AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
BATCH 45

1. SUBJECT CLASSIFICATION

A. PRIMARY: Food production and nutrition — AF00-0100-G514

B. SECONDARY: Plant production--Cereals--Brazil

2. TITLE AND SUBTITLE
Soil-plant-water relationships as influenced by various soil and plant management practices on Campo Cerrado soils in the central plateau of Brazil

3. AUTHOR(S)
Bandy,D.E.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1976	261p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Cornell

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(Diss.--Cornell)

9. ABSTRACT
Discussion and results of a two-year experiment in Brazil to study the effect of a veranico (drought) on corn (Zea mays L.) growth and yield. The experiments were designed to provide a drought avoidance mechanism for the corn plant. In one experiment, soil management techniques were used to allow a crop to tap a greater quantity of the soil water stored in the soil. A second experiment used crop management techniques to increase water use efficiency by decreasing water loss from the soil surface and from the corn leaf. The soil management experiment consisted basically of lime rates and depths of lime incorporation, i.e., 0-lime, 8 T/ha lime incorporated to a 15 cm depth and 8 T/ha lime incorporated to a 30 cm depth, and a broadcast verses banding application of phosphorus. Without plant water stress, no depth of lime effect was noted on plant growth before the tasseling stage. From silking to grain maturity, the deep limed plants maintained a longer period of active plant growth by delaying leaf senescence. The unlimed corn plants were always inferior to the limed plants with the dry-cool season crop showing a more pronounced decrease in plant growth. The second experiment used two types of mulches, two antitranspirants, two corn varieties, and two lime depth incorporations. Mulching was shown to influence corn growth and development. Grass mulch decreased plant growth and development due to cooler soil temperatures (2-3°C) while black plastic mulch increased plant growth and development due to warmer soil temperatures (3-4°C) in relation to the non-mulched plots. An upland rice (Oriza sativa L.) experiment was conducted to study depth of lime incorporation and row spacing on the rice plant's internal water balance and final grain yield with two rice varieties. An analysis of growth and yield parameters showed that Pratao Precoce was more influenced by row spacing than by lime depth incorporation. The 15 cm row spacing showed more grain sterility and lighter grain weights which influenced a lower grain:straw ratio and lower grain yield/plant. Final

10. CONTROL NUMBER
PN-AAC-887

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Acidity	Liming
Brazil	Maize
Cerrado,Brazil?	Mulching
Drought	Rice
Evaporation	Soil water

13. PROJECT NUMBER

14. CONTRACT NUMBER
AID/ta-C-1104 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

yield results showed that narrow row spacing (15 cm) produced 400 kg/ha less than the 45 cm row spacing. Shallow lime treatments outyielded deep lime treatments by 400 kg/ha because they produced greater panicle weights which in turn produced more grain/plant.

AID/ta-C 1104 Rec.
PN-AAC-887

This work is supported in part by the Agency for International Development under the Cornell [illegible] research contract AID/ta-c-1104 "Soil Fertility in the Humid Tropics."

SOIL-PLANT-WATER RELATIONSHIPS AS INFLUENCED BY VARIOUS SOIL AND PLANT MANAGEMENT PRACTICES ON CAMPO CERRADO SOILS IN THE CENTRAL PLATEAU OF BRAZIL.

Dale Eugene Bandy, Ph.D.

Cornell University 1976

Short term drought periods during the rainy season, low soil water storage capacity, and highly acidic soils with 80 % Al Sat. which inhibit root growth all give a combined effect of limiting yields for most crops in the Central Cerrado of Brazil.

With those problems in mind, experiments were conducted in Brazil for two years to study the effect of a veranico (drought) on corn (Zea mays L.) growth and yield. The experiments were designed to provide a drought avoidance mechanism for the corn plant. In one experiment, soil management techniques were used to allow a crop to tap a greater quantity of the soil water stored in the soil. A second experiment used crop management techniques to increase water use efficiency by decreasing water loss from the soil surface and from the corn leaf.

The soil management experiment consisted basically of lime rates and depths of lime incorporation, i.e. 0-lime, 8T/ha lime incorporated to a 15 cm depth and 8T/ha lime incorporated to a 30 cm depth, and a broadcast verses banding application of phosphorus.

Without plant water stress, no depth of lime effect was noted on

on plant growth before the tasseling stage. From silking to grain maturity, the deep limed plants maintained a longer period of active plant growth by delaying leaf senescence. The unlimed corn plants were always inferior to the limed plants with the dry-cool season crop showing a more pronounced decrease in plant growth.

Measurements taken during an actual veranico or a simulated veranico showed that deep liming had a large effect in providing a drought avoidance mechanism for the corn plants. Corn roots were able to penetrate to deeper soil depths to extract water which in turn reduced the plant's internal water stress, i.e. leaf water potential and relative water content, and reduced stomatal resistance thus allowing the plant to continue to transpire and take up CO_2.

At final grain harvest, deep lime incorporation plots outyielded shallow limed plots in both water stressed and non-water stressed treatments. A 10-15 day water stress period during the vegetative growth stage (Hanway stages 2.5-3.0) permanently reduced plant size but it did not significantly reduce grain yield. A 10-15 day stress period during the grain formation stage (Hanway stage 5) decreased yields by 100-150 kg/ha per day. On a three season average, stress during the grain formation stage reduced yields by 19 % for deep limed treatments, 27 % for shallow limed treatments, and 31 % for unlimed soils. Broadcast application of phosphorus gave less reduction in yield in relation to plant water stress for two of the three seasons when compared to the banded application of phosphorus.

The second experiment used two types of mulches, two antitranspirants, two corn varieties, and two lime depth incorporations. Mulching was shown

to influence corn growth and development. Grass mulch decreased plant growth and development due to cooler soil temperatures (2-3°C) while black plastic mulch increased plant growth and development due to warmer soil temperatures (3-4 ^{o}C) in relation to the non-mulched plots.

Both mulches reduced soil surface evaporation of soil water by 4-7 mm in the top 20 cm of the soil during the stress periods. During a veranico, plant water stress was greatly reduced by depth of liming, mulching, and their combinations. Deep liming with mulch reduced leaf water potential and showed no loss in cell turgidity. Transpiration suppressants reduced internal plant water stress by over 30 % but one of the antitranspirants caused a serious reduction in plant growth and yield by causing severe premature leaf senescence.

Mulching had a significant effect on grain yield. Plastic mulch increased yields by 1000 kg/ha. Grass mulch increased grain yield by 400-500 kg/ha despite its negative effect on plant growth during the vegetative stage. The phenyl mercuric acetate antitranspirant reduced yields by 4000 kg/ha while Wilt Pruf had no significant effect on yield.

An upland rice (Oriza sativa L.) experiment was conducted to study depth of lime incorporation and row spacing on the rice plant's internal water balance and final grain yield with two rice varieties.

An analysis of growth and yield parameters showed that Pratao Precoce was more influenced by row spacing than lime depth incorporation. The 15 cm row spacing showed more grain sterility and lighter grain weights which influenced a lower grain:straw ratio and lower grain yield/plant. Final yield results showed that narrow row spacing (15 cm) produced 400 kg/ha less than the 45 cm row spacing.

IAC-1246 growth and yield parameters were not influenced by row spacing. Lime depth did have a significant effect. Shallow lime treatments outyielded deep lime treatments by 440 kg/ha because they produced greater panicle weights which in turn produced more grain/plant.

IAC-1246 significantly outyielded Pratao Precoce because it produced fewer unproductive tillers, produced heavier grain weights, and had a lower percentage of flower sterility. Those factors contributed to a 660 kg/ha yield difference.

SOIL-PLANT-WATER RELATIONSHIPS AS INFLUENCED BY VARIOUS SOIL AND PLANT MANAGEMENT PRACTICES ON CAMPO CERRADO SOILS IN THE CENTRAL PLATEAU OF BRAZIL

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment for the Degree of

Doctor of Philosophy

by

Dale Eugene Bandy

September 1976

BIOGRAPHICAL SKETCH

The author was born in Alliance, Ohio on December 13, 1941. He graduated from Sebring McKinley High School in 1959. After working on the family farm in Ohio for five years, the author joined the Peace Corps in June 1965. While in the Peace Corps he received training in poultry production for the tropics at the University of California at Davis; in subsistance farm production systems in Guam; and in lowland rice production methods at the International Rice Research Institute in Los Banos, Philippines. For approximately ten months the author helped to establish small school and family garden plots in cooperation with CARE in Mahaboobabad, Warangal District, Andhra Pradesh, India. During the second year as a Peace Corps Volunteer he was transferred to the Andhra State Poultry Hatchery in Patancheru where he was responsible for improving and increasing baby chick production and poultry husbandry practices. Upon leaving the Peace Corps he entered San Bernardino Valley College for 2 years, then transferred to the University of California at Davis where he graduated with honors in 1971. In September 1971, he began work on a M.S./Ph.D. program at Cornell University. Since that time, the author has spent two years in Brazil at the Centro de Pesquisa Agropecuaria dos Cerrados where he conducted his Ph.D. research in conjunction with the Cornell/USAID/EMBRAPA program.

He is married to the former Marinalva Maria dos Santos from Aracaju-Sergipe, Brazil.

DEDICATION

DEDICAÇÃO

Como prova de agradecimento, o autor dedica esta Tese a

NAÇÃO BRASILEIRA

Onde durante (2) anos de luta pela conquista de uma boa pesquisa encontrou apoio, amor, confiança e espírito de solidariedade

HUMANA.

BRASIL - SÍMBOLO DE AMOR, PAZ E PROGRESSO.

ACKNOWLEDGMENTS

The author is indebted to many individuals for the development of this thesis. In particular the author wishes to acknowledge the contribution made by Professor Robert B. Musgrave who served as chairman of the author's special committee. His advise and logistical support during the two years in Brazil has been invaluable.

Professor Vernon E. Gracen of the Plant Breeding Department served as a minor committee member for both the M.S. and Ph.D. program. His interest and technical input to the thesis and especially his advise in the final presentation of the thesis were greatly appreciated.

Professor William C. Kelly of the Vegetable Crops Department served as a minor committee member. His advise on the statistical aspects of conducting field experiments and their interpertation has been a valuable experience.

The author spent two years in Brazil as a member of a Cornell/North Carolina/USAID team. The members of that group, George Naderman, Enrique Gonzales, Jim Wolf, Russ Yost, Jose Salinas and Dale Ritchey were sources of invaluable assistance in the implementation and execution of this thesis.

Brazilians also contributed greatly to the making of this thesis. The author wishes to acknowledge the support of EMBRAPA, especially the President and the Directors for the support of research at the Cerrado Center.

To Engo. Agro. Ricardo Pereira Lima Carvalho, Ex-Director at CPAC,

Dr. Wenceslau J. Goedert, Research Director at CPAC and Engo. Agro. João Pereira, Administration Director at CPAC all deserve the author's sincere gratitude for providing the logistical support needed to carry out the thesis research, and for providing a Brazilian perspective to the needs and aims for research in the Central Cerrado.

In addition, Engo. Agro. Wilson Soares and Edson Lobato assistance in conducting the research and their ideas for research from a different perspective made for an excellent research environment at CPAC.

To Engo. Agro. Milton Jarreta Junior who was able to assist the author greatly because of his ability and enthusiasm to grasp new ideas and methodology, the author is particularly appreciative.

Leonidas and Valdevino deserve special credit for they worked very closely with the author for two years and collected the bulk of the data. Without their assistance this thesis would not have been as all inclusive as it is.

Special thanks are also due to Elcios and Paulo, two experimentalists who had the capability of organizing and executing field work in the precise and accurate fashion needed for conducting field experiments.

It is impossible to name all the Brazilians who made this thesis possible, but to all the rest of the people at CPAC, the author extends his sincere thanks for their assistance and friendship.

To the author's family he would like to thank them for their encouragement in pursuing a college career and understanding of the author's wishes to continue working in the international field.

To the author's family-in-law in Brazil, who provided a home away from home the author is indebted to their acceptance of a stranger into

their lives.

Lastly, the author will never be able to express all the thanks and gratitude needed to acknowledge the love, comprehension and support he received from his wife, who made life in Brazil an extreme pleasure, and who had to type this thesis on her honeymoon.

TABLE OF CONTENTS

	Page
Introduction	1
Chapter I	4
Materials and Methods	4
1974 Dry Season Soil Management Experiment	18
1974-5 Wet Season Soil Management Experiment	43
1975 Dry Season Soil Management Experiment	75
Conclusion	108
Chapter II	114
1974-5 Wet Season Crop Management Experiment	114
1975 Dry Season Crop Management Experiment	138
Conclusion	160
Chapter III	164
1974-5 Wet Season Rice Experiment	164
Conclusion	181
General Conclusions	183
Bibliography	187
Appendix Tables	191
Appendix Figures	234

LIST OF TABLES

CHAPTER I

Table		Page
1	Water balance for the Brasilia-Formosa area. Results are based on 42 years of meteorological data.	1
2	Soil water use by corn during the first and second stress periods in relation to five fertility management practices.	25
3	Leaf water potential and relative water content for maize leaves during the two stress periods of the 1974 dry season experiment.	28
4	Grain and stover yields for the '74 dry season corn experiment grown at Planaltina, Brazil. Grain yields are corrected to 15.5 % moisture and stover yields are on an oven-dry weight basis.	32
5	Effects of water stress on corn grain yield as influenced by five soil management practices.	33
6	Plant uptake of P, K, Ca, and Mg during the growing season in relation to water stress and fertility management practice. Results are expressed in g/100g.	37
7	Stover uptake of P, K, Ca, and Mg in relation to water stress and fertility management. Results are expressed in kg/ha.	39
8	Soil analysis for '74 dry season corn experiment.	41
9	R^2 values from the regression analysis of leaf area and plant dry weight.	53
10	Soil temperatures for bare soil and within the corn canopy. Readings were taken daily at 15:00 hours for 9 days (5/3 through 13/3/75).	54
11	Average daily ET rates over a 5-day period for corn (Hanway stage 5-6) in relation to five fertility management practices and LAI.	55

Table		Page
12	Evapotranspiration rates from stressed and non-stressed corn plants during a veranico.	55
13	Difference in the amount of soil water used by the corn plants during a veranico in relation to deep and shallow liming.	57
14	Daily soil water flux and use by the corn plants under optimum soil water conditions.	58
15	Soil water (%) extraction pattern for corn, 1-5 days after irrigation.	61
16	Daily leaf water potential and relative water content for maize during the 7th through 15th days of a veranico in relation to the five fertility management treatments.	62
17	Stomatal resistance results for both adaxial and abaxial sides of the corn leaves in relation to the five fertility management practice during the veranico.	64
18	Corn leaf number during the veranico in relation to the five soil management practices.	66
19	Influence of plant water stress and fertility treatment on the photosynthetic rate of maize.	66
20	Grain yield, stover yield, and grain:stover ratio for maize grown during the '74-5 season at Planaltina, Brazil.	67
21	Relationship between stover dry weight and ear dry weight accumulation for a 30-day period begining from the silk emergence stage in relation to plant water stress.	69
22	Uptake of P, K, Ca, and Mg by the grain and stover in relation to plant water stress and fertility. Results are expressed in kg/ha.	72
23	Post-harvest soil analysis results at three depths and five fertility regimes.	73
24	Soil water use during the two water stress periods for the five fertility treatments.	84

Table		Page
25	Influence of plant stress on stomatal resistance in relation to the fertility treatments. Readings were taken during the late stress period.	87
26	Air temperature and % RH within the corn canopy at 12:30 and 14:30 hours during the second stress period.	90
27	Vapor pressure deficit within the corn canopy and in the open air at 12:30 and 14:30 hours during the second stress period.	90
28	Percent root distribution for corn as determined by the rubidium-86 method.	92
29	Root length (cm/100 cm^3) for corn at the start of the tasseling stage (Hanway stage 4) grown during the 1975 dry season.	93
30	Final grain and stover yields for the 1975 dry season experiment.	95
31	Yield component analysis for the 1975 Dry Season Maize experiment.	97
32	Correlation analysis between the yield components and grain yield/plant in relation to plant water stress.	98
33	Relationship between ear dry weight accumulation and stover dry weight as influenced by the three water treatments.	100
34	Uptake of P, K, Ca, Mg, and Zn by corn grain and stover in relation to water stress and fertility. Results are expressed in kg/ha.	105
35	Soil analysis results for two measurements periods during the 1975 dry season maize experiment.	106

CHAPTER II

36	Leaf area index (LAI), plant height (Ht), and number of leaves for corn grown during the 1974-5 wet season at Planaltina, Brazil. Results for LAI and Ht are expressed in cm^2/cm^2 and cm respectively.	119

Table		Page
37	Average percent soil water content for six days of measurements (14/1 through 19/1/75) during a 15 day veranico (5/1-19/1/75) at five soil depths of a 0-45 cm soil profile.	119
38	Stomatal resistance for the top and bottom side of corn leaves under water stress conditions.	126
39	Transpiration rates for the top and bottom side of the corn leaves as influenced by mulching and antitranspirants.	129
40	The effect of plant water stress on number of corn leaves that remain active in relation to plant and soil management practices.	130
41	Grain yields for corn grown during the 1974-5 wet season at Planaltina, Brazil. All yield results are based on 15.5 % moisture content. Deep lime refers to a 0-30 cm depth of lime incorporation and shallow lime refers to a 0-15 cm depth incorporation.	131
42	Stover yields for corn grown during the 1974-5 wet season at Planaltina, Brazil. All yield results are based on oven-dry weights. Deep lime refers to a 0-30 cm depth of lime incorporation and shallow lime refers to a 0-15 cm depth of lime incorporation.	132
43	Growth measurements before and after the veranico in relation to mulching and variety.	133
44	Ear leaf nutrient concentration of P, Mg, Ca, K, and Zn as influenced by corn variety, depth of lime incorporation and mulching.	135
45	Uptake of P, Mg, Ca, and K by the stover. Results are expressed in kg/ha.	135
46	Correlation of nutrient uptake by the stover yield in relation to mulching and maize variety.	136
47	Soil analysis results taken at harvest time of the 1974-5 wet season mulch experiment. Results are for the 0-15 cm soil layer only.	136

Table		Page
48	Number of days to 50 % tasseling.	144
49	Influence of mulching on soil temperatures throughout the 0-45 cm soil layer.	147
50	Soil water content at five soil depths in relation to the crop management practices. Results are averaged over the six-day stress period.	148
51	Leaf water potential for corn in relation to mulches and antitranspirants. Mulch and antitranspirant measurements were made on alternate days during the stress period.	150
52	Relative water contents (RWC) for corn in relation to mulchs and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.	150
53	Maize leaf stomatal resistance (R_s) as influenced by mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.	151
54	Effect of the antitranspirants on leaf area and leaf number before and after water stress period.	151
55	Corn leaf temperatures taken during the stress period in relation to mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.	152
56	Corn canopy air temperature and percent relative humidity during the stress period in relation to the crop management practices.	154
57	Final grain and stover yields for the 1975 dry season mulching experiment. Grain yield is expressed at 15.5 % moisture. Stover yield is on an over-dry weight basis.	155
58	Ear leaf nutrient analysis in relation to the crop management practices.	157

Table		Page
59	Uptake of P, Mg, Ca, K, and Zn in the grain and stover. Results are expressed in kg/ha.	157
60	Soil analysis for the 1975 Dry Season Mulching Experiment. Comparison made between deep and shallow lime incorporation.	158
61	Corn root length (cm cm^{-3}) for three soil depth as influenced by depth of lime incorporation and mulching.	159

CHAPTER III

62	Fifty percent flowering response of two rice varieties in relation to 3 row spacings and 2 lime depth incorporations.	166
63	Growth measurements for the rice variety IAC-1246 taken during the 5 days of water stress measurements (7-9 & 12-13/4/75).	169
64	Soil water content (%) for IAC-1246 in relation to 2 lime depths and 3 row spacings. Measurements were taken for six days (7-10 and 12-13/4/75).	170
65	Leaf water potential (Ψ_L) and relative water content (RWC) for rice as influenced by depth of lime incorporation and row spacing.	171
66	Photosynthetic rate (Pn) measurements for IAC-1246 as influenced by 2 lime depths and 3 plant-row spacing. Measurements were taken for 5 days (7-9 and 12-13/4/75). Results are expressed in mg $CO_2/dm^2/hr$.	172
67	Influence of two lime depths and three row spacings on the stomatal resistance for the rice variety IAC-1246.	173
68	Transpiration rate for IAC-1246 in relation to depth of lime incorporation and row spacing.	175
69	Row spacing and depth of liming effect on growth and yield parameters for Pratao Precoce. Measurements were taken from a square meter area on 19/4/75.	176

Table		Page
70	Grain yield for Pratao Precoce grown during the '74-5 wet season at Planaltina, Brazil. Results are expressed in kg/ha at 14 % moisture.	176
71	Row spacing and depth of liming effect on growth and yield parameters for IAC-1246. Measurements were taken from a square meter area on 10/15/75.	177
72	Grain yield for IAC-1246 grown during the '74-5 wet season at Planaltina, Brazil. Results are expressed in kg/ha at 14 % moisture.	177
73	Uptake of P, K, Ca, and Mg by the grain and stover of two rice varieties, IAC-1246 and Pratao Precoce.	179
74	Post harvest soil analysis data for the rice experiment.	180

CHAPTER I APPENDIX

Appendix Table		
1	Growth analysis for corn grown during the 1974 dry season. Measurements were taken approximately every 10-12 days.	191
2	Morning and afternoon soil temperatures at six depths in the 0-45 cm soil profile.	195
3	Stomatal resistance for both adaxial and abaxial sides of the corn leaf taken four times daily during the first stress period.	196
4	Stomatal resistance for both adaxial and abaxial sides of the corn leaf taken four times daily during the second stress period.	200
5	Vapor pressure deficit within the corn canopy at four time periods during the day for both stress periods.	204
6	Percent concentration of P, K, Ca and Mg in the stover for the 1974 dry season experiment.	205
7	Growth analysis results for the 1974-5 wet season maize experiment in relation to plant water stress and five soil management practices.	206

Appendix Table		Page
8	Transpiration rates for maize during the veranico in relation to five fertility treatments.	210
9	Plant uptake of P, K, Ca, and Mg throughout the season in relation to the five fertility treatments and late stress period.	212
10	Percent concentration of P, K, Ca, and Mg in corn grain and stover from the 1974-5 wet season experiment.	214
11	Growth analysis results for corn grown during the 1975 dry season in relation to plant water stress and to five fertility management practices.	215
12	Leaf water potential and relative water content results for the early stress period.	220
13	Leaf water potential and relative water content results for the late stress period.	221
14	Stomatal resistance for corn leaves during the first stress period in relation to the fertility treatments.	222
15	Chlorophyll content of corn leaves as effected by water stress duration. Results are in mg chlorophyll/gram leaf fresh weight.	223
16	Sample leaf area, plant height, and number of leaves on the sample plants during the early stress period.	224
17	Sample leaf area, plant height, and number of leaves on sample plant during the second stress period.	225
18	Uptake of P, K, Ca, Mg, and Zn by the corn plant in relation to plant water stress and fertility management practices.	226

CHAPTER II APPENDIX

19	Corn leaf water potential (Ψ_L) in relation to water stress and certain crop and soil management practices. Results expressed in bars (14.5 psi = 1 bar).	231

Appendix Table		Page
20	Relative water content (RWC) of corn leaves as affected by water stress and RWC after 47.3 mm of rainfall during a 10 day period.	232
21	Transpiration rate for corn leaves in relation to mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.	233

LIST OF FIGURES

Figure		Page
1	Lime incubation study for determination of lime rates in LVE soil.	8
2	Calibration of the ventilated diffusion porometer at five different temperatures for determination of stomatal resistance (sec cm^{-1}).	12
3	Calibration of ventilated diffusion porometer in relation to temperature for determination of leaf transpiration (μ g H_2O cm^{-2} sec^{-1}).	15
4	Meteorological data for the early stress period on maize grown during the 1974 dry season (28/8-10/9/74).	19
5	Meteorological data for the second water stress period on maize grown during the 1974 dry season (21/9/74 - 2/10/74).	20
6	Photosynthetic active radiation (PAR) taken during the two periods of water stress measurements.	21
7	Leaf area index (LAI) in relation to 3 lime treatments for corn grown during the '74 dry season at Planaltina, Brazil.	23
8	Leaf area index (LAI) in relation to 2 phosphorus treatments for corn grown during the '74 dry season at Planaltina, Brazil.	24
9	Morning and afternoon soil temperature in relation to the five treatments. Results are the mean of the daily measurements taken during the first stress period.	26
10	Stress duration effect on diurnal stomatal resistance in relation to the three lime treatments during the first stress period. (a) 0-lime; (b) shallow-lime; (c) deep-lime.	30
11	Stomatal resistance for bottom side of corn leaves taken four times daily. (a) 0-lime; (b) shallow-lime; (c) deep-lime.	31

Figure		Page
12	Leaf temperatures for maize in relation to the five fertility treatments taken four times during the day.	33
13	Corn canopy microclimate at 13:30-14:30 hrs during the second stress period.	34
14	Meteorological data for corn, 1974-5 wet season. Time period (days) corresponds to drought period (veranico) (27/2/75 through 16/2/75).	44
15	Photosynthetic active radiation measurements for time period 5-3-75 through 13-3-75. This time period corresponds to water stress measurements taken during the veranico.	45
16	Leaf area index (LAI) for corn grown during the 1974-5 wet season at Planaltina, Brazil.	47
17	Leaf area index (LAI) for corn grown during the 1974-5 wet season at Planaltina, Brazil.	48
18	Total dry matter accumulation for corn grown during the 1974-5 wet season.	49
19	Total dry matter accumulation for corn growth during the 1974-5 wet season.	50
20	Relative growth rate (RGR) for corn grown during the 1974-5 wet season; (a) RGR from destructive sampling of two plants/plot; (b) Comparison between actual RGR and calculated RGR; (c) Calculated RGR based on results from non-destructive leaf measurements.	52
21	Decreasing soil water content under a bare soil during 14 days without rain. Numbers refer to days since last rainfall.	56
22	Leaf water potential for corn (third leaf from top) taken during a veranico (27/2/75 - 17/3/75); (a) Shallow lime incorporation (0-15 cm) verses deep lime incorporation (0-30 cm); (b) Broadcast-P verses banded-P application.	59
23	Nutrient uptake curves in relation to the five soil management practices; (a) Phosphorus uptake; (b) Magnesium uptake.	71

Figure		Page
24	General meteorological data for the first stress period (4/8 to 21/8/75).	76
25	General meteorological data for the second stress period (10/9 to 19/9/75).	77
26	Diurnal photosynthetic active radiation curve for both the first and second stress periods.	78
27	The effect of plant water deficit on corn leaf area; (a) shallow lime; (b) deep lime.	79
28	Leaf area for corn comparing the 3 lime (a) and 2 P treatments (b).	81
29	Soil temperature through the 0-45 cm soil profile as influenced by crop and time of measurement.	83
30	Leaf water potential for corn during the 10 days of water stress in relation to broadcast and banded application of phosphorus; (a) lime comparison; (b) P-application comparison.	86
31	Corn leaf temperatures during two water stress periods in relation to five fertility treatments. Results are averaged over the corresponding stress period.	89
32	Plant uptake of phosphorus throughout the growing season in relation to the five fertility treatments.	102
33	Plant uptake of magnesium throughout the growing season in relation to the five fertility treatments.	103
34	Plant uptake of calcium throughout the growing season in relation to the five fertility treatments.	104
35	Meteorological data for the 1974-5 wet season. Time period (days) corresponds to plant measurements taken during the veranico in January'75 and recovery period.	116

Figure		Page
36	Photosynthetic active radiation measurements taken daily during the 8 days of water stress measurements. (14/1 - 19/1/75 and 29/1 - 30/1/75).	117
37	Leaf area index (LAI) for maize grown during the 1974-5 wet season at Planaltina, Brazil.	118
38	Soil temperatures for mulched and unmulched corn plots. Measurements were taken at six soil depths daily for 8 days at 15:00 hours. Time period corresponds to water stress measurement period.	121
39	Air temperature and % relative humidity within a corn canopy of mulched and unmulched plots. Data was collected at 12:30 hours daily for six days during the veranico (14/1-19/1/75).	122
40	Daily air temperature and % relative humidity in the corn canopy. Measurements were taken at 12:30 hours.	122
41	Leaf water potential and relative water content for corn plants under water stress as a result of a 15 day veranico during the 1974-5 wet season. Measurements were taken daily at 14:30-15:30 hours for six days.	124
42	Leaf temperatures for corn plants in relation to various treatment effect. Measurements were taken for six days a 15 day veranico.	128
43	General meteorological data corresponding to the water stress period of measurements at CPAC, Planaltina, Brazil.	140
44	Photosynthetic active radiation curve during the first five days of the water stress period in the corn mulching experiment.	141
45	Leaf area index (LAI) for corn in relation to the three mulch treatments.	142

Figure		Page
46	Influence of mulches on corn plant height.	143
47	Morning and afternoon soil temperatures at 5 cm depth in relation to mulching.	145
48	Meteorological data for rice '74-5 wet season. Time period (days) corresponds to period of plant measurements (7/4 - 13/4/75).	165
49	Photosynthetic active radiation (PAR) during the period of water stress measurements on the rice variety IAC-1246 at Planaltina, Brazil. Measurements were taken every one-half hour during the day for 5 days (7-9 and 12-13/4/75).	167

APPENDIX

Appendix Figure		Page
1	Dry weight accumulation of corn in relation to five soil management practices; (a) Comparison of the 3 lime treatments; (b) Comparison of the 2 phosphorus treatments.	231
2	Comparison of the net assimulation rate between the banded and broadcast-P treatments (a). Influence of plant water stress on the relative growth rate of corn (b).	232
3	Soil temperatures at four dpths, 5, 15, 30 & 60 cm, during the dry season's crop grow period at Planaltina, Brazil.	233

INTRODUCTION

The central part of Brazil consists of generally one vast tropical savanna commonly called a cerrado. The cerrado area covers approximately 22% of Brazil or 183 million hectares.

