness of the fertilization program.

The final N and K content of the banana plant may not be a very good measure of pre-maturity growth conditions. For one thing, translocation of nutrients from the fruit-bearing pseudostem to other pseudostems in the mat may occur. Opposite to the loss of nutrients, uptake from the soil during post-flowering bunch development also occurs. Potential bunch weight is largely determined by pre-flowering nutritional conditions. Post-flowering uptake and redistribution of nutrients may have a leveling effect on variations in pre-flowering nutrient concentrations which may have been closely related to the yield potential established prior to bunch emergence. Study of the relationship between fertilization (and other factors) and the process of floral initiation and differentiation may also provide management information of use to growers.

A factor affecting yield in the experiment which has significant economic importance is climate. Climate is of special importance in Hawaii because the weather here is less ideal than the hot humid environment where bananas occur naturally. Our results suggested when fertility status was high that climate was the primary factor limiting bunch weights, and to a lesser extent total yield. The economic analysis of banana production is most directly concerned with annual yield performance vs. annual costs and prices. Because prices paid to growers in Hawaii vary on a seasonal basis (Loudat, 1980), however, the potential exists to manage the seasonal yield pattern and therefore to maximize income by optimizing monthly production totals.

Control of monthly production requires more than knowledge of the numbers of flowering stems required in each month: the number of stems reaching maturity at those times further requires that viable suckers are produced in sufficient quantities and in the months (approximately one year before flowering) that will result in the desired final outcome. Further study is needed to determine the monthly suckering frequency that will result in the final optimization of income. It appears that high rates of N will allow a surplus of suckers, from which the "best" can be selected. Other methods of sucker induction are known to exist (e.g. growth hormones) and should also be investigated.

Other aspects of climate which out to be considered include rainfall totals and patterns, fruit-loss risk factors from winds and heavy rain, and the optimization of fertilizer frequency in relation to growth rates which are weather-related. Disease incidence, particularly from Black Leaf-streak and other aerial fungi, is weather related and needs to be separated from the overall climate effect so more general conclusions can be reached regarding temperature and solar radiation.

A key to derive the quantitative relationships among pseudostem volume, leaf area and yield may be had by studying populations having constant leaf numbers but variable pseudostem sizes in plots where mat spacing and harvest frequency are strictly controlled. The contribution of total leaf area per mat towards production of new vegetative weight, besides current fruit weight, would also have to be considered.

The ability to predict bunch weight from measurements taken at shooting or earlier can mean several months' time saved in evaluating yield trials and would provide estimates of fruit losses due to blow-down, theft, etc.. It would also permit more accurate estimates of fruit supply. Another potentially valuable aspect of the bunch weight vs. plant volume relationship is in the interpretation of tissue analysis results. Because plant volume (or bunch weight) may not be always proportional to nutrient concentration, consideration of the total nutrient content (e.g., nutrient concentration x plant weight estimate) may indicate the adequacy or deficiency of nutrients in a more consistent manner. In cases where one or more nutrients are responsible for small plants (having too few leaves) time can be saved in taking corrective measures. If tissue analysis does not indicate a nutrient deficiency, then the cause(s) of poor plant growth can be sought elsewhere; e.g., water stress, disease, etc. Fertilizer can be saved if it is known that nutrition is not the limiting factor.

Bunch weight prediction should be of great value to commercial banana growers. There may be little interest in individual bunch weights, but the average of several estimates can be used to very accurately predict total production.

Appendix Table 1. Taxonomic description of the representative profile of the Waimanalo banana plot soil (Kawaihapai gravelly clay loam).[1,2]

Horizon	Depth	Description
Apl	0 to 18 cm	Very dark brown (7.5YR 2/2) gravelly clay loam; weak fine and medium subangular blocky structure; friable when moist, sticky and plastic when wet; few roots; common pores; many sand grains; common gravels; clear wavy boundary.
AP2	18 to 33 cm	Very dark brown (7.5YR 2/2) clay loam; cloddy; slightly firm when moist, sticky and plastic when wet; few roots; few pores; many sand grains; common gravels; clear wavy boundary.
Cl	33 to 48 cm	Very dark grayish-brown (10YR 3/2) loamy sand; single grain; very friable when moist; non-sticky and nonplastic when wet; many sand grains; many gravels; clear smooth boundary.
C2	48 to 61 cm	Very dark brown (10YR 2/2) sandy loam; weak very fine subangular blocky structure; friable when moist, sticky and plastic when wet; few roots; common fine and very fine pores; clear slightly wavy boundary; many sand grains; few gravels; clear smooth boundary.
C3	61 to 94 cm	Very dark grayish-brown loamy sand; single grain; loose when moist, slightly sticky and slightly pastic when wet; stratified layers of sand and gravel; few cobbles; clear wavy boundary.
C4	94 to 119 cm	Very dark brown silt loam; massive; very friable when moist, slightly sticky and slightly plastic when wet; common fine and very fine pores; many sand grains.

[1] (Ikawa et al., 1982)

[2] Soil name: Kawaihapai gravelly clay loam, 2 to 6 percent slopes (KlgA).

Appendix Table 2. Laboratory data of Kawaihapai gravelly clay loam.[1]

Depth	Horizon	Particle size analysis: Sand	Silt	Clay	Bulk density	15-bar Water content	Organic C	Extractable iron: Fe	Fe_2O_3
--cm--		------ % < 2 mm ------			-g/cc-	%	%	%	%
0-18	AP1	33.1	33.3	33.6	1.34	24.8	1.09	3.8	5.4
18-33	AP2	38.8	36.1	25.1	1.33	22.9	0.93	4.1	5.9
33-48	C1	66.9	6.8	26.3		18.9	0.29	3.3	4.7
48-61	C2				1.21		0.63	3.9	5.6
61-94	C3				1.14		0.38	3.8	5.4
94-119	C4				1.08		0.82	4.7	6.7

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Cation-exchange capacity NH_4OAc	Base saturation NH_4OAc	pH: H_2O	KCl	Difference
-cm-	------meq/100 g soil------						%			
0-18	21.92	22.91	0.43	1.09	46.35	41.1	>100	6.70	5.32	-1.38
18-33	22.55	22.60	0.52	1.07	46.74	49.0	95	6.65	5.35	-1.30
33-48	18.67	20.73	0.70	0.43	40.53	27.2	>100	7.10	5.32	-1.78
48-61	22.68	25.07	0.80	0.20	48.75	48.1	>100	6.70	5.40	-1.30
61-94	19.08	21.75	0.80	0.09	41.72	38.5	>100	6.80	5.45	-1.35
94-119	23.16	24.32	1.09	0.09	48.66	47.6	>100	7.15	5.55	-1.60

[1] (Ikawa et al., 1982)

Appendix Table 3. Nitrogen fertilization history of the Williams Hybrid banana experiment at Waimanalo.

date	Nitrogen Treatment									
	N_1		N_3		N_5		N_7		N_9	
	grams N/mat[1]									
8/71	45[2]	45[3]	135	135	225	225	315	315	405	405
12/71	45	90	135	270	225	450	315	630	405	810
5/72	10	100	30	300	50	500	70	700	90	900
6/72	20	120	60	360	100	600	140	840	180	1080
7/72	20	140	60	420	100	700	140	980	180	1260
12/72	20	160	60	480	100	800	140	1120	180	1440
2/73	14	174	42	522	70	870	98	1218	126	1566
5/73	14	188	42	564	70	940	98	1316	126	1692
8/73	14	202	42	606	70	1010	98	1414	126	1818
11/73	14	216	42	648	70	1080	98	1512	126	1944
2/74	8	224	24	672	40	1120	56	1568	72	2016
5/74	8	232	24	696	40	1160	56	1624	72	2088
8/74	8	240	24	720	40	1560	56	1680	72	2160
11/74	8	248	24	744	40	1600	56	1736	72	2232
2/75	18	266	54	798	90	1690	126	1862	162	2394
12/75	18	284	54	852	90	1780	126	1988	162	2556
1/76	18	302	54	906	90	1870	126	2114	162	2718
3/76	18	320	54	960	90	1960	126	2240	162	2880
8/76	21	341	63	1023	105	2065	147	2387	189	3069
10/76	21	362	63	1086	105	2170	147	2534	189	3258
12/76	21	383	63	1149	105	2275	147	2681	189	3447
3/77	21	404	63	1212	105	2380	147	2828	189	3636
5/77	42	446	126	1338	210	2590	294	3122	378	4014
7/77	21	467	63	1401	105	2695	147	3269	189	4203
9/77	21	488	63	1464	105	2800	147	3416	189	4392
1/78	21	509	63	1527	105	2905	147	3563	189	4581
4/78	21	530	63	1590	105	3010	147	3710	189	4770
7/78	21	551	63	1653	105	3115	147	3857	189	4959
8/78	21	572	63	1716	105	3220	147	4004	189	5148
1/79	21	593	63	1779	105	3325	147	4151	189	5337
2/79	21	614	63	1842	105	3430	147	4298	189	5526
4/79	21	635	63	1905	105	3535	147	4445	189	5715

(1) 718 mats/hectare

(2) left-hand column is amount of N added on the respective date

(3) right-hand column is cumulative N added through the respective date

Appendix Table 4. Potassium fertilization history of the Williams Hybrid banana experiment at Waimanalo.

date	Potassium Treatment													
	K_1		K_3		K_5		K_7		K_9		K_{11}		K_{13}	
	grams elemental K/mat[1]													
8/71	46[2]	46[3]	138	138	230	230	322	322	414	414	506	506	598	598
12/71	46	92	138	276	230	460	322	644	414	828	506	1012	598	1196
5/72	23	115	69	345	115	575	161	805	207	1035	253	1265	299	1495
7/72	23	138	69	414	115	690	161	966	207	1242	253	1518	299	1794
12/72	23	161	69	483	115	805	161	1127	207	1449	253	1771	299	2093
2/73	34	195	102	585	170	975	238	1365	306	1755	374	2145	442	2535
5/73	34	229	102	687	170	1145	238	1603	306	2061	374	2519	442	2977
8/73	34	263	102	789	170	1315	238	1841	306	2367	374	2893	442	3419
11/73	34	297	102	891	170	1485	238	2079	306	2673	374	3267	442	3861
4/74	23	320	69	960	115	1600	161	2240	207	2880	253	3520	299	4160
10/74	87	407	174	1134	261	1861	348	2588	435	3315	522	4042	609	4769
2/75	87	494	174	1308	261	2122	348	2936	435	3750	522	4564	609	5378
4/75	174	668	348	1656	522	2644	696	3632	870	4620	1044	5608	1218	6596
10/75	87	755	174	1830	261	2905	348	3980	435	5055	522	6130	609	7250
10/76	87	842	174	2004	261	3176	348	4328	435	5490	522	6652	609	7814
1/77	87	929	174	2178	261	3427	348	4676	435	5925	522	7174	609	8423
3/77	87	1016	174	2352	261	3688	348	5024	435	6360	522	7696	609	9032
7/77	87	1103	174	2526	261	3949	348	5372	435	6795	522	8218	609	9641
9/77	87	1190	174	2700	261	4210	348	5720	435	7230	522	8740	609	10250
10/78	174	1364	348	3048	522	4732	696	6416	870	8100	1044	9784	1218	11468
2/79	0	1364	0	3048	0	4732	60	6476	227	8327	392	10176	566	12034
4/79	0	1364	0	3048	111	4843	305	6781	392	8719	479	10655	566	12600

(1) 718 mats/hectare

(2) left-hand column is amount of K added on the respective date

(3) right-hand column is cumulative K added through the respective date

Note: From 8/71 through 4/74 K was applied at 3, 5, 7, 9, 11 and 13 times the K-1 level for the respective treatments (K-3 through K-13); from 10/74 through 10/78 the relative rates were in the order 1, 2, 3, 4, 5, 6 and 7 for K-1 through K-13; since 2/79 adjustments have been made to eventually restore the original relative levels.

Appendix Table 5. Nitrogen supplied to Williams Hybrid bananas at Waimanalo on an annual basis.

production year	dates (inclusive)	N-1	N-3	N-5	N-7	N-9
		Nitrogen Treatment				
				N, Kg/ha		
-	8/71 - 4/72	65	194	323	452	581
1	5/72 - 4/73	60	181	302	422	543
2	5/73 - 4/74	36	108	180	251	323
3	5/74 - 4/75	30	90	151	211	271
4	5/75 - 4/76	39	116	194	271	349
5	5/76 - 4/77	60	181	302	422	543
6	5/77 - 4/78	90	271	452	633	814
7	5/78 - 4/79	75	226	377	528	678
annual average (excluding 8/71 - 4/72)		56	168	280	391	503

Appendix Table 6. Potassium supplied to Williams Hybrid bananas at Waimanalo on an annual basis.

production year	dates (inclusive)	K-1	K-3	K-5	K-7	K-9	K-11	K-13
		Potassium Treatment						
		elemental K, Kg/ha						
-	8/71 - 4/72	66	198	330	462	594	727	859
1	5/72 - 4/73	74	222	370	518	666	813	961
2	5/73 - 4/74	90	269	449	628	808	987	1167
3	5/74 - 4/75	250	500	750	999	1249	1499	1749
4	5/75 - 4/76	62	125	187	250	312	375	437
5	5/76 - 4/77	187	375	562	750	937	1124	1312
6	5/77 - 4/78	125	250	375	500	625	750	874
7	5/78 - 4/79	125	250	454	762	1069	1375	1687
annual average (excluding 8/71 - 4/72)		130	284	450	629	809	989	1170

Appendix Table 7. Summary of dry weight, in grams, of various parts of individual Williams Hybrid banana pseudostems at harvest; sampled from the Waimanalo experiment during March to April, 1979.

Plant Number	Leaves	Pseudostem	Leaves + Pseudostem	Fruit Stalk	Fruit	Total Bunch	Total Plant
1	1035	3006	4041	215	6812	7027	11068
2	1788	2704	4492	218	6647	6865	11357
3	2466	3675	6141	198	6503	6701	12842
4	1564	2552	4116	176	6034	6210	10326
5	2447	3164	5611	192	5856	6048	11659
6	1682	2517	4199	148	5083	5231	9430
7	1173	2384	3557	151	5080	5231	8788
8	1610	3092	4702	165	4902	5067	9769
9	1504	2082	3586	106	4961	5067	8653
10	938	1851	2789	151	4752	4903	7692
11	1328	1982	3310	151	4752	4903	8213
12	1568	2353	3921	137	4685	4822	8743
13	1247	2215	3462	127	4612	4739	8201
14	1543	2610	4153	158	4418	4576	8729
15	924	1741	2665	143	4433	4576	7241
16	1322	2272	3594	121	4293	4414	8008
17	1055	1633	2688	109	4141	4250	6938
18	1513	1991	3504	80	3842	3922	7426
19	1390	2164	3554	96	3826	3922	7476
20	609	2077	2686	93	3503	3596	6282
21	1181	1966	3147	97	3336	3433	6580
22	452	2600	3052	86	2367	2452	5504
23	644	1272	1916	74	2214	2288	4204
24	858	1765	2623	73	2051	2124	4747
25	505	1580	2085	72	1890	1962	4047
26	364	1300	1664	62	1736	1798	3462

Appendix Table 8. Potassium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest.

Plant	PETIOLES										
Number	1	2	3	4	5	6	7	8	9	10	11
1	3.87	3.40	2.64	2.69	2.10	-	-	-	-	-	-
2	4.80	2.61	1.71	1.50	1.35	0.99	0.96	0.62	-	-	-
3	5.06	3.30	2.78	2.69	2.30	1.83	1.76	1.14	0.89	0.72	0.49
4	4.69	2.76	2.10	1.77	1.43	1.15	0.99	0.55	-	-	-
5	3.74	3.61	2.83	2.11	2.33	1.58	1.70	1.14	1.00	0.79	-
6	4.20	3.42	2.38	1.97	1.67	1.44	1.10	0.95	0.43	0.56	-
7	4.91	4.13	3.99	4.25	3.08	2.92	1.40	-	-	-	-
8	2.79	2.11	1.38	1.80	1.18	1.50	0.61	0.51	-	-	-
9	2.50	1.81	1.54	1.08	1.25	0.51	0.53	0.28	0.23	-	-
10	5.46	3.93	3.08	2.35	2.36	1.71	-	-	-	-	-
11	4.00	2.80	2.30	2.30	1.90	1.80	1.80	-	-	-	-
12	3.73	1.85	1.62	1.16	0.98	0.66	-	-	-	-	-
13	4.34	4.23	2.99	2.42	3.43	1.97	1.55	1.21	-	-	-
14	5.06	3.49	3.64	3.06	2.43	2.64	2.43	1.19	-	-	-
15	4.40	3.24	2.64	1.70	2.07	-	-	-	-	-	-
16	3.62	4.09	3.73	3.27	3.02	2.03	2.35	1.80	-	-	-
17	1.89	3.22	3.60	2.88	2.30	2.75	1.98	1.97	-	-	-
18	3.99	3.11	2.23	2.22	1.15	1.37	0.99	0.66	0.60	0.30	0.38
19	4.74	4.47	3.79	4.26	2.99	3.27	2.40	2.30	-	-	-
20	1.07	0.20	0.22	0.08	-	-	-	-	-	-	-
21	4.00	3.24	1.94	1.80	1.20	0.90	0.67	0.42	0.23	-	-
22	4.41	4.19	3.97	3.56	-	-	-	-	-	-	-
23	4.34	4.37	3.54	4.04	2.89	3.19	-	-	-	-	-
24	3.04	2.65	1.36	1.72	0.93	1.13	0.85	0.67	1.13	-	-
25	4.72	4.86	4.64	4.16	3.80	-	-	-	-	-	-
26	4.40	4.35	4.63	3.18	3.04	-	-	-	-	-	-

Appendix Table 8. Potassium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest. (Continued)

Plant	LEAVES										
Number	1	2	3	4	5	6	7	8	9	10	11
1	2.09	1.68	1.17	1.53	1.18	-	-	-	-	-	-
2	2.10	1.60	1.74	1.32	1.43	1.65	1.98	1.97	-	-	-
3	1.84	1.46	1.19	1.27	1.60	1.04	1.48	1.47	1.09	1.23	1.20
4	2.73	1.24	1.45	1.63	2.61	1.83	1.78	1.70	-	-	-
5	2.51	1.27	1.24	1.41	1.42	1.37	2.29	1.16	1.65	1.33	-
6	3.63	1.22	1.51	1.02	1.90	1.40	1.75	2.11	1.27	1.54	-
7	1.67	1.48	1.49	1.33	1.21	1.70	1.51	-	-	-	-
8	1.52	1.28	1.60	1.67	1.58	1.51	1.78	1.63	-	-	-
9	2.50	1.18	1.20	2.11	1.42	1.33	1.23	1.08	0.88	-	-
10	1.71	1.32	1.82	1.32	1.45	1.57	-	-	-	-	-
11	1.32	1.67	1.59	1.64	1.89	2.01	1.56	-	-	-	-
12	2.04	1.39	1.66	1.28	0.97	1.54	-	-	-	-	-
13	1.74	1.73	1.77	2.29	1.60	2.20	2.18	2.25	-	-	-
14	1.48	1.42	1.70	1.52	1.63	1.54	1.63	2.06	-	-	-
15	2.51	0.83	0.99	0.82	0.81	-	-	-	-	-	-
16	2.13	1.42	1.69	1.60	1.96	1.99	1.71	1.77	-	-	-
17	1.72	1.63	1.40	1.87	1.55	1.77	1.29	1.30	-	-	-
18	1.83	1.41	1.25	1.55	1.56	1.51	1.40	1.30	1.71	1.13	0.89
19	1.65	1.84	1.98	1.80	1.82	2.04	1.81	1.60	-	-	-
20	1.39	0.59	1.15	0.29	-	-	-	-	-	-	-
21	2.28	1.41	1.67	1.30	1.81	1.31	1.38	0.86	0.67	-	-
22	1.61	1.55	1.65	1.69	-	-	-	-	-	-	-
23	2.96	1.51	1.79	1.59	1.91	2.37	-	-	-	-	-
24	1.80	1.67	1.62	1.67	1.72	1.81	1.76	1.85	2.04	-	-
25	2.40	1.71	1.69	1.81	1.92	-	-	-	-	-	-
26	1.86	1.88	1.68	1.78	1.93	-	-	-	-	-	-

Appendix Table 8. Potassium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest. (Continued)

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	FRUIT STALK	HANDS	TOTAL BUNCH	ROOTS	TOTAL (EXCL. ROOTS)
1	1.25	5.00	4.12	9.82	1.93	2.11	4.30	2.85
2	1.34	2.66	2.23	8.33	1.69	1.84	5.22	1.99
3	1.31	4.84	3.49	10.02	1.90	2.07	2.40	2.75
4	1.36	2.50	2.16	9.58	1.82	1.98	1.53	2.05
5	1.34	4.15	2.99	9.41	1.82	1.99	5.23	2.47
6	1.38	2.92	2.38	9.35	1.87	2.01	3.42	2.18
7	1.69	4.36	3.54	9.85	2.03	2.21	3.28	2.75
8	1.22	2.18	1.89	8.40	1.63	1.81	3.08	1.85
9	1.14	1.18	1.21	8.00	1.65	1.75	4.53	1.53
10	1.57	3.86	3.23	10.31	2.03	2.19	2.01	2.57
11	1.60	3.29	2.67	8.93	1.79	1.96	4.99	2.25
12	1.35	1.88	1.71	9.25	1.92	2.09	4.67	1.92
13	1.78	4.75	3.73	9.67	2.02	2.17	1.97	2.84
14	1.87	3.47	2.94	9.10	1.87	2.06	4.36	2.48
15	1.23	4.12	3.13	8.60	1.73	1.90	2.27	2.36
16	1.75	5.22	3.95	9.12	2.06	2.21	5.52	2.99
17	1.73	5.36	3.97	9.36	2.07	2.22	2.30	2.90
18	1.23	1.74	1.55	7.90	1.85	1.95	3.94	1.76
19	1.95	4.26	3.39	9.23	1.99	2.13	3.56	2.73
20	0.59	0.52	0.57	5.70	1.49	1.57	1.85	1.14
21	1.17	2.56	2.08	7.89	1.85	1.97	1.79	2.03
22	2.18	4.72	4.36	8.02	1.86	2.02	3.45	3.32
23	1.96	4.43	3.65	8.51	1.81	1.96	2.96	2.74
24	1.48	1.80	1.76	8.05	1.63	1.76	1.87	1.76
25	2.07	5.52	4.72	9.64	2.00	2.20	1.78	3.50
26	1.85	5.18	4.50	8.97	1.98	2.16	3.37	3.29

Appendix Table 9. Nitrogen concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest.