The macroclimatic conditions range from the Aw to the Cfb types according to the Koppen climate classification. Most of the cerrado has a tropical humid seasonal climate (Aw), mean temperature range of 20-26 ^{o}C, annual rainfall of 1000-2000 mm, and a well defined wet and dry season. Rainfall is most abundant in the southern part of the cerrado and decreases as one goes north to the extent that potential evapotranspiration exceeds annual rainfall.

The majority of the soils of the cerrado are deep, well drained, and acidic. Fifty-six percent of the soils are classified as oxisols in the soil taxonomy system or as latosols in the Brazilian system of which Latosol Vermelho Amarelo (LVA) is dominant.

The cerrado is similar to many other areas of the tropics in that there is a large variation in both amounts of rainfall and its distribution throughout the rainy season. One of the important factors related to crop growth is the common occurrence of short term droughts (veranicos). Warming (1892) 'father of plant ecology' was one of the first persons to define the cerrado of Brazil. He was also able to describe the seriousness of the effect of the veranico on cerrado vegetation and on farming in the area. He observed that the veranico commonly occurred in January during the middle of the wet

season. The probablity of the occurrence of a veranico in the Brazilian area has been developed by Wolf (1974). Wolf and other researchers at North Carolina State University have shown that the soil moisture storage capacity of cerrado soils is only about 10%. Due to this limited soil moisture storage, the effect of a 10-day veranico on crop growth can be very serious and cause substantial reductions in yields.

Other workers, especially Arens (1963), have shown that the climatic conditions needed for the production of photosynthate (sunlight, temperature, water, etc.) are more than adequate for optimum crop growth. The limiting factors to cerrado vegetation's normal growth is the nutrient deficient soils (N, P, K, S, Mo, Zn, and B).

Goodland (1971) has expanded on Aren's work. He maintains that excess aluminum is the principle growth limiting factor of the cerrado soils by its effect of decreasing the availability of N, P, K, Ca, Mg and possibly other nutrients.

The effect of aluminum on root growth and development and in turn its relation to nutrient and water uptake is well documented by Foy, et.al. (1972).

Previous work conducted by the Cornell-NCSU team in Brasilia (1972-3) has shown the importance of lime and depth of lime incorporation, rates and residual effects of phosphorus, and rates of application of nitrogen and zinc. Water management studies conducted in 1973-4 have also suggested the importance of regulating the availability of soil water to minimize the veranico effect.

The principle objectives of this thesis are to;

1. Study the effect of short term droughts, simulated (with-holding irrigation water in dry season) and actual (veranico) on the physiology of plant growth and production in relation to certain soil fertility and management practices.

2. Study the ecological effects on plant growth and production. Compare the environmental influence of wet and dry seasons on such crops as corn and upland rice.

3. Develop practial production methods inter-relating soil and crop management concepts to reduce the cerrado's negative influence on productive agriculture.

CHAPTER I

Materials and Methods

The experiments were conducted near Brasilia, Brazil at the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC), formerly called Estacao Experimental de Brasilia (EEB). It is located at an elevation of 1010 meters at latitude 15° 36'S longitude 47° 42'W. The area is characterized by a marked wet and dry season. Average rainfall is 1580 mm with 80% of that occurring from November to March. Table 1 shows a water balance in relation to potential evapotranspiration (Penman method) for 42 years of precipitation data in the Brasilia-CPAC area. Mean annual temperature is 21.3 ^{o}C with the hottest month occurring in September and the coolest period in July. The soil type is Latosol Vermelho Escuro, distrofico, textura argilosa, fase cerrado or a Typic Haplustox, fine, isohyperthermic, kaolinitic in the soil taxonomy system of the United States (Cline and Buol, 1973). The maize cultivar, Cargill-111, was used. It was a three-way hybrid produced in Southern Brazil and considered representative of the agronomic type grown in the area.

The native soil was sampled on a square meter by square meter basis for two 16 m^2 areas to check for soil micro-variability and to determine virgin soil pH and percent aluminium saturation. No micro-variability was found and the virgin soil pH and % Al. Sat. were 4.6 and 88.1 respectively for the 0-20 cm soil layer.

The experiment was conducted as a randomized, complete block in a split-plot design with water treatments (12 m x 32 m) as main plots and

nutrient treatments as subplots (12 m x 6.4 m). Three replications were included. Individual plot rows were 12 m long and 0.8 m apart. A plant population of about 50,000 plants/ha was obtained by overplanting and then thinning during the early seedling stage (approx. 20 days after planting).

The main plots consisted of three water treatments which were identified as no stress, late stress, and early stress. The no stress treatment was never allowed to have more than a 0.4 bar soil water tension between the 10-45 cm soil layer in either wet or dry season. The early stress treatment was applied to the maize plants during their rapid period of vegetative growth (Hanway growth stage 2-2.5) (Hanway, 1966). The late stress period coincided with the 50% tasseling stage to early grain formation stage (Hanway stage 5 and 6).

The five nutrient treatments (subplots) were as follows: (1) 0-lime with 400 kg/ha P_2O_5 broadcast and 100 kg/ha P_2O_5 banded, (2) 8 metric tons/ha lime incorporated 0-15 cm with 400 kg/ha P_2O_5 broadcast and 100 kg/ha P_2O_5 banded, (3) 8 metric tons/ha lime incorporated 0-30 cm with 400 kg/ha P_2O_5 broadcast and 100 kg/ha P_2O_5 banded, (4) 640 kg/ha P_2O_5 broadcast with 4 metric tons/ha lime incorporated 0-15 cm, and (5) 160 kg/ha P_2O_5 banded with 4 metric tons/ha incorporated 0-15 cm. The broadcast phosphorus application was applied only once, at the start of the experiment. The banded phosphorus application was applied three times, at planting time for each cropping season.

A blanket application of nitrogen (200 kg/ha), potassium (150/ha), magnesium (50 kg/ha), borax (10 kg/ha), zinc (10 kg/ha) and molybdenum (0.5 kg/ha) was applied in accordance with preliminary findings by the

Table 1. Water balance for the Brasilia-Formosa area. Results are based on 42 years of meteorological data.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	mm												
P	239.5	210.0	225.9	104.7	17.8	3.4	5.4	6.1	37.0	144.6	254.9	330.9	1580.2
Eo**	134.9	116.5	140.1	121.8	116.9	102.3	134.2	157.5	154.8	139.8	138.6	134.9	1592.3
Et**	155.1	134.0	161.1	140.1	134.4	117.6	154.3	181.1	178.0	160.8	159.4	155.1	1831.0
Available* Soil Water	51.0	51.0	51.0	15.6	0	0	0	0	0	0	51.0	51.0	270.6
Excess	84.4	76.0	64.8	0	0	0	0	0	0	0	44.5	175.8	445.5
Deficit	0	0	0	0	101.0	114.2	148.9	175.0	141.0	16.2	0	0	696.3

* Available soil water for 0-45 cm soil depth = 51 mm (Wolf, 1975).

** Pruntel, 1975.

Cornell/NCSU/USAID/Brazil program (Cornell Annual Progress Report, 1973). Nitrogen and potassium were reapplied for each crop while Mg, Zn, B, and Mo were applied only at the start of the experiment. Lime rates and incorporation depths were based upon a lime incubation study (Fig.1) and preliminary results of Gonzalez (Cornell Annual Progress Report, 1973). Phosphorus rates and methods of application were in accordance with the previous findings by Yost (Cornell Annual Progress Report, 1973).

The triple super phosphate applied at the start of the 1974 dry season was in error. A fertilizer analysis showed that only 38.5% of the P being applied that was planned. In order to have the desired P level in the soil solution, P_2O_5 was reapplied at the corrective rates in all treatments at the begining of the 1974-5 wet season experiment.

The experiment was repeated for three growing seasons. It was grown twice during the dry season (1974 & 1975) where water stress was imposed on the appropriate water treatment by with-holding irrigation water. The 1974-5 wet season experiment had no serious drought periods during the vegetative stage but a natural drought did occur shortly after the 50% tasseling stage which allowed the late water stress treatment to be induced. During all stress periods, the other water treatments were irrigated before the soil moisture tension reached 0.4 bars in the 10-45 cm soil layer.

Soil water contents were continuously monitored throughout the maize growing seasons by tensionmeters and gypsom blocks. The instruments were installed in the row between the plants at 15.0, 22.5, 30.0, and 45.0 cm depths in each nutrient treatment. They were replicated three times for a total of 60 tensionmeters and 60 gypsom

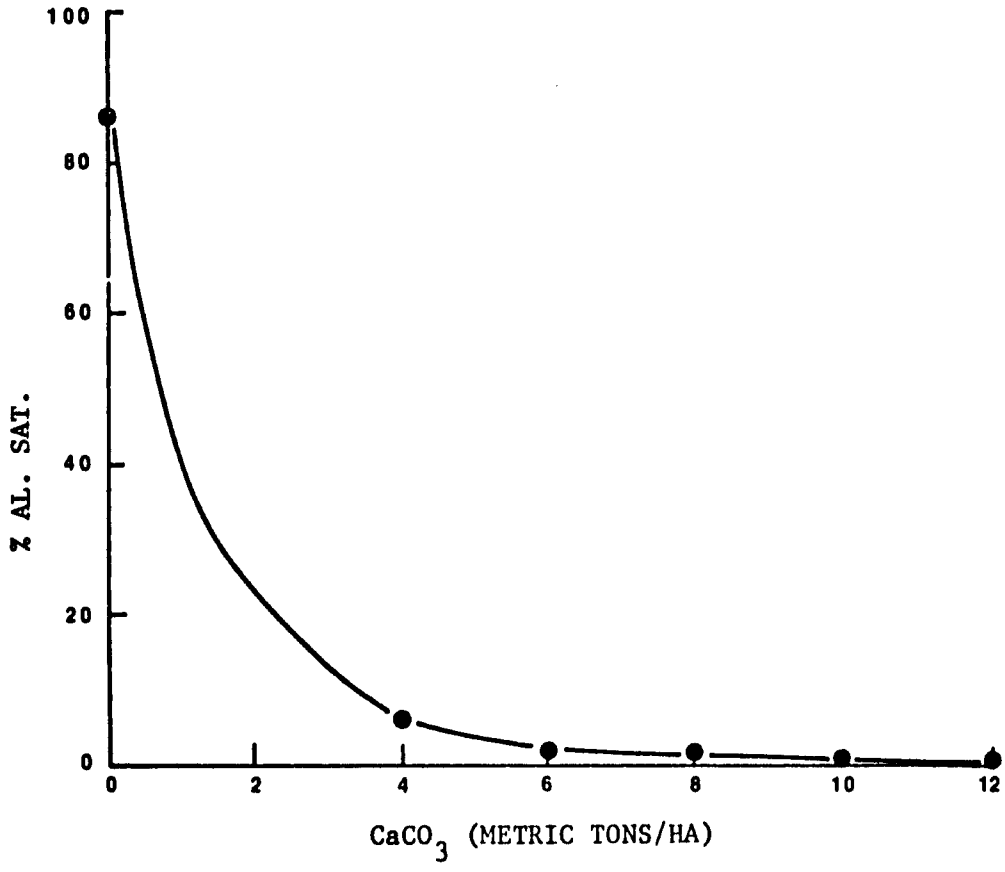


Fig. 1. Lime incubation study for determination of lime rates in LVE soil.

blocks. During the water stress periods, gravimetric sampling was conducted daily at the same depths stated above to insure accurate results. Soil samples for gravimetric sampling were dried at 105 ^{o}C for calculation of percent soil water by weight.

Soil temperatures were measured within the maize experiment and outside the experiment (5 m) under bare soil conditions. Measurements were made at 5, 10, 15, 22.5, 30, and 45 cms within the maize plots and at 5, 10, 15, 20, 25, 30, 45, and 60 cms under the bare soil. Soil temperatures were measured by copper-constantan thermocouples with readings being made on a portable, battery powered, potentiometer which had a built-in cold reference junction. Thermocouples were installed in each nutrient treatment and water treatment for a total of 15 sites. Bare soil measurements were made at two sites which were kept free of all vegetation the year around.

Plant height and total leaf area were measured on the same four plants per plot every 10-12 days throughout the crop season. These non-destructive leaf area measurements were made with a Lambda* leaf area meter. In addition, plant destructive measurements were taken on two plants per plot at the same time as the non-destructive measurements to determine leaf dry weight, stem dry weight, ear dry weight, tassel dry weight, net assimilation rate, relative growth rate and nutrient uptake. The plant samples were dried at 65 ^{o}C for 48 hours in a forced air oven. The samples were then weighed for dry weights, afterwards they

---

* Lambda Instruments Corporation, 4421 Superior Street, Lincoln, Nebraska, 68504.

were ground and prepared for determinations of P, K, Ca, Mg, and Zn.

During the water stress periods, daily measurements of leaf water potential (Ψ_L), relative water content (RWC), stomatal resistance (R_s), transpiration (E), photosynthetic rate (Pn) and leaf temperature (T_L) were taken. All measurements were made on the same leaf, third down from the top and in direct sunlight. One-half of the leaf blade lengthwise, excluding the midvein, was used for Ψ_L determination. The other half of the same leaf blade was used for RWC, R_s, E, Pn, and T_L.

Leaf water potential was measured with a modified Scholander pressure bomb which was built by Cayuga Development* (Scholander, et-al, 1965). Relative water contents were based on the methodology explained by Barrs, 1968. Stomatal resistances, transpiration, photosynthetic rates and leaf temperatures were all measured with a ventilated diffusion porometer built by Cayuga Development. Wallihan (1964) originally demonstrated a technique for direct measurement of leaf resistance on the plant with minimum disturbance to the plant itself. The porometer's construction was based upon the diffusion porometer types described by van Bavel et-al, (1965) Kanemasu et-al, (1969) Byrne et-al, (1970) and Turner et-al, (1970) but mainly on the design selected and used by Bravdo (1972) with modifications made by Cayuga Development and Dr. R. B. Musgrave (Agronomy Department, Cornell University, Ithaca, N.Y.). Leaf temperature was measured by placing a thermistor in contact with the leaf while stomatal resistances were being measured. A lithium chloride

---

* Cayuga Development, 1250 Warren Rd., Ithaca, N.Y. 14850.

sensor* was used to measure air humidity for determination of stomatal resistance. Pn was measured by purging and filling the porometer chamber with a known amount of $^{14}CO_2$ labeled air, i.e., 1 μ ci ^{14}C/ liter air, and exposing the leaf to the labeled air for 30 seconds by opening and closing the porometer aperture. Immediately after exposure to $^{14}CO_2$ and direct sunlight the exposed leaf disc was cut out of the leaf and placed in a liquid scintillation vial containing 5 ml of Protosol+. Tissue digestion was allowed to occur for a minimium of 5 days (Hansen and Bush, 1967). The digested sample was then prepared for counting by a liquid scintillation counter (Incoll, 1969).

Calibration of the porometer was accomplished by using resistance plates as demonstrated by Kanemasu, et-al, 1969. Resistance plate construction and calibration methodology were in agreement with those selected by Bidinger (1976). Six resistance plates were used. Hole size and/or hole frequency varied with each plate. The resistance plates were placed over a sponge reservoir of water to allow free diffusion of water from the sponge, through the resistance plates and into the porometer. A walk-in growth chamber was used for a constant temperature environment. Four calibration lines were made between the temperature extremes of 19.2 & 39.2 ^{o}C (Fig. 2). Each point was the average of 20 measurements. The six resistance plates consisted of one, which had one large hole, two were seive membranes 30 R and 40 P and three were aluminum plates having either 9, 15, or 24 holes. The

---

* Hygrodynamics Inc., 949 Selim Rd, Silver Spring, Maryland, 20910.

+ New England Nuclear, 575 Albany St. Bostom, Mass. 02118.

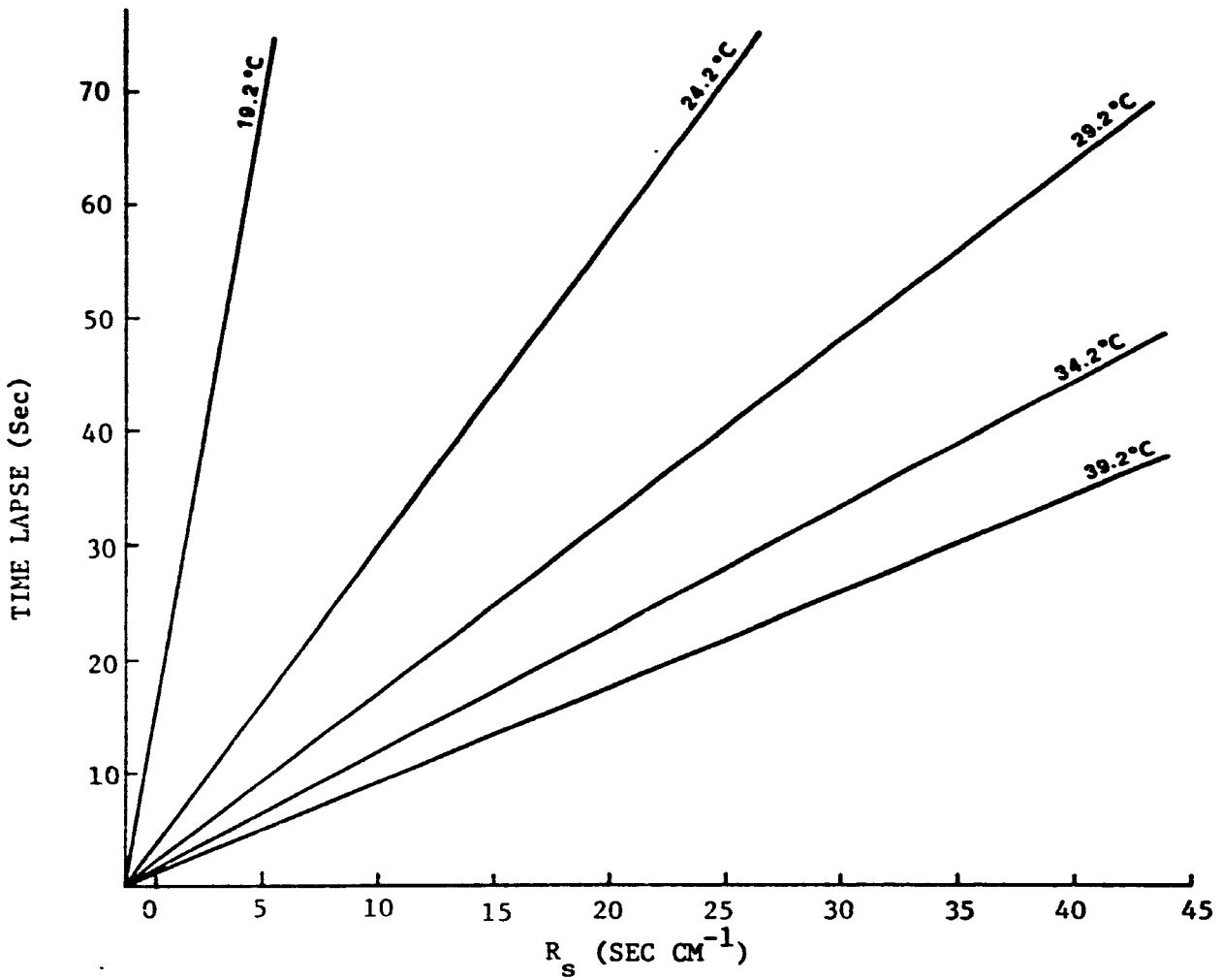


Fig. 2. Calibration of the ventilated diffusion porometer at five different temperatures for determination of stomatal resistance (sec cm^{-1}).

following formula was used to calculate the three aluminum plate's resistances:

$$R_{plate} = \frac{4t}{\pi d^2 nD} + 2\left(\frac{1}{2dnD}\right)$$

where t= thickness of plate; d= diameter of hole in plate; n= number of holes in plate; and D= diffusivity of water at plate temperature. Resistance for the two membranes were calculated with the use of the following formula (Stigter and Lammers, 1974).

$$R_{Membrane} = \frac{4t}{\pi (d')^2 nD} + \frac{1}{2\,d'\,nD} + \frac{1}{2d_t nD}$$

where t= thickness of membrane; d_t= diameter of the hole at one side of the membrane; dm = diameter of the hole at the other side of the membrane;

$$d' = \sqrt{d_t \sqrt{d_t \cdot dm}}\ ; \quad \text{and} \quad n = \frac{1}{1^2 \sqrt{3/2}}$$

whose value is supplied by the manufactures of the membrane. The sixth plate, which was an open hole, has a resistance related only to the length of diffusion (l) and diffusivity of water (D).

$$R_{Hole} = 1/D$$

In addition, the porometer could be used to measure transpiration rates by two methods. One method was to calibrate the porometer by weighing the amount of water it takes to wet the lithium chloride sensor in the same manner as the leaf of the plant does. Porometer air chamber

temperature was measured by a thermistor in the porometer. Fig. 3 shows the calibration line for the amount of H_2O absorbed in relation to temperature. The second method for calculating transpiration was by the use of the following modified formula by van Bavel (1964).

$$\frac{\text{gm } H_2O}{\text{cm}^2 \text{ sec}} = \frac{(\text{gm } H_2O/\text{cm}^3)^{\text{Sat.}} - (\text{gm } H_2O/\text{cm}^3)^{\text{Sensor}}}{r_p + r_l}$$

where: gm H_2O/cm^3(Sat.)= density of pure water vapor at saturation; gm H_2O/cm^3(Sensor)= density of pure water vapor within the effective percent relative humidity range of the lithium chloride sensor in the porometer; r_p= resistance of the porometer; and r_l= leaf resistance.

Photosynthetically active radiation (PAR) was measured daily at 30 minutes intervals during the water stress periods. A Lambda* light meter with a quantum sensor was used.

Daily measurements of wet and dry bulb temperatures at 12:30 and 14:30 hours were made during the water stress periods. Measurements were made in each nutrient treatment, within the corn canopy, above the corn canopy, and by the side of the plots in an open area.

Chlorophyll contents of the maize leaves were determined as plant water stress increased. Five plant samples were taken from each nutrient treatment, composited, and then analysed for total chlorophyll content as described in the "Laboratory Manual for Physiological Studies of Rice" (1972).

---

* Lambda Instruments Corporation, 4421 Superior Street, Lincoln, Nebraska, 68504.

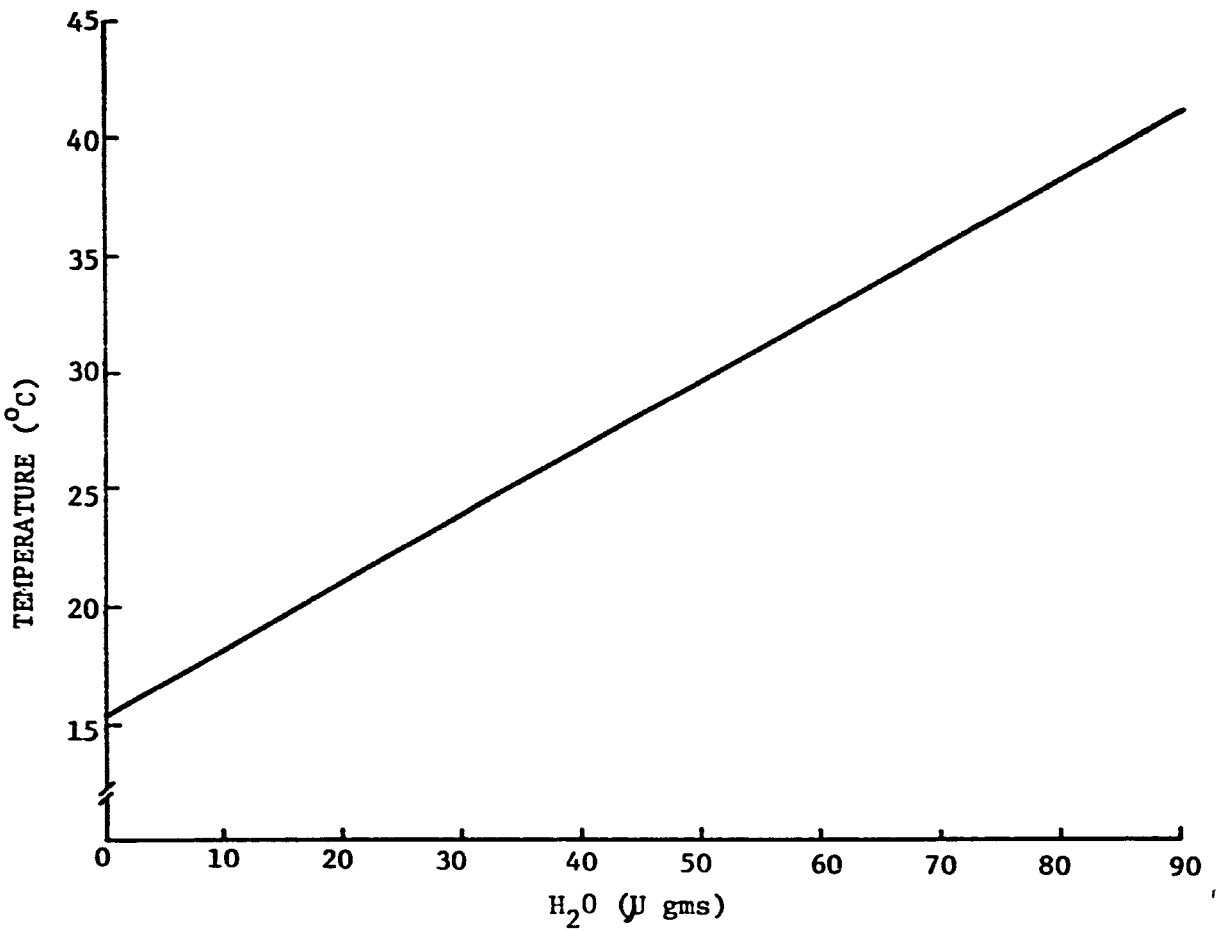


Fig. 3. Calibration of ventilated diffusion porometer in relation to temperature for determination of leaf transpiration (u g H_2O cm^{-2} sec^{-1}).

Root studies were made by two different methods. One method involved the use of rubidium-86 and a solid scintillation counter (Ellis and Barnes, 1973). The technique was modified for use with maize plants. Ten microliters of the ^{86}Rb isotope were injected into the base of the corn plant at 17:00 hours. Three plants per each nutrient treatment were used. The following day at 08:00 hours soil core samples, including the corn roots, were taken at three depths (0-15, 15-30, and 30-45 cms) and at five locations around each injected plant. The locations were 2.5 and 17.5 cms distance from the base of the injected plant within the row and 15, 30, and 45 cms distance between the rows. No sample preparation was needed. Samples including roots and soil were placed in a lead container over a 3 inch thallium activated sodium iodide crystal for detection of gamma radiation. The energy from the gamma radiation was analized and counted on a Nuclear-Chicago* analyzer/scaler, Model 8725. The second method used for the study of root distribution was a modified version of the Newman method (1966). The modified technique was devised by Gonzalez (1976). Root samples were taken in each nutrient treatment, 4 plants/ treatment at three depths (0-15, 15-30, and 30-45 cms) with three replications. Samples were taken at three locations around each plant, one location within row and two locations between the rows. The three locations and four plants/plot were all composited for each depth which then gave one sample per depth per nutrient treatment. All measurements were made in the no water stress plots.

The center two rows of the eight row plots, with a two meter border

---

* N.C. Corporation, 332 E. Howard Ave. Des Plaines, Ill. 60018.

on each end, were used for final grain and stover yield determinations (12.8 m^2 area). Grain moisture was determined on a Steinlite* Moisture Meter. All grain results were based on a 15.5% moisture content. Stover yields were based on oven-dry wieghts by drying subsamples at 65 ^{o}C. Subsamples of both grain and stover were then ground in a Wylie mill for determination of the nutrients, P, Ca, Mg, K, and Zn.

Soil sampling was done two times per growing season, midway and end of season. Samples were taken in every plot at four locations, then composited. Three soil depths were measured, 0-15, 15-30, and 30-45 cms. Samples were prepared for soil analysis by air drying, grinding, and then passing the soil through a no. 9 mesh screen.

---

* Seedburo Equipment Co. 618-626 West Jackson Blvd. Chicago, Ill. 60606.

1974 Dry Season Soil Management Experiment

The principle objective of the experiment was to study the effect of five soil management practices on plant water use during periods of water stress. The dry season crop used irrigation as the only water source. Early stress and late stress treatments were accomplished by with-holding irrigation water for a certain number of days to simulate a veranico. The two water stress periods were conducted when the corn plants were in the boot stage (Hanway stage 3-3.5) and after 50% tasseling (Hanway stage 5). General meteorological data during the two stress periods are shown in Figures 4 and 5. The first stress period lasted for 14 days (28/8-10/9/74) and the second stress period lasted for 12 days (21/9-2/10/74). Pan ET shows a high evaporation demand which was accentuated by constant winds. Solar radiation was quite stable due to nearly cloudless weather but maximum temperatures were not very high. Photosynthetically active radiation (PAR) measurements taken during the two stress periods were similar (Fig. 6). PAR intensity was not very high, failing to reach 2,000 $\mu E\ M^{-2} Sec^{-1}$.