Plant Number	PETIOLES 1	2	3	4	5	6	7	8	9	10	11
1	1.22	0.84	0.64	0.60	0.48	-	-	-	-	-	-
2	1.00	0.54	0.44	0.49	0.36	0.40	0.42	0.38	-	-	-
3	0.88	0.69	0.54	0.62	0.52	0.56	0.50	0.38	0.40	0.42	0.41
4	0.78	0.76	0.58	0.52	0.44	0.46	0.42	0.39	-	-	-
5	0.88	0.76	0.68	0.55	0.59	0.50	0.48	0.48	0.43	0.44	-
6	1.40	1.06	0.86	0.85	0.72	0.78	0.50	0.58	0.40	0.46	-
7	1.04	0.78	0.72	0.84	0.65	0.68	0.42	-	-	-	-
8	1.04	0.70	0.54	0.60	0.46	0.58	0.46	0.46	-	-	-
9	1.10	0.78	0.60	0.54	0.70	0.35	0.50	0.48	0.37	-	-
10	1.00	0.62	0.56	0.50	0.64	0.44	-	-	-	-	-
11	0.60	0.50	0.50	0.40	0.30	0.30	0.30	-	-	-	-
12	0.52	0.48	0.42	0.46	0.41	0.34	-	-	-	-	-
13	0.41	0.34	0.26	0.26	0.26	0.24	0.24	0.22	-	-	-
14	1.05	0.77	0.64	0.67	0.65	0.65	0.60	0.55	-	-	-
15	1.14	1.19	1.02	0.90	1.02	-	-	-	-	-	-
16	0.68	0.42	0.37	0.34	0.36	0.35	0.32	0.30	-	-	-
17	1.06	0.60	0.58	0.42	0.36	0.42	0.34	0.38	-	-	-
18	0.98	0.91	0.67	0.72	0.62	0.60	0.60	0.58	0.47	0.50	0.46
19	0.64	0.51	0.42	0.54	0.50	0.48	0.36	0.48	-	-	-
20	0.91	0.61	0.43	0.51	-	-	-	-	-	-	-
21	1.00	0.92	0.80	0.84	0.62	0.72	0.54	0.42	0.45	-	-
22	0.42	0.32	0.30	0.29	-	-	-	-	-	-	-
23	0.54	0.41	0.35	0.34	0.32	0.32	-	-	-	-	-
24	0.91	0.62	0.71	0.50	0.43	0.46	0.43	0.44	0.47	-	-
25	0.45	0.35	0.34	0.32	0.28	-	-	-	-	-	-
26	0.52	0.38	0.34	0.32	0.28	-	-	-	-	-	-

Appendix Table 9. Nitrogen concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest. (Continued)

Plant Number	LEAVES 1	2	3	4	5	6	7	8	9	10	11
1	2.40	2.54	2.46	2.46	2.25	-	-	-	-	-	-
2	2.20	2.12	1.94	2.00	2.11	1.84	1.80	1.60	-	-	-
3	2.16	2.34	2.18	2.34	2.18	2.35	2.27	1.84	1.76	1.82	1.50
4	2.13	2.17	2.24	2.38	1.92	1.78	1.84	1.70	-	-	-
5	2.23	2.28	2.30	2.33	2.26	2.17	2.32	1.97	1.65	1.50	-
6	1.13	2.43	2.16	2.40	2.24	2.32	1.99	2.14	1.23	1.67	-
7	2.07	2.12	2.23	2.22	2.30	2.30	1.80	-	-	-	-
8	2.58	2.58	2.56	2.60	2.50	2.42	2.50	2.49	-	-	-
9	2.10	2.15	2.06	2.00	1.97	1.83	1.80	1.73	1.82	-	-
10	2.12	2.04	2.00	1.99	1.95	1.62	-	-	-	-	-
11	2.20	2.36	2.19	2.26	2.06	1.68	2.01	-	-	-	-
12	2.06	2.23	1.95	2.22	2.16	1.84	-	-	-	-	-
13	1.69	1.74	1.79	1.66	1.68	1.48	1.54	1.43	-	-	-
14	2.47	2.38	2.44	2.44	2.41	2.32	2.41	2.12	-	-	-
15	2.48	2.12	2.40	2.25	2.39	-	-	-	-	-	-
16	2.00	1.82	1.67	1.92	1.85	1.60	1.27	1.27	-	-	-
17	2.45	2.42	2.41	2.12	2.22	2.03	2.14	2.10	-	-	-
18	2.06	1.94	1.82	1.82	2.02	1.80	1.80	1.60	1.56	1.45	1.34
19	2.29	2.28	2.02	2.12	2.20	2.18	2.00	2.01	-	-	-
20	2.50	1.95	1.99	1.68	-	-	-	-	-	-	-
21	2.42	2.25	2.36	2.20	2.26	2.29	1.76	1.70	1.40	-	-
22	1.81	1.90	1.86	1.67	-	-	-	-	-	-	-
23	1.41	1.86	1.88	1.65	1.78	1.60	-	-	-	-	-
24	2.54	2.84	2.75	2.82	2.33	2.78	2.14	2.70	2.48	-	-
25	1.90	1.70	1.70	1.48	1.56	-	-	-	-	-	-
26	1.60	1.38	1.36	1.58	1.21	-	-	-	-	-	-

Appendix Table 9. Nitrogen concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems at harvest. (Continued)

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	FRUIT STALK	HANDS	TOTAL BUNCH	ROOTS	TOTAL (EXCL. ROOTS)
1	1.71	0.62	0.90	1.06	0.75	0.75	1.02	0.81
2	1.47	0.44	0.86	0.87	0.69	0.69	0.92	0.76
3	1.25	0.66	0.90	1.22	0.75	0.76	0.98	0.83
4	1.46	0.86	1.09	1.43	0.77	0.78	1.04	0.91
5	1.51	0.76	1.09	1.14	0.74	0.75	1.18	0.91
6	1.57	1.17	1.34	1.82	0.92	0.94	0.97	1.12
7	1.56	1.05	1.22	1.48	0.75	0.77	1.19	0.95
8	1.68	0.82	1.12	1.32	0.81	0.83	1.18	0.97
9	1.41	0.76	1.03	0.93	0.77	0.77	1.32	0.88
10	1.55	0.80	1.06	1.22	0.75	0.76	0.86	0.87
11	1.36	0.35	0.75	0.56	0.59	0.59	0.98	0.65
12	1.57	0.56	0.97	1.75	0.81	0.83	1.15	0.89
13	1.09	0.34	0.61	0.54	0.59	0.59	1.14	0.60
14	1.78	1.05	1.33	1.69	0.83	0.86	1.28	1.08
15	1.82	1.44	1.58	2.25	0.88	0.91	1.17	1.16
16	1.46	0.35	0.76	0.52	0.59	0.59	0.76	0.66
17	1.45	0.59	0.93	1.42	0.69	0.71	1.22	0.79
18	1.45	1.07	1.23	1.26	0.83	0.83	1.08	1.02
19	1.46	0.58	0.93	1.08	0.69	0.70	1.30	0.81
20	1.70	0.65	0.89	1.14	0.81	0.82	1.20	0.85
21	1.56	1.04	1.24	2.30	0.93	0.96	1.16	1.10
22	1.27	0.26	0.41	0.42	0.48	0.48	0.44	0.44
23	1.51	0.27	0.69	0.44	0.52	0.51	0.45	0.59
24	1.77	0.91	1.20	1.84	0.81	0.83	1.16	1.03
25	1.45	0.26	0.55	0.49	0.46	0.46	0.52	0.50
26	1.05	0.31	0.47	0.44	0.50	0.50	0.56	0.49

Appendix Table 10. Summary of total N and K, in grams, for various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

Plant Number	Leaves		Pseudostem		Total Veg.		Bunch		Total Plant	
	N	K	N	K	N	K	N	K	N	K
1	18	13	19	150	37	168	53	148	90	317
2	26	24	12	72	39	102	47	126	86	228
3	31	32	24	178	56	216	51	139	107	355
4	23	21	22	64	45	90	48	123	94	213
5	37	33	24	131	62	169	45	121	107	290
6	26	23	29	73	57	101	49	105	106	206
7	18	20	23	104	44	127	40	116	84	243
8	27	20	25	67	53	89	42	92	95	181
9	21	17	16	25	37	44	39	89	76	132
10	15	15	15	71	30	92	37	107	67	199
11	18	21	7	65	25	89	29	96	54	185
12	25	21	13	44	38	68	40	101	78	169
13	14	22	8	105	21	130	28	103	49	233
14	27	29	27	91	56	123	39	94	95	217
15	17	11	25	72	43	54	42	87	84	171
16	19	23	8	119	27	143	26	97	53	241
17	15	18	10	88	25	108	30	94	55	202
18	22	19	21	35	43	54	33	76	76	131
19	20	27	13	92	33	121	27	83	60	205
20	10	4	14	11	24	16	29	56	54	72
21	18	14	20	50	39	66	33	68	72	134
22	6	10	7	123	13	134	12	50	24	184
23	10	13	3	56	13	71	12	45	25	116
24	15	13	16	32	32	47	15	37	49	84
25	7	10	4	87	12	99	9	43	20	143
26	4	7	4	67	8	76	9	39	17	114

Appendix Table 11. Phosphorus concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT	PETIOLES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	0.22	0.18	0.12	0.11	0.09	-	-	-	-	-	-
2	-	0.17	0.12	0.12	0.10	0.10	0.10	0.09	-	-	-
3	0.17	0.12	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
4	0.15	0.12	0.10	0.10	0.09	0.09	0.09	0.09	-	-	-
5	0.18	0.16	0.12	0.10	0.10	0.09	0.09	0.09	0.09	0.09	-
6	-	0.13	0.11	0.10	0.09	0.10	0.09	0.09	0.08	0.09	-
7	0.16	0.11	0.10	0.10	0.10	0.09	0.09	-	-	-	-
8	-	0.12	0.10	0.10	0.10	0.09	0.10	0.10	0.09	-	-
9	0.17	0.12	0.10	0.10	0.09	0.10	0.09	0.09	-	-	-
10	0.15	0.10	0.10	0.09	0.09	0.09	-	-	-	-	-
11	0.16	0.16	0.16	0.16	0.16	0.16	0.16	-	-	-	-
12	0.14	0.11	0.09	0.09	0.09	0.09	-	-	-	-	-
13	0.36	0.31	0.27	0.27	0.27	0.23	0.29	0.24	-	-	-
14	0.15	0.10	0.10	0.09	0.09	0.09	-	0.09	-	-	-
15	0.19	0.13	0.10	0.09	0.10	-	-	-	-	-	-
16	0.33	0.36	0.34	0.31	0.28	0.26	0.30	0.28	-	-	-
17	0.11	0.10	0.12	0.09	0.09	0.09	0.09	0.09	-	-	-
18	0.12	0.11	0.10	0.10	0.10	0.09	0.10	0.10	0.10	0.10	0.09
19	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	-	-	-
20	-	0.12	0.11	0.11	-	-	-	-	-	-	-
21	0.15	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.09	-	-
22	0.74	0.61	0.61	0.61	-	-	-	-	-	-	-
23	0.65	0.79	0.67	0.72	0.65	0.80	-	-	-	-	-
24	0.12	0.12	0.10	0.10	0.09	0.09	0.09	0.09	0.09	-	-
25	1.04	0.88	0.91	0.79	0.82	-	-	-	-	-	-
26	0.79	0.95	0.88	0.76	0.76	-	-	-	-	-	-

Appendix Table 11. Phosphorus concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT	LEAVES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	0.28	0.17	0.16	0.16	0.16	-	-	-	-	-	-
2	-	0.17	0.16	0.15	0.16	0.24	0.17	0.15	-	-	-
3	0.17	0.16	0.15	0.15	0.24	0.15	0.16	0.15	0.14	0.14	0.13
4	0.20	0.15	0.16	0.16	0.16	0.15	0.15	-	-	-	-
5	0.21	0.16	0.16	0.16	0.16	0.15	0.16	0.15	0.14	0.14	-
6	0.17	0.15	0.16	0.15	0.16	0.16	0.15	0.15	0.12	0.15	-
7	0.17	0.16	0.16	0.16	0.16	0.16	0.14	-	-	-	-
8	-	0.15	0.15	0.16	0.16	0.15	0.15	0.15	0.15	-	-
9	0.16	0.16	0.16	0.17	0.17	0.16	0.16	0.17	-	-	-
10	0.16	0.15	0.16	0.15	0.16	0.14	-	-	-	-	-
11	0.16	0.16	0.16	0.16	0.16	0.15	0.15	-	-	-	-
12	0.17	0.16	0.15	0.16	0.15	0.15	-	-	-	-	-
13	0.22	0.17	0.17	0.16	0.16	0.15	0.16	0.15	-	-	-
14	0.16	0.16	0.16	0.16	0.16	0.16	0.15	-	-	-	-
15	0.22	0.24	0.16	0.15	0.15	-	-	-	-	-	-
16	0.22	0.19	0.18	0.16	0.17	0.16	0.15	0.14	-	-	-
17	0.17	0.16	0.16	0.15	0.15	0.15	0.15	-	-	-	-
18	0.15	0.15	0.15	0.16	0.15	0.16	0.15	0.15	0.15	0.14	0.14
19	0.15	0.16	0.15	0.15	0.15	0.15	0.15	0.15	-	-	-
20	0.17	0.15	0.16	0.14	-	-	-	-	-	-	-
21	0.20	0.16	0.16	0.15	0.16	0.15	0.14	0.13	0.12	-	-
22	0.29	0.30	0.29	0.26	-	-	-	-	-	-	-
23	0.47	0.28	0.28	0.28	0.28	0.30	-	-	-	-	-
24	-	0.17	0.17	0.17	0.16	0.17	0.16	0.17	0.17	-	-
25	-	0.36	0.37	0.35	0.34	-	-	-	-	-	-
26	0.78	0.46	0.40	0.40	0.35	-	-	-	-	-	-

Appendix Table 11. Phosphorus concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	0.15	0.10	0.11	0.12	0.11
2	0.15	0.11	0.12	0.12	0.12
3	0.13	0.10	0.11	0.11	0.11
4	0.14	0.11	0.12	0.11	0.11
5	0.13	0.10	0.11	0.11	0.11
6	0.14	0.11	0.12	0.11	0.11
7	0.14	0.10	0.11	0.11	0.11
8	0.14	0.10	0.11	0.10	0.11
9	0.14	0.10	0.11	0.12	0.11
10	0.14	0.10	0.11	0.10	0.10
11	0.15	0.14	0.14	0.12	0.13
12	0.14	0.09	0.11	0.11	0.11
13	0.19	0.34	0.29	0.14	0.20
14	0.14	0.10	0.11	0.11	0.11
15	0.14	0.11	0.12	0.12	0.11
16	0.19	0.28	0.25	0.15	0.19
17	0.14	0.09	0.11	0.10	0.10
18	0.13	0.10	0.11	0.10	0.10
19	0.13	0.09	0.10	0.11	0.10
20	0.16	0.10	0.11	0.11	0.11
21	0.13	0.10	0.11	0.11	0.11
22	0.33	0.43	0.42	0.16	0.29
23	0.31	0.75	0.62	0.15	0.35
24	0.15	0.10	0.11	0.11	0.11
25	0.38	1.03	0.89	0.17	0.52
26	0.46	0.88	0.80	0.17	0.45

Appendix Table 12. Calcium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	PETIOLES 1	2	3	4	5	6	7	8	9	10	11
1	0.72	1.06	1.17	1.18	1.08	-	-	-	-	-	-
2	-	0.84	1.11	0.90	1.05	1.03	0.97	0.82	-	-	-
3	1.01	1.01	1.06	1.15	1.14	1.20	1.13	1.05	1.05	1.02	0.81
4	0.69	1.11	1.04	1.05	0.93	1.05	0.90	0.85	-	-	-
5	0.58	1.19	1.25	1.18	1.29	1.27	1.21	1.10	1.05	0.98	-
6	-	0.87	0.85	0.88	0.69	0.92	0.54	0.69	0.62	0.62	-
7	1.26	1.26	1.33	1.21	1.29	1.23	1.18	-	-	-	-
8	-	0.87	1.07	1.12	1.08	0.88	1.02	0.82	0.83	-	-
9	0.95	0.88	0.81	1.05	0.87	1.08	0.76	0.68	-	-	-
10	1.43	1.20	1.22	1.13	1.26	0.97	-	-	-	-	-
11	1.02	1.02	1.02	1.02	1.02	1.02	1.02	-	-	-	-
12	0.63	0.82	0.90	0.86	1.03	0.67	-	-	-	-	-
13	0.84	0.86	0.90	1.00	0.87	0.76	0.96	0.77	-	-	-
14	1.27	1.11	1.07	1.03	1.20	0.95	-	1.06	-	-	-
15	0.65	1.05	1.02	0.96	1.07	-	-	-	-	-	-
16	0.54	0.98	0.97	1.11	1.03	1.00	1.04	0.98	-	-	-
17	0.64	0.91	0.81	0.92	0.89	0.94	0.67	0.76	-	-	-
18	1.01	1.13	1.17	1.24	1.01	1.08	1.00	0.89	0.87	0.85	0.83
19	0.95	0.80	0.80	1.16	0.97	0.92	0.71	1.14	-	-	-
20	-	0.43	0.65	0.66	-	-	-	-	-	-	-
21	0.69	0.69	0.76	0.85	0.56	0.68	0.46	0.49	0.62	-	-
22	0.82	0.83	0.90	0.85	-	-	-	-	-	-	-
23	0.52	0.86	0.98	1.03	1.04	1.04	-	-	-	-	-
24	0.60	0.76	0.68	0.52	0.71	0.76	0.68	0.65	0.68	-	-
25	0.88	1.07	0.96	0.98	0.99	-	-	-	-	-	-
26	0.55	0.97	1.01	1.03	0.99	-	-	-	-	-	-

Appendix Table 12. Calcium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT	LEAVES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	0.51	1.01	1.22	1.21	1.30	-	-	-	-	-	-
2	-	1.01	1.17	1.57	1.22	1.25	1.23	1.04	-	-	-
3	0.90	1.17	1.28	1.27	1.25	1.46	1.37	1.24	1.40	1.29	1.17
4	0.53	1.11	1.21	1.26	0.85	1.09	1.08	-	-	-	-
5	0.36	1.16	1.27	1.17	1.41	1.39	1.38	1.33	1.09	1.06	-
6	0.61	1.18	1.09	1.42	1.09	1.29	0.87	0.84	1.16	1.06	-
7	1.19	1.36	1.40	1.44	1.44	1.30	1.25	-	-	-	-
8	-	1.10	1.40	1.25	1.40	1.23	1.29	1.40	1.38	-	-
9	1.02	1.19	1.03	1.09	1.03	1.13	1.07	1.04	-	-	-
10	0.98	1.24	1.16	1.28	1.23	0.95	-	-	-	-	-
11	1.03	0.97	1.06	0.98	1.04	0.93	1.10	-	-	-	-
12	0.86	1.13	1.13	1.32	1.47	1.10	-	-	-	-	-
13	0.87	0.90	0.95	0.89	1.11	0.95	1.14	1.01	-	-	-
14	1.06	1.13	0.99	1.05	1.05	1.04	1.06	-	-	-	-
15	0.66	1.24	1.26	1.41	1.43	-	-	-	-	-	-
16	0.29	0.94	1.06	1.18	0.98	1.10	1.15	1.11	-	-	-
17	0.85	0.96	0.92	0.87	0.87	0.75	0.92	-	-	-	-
18	0.83	1.27	1.37	1.31	1.30	1.17	1.28	1.31	1.15	1.26	1.15
19	0.88	0.91	0.85	0.97	1.09	0.85	0.92	1.10	-	-	-
20	1.14	1.30	1.35	1.52	-	-	-	-	-	-	-
21	0.51	1.26	1.03	1.34	0.93	1.43	0.86	0.87	1.04	-	-
22	0.75	0.92	0.93	0.97	-	-	-	-	-	-	-
23	0.51	1.00	1.01	1.06	1.08	1.08	-	-	-	-	-
24	-	0.89	0.96	1.04	1.02	1.08	0.85	0.80	0.81	-	-
25	-	1.03	0.96	1.15	1.11	-	-	-	-	-	-
26	0.51	0.92	1.06	1.07	1.11	-	-	-	-	-	-

Appendix Table 12. Calcium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	1.23	0.56	0.71	0.07	0.28
2	1.23	0.47	0.74	0.07	0.31
3	1.26	0.52	0.79	0.06	0.38
4	1.30	0.56	0.81	0.07	0.34
5	1.57	0.42	0.88	0.07	0.43
6	1.16	0.59	0.80	0.06	0.36
7	1.38	0.64	0.85	0.07	0.36
8	1.50	0.51	0.88	0.07	0.38
9	1.22	0.40	0.65	0.07	0.33
10	1.23	0.64	0.82	0.07	0.32
11	1.77	0.46	0.92	0.06	0.38
12	2.64	0.61	1.36	0.07	0.61
13	1.06	0.47	0.66	0.06	0.29
14	1.13	0.45	0.67	0.07	0.33
15	1.29	0.47	0.72	0.07	0.28
16	1.12	0.51	0.71	0.06	0.33
17	1.02	0.63	0.76	0.07	0.31
18	1.26	0.59	0.85	0.07	0.41
19	0.99	0.68	0.79	0.06	0.38
20	1.32	0.20	0.42	0.08	0.21
21	1.05	0.45	0.65	0.06	0.32
22	0.97	0.42	0.49	0.07	0.29
23	1.07	0.40	0.60	0.06	0.29
24	1.10	0.45	0.63	0.07	0.36
25	1.06	0.42	0.55	0.06	0.30
26	1.17	0.49	0.62	0.07	0.32

Appendix Table 13. Magnesium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	PETIOLES 1	2	3	4	5	6	7	8	9	10	11
1	0.69	1.59	1.76	1.53	1.57	-	-	-	-	-	-
2	-	1.81	1.87	1.84	1.69	1.97	1.59	1.35	-	-	-
3	0.97	1.73	1.83	1.67	1.65	1.81	1.51	1.52	1.74	1.67	1.56
4	0.61	1.93	1.61	1.62	1.46	1.56	1.45	1.73	-	-	-
5	0.55	1.61	1.55	1.44	1.42	1.47	1.39	1.53	1.27	1.34	-
6	-	1.89	1.76	1.88	1.34	1.56	1.10	1.26	1.33	1.34	-
7	1.37	1.28	1.21	1.22	1.20	1.22	1.15	-	-	-	-
8	-	2.07	0.19	1.77	1.84	1.70	0.19	1.84	1.80	-	-
9	1.53	1.54	1.33	1.35	1.21	1.36	1.47	1.21	-	-	-
10	1.33	1.52	1.32	1.51	1.39	1.05	-	-	-	-	-
11	1.59	1.59	1.59	1.59	1.59	1.59	1.59	-	-	-	-
12	0.78	1.65	1.65	1.54	1.70	1.18	-	-	-	-	-
13	1.41	1.33	1.41	1.71	1.25	1.37	1.68	1.48	-	-	-
14	1.13	1.11	0.89	0.95	1.17	1.04	-	1.29	-	-	-
15	0.66	1.67	1.28	1.52	1.69	-	-	-	-	-	-
16	0.56	1.37	1.18	1.33	1.23	1.37	1.38	1.25	-	-	-
17	0.74	0.97	0.87	0.93	0.85	0.93	0.68	0.82	-	-	-
18	0.82	1.53	1.55	1.39	1.37	1.25	1.41	1.63	1.45	1.71	1.43
19	0.92	0.80	0.71	1.07	0.92	0.87	0.77	1.08	-	-	-
20	-	2.42	1.39	2.05	-	-	-	-	-	-	-
21	1.91	1.62	1.53	1.77	0.96	1.71	1.04	1.28	1.52	-	-
22	0.90	1.08	1.22	1.12	-	-	-	-	-	-	-
23	0.68	1.40	1.35	1.31	1.05	1.44	-	-	-	-	-
24	0.76	1.11	0.93	1.08	1.10	1.08	1.05	1.15	1.07	-	-
25	1.26	1.33	1.22	1.22	1.30	-	-	-	-	-	-
26	0.60	1.20	1.24	1.34	1.33	-	-	-	-	-	-