Growth analysis for the dry season maize crop shows that plant growth was very slow and quite poor. For the first 50 days after planting, the 0-lime treatment had a significantly slower leaf area growth rate than the two lime incorporation treatments but no significant differences were noted betwwen deep and shallow liming until after 110 days of growth (Fig. 7). Banded application of phosphorus gave significantly better leaf growth for the first 50 days in comparison to the

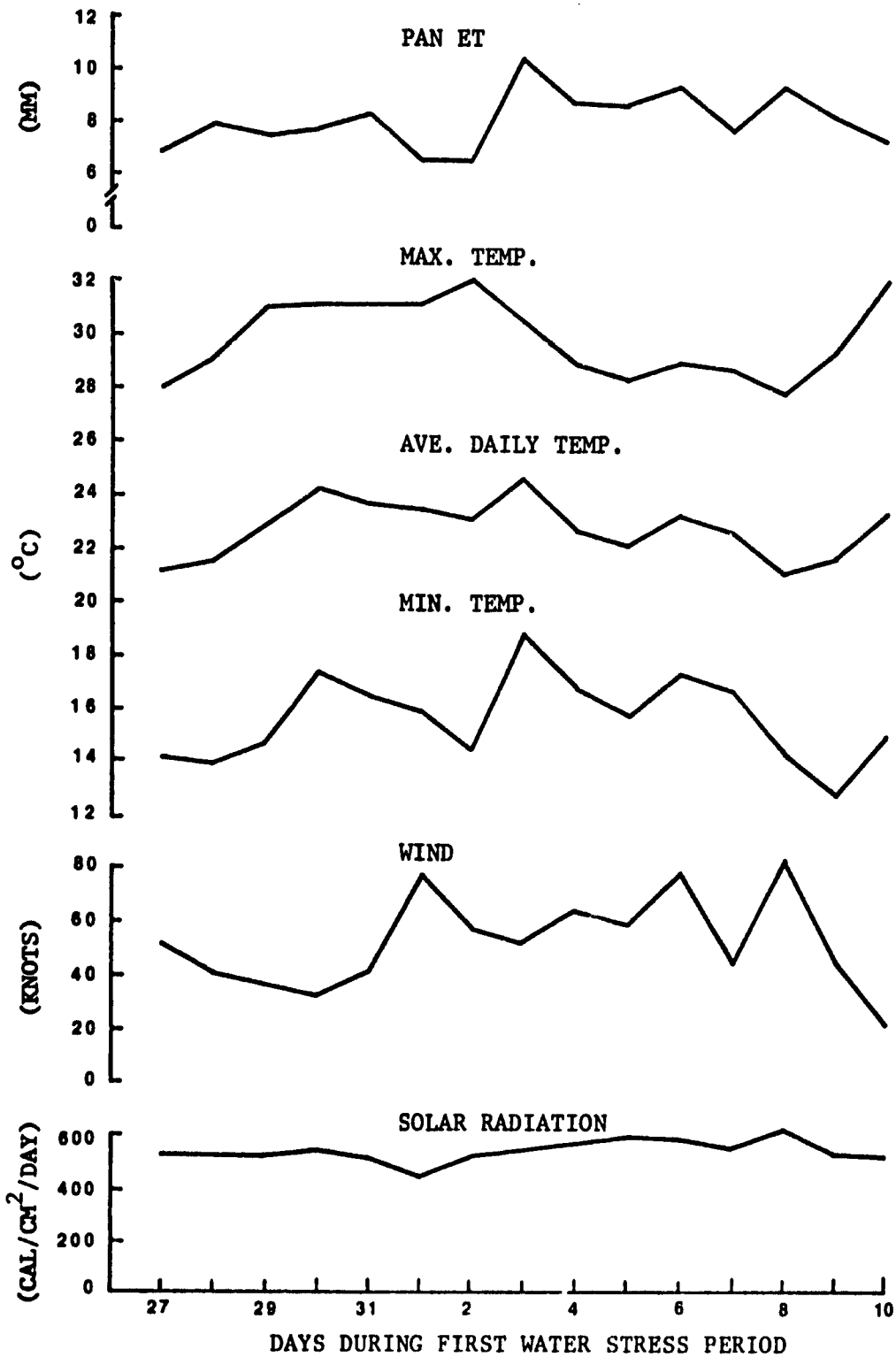


Fig. 4. Meteorological data for the early stress period on maize grown during the 1974 dry season (28/8 - 10/9/74).

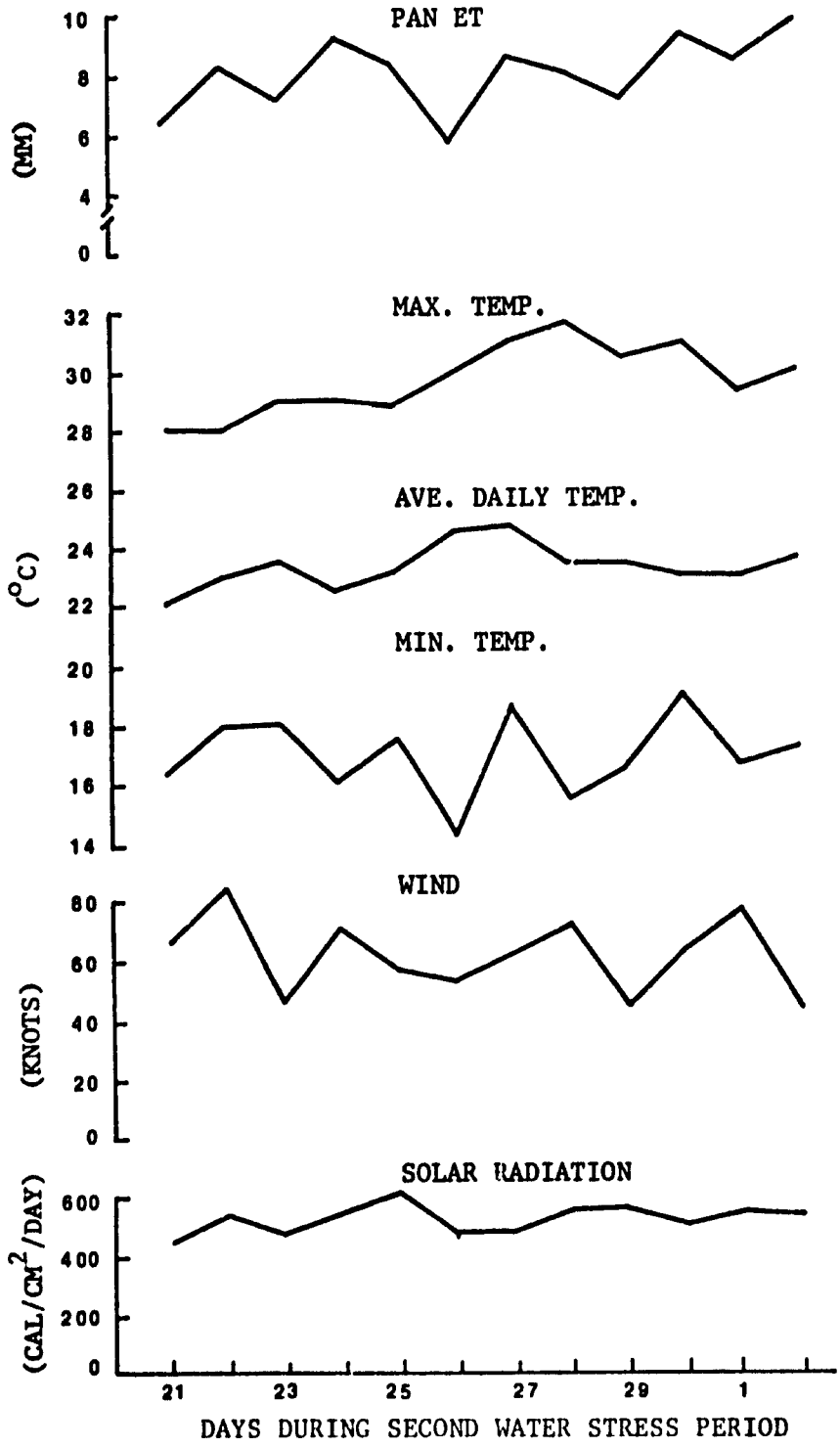


Fig. 5. Meteorological data for the second water stress period on maize grown during the 1974 dry season (21/9/74 - 2/10/74).

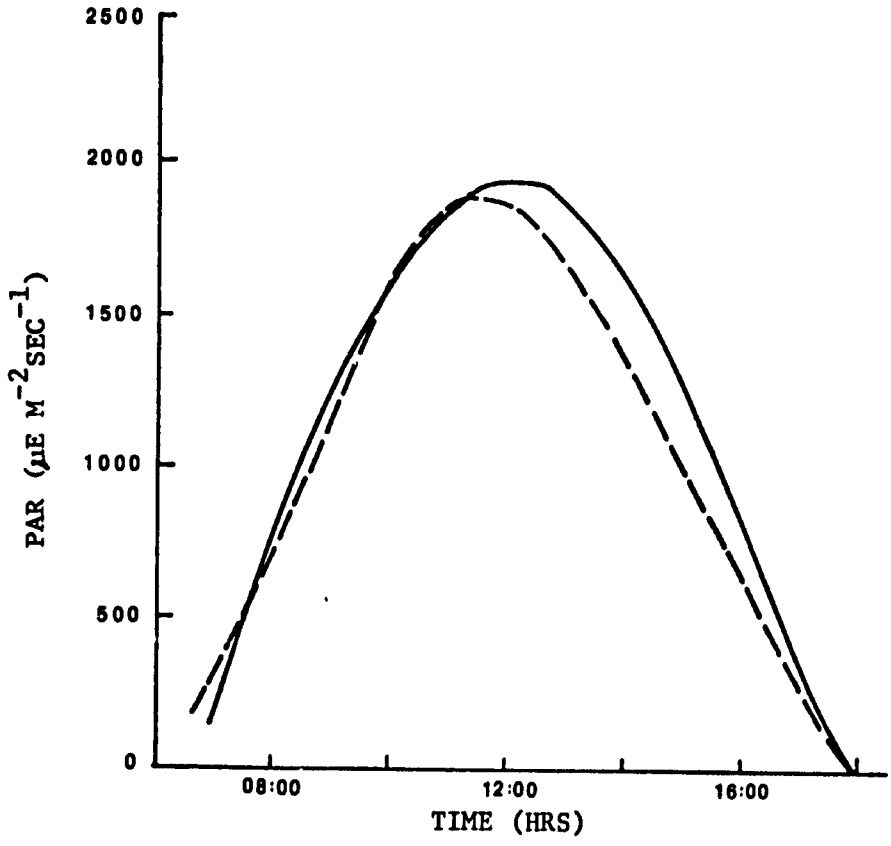


Fig. 6. Photosynthetic active radiation (PAR) taken during the two periods of water stress measurements. Solid line indicates first period and second period is designated by broken line.

broadcast phosphorus treatment. The very poor growth of the banded-P_2O_5 treatment after 50 days suggests that 160 kgs P_2O_5/ha was not sufficient to maintain good corn growth (Fig. 8). The leaf area index results shown in Figures 7 and 8 were taken from the same plants each sampling period to keep canopy intact. That was possible since a non-destructive method of measuring total leaf area was used.

The effect of the first water stress period on leaf area was shown by the dashed lines (Fig. 7). The 0-lime treatment didn't recover from the imposed water stress as did the other two lime treatments. The banded-P treatment did not show a significant reduction in leaf area due to its very small leaf area in relation to the other treatments. A more detailed growth analysis using plant height, dry weights of plants parts, net assimulation rates, and relative growth rates is shown in Appendix Table 1. Those results show the same nutrient and water stress differences that were demonstrated in Figures 7 & 8. Net assimulation rates and relative growth rates were calculated but they gave very fluctuating and non-significant results. In general, poor crop growth and large plant variability, as noted by the high C.V.'s, were responsible for the poor NAR and RGR results.

During the two stress periods soil moisture content was measured daily by gravimetric sampling. The results in the 22.5 to 45.0 cm soil layer suggest that deep lime incorporation (0-30 cm) allowed for deeper root penetration, thus greater water availability and use by the corn plant (Table 2). To find a quantitative difference in the amount of water used by the corn plants in relation to the nutrient treatments, the following formula was used.

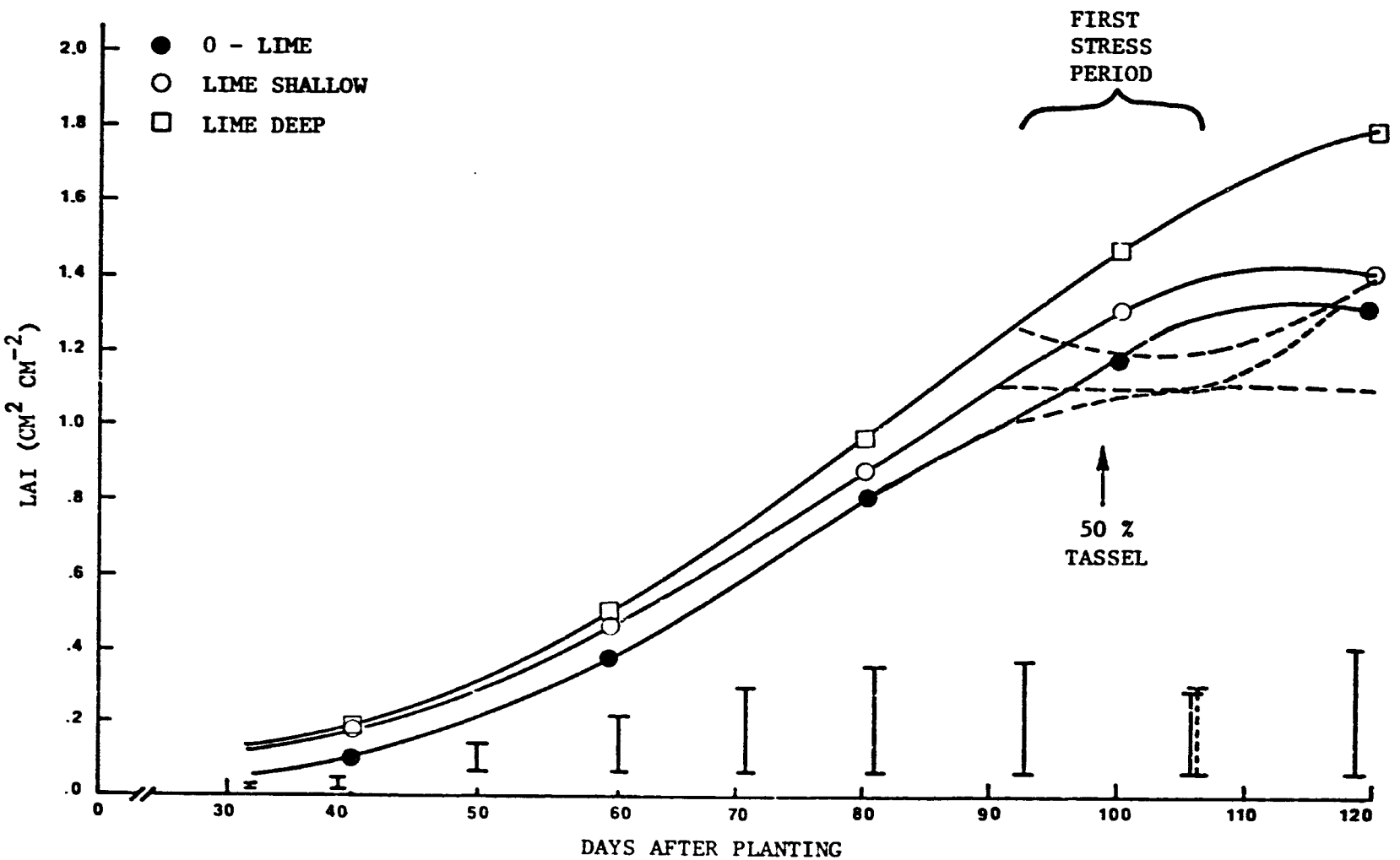


Fig. 7. Leaf area index (LAI) in relation to 3 lime treatments for corn grown during the '74 dry season at Planaltina, Brazil. Solid lines indicate control plots where no water stress occurred. Broken lines indicate the effect of the first water stress period on LAI.

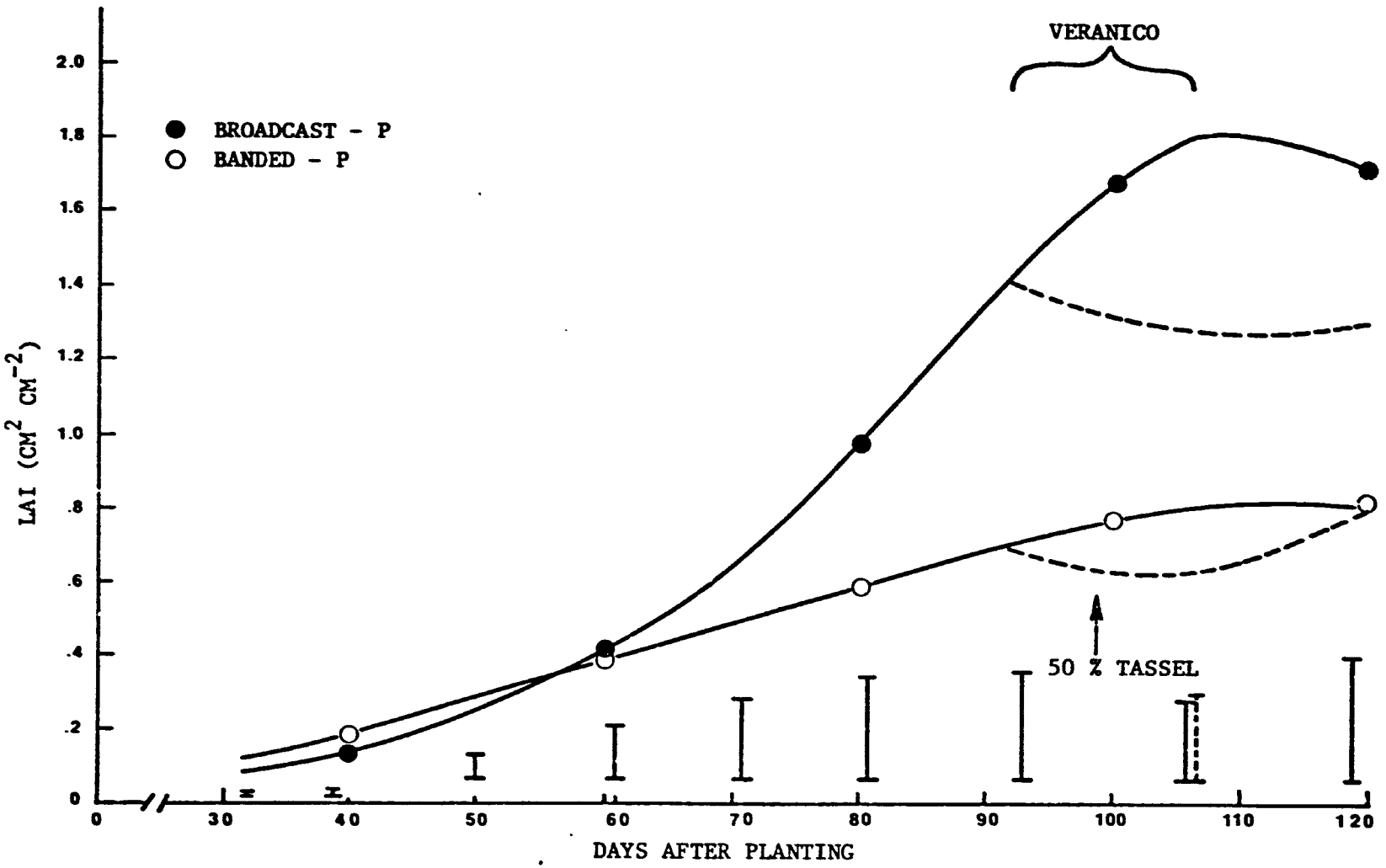


Fig. 8. Leaf area index (LAI) in relation to 2 phosphorus treatments for corn grown during the '74 dry season at Planaltina, Brazil. Solid lines indicate control plots where no water stress occurred. Broken lines indicate the effect of the first water stress period on LAI.

$$d = \frac{Pw_S - Pw_D}{100} \times BD \times D$$

where: d= difference in amount of water used; Pw_S= soil water contents for shallow lime incorporation; Pw_D= soil water content for deep lime incorporation; BD= bulk density of 1.06 for the LVE soil (Wolf, 1975); and D= depth of soil profile for each measurement increment. The larger amount of water made available by deep liming could be very important in diminishing or delaying severe plant water stress during a veranico. The 4-8 mms of soil water would be equal to 2-4 days of evapotranspiration from corn plants growing under low stress conditions.

Table 2. Soil water use by corn during the first and second stress periods in relation to five fertility management practices.

Treatment	Soil Depth 0-15 cm	15-22.5 cm	22.5-30 cm	30-45 cm	d
	Soil Water Content (g/100g)				mm H_2O
			First Water Stress Period		
0-Lime	17.2	22.1	24.1	24.1	4.4
Lime-Shallow	17.2	21.9	23.9	24.1	4.2
Lime-Deep	17.3	21.5	21.8	23.9	0
Broadcast-P	17.2	22.1	23.7	24.9	5.2
Banded-P	18.3	22.8	23.6	25.3	7.2
			Second Water Stress Period		
0-Lime	22.0	25.0	25.9	26.1	5.0
Lime-Shallow	20.2	25.3	27.2	25.9	4.1
Lime-Deep	20.7	24.5	24.8	25.6	0
Broadcast-P	21.2	24.9	25.6	25.0	1.5
Banded-P	22.2	26.3	26.4	26.4	8.8

Soil temperatures were taken in the morning and afternoon for July and August (Fig. 9 and Appendix Table 2). The 20-35 ^{o}C soil temperature range was within high or low temperature limitations for corn growth.

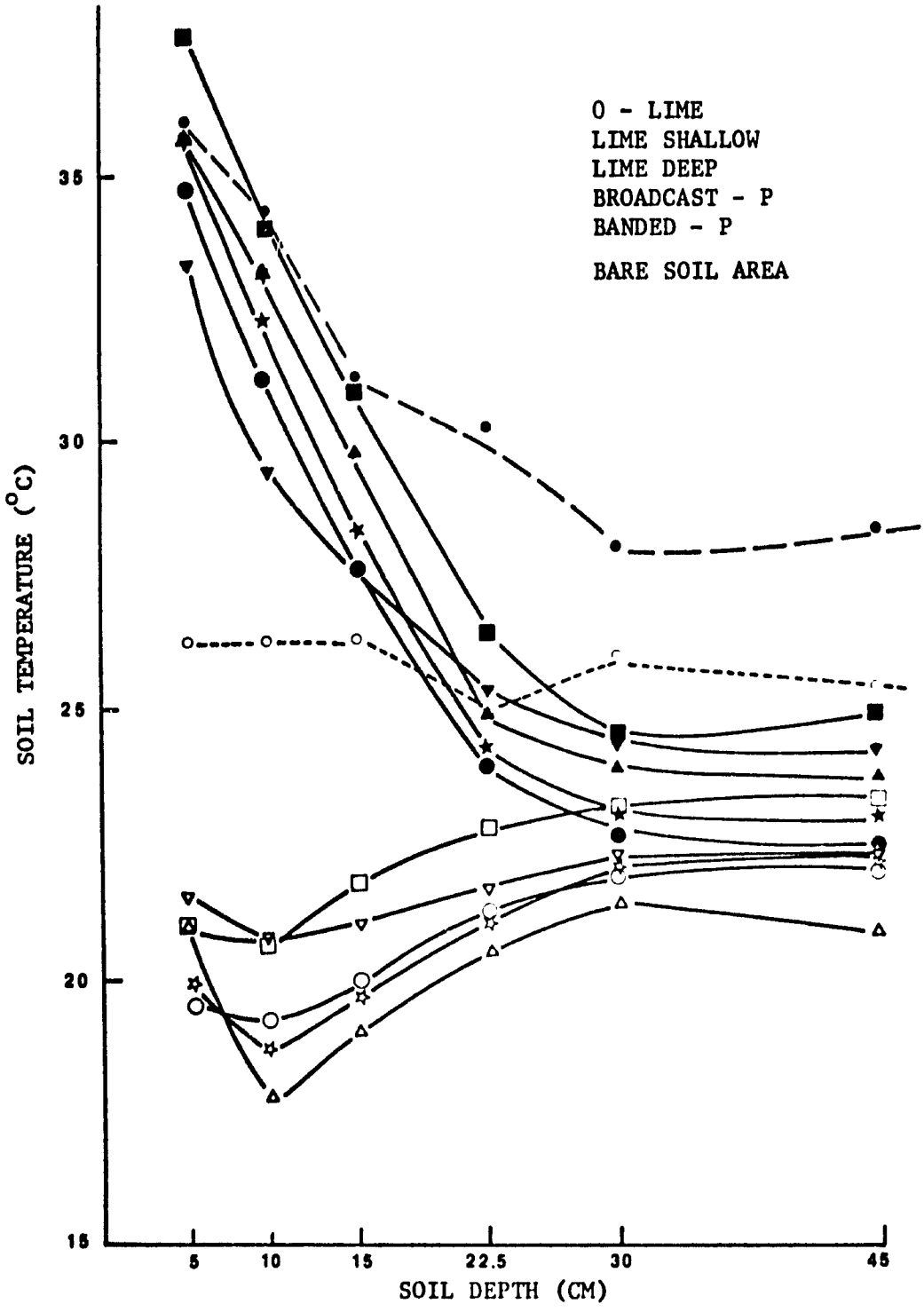


Fig. 9. Morning and afternoon soil temperatures in relation to the five soil treatments. Results are the mean of the daily measurements taken during the first stress period. Solid symbols=afternoon measurements (15:00 hrs); Clear symbols=morning measurements (08:30 hrs).

The 10-15 ^{o}C daily fluctuation suggests that there was some soil water movement up from lower soil depths due to pressure head differences. Upward water movement from below the rooting zone could be very benifical to a stressed plant by allowing it to return to normal turgor pressure during the night. Deep liming would benifit more from upward water movement in comparison to shallow liming since a greater soil area was involved. This ability to extract water from below the rooting zone would greatly increase the total amount of water made available to plants. For example, 17 mm more water is made available by increasing the plant water extraction depth from 30 cm to 45 cm.

Leaf water potential and relative water content (RWC) were measured three times daily during the two water stress periods. The average Ψ_L and RWC results are shown in Table 3. The deep lime results for early morning and late afternoon suggest that the corn plants didn't become stressed as early in the day and returned to less negative Ψ_L earlier in the afternoon than the other lime treatments. The RWC results substantiate the Ψ_L results. The comparison between the phosphorus application treatments show that banding P was superior to broadcast P but that may not be an entirely correct assumption. The maize plants in the banded-P treatment had less than half the leaf area of the broadcast-P plants (Fig. 8). Thus use of soil water for ET would be much less which in turn would give less negative Ψ_L and RWC results. In addition, note that Ψ_L tended to be more negative for older plants whereas RWC stayed the same. This suggests that as plants become older Ψ_L becomes more negative.

As a plant comes under water stress the stomates close and conserve water lost by transpiration. Measurements of stomatal resistance (R_s)

Table 3. Leaf water potential and relative water content for maize leaves during the two stress periods of the 1974 dry season experiment.

	09:00 - 10:00hrs		13:00 - 14:00hrs		15:00 - 16:00hrs	
Treatment	First	Second	First	Second	First	Second
	Leaf Water Potential (Bars)					
O-Lime	-14.4	-15.0	-14.3	-16.3	-14.9	-16.3
Lime-Shallow	-12.6	-14.5	-14.1	-16.0	-14.9	-16.6
Lime-Deep	-12.4	-14.5	-14.2	-16.5	-13.8	-16.5
Broadcast-P	-14.3	-16.5	-15.3	-17.0	-15.5	-17.0
Banded-P	-11.4	-14.0	-13.2	-15.4	-12.3	-14.8
	R W C (%)					
O-Lime	83.0	88.2	79.7	80.2	82.8	81.5
Lime-Shallow	84.7	87.4	80.3	83.5	82.0	81.4
Lime-Deep	83.9	89.4	82.5	84.1	82.3	84.2
Broadcast-P	79.2	84.7	78.6	81.0	78.2	81.0
Banded-P	81.5	81.2	81.2	80.8	85.2	85.3

will show whether a plant is transpiring rapidly, i.e. low R_s, or if it is transpiring very little, i.e. high R_s. Figures 10 & 11 show a series of R_s results for the three lime treatments in relation to diurnal stress and to stress duration. During the first stress period note that in the 0-lime treatment (Fig. 10 a) the stomates closed by 11:00 hrs after five days of water stress and with the shallow lime treatment plants, the stomates closed in the morning four days later (Fig. 10 b). Deep liming plants did not have closed stomates in the morning (Fig. 10 c). These results coincide with the Ψ_L and RWC observations. In addition, note that stomates were starting to close at 16:00 hrs for plants not under stress while the stressed plant's stomates, which had been closed during the day, were opening. The effect of stress duration during the second stress period on stomatal resistance continues to show the advantage of deep lime incorporation as was shown above. For 0-lime (Fig. 11 a) and shallow lime (Fig. 11 b) plants, the stomates started to close in the morning after seven days of stress. For deep limed plants, the stomates started to close in the afternoon after nine days of stress but did not close in the morning (Fig. 11 c). The results clearly show that deep lime incorporation delayed and reduced plant water stress in terms of stomatal resistance. Appendix tables 3 and 4 show the daily R_s for both adaxial and abaxial sides of the corn leaf for all five nutrient treatments and for both stress periods. Banded-P plants generally showed lower R_s than broadcast-P plants, thus agreeing with the previous Ψ_L and RWC results. This researcher believes that the much smaller plants in the banded-P treatment was the main reason for less plant water stress than was the effect of P application.

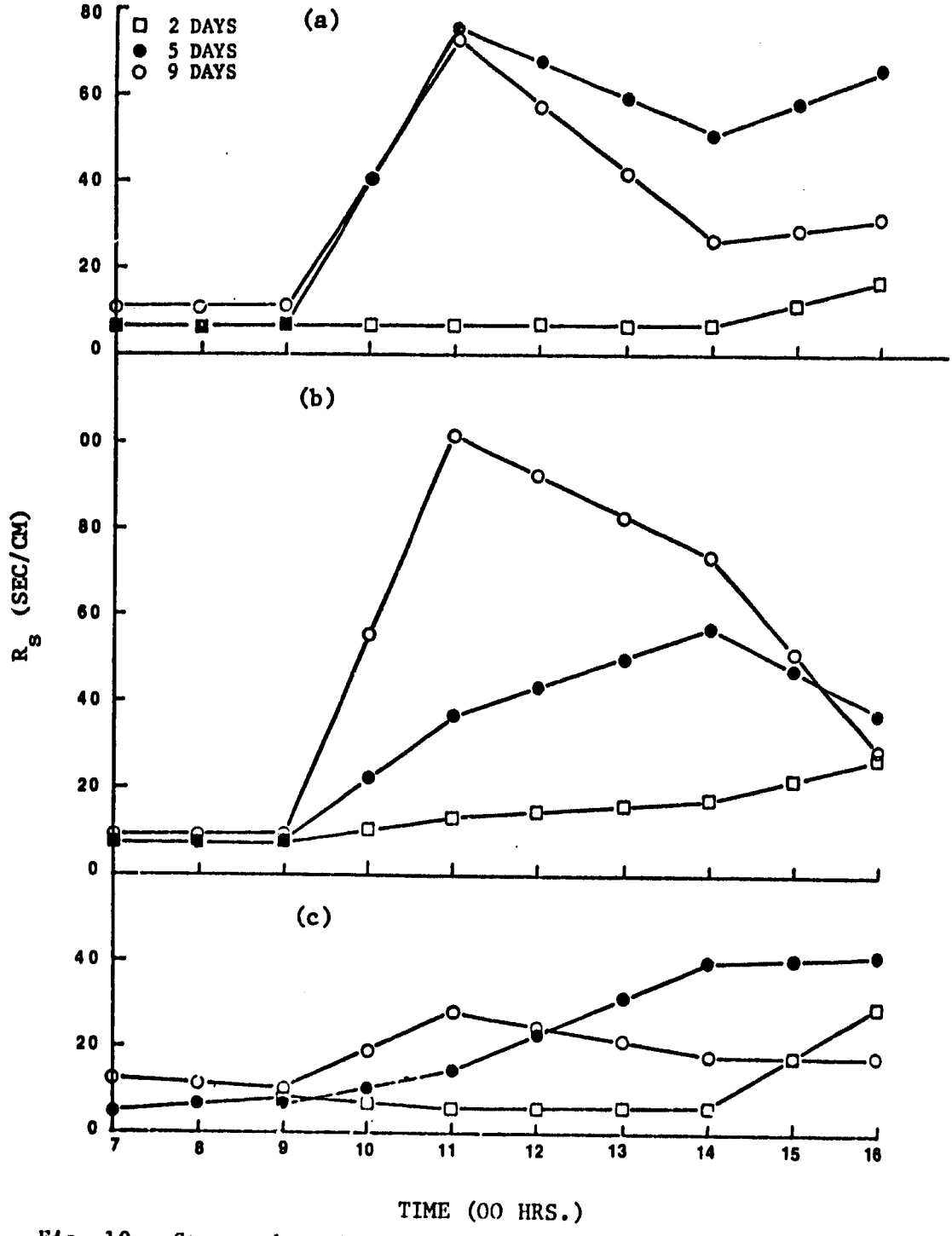


Fig. 10. Stress duration effect on diurnal stomatal resistance in relation to the three lime treatments during the first stress period. (a) 0-lime; (b) shallow-lime; (c) deep-lime.

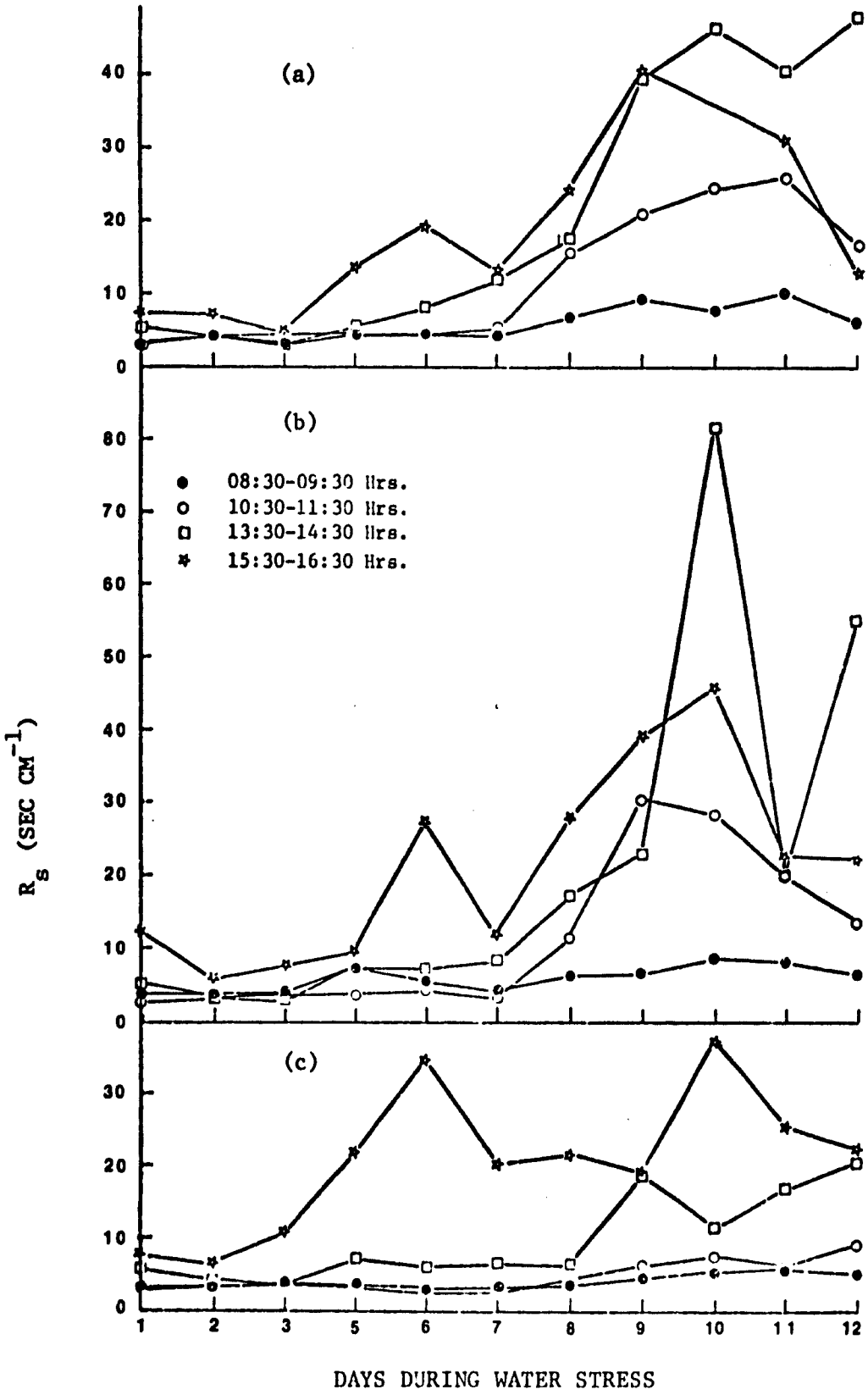


Fig. 11. Stomatal resistance for bottom side of corn leaves taken four times daily. (a) 0-lime; (b) shallow-lime; (c) deep-lime.

Table 4. Grain and stover yields for the '74 dry season corn experiment grown at Planaltina, Brazil. Grain yields are corrected to 15.5% moisture and stover yields are on an oven-dry weight basis.

Treatment	Grain Yield	Stover Yield	Grain:Stover
	(kg/ha)	(kg/ha)	(ratio)
		No Water Stress	
0-Lime	3857	3676	1.05
Lime-Shallow	3480	3237	1.08
Lime-Deep	3689	3935	.94
Broadcast-P	4384	4447	.99
Banded-P	734	1848	.40
		Late Stress	
0-Lime	2246	3335	.67
Lime-Shallow	2166	3438	.63
Lime-Deep	3402	4667	.73
Broadcast-P	3490	4690	.74
Banded-P	625	1822	.34
		Early Stress	
0-Lime	3623	3700	.98
Lime-Shallow	3138	3097	1.01
Lime-Deep	2786	3396	.82
Broadcast-P	3850	4760	.81
Banded-P	748	1758	.43
Nutrient $LSD._{01}$	636	720	
Stress $LSD._{05}$	477	n.s.	
Nut*Stress $LSD._{05}$	909	n.s.	
C.V. (%)	17.16	21.44	

When a corn leaf is transpiring rapidly, the evaporating water vapor will have a cooling effect on the leaf. Figure 12 shows the average leaf temperatures for abaxial and adaxial sides of the corn leaf at four time periods during the day. The leaf temperature results agree with the R_s results in that deep liming was the superior treatment. Leaf temperatures were also influenced by the surrounding environment. Measurements of air temperature and % RH within the corn canopy were shown to be closely related to leaf temperature (Fig. 13). Note that T_L for the deep lime treatment was cooler than the shallow lime T_L. The vapor pressure deficit (VPD) was calculated during both stress periods and for four times periods during the day (Appendix table 5). VPD did not seem to have a large influence on R_s until the plants became severely stressed. For example, the tenth day of water stress during the second stress period shows very high R_s and a very high vapor pressure deficit (Fig.13).

The experiment was harvested on 21/11/74 or 177 days after planting. Both water stress periods had a negative effect on grain yields (Table 4). The late stress period, which occurred after tasseling, resulted in a highly significant reduction in yield for shallow and 0-lime treatments but not for the deep lime treatment. Percent reduction in grain yields due to plant water stress is shown in Table 5. The comparison is made only between no stress and late stress treatments.

Table 5. Effects of water stress on corn grain yield as influenced by five soil management practices.

Nutrient Treatment	% Reduction in Yield
0-Lime	42
Lime-Shallow	38
Lime-Deep	8
Broadcast-P	20
Banded-P	15

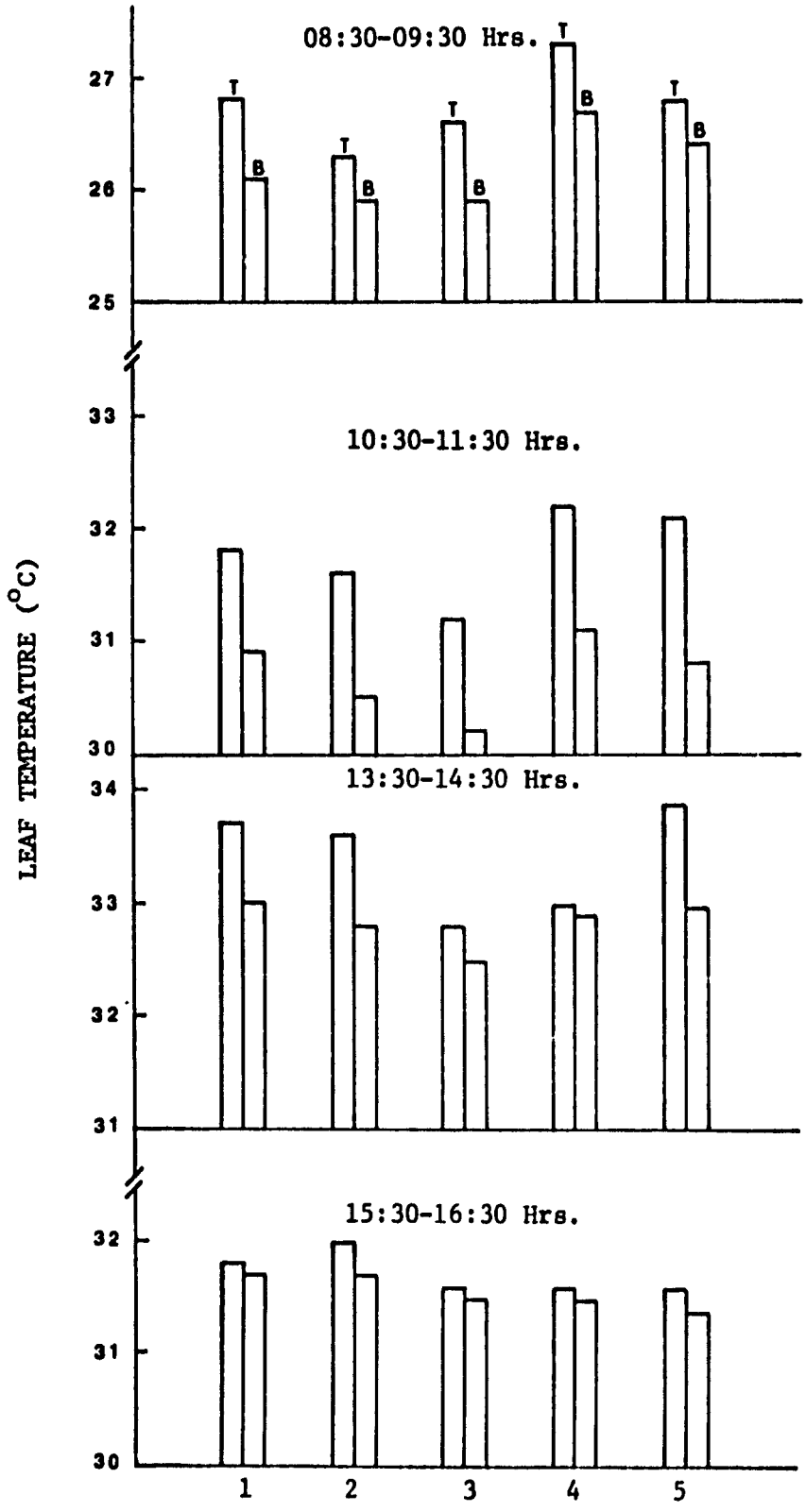


Fig. 12 Leaf temperatures for maize in relation to the five fertility treatments taken four times during the day. (1) 0-lime; (2) shallow-lime; (3) deep-lime; (4) broadcast-P; (5) banded-P. T= Top of the leaf; B= Bottom of the leaf.

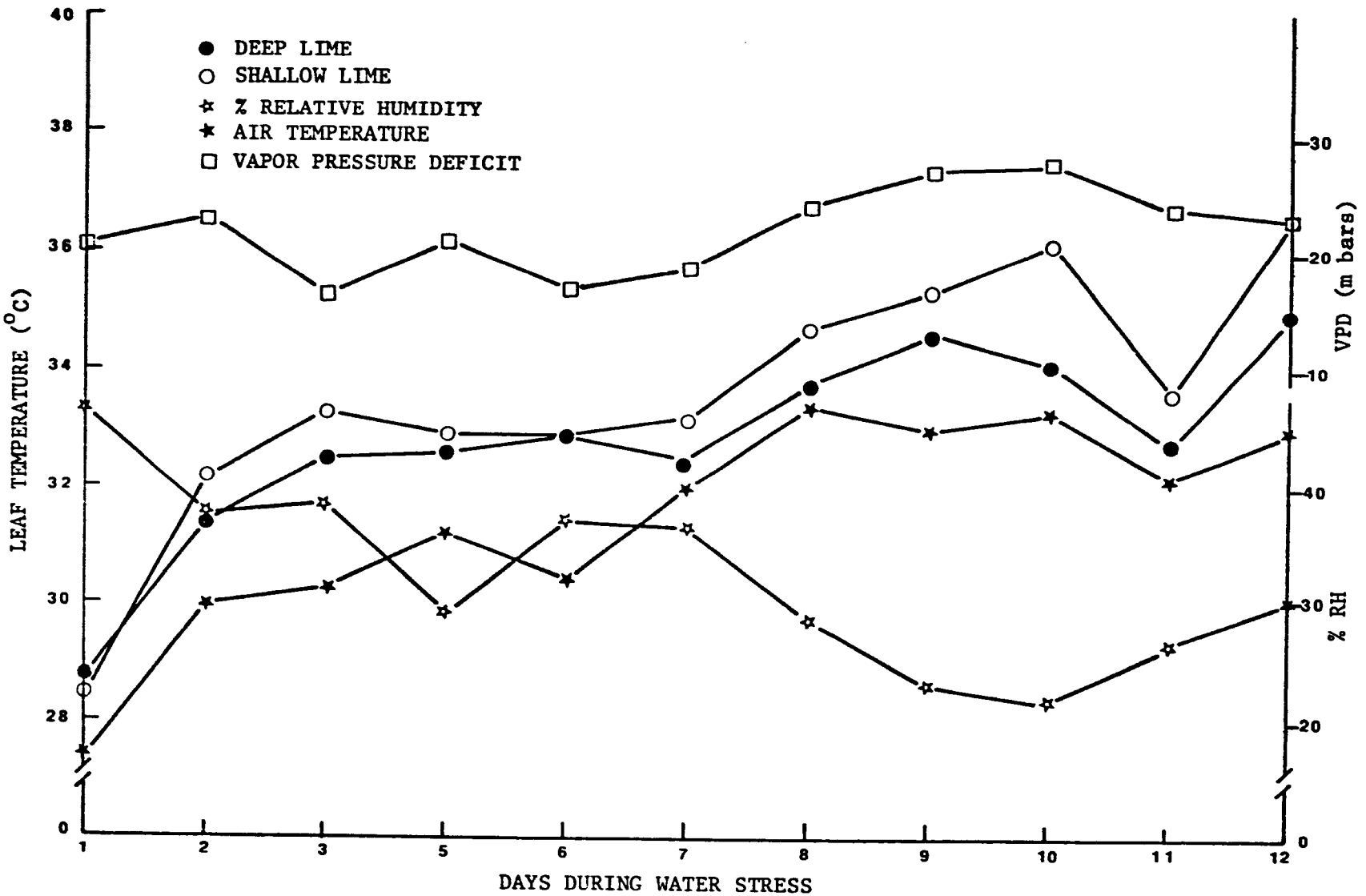


Fig. 13. Corn canopy microclimate at 15:30-14:30 hrs during the second stress period.

Neither stress period significantly reduced stover yields. Late stress occurred at the end of the vegetative growth stage, thus no stress effect was expected. The early stressed plants may have recovered from any stress-related reduction in plant growth as was suggested earlier from the results shown before . The 106 day old plants showed a significant reduction in such growth parameters as total dry weight, stem dry weight, plant height and leaf area. Thirteen days later there were not any significant stress-related reductions in plant growth (Appendix table 2).

It was speculated that one possible reason for the poor corn growth was a soil fertility problem. Nutrient uptake results (Table 6) support the above assumption, especially for phosphorus and magnesium. Note that the 0-lime treatment shows magnesium uptake for the first 100 days of corn growth about equal to the treatments which received 8 metric tons/ha of dolomitic limestone. Phosphorus uptake never did increase, especially for the banded-P treatment. Nutrient uptake was reduced due to water stress for the shallow and 0-lime treatments but not for deep lime incorporation at 106 days after planting.

Nutrient uptake in stover (Table 7) verifies the fact that phosphorus was very limiting for plant growth. Water stress did not have any significant effect on nutrient uptake in the stover. Concentrations of calcium and magnesium in the maize stover were significantly less in the 0-lime treatment compared to the deep and shallow lime treatments (Appendix table 6).

Soil analysis confirm that soil fertility was the major reason for poor corn growth. Soil samples were taken at three depths (0-15, 15-30,

Table 6. Plant uptake of P, K, Ca, and Mg during the growing season in relation to water stress and fertility management practice. Results are expressed in $1x10^{-2}$ g/plant.

Treatment	Phosphorus	Potassium	Calcium	Magnesium
	29 Days after Planting			
0-Lime	.07	1.9	.13	.13
Lime-Shallow	.12	3.2	.35	.29
Lime-Deep	.14	3.9	.46	.40
Broadcast-P	.68	2.0	.46	.38
Banded-P	.20	4.9	.40	.36
	39 Days after Planting			
0-Lime	.37	9.5	.64	.91
Lime-Shallow	.43	14.5	1.39	1.38
Lime-Deep	.52	13.3	1.45	1.59
Broadcast-P	.32	8.3	.82	.47
Banded-P	.43	12.9	1.20	1.30
	50 Days after Planting			
0-Lime	.62	17.5	1.13	1.05
Lime-Shallow	.81	31.0	3.08	3.50
Lime-Deep	1.10	39.3	4.38	4.64
Broadcast-P	.50	14.8	1.56	1.80
Banded-P	.63	21.6	2.05	2.22
	61 Days after Planting			
0-Lime	1.28	37.1	5.72	3.15
Lime-Shallow	1.23	43.3	6.76	6.88
Lime-Deep	1.00	42.8	5.07	5.88
Broadcast-P	.90	30.3	4.66	4.28
Banded-P	.76	34.8	3.37	5.67
	71 Days after Planting			
0-Lime	2.52	72.5	7.81	6.15
Lime-Shallow	2.63	103.0	14.85	14.76
Lime-Deep	2.37	109.0	14.93	14.93
Broadcast-P	3.65	119.0	15.41	16.82
Banded-P	1.40	64.5	9.61	10.50
	81 Days after Planting			
0-Lime	3.73	118	18.47	10.59
Lime-Shallow	2.61	113	18.51	21.00
Lime-Deep	3.22	124	15.82	24.05
Broadcast-P	3.26	113	13.87	15.19
Banded-P	1.77	80	8.54	14.34

Table 6. (cont.)

Treatment	Phosphorus	Potassium	Calcium	Magnesium
	92 Days after Planting			
0-Lime	5.83	166	25.28	16.04
Lime-Shallow	3.38	124	19.03	25.37
Lime-Deep	--	193	22.76	26.26
Broadcast-P	--	282	32.75	38.58
Banded-P	--	70	10.85	13.17
	106 Days after Planting (No Stress)			
0-Lime	10.38	249	38.43	31.84
Lime-Shallow	9.03	282	50.19	68.83
Lime-Deep	9.01	291	43.26	67.15
Broadcast-P	13.12	375	62.02	75.14
Banded-P	2.31	105	18.32	24.09
	106 Days after Planting (Early Stress)			
0-Lime	7.47	179	27.67	22.89
Lime-Shallow	5.83	182	32.41	44.45
Lime-Deep	9.38	301	44.80	69.02
Broadcast-P	10.17	292	48.34	58.51
Banded-P	2.14	97	16.95	22.29
	119 Days after Planting (No Stress)			
0-Lime	10.01	217	41.54	31.44
Lime-Shallow	9.38	208	55.68	80.65
Lime-Deep	6.78	228	43.67	62.75
Broadcast-P	6.31	220	36.38	56.02
Banded-P	3.21	113	23.12	32.98
	119 Days after Planting (Early Stress)			
0-Lime	6.98	150	28.71	21.73
Lime-Shallow	7.92	176	47.08	68.20
Lime-Deep	5.85	195	37.87	54.38
Broadcast-P	8.21	289	47.73	71.59
Banded-P	2.81	99	20.30	28.94

Table 7. Stover uptake of P, K, Ca, and Mg in relation to water stress and fertility management. Results are expressed in kg/ha.

Treatment	Phosphorus	Magnesium	Calcium	Potassium
		No Stress		
0-Lime	1.84	16.03	11.55	27.80
Lime-Shallow	1.94	19.04	10.37	24.61
Lime-Deep	2.06	21.07	13.61	33.50
Broadcast-P	2.24	27.12	14.61	38.56
Banded-P	1.01	9.32	6.51	15.10
		Late Stress		
0-Lime	2.50	6.58	8.64	23.06
Lime-Shallow	2.62	21.18	12.30	25.06
Lime-Deep	2.60	24.56	14.97	34.00
Broadcast-P	3.07	21.23	13.69	43.22
Banded-P	1.28	9.12	5.41	10.02
		Early Stress		
0-Lime	1.66	7.82	10.03	31.64
Lime-Shallow	1.94	21.66	14.27	27.29
Lime-Deep	1.42	21.80	13.40	29.83
Broadcast-P	2.42	23.40	18.02	37.54
Banded-P	1.11	9.83	5.76	11.29
F Test-Nutrient	5 %	0.1 %	0.1 %	0.1 %
F Test-Stress	n.s.	n.s.	n.s.	n.s.
C.V. (%)	40.7	29.5	29.4	28.3

and 30-45 cm) in every plot on 23/8/74. The results of the analysis show that even after 3 months of crop growth pH, Ca + Mg, Al conc. and % Al saturation were less than optimum for plant growth (Table 8). Eight tons/ha of lime, 0-15 cm incorporation, gave a pH of 4.93 and a % Al Sat. of 25.1. Also P content in the soil solution was very low with only one treatment in the 0-15 cm soil depth giving the required 10 ppm of P for good corn growth.

A second sampling of the soil was done on 24/11/74. These results show soil pH, Ca + Mg, Al conc. and % Al sat. at levels much more in accordance with the amounts of lime applied. For example, 8T/ha of lime, shallow incorporation, gave a pH of 5.78 and a % Al saturation of 2.2.

The conclusion is that the lime never reacted. The lime was applied during the first week in May '74 which was after the rainy season had stopped, but, the soil was still very moist since all vegetation had been removed.

The soil analysis results as well as the poor corn growth show that the lime never started to dissolve until the rainy season had commenced even though irrigation was conducted every 4-7 days during the dry season. Either the lime mesh size was too large, thus slow reaction rates, or the soil never stayed moist long enough to dissolve the lime. Another possible error was poor physical distribution and mixing of the lime in the soil. For example, in the deep lime incorporation treatment a rotavator was used to incorporate the lime to a 30 cm soil depth. This treatment's soil analysis results show that the lime had started to react during the dry season. The late lime reaction explains why 0-lime plant

Table 8. Soil analysis for '74 dry season corn experiment.

Nutrient	pH 1:1 H_2O		Ca + Mg meq/100ml		Al meq/100ml		Al Sat. %		P ppm
Treatment	23/8/74	24/11/74	23/8/74	24/11/74	23/8/74	24/11/74	23/8/74	24/11/74	23/8/74
					0-15 cm				
0-Lime	4.48	4.61	.32	.60	1.63	1.28	83.3	68.4	3.84
Lime-Shallow	4.93	5.78	2.21	4.37	.69	.10	25.1	2.2	3.60
Lime-Deep	5.41	5.86	3.51	4.45	.25	.11	6.9	2.6	3.76
Broadcast-P	4.93	5.41	1.88	2.90	.84	.26	32.0	9.1	10.40
Banded-P	4.79	5.27	1.49	2.77	.99	.33	40.0	10.6	1.52
					15-30 cm				
0-Lime	4.18	--	.19	--	1.79	--	90.4	--	1.80
Lime-Shallow	4.46	--	.58	--	1.38	--	70.4	--	1.70
Lime-Deep	4.92	--	2.77	--	.60	--	17.8	--	1.56
Broadcast-P	4.37	--	.60	--	1.49	--	71.3	--	1.90
Banded-P	4.25	--	.44	--	1.90	--	81.2	--	1.02
					30-45 cm				
0-Lime	4.27	--	.16	--	1.44	--	90.0	--	1.10
Lime-Shallow	4.40	--	.37	--	1.26	--	77.3	--	0.98
Lime-Deep	4.41	--	.59	--	1.22	--	67.4	--	1.28
Broadcast-P	4.41	--	.28	--	1.21	--	81.8	--	1.17
Banded-P	4.40	--	.26	--	1.32	--	83.5	--	0.95

growth and nutrient uptake were about equal to the limed plots until approximately 100 days after planting. The phosphorus problem was easily solved by analysing the triple super phosphate used in the experiment. Instead of a 45-46% P_2O_5 content the TSP had only 17.4% P_2O_5. This resulted in only 38.5% of the P being applied that was planned.

1974-5 Wet Season Soil Management Experiment

The wet season experiment had only one major change from the previous dry season experiment. The water stress treatments depended on naturally occurring veranicos (a short-term drought period within the rainy season). They could not be simulated as in the dry season. No stress measurements were taken during the vegetative growth stage of maize because there weren't any severe veranicos. There was a slight veranico for nine days at the end of January, 1975 (40-50 days after planting) but it did not cause serious plant water stress due to cloudiness and high humidities. The no stress and late stress treatments were irrigated once during the slight veranico in January because soil moisture tension was approaching 0.5 bars. The early stress treatment was not irrigated at that time, thus soil moisture tensions approached one bar before the rains came. A severe veranico did occur during the early grain formation stage (Hanway stage 5 & 6). The veranico lasted for 18 days (27/2 through 16/3/75). Stress measurements were taken daily from 5/3 through 13/3/75. The no stress and early stress plots were irrigated every four days during the veranico.

General meteorological data taken during the 18 day veranico is shown in Fig. 14. Pan ET and maximum air temperatures were quite high which was ideal for causing severe plant water stress. Total solar radiation and photosynthetically active radiation (PAR) were reduced somewhat due to cloudiness. Fig. 15 shows a general PAR curve averaged over nine days of stress measurements.

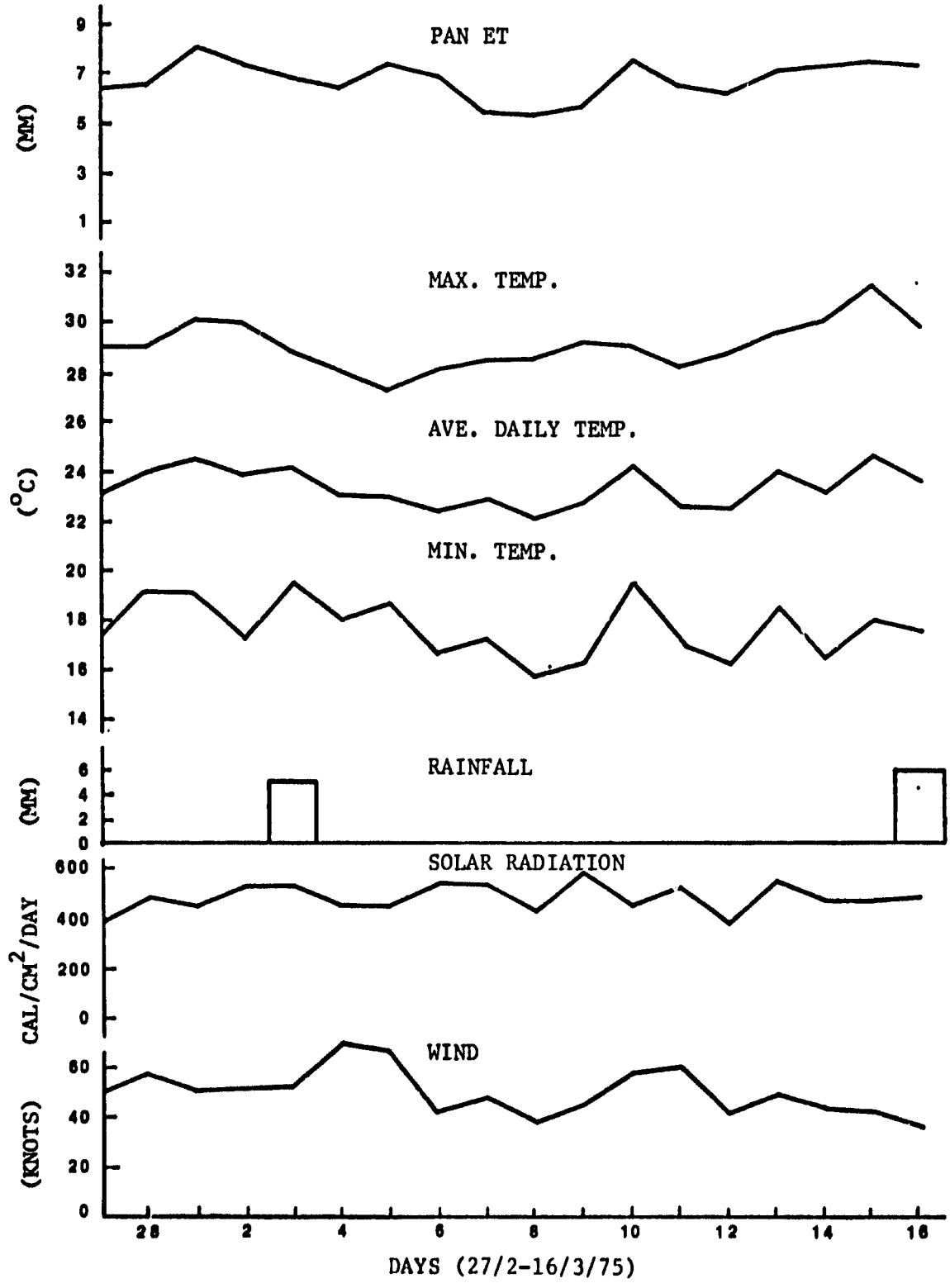


Fig. 14. Meteorological data for corn, 1974-5 wet season. Time period (days) corresponds to drought period (veranico) (27/2/75 through 16/2/75).