Appendix Table 13. Magnesium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT	LEAVES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	0.28	0.53	0.62	0.66	0.59	-	-	-	-	-	-
2	-	0.49	0.58	0.67	0.57	0.59	0.52	0.63	-	-	-
3	0.40	0.66	0.66	0.76	0.67	0.73	0.70	0.72	0.81	0.77	0.67
4	0.43	0.62	0.64	0.60	0.56	0.64	0.67	-	-	-	-
5	0.34	0.62	0.68	0.62	0.70	0.68	0.60	0.66	0.62	0.63	-
6	0.64	0.61	0.58	0.73	0.59	0.63	0.64	0.59	0.88	0.79	-
7	0.57	0.69	0.68	0.69	0.72	0.63	0.68	-	-	-	-
8	-	0.67	0.76	0.66	0.68	0.69	0.72	0.75	0.78	-	-
9	0.60	0.75	0.58	0.63	0.60	0.61	0.56	0.55	-	-	-
10	0.46	0.63	0.60	0.58	0.62	0.61	-	-	-	-	-
11	0.62	0.54	0.62	0.57	0.57	0.52	0.52	-	-	-	-
12	0.43	0.49	0.54	0.59	0.65	0.63	-	-	-	-	-
13	0.46	0.46	0.54	0.53	0.56	0.55	0.58	0.57	-	-	-
14	0.55	0.57	0.50	0.56	0.56	0.52	0.58	-	-	-	-
15	0.42	0.75	0.65	0.78	0.81	-	-	-	-	-	-
16	0.38	0.57	0.54	0.63	0.50	0.57	0.58	0.61	-	-	-
17	0.43	0.51	0.50	0.52	0.48	0.51	0.48	-	-	-	-
18	0.37	0.61	0.70	0.67	0.65	0.59	0.66	0.68	0.65	0.71	0.65
19	0.42	0.44	0.51	0.53	0.50	0.49	0.52	0.56	-	-	-
20	0.61	1.19	0.72	0.11	-	-	-	-	-	-	-
21	0.39	0.65	0.55	0.71	0.55	0.67	0.66	0.66	0.83	-	-
22	0.38	0.46	0.46	0.44	-	-	-	-	-	-	-
23	0.34	0.54	0.49	0.51	0.47	0.52	-	-	-	-	-
24	-	0.42	0.52	0.59	0.66	0.54	0.62	0.52	0.52	-	-
25	-	0.42	0.40	0.47	0.42	-	-	-	-	-	-
26	0.28	0.41	0.48	0.45	0.49	-	-	-	-	-	-

Appendix Table 13. Magnesium concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	0.81	1.59	1.42	0.16	0.58
2	0.80	1.46	1.22	0.16	0.54
3	0.95	1.63	1.38	0.15	0.69
4	0.81	1.73	1.42	0.15	0.61
5	0.84	1.32	1.13	0.15	0.58
6	0.86	1.93	1.54	0.14	0.72
7	0.79	1.65	1.40	0.14	0.61
8	0.97	1.80	1.49	0.14	0.65
9	0.80	1.64	1.39	0.17	0.71
10	0.74	1.52	1.29	0.13	0.52
11	0.78	1.47	1.23	0.15	0.54
12	0.75	1.54	1.25	0.16	0.62
13	0.71	1.26	1.09	0.16	0.52
14	0.67	1.14	0.99	0.16	0.51
15	0.87	1.60	1.38	0.14	0.56
16	0.67	0.94	0.85	0.15	0.43
17	0.51	0.10	0.24	0.14	0.17
18	0.84	1.83	1.45	0.14	0.70
19	0.59	1.22	1.00	0.13	0.51
20	1.06	2.21	1.99	0.16	0.90
21	0.88	1.75	1.46	0.15	0.72
22	0.55	0.98	0.93	0.14	0.56
23	0.56	0.92	0.81	0.14	0.42
24	0.71	1.42	1.22	0.15	0.69
25	0.49	0.81	0.74	0.16	0.44
26	0.61	0.81	0.77	0.15	0.43

Appendix Table 14. Sulfur concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	PETIOLES 1	2	3	4	5	6	7	8	9	10	11
1	0.10	0.08	0.09	0.08	0.08	-	-	-	-	-	-
2	-	0.09	0.11	0.12	0.12	0.12	0.11	0.07	-	-	-
3	0.12	0.10	0.11	0.11	0.10	0.12	0.10	0.10	0.10	0.12	0.11
4	0.21	0.11	0.10	0.11	0.10	0.12	0.10	0.08	-	-	-
5	0.10	0.09	0.08	0.08	0.09	0.08	0.08	0.09	0.07	0.07	-
6	-	0.14	0.11	0.13	0.08	0.12	0.04	0.07	0.07	0.06	-
7	0.10	0.08	0.08	0.08	0.08	0.08	0.07	-	-	-	-
8	-	0.11	0.11	0.12	0.12	0.11	0.13	0.12	0.11	-	-
9	0.09	0.08	0.07	0.09	0.07	0.09	0.09	0.06	-	-	-
10	0.12	0.09	0.09	0.09	0.10	0.06	-	-	-	-	-
11	0.18	0.18	0.18	0.18	0.18	0.18	0.18	-	-	-	-
12	0.07	0.08	0.09	0.08	0.11	0.05	-	-	-	-	-
13	0.13	0.16	0.17	0.27	0.20	0.20	0.27	0.22	-	-	-
14	0.11	0.07	0.06	0.07	0.08	0.07	-	0.07	-	-	-
15	0.10	0.09	0.08	0.09	0.10	-	-	-	-	-	-
16	0.11	0.11	0.12	0.16	0.15	0.14	0.14	0.11	-	-	-
17	0.03	0.06	0.08	0.05	0.05	0.06	0.04	0.04	-	-	-
18	0.12	0.08	0.08	0.07	0.07	0.07	0.08	0.09	0.08	0.09	0.08
19	0.08	0.06	0.05	0.07	0.07	0.05	0.05	0.08	-	-	-
20	-	0.14	0.12	0.18	-	-	-	-	-	-	-
21	0.12	0.08	0.07	0.09	0.04	0.08	0.04	0.04	0.10	-	-
22	0.08	0.13	0.17	0.18	-	-	-	-	-	-	-
23	0.09	0.17	0.24	0.31	0.32	0.41	-	-	-	-	-
24	0.08	0.07	0.06	0.09	0.06	0.08	0.07	0.08	0.08	-	-
25	0.12	0.29	0.21	0.31	0.37	-	-	-	-	-	-
26	0.08	0.17	0.26	0.29	0.33	-	-	-	-	-	-

Appendix Table 14. Sulfur concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	LEAVES 1	2	3	4	5	6	7	8	9	10	11
1	0.13	0.17	0.18	0.20	0.20	-	-	-	-	-	-
2	-	0.16	0.19	0.17	0.18	0.18	0.20	0.17	-	-	-
3	0.13	0.19	0.20	0.20	0.21	0.21	0.22	0.21	0.20	0.19	0.18
4	0.17	0.19	0.20	0.22	0.20	0.19	0.19	-	-	-	-
5	0.13	0.20	0.21	0.21	0.23	0.23	0.22	0.20	0.17	0.15	-
6	0.09	0.17	0.20	0.21	0.21	0.20	0.18	0.17	0.17	0.18	-
7	0.19	0.21	0.22	0.24	0.22	0.23	0.19	-	-	-	-
8	-	0.18	0.25	0.21	0.23	0.21	0.22	0.21	0.21	-	-
9	0.18	0.22	0.21	0.22	0.21	0.21	0.21	0.21	-	-	-
10	0.17	0.20	0.21	0.21	0.21	0.18	-	-	-	-	-
11	0.17	0.21	0.22	0.23	0.26	0.24	0.23	-	-	-	-
12	0.15	0.17	0.19	0.19	0.18	0.17	-	-	-	-	-
13	0.16	0.19	0.23	0.23	0.24	0.26	0.30	0.25	-	-	-
14	0.18	0.20	0.21	0.20	0.21	0.20	0.19	-	-	-	-
15	0.18	0.15	0.17	0.18	0.18	-	-	-	-	-	-
16	0.11	0.17	0.20	0.23	0.23	0.23	0.24	0.21	-	-	-
17	0.18	0.19	0.20	0.19	0.19	0.17	0.18	-	-	-	-
18	0.14	0.19	0.21	0.22	0.20	0.21	0.20	0.20	0.20	0.18	0.16
19	0.16	0.18	0.19	0.19	0.22	0.19	0.19	0.20	-	-	-
20	0.19	0.19	0.20	0.19	-	-	-	-	-	-	-
21	0.18	0.19	0.18	0.20	0.19	0.20	0.17	0.15	0.13	-	-
22	0.14	0.20	0.22	0.23	-	-	-	-	-	-	-
23	0.14	0.23	0.25	0.28	0.32	0.36	-	-	-	-	-
24	-	0.17	0.20	0.22	0.21	0.22	0.20	0.20	0.20	-	-
25	-	0.26	0.25	0.33	0.33	-	-	-	-	-	-
26	0.09	0.22	0.27	0.29	0.31	-	-	-	-	-	-

Appendix Table 14. Sulfur concentration (percent) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	0.17	0.06	0.08	0.02	0.04
2	0.16	0.04	0.08	0.02	0.04
3	0.17	0.08	0.11	0.02	0.06
4	0.17	0.08	0.11	0.02	0.05
5	0.18	0.06	0.11	0.02	0.06
6	0.17	0.07	0.11	0.03	0.06
7	0.19	0.09	0.12	0.03	0.06
8	0.20	0.07	0.12	0.02	0.06
9	0.18	0.05	0.09	0.02	0.05
10	0.18	0.07	0.10	0.02	0.05
11	0.21	0.05	0.11	0.01	0.05
12	0.15	0.03	0.07	0.03	0.05
13	0.21	0.09	0.13	0.02	0.06
14	0.18	0.05	0.09	0.02	0.05
15	0.15	0.07	0.09	0.02	0.05
16	0.19	0.09	0.12	0.02	0.06
17	0.17	0.04	0.08	0.02	0.04
18	0.17	0.07	0.11	0.02	0.06
19	0.16	0.04	0.08	0.02	0.05
20	0.17	0.06	0.08	0.02	0.05
21	0.15	0.06	0.09	0.03	0.05
22	0.19	0.07	0.08	0.01	0.05
23	0.26	0.10	0.15	0.02	0.07
24	0.18	0.04	0.08	0.02	0.05
25	0.28	0.06	0.11	0.02	0.06
26	0.25	0.12	0.14	0.02	0.07

Appendix Table 15. Manganese concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT	PETIOLES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	150	65	92	75	83	-	-	-	-	-	-
2	-	77	94	127	136	140	131	177	-	-	-
3	134	99	107	119	125	123	128	173	149	209	165
4	167	92	88	88	114	142	157	146	-	-	-
5	220	114	113	128	105	122	101	134	162	136	-
6	-	82	81	68	94	86	148	120	110	157	-
7	105	97	106	92	96	103	115	-	-	-	-
8	-	126	114	119	133	142	153	150	149	-	-
9	.99	97	112	115	126	139	141	129	-	-	-
10	88	76	95	84	86	165	-	-	-	-	-
11	148	148	148	148	148	148	148	-	-	-	-
12	81	96	108	122	123	163	-	-	-	-	-
13	65	68	89	101	85	96	130	124	-	-	-
14	53	61	71	64	92	81	-	121	-	-	-
15	132	95	84	97	96	-	-	-	-	-	-
16	279	115	123	155	137	185	149	251	-	-	-
17	380	111	124	103	142	130	161	142	-	-	-
18	133	80	85	91	105	112	112	95	111	97	114
19	89	84	139	95	114	105	129	130	-	-	-
20	-	83	104	88	-	-	-	-	-	-	-
21	132	78	103	101	99	83	122	149	128	-	-
22	71	72	68	95	-	-	-	-	-	-	-
23	170	108	98	112	129	143	-	-	-	-	-
24	175	117	122	124	224	126	247	164	197	-	-
25	77	74	81	86	81	-	-	-	-	-	-
26	116	114	72	71	108	-	-	-	-	-	-

Appendix Table 15. Manganese concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT	LEAVES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	205	426	516	619	667	-	-	-	-	-	-
2	-	367	546	465	606	618	618	602	-	-	-
3	330	457	560	601	717	786	780	890	921	902	897
4	261	478	537	537	453	553	621	-	-	-	-
5	161	552	580	598	660	814	741	1744	711	744	-
6	326	362	425	528	546	552	441	458	651	639	-
7	559	640	616	786	826	646	739	-	-	-	-
8	-	440	610	664	588	596	625	614	706	-	-
9	420	492	511	530	594	641	591	602	-	-	-
10	358	452	474	569	557	582	-	-	-	-	-
11	627	525	604	586	600	708	621	-	-	-	-
12	329	407	470	671	620	583	-	-	-	-	-
13	384	448	536	547	670	689	712	873	-	-	-
14	367	409	394	445	481	438	452	-	-	-	-
15	276	489	505	574	576	-	-	-	-	-	-
16	204	442	554	675	626	809	725	892	-	-	-
17	419	527	678	617	683	660	673	-	-	-	-
18	305	437	452	469	512	524	502	587	600	618	588
19	412	409	481	460	604	461	574	623	-	-	-
20	427	580	584	715	-	-	-	-	-	-	-
21	233	389	458	491	475	601	402	570	583	-	-
22	366	529	513	550	-	-	-	-	-	-	-
23	327	447	467	512	526	614	-	-	-	-	-
24	-	414	458	520	522	551	494	447	493	-	-
25	-	377	403	516	533	-	-	-	-	-	-
26	260	454	476	490	584	-	-	-	-	-	-

Appendix Table 15. Manganese concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	386	105	167	2	58
2	408	63	187	0	68
3	449	129	245	5	111
4	421	167	253	1	94
5	524	86	261	3	118
6	326	157	218	0	90
7	493	159	256	2	97
8	456	161	271	0	103
9	443	96	200	2	90
10	383	162	228	1	78
11	495	130	259	4	97
12	516	196	314	2	133
13	415	140	227	4	91
14	313	67	148	1	65
15	380	86	175	1	60
16	449	136	238	2	99
17	487	152	267	3	96
18	356	178	247	0	107
19	400	158	241	4	107
20	440	91	159	4	66
21	329	121	190	0	84
22	358	109	140	4	76
23	380	81	169	4	74
24	462	152	240	3	124
25	386	97	157	1	77
26	371	134	178	6	84

Appendix Table 16. Iron concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT	PETIOLES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	342	0	221	0	0	-	-	-	-	-	-
2	-	0	232	519	114	70	49	83	-	-	-
3	0	0	0	0	0	0	0	77	0	34	90
4	311	0	10	0	0	263	105	178	-	-	-
5	115	0	0	0	0	0	0	0	283	97	-
6	-	0	0	0	51	0	76	39	91	90	-
7	320	0	360	0	117	0	40	-	-	-	-
8	-	1743	0	0	243	18	0	21	16	-	-
9	48	0	0	0	18	0	148	205	-	-	-
10	0	0	163	12	0	238	-	-	-	-	-
11	86	86	86	86	86	86	86	-	-	-	-
12	14	0	0	220	0	217	-	-	-	-	-
13	0	0	7	0	0	7	79	106	-	-	-
14	0	0	0	0	52	0	-	27	-	-	-
15	203	0	0	0	194	-	-	-	-	-	-
16	244	76	0	193	0	7	30	108	-	-	-
17	5326	437	374	126	169	233	178	186	-	-	-
18	71	0	0	0	32	164	43	242	52	40	234
19	109	0	23	0	65	0	23	153	-	-	-
20	-	13	560	33	-	-	-	-	-	-	-
21	215	0	0	0	70	4	141	254	285	-	-
22	0	0	0	0	-	-	-	-	-	-	-
23	115	0	0	0	0	0	-	-	-	-	-
24	176	6	49	7	161	55	119	140	257	-	-
25	0	0	0	0	0	-	-	-	-	-	-
26	255	3631	681	220	1579	-	-	-	-	-	-

Appendix Table 16. Iron concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT	LEAVES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	108	106	116	143	231	-	-	-	-	-	-
2	-	112	128	167	137	146	146	243	-	-	-
3	100	98	107	105	127	109	132	190	158	163	170
4	181	124	166	189	264	369	508	-	-	-	-
5	158	100	104	115	118	129	155	152	181	208	-
6	91	106	107	109	145	122	203	169	246	213	-
7	134	154	204	196	214	248	423	-	-	-	-
8	-	107	122	132	200	161	121	234	154	-	-
9	107	111	116	158	132	231	202	211	-	-	-
10	109	125	182	163	232	311	-	-	-	-	-
11	99	107	103	125	148	203	154	-	-	-	-
12	135	113	172	140	131	225	-	-	-	-	-
13	126	117	118	211	149	186	198	213	-	-	-
14	104	106	124	109	125	125	154	-	-	-	-
15	154	108	104	166	133	-	-	-	-	-	-
16	207	110	111	128	125	142	160	284	-	-	-
17	105	134	234	258	210	422	385	-	-	-	-
18	104	115	113	139	159	140	187	153	225	224	215
19	133	142	375	146	172	189	215	186	-	-	-
20	113	118	192	142	-	-	-	-	-	-	-
21	185	103	111	119	166	112	230	232	198	-	-
22	102	98	101	104	-	-	-	-	-	-	-
23	149	104	104	105	112	116	-	-	-	-	-
24	-	106	133	127	245	159	320	193	230	-	-
25	-	104	104	108	114	-	-	-	-	-	-
26	138	107	113	132	192	-	-	-	-	-	-

Appendix Table 16. Iron concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	164	142	147	67	93
2	147	143	144	79	101
3	149	142	145	71	102
4	229	2653	1832	79	721
5	172	280	237	74	144
6	127	1247	842	80	392
7	308	1444	1115	76	464
8	273	910	672	81	303
9	145	270	233	77	144
10	361	2588	1924	66	690
11	234	267	255	69	135
12	194	886	632	74	306
13	278	1008	776	65	340
14	119	214	183	72	119
15	142	711	540	87	238
16	151	688	514	62	247
17	534	533	533	68	231
18	205	1192	808	72	389
19	371	645	550	70	277
20	148	652	554	93	278
21	162	585	445	81	239
22	108	206	194	71	135
23	118	306	250	67	143
24	193	1735	1298	88	703
25	319	142	179	65	119
26	263	1142	978	63	477

Appendix Table 17. Copper concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT	PETIOLES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	6	3	4	5	7	-	-	-	-	-	-
2	-	3	4	5	5	6	5	5	-	-	-
3	4	4	4	6	7	7	8	7	7	7	7
4	7	4	7	7	7	7	7	9	-	-	-
5	7	3	4	5	6	6	6	7	7	7	-
6	-	5	6	6	7	6	6	6	5	5	-
7	2	4	4	6	6	6	6	-	-	-	-
8	-	3	4	6	4	6	6	7	6	-	-
9	2	4	5	5	6	6	6	6	-	-	-
10	2	6	7	7	6	8	-	-	-	-	-
11	6	6	6	6	6	6	6	-	-	-	-
12	8	6	6	7	6	6	-	-	-	-	-
13	3	5	5	6	6	7	6	6	-	-	-
14	2	5	6	6	6	8	-	7	-	-	-
15	6	3	4	5	4	-	-	-	-	-	-
16	6	2	4	4	5	5	4	6	-	-	-
17	2	6	6	7	8	8	10	9	-	-	-
18	4	2	5	5	6	5	6	6	6	4	5
19	6	8	8	6	8	8	8	7	-	-	-
20	-	2	4	4	-	-	-	-	-	-	-
21	2	5	5	5	6	5	5	4	4	-	-
22	0	3	2	4	-	-	-	-	-	-	-
23	5	2	3	3	4	3	-	-	-	-	-
24	7	5	6	6	6	7	7	6	7	-	-
25	0	1	2	3	3	-	-	-	-	-	-
26	1	0	1	2	3	-	-	-	-	-	-

Appendix Table 17. Copper concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	LEAVES 1	2	3	4	5	6	7	8	9	10	11
1	6	6	3	7	5	-	-	-	-	-	-
2	-	2	5	0	3	4	36	7	-	-	-
3	1	2	3	2	4	3	5	6	3	5	4
4	11	0	4	5	9	6	6	-	-	-	-
5	10	1	1	4	5	6	9	4	6	5	-
6	10	0	6	1	8	5	8	9	5	7	-
7	1	2	3	5	4	6	7	-	-	-	-
8	-	0	4	8	7	6	3	4	4	-	-
9	1	3	5	7	6	8	8	7	-	-	-
10	1	1	8	3	5	7	-	-	-	-	-
11	2	3	6	6	6	8	5	-	-	-	-
12	5	3	5	4	2	6	-	-	-	-	-
13	1	4	4	8	4	7	7	9	-	-	-
14	3	3	5	6	7	6	9	-	-	-	-
15	8	0	1	1	0	-	-	-	-	-	-
16	17	1	3	4	7	6	6	5	-	-	-
17	3	4	4	6	5	9	6	-	-	-	-
18	4	2	2	4	6	5	5	4	8	5	4
19	3	4	8	5	8	8	8	6	-	-	-
20	3	0	5	0	-	-	-	-	-	-	-
21	13	1	5	2	7	32	7	5	3	-	-
22	1	2	5	4	-	-	-	-	-	-	-
23	5	0	2	5	5	7	-	-	-	-	-
24	-	3	6	6	7	6	8	9	8	-	-
25	-	2	2	3	5	-	-	-	-	-	-
26	0	0	1	3	3	-	-	-	-	-	-

Appendix Table 17. Copper concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	7	6	6	8	7
2	4	6	5	11	8
3	6	7	7	12	9
4	6	7	7	11	9
5	5	5	5	11	8
6	5	9	8	12	10
7	4	7	6	11	9
8	5	10	8	10	9
9	6	8	7	10	9
10	6	7	7	11	9
11	8	7	7	11	10
12	8	6	7	11	9
13	6	5	5	11	9
14	6	7	7	11	9
15	3	7	6	10	9
16	10	7	8	10	9
17	9	9	9	11	10
18	7	9	8	10	9
19	7	6	6	11	9
20	3	5	5	11	8
21	4	6	5	10	8
22	4	5	5	10	7
23	5	3	4	11	8
24	8	8	8	10	9
25	3	2	2	10	6
26	2	0	0	10	6

Appendix Table 18. Zinc concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT	PETIOLES										
NUMBER	1	2	3	4	5	6	7	8	9	10	11
1	27	29	33	29	34	-	-	-	-	-	-
2	-	37	33	41	38	41	35	33	-	-	-
3	26	30	32	31	36	35	37	38	38	42	42
4	26	36	36	37	35	40	36	47	-	-	-
5	27	28	30	30	30	31	30	35	31	32	-
6	-	36	36	35	34	36	31	34	34	37	-
7	22	25	23	26	24	25	27	-	-	-	-
8	-	39	38	37	37	40	44	43	44	-	-
9	30	29	29	28	29	30	35	31	-	-	-
10	24	32	30	33	31	32	-	-	-	-	-
11	34	34	34	34	34	34	34	-	-	-	-
12	25	36	36	39	38	31	-	-	-	-	-
13	32	31	31	37	32	35	40	37	-	-	-
14	19	21	21	18	24	26	-	33	-	-	-
15	20	30	23	31	31	-	-	-	-	-	-
16	35	30	28	30	32	34	34	37	-	-	-
17	17	21	20	21	23	23	25	24	-	-	-
18	26	25	34	30	34	30	37	40	38	40	36
19	21	21	20	21	24	24	21	27	-	-	-
20	-	50	36	42	-	-	-	-	-	-	-
21	43	34	34	36	28	37	30	33	37	-	-
22	28	28	30	32	-	-	-	-	-	-	-
23	39	37	38	37	36	43	-	-	-	-	-
24	50	27	26	25	30	30	33	32	31	-	-
25	39	38	39	37	40	-	-	-	-	-	-
26	33	32	35	39	41	-	-	-	-	-	-

Appendix Table 18. Zinc concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	LEAVES 1	2	3	4	5	6	7	8	9	10	11
1	22	23	17	28	21	-	-	-	-	-	-
2	-	14	21	14	19	22	24	27	-	-	-
3	12	22	20	18	25	20	28	63	31	34	35
4	32	12	21	19	28	26	28	-	-	-	-
5	30	23	19	23	28	31	33	26	24	28	-
6	35	13	25	23	33	29	31	35	38	42	-
7	17	22	21	30	28	27	32	-	-	-	-
8	-	15	25	32	29	30	27	29	33	-	-
9	13	23	25	24	27	29	27	26	-	-	-
10	14	20	29	24	23	31	-	-	-	-	-
11	19	17	28	24	28	35	20	-	-	-	-
12	19	16	21	20	18	26	-	-	-	-	-
13	15	19	21	27	27	28	35	34	-	-	-
14	17	19	21	24	30	22	29	-	-	-	-
15	31	15	18	21	20	-	-	-	-	-	-
16	37	15	22	25	25	29	30	36	-	-	-
17	16	16	18	20	21	27	23	-	-	-	-
18	21	23	28	29	31	35	56	33	65	38	35
19	14	18	28	18	27	24	29	25	-	-	-
20	23	21	29	23	-	-	-	-	-	-	-
21	33	16	28	21	28	30	35	35	30	-	-
22	15	26	24	25	-	-	-	-	-	-	-
23	34	14	16	16	24	29	-	-	-	-	-
24	-	16	23	23	28	21	32	26	32	-	-
25	-	18	25	28	30	-	-	-	-	-	-
26	33	22	21	22	29	-	-	-	-	-	-

Appendix Table 18. Zinc concentration (ppm) in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest (continued).