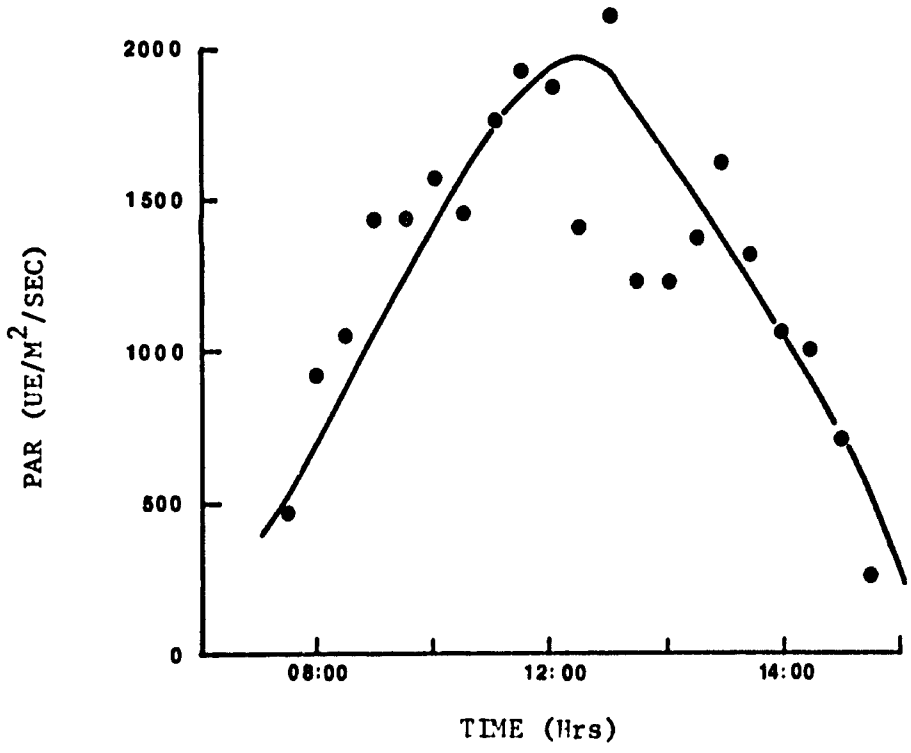


Fig. 15. Photosynthetic active radiation measurements for time period 5-3-75 through 13-3-75. This time period corresponds to water stress measurements taken during the veranico.

The leaf area index (LAI) for the five soil fertility treatments is shown in figures 16 and 17. Measurements began 28 days after planting and were taken approximately every 12 days there after to 107 days after planting. Four plants per plot were measured each time for both total leaf area and plant height. Deep lime and broadcast treatment of phosphorus gave the largest LAI throughout the growing season. Fifty percent tasseling occurred 68 days after planting. The veranico occurred from 74 to 93 days after planting. The solid lines in the graphs indicate the no stress treatments which were irrigated during the veranico. The dotted lines in the graphs represent the reduction in LAI due to plant water stress caused by the veranico. The results suggest no real benefit was realized from any of the five soil fertility treatments in reducing the loss of leaf area due to plant water stress. The effect of a veranico on plant growth was clearly demonstrated by a large reduction in leaf area for all stressed plots.

Figures 18 and 19 show total dry weight accumulation for maize. Two plants per plot were selected by a randomized location sequence for each plot. The two plants/plot were measured for leaf area, height, number of leaves, stem dry weight, leaf dry weight, and when appropriate tassel dry weight and ear dry weight. The negative effect of the veranico (dotted lines in graph) was influenced by fertility treatments. The deep lime treatment shows only a slight decrease in dry weight accumulation after the veranico whereas the shallow lime treatment shows a large decrease. The unlimed treatment showed a small dry weight loss to stress because the plant was placed under less water stress due to its inferior growth. Also note that both the shallow lime and phosphorus

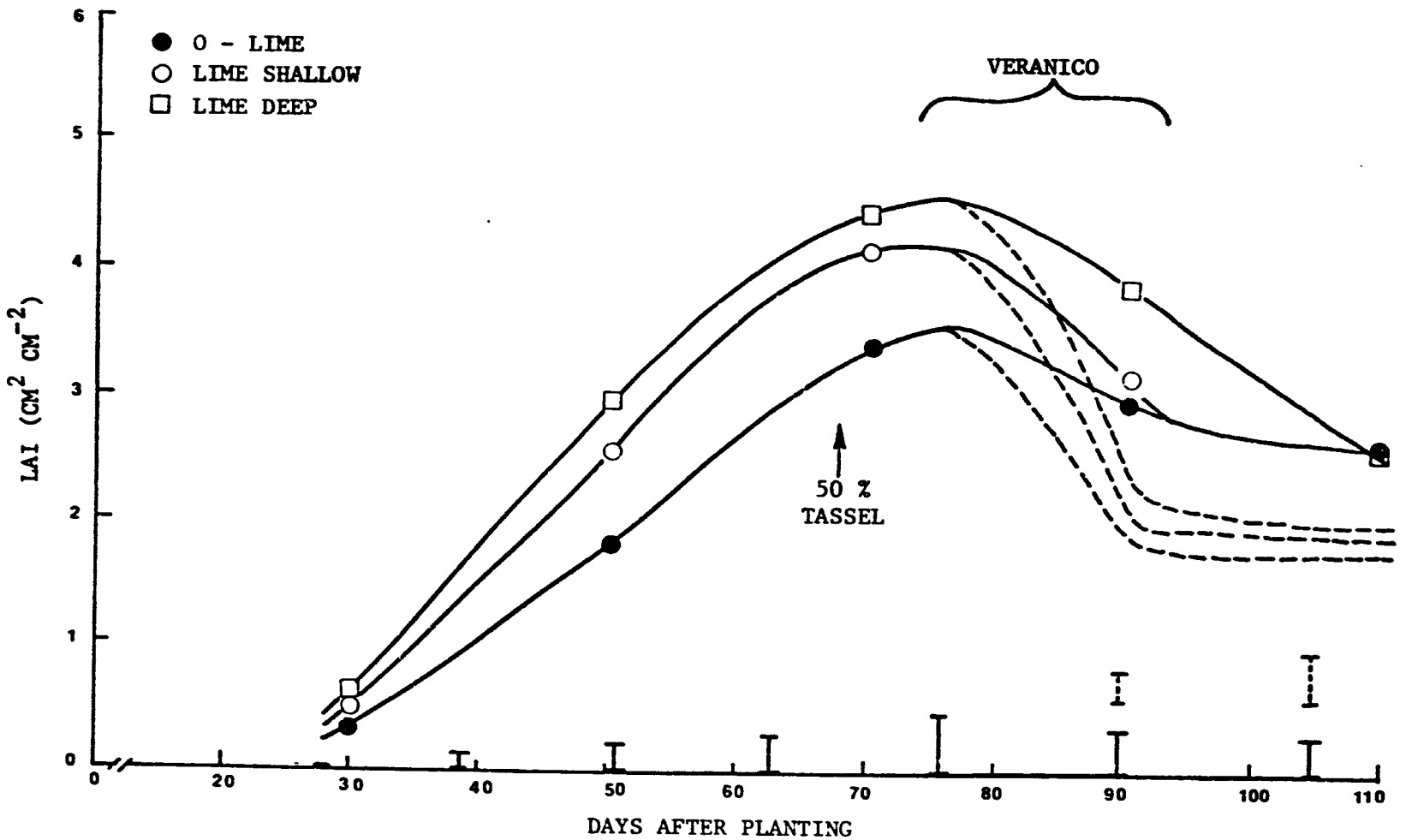


Fig. 16. Leaf area index (LAI) for corn grown during the 1974-5 wet season at Planaltina, Brazil. Solid limes indicate the controls where no water stress occurred. Dashed lines indicate the effect of the veranico on corn leaf area for the 3 lime treatments. LSD is at a 5 % level of sign.

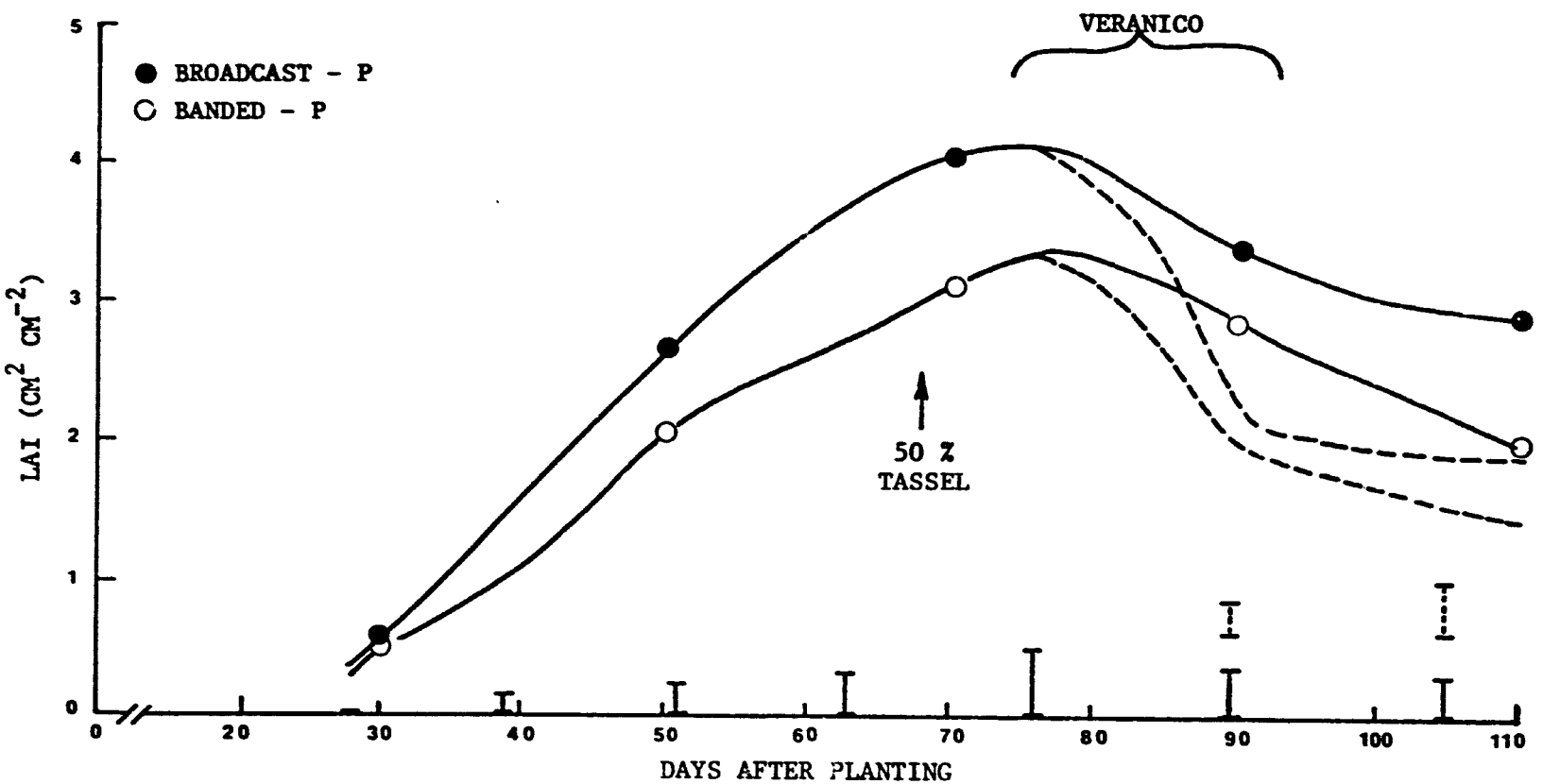


Fig. 17. Leaf area index (LAI) for corn grown during the 1974-5 wet season at Planaltina, Brasil. Solid lines are controls where no water stress occurred. Dashed lines indicate the effect of the veranico on leaf area for the 2 phosphorus treatments. LSD is at a 5 % level of sign.

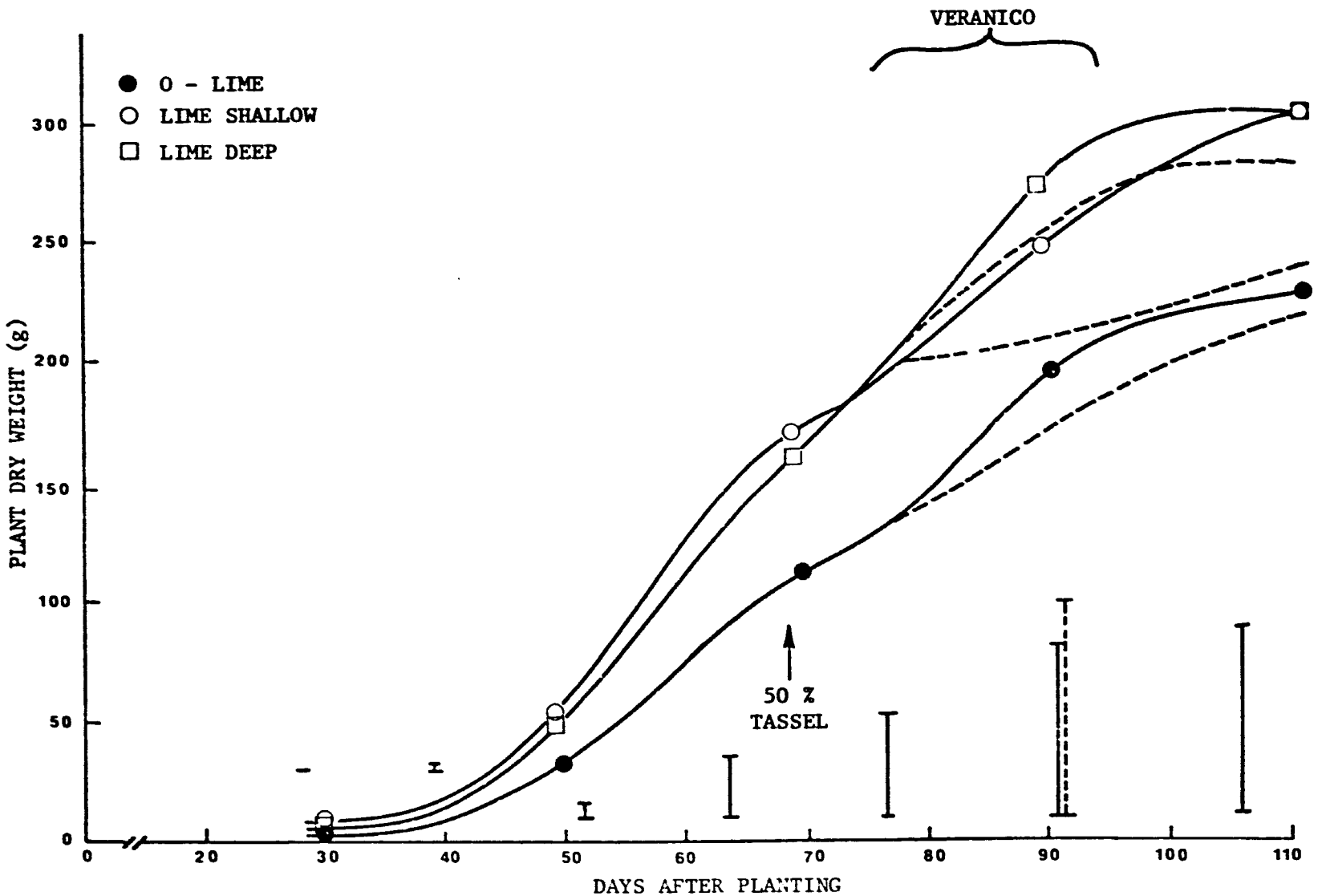


Fig. 18. Total dry matter accumulation for corn grown during the 1974-5 wet season. Solid lines indicate no water stress. Dashed lines indicate the effect of the veranico. LSD is at a 5 % level of sign.

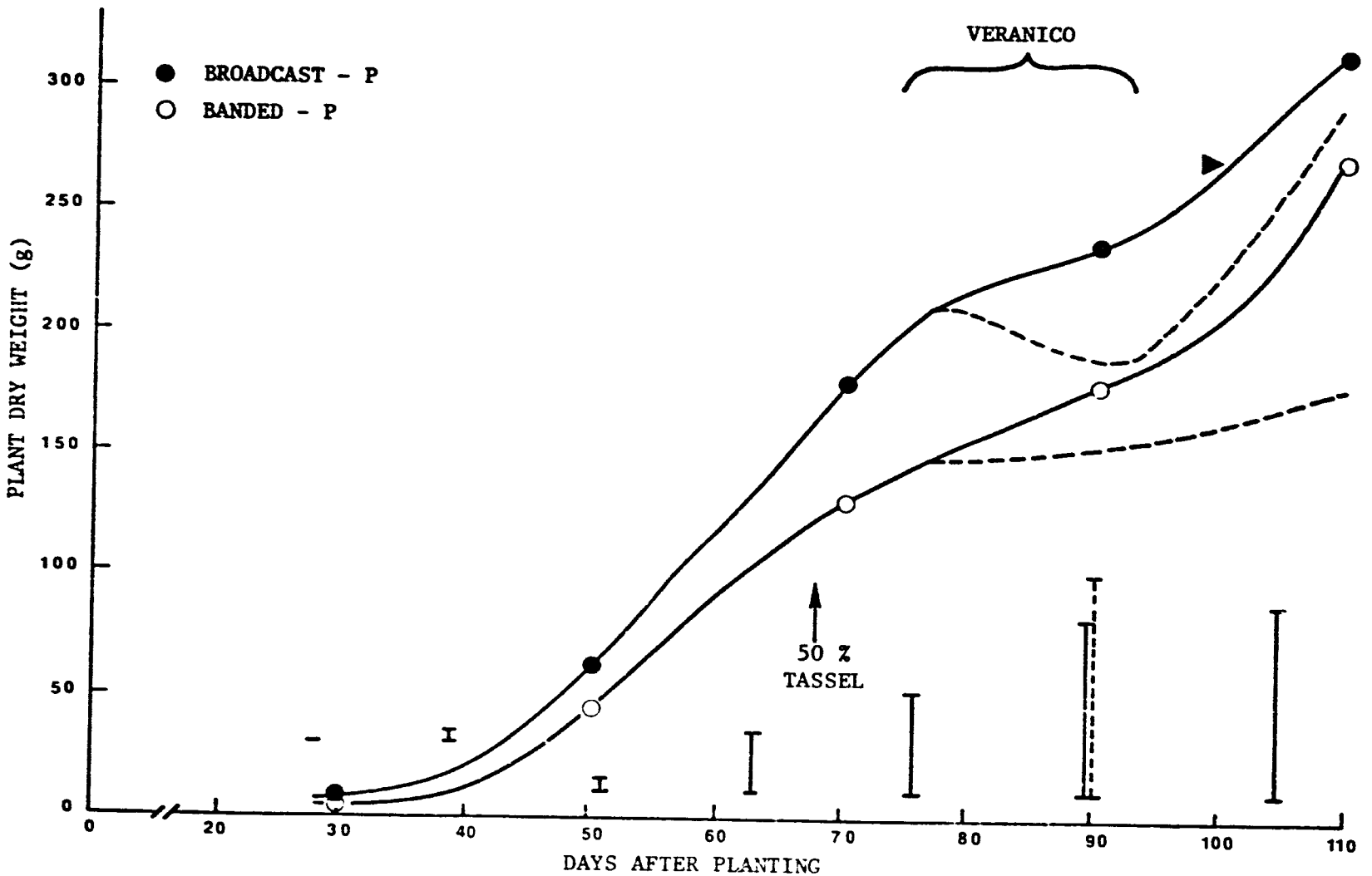


Fig. 19. Total dry matter accumulation for corn growth during the 1974-5 wet season. Solid lines are controls where no water stress occurred. Dashed lines indicate the effect of the veranico on the 2 phosphorus treatments. LSD is at a 5 % level of sign.

(banded) did not recover from the veranico as did the broadcast phosphorus treatment. The increase in dry matter production for deep lime over shallow lime treatments at 90 days was mainly due to corn ear weight differences.

A more complete growth analysis is shown in Appendix table 7. Plant height in the limed treatments were always significantly superior to unlimed plots. No significant differences were realized between deep and shallow liming for plant height. Leaf dry weights were similar to plant height results except that there was a significant increase for deep over shallow liming after ninety days. Stem dry weights and total dry weight show a slight but significant negative effect from the early stress period. The early veranico was very weak since the stressed plants quickly grew out of the stress effects. At 90 days deep liming was superior to shallow liming for stem and total dry weight. The late stress period had no significant negative effect on plant height or stem dry weight but it did significantly reduce leaf area, leaf dry weight, total dry weight, tassel dry weight and ear dry weight. Net assimulation rates and relative growth rates were not influenced by either nutrient or water treatments.

There are many limitations to conducting a typical growth analysis study. Large experimental plots are required to allow for adequate plant sampling and sufficient facilities for drying and weighing samples. It would be very helpful if non-destructive, periodic measurement of total leaf area could adequately predict plant growth. Figure 20 demonstrates that leaf area measurements can adequately predict relative growth rates. Dry weight accumulation and net assimulation rates were also predicted

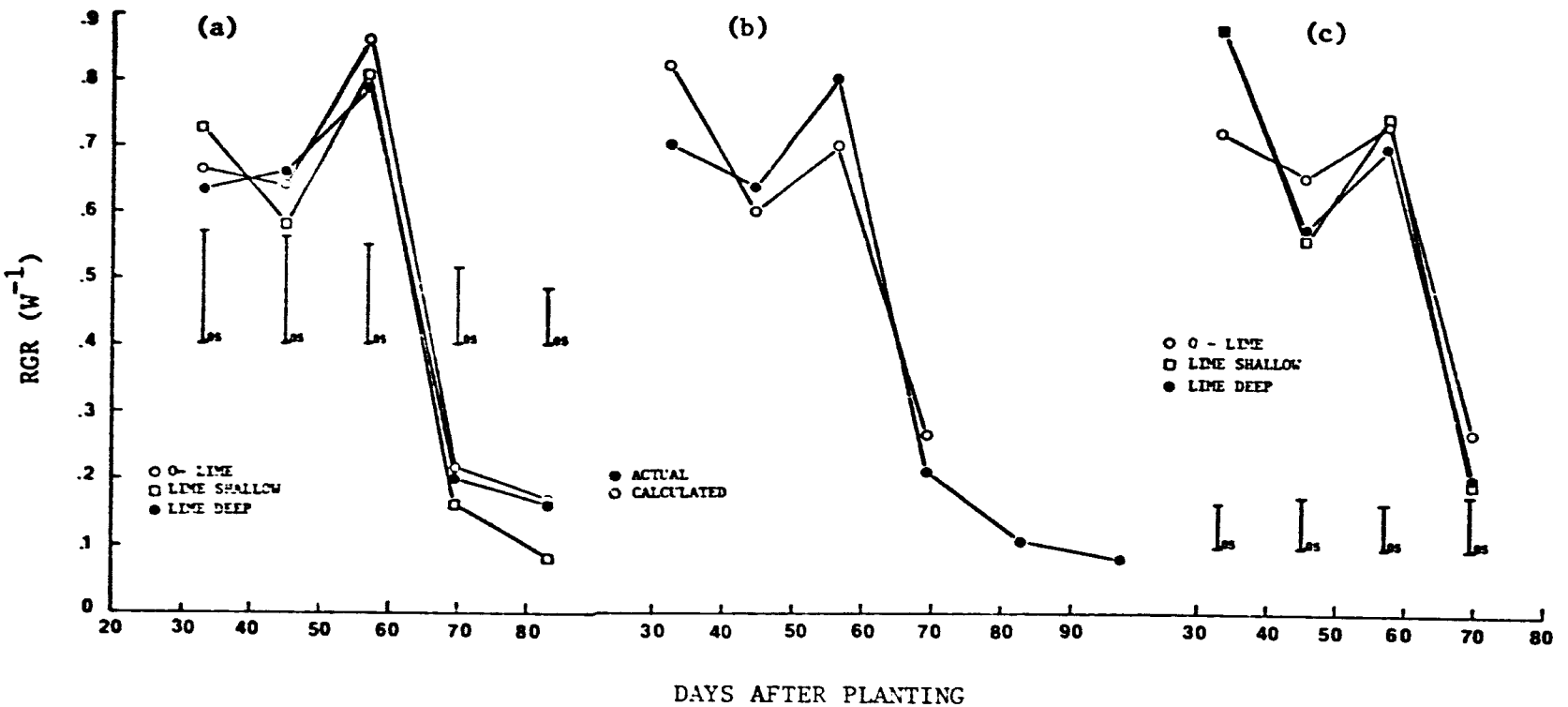


Fig. 20. Relative growth rate (RGR) for corn grown during the 1974-5 wet season. (a) RGR from de structive sampling of two plants/plot; (b) Comparison between actual RGR and calculated RGR; (c) Calculated RGR based on results from non-destructive leaf measurements.

from the leaf area measurements. They showed a very small difference from the results presented in Appendix table 7. Measuring the same plant each time also has the added advantage of negating plant to plant variability, thus reducing LSD's and C.V.'s. The use of leaf area to predict plant growth is only valid during the vegetative growth stage (Table 9).

Regression analysis was used to predict plant growth over short periods of time. This produced a series of straight lines for short periods along the growth curve. The following Table shows the R^2 values for each measurement period in relation to the three water treatments.

Table 9. R^2 values from the regression analysis of leaf area and plant dry weight.

Days after Planting	No Stress	Early Stress	Late Stress
27	.97	.88	.92
39	.98	.96	.94
51	.60	.81	.81
63	.69	.89	.89
76	.80	.78	.72
90	.68	.73	.27
105	.27	.20	.45

Further study is required to learn if one regression equation can adequately predict maize growth. The main objective of this researcher was to learn if the measurement of total leaf area was sufficient to demonstrate the changes in the growth of a corn plant under such variable conditions as plant water stress and soil fertility. In the opinion of this researcher, the objective has been met.

Soil temperature measurements were taken daily at 15:00 hours during the 9 days of water stress measurements (Table 10). The control or bare

ground measurements were taken at two sites approximately 5 meters outside the experimental area. The untressed plots correspond to the plots that were irrigated during the veranico. The water stress plots were not irrigated. More than a 10°C soil temperature difference is seen between the well-watered, corn shaded areas verses the bare soil areas. Soil temperatures are shown to fluctuate to a depth of 60 cm. The water stressed plots show an increase in soil temperature over the unstressed plots. This was probably due to a decrease in soil water content, decrease in soil surface evaporation of water, and a decrease in the shadiness of the soil due to leaf rolling.

Table 10. Soil temperatures for bare soil and within the corn canopy. Readings were taken daily at 15:00 hours for 9 days (5/3 through 13/3/75).

Soil Depth (cm)	Ave. soil temp. for water stress plots (°C)	Ave. soil temp. for unstressed plots (°C)	Control-bare ground areas (°C)
5	27.7	23.8	36.6
10	22.3	21.1	34.3
15	20.1	19.5	28.7
20			26.7
22.5	19.5	18.6	
25			25.3
30	19.2	17.9	24.1
45	19.8	18.2	25.2
60			25.1

For a proper study of soil-plant water use it was necessary to get an understanding of the amount of soil water used by a corn crop grown under well-watered conditions and under veranico conditions where the water contents become very limiting. The 26th of February, 1975 was the last day of a 4-day 96.3 mm rain. Soil water measurements began two

days later to determine soil water use by corn in relation to five fertility management practices (Table 11).

Table 11. Average daily ET rates over a 5-day period for corn (Hanway stage 5-6) in relation to five fertility management practices and LAI.

Treatment	ET (mm)	LAI (cm^2 cm^{-2})
0-Lime	5.12	3.1
Lime-Shallow	6.44	4.2
Lime-Deep	6.16	4.1
Broadcast-P	4.67	3.9
Banded-P	5.07	3.6
Bare Soil	3.10	--

Over the same 5-day period soil water lost from a bare soil, with no vegetative growth (0-45 cm soil profile), to surface evaporation and drainage amounted to 3.10 mm. Soil water contents in the same bare soil area for 12 days of the 18-day veranico are shown in Fig. 21. The top 22.5 cm dried out at the rate of 1.53 mm per day. A 5-day comparison (Table 12) was made between the ET rates from stressed and non-stressed plants during the veranico to learn their respective ET rates or amount of soil water used per day.

Table 12. Evapotranspiration rates from stressed and non-stressed corn plants during a veranico. * 10 days to 15 days from last rainfall ** One day after irrigation.

Date	ET-Stressed*	ET-Non-stressed**
	(mm)	(mm)
8/3	5.66	3.79
9/3	1.12	8.15
10/3	0.95	7.24
11/3	1.95	5.10
12/3		
$\bar{X}$	2.41/day	6.07/day

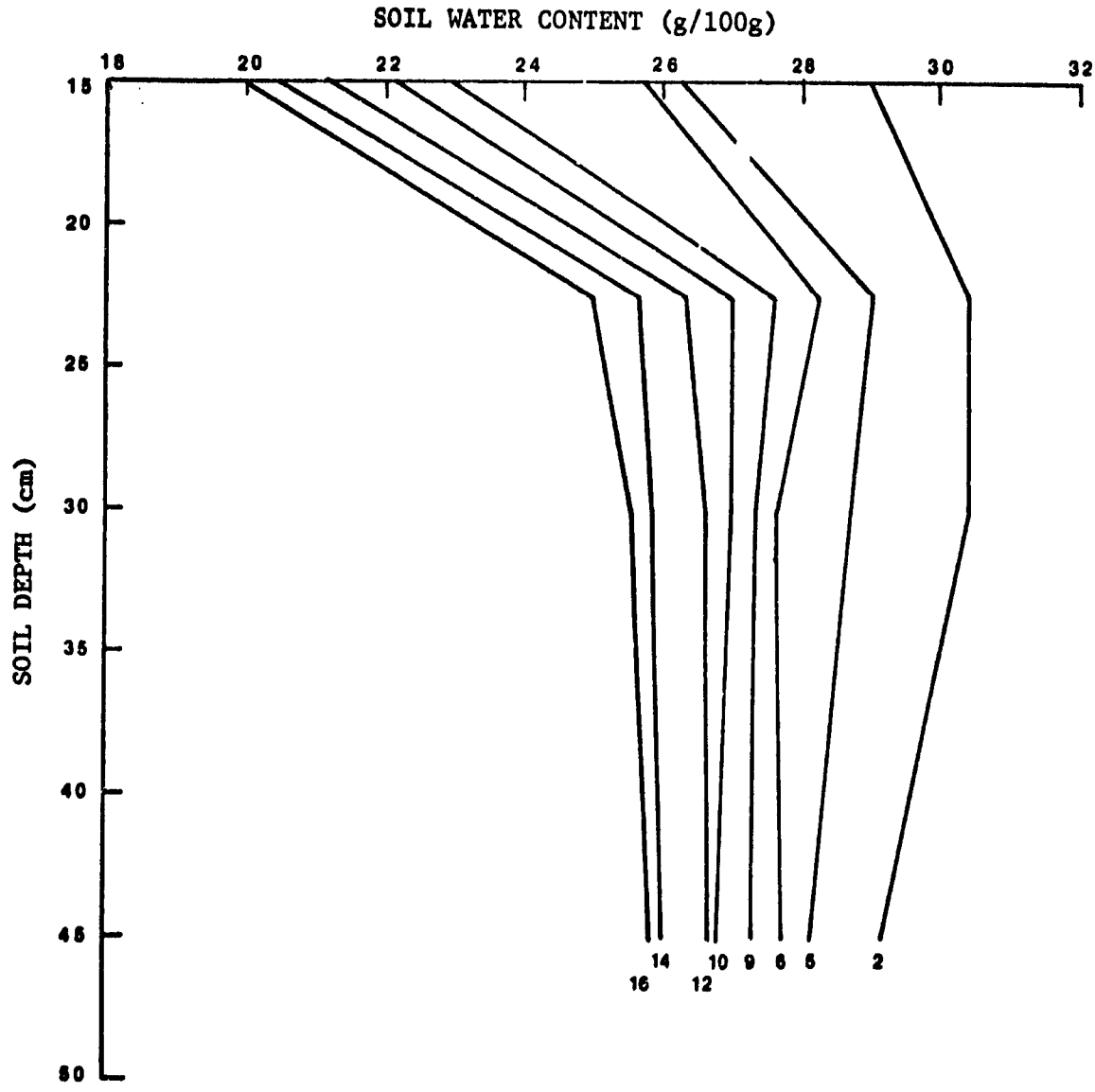


Fig. 21. Decreasing soil water content under a bare soil during 14 days without rain. Numbers refer to days since last rainfall.

Over the same 5-day period the bare soil area showed a loss of 1.37 mm per day.

The difference in the amount of water used during the veranico in relation to deep and shallow liming is shown in Table 13. The results suggest that deep liming reduced or delayed plant water stress by one day's ET rate value. The 1974 dry season experiment showed a 2-4 day delay.

Table 13. Difference in the amount of soil water used by the corn plants during a veranico in relation to deep and shallow liming.

Treatment	Soil Depth 0-15cm	15-22.5cm	22.5-30cm	30-37.5cm	37.5-45cm	d
	Water Content (g/100g)					mm H_2O
0-Lime	15.8	18.3	21.2	22.6	23.7	5.1
Lime-Shallow	15.9	18.2	20.1	21.1	23.1	2.1
Lime-Deep	15.9	18.4	19.3	20.8	22.2	0
Broadcast-P	15.9	18.6	20.3	21.0	22.7	2.0
Banded-P	15.7	18.8	21.4	22.5	24.1	6.2

Soil water contents were measured in the early morning and late afternoon to study the daily soil water flux and extraction patterns (Table 14). In four days under optimum soil water conditions the corn plants used 47.7% of the total available water in the 0-45 cm soil profile. The average soil water tension after four days was 37.75 centibars. Note that the 30 cm soil depth always showed that soil water was used during the night. The reason was probably related to the water extraction pattern for the corn plants as shown in Table 13 & 15. The extraction pattern was a dynamic process, changing daily as the soil dries out. For example, the 0-15 cm soil layer supplied more than half of the water used during the first few days but its supplying

Table 14. Daily soil water flux and use by the corn plants under optimum soil water conditions.

	Soil Depth (cm)								
	15.0		22.5		30.0		45.0		SUM
Date	AM	PM	AM	PM	AM	PM	AM	PM	mm H_2O
8/3	29.89	28.31	28.97	27.89	28.29	27.60	28.08	27.91	3.79
	% By Vol.	mm	% By Vol.	mm	% By Vol.	mm	% By Vol.	mm	
AM-AM	1.67	1.88	1.04	.78	0.85	1.13	-0.12	-.18	3.61
AM-PM	1.58	1.78	1.08	.81	0.69	.78	0.17	.26	3.63
PM-AM	-0.09	-.10	.04	.03	-0.16	-.35	+0.29	.44	.02
9/3	28.22	24.26	27.93	26.37	27.44	26.24	28.20	27.42	8.15
AM-AM	2.91	3.27	0.77	.58	1.47	1.65	0.88	1.32	6.82
AM-PM	3.96	4.46	1.56	1.17	1.20	1.35	0.78	1.17	8.15
PM-AM	1.05	1.18	0.79	.59	-0.27	-.30	-.10	-.15	1.32
10/3	25.31	22.98	27.16	25.31	25.97	24.80	27.32	26.09	7.24
AM-AM	2.45	2.76	1.95	1.46	1.44	1.62	0.93	1.40	7.24
AM-PM	2.33	2.62	1.85	1.39	1.17	1.32	1.23	1.85	7.18
PM-AM	-0.12	-.14	-0.10	-.07	-0.27	-.30	.30	.45	-.06
11/3	22.86	22.55	25.21	23.55	24.53	22.90	26.39	25.28	5.10
AM-AM	0.49	.55	1.35	1.01	1.65	1.86	0.69	1.04	4.46
AM-PM	0.31	.35	1.66	1.25	1.63	1.83	1.11	1.67	5.10
PM-AM	-0.18	-.20	0.31	.24	-0.02	-.03	0.42	.63	.64
12/3	22.37	--	23.86	--	22.88	--	25.70	--	--

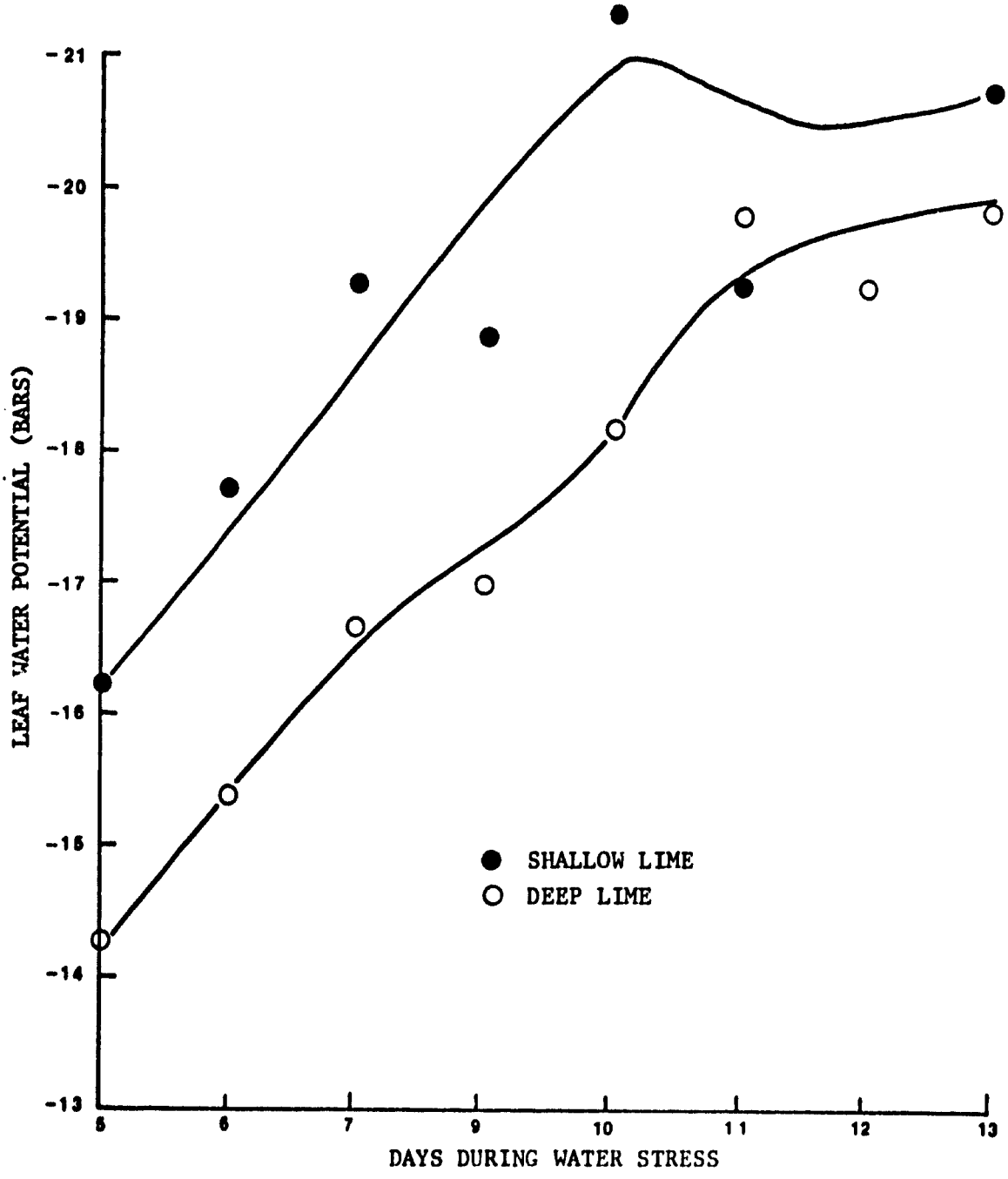


Fig. 22. Leaf water potential for corn (third leaf from top) taken during a veranico (27/2/75 - 17/3/75). (a) Shallow lime incorporation (0-15 cm) verses deep lime incorporation (0-30 cm); (b) Broadcast-P verses banded-P application.

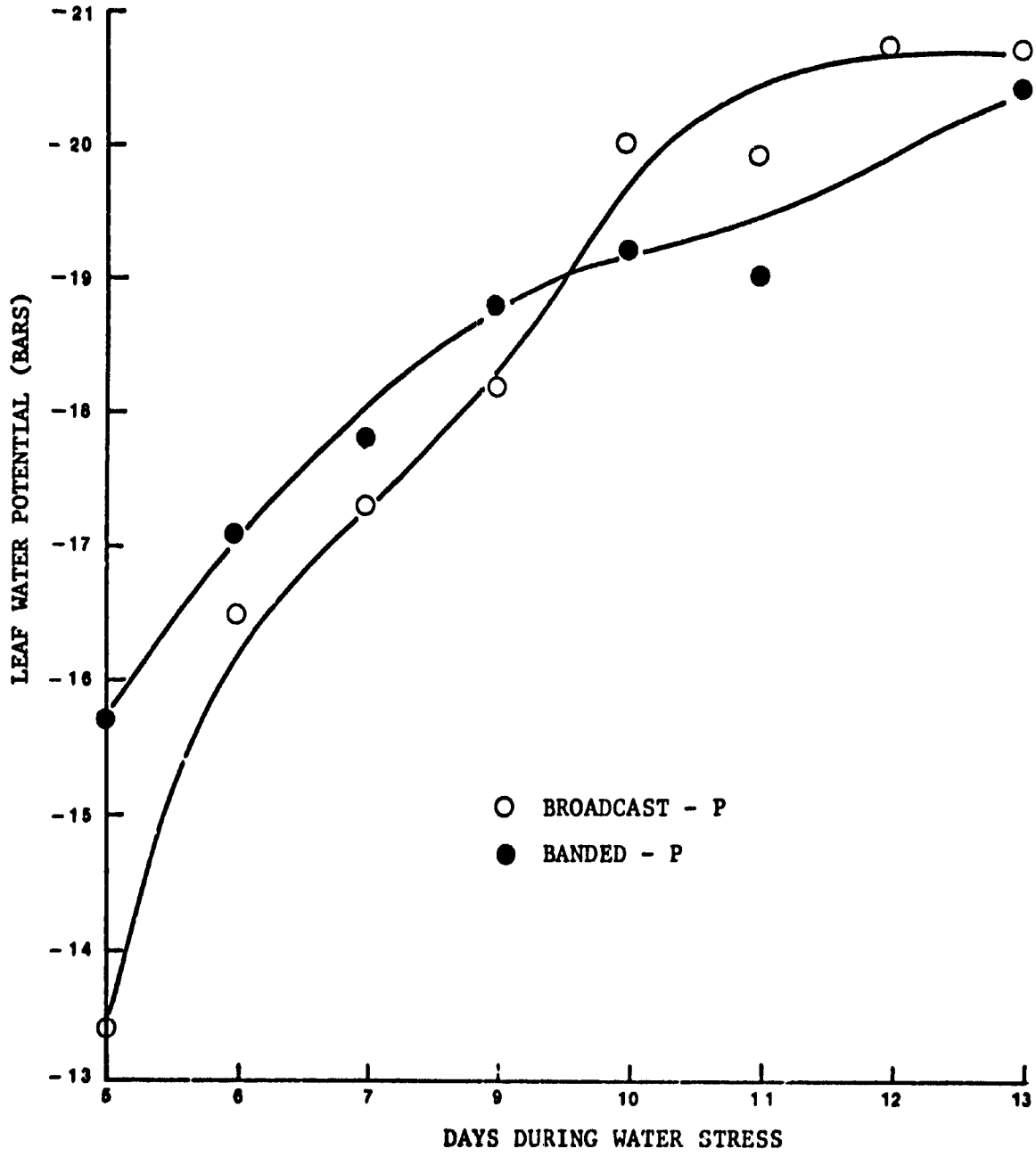


Fig. 22. (cont.) (b) Broadcast-P verses banded-P application.

power diminishes as the soil dries out. The 45 cm soil layer supplied very little water at first but it was supplying over 20% of the available water within five days after irrigation.

Table 15. Soil water (%) extraction pattern for corn, 1-5 days after irrigation.

	Soil Depth (cm)			
Date	0-15	15-22.5	22.5-30	30-45
8/3	44.9	30.7	19.6	4.8
9/3	52.8	20.8	16.0	10.4
10/3	36.2	28.8	21.3	13.7
11/3	6.6	35.4	34.5	23.5
$\bar{X}$	35.5	28.9	22.9	13.1

Leaf water potential (Ψ_L) was measured on five plants per plot during the nine days of measurements. Table 16 and figure 22 a demonstrate increasing plant water stress during the veranico. As expected, increased soil water use by the plant in the deep lime treatment resulted in a lower leaf water potential. Note that the shallow lime plants reached a - 20 bar Ψ_L four days before the deep lime plants. Broadcast-P plants seemed to enjoy a better plant water status until the veranico become too severe (Fig. 22 b). The larger leaf area, thus higher transpiration losses, caused the broadcast-P plants to become more stressed than the banded-P plant. The benefit of deep liming was not available to the broadcast-P treatment.

For relative water content (RWC) determinations, five leaf discs, one cm in diameter, were taken on each plant of five plants per nutrient treatment. The RWC results substantiated the Ψ_L measurements (Table 16). After 15 days of veranico the deep lime treatment still had an average

Table 16. Daily leaf water potential and relative water content for maize during the 7th through 15th days of a veranico in relation to the five fertility management treatments.

Treatment	Sampling Days During Water Stress									
	5/3	6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	Av.
	Leaf Water Potential (Bars)									
0-Lime	-14.8	-18.0	-17.5	-14.4	-17.8	-19.1	-18.5	-20.8	-20.7	-17.9
Lime-Shallow	-16.2	-17.7	-19.3	-14.6	-18.9	-21.4	-19.3	-19.3	-20.8	-18.6
Lime-Deep	-14.3	-15.4	-16.7	-14.0	-17.0	-18.2	-19.8	-19.3	-19.9	-17.2
Broadcast-P	-13.4	-16.5	-17.3	-14.7	-18.2	-20.0	-19.9	-20.7	-20.7	-17.9
Banded-P	-15.7	-17.1	-17.8	-13.5	-18.8	-19.2	-19.0	-20.7	-20.4	-18.0
	R W C (%)									
0-Lime	94.3	88.6	86.2	94.6	79.5	80.8	83.1	79.1	81.2	85.3
Lime-Shallow	95.0	87.6	88.0	94.6	77.5	81.6	83.8	77.1	77.9	84.8
Lime-Deep	96.0	92.6	90.9	96.9	84.2	87.2	88.0	84.3	82.8	89.2
Broadcast-P	95.5	89.1	83.6	93.5	80.3	82.8	80.7	75.7	76.0	84.1
Banded-P	98.1	89.9	87.1	94.8	79.2	85.5	82.0	84.5	76.1	86.4

RWC of 89.2 whereas the shallow lime treatment's were averaging 4-5% less. The unlimed and banded-P treatments were not stressed as severe as the other shallow limed plants due to their reduced leaf area.

Stomatal resistance (R_s) measurements overwhelmingly supports the assumption that deep liming reduces plant water stress in comparison to the shallow and no lime treatments (Table 17). Table 17 also shows that the deep lime treatments were very superior to the two phosphorus application treatments. The banded-P plants continue to show less water stress than the broadcast-P plants.

To verify the previous R_s findings, transpiration rates were calculated (Appendix table 8). Note again the superiority of deep liming. Transpiration rates were reduced by 78% during the eight days of measurement.

Air temperature and % relative humidity were measured daily within the corn canopy at 12:30 and 15:00 hours during the period of veranico water stress measurements (5/3/75-13/3/75). The measurements were taken with the corn canopy. Average results from the 9 days of measurements and two time periods gives an air temperature of 30.2 ^{o}C and a % RH of 37.8. The following table shows a treatment effect of deep and shallow lime incorporation on air temperature and % RH.

Relative Humidity (%)					Air Temperature (°C)			
Deep		Shallow			Deep		Shallow	
12:30	15:00	12:30	15:00	hrs	12:30	15:00	12:30	15:00 hrs
39.6	40.2	36.8	35.8		29.8	30.0	30.9	29.7

The results above were from an average of 18 measurements. They tend to suggest that the higher value of % RH of the deep lime treatment was

Table 17. Stomatal resistance results for both adaxial and abaxial sides of the corn leaves in relation to the five fertility management practices during the veranico.

Treatment		Sampling Days During Water Stress								
		6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	Av.
		sec/cm								
0-Lime	1/	8.5	35.2	40.1	69.5	56.5	79.1	52.1	41.1	47.80
	2/	8.2	29.0	28.0	45.6	38.7	78.9	49.4	44.1	40.27
Lime-Shallow		13.3	14.6	22.6	48.8	22.1	59.7	52.9	36.7	33.87
		6.9	11.2	21.3	36.2	22.4	51.5	42.9	33.5	28.29
Lime-Deep		2.5	4.7	3.1	7.0	9.9	12.7	8.2	8.8	7.16
		2.9	4.6	2.1	8.9	14.1	13.3	7.7	12.1	8.28
Broadcast-P		9.4	22.5	26.5	43.5	37.1	73.3	52.1	81.4	43.26
		11.8	19.3	35.1	32.1	17.7	82.8	58.5	59.7	39.66
Banded-P		14.3	18.7	28.6	61.4	51.9	47.9	35.8	63.8	40.35
		10.1	9.4	12.0	19.9	38.9	43.6	25.4	63.4	27.89

1/ adaxial side of the leaf

2/ abaxial side of the leaf

due to higher transpiration rates of the corn plants. Deep lime incorporation increased soil water availability resulting in higher transpiration rates over the shallow lime incorporation treatments during this period of water stress caused by the veranico.

Once leaf water stress reaches a critical point, the leaf is no longer able to continue functioning, thus senescence commences. Table 18 shows that leaf number decreased less in the deep lime treatments verses the shallow lime treatments.

As a plant becomes more and more water stressed the stomatal resistance should increase to the point that transpiration and CO_2 uptake are greatly inhibited. CO_2 uptake results are shown in Table 19. Deep lime treatment plants averaged a Pn of 10 mg $CO_2/dm^2/hr$ more than the shallow lime treatments. Although the Pn results reflect a fertility treatment effect and correlate with previous findings, Pn is quite high. It was expected that as the plants approached - 20 bars , Pn would have decreased more than was demonstrated.

Final yield results are shown in Table 20. Grain yields do not reflect the big differences that were demonstrated by the physiological measurements. Deep liming did not outyield shallow liming at the 5 % level of significance whereas the 0-lime and banded-P were significantly inferior to the other three treatments. Stover yields were not significantly effected by the water stress treatments because the veranico occurred late in the season. No real veranico occurred during the vegetative stage, thus only the late stress results reflect the effect of water stress on grain yield. The following table shows the percent yield reduction due to the veranico that occurred at approximately 80

Table 18. Corn leaf number during the veranico in relation to the five soil management practices.

Treatment	Sampling Days During Water Stress									Av.
	5/3	6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	
	Leaf No.									
0-Lime	12.6	12.6	11.0	11.6	9.8	11.0	10.0	9.6	7.0	10.6
Lime-Shallow	14.0	13.2	11.0	11.2	10.2	10.8	8.8	10.0	7.6	10.8
Lime-Deep	13.2	12.6	12.6	12.6	11.2	12.2	10.2	9.8	9.2	11.5
Broadcast-P	13.2	12.6	10.8	10.0	10.0	10.4	9.0	8.8	7.2	10.2
Banded-P	12.4	12.0	10.8	10.4	9.6	10.8	8.6	9.2	6.8	10.1

Table 19. Influence of plant water stress and fertility treatment on the photosynthetic rate of maize.

Treatment	Sampling Days During Water Stress								Av.
	6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	
	mg $CO_2/cm^2/hr$								
0-Lime	40.0	30.0	33.2	31.5	45.2	43.5	43.5	27.6	36.5
Lime-Shallow	34.2	24.4	29.3	30.7	51.2	35.1	36.3	30.2	33.9
Lime-Deep	48.0	33.3	52.6	32.4	46.0	59.0	41.9	34.0	43.4
Broadcast-P	28.1	30.3	28.5	44.3	48.0	29.1	34.1	43.3	35.7
Banded-P	34.0	38.8	29.1	40.4	47.2	31.9	43.9	37.5	37.9

Table 20. Grain yield, stover yield, and grain:stover ratio for maize grown during the '74-5 season at Planaltina, Brazil.

Nutrient Treatment	Grain Weight 15.5% moisture (Kg/ha)	Stover Weight (Oven - dry) (kg/ha)	Grain:Stover Ratio
		No Stress	
0-Lime	5165	6667	.77
Lime-Shallow	6266	8542	.73
Lime-Deep	6292	8724	.72
Broadcast-P	5985	9037	.66
Banded-P	5146	7474	.69
		Late Stress	
0-Lime	3650	6797	.54
Lime-Shallow	4417	7474	.59
Lime-Deep	4845	8828	.55
Broadcast-P	4530	8490	.53
Banded-P	3638	5651	.64
		Early Stress	
0-Lime	5206	6641	.78
Lime-Shallow	6401	8594	.74
Lime-Deep	6606	9115	.72
Broadcast-P	6340	8255	.77
Banded-P	4555	5911	.77
Nutrient $LSD_{.05}$	460	925	n.s.
Stress $LSD_{.05}$	457	n.s.	.12
Nutrient*Stress $LSD_{.05}$	n.s.	n.s.	n.s.
C.V. (%)	8.96	12.27	10.50

days after planting. Comparison is made between no stress and late stress water treatments. The seriousness of a 15 day veranico is

Nutrient Treatments	% Yield Reduction Grain	Stover
0-Lime	29	0
Lime-Shallow	30	13
Lime-Deep	23	0
Broadcast-P	24	6
Banded-P	29	24

amply demonstrated by the 1500-2000 kg/ha reduction in yield. The importance of having the capacity to irrigate during the wet season to offset the effect of a veranico should not be neglected. Only three irrigations were used for the no stress treatment to gain the extra 30 % yield.

The effect of the late water stress period on final grain yield was directly related to photosynthate production and translocation to the ear. Table 21 shows ear dry weight accumulation for a 30-day period begining from the silk emergence stage. Stover dry weight decreased during the ear filling stage which suggests that photosynthate stored in the culm during the vegetative stage was translocated to the ear. The results also suggest that the late water stress period (79-90 days after planting) slowed photosynthate production but increased photosynthate partitioning. Over 30 % of the ear dry weight accumulation occurring during the water stress period came from photosynthate stored in the culm, whereas only 2.9 % was translocated in the no water stress period treatment over the same time period. In addition, plant water stress resulted in approximately one gram per day

Table 21. Relationship between stover dry weight and ear dry weight acumulation for a 30-day period begining from the silk emergence stage in relation to plant water stress.

Days after Planting	No Water Stress		Late Water Stress		Early Water Stress	
	g plant^{-1}	g d^{-1}	g plant^{-1}	g d^{-1}	g plant^{-1}	g d^{-1}
			Ear Dry Weight			
Day 76	23.69		22.30		21.78	
		3.74		2.46		3.88
Day 90	76.00		56.74		76.08	
		4.17		3.10		3.51
Day 105	138.52		103.22		128.66	
Grain @ 15.5%	130.30 g/plant		90.70 g/plant		127.95 g/plant	
Grain @ 15.5%	5771 kg/ha		4216 kg/ha		5822 kg/ha	
			Stover Dry Weight			
Day 63	123.78		119.84		112.02	
		+2.34		+2.32		+2.14
Day 76	154.15		159.04		139.88	
		-0.11		-0.76		+1.20
Day 90	152.58		139.38		156.74	
		-0.87		+0.12		-1.74
Day 105	139.48		141.14		130.68	
			Tassel Dry Weight			
Day 76	6.90		6.30		6.42	
Day 90	6.58		4.72		5.28	
Day 105	4.46		5.40		4.14	

less of ear dry weight accumulation when compared to the no water stress treatment. One g $d^{-1} \approx 50$ kg/ha lost each day for 30 days which equals 1500 kg/ha or approximately the final yield difference between stressed and non-stressed treatments.

Based on the results from the 1974 experiment's analysis of plants, soil and triple superphosphate fertilizer it was decided to reapply all phosphorus rates in all five nutrient treatments before the planting of the 1974-5 wet season experiment. The wet season nutrient uptake (Fig. 23) findings (Appendix table 9) as well as the grain and stover nutrient analysis (Table 22) show the benefit of the phosphorus reapplication. Wet season P-uptake more than doubled the 1974 dry season's P-uptake. The continued reaction of lime allowed for a more rapid uptake of Mg and Ca. The results suggest that Mg is the most important nutrient limiting factor for plant growth in low-lime conditions. The late stress period reduced nutrient uptake with Mg showing a statistically significant reduction in both grain and stover. Nutrient concentrations in the grain and stover were not significantly reduced by plant water stress (Appendix table 10). The 160 kg/ha P_2O_5 applied in bands was still not enough phosphorus to sustain optimum plant growth and yield. In fact, the banded treatment's concentration of phosphorus in the grain was close to being P-deficient. The expected P conc. range for corn grain at maturity is 0.2 - 0.6 % (Jones and Eck,1973).