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	23	28	27	11	16
2	24	28	27	15	19
3	35	28	31	16	22
4	30	34	33	13	20
5	29	26	27	16	21
6	25	42	36	15	23
7	26	35	32	14	21
8	33	40	37	11	21
9	33	36	35	14	23
10	29	29	29	14	19
11	35	30	32	15	21
12	39	34	36	17	24
13	29	37	34	16	23
14	24	25	25	14	18
15	23	37	33	14	20
16	27	37	34	14	22
17	25	20	22	14	16
18	31	37	35	12	22
19	24	20	21	14	17
20	28	48	44	16	27
21	28	36	33	14	22
22	25	37	36	15	26
23	23	37	33	16	23
24	31	32	32	13	22
25	26	46	42	15	28
26	25	48	44	14	27

Appendix Table 19. Summary of total phosphorus, in grams, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	1.3	3.0	4.3	8.5	12.8
2	2.3	3.0	5.2	8.8	14.0
3	2.7	3.7	6.4	7.6	14.0
4	1.8	2.8	4.6	6.8	11.4
5	2.7	3.2	5.9	6.9	12.8
6	2.0	2.8	4.8	6.1	10.9
7	1.4	2.4	3.7	6.2	9.9
8	1.7	2.1	3.8	5.4	9.2
9	1.8	3.1	4.9	6.0	11.0
10	1.1	1.9	3.0	5.2	8.2
11	1.6	2.8	4.4	6.2	10.6
12	1.9	2.1	4.0	5.6	9.6
13	2.0	7.5	9.5	6.9	16.4
14	1.8	2.6	4.4	5.3	9.7
15	1.0	1.9	3.0	5.4	8.4
16	2.1	6.4	8.4	6.8	15.2
17	1.2	1.5	2.7	4.4	7.1
18	1.6	2.0	3.6	4.0	7.7
19	1.5	1.9	3.4	4.3	7.7
20	0.8	2.1	2.9	4.2	7.1
21	1.3	2.0	3.2	3.9	7.1
22	1.2	11.2	12.4	4.0	16.4
23	1.7	9.5	11.2	3.6	14.8
24	1.0	1.8	2.8	2.4	5.2
25	1.6	16.3	17.9	3.5	21.4
26	1.4	11.4	12.8	3.2	16.0

Appendix Table 20. Summary of total calcium, in grams, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	10.5	16.8	27.3	4.8	32.1
2	18.6	12.7	31.3	4.8	36.1
3	26.2	19.1	45.3	4.4	49.7
4	17.0	14.3	31.3	4.2	35.5
5	33.0	13.3	46.3	4.5	50.8
6	16.5	14.9	31.4	3.4	34.8
7	13.4	15.3	28.6	3.7	32.4
8	18.6	10.6	29.2	3.8	33.1
9	16.1	12.4	28.5	3.9	32.3
10	9.7	11.8	21.5	3.3	24.8
11	19.2	9.1	28.3	3.2	31.5
12	36.1	14.4	50.5	3.4	53.9
13	10.9	10.4	21.3	3.1	24.4
14	14.5	11.7	26.2	3.5	29.7
15	9.7	8.2	17.9	3.2	21.0
16	12.2	11.6	23.8	2.8	26.7
17	8.7	10.3	19.0	2.9	21.9
18	16.0	11.7	27.7	2.9	30.6
19	11.3	14.7	26.0	2.5	28.5
20	6.6	4.2	10.8	2.9	13.7
21	10.2	8.8	19.0	2.1	21.1
22	3.6	10.9	14.5	1.8	16.2
23	5.7	5.1	10.8	1.5	12.3
24	7.7	7.9	15.6	1.5	17.1
25	4.4	6.6	11.1	1.3	12.4
26	3.5	6.4	9.9	1.4	11.2

Appendix Table 21. Summary of total magnesium, in grams, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	6.9	47.8	54.7	11.3	66.0
2	12.1	39.5	51.6	11.2	62.7
3	19.8	59.9	79.7	10.1	89.8
4	10.6	44.1	54.7	9.3	64.0
5	17.7	41.8	59.4	9.4	68.8
6	12.3	48.6	60.8	7.7	68.6
7	7.7	39.3	47.0	7.6	54.6
8	12.0	37.5	49.5	7.2	56.7
9	10.6	50.7	61.3	9.1	70.3
10	5.8	28.1	34.0	6.8	40.7
11	8.4	29.1	37.6	7.5	45.1
12	10.3	36.2	46.5	8.2	54.7
13	7.3	27.9	35.2	7.9	43.2
14	8.6	29.8	38.3	7.3	45.7
15	6.5	27.9	34.4	6.8	41.1
16	7.3	21.4	28.7	6.6	35.3
17	4.4	1.6	6.0	5.9	11.9
18	10.7	36.4	47.1	5.7	52.8
19	6.7	26.4	33.1	5.3	38.4
20	5.3	45.9	51.2	5.9	57.1
21	8.5	34.4	42.9	5.4	48.3
22	2.0	25.5	27.5	3.6	31.1
23	3.0	11.7	14.7	3.2	17.9
24	4.9	25.1	30.0	3.2	33.2
25	2.0	12.8	14.8	3.3	18.2
26	1.8	10.5	12.3	2.8	15.1

Appendix Table 22. Summary of total sulfur, in grams, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	1.4	1.8	3.2	1.7	5.0
2	2.4	1.1	3.5	1.2	4.7
3	3.5	2.9	6.5	1.6	8.1
4	2.2	2.0	4.3	1.5	5.7
5	3.8	1.9	5.7	1.4	7.1
6	2.4	1.8	4.2	1.8	6.0
7	1.8	2.1	4.0	1.4	5.4
8	2.5	1.5	3.9	1.2	5.1
9	2.4	1.5	3.9	1.1	5.1
10	1.4	1.3	2.7	1.1	3.9
11	2.3	1.0	3.3	0.7	4.0
12	2.1	0.7	2.8	1.3	4.1
13	2.2	2.0	4.2	0.9	5.0
14	2.3	1.3	3.6	1.2	4.8
15	1.1	1.2	2.3	1.1	3.5
16	2.1	2.0	4.1	0.8	4.9
17	1.5	0.7	2.1	1.0	3.1
18	2.2	1.4	3.5	0.9	4.4
19	1.8	0.9	2.7	0.9	3.6
20	0.8	1.2	2.1	0.8	2.9
21	1.5	1.2	2.6	1.0	3.6
22	0.7	1.8	2.5	0.3	2.9
23	1.4	1.3	2.7	0.4	3.0
24	1.3	0.7	2.0	0.5	2.5
25	1.2	0.9	2.1	0.3	2.5
26	0.7	1.6	2.3	0.3	2.6

Appendix Table 23. Summary of total manganese, in mg, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	328.1	315.6	643.7	10.9	654.7
2	616.5	170.4	786.8	2.8	789.7
3	934.9	474.1	1409.0	32.5	1441.5
4	549.8	426.2	976.0	8.5	984.5
5	1102.0	272.1	1374.1	20.4	1394.4
6	464.5	395.2	859.7	0.9	860.6
7	478.2	379.1	857.3	9.9	867.2
8	566.4	335.2	901.6	2.6	904.1
9	584.3	296.8	881.1	11.8	893.0
10	301.4	299.9	601.3	7.3	608.6
11	536.1	257.7	793.7	21.7	815.4
12	705.9	461.2	1167.1	9.8	1176.8
13	428.3	310.1	738.4	19.1	757.5
14	400.6	174.9	575.5	4.7	580.2
15	285.0	149.7	434.7	4.9	439.6
16	490.3	309.0	799.3	9.2	808.5
17	417.4	248.2	665.6	11.8	677.4
18	450.4	354.4	804.8	1.0	805.8
19	456.0	341.9	797.9	14.1	812.0
20	220.0	189.0	409.0	13.8	422.9
21	318.5	237.9	556.4	1.3	557.6
22	131.4	283.4	414.8	8.9	423.7
23	202.9	103.0	306.0	8.9	314.9
24	322.0	268.3	590.3	6.1	596.4
25	161.0	153.3	314.2	1.6	315.8
26	110.6	174.2	284.8	10.5	295.3

Appendix Table 24. Summary of total iron, in mg, in various tissnes of individual Williams Hybrid banana pseudostems sampled at harvest.

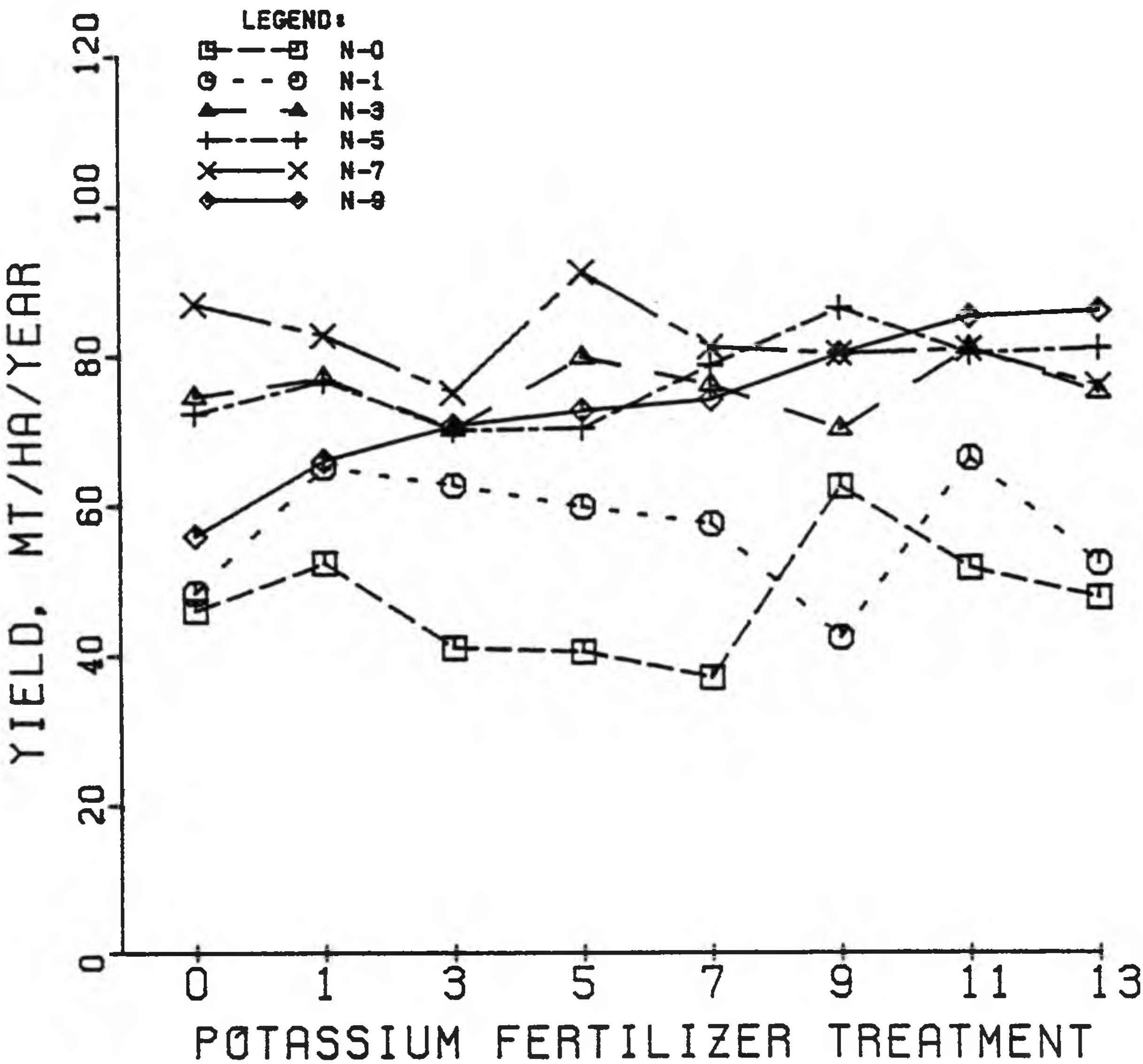
PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	139.4	426.9	566.3	482.5	1048.8
2	222.1	386.7	608.8	562.9	1171.7
3	310.3	521.8	832.2	491.4	1323.6
4	299.1	6770.5	7069.5	503.0	7572.5
5	361.7	885.9	1247.6	461.7	1709.3
6	181.0	3138.7	3319.7	430.7	3750.3
7	298.8	3442.5	3741.3	406.5	4147.7
8	339.1	1894.6	2233.7	417.9	2651.5
9	191.3	834.8	1026.1	402.0	1428.1
10	284.1	4790.4	5074.5	333.4	5407.9
11	253.4	529.2	782.6	346.5	1129.1
12	265.4	2084.8	2350.1	368.1	2718.2
13	286.9	2232.7	2519.6	314.4	2834.0
14	152.3	558.5	710.9	343.2	1054.0
15	106.5	1237.9	1344.4	412.8	1757.1
16	164.9	1563.1	1728.0	281.0	2009.0
17	457.6	870.4	1328.0	296.3	1624.4
18	260.0	2373.3	2633.3	287.6	2920.9
19	422.9	1395.8	1818.7	280.8	2099.5
20	74.0	1354.2	1428.2	341.9	1770.1
21	156.8	1150.1	1306.9	286.0	1593.0
22	39.6	535.6	575.2	180.6	755.8
23	63.0	389.2	452.2	157.9	610.1
24	134.5	3062.3	3196.8	194.0	3390.8
25	133.0	224.4	357.4	131.5	488.8
26	78.4	1484.6	1563.0	117.9	1680.8

Appendix Table 25. Summary of total copper, in mg, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

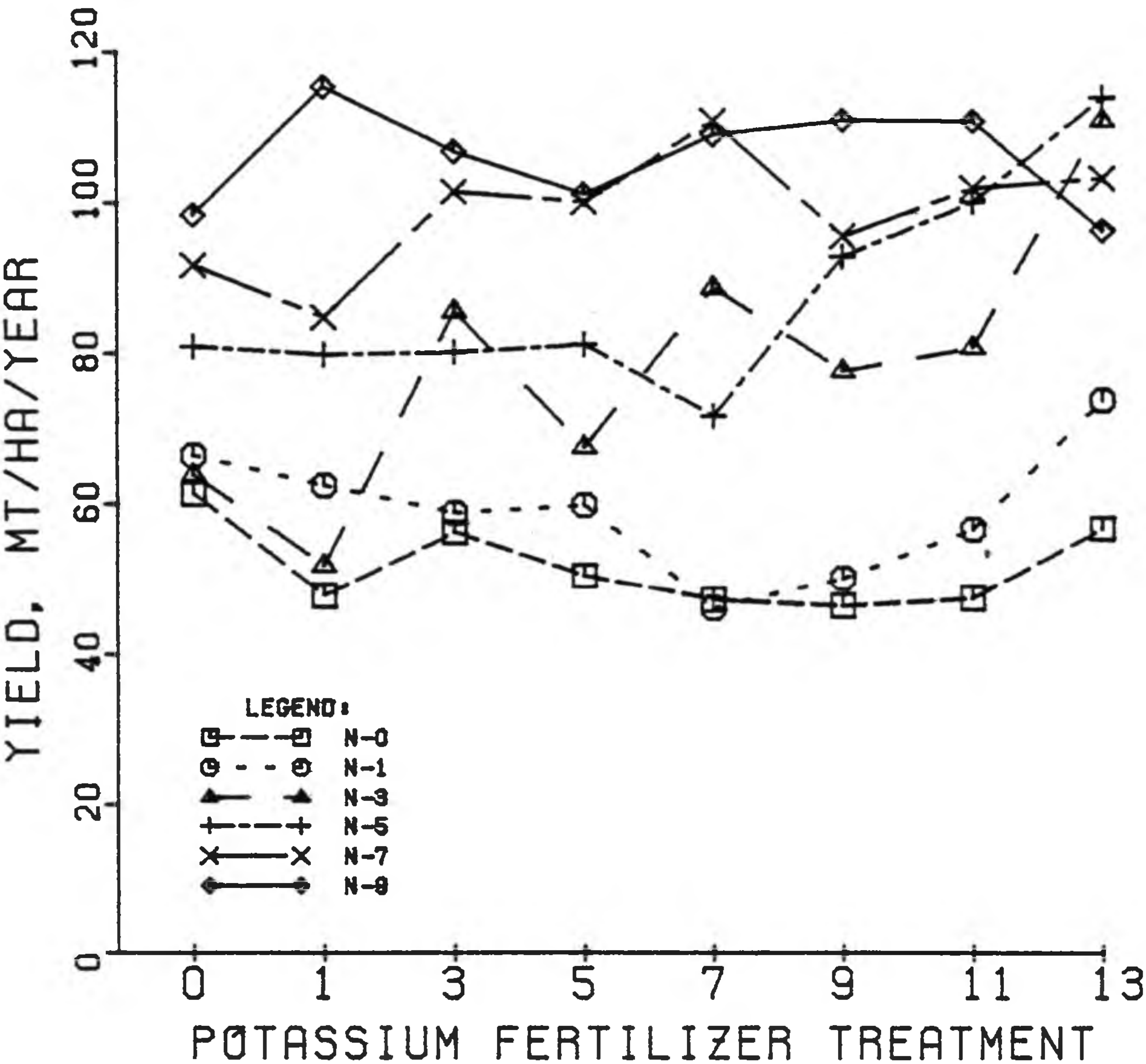
PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	5.9	18.0	24.0	56.2	80.2
2	6.0	16.2	22.3	76.0	98.2
3	12.5	25.7	38.2	80.4	118.6
4	7.8	17.9	25.7	68.3	94.0
5	10.5	15.8	26.3	70.6	96.9
6	7.1	22.7	29.8	62.8	92.5
7	3.9	16.7	20.6	57.5	78.1
8	6.2	20.8	27.0	50.9	77.9
9	7.9	24.7	32.6	54.5	87.1
10	4.7	13.0	17.7	55.6	73.2
11	8.7	13.9	22.5	57.4	79.9
12	10.9	14.1	25.1	56.3	81.3
13	6.2	11.1	17.3	55.3	72.6
14	7.7	18.3	25.9	50.3	76.3
15	2.3	12.2	14.4	48.8	63.2
16	10.9	15.9	26.8	47.1	73.9
17	7.7	14.7	22.4	48.2	70.6
18	8.9	17.9	26.8	40.6	67.4
19	8.0	13.0	21.0	45.8	66.7
20	1.5	10.4	11.9	40.2	52.1
21	3.9	11.8	15.7	36.8	52.4
22	1.5	13.0	14.5	26.2	40.6
23	2.7	3.8	6.5	25.9	32.4
24	5.6	14.1	19.7	22.8	42.5
25	1.3	3.2	4.4	19.7	24.1
26	0.6	0.0	0.6	18.9	19.5

Appendix Table 26. Summary of total zinc, in mg, in various tissues of individual Williams Hybrid banana pseudostems sampled at harvest.

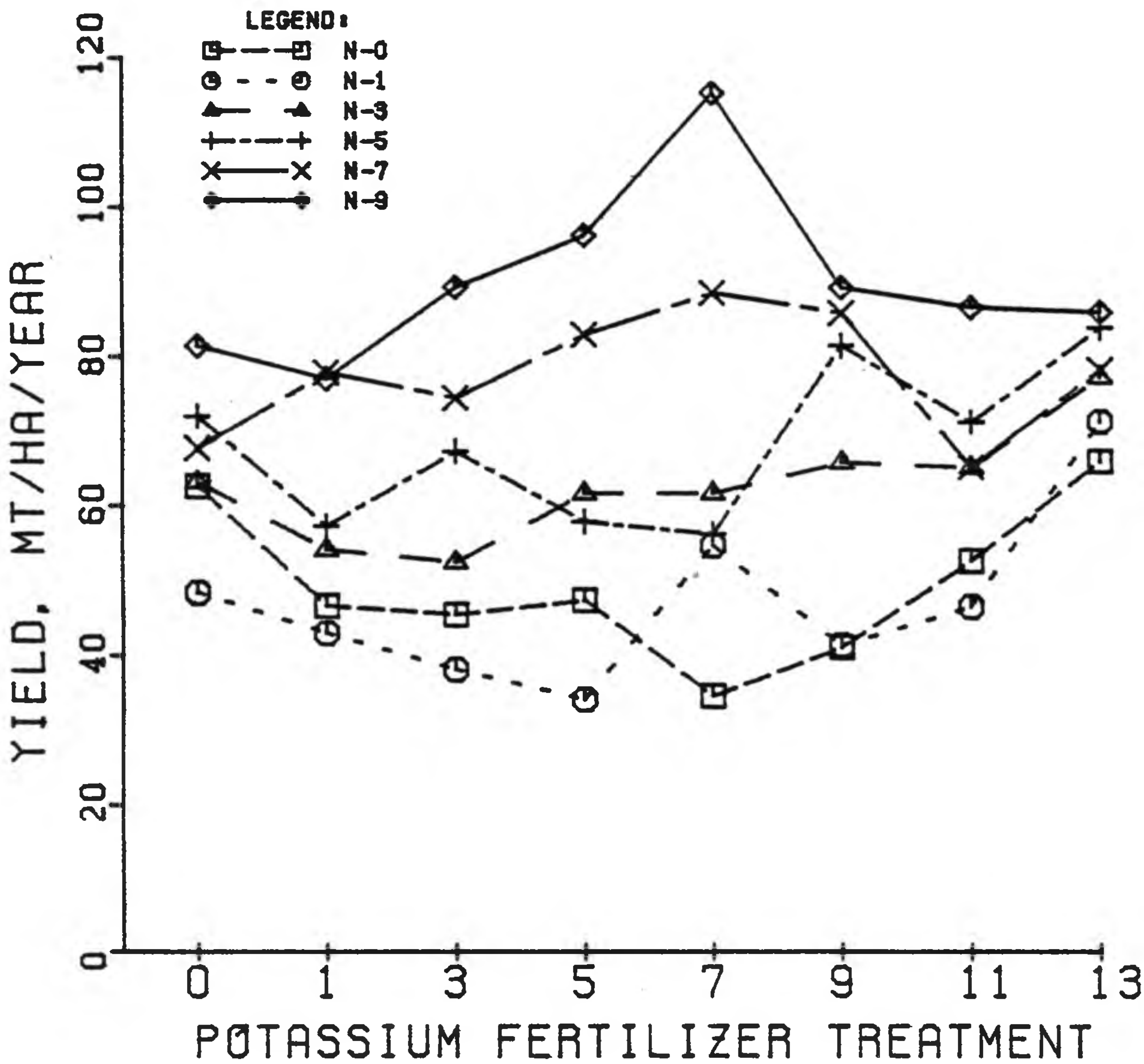
PLANT NUMBER	TOTAL LEAVES + PETIOLES	PSEUDO-STEM	TOTAL VEGETATIVE	TOTAL BUNCH	TOTAL PLANT
1	19.5	84.2	103.7	80.1	183.9
2	36.3	75.7	112.0	106.5	218.5
3	72.7	102.9	175.6	110.1	285.7
4	39.2	86.8	125.9	85.4	211.3
5	61.0	82.3	143.3	101.1	244.3
6	35.6	105.7	141.3	80.6	221.9
7	25.2	83.4	108.7	75.0	183.6
8	41.0	83.3	124.3	56.2	180.5
9	43.5	111.3	154.8	73.5	228.4
10	22.8	53.7	76.5	70.4	146.9
11	37.9	59.5	97.4	74.2	171.5
12	53.4	80.0	133.4	82.4	215.8
13	29.9	82.0	111.9	76.5	188.4
14	30.7	65.3	96.0	64.1	160.0
15	17.3	64.4	81.7	67.8	149.5
16	29.5	84.1	113.5	62.3	175.9
17	21.4	32.7	54.1	59.5	113.6
18	39.2	73.7	112.8	49.8	162.7
19	27.4	43.3	70.6	55.0	125.6
20	14.0	99.7	113.7	57.4	171.1
21	27.1	70.8	97.9	48.6	146.4
22	9.2	96.2	105.4	38.3	143.7
23	12.3	47.1	59.3	38.2	97.5
24	21.6	56.5	78.1	29.5	107.6
25	10.8	72.7	83.5	30.6	114.2
26	7.4	62.4	69.8	26.9	96.7



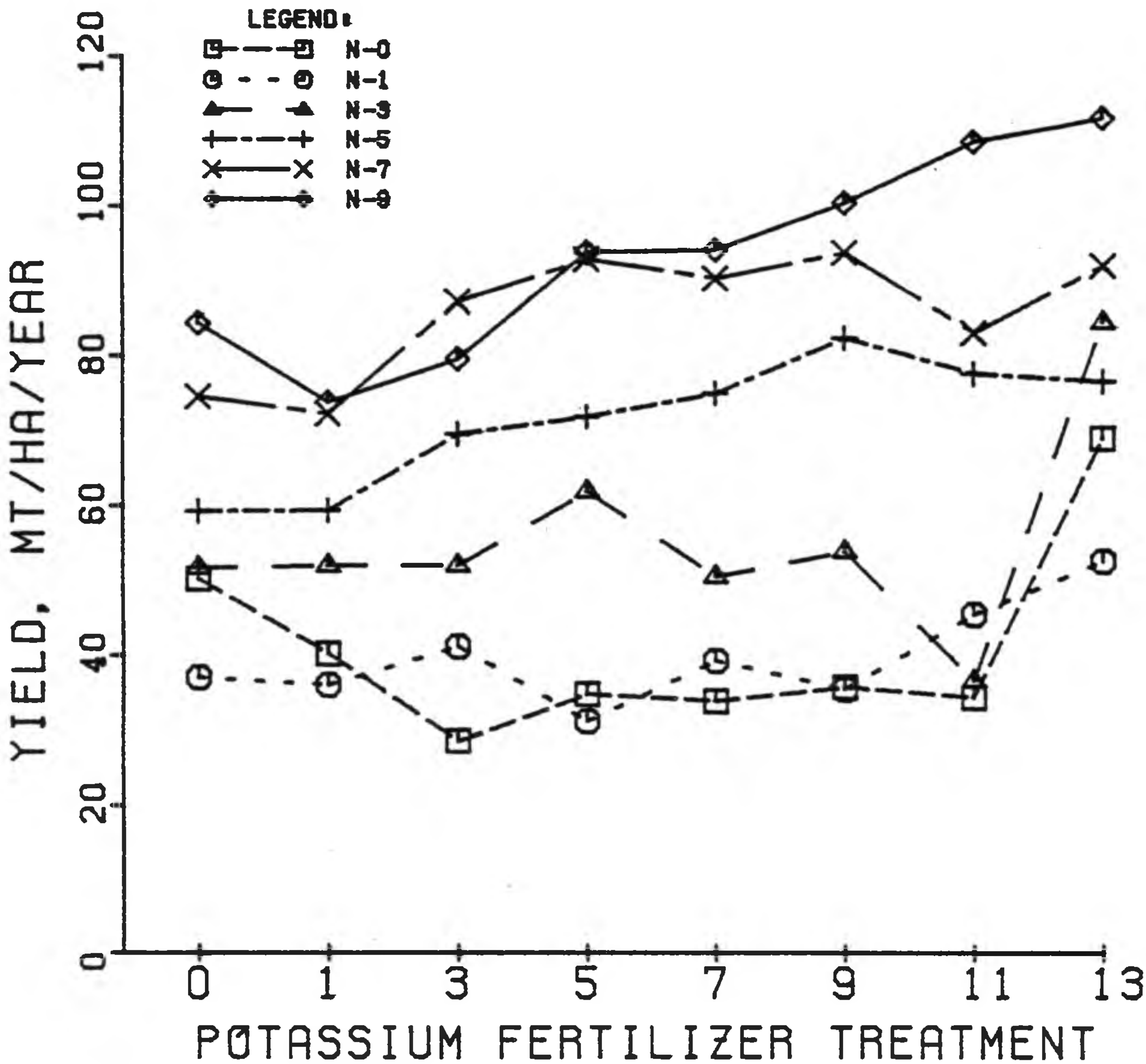
Appendix Fig. 1. Total production of Williams Hybrid bananas at Waimanalo during the first production year (May, 1972 through April, 1973) in relation to 6 N x 8 K fertilization levels.



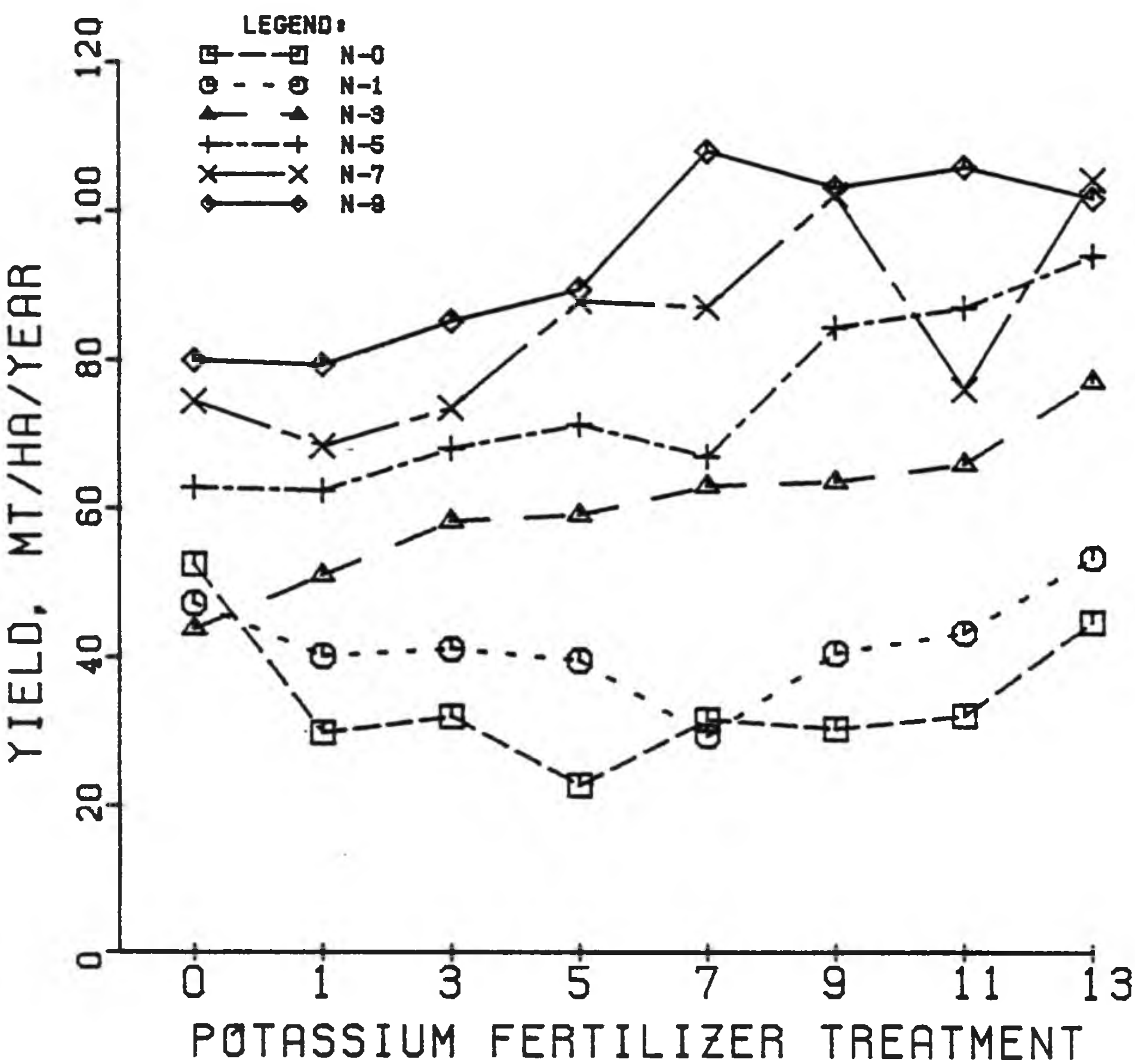
Appendix Fig. 2. Total production of Williams Hybrid bananas at Waimanalo during the second production year (May, 1973 through April, 1974) in relation to 6 N x 8 K fertilization levels.



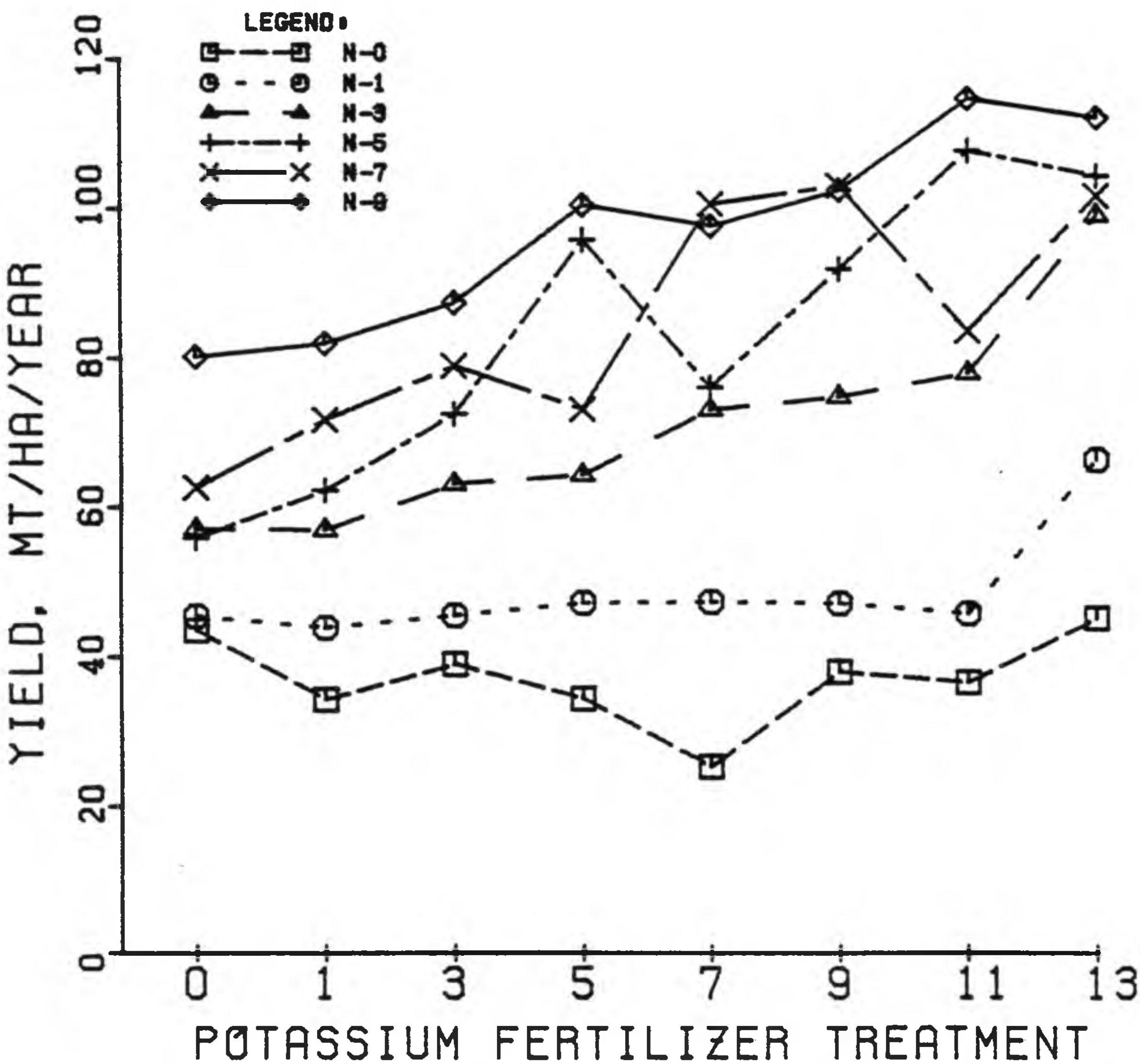
Appendix Fig. 3. Total production of Williams Hybrid bananas at Waimanalo during the third production year (May, 1974 through April, 1975) in relation to 6 N x 8 K fertilization levels.



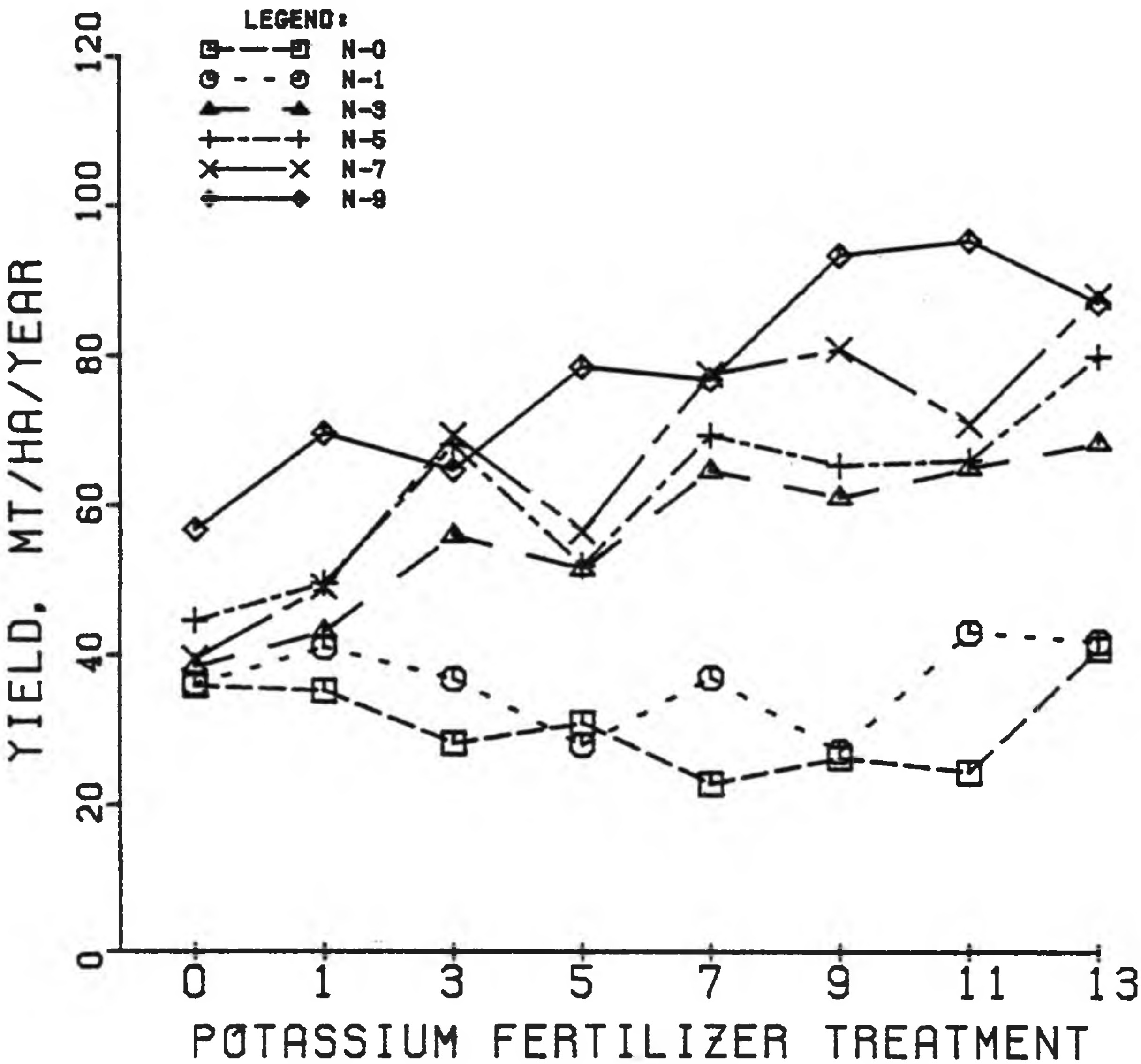
Appendix Fig. 4. Total production of Williams Hybrid bananas at Waimanalo during the fourth production year (May, 1975 through April, 1976) in relation to 6 N x 8 K fertilization levels.



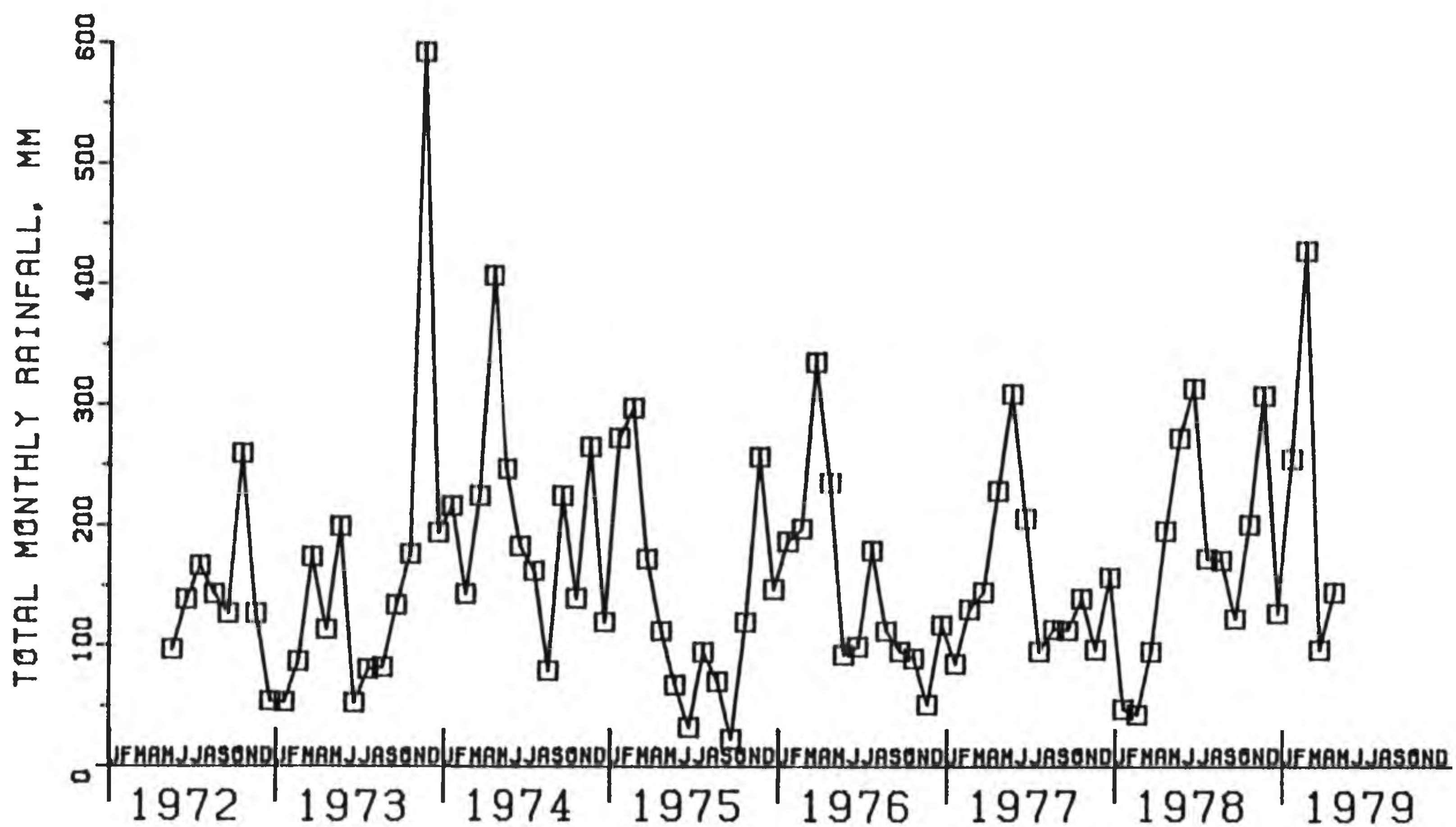
Appendix Fig. 5. Total production of Williams Hybrid bananas at Waimanalo during the fifth production year (May, 1976 through April, 1977) in relation to 6 N x 8 K fertilization levels.



Appendix Fig. 6. Total production of Williams Hybrid bananas at Waimanalo during the sixth production year (May, 1977 through April, 1978) in relation to 6 N x 8 K fertilization levels.



Appendix Fig. 7. Total production of Williams Hybrid bananas at Waimanalo during the seventh production year (May, 1978 through April, 1979) in relation to 6 N x 8 K fertilization levels.