A soil analysis was conducted after the experiment was harvested (Table 23). Note that the lime was still reacting. A higher pH and lower % Al. Sat. was realized in all treatments. Ca and Mg availability were also increased. The effect of the reapplied phosphorus fertilizer

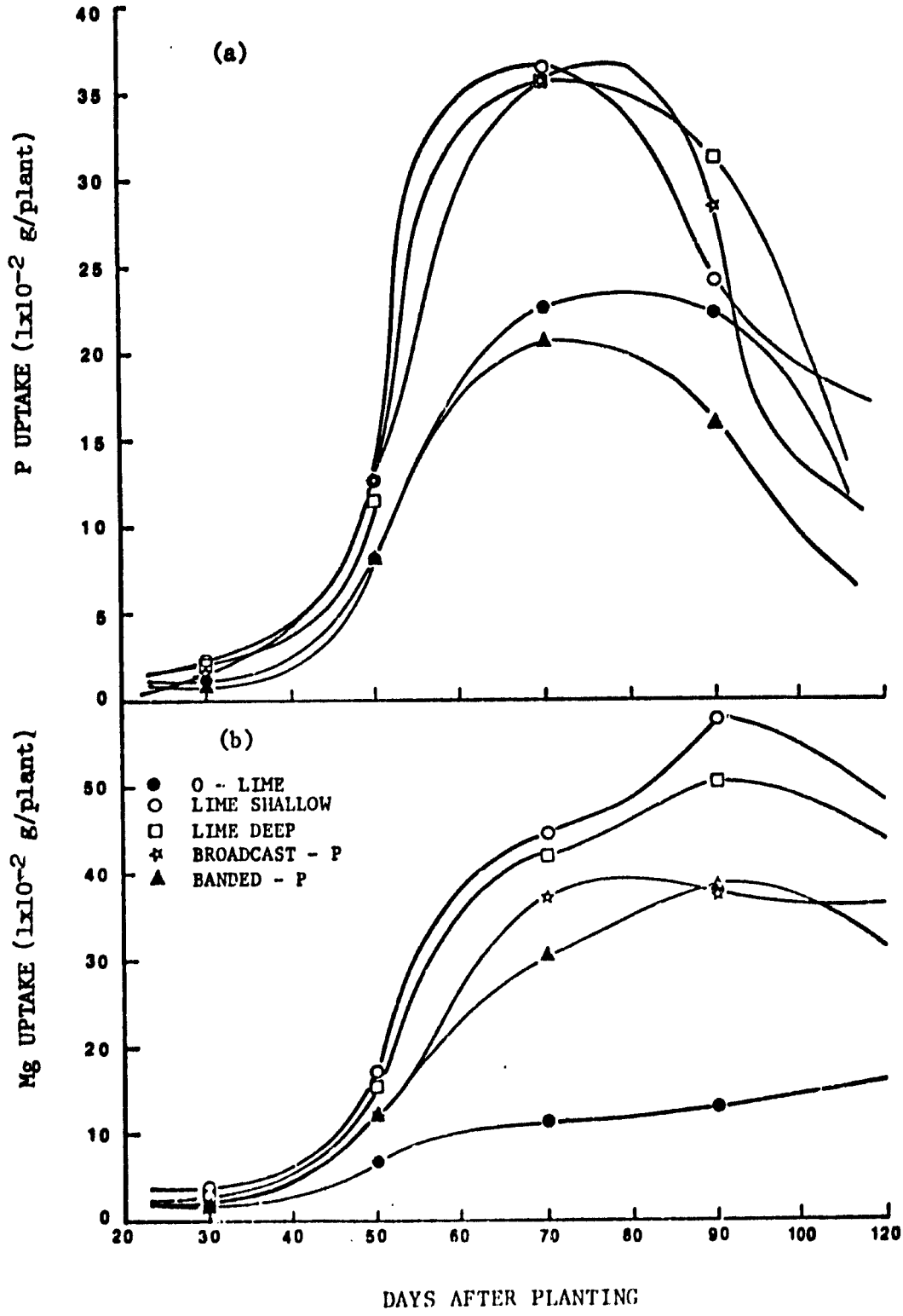


Fig. 23. Nutrient uptake curves in relation to the five soil management practices. (a) Phosphorus uptake; (b) Magnesium uptake.

Table 22. Uptake of P, K, Ca, and Mg by the grain and stover in relation to plant water stress and fertility. Results are expressed in kg/ha.

Treatment	Phosphorus		Magnesium		Calcium		Potassium	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
				No Stress				
0-Lime	21.76	2.16	8.56	8.24	1.36	12.31	20.65	65.73
Lime-Shallow	23.41	4.31	8.78	20.00	1.88	13.44	25.06	90.00
Lime-Deep	25.20	5.01	9.87	23.53	1.69	15.18	29.38	99.51
Broadcast-P	19.98	6.44	9.19	20.08	1.20	17.00	23.92	108.44
Banded-P	14.61	3.42	6.33	19.83	2.28	16.86	19.13	78.07
				Late Stress				
0-Lime	12.51	3.36	4.84	3.82	1.35	12.12	14.69	72.26
Lime-Shallow	11.69	3.98	5.19	17.17	1.33	12.94	13.25	84.71
Lime-Deep	15.90	4.88	6.41	18.55	2.03	14.04	17.60	98.91
Broadcast-P	16.08	3.40	6.07	14.35	1.66	13.82	16.72	86.90
Banded-P	9.60	1.78	3.87	12.97	1.45	9.70	11.34	53.87
				Early Stress				
0-Lime	15.39	3.32	6.74	6.84	1.87	12.86	17.25	72.68
Lime-Shallow	28.45	3.66	10.77	19.26	1.48	14.59	29.66	104.63
Lime-Deep	25.19	3.99	10.15	21.59	1.58	15.46	26.43	86.90
Broadcast-P	21.80	4.39	8.47	17.24	1.88	14.43	25.35	86.77
Banded-P	16.13	1.58	6.54	15.62	1.33	11.42	18.21	61.19
F Test-Nut.	1 %	1 %	1 %	0.1 %	n.s.	n.s.	1 %	0.1 %
F Test-Stress	5 %	n.s.	5 %	10 %	n.s.	n.s.	1 %	n.s.
C.V. (%)	25.51	41.25	25.96	25.55	34.42	19.77	24.58	20.85

Table 23. Post-harvest soil analysis results at three depths and five fertility regimes.

Treatment	pH 1:1 H_2O	Ca + Mg meq/100ml	Al meq/100ml	Al Sat. %	P ppm
			0-15 cm		
0-Lime	4.86	.84	1.07	56.0	26.8
Lime-Shallow	6.03	4.81	.09	1.8	33.4
Lime-Deep	5.92	3.82	.09	2.3	33.3
Broadcast-P	5.58	3.61	.16	4.2	61.7
Banded-P	5.56	2.98	.19	6.0	4.8
			15-30 cm		
0-Lime	4.52	.36	1.29	78.2	5.4
Lime-Shallow	5.10	1.90	.57	23.1	5.5
Lime-Deep	5.69	3.22	.14	4.2	5.1
Broadcast-P	4.92	1.53	.85	35.7	6.2
Banded-P	4.95	1.29	.73	36.1	2.8
			30-45 cm		
0-Lime	4.36	.26	1.18	81.9	2.2
Lime-Shallow	4.59	.74	.84	53.2	3.0
Lime-Deep	4.86	1.38	.61	30.7	3.3
Broadcast-P	4.52	.58	1.03	64.0	3.0
Banded-P	4.44	.53	1.09	67.3	1.9

was shown quite clearly in the amount of P in solution; six to ten fold increases over the 1974 soil analysis results. The banded-P results still show that it was below the required 10 ppm for optimum corn growth and yield. The deep lime effect in the 15-30 cm soil layer shows an increase in pH and decrease in % Al Sat. when compared to the 1974 dry season's soil analysis.

1975 Dry Season Soil Management Experiment

There were no major changes in the planning and execution of the '75 dry season experiment from the previous two experiments. Two veranicos were simulated by with-holding irrigation water. The first veranico (early stress period) occurred during the rapid stage of vegetative growth, 63-80 days after planting. The late stress period commenced 100 days after planting and lasted for 10 days. The experiment was planted on June 2, 1975 and was harvested 164 days later. Fifty percent tasseling was obtained 98 days after planting for the non-stressed plants and 100-104 days for the early stressed plants.

General meteorological data taken during the two simulated veranicos are shown in Figure 24 and 25. The early stress period's climate was cool, windy, and cloudy with 30-35 % RH during the days. The second stress period's climate was much warmer and less cloudy. Pan ET was quite high and % RH during the day became quite low, 14.3 % on 17/9/75. Needless to say, the second period's effect on plant stress was quite severe. In addition, photosynthetically active radiation was more intense and stable during the second stress period (Fig. 26).

Periodic growth measurements were taken from 24 days after planting to 127 days. All graphs displaying plant growth were either measured directly, i.e. LAI, or were calculated by regression analysis from the non-destructively sampled 4 plants per plot as explained in the previous experiment. Figure 27 displays a series of LAI curves for the deep and shallow lime soil fertility treatments in relation to the three water

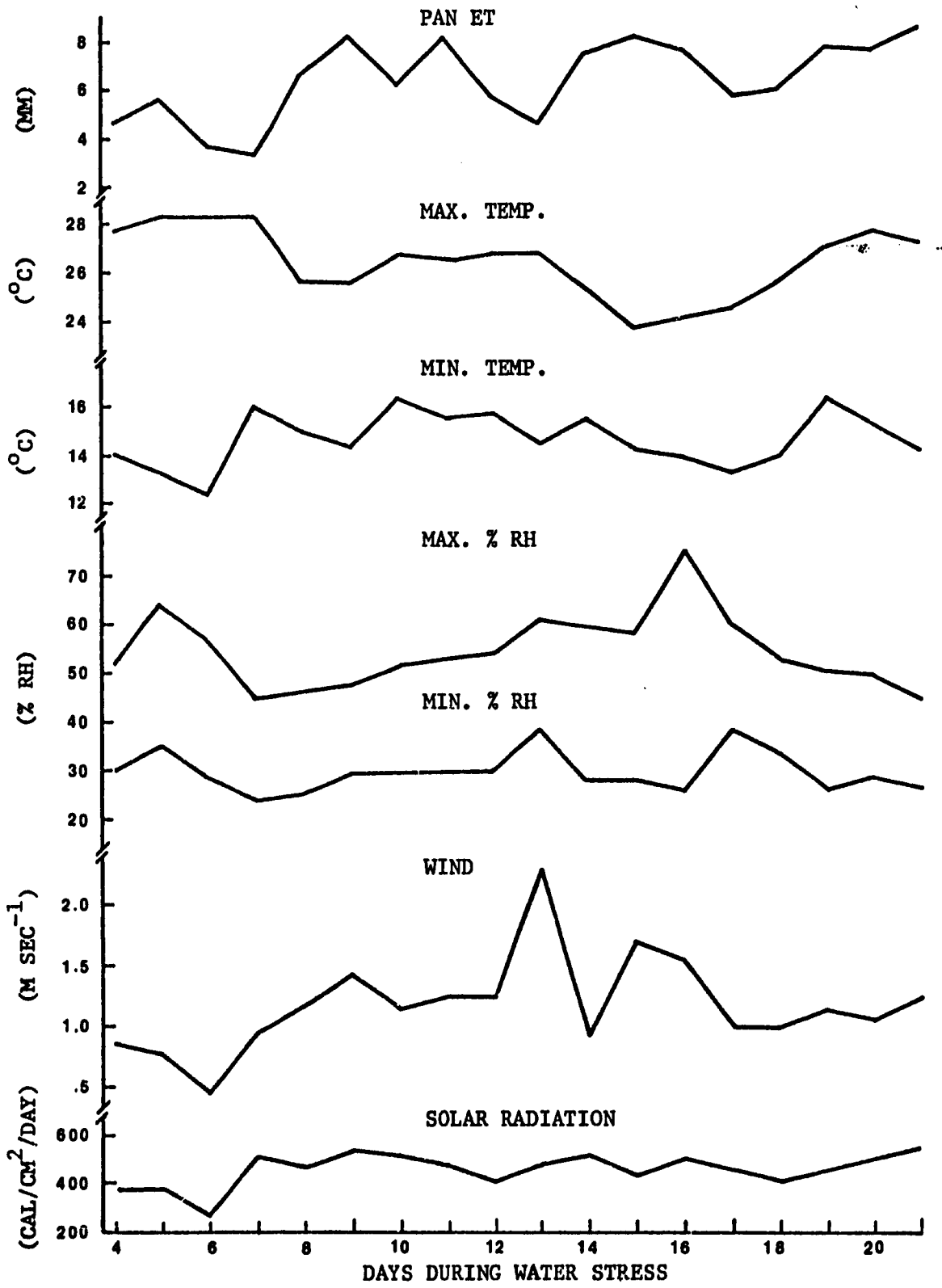


Fig. 24. General meteorological data for the first stress period (4/8 to 21/8/75).

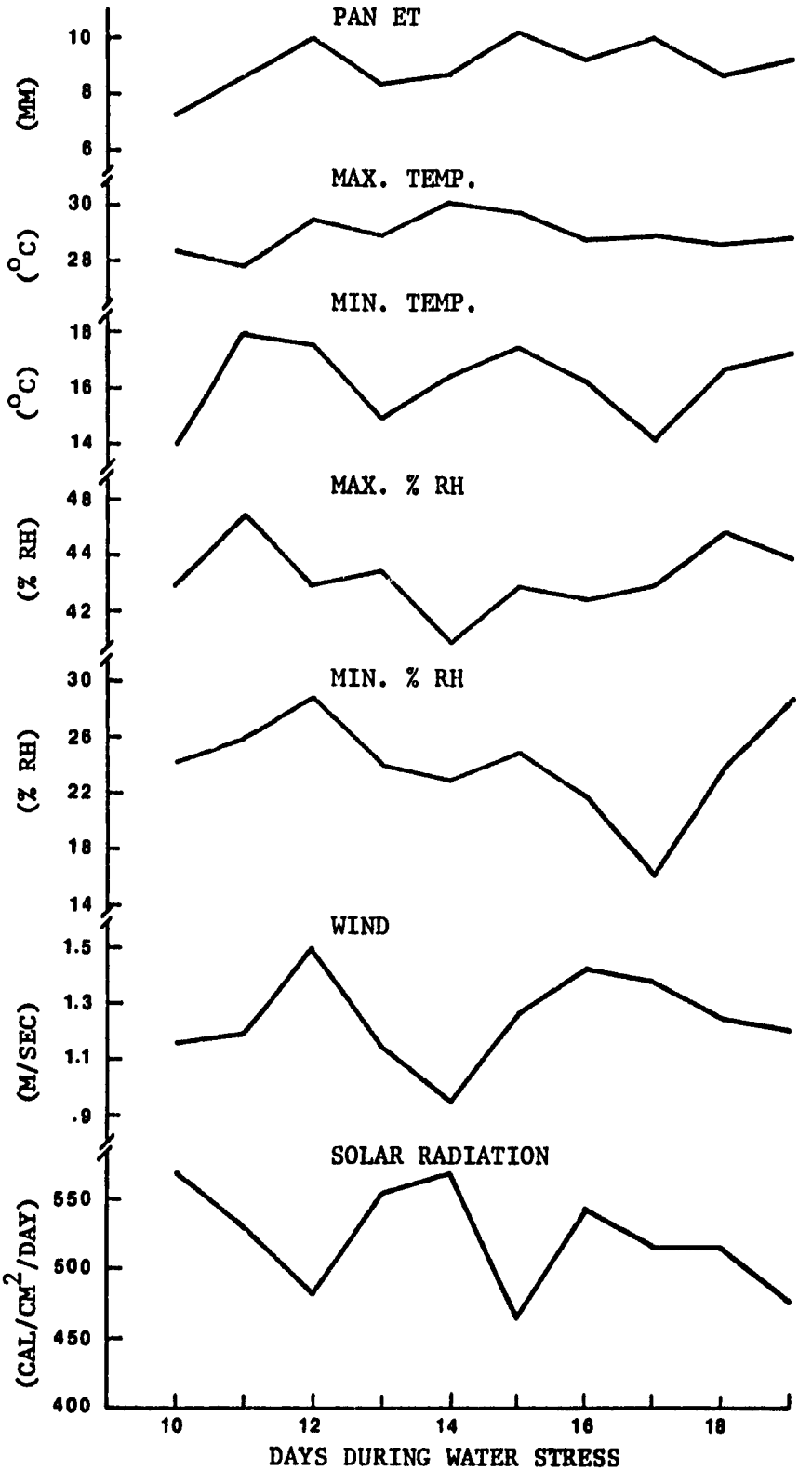


Fig. 25. General meteorological data for the second stress period (10/9 to 19/9/75).

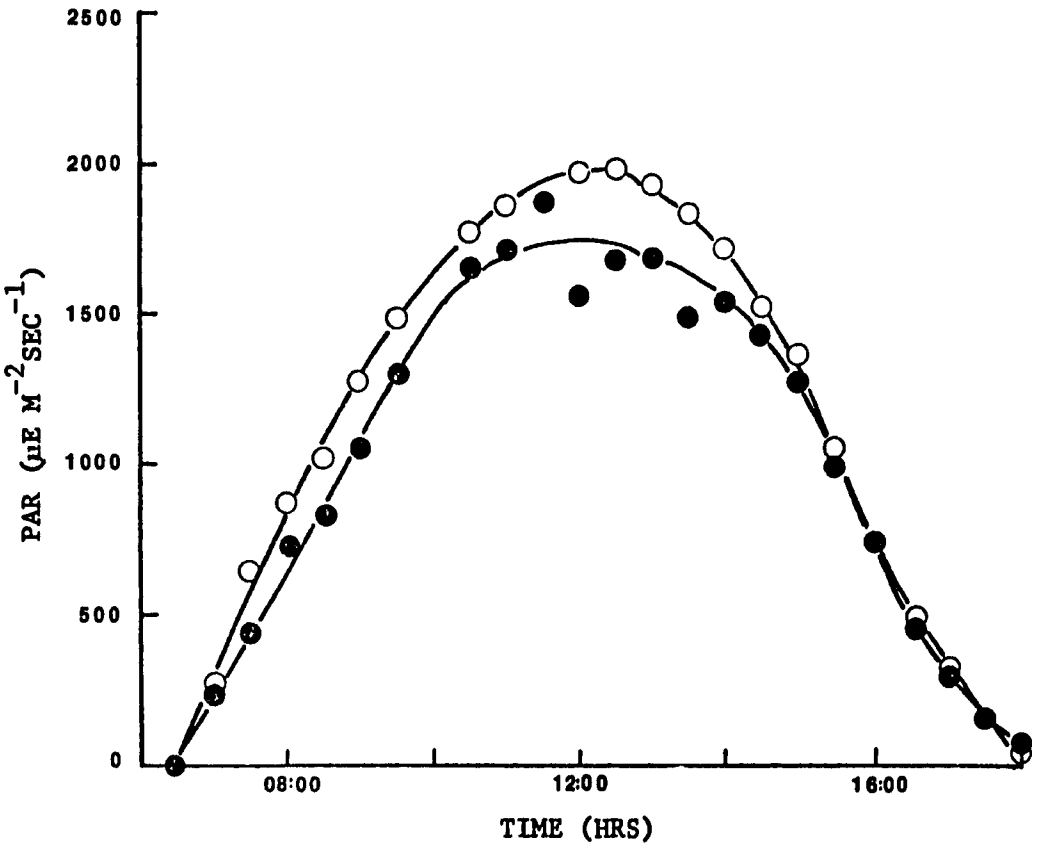


Fig. 26. Diurnal photosynthetic active radiation curve for both the first and second stress periods. Solid circles denote the first stress period and open circles denote the second stress period.

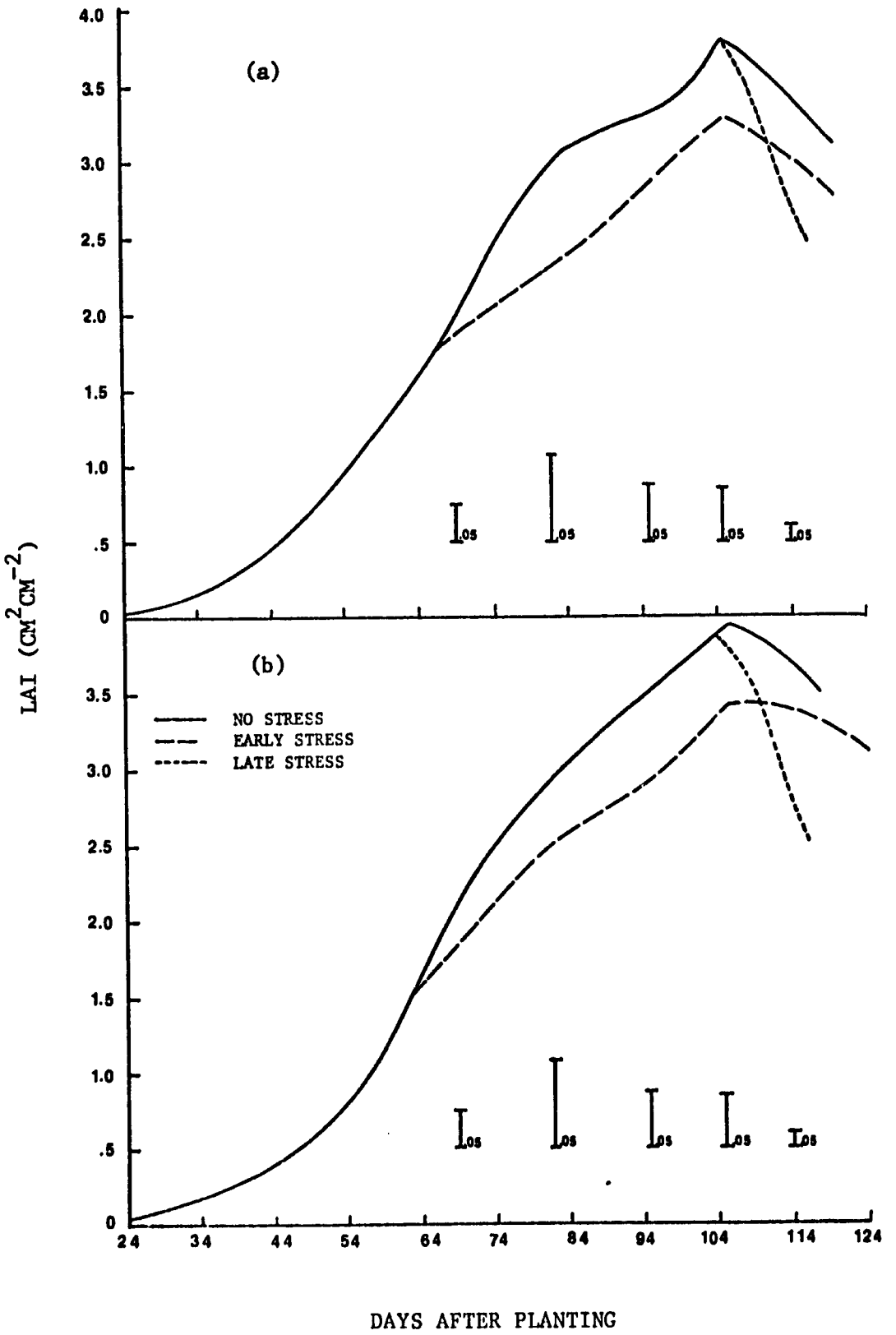


Fig. 27. The effect of plant water deficit on corn leaf area. (a) shallow lime; (b) deep lime.

stress measurements. The early water stress effect on reducing leaf area was permanent. The late stress period significantly increased the rates of leaf senescence for all nutrient treatments. No leaf-area differences were seen between deep and shallow liming but the 0-Lime treatment's leaf area was only 50 % of the limed treatments (Fig. 28). The banded-P treatment had a reapplication of 160 kg/ha P_2O_5 before planting but the broadcast did not. The result of the added P_2O_5 was quite evident. The previous two experiments always showed banded-P being quite inferior to the broadcast-P treatment. The 1975 dry season results show that the leaf area for the banded-P plants were significantly superior for the first 60 days. Total dry weight accumulation for the five nutrient treatments are shown in Appendix Fig. 1. They reflect LAI results quite closely. The effect of the early stress period on dry weight was permanent, as the leaf area results were. Net assimulation rates (NAR) and relative growth rates (RGR) were calculated on a weekly basis throughout the season. They both tended to reinforce the LAI and total dry weight findings in relation to both nutrient and water treatments. Appendix Fig. 2 shows NAR for the two phosphorus treatments. Note NAR reduction due to plant water stress (62-80 days after planting). RGR was also able to detect the negative effect of water stress on plant growth (Appendix Fig. 2). The early stressed plants had a late surge of growth to compensate for the early slower rate of growth.

Two plants per plot were destructively sampled every 10-12 days for dry weight increment determinations (Appendix table 11). The 0-lime treatment was inferior for all growth measurements. Plant stress during the vegetative stage caused a statistically significant

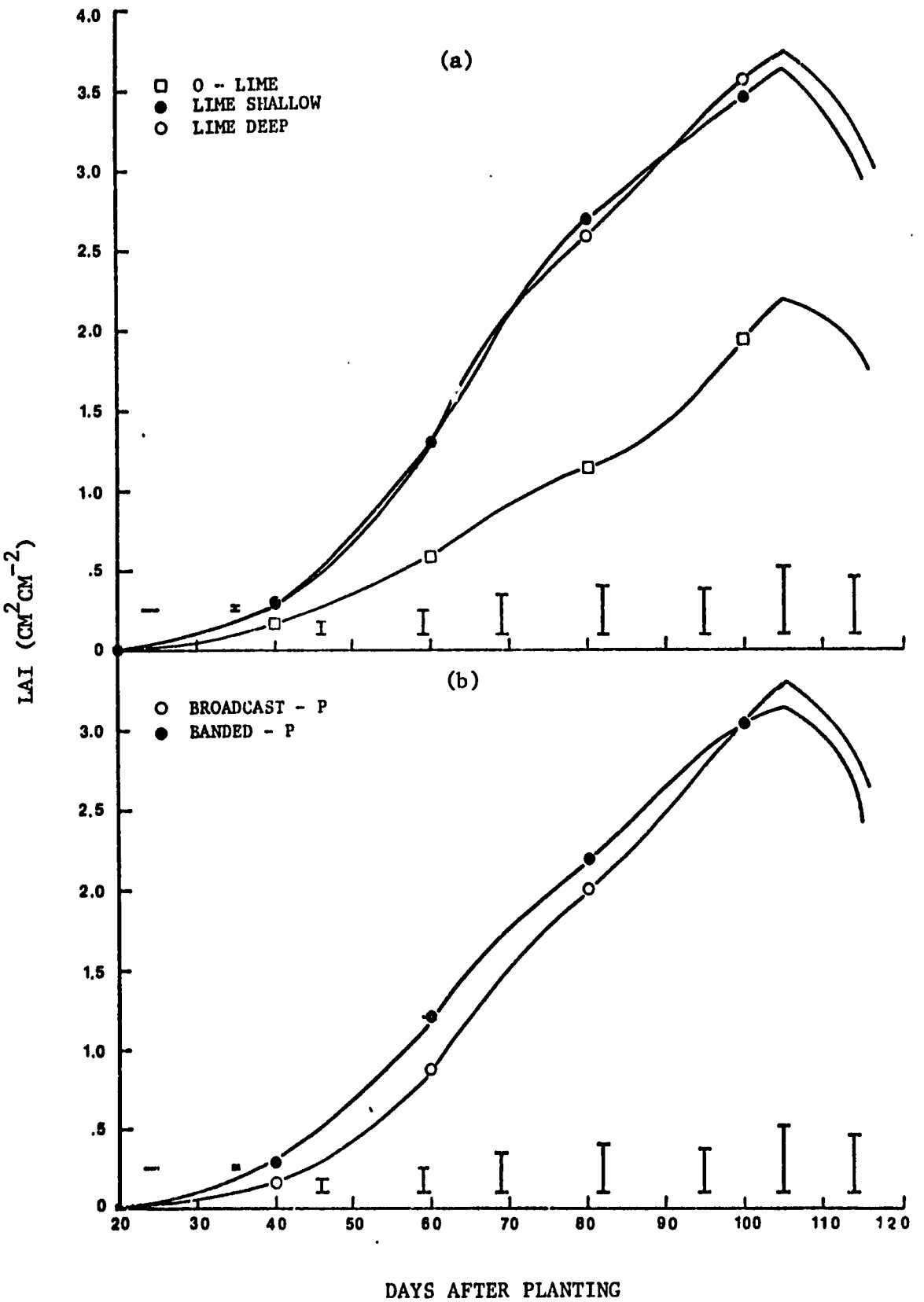


Fig. 28. Leaf area for corn comparing the 3 lime (a) and 2 P treatments (b).

reduction for all growth measurements (82 days after plants). Twelve days later, the corn plants were able to overcome water stress effects except for plant height, leaf dry weight and leaf number. The late stress period significantly reduced leaf area, leaf number, and dry weights of leaves, ears, and tassels.

The dry season is not only without rainfall, it is also the coldest season of the year with May through August night temperatures averaging 4-5 ^{o}C cooler than for the rest of the year. Night temperatures for 1975 were quite cool in June and July averaging 13 & 12°C respectively The coolest night was 4 ^{o}C. The cool nights resulted in cool soil temperatures which were not conducive to optimum corn growth. The soil temperature at 08:00 hours for four soil depths are shown in Appendix Fig. 3. The measurements were taken from the two bare soil sites, 5 m outside of the maize experimental plots. Soil temperatures during the two simulated veranicos reflect the air temperature differences as the season progresses (Fig. 29). September soil temperatures averaged 6 ^{o}C warmer than August's soil temperatures.