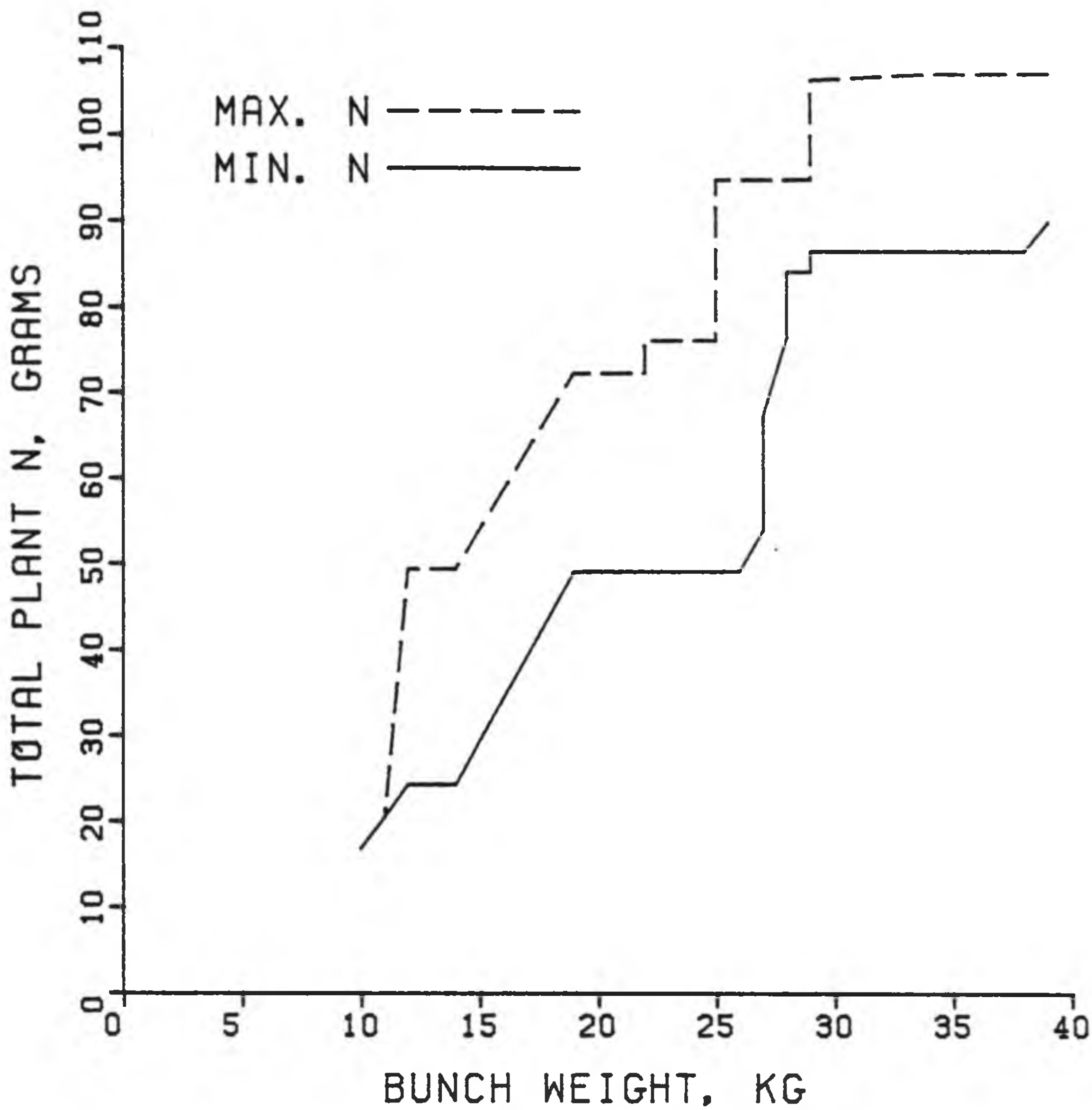
Appendix Fig. 8. Monthly rainfall summaries for the Waimanalo Research Station for the period January, 1972 through April, 1979.

Appendix Section I

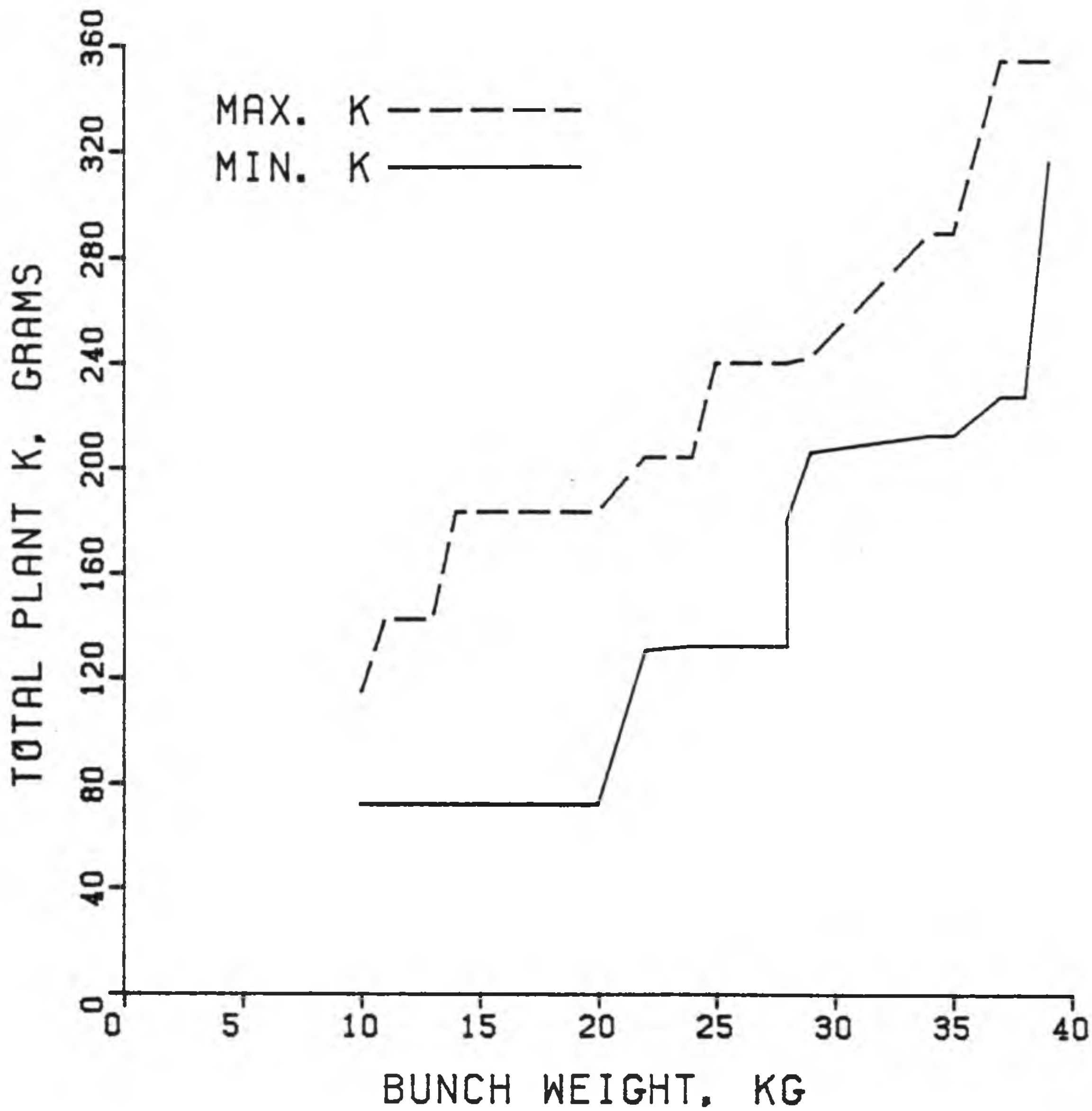
Bunch Weight of Williams Hybrid Banana in Relation to the Total Uptake of N and K at the Harvest Stage

Appendix Figure 9 shows the data (cf. Appendix Table 10) for total plant N, bunch included, of harvested Williams Hybrid bananas plotted vs. bunch weight according to the minimum and maximum values of total N in order of decreasing and increasing bunch weights, respectively. For example, in plant number 12 the total N content was 78 g. But at least one plant (number 14) having a smaller bunch (25.4 kg) contained 95 g N; thus, the value 95 was plotted along the maximum N curve corresponding to the weight of bunch number 12 (26.8 kg). Likewise, plant number 11 contained only 54 g N but yielded a larger bunch than plant number 12; thus, the value 54 was plotted along the minimum N curve corresponding to the weight of bunch number 11 (27.2 kg). The resulting plot delineates an approximate yield boundary. In the vertical direction the range of expected total N uptake for any given bunch weight is found, while in the horizontal direction the range of expected bunch weights for any given N content is estimated.

In a similar manner yield boundary curves were constructed based on minimum and maximum K contents (Appendix Fig. 10). For plant number 12 it is shown that the range of total K associated with that size bunch may be from approximately 125 to 250 g. No attempt was made to "smooth" the curves in either figure because it was felt much more data would be required before this could be done with sufficient accuracy. For the present we wish only to demonstrate this concept as a method for arriving at nutrient supply requirements.



Appendix Fig. 9. Empirically determined N-uptake boundary illustrating the minimum N required for a desired banana bunch yield and the maximum N uptake likely for a pseudostem which yields a given sized bunch; data from Williams Hybrid bananas sampled at harvest.

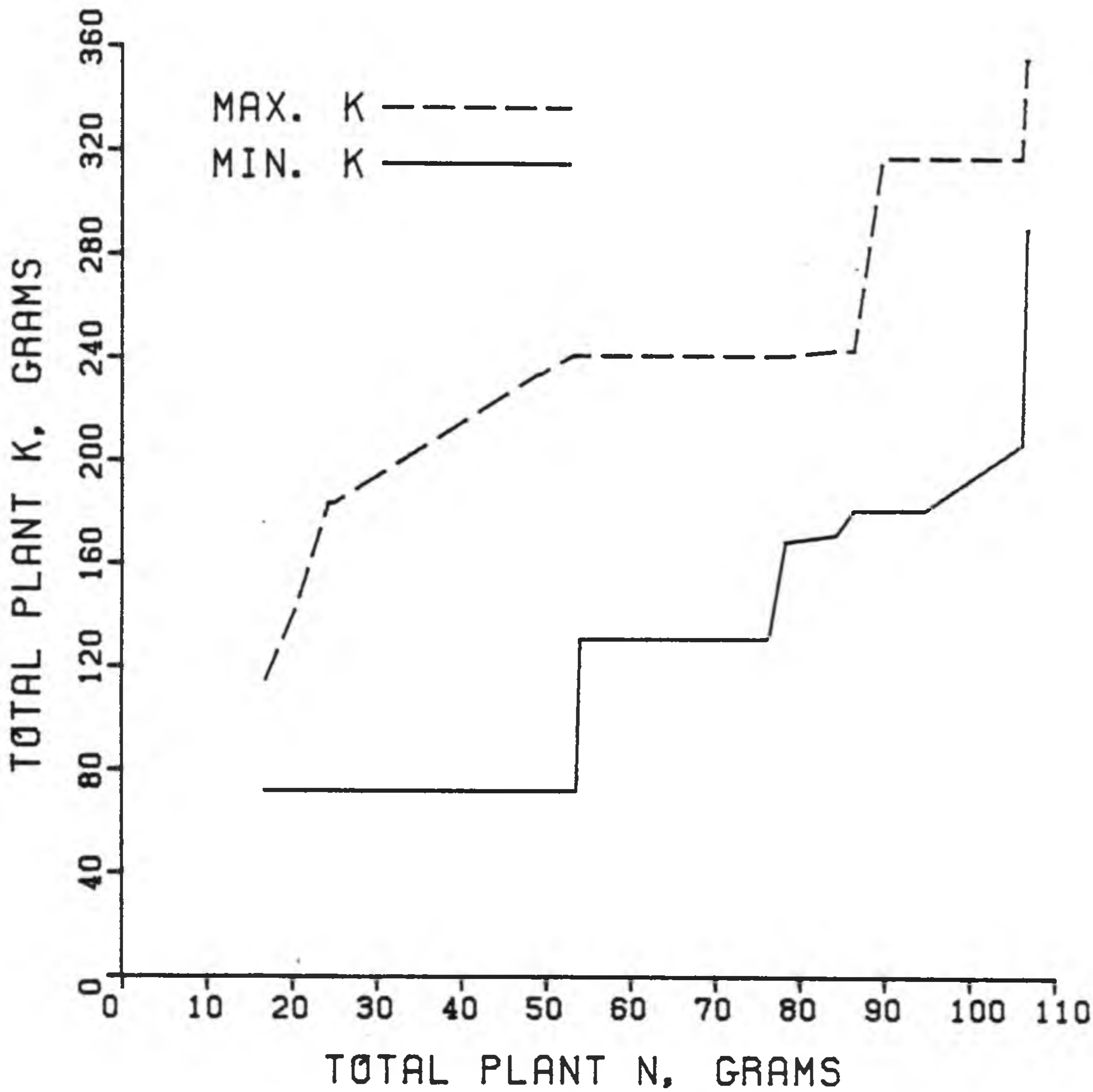


Appendix Fig. 10. Empirically determined K-uptake boundary illustrating the minimum K required for a desired banana bunch yield and the maximum K uptake likely for a pseudostem which yields a given sized bunch; data from Williams Hybrid bananas sampled at harvest.

The data suggest that a 26.8 kg bunch can occur when total plant uptake of N and K range from as low as 54 g N and 25 g K up to 95 g N and 250 g K. To check this we need to know the empirical relationship between total N and total K. Appendix Figure 11 shows the expected boundary for K vs. N following a procedure analogous to the above. It shows that when total N uptake is 54 g we might expect to find total K ranging from about 60 g to 240 g. The minimum K expected for a 26.8 kg bunch was 125 g (App. Fig. 10), so this minimum N-K combination (54 g N with 125 g K) is reasonable to expect for plants which produce a bunch of this size.

The maximum K value expected to occur when the plant contains 54 g N is 240 g K, just under the proposed 250 g limit of K uptake for a bunch this size. If the plant is limited to only 54 g N then it is less likely to obtain a bunch weighing 26.8 kg and have a total K content of 240 g, because the amount of K required would be at the limit for K corresponding to this bunch size (App. Fig. 10).

By increasing N to 94 g we find an expected K range of about 180 g to 320 K (App. Fig. 11). The K limit of 240 g for a 26.8 kg bunch falls well within that range, so we could expect bunches of this size to occur at this level of N. The minimum K limit of 125 g for a bunch this size is much less than the minimum K uptake expected to occur in plants which contain 95 g N (e.g., 180 g K, App. Fig. 11), so we should not expect bunches of any size to be produced by 94 g N and 125 g K in combination. In other words, if the supply of K was so low that only 125 g K could be taken up then the growth and bunch yield of the plant would be limited such that it would not be able to take up 95 g N.



Appendix Fig. 11. Empirically determined range of total K uptake likely to occur for banana plants which contain a given amount of N; data from Williams Hybrid bananas sampled at harvest.

The foregoing arguments are highly empirical. The 3-dimensional nature of the problem makes discussion of the data very difficult. We are dealing not only with internal nutrient levels that may interact to impose mutual boundaries, but we also have the additional problem of absolute minimum and maximum levels of N and K associated with plants of a given size. The range in bunch weights and plant sizes is also biologically limited. Suffice it to say that within certain boundaries there is a range of both total N and total K possible for any given bunch weight, and that any yield prediction model based on total N and K would have to take these facts into consideration.

Appendix Section II

Survey of Banana Plantings on Oahu

PREFACE

Some of the results obtained from the survey discussed in this section were reported, in a summarized form, in the publication by Lower and Fox (1979). The following materials are included as an appendix to the present thesis, although additional, original results are presented here as well.

Materials and Methods

With the help of the Oahu County Extension Service and the Oahu Banana Growers' Association, ten sites were selected for survey of the fertility status of commercial Williams Hybrid banana plantings. Valery (Giant Cavendish group) and Brazilian (locally known as "Apple"; AAB group) were sampled at some locations. Results for each variety are analyzed and reported separately. Three experimental plots at the Waimanalo Research station containing mature stands of Williams Hybrid were also surveyed. Sampling work was done during the summer and fall of 1979.

At each farm the grower helped map the area according to variety, age of stand, management variability, production, or other relevant divisions. The largest of the sampling units was 2 hectares (on a farm about 15 hectares in area) and the smallest consisted of 10 mats along the side of a road. Plants which had just begun to flower were located in the sampling unit, or if no flowering plants were available the largest pseudostems were chosen. Usually 3-5 plants in each unit were selected for leaf sampling (mid-section of third leaf). The height (from ground to fruit stalk), girth (at 30 cm above ground), and number of healthy leaves on these plants were recorded.

Soil samples were taken from each sampling unit. Each soil sample was a composite of sub-samples taken near the base of the plants from which leaf samples were taken. Soil samples from 0-5 cm (0-2 inches) and 15-30 cm (6-12 inches) were taken and bagged separately. After air-drying and passing through a 4 mm sieve, samples were shaken with 1N ammonium acetate to extract cations (K, Ca, Mg, Na). Soil pH was determined (water-saturated paste), and phosphorus was extracted with 0.5M sodium bicarbonate (Olsen's method).

The leaf samples were analyzed for nitrogen by Kjeldahl digestion and colorimetric determination; P, K, Ca, Mg, S, Fe, Mn, Cu, Zn were determined by x-ray flourescence spectroscopy; and several samples were chosen at random and analyzed for boron (carminic acid method).

Obtaining bunch yields for the purpose of correlating soil and tissue analysis data was impractical, hence, potential yields were determined from pseudostem height and girth measurements. Section III describes how these measurements, when combined to calculate pseudostem volume usually correlate well with bunch weight of the Williams Hybrid cultivar. It was not possible to determine a yield equation for either the Valery or Brazilian banana. The assumption is made that the computed pseudostem volume for these cultivars provides an index to their respective yield potentials. The absolute bunch weight per unit of pseudostem volume no doubt differs substantially among the three banana cultivars.

Results and Discussion

Appendix Tables 27, 28 and 29 summarize the results from each location for Williams Hybrid, Valery, and Brazilian varieties, respectively.

1. Williams Hybrid

Average plant size, as determined by the computed pseudostem volume, ranged from 26.3 dm^3.[1] Using a formula modified from Section III, Y=0.61 (V) + 4.2, where Y is bunch weight in kg and V is pseudostem volume in dm^3, the yields expected from these plants would range from 20.2 to 45.3 kg/bunch. Assuming a planting density of 700 mats/ha and 3 bunches/mat/ year we might expect total production to range from 42 to 95 Mt/ha/ year.[2] By contrast, the 'official' production figures for Cavendish bananas on Oahu indicate poor yields: (Statistics of Hawaiian Agriculture, 1980)

Year	tons/ac[3]	(Mt/ha)
1977	6.8	15.2
1978	6.5	14.5
1979	5.9	13.2
1980	6.0	13.4

---

1 dm^3=cubic decimeters; pseudostem volume computed as $V=(g^2.h)/12\pi$, where g and h are pseudostem girth and height, in decimeters

2 Mt=metric ton (1 metric ton/ha = 892 lbs/acre)

3 based on harvested acreage of Williams, Valery, and Dwarf Cavendish ('Chinese')

Appendix Table 27. Average plant and soil analysis results for Williams Hybrid banana plants sampled at the mature, pre-flowering stage or at flowering on twelve farms on the island of Oahu.

	pseudostem*				leaf analysis, %						soil analysis**					
farm	H	G	V	leaves	N	K	P	Ca	Mg	S	K	Na	Ca	Mg	P	pH
1	192	67	26.3	6.5	2.79	3.18	.21	.54	.33	.21	1.4	1.3	10.0	6.4	5	5.7
2	235	73	34.5	8.9	2.91	3.12	.19	.57	.32	.21	2.8	1.2	15.2	6.0	23	5.4
3	256	76	40.7	12.3	2.54	2.82	.25	.56	.40	.19	3.3	1.2	18.7	9.4	173	6.2
4	-	-	-	-	2.91	2.99	.19	.66	.36	.22	1.8	1.5	17.7	7.5	45	6.3
5	250	76	39.3	11.4	2.69	3.16	.21	.72	.40	.24	0.9	2.1	31.1	9.9	91	7.7
6	274	73	39.9	11.1	3.05	2.82	.19	.70	.35	.21	3.2	1.2	21.2	10.4	157	5.4
7	241	70	32.5	10.3	2.63	2.69	.17	.42	.39	.19	2.2	0.9	5.4	1.2	49	5.0
8	314	91	67.4	11.0	2.88	3.84	.21	.68	.23	.21	10.1	0.7	18.3	3.6	203	6.0
9	244	67	29.4	11.5	2.88	2.81	.19	.81	.43	.24	0.7	2.2	42.8	14.0	11	7.4
10	329	82	61.4	9.5	2.82	2.71	.18	.59	.39	.22	1.9	1.1	15.6	12.9	65	4.5
11	244	70	33.9	9.1	2.67	2.63	.26	.66	.45	.24	1.8	1.2	22.5	24.8	21	6.3
12	314	85	60.5	10.5	2.61	2.95	.19	.55	.32	.21	1.5	1.3	23.7	13.8	131	5.2

*H=pseudostem height, cm; G=pseudostem girth, cm; V=pseudostem volume, dm^3

**expressed as meq/100g for K,Na,Ca,Mg; ppm for P

Appendix Table 28. Average plant and soil analysis results for Valery banana plants sampled at the mature, pre-flowering stage or at flowering on three farms on the island of Oahu.

	pseudostem*				leaf analysis, %						soil analysis**					
farm	H	G	V	leaves	N	K	P	Ca	Mg	S	K	Na	Ca	Mg	P	pH
1	229	67	28.3	9.6	3.00	2.95	.19	.61	.33	.22	1.0	1.6	14.0	5.2	5	5.8
2	427	96	110.8	12.7	2.98	3.30	.20	.72	.24	.22	5.2	1.0	19.7	3.9	183	6.0
3	341	79	55.7	9.1	3.15	2.90	.20	.51	.19	.22	2.0	1.4	5.6	1.0	85	3.5

Appendix Table 29. Average plant and soil analysis results for Brazilian ('Apple') banana plants sampled at the mature, pre-flowering stage or at flowering on twelve farms on the island of Oahu.

	pseudostem*				leaf analysis, %						soil analysis**					
farm	H	G	V	leaves	N	K	P	Ca	Mg	S	K	Na	Ca	Mg	P	pH
1	478	94	120.2	11.9	2.91	2.43	.19	.56	.35	.19	3.1	1.6	18.9	6.3	53	5.7
2	561	91	131.2	10.9	2.49	2.39	.18	.39	.32	.20	2.7	0.8	8.9	7.6	56	4.9
3	576	98	144.5	11.0	2.55	2.40	.19	.43	.31	.20	2.3	1.1	7.8	4.4	52	4.6
4	454	73	65.9	9.3	2.21	2.35	.20	.68	.54	.22	0.9	2.4	29.1	9.0	78	7.7
5	372	67	47.5	8.4	2.32	2.47	.19	.56	.39	.17	3.0	1.3	21.7	11.6	100	5.8
6	494	88	107.7	10.6	2.34	2.11	.17	.39	.45	.17	1.7	1.0	6.0	1.7	44	5.7
7	518	91	117.1	10.9	1.92	2.38	.19	.42	.31	.19	0.4	0.8	8.3	6.1	20	5.2
8	414	73	96.7	8.2	2.22	2.26	.18	.57	.40	.18	2.0	1.7	23.5	13.5	18	6.7
9	250	52	26.0	8.0	3.02	2.61	.22	.52	.36	.22	1.1	1.7	11.3	8.2	2	6.0
10	448	82	81.7	11.5	2.95	2.16	.18	.44	.25	.20	2.0	1.4	5.6	1.0	85	3.5
12	314	85	60.5	10.5	2.61	2.95	.19	.55	.32	.21	1.5	1.3	23.7	13.8	131	5.2

*H=pseudostem height, cm; G=pseudostem girth, cm; V=pseudostem volume, dm^3
*expressed as meq/100g for K,Na,Ca,Mg; ppm for P

These estimates leave the impression that local banana producers are not achieving the potential yield that even modest inputs could provide. The yield estimates based on this survey are much greater than the island-wide average reported by the State and are comparable to actual yields obtained from our experimental plantings at Waimanalo during 1972 through 1979 (cf. Section I).

The number of leaves retained by the plants at the time of sampling ranged from an average of 6.5 to 12.3. The smallest plants had the fewest leaves, but those plants with the most leaves were also relatively small, having an average pseudostem volume of only 40.8 dm^3. It was observed that plants growing at one site (farm 3) were abnormal, the leaves were "choked" and not fully emerged from the pseudostem. Conditions were very dry there and plants received only intermittent irrigation.

Correlations between pseudostem volume (or the number of leaves) and any leaf nutrient concentration or soil test values were low. The highest (in absolute value) correlation coefficients, were $r = -0.38$ for pseudostem volume vs. leaf Mg, and $r = 0.35$ for no. of leaves vs. leaf B. The correlation between pseudostem size and the number of leaves was $r = 0.15$.

Relatively speaking, pseudostem volume and leaf K concentration were much more highly correlated with subsoil K than with surface K (the correlations were low in either case), but this was not true of the other soil cations:

Correlation Coefficients

pseudostem volume			leaf concentration		
Soil			K	Ca	Mg
surface	K	0.16^{ns}	0.21*		
	Ca	0.32***		0.58***	
	Mg	-0.05^{ns}			0.24**
subsoil	K	0.28**	0.39***		
	Ca	-0.23**		0.51***	
	Mg	-0.01^{ns}			0.21*

^{ns}not sig. at 5%
* 5%
** 1%
***.1%

Leaf K was negatively correlated with leaf Ca (r = -0.41***) and with leaf Mg (r = -0.60***). Leaf N was well correlated with leaf Ca (r = 0.37***) but not with leaf Mg (ns) nor with any soil test value. Leaf N was negatively related to leaf P (r = -0.32***).

The above statistics were obtained from the full correlation matrix (not presented here) of all variables. There was no single factor identifiable which offered definite clues regarding potential yield. Multiple regression models using as many as four variables did not significantly enhance the interpretation of pseudostem size variability. It was concluded that, for Williams Hybrid, the differences in plant size were heavily influenced by management factors (especially irrigation and disease control) which were not explainable by leaf and soil analyses.

2. Valery

The Valery cultivar in Hawaii is believed to be the same commercial dessert banana grown in South America, from where over 60% of the Hawaii banana supply is imported. The name "Taiwan" is given to a local Giant Cavendish type that we consider to be identical to the local Valery. We really don't know whether they are in fact the same nor if either type is identical to the imported banana.

Under good management this banana can be quite large and one local grower has produced bunches as heavy as 170 pounds (76 kg). In the survey we found plants as large as 6 meters tall (20 ft) with pseudostem circumferences exceeding 130 cm (4.3 ft) and with pseudostem volumes ranging from 16 dm^3 to 247 dm^3. Average results for each farm are summarized in Appendix Table 28.

At farm 2, plants averaged 4 times as large as those at farm 1. One reason for this is that the planting at farm 1 was less than 2 years old, whereas at farm 2 the mats had been established for several years and were just past their production peak. Soil conditions at farm 1 were very poor by comparison; the fields were stripped of topsoil prior to planting. This evidenced by an extremely low level of phosphorous; only 5 ppm P in the top 30 cm. The supply of K was also low relative to farm 2, but leaf K levels did not indicate a problem, assuming that nutrient sufficiency levels for Valery are similar to those of Williams Hybrid.

At farm 3, where plants were intermediate in size, it was possible that there was an unfavorably high N-K balance. The soil was extremely acid at this site (pH avg. 3.5), and very low levels of Ca and Mg were found in the soil and in the leaves. The area where bananas were growing had formerly been under paddy rice for many years and the water table was only 15-30 cm below the surface. Despite the acid soil conditions phosphorus was reasonably well supplied (via heavy fertilization), as evidenced by an average P content of 0.20% in the leaves.

Pseudostem volume of the Valery banana was significantly correlated with several factors, as summarized below:

factor	correlation coefficient
leaf Mn	-.62**
" B	.88***
soil surface K	.62**
" sub K	.55**
" surface Ca	.59**
" sub Ca	.47*
" surface Mg	-.45*
" surface P	.41*

* sig. at .05
** sig. at .01
*** sig. at .001

The striking correlation between leaf boron B and pseudostem size was unexpected. Correlations between leaf B and several other factors were as follows:

factor	correlation coefficient
number of leaves	.48*
leaf wt.	.86***
" N	$-.34^{ns}$
" K	$.36^{ns}$
" P	$-.01^{ns}$
" Ca	$.11^{ns}$
" Mg	-.60**

^{ns} not sig. at .05
* sig. at .05
** sig. at .01
*** sig. at .001

It is generally believed that microelements such as boron accumulate in older tissues, but in our samples the physiological age of the leaves was probably a constant. The high correlation between the B concentration of the leaf and the size of that leaf (as measured by the dry weight of the sample) may be only coincidental but perhaps warrants further investigation. Almost zero correlation was observed between B concentration and leaf weight in Williams Hybrid (r=.002) and was insignificant for Brazilian (r=-.11).

Although the correlation between B and soil Ca was very high very little relationship was observed for B vs. leaf Ca (see above). B was significantly correlated with leaf Mg, and there was a non-significant relationship between B and soil Mg. Leaf Ca was poorly related to soil Ca, but leaf Mg did reflect soil Mg levels:

Correlations Coefficients

	soil factor			
	surface		subsurface	
Nutrient	Ca	Mg	Ca	Mg
leaf Ca	$.19^{ns}$	$-.26^{ns}$	$.34^{ns}$	$-.18^{ns}$
leaf Mg	$-.40^{ns}$	.64**	$-.33^{ns}$	.55*
leaf B	.73***	$-.27^{ns}$	.75***	$-.00^{ns}$

The levels of leaf Mg observed at farms 2 (0.24%) and 3 (0.19%) were at or below Mg concentrations believed to be deficient (Lacoeuilhe and Martin-Prével, 1971). Besides the correlation between leaf Mg and soil Mg already shown, there was the additional depressive influence of relatively high levels of soil K and Ca at those farms; both factors produced a negative effect on leaf Mg, especially soil K. Increasing leaf K was also highly related to a reduction in leaf Mg. Leaf Ca was not , however, significantly correlated with leaf Mg.

In a newly planted field at farm 2 where leaf analysis of large, pre-flowering plants showed consistently low Mg levels, an attempt was made to increase plant Mg by application of a commercial fertilizer (epsom salts, $MgSO_4 \cdot 7H_2O$). Surface application of 510 kg Mg/ha had no effect on the Mg concentration in the leaves. Leaf samples were taken periodically from the treated mats and from "control" mats in the same field for 9 months after fertilization. No treatment effect was observed either from leaf analyses or yield measurements. It was possible that the vigorous growth and high levels of other nutrients were responsible for "apparent" Mg deficiency (Garcia et al., 1977b, 1978).

3. Brazilian

While "Brazilian" is the more accepted name of this banana, locally it is known almost exclusively as the "Apple" banana, and is the undisputed favorite of local consumers. Because of its preference in Hawaii as a dessert banana and because of a lack of outside competition, the Apple banana commands a 50-100% higher price than either Cavendish variety. Because of its inherent genetic limitations, however, individual bunch yields are typically only 30-50% of the Cavendish type. The plants grow very tall (up to 25 ft) and are prone to wind damage. This variety is frequently grown on relatively poor soil in locations which increase the susceptibility to storm damage. Total production of Apple bananas because of small bunches and a lower percentage of harvestable fruit on Oahu for 1980 was reported to be 2.3 tons/ac (5.1 Mt/ha), about 30% of that reported for the Cavendish varieties.

At least a few Apple banana plants were found at every commercial farm surveyed. Appendix Table 29 summarizes the findings for each site. Average pseudostem volumes ranged from less than 28 dm^3 to over 140 dm^3. As with Williams, the fewest leaves were found on the smallest plants. Plants having the most leaves were intermediate in size. Both leaf N and leaf K levels were generally lower than those in the Cavendish plants. Inspection of the soil test results shows that fertility conditions were relatively poor.

Correlations between pseudostem volume and various factors were as follows:

factor	correlation coefficient
number of leaves	.48***
leaf N	.25**
" K	$.11^{ns}$
" P	$-.11^{ns}$
" Ca	$-.02^{ns}$
" Mg	$-.14^{ns}$
" B	$-.09^{ns}$
surface soil K	.26**
" " Ca	$-.07^{ns}$
" " Mg	$.13^{ns}$
" " P	.25**
" " pH	-.26**

As with Williams, there was little correlation between plant size and any single internal or external factor. Leaf number and leaf size were also not well correlated with any nutrient or soil factor.

The correlations between leaf nutrient concentration and soil components revealed some interesting relationships:

Correlation coefficients

nutrient	Surface Soil K	Surface Soil Ca	Surface Soil Mg	Surface Soil P	Surface Soil pH	Subsurface Soil K	Subsurface Soil Ca	Subsurface Soil Mg	Subsurface Soil P	Subsurface Soil pH
leaf K	.30**	.24**	.24**	.15	-.06	.18*	.18	.24**	.04	-.03
" Ca	.12	.65***	.38***	-.06	.54***	.10	.64***	.46***	.38***	.54***
" Mg	.01	.51***	.28**	-.23*	.77***	.02	.57***	.36***	.43***	.73***
" P	.03	.38***	.41***	.09	-.14	-.03	.38***	.47***	.21*	.24**
" B	.08	.49***	.23	.06	.45***	.13	.52***	.38**	.26*	.42***
" Mn	.29**	-.13	.04	.32***	-.49***	.08	-.29**	-.10	-.27**	-.49***

* = sig. at .05
** = sig. at .01
*** = sig. at .001

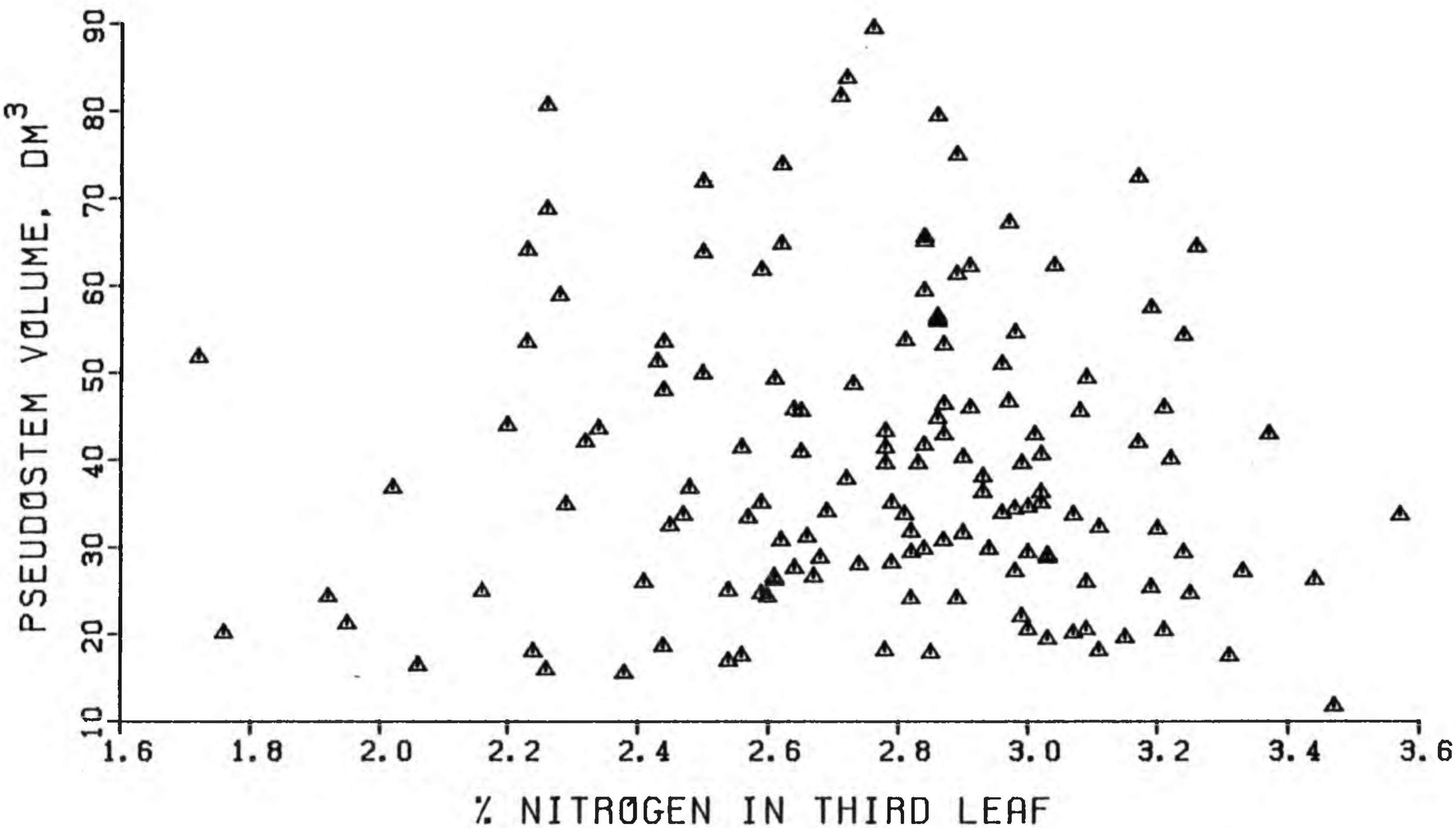
Leaf K was somewhat related to soil K, but was about as well correlated with either soil Ca or soil Mg. Leaf K was negatively related , however, to leaf Ca (ns) and leaf Mg (r=-.22*). Leaf Ca was very closely related to soil Ca, and also to soil Mg. Leaf Mg was more highly correlated with soil Ca than soil Mg, and the relationship between leaf Mg and soil pH was high. Leaf B was also well correlated with soil pH (and Ca and Mg), as was leaf Mn. Manganese, however, was only weakly related to soil cations. Leaf P was better explained by soil Ca, Mg, or pH than by levels of soil P.

These results did not lead to any good explanation of plant size differences. Only 26% of the variation in pseudostem volume was accounted for by the "best" regression model (which included leaf N, soil Mg, and pH values). This was similar to the results of the correlation study done for Williams Hybrid. In both cases there was such a wide variety of soils, climates, and management practices that nutritionally-related yield generalizations are nearly impossible. The within-site variation of growth conditions was uncontrolled.

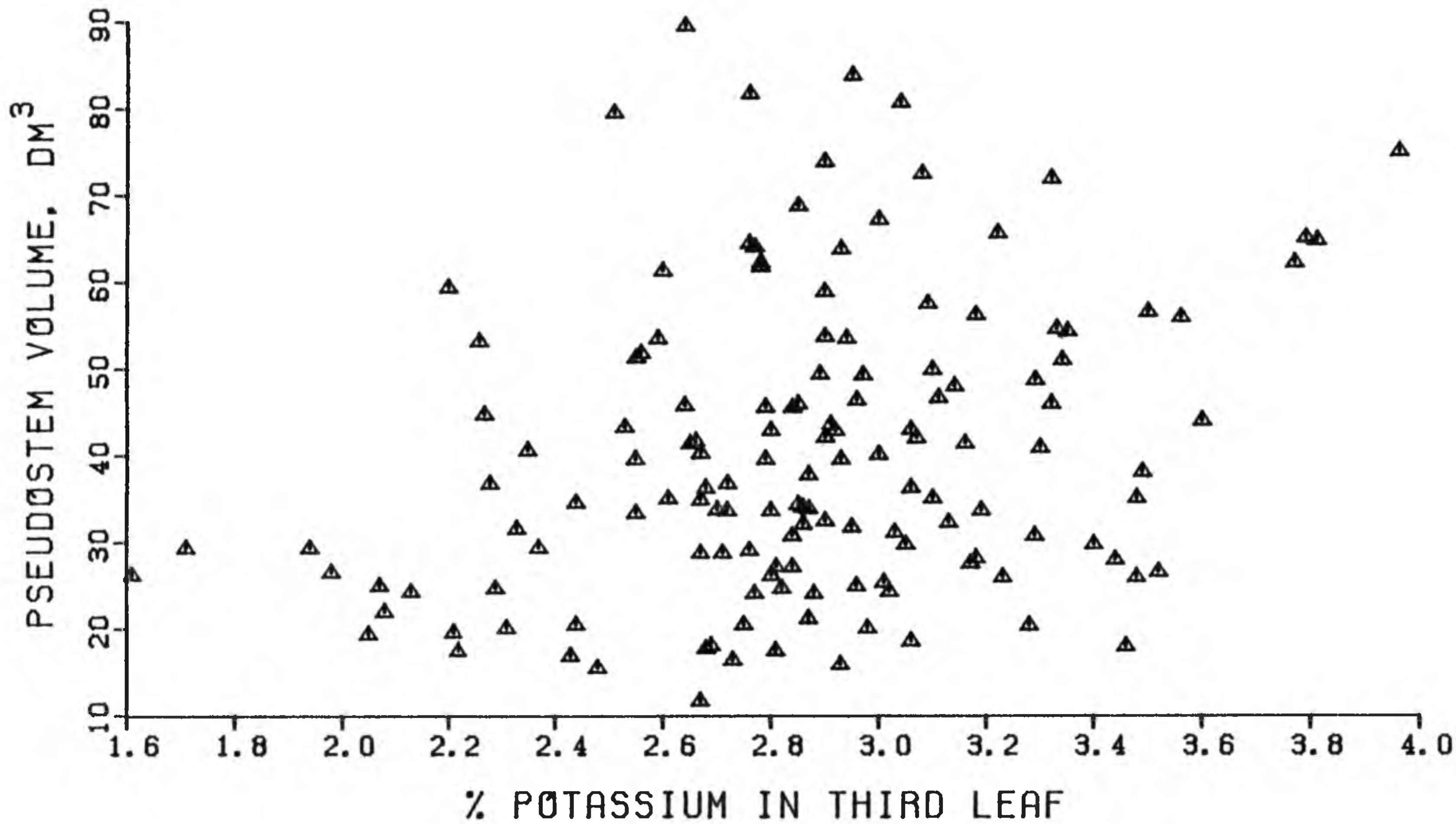
4. Miscellaneous Findings

Because N and K are by far the most common factors associated with a growth response in banana it is probable that unmeasured factors were primarily responsible for plant size variations.

Plots of pseudostem volume vs. leaf N and leaf K for Williams Hybrid are shown in Appendix Figures 12 and 13, respectively. It is immediately apparent why correlation coefficients for pseudostem volume vs. leaf N or K were so low. However, the relationship is not entirely without explanation. For the smallest pseudostem volumes (17 to 28 dm^3)



Appendix Fig. 12. Relationship between the size of the pseudostem of Williams Hybrid banana plants and the concentration of N in the 3rd leaf lamina.



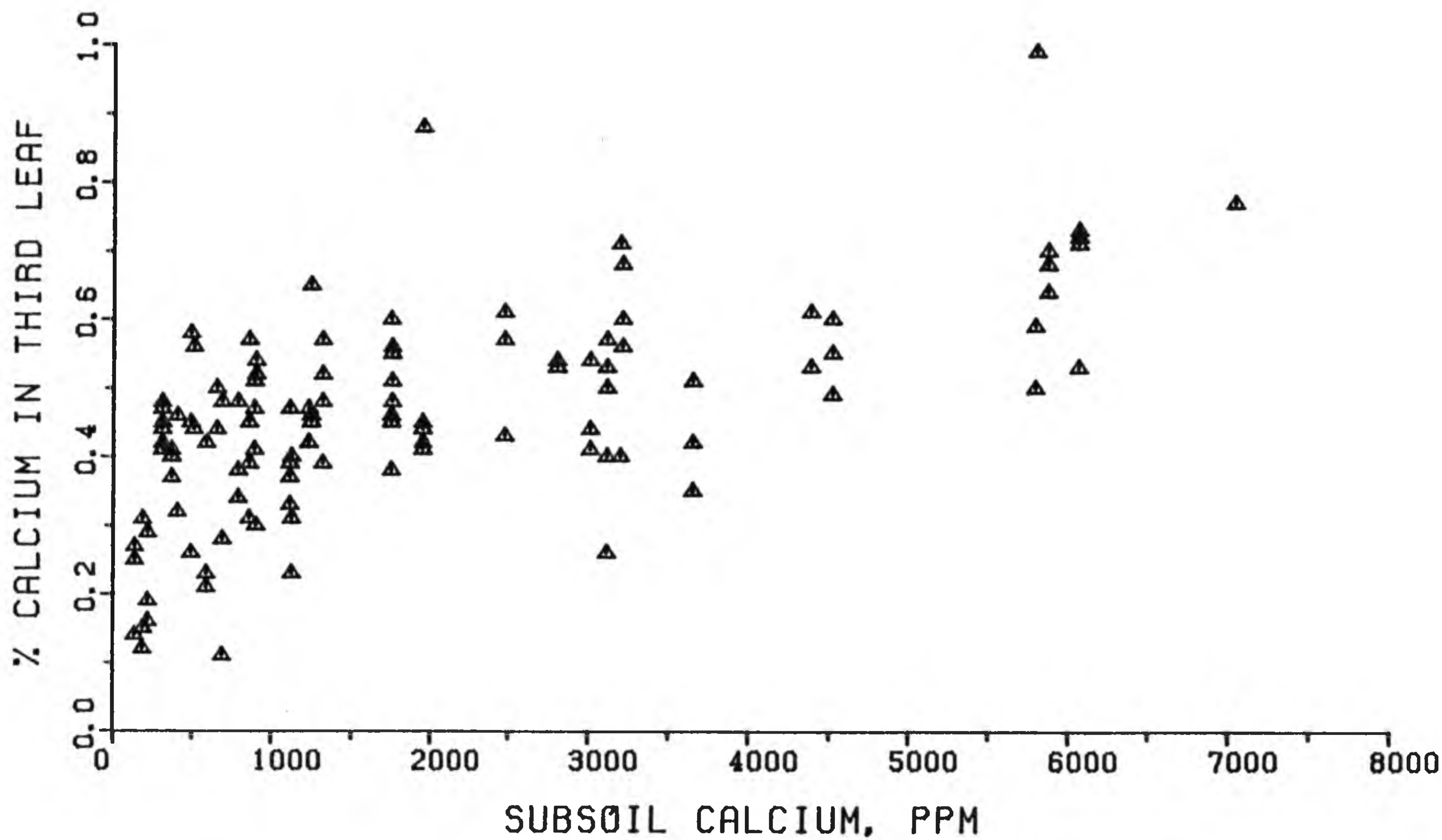
Appendix Fig. 13. Relationship between the size of the psendostem of Williams Hybrid banana plants and the concentration of K in the 3rd leaf lamina.

leaf N ranged from 1.8 to 3.6% and leaf K from 1.7 to 3.5% but as volume was increased the concentration ranges became more restricted. At pseudostem volumes of 60 to 75 dm^3 leaf N ranged from 2.3 to 3.3%, and leaf K ranged from 2.3 to 3.9%. It is possible that there is a limit on pseudostem size imposed by nutrient concentration, such that large plants can seldom be produced by N or K concentrations lower than a certain level, as defined by the left-hand side boundary of the data points illustrated in Appendix Figures 12 and 13. When plants were small there was a wide range of nutrient concentration, perhaps because the growth-limiting factor was other than either N or K. In the case of N and K the "antagonistic" effect of one on the other would be expected to magnify concentration extremes when one of these nutrients is very deficient; e.g. if K was very low, N might be expected to be unusually high, but plant size would be limited by the low level of K. This is in line with the discussion of total plant nutrient content vs. bunch weight (Section II) and the findings of other workers (Twyford and Coulter, 1964; Fox et al., 1978).

A full quadratic model in terms of leaf N and K was tested vs. pseudostem volume to see if the combined effects would better explain the above idea. This was not successful, as only 11% of pseudostem volume variability was accounted for and none of the parameter estimates were significant. It would seem that in the present data the limiting cofactor was neither N or K in the majority of cases. Our general observation in the field was that soil moisture was inadequate, and that many plants had poor root systems as a result of this and/or nematode infestation or other (undetermined) conditions.

One finding of this survey was a close relationship between levels of soil Ca and the concentration of Ca in leaves of Williams and Brazilian varieties. There was an obvious response to soil Ca in the leaves of the Brazilian variety, which was found growing in soils having a very wide range of soil pH and Ca levels. Appendix Figure 14 shows this relationship. There was suggestion of a classical Mitscherlich-type response, with leaf Ca rising rapidly from 0.1 to 0.5% as soil Ca increased from nearly zero to 1000 ppm Ca. Increasing soil Ca from 1000 to 6000 ppm resulted in an increase of leaf Ca from 0.5% to only 0.6%, and a maximum likely leaf Ca concentration of 1.0% was indicated for soil Ca in excess of 6000 ppm.

It was unknown whether or not an actual yield increase was associated with increased Ca levels, however, the comments of several growers suggested there was a positive connection. Soil pH was highly correlated with soil Ca (and Mg) levels. In several cases soil K levels were generally higher if soil pH and Ca were relatively high, at least in those areas where soil pH was initially acid. To evaluate the effect of pH on soil K levels we simulated the liming effect by adding calcium carbonate ($CaCO_3$) to several subsamples in the laboratory. When soil pH was raised from 4.5 to 6.5 over 30 times as much K was held from leaching by deionized water in the limed soil vs. unlimed samples. We assumed that a rise in pH (and Ca) in these soils increased the CEC significantly enough to affect K retention. A similar effect was observed in the field in an unrelated experiment in Hawaii (Tamimi et al., 1975). If the same conditions hold true in the field, then the relatively better growth of bananas grown under favorable pH conditions



Appendix Fig. 14. Concentration of calcium in the 3rd leaf lamina of Brazilian bananas in relation to the level of Ca in the subsoil.

may reflect not only an increased supply of Ca and Mg, but also of K when added as a fertilizer. There may also be some improvement in nitrogen availability in these acid soils if they are limed to a pH of about 6.5.

LITERATURE CITED

Arnold, C.Y. (1959) The determination and significance of the base temperature in a linear heat unit system. Proc. Amer. Soc. Hort. 74:430-445.

Arscott, T.G. (1970) Nitrogen fertilization of bananas (Musa cavendishii (Lambert) through a sprinkler irrigation system. Trop. Agric. Trin. 47:17-22.

Arscott, T.G., Bhangoo, M.S. and Karon, M.L. (1965) Irrigation investigations of the Giant Cavendish banana. II. Effects of climate on plant growth and fruit production in the upper Aguan valley, Honduras. Trop. Agric. Trin. 42:205-209.

Baillon, A.F., Holmes, E. and Lewis, A.H. (1933) The composition of and nutrient uptake by the banana plant with special reference to the Canaries. Trop. Agric. Trin. 10:139-144.

Barrow, N.J. (1980) Recent advances in soil/plant relations. In: National Soils Conference (1980) Rev. Papers, Abbott, T.S., C.A. Hawkins and P.G.E. Searle, eds. Aust. Soc. Soil Sci. Inc., pp. 67-78.

Beugnon, M. and Champion, J. (1966) Étude sur les racines du bananier. Fruits 21:309-327.

Bhangoo, M.S., Altman, F.G. and Karon, M.L. (1962) Investigations on the Giant Cavendish banana. I. Effect of nitrogen, phosphorus and potassium on fruit yield in relation to nutrient content of soil and leaf tissue in Honduras. Trop. Agric. Trin. 39:189-201.

Boland, D.E. (1975) Fertilizer requirements of Valery Bananas. A. Rep. Banana Bd. Res. Dev. Dept., Jamaica. pp. 15-24.

Champion, J. and Oliver, P. (1961) Etudes préliminaires sur les racines de bananier. Fruits 16:371-375.

Cooil, B.J. and Shoji, K. (1953) Observations and experiments on the control of a chlorosis in Cavendish bananas. Hawaii Agric. Exp. Sta. Prog. Notes 87:1-4.

Costas, R.C. (1968) Effect of plant population and distribution on yields of plantains. J. Agr. Univ. Puerto Rico 52:256-259.

Davis, J.C. (1973) Statistics and Data Analysis in Geology. J. Wiley and Sons, Inc., New York. 550 pp.

Fernández-Caldas, E. and Borges-Perez, A. (1971) Les réserves de potassium dans les sols de bananeraies aux Canaries. Fruits 26:651-656.

Fernández-Caldas, E. et Garcia, V. (1972) Etude sur la nutrition du bananier aux îles Canaries. I. Effet de la nutrition azotée sur la circonférence du pseudotronc. Fruits 27:509-412.

Fernández-Caldas, E., Garcia, V., Perez-Garcia V. y Diaz, A. (1977) Análisis foliar del plátano en dos fases de su desarrollo: floraciōon y corte. Fruits 32:665-669.

Fox, R.L. (1980) Some thoughts on the quantitative assessment of banana plant nutrition - an experimental approach. pp. 12-14. In: Intl. Banana Newsletter no. 2. Intl. Group on Mineral Nutrition of Bananas.

Fox, R.L., Kang, B.T. and Wilson, G.F. (1979) A comparative study of the sulfur nutrition of banana and plantain. Fruits 34:525-532.

Fox, R.L. and Lower, R.A. (1980) Root-room and banana fertilization. pp. 1-8. In: Proc. Hawaii Ban. Ind. Assoc. 12th Ann. Conf. State of Hawaii Dept. of Ag. Commod. Br. Div. of Marketing and Consumer Services.

Fox, R.L., Lower, R.A. and Warner, R.M. (1978) Fertilizer requirements for near-term and long-term banana production in Hawaii. Proc. Hawaii Banana Ind. Assoc. 10th Ann. Conf. pp. 3-13.

Gabuin, J.N. (1969) Nutrient distribution in banana and its relationship to leaf spot disease. M.Sc. thesis, Department of Agronomy and Soil Science, Univ. of Hawaii, Honolulu.

Ganry, J. and Meyer, J.P. (1975) Recherche d'une loi d'action de la température sur la croissance des fruits du bananier. Fruits 30:375-392.

Ganry, J. and Souissaram, D. (1978) Recherche d'une méthode d'estimation de la date du bananier à partir de données climatiques dan les conditions des Antilles. Fruits 33:669-680.

Garcia, V. (1977) Etat actuel des études de nutrition et fertilité en culture bananière à Ténérife. Fruits 33:15-23.

Garcia, V., Bravo, J.J., Robles, J.J., et Alvarez, C.E. (1979) Etude de relation sol-plante sur les cultures de bananiers de l'île de La Palma (Canaries). Fruits 34:393-397.

Garcia, V., Fernández-Caldas, E., Alvarez, C.E. y Robles, J. (1978) Desequilibrios potásico-magnésicos en los cultivos de plátanos de Tenerife. Fruits. 33:7-13.

Garcia, V., Fernández-Caldas, E., Diaz, A., Alvarez, C.E. (1977a) Efecto de la nutricion potasica en la produccion del platano. Agrochimica 21:28-36.

Garcia, V., Fernández-Caldas, E., Diaz, A. y Bravo, J.J. (1977b) Análisis foliar del plátano en dos fases de su floración. Fruits 32:525-530.

Gonçalves, M.M. and Cardoso, A.P.S. (1979) Nutritional deficiencies of banana in Santiago Island - Cape Verde. In: Intl. Banana Nutrition Newsletter no. 1. Intl. Group in Mineral Nutrition of Bananas. pp. 7-11.

Green, G.C. and Kuhne, F.A. (1975) Estimating the state of maturation of a banana bunch from meteorological and supporting data. Agrochemophysica 7:27-32.

Hagin, J., Kafkafi, U., Halevy, Y. and Peled, A. (1964) Fertilizer experiments in Israeli banana plantations. Emp. J. Exp. Ag. 32:311-318.

Hardy, F. (1974) Root Room. Trop. Agric. Trin. 51:272-278.

Hartman, A.N. (1930) Banana Growth and Fruiting. United Fruit Co. Res. Dept., Honduras (cited in Walker, 1970).

Hasselo, H.N. (1961) Premature yellowing of Lacatan bananas. Trop. Agric. Trin. 38:29-34.

________ (1962) An evaluation of the circumference of the pseudostem as a growth index for the Gros Michel banana. Trop. Agric. Trin. 39:57-63.

Hewitt, C.W. (1955) Leaf analysis as a guide to the nutrition of bananas. Emp. J. Exp. Ag. 23:11-16.

Hewitt, C.W. and Osborne, R.E. (1962) Further field studies on leaf analysis of Lacatan bananas as a guide to the nutrition of the plant. Emp. J. Exp. Ag. 30:249-256.

Ho, C.T. (1967) The influence of potash split application on fruit yield and some characters of banana. Soils Fertil. Taiwan 1967:48-62.

________ (1969) Study on correlation of banana fruit yield with leaf potassium content. Fertilité 33:19-29.

Hord, H.H.V. and Spell, D.P. (1962) Temperature as a basis for forecasting banana production. Trop. Agric. Trin. 39:219-223.

Hussain, A. and Jagirdar, S.A.P. (1975) The effect of partial or complete replacement of farm yard manure on the growth and production of Cavendish banana. Agric. Pakistan 26:159-163.

Ikawa, H., Sato, H.H., Chang, A.K.S., Nakamura, S., Robello, E. Jr. and Periaswamy, S.P. (1982) Soils of the Hawaii Agricultural Experiment Station, University of Hawaii--Soil Survey, Laboratory Data, and Soil Descriptions. HITAHR Research Extension Series 000 (in press).

Jenkins, G.M. and Watts, D.G. (1968) Spectral Analysis and its Applications. Holden-Day, Inc., San Francisco. 525 pp.

Kuhne, F.A. (1980) Banana phenology. Subtropica 1(3):18-19.

Lacoeuilhe, J.J. et Martin-Prével, P. (1971) Culture sur milieu artificiel. II. Carences en K, Ca, Mg, chez les bananier; analyse foliaire. Fruits 26:243-253.

Lahav, E. (1973a) Effect and interactions of manure and fertilizers in a banana plantation. Israel J. agric. Res. 23:45-57.

________ (1973b) Phosphorus and potassium penetrability in the soil and their influence in a mature banana plantation. Trop. Agric. Trin. 50:297-301.

________ (1977a) The suitability of sampling the leaf petiole for determining the mineral content of the banana sucker. Fruits 32:297-307.

________ (1977b) Effect of manure and fertilizer treatments on cv. 'Williams Hybrid' banana and its mineral content. Trop. Agric. Trin. 54:113-118.

________ (1980) Bibliography on Mineral Nutrition of Bananas. Intl. Group on Mineral Nutrition of Bananas, 99 pp.

Lahav, E., Bareket, M. and Zamet, D. (1981) The value of KNO_3, organic manure and poly-feed in a banana plantation under drip irrigation. Fruits 36:151-155.

Langenegger, W. and Plessis, S.F. du (1977) The determination of the nutritional status of 'dwarf cavendish' bananas in South Africa. Fruits 32:711-724.

Long, P.G. (1973) Control of banana black leaf streak disease in Western Samoa. Trop. Agric. Trin. 50:75-84.

Lossois, P. (1963) Recherche d'une méthode de prévision des récoltes en culture bananière. Fruits 18:283-293.

Loudat, T.A. (1980) An economic analysis of the competitive position of the Hawaiian banana industry in the Honolulu market. Ph.D. Thesis, Dept. of Ag. Economics, Univ. of Hawaii, Honolulu. 177 pp.

Lower, R.A. and Fox, R.L. (1979) Banana fertility management. In: Proc. Hawaii Ban. Ind. Assoc. 12th Ann. Conf., State of Hawaii, Dept. of Ag. Commod. Br. Div. of Marketing and Consumer Services. pp 23-40.

Marchal, J., Martin-Prével, P. et Melin, Ph. (1972) Le soufre et le bananier. Fruits 27:167-177.

Martin-Prével, P. (1962) Les éléments mineraux dans le bananier et dans son régime. Fruits 17:123-128.

________ (1964) Nutrient elements in the banana plant and fruit. Fertilité 22:3-14.

________ (1969) Un essai "variantes systematiques" sur bananier. Fruits 24:192-215.

________ (1974) Les méthodes d'échantillonnage pour l'analyse foliaire du bananier: résultats d'une enquête internationale et propositions en vue d'une référence commune. Fruits 29:583-588.

________ (1977) Enchantillonnage du bananier pour l'analyse foliaire: conséquences des différences de techniques. Fruits 32:151-166.

________ (1980) Sampling for quantitative assessment of the nutritional level of the banana plant. In: Intl. Banana Newsletter no. 2. Intl. Group on Mineral Nutrition of Bananas. pp. 9-11.

Martin-Prével, P. et Montagut, G. (1966) Les interactions dans la nutrition mineral du bananier. Fruits 21:19-36.

Meir, J.B. (1979) A case of iron excess in Canary Island bananas. In: Intl. Banana Nutrition Newsletter no. 1. Intl. Group on Mineral Nutrition of Bananas. pp. 11-14.

Messing, J.H.L. (1974) Long term changes in potassium, magnesium and calcium content of banana plants and soils in the Windward Islands. Trop. Agric. Trin. 51:154-160.

________ (1978) A comparison of diagnostic sampling methods in bananas. Fruits 33:167-176.

Montagut, G. et Martin-Prével. P. (1965) Besoins en engrais des bananeraies antillaises. Fruits 20:265-273.

Moreau, B. (1965) La croissance et le développement du bananier 'Gros Michel' en Équateur. Fruits 20:201-220.

Murray, D.B. (1961) Shade and fertilizer relations in the banana. Trop. Agric. Trin. 38:123-132.

Perumal, A. and Adam, A.V. (1968) Bagging of Giant Cavendish banana stems in Honduras. I. Effect on number of days from flower emergence to fruit harvest. Trop. Agric. Trin. 45:109-111.

Plessis, S.F. du, Langenegger, W., Koen, T.J., Kuhne, F.A. and Smart, G. (1977) Bemestingsproef met piesangs (Dwarf Cavendish) in die Levubu-area. Cit. Sub. Trop. Fruit J. 521:5-8,11.

Prasomsook, S. (1973) Banana yields in relation to nitrogen and potassium composition of leaves. M.Sc. thesis, Dept. of Agronomy and Soil Science, Univ. of Hawaii, Honolulu. 109 pp.

Ramaswamy, N., Sundararajan, S. and Kader, M.D.A. (1977) Effect of application of different levels of potash on the yield of Dwarf Cavendish banana. Madras Agric. J. 64:363-368.

Randhawa, G.S., Sharma, C.B., Kohli, R.R. and Chacko, E.K. (1973) Studies on nutrient concentration in leaf tissue and fruit yield with varying planting distance and nutritional levels in Robusta banana. Indian J. Hort. 30:467-474.

Rodríguez-Gómez, M. (1980) Estudios preliminares sobre la nutrición con potasio de los bananales en América central. Fruits 35:283-291.

Samuels, G., Orengo-Santiago, E. and Beale, A. (1978) Influence of fertilizers on the production of plantains with irrigation. J. Agric. Univ. Puerto Rico 62:1-9.

Sarma, A.K. and Roy, A.R. (1972) Fertilizer-cum-spacing trial on banana (*Musa paradisica* L.) Indian J. agric. Sci. 42:493-498.

SAS (1979) *SAS User's Guide, 1979 Edition*. Helwig, J.T. and Council, K.A., eds. 494 pp. SAS Institute Inc., Raleigh, North Carolina.

Shand, C.R. (1975) Effect of varying levels of fertilizer on the growth and yield of Valery bananas. In: A. Rep. Banana Bd. Res. Dep. Dep., Jamaica. pp. 11-14.

Shawky, I., Zidan, Z. and Riad, M. (1974) Comparative studies concerning foliar and soil nitrogen application on banana plants. Egypt. J. Hort 1:157-169.

Simmonds, N.W. (1966) *Bananas, 2nd Ed*. Longmans Green and Co., Ltd., London.

Soil Survey Staff (1975) *Soil Taxonomy*, U.S. Soil Cons. Serv. Agriculture Handbook no. 436, 754 pp.

Spurling, D. and Spurling A.T. (1975a) Field trials on Dwarf Cavendish bananas in southern Malaŵi - Part I. Spacing and Pruning. Acta Hort. 49:259-262.

________ (1975b) Field trials on Dwarf Cavendish bananas in southern Malaŵi - Part II. Fertilizers and mulching. Acta Hort. 49:263-269.

Statistics of Hawaiian Agriculture 1980. Hawaii Agricultural Reporting Service, Honolulu (June, 1981). p. 37.

Stover, R.H. (1979) Pseudostem growth, leaf production and flower initiation in the Grand Nain banana. Bull. Trop. Ag. Res. Serv. (SIATSA, La Lima, Honduras) no. 8, 37 pp. (in Hort. Abstr. 50:9622).

Tamimi, Y.N., Uchida, R.S. and Matsuyama, D.T. (1975) The importance of the pH dependency of charge in tropical soils on crop fertilizer management. Proc. Fert. INPUTS Project, East-West Center, Honolulu, Hawaii (1974). pp. 81-90.

Teaotia, S.S. and Dubey, P.S. (1971) Effect of sources of nitrogen on growth and yield of banana (Musa cavendishii L.) var. Harichhal. Prog. Hort. 3(3):39-44.

Turner, D.W. (1970) The growth of the banana. J. Aust. Inst. Ag. Sci. 36:102-110.

________ (1971) Bunch covers, leaf number and yield of bananas. Aust. J. Exp. Ag. and An. Husb. 10:802-805.

________ (1980) Some factors related to yield components of bananas, in relation to sampling to assess nutrient status. Fruits 35:19-22.

Turner, D.W. and Barkus, B. (1977) A comparison of leaf sampling methods in bananas. Fruits 32:725-730.

________ (1980a) An empirical relationship between climate, nutrition and nutrient concentrations in banana leaves. Fruits 35:151-158.

________ (1980b) Plant growth and dry-matter production of the 'Williams' banana in relation to supply of potassium, magnesium and manganese in sand culture. Scientia Hort. 12:27-45.

________ (1981) Nutrient concentrations in the leaves of a range of banana varieties grown in the subtropics. Fruits 36:217-222.

Twyford, I.T. (1967) Banana nutrition: a review of principles and practice. J. Sci. Fd. Agric. 18:177-183.

Twyford, I.T. and Coulter, J.K. (1964) Foliar diagnosis in banana fertilizer trials. In: Plant Analysis and Fertilizer Problems. IV. C. Bould, P. Prevot, J.R. Magness eds., Am. Soc. Hort. Sci. pp. 357-370.

Twyford, I.T. and Walmsley, D. (1973) The mineral composition of the Robusta banana plant. I. Methods and plant growth studies. Pl. Soil 39:227-243.

________ (1974a) The mineral composition of the Robusta banana plant. II. The concentration of mineral constituents. Pl. Soil 41:459-470.

________ (1974b) The mineral composition of the Robusta banana plant. III. Uptake and distribution of mineral constituents. P. Soil. 41:471-491

Venkatesam, C., Venkatareddy, K. and Rangacharlu, V.S. (1965) Studies on the effects of nitrogen, phosphoric acid and potash fertilization on the growth and yield of banana. Indian J. Hort. 22:175-184.

Walker, L.A. (1970) A study of the growth and yield of the Valery, Lacatan and Robusta cultivars of banana in Jamaica. Trop. Agric. Trin. 47:233-242.

________ (1973) Plant population, yield and fruit quality of banana. Res. and Dev. Dept. Ban. Board, Jamaica, Bull. no. 5.

Walmsley, D., Twyford, I.T. and Cornforth, I.S. (1971) An evaluation of soil analysis methods for nitrogen, phosphorus and potassium, using banana. Trop. Agric. Trin. 48:141-155.

Warner, R.M. (1972) Banana nutrition. Proc. 3rd A. Hawaii Banana Ind. Ass. 3:30-41. Univ. of Hawaii. CES Misc. Pub. 87.

Warner, R.M. and Fox, R.L. (1976) Effect of nitrogen and climatic factors on seasonality of banana production in Hawaii. Comb. Proc. Int. Pl. Propagators Soc. 26:38-47.

________ (1977) Nitrogen and potassium nutrition of Giant Cavendish banana in Hawaii. J. Amer. Soc. Hort. Sci. 102:739-743.

Warner, R.M., Fox, R.L. and Bullock, R.M. (1973) Nutrition and density studies on the Williams hybrid banana. 1973 Proc. Hawaii Banana Ind. Ass. 5:13-22. Univ. of Hawaii CES Misc. Pub. 119.

________ (1974a) Nutritional and density studies on the Williams hybrid banana. Proc. Hawaii Banana Ind. Ass. Univ. of Hawaii Misc. Publ. 126:57-65.

Warner, R.M., Fox, R.L. and Prasomsook, S. (1972) Nutrition and density studies on the Williams hybrid banana. Proc. Hawaii Banana Ind. Ass. 4:8-18. Univ. of Hawaii CES Misc. Pub. 109.

________ (1974b) Nutritional guidelines for the 'Williams Hybrid' banana. Hawaii Fm Sci. 21/22(4/1-4):4-6.

Weir. C.C. (1974a) Application of fertilisers to bananas in Jamaica. In: A. Rep. Banana Bd Res. Dep. Dept. Jamaica. pp. 111-114.

________ (1974b) Nutrient uptake by the banana plant. In: A. Rep. Banana Bd. Res. Dep. Dept. Jamaica. pp. 20-30.

Weir, C.C. and Miller, P. (1974) Potash fixation in Jamaican banana soils. In: A. Rep. Banana Bd. Res. Dep. Dept. Jamaica. pp. 92-96.