Soil water use by the corn plants during the two stress periods was measured daily at five depths by gravimetric sampling (Table 24). The first sampling period shows very little advantage to deep liming over shallow liming. Perhaps root distribution was limited due to the cool soil temperatures. The second stress period shows a 3-day advantage for deep liming. The 0-lime treatment didn't use much water because of its reduced leaf area as well as probable poor root distribution. Broadcast-P results suggested that better root distribution gave better soil water utililization than the banded-P did. Since above ground leaf areas are

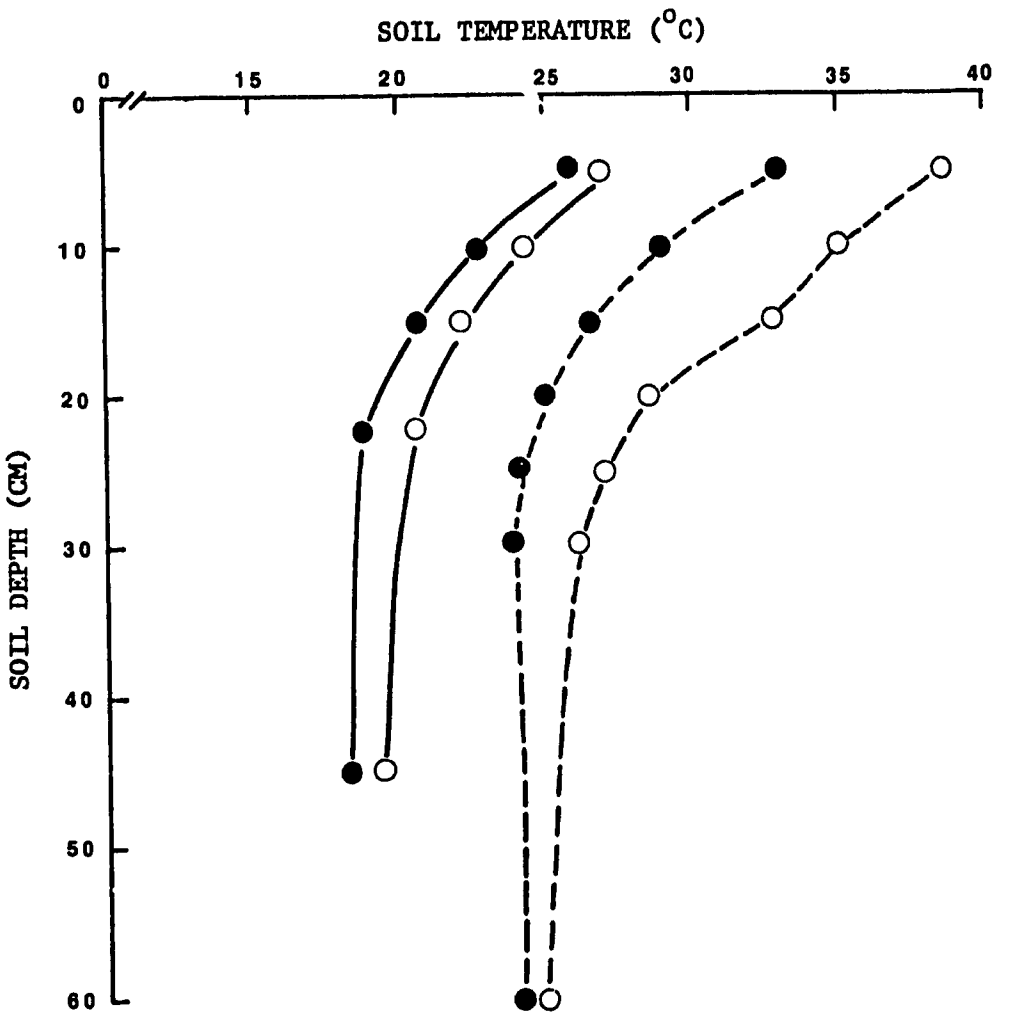


Fig. 29. Soil temperature through the 0-45 cm soil profile as influenced by crop and time of measurement. Solid line represents measurements taken within corn canopy and dashed line represents measurements taken in bare soil area. Solid circle= first stress period; open circle= second stress period.

Table 24. Soil water use during the two water stress periods for the five fertility treatments.

Treatment	Soil Depths 0-15 cm	15-22.5 cm	22.5-30 cm	30-37.5 cm	37.5-45 cm	d
	Soil Water Content (g/100g)					mm H_2O
			First Time			
0-Lime	21.3	23.9	24.2	24.1	25.1	8.4
Lime-Shallow	19.3	21.5	22.7	23.4	24.4	1.5
Lime-Deep	19.6	21.6	22.7	23.1	23.9	0
Broadcast-P	20.5	23.1	23.8	24.4	25.0	6.2
Banded-P	19.7	22.2	22.8	24.3	25.3	4.0
			Second Time			
0-Lime	21.5	24.9	25.8	25.5	25.9	18.6
Lime-Shallow	19.9	21.3	22.3	23.6	24.6	6.7
Lime-Deep	19.2	20.4	21.2	21.7	23.0	0
Broadcast-P	19.8	21.2	22.0	23.9	24.2	5.8
Banded-P	20.7	21.9	24.8	25.0	24.7	11.8

almost equal, plant water stress measurements should show the broadcast-P plants were under less water stress than plants in the banded-P treatment.

Plant water stress measurements reflect soil water use for both stress periods. Leaf water potential (ψ_L) and relative water content (RWC) results (Appendix table 12) for the early stress period produced no real differences between the nutrient treatments. The late stress period's results show that deep liming and broadcast-P treatment were superior to shallow liming and banded-P respectively as predicted by the above soil water use results (Figure 30). Note also that ψ_L 's were more negative for older plants while RWC results did not change as plants become older (Appendix table 13). That same effect was seen in the 1974 results. The 0-lime plants did not show as severe of a plant stress in comparison to the other nutrient treatments because of their inferior leaf area (See Fig 28 a) which reduced water loss to transpiration per cm of leaf area.

Stomatal resistance (R_s) findings supported the previously shown results for the first stress period (Appendix table 14). No differences between deep and shallow liming were found. Banded-P R_s results were half the R_s for the broadcast-P plants. The superiority of banding over broadcasting-P also continued for the second stress period (Table 25) which seemed to be counter to earlier reported ψ_L , RWC, and Pw results. By the 8th day of stress, the broadcast-P plants stopped transpiring. The superiority of deep liming on reducing plant water stress continued to hold true for the late stress period. Unlimed plants closed their stomates by the 9th day of stress.

Leaf temperature (T_L) measurements substantiate R_s results for both

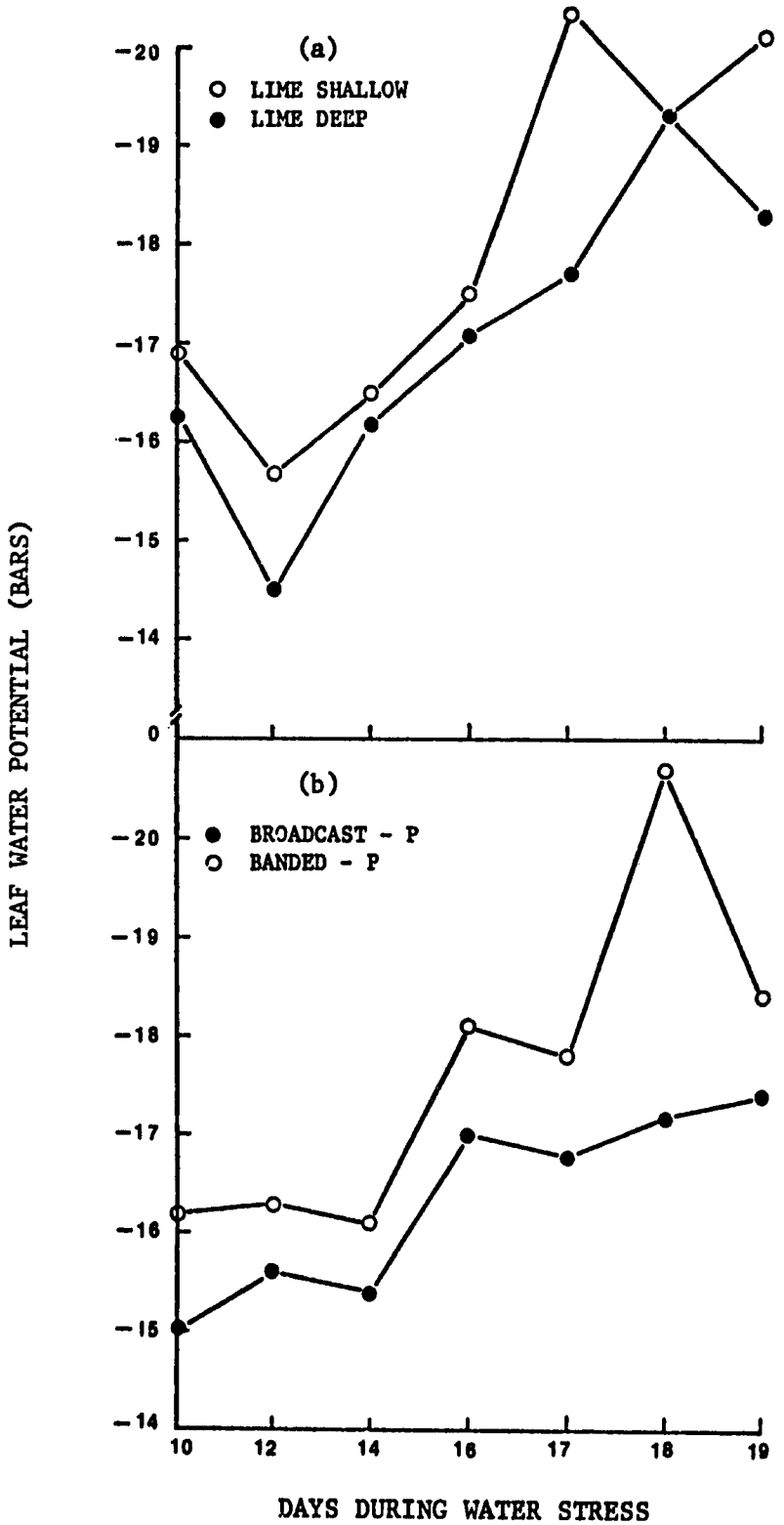


Fig. 30. Leaf water potential for corn during the 10 days of water stress in relation to broadcast and banded application of phosphorus; (a) lime comparison; (b) P-application comparison.

Table 25. Influence of plant stress on stomatal resistance in relation to the fertility treatments. Readings were taken during the late stress period.

Treatment		Sampling Days During Water Stress							Av.
		10/9	12/9	14/9	16/9	17/9	18/9	19/9	
		sec/cm							
0-Lime	1/	4.51	6.94	7.59	25.36	30.81	86.02	106.95	38.31
	2/	3.18	4.03	5.11	11.41	22.52	89.36	152.07	41.10
Lime-Shallow		6.87	8.57	3.99	54.65	123.66	77.06	87.65	51.78
		5.42	4.59	3.84	35.63	56.63	43.07	51.19	28.59
Lime-Deep		5.81	9.82	10.44	25.22	105.87	47.36	41.39	35.13
		4.65	2.89	5.19	20.68	35.75	18.65	44.09	18.84
Broadcast-P		8.32	9.65	9.34	45.36	94.62	154.08	--	53.56
		5.22	4.93	9.36	30.70	149.37	111.66	--	51.87
Banded-P		17.71	7.41	9.60	43.22	80.86	173.40	--	55.37
		5.30	4.51	7.37	26.99	51.40	98.49	--	32.34

1/ adaxial

2/ abaxial

stress periods (Fig. 31). The treatments which had the least R_s also have the lower T_Ls. The second stress period, especially, shows the relationship between R_s and T_L .

It was noted in the previous experiment that as the plants become more and more water stressed their green color turned lighter and lighter. To determine if the color change was due to a loss of chlorophyll in the leaves, measurements were made on the chlorophyll content of the leaves as they became more and more stressed. Appendix table 15 shows the chlorophyll contents for the five nutrient treatments during both stress periods. All treatments showed a loss in chlorophyll with time but no nutrient differences are shown. Several investigators (Boyer and Bower, 1970; Keck and Boyer, 1974) have shown that electron transport and photophosphorylation were inhibited by chloroplast changes during leaf desiccation. Plaut and Bravdo (1973) have also shown that carbon dioxide fixation was reduced. Thus it seems that water stress inhibits photosynthesis at the chloroplast level and/or by stomatal effect.

The water stress measurements should not only reflect the decreasing soil water availability but should also reflect the plant's microclimate and the surrounding macroclimate . Table 26 demonstrates how the plant's microclimate was modified by transpiration. In another instance the vapor pressure deficit results (VPD) show how the macroclimate influenced plant stress results (Table 27). For example, the high VPD on 17/9/75 and its effect on R_s in the deep and shallow lime treatments (Table 25).

To help interpret the water stress data, if needed, leaf area, plant height and the number of leaves were measured on the same 5 plants per plot that the stress measurements were made on. During the first stress

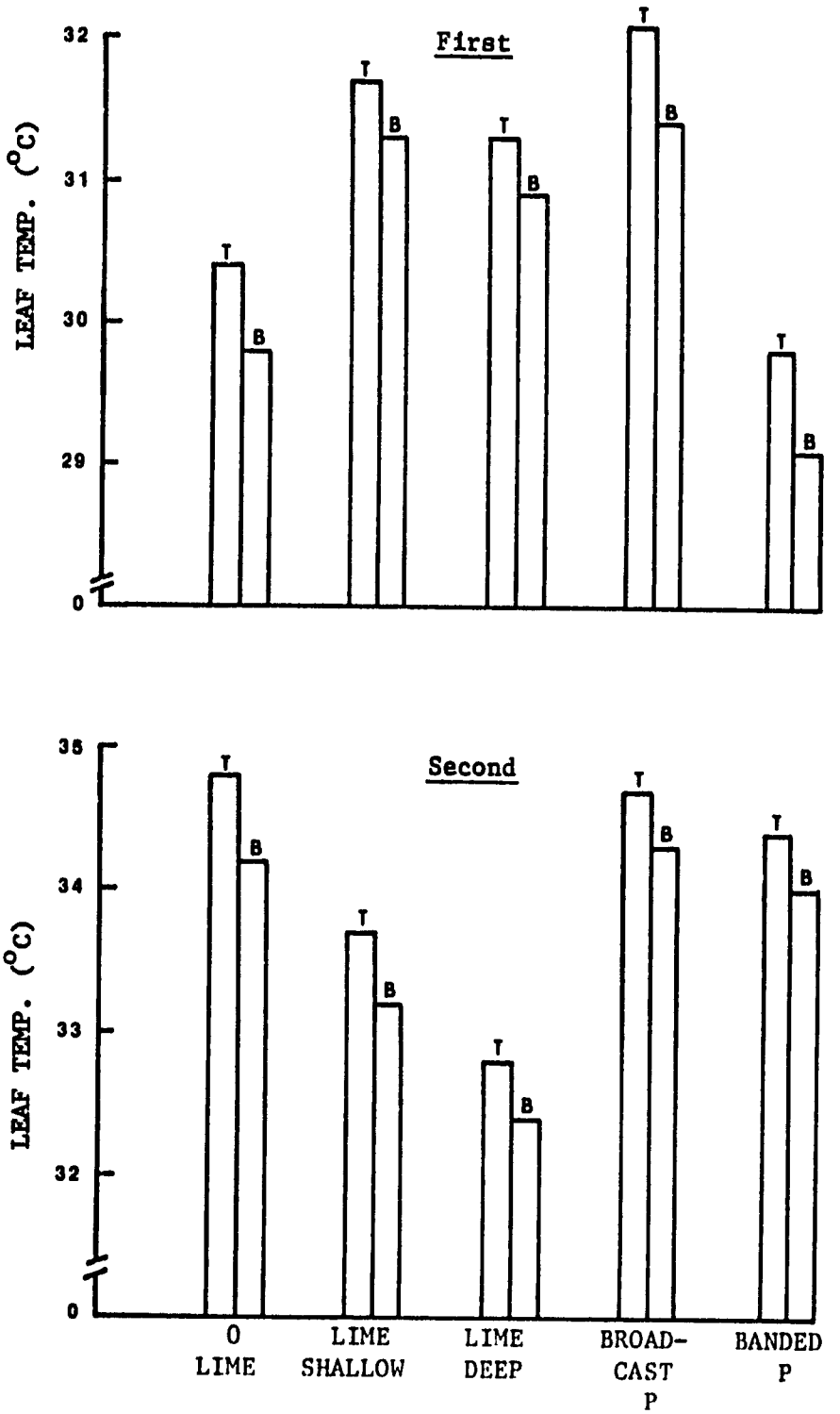


Fig. 31. Corn leaf temperatures during two water stress periods in relation to five fertility treatments. Results are averaged over the corresponding stress period.

Table 26. Air temperature and % RH within the corn canopy at 12:30 and 14:30 hours during the second stress period.

% Relative Humidity				Air Temperature °C			
Deep		Shallow		Deep		Shallow	
12:30-14:30		12:30-14:30 hrs.		12:30-14:30		12:30-14:30 hrs.	
26.0	24.1	22.8	21.4	30.1	30.0	30.5	29.6

Table 27. Vapor pressure deficit within the corn canopy and in the open air at 12:30 and 14:30 hours during the second stress period.

	Vapor Pressure Deficit (mbars)			
	12:30 Hours		14:30 Hours	
Date	Within Canopy	Clear Area	Within Canopy	Clear Area
	mbars		mbars	
10/9	27.99	28.90	29.82	31.71
12/9	28.53	29.71	30.96	32.36
14/9	31.93	30.45	31.96	34.27
16/9	32.99	32.05	34.86	36.03
17/9	34.78	36.21	38.41	39.48
18/9	35.26	33.87	32.86	33.78
19/9	35.02	31.42	34.49	35.53

period, only the 0-lime plants were inferior to the other treatment's plants (Appendix table 16). The sample plants for the second stress period were smallest for 0-lime and banded-P treatments (Appendix table 17). As a plant leaf becomes too stressed, i.e., high R_s and T_L, the leaf will prematurally senesce. The results from the second stress period show that the deep lime treatment was superior to all other treatments in delaying or reducing premature leaf senescence.

Many of the findings shown so far in this report have been based on the corn plant's root distribution and ability to extract soil water in relation to the low pH and high % Al. Sat. of the LVE soil. To verify the previous results, root measurements were taken when the corn plants had just started to tassel (Hanway stage 4). Two methods were used. The rubidium-86 method is supposed to only detect the active portion of the root zone. When this method was used the objective was to learn if the corn roots were entering the acidic, aluminium saturated soil and still staying active. The second method was supposed to measure total root length per volume of soil. When using this method, the main objective was to measure the total root distribution in relation to soil depth as influenced by the five fertility management treatments.

The percent root distribution as determined by the rubidium-86 method is shown in Table 28. Both depth and lateral distribution of roots are shown. Deep liming resulted in a fairly uniform rooting distribution while 0-liming, for example, showed a high concentration of roots in the 0-15 cm soil layer. The general root pattern was as expected. Many roots were shallow close to the row and as lateral

Table 28. Percent root distribution for corn as determined by the rubidium-86 method.

Location	Soil Depth 0 - 15	15 - 30	30 - 45
		0-Lime	
1	5.11	4.1	1.6
2	11.5	5.6	5.6
3	10.2	7.6	6.1
4	12.2	3.9	10.1
5	8.3	6.2	1.9
$\bar{X}$	47.3	27.4	25.3
		Lime-Shallow	
1	7.7	1.0	10.6
2	9.1	5.7	8.6
3	2.8	10.4	4.6
4	7.6	2.4	11.4
5	6.6	5.5	6.0
$\bar{X}$	33.8	25.0	41.2
		Lime-Deep	
1	6.2	6.2	2.6
2	7.4	5.8	5.7
3	8.5	5.2	3.5
4	8.8	7.6	9.6
5	5.2	7.4	10.4
$\bar{X}$	36.1	32.2	31.8
		Broadcast-P	
1	15.7	2.8	0.6
2	8.3	7.7	2.2
3	14.2	10.1	5.1
4	4.4	7.5	7.0
5	6.2	4.1	4.0
$\bar{X}$	48.8	32.2	18.9
		Banded-P	
1	5.7	11.9	2.5
2	6.0	1.6	7.4
3	9.3	6.6	4.7
4	2.8	13.5	7.2
5	4.3	11.9	4.6
$\bar{X}$	28.1	45.5	26.4

1 = 2.5 cm from plant within row

2 = 17.5 cm from plant within row

3 = 15 cm from plant beside plant between row

4 = 30 cm from plant beside plant between row

5 = 45 cm from plant beside plant between row

distance became greater, more of the roots were deep. The effect of phosphorus application on root distribution was not clearly shown.

The second method, modified Newman technique, measures root length per 100 cm^3 (Table 29). No effort was made to analyse lateral root distribution per se, only depth of rooting. The results show the beneficial effects of deep liming as well as liming itself. The banded-P treatment shows more roots and deeper root penetration than the broadcast-P treatment. The largest amount of roots in the 0-15 cm soil layer for the banded-P treatment could be related to the high concentration of roots in the band of phosphorus.

Table 29. Root length (cm/100 cm^3) for corn at the start of the tasseling stage (Hanway stage 4) grown during the 1975 dry season.

	Soil Depth (cm)		
Treatment	0-15	15-30	30-45
0-Lime	68.8	23.1	10.5
Lime-shallow	99.4	58.4	24.7
Lime-Deep	96.5	76.2	40.4
Broadcast-P	103.0	26.1	4.4
Banded-P	133.6	52.9	10.0

The reason the rubidium-86 method did not show root distribution in relation to lime depth as clearly as the Newman technique was related to what each method was measuring. Root length per volume of soil shows the total mass of active and inactive roots, thus the results reflect just that, total root mass and nothing more. The rubidium results showed only where the most active portion of the root system was on that certain day. The results shown in Table 28 demonstrate that roots are able to enter the acid subsoil and remain active. The method does not say how

long these roots will remain active or how many of these roots there actually were at that depth. Preliminary results by Dr. Rhue at Cornell University (personal communication) with Cargill-111 show that it was very tolerant to high concentrations of aluminum when compared with many other maize cultivars. His method was based on the activity of a young corn root after it had been grown in a nutrient solution with a high aluminum concentration for a certain amount of time. If Cargill-111 was able to put some roots down into the acid subsoil and they remained active for a certain amount of time, this would explain why rubidium detected a larger portion of roots at greater depths than the Newman technique did.

In conclusion, the rubidium technique is probably a good method to use to determine if roots have reached a certain distance from a specific plant by a certain day. The Newman technique is a good method to demonstrate the cumulated total root distribution of a crop from day of planting to day of sampling.

The 10-day late stress period reduced grain yields by approximately 20 % or 1500 kg/ha, an average of 150 kilograms/day (Table 30). No statistically significant decrease in stress-related yield reduction was realized by deep liming at the 5 % level of significance but deep liming continued to show its usual superiority by out-yielding all nutrient treatments in all three water treatments. Banded-P outyielded broadcast-P in the no stress treatment but the broadcast-P treatment was superior in both the stress treatments. The early stress period continued to show its effect on plant vegetative growth. Stover yield was significantly lower in the early stress treatment but the decreased plant growth did

Table 30. Final grain and stover yields for the 1975 dry season experiment.

Nutrient Treatment	Grain Weight (15.5% moisture)	Stover Weight (Over-dry)	Grain:Stover Ratio
	(kg/ha)	(kg/ha)	
		No Stress	
0-Lime	5523	5312	1.04
Lime-Shallow	7237	7979	.91
Lime-Deep	7954	7782	1.02
Broadcast-P	6923	7872	.88
Banded-P	7313	7779	.94
		Late Stress	
0-Lime	4167	4358	.96
Lime-Shallow	5859	8392	.70
Lime-Deep	6240	8081	.77
Broadcast-P	6330	7657	.83
Banded-P	5638	6531	.86
		Early Stress	
0-Lime	5271	4624	1.14
Lime-Shallow	7373	7086	1.04
Lime-Deep	7454	7167	1.04
Broadcast-P	7224	7067	1.02
Banded-P	6647	6390	1.04
Nutrient $LSD._{05}$	520	733	.07
Stress $LSD._{05}$	457	436	.06
Nutrient*Stress $LSD._{05}$	n.s.	n.s.	n.s.
C.V. (%)	8.24	10.87	8.07

not reduce grain yield.

A yield component analysis was conducted to learn which yield component (s) was the most sensitive to plant water stress. The four plants/plot that were non-destructively measured for leaf area throughout the growing season were used for yield component measurements. Nine variables were selected. Table 31 shows the nine component variables in relation to nutrient and water treatments and their respective statistical analysis. The nutrient treatments significantly effected seven of the nine variables. Deep lime was superior to shallow lime for four of the variables.

The effect of water stress on the yield components was not very clear. Late plant stress had a negative influence on all the components. The reduction in number of rows of kernels/ear were the main influence on the yield per ear and per plant. Cob weight was not influenced by stress and since kernel weight was, the grain:cob ratio was reduced. It was expected that 1000 kernel weight would be most influenced by the late stress period, not the number of rows of kernels per ear. A regression analysis was conducted between the yield components and grain yield/plant (Table 32). Under no water stress conditions, the number of kernels/ear were highly significant in influencing yield. For early stress conditions, ear and kernel length/ear were highly correlated to yield. This seems logical since the plant stress occurred during the ear shoot formation stage (Hanway stage 2.5). The late stress treatment shows that all components were significantly correlated to yield. As shown in the ANOVA results, the number of kernels/row and per ear were highly correlated to yield. Percent ear filling and 1000 kernel weight were

Table 31. Yield component analysis for the 1975 Dry Season Maize experiment.

Yield Component	0-Lime	Lime Shallow	Lime Deep	Broadcast P	Banded P	Nutrient $LSD_{.05}$	No Stress	Late Stress	Early Stress	Stress $LSD_{.05}$	C.V. (%)
1	16.5	16.5	17.1	17.7	16.8	0.91	17.0	16.5	17.3	n.s.	5.55
2	14.8	14.4	15.3	16.3	15.3	1.02	15.3	14.6	15.8	n.s.	6.87
3	12.4	12.4	12.7	12.4	12.2	n.s.	12.8	12.3	12.2	0.49	7.10
4	34.0	33.8	37.2	38.6	37.1	2.55	36.9	34.3	37.2	n.s.	7.26
5	443	427	520	492	469	52.7	496	424	491	60.1*	11.52
6	270	293	298	283	288	20.2	291	285	282	n.s.	7.27
7	120	125	150	139	134	15.3	143	122	136	20.1	11.81
8	27.4	28.3	31.7	30.3	30.7	n.s.	30.6	28.8	29.6	n.s.	18.45
9	5.07	4.72	5.79	5.00	5.18	0.62	5.33	4.50	5.62	0.73	12.46

* LSD at 10% level

1= Ear Length (cm)
2= Kernel Length/ear (cm)
3= No. of rows of kernels/ear
4= No. of corn kernels/row
5= No. of corn kernels/ear
6= 1000 Kernel Wt. (g)
7= Grain Wt./plant
8= Cob Wt. (g)
9= Grain:Cob Ratio

Table 32. Correlation analysis between the yield components and grain yield/plant in relation to plant water stress.

Yield Component	No Water Stress	Late Water Stress	Early Water Stress
Length of Ear	.42	.71***	.87****
Length of Kernels/Ear	.46*	.70***	.82****
% Filling	.28	.49*	-.43
# Rows of Kernels	.43*	.49*	.16
# Kernels/Row	.39	.80****	.82****
# Kernels/Ear	.83****	.83****	.87****
1000 Kernel Wt.	.42	.48*	.31
Cob Wt.	.87****	.89****	.73***
Grain:Cob Ratio	.75****	-.54**	.53**

**** = 0.1%; *** = 1 %; ** = 5 %; * = 10 %.

only slightly correlated to yield. The main conclusion drawn from the yield component analysis is that plant water stress decreased grain yield because it reduced the number of kernels per ear by reducing the number of rows of kernels/ear and the number of kernels/row. Since a sample size of 60 was used in determining the row number-stress relationship, this researcher believes that the results were not related to genetic variability of the hybrid. Claassen and Shaw (1970) showed that water stress during Hanway stage 5 reduced ear size and row number which resulted in a 53 % drop in yield. Other researchers (Boyer and McPherson, 1975) showed that row number would not be effected if water stress was applied at later stages in the grain filling stage.

Table 33 shows ear dry weight accumulation in relation to stover dry weight as influenced by the three water treatments. Stover dry weights did not decrease during the grain filling period, thus photosynthate was able to account for all the increase in ear dry weight plus respiration losses in the unstressed treatments. The late water stress treatment (days 100 through 109) does show a slight translocation effect (9.7 %). A larger effect was shown in the 1974-5 wet season results. Boyer and McPherson (1975) showed that translocation was less sensitive than photosynthesis to plant water stress. Leaf photosynthesis was almost completely stopped but carbohydrates continued to be translocated from the culm and accumulate in the grain. These findings agree with Wardlaw (1969) that stress reduced the transport of recent photosynthate from the leaf but do not effect the translocation mechanism itself.

Both water stress treatments decreased the rate of ear dry weight accumulation. The early stress period (63-80 days after planting) gave

Table 33. Relationship between ear dry weight accumulation and stover dry weight as influenced by the three water treatments.

Days after Planting	No Water Stress		Late Water Stress		Early Water Stress	
	g/plant	g d^{-1}	g/plant	g d^{-1}	g/plant	g d^{-1}
			Ear Dry Weight			
Day 105	30.9		24.3		26.7	
Day 114	77.3	5.16	53.1	3.20	61.3	3.84
Day 127	137.8	4.65	94.4	3.18	115.2	4.15
Grain @ 15.5%	160.0 g/plant		132.9 g/plant		149.8 g/plant	
Grain @ 15.5%	6990 kg/ha		5647 kg/plant		6794 kg/plant	
			Stover Dry Weight			
Day 95	134.91		139.00		115.68	
Day 105	158.15	+2.32	153.99	+1.50	132.71	+1.70
Day 114	162.91	+0.53	151.17	-0.31	136.58	+0.43
Day 127	163.47	+0.04	153.40	+0.17	135.81	-0.06
			Tassel Dry Weight			
Day 105	6.67		2.67		5.49	
Day 114	6.38		5.79		5.61	
Day 127	7.11		6.49		5.23	

a slower rate of accumulation than the no stress treatment which could be related to slightly later maturity development or to smaller plant size. The late water stress had a very serious decreasing effect on ear dry matter accumulation which resulted in a loss in final grain yield of over 1300 kg/ha.

It was expected that the early stress period would reduce tassel dry weight since the stress period occurred during the tassel formation stage. The results show an 18 % decrease compared to the no stress treatment.

Nutrient uptakes were calculated for P, K, Ca. Mg, and Zn. Figures 32, 33, and 34 show that the 0-Lime's P,Ca, and Mg uptakes were significantly less than the other four treatments. Banded-P's phosphorus uptake was equal to the broadcast-P's uptake until 105 days after planting. Mg-uptake was extremely low in the 0-lime treatment, much more than Ca-uptake, suggesting that magnesium is the most critical nutrient limiting yield in the 0-lime treatment. A more complete nutrient uptake analysis is shown in Appendix table 18, Nutrient uptake was reduced by the late stress period. Ca and Mg uptake were reduced by 61 % and 52 % respectively. P translocation was slowed down by 48 %.

Grain uptake of phosphorus was significantly reduced by the late stress period while P-uptake in the stover was increased (Table 34). This suggests that plant water stress reduced P translocation from the stover to the grain. The results also suggest that plant stress reduced Mg and Ca translocation to the ear.

Soil samples were taken during the 1975 dry season at two times. The first sampling period was in September before the rains started.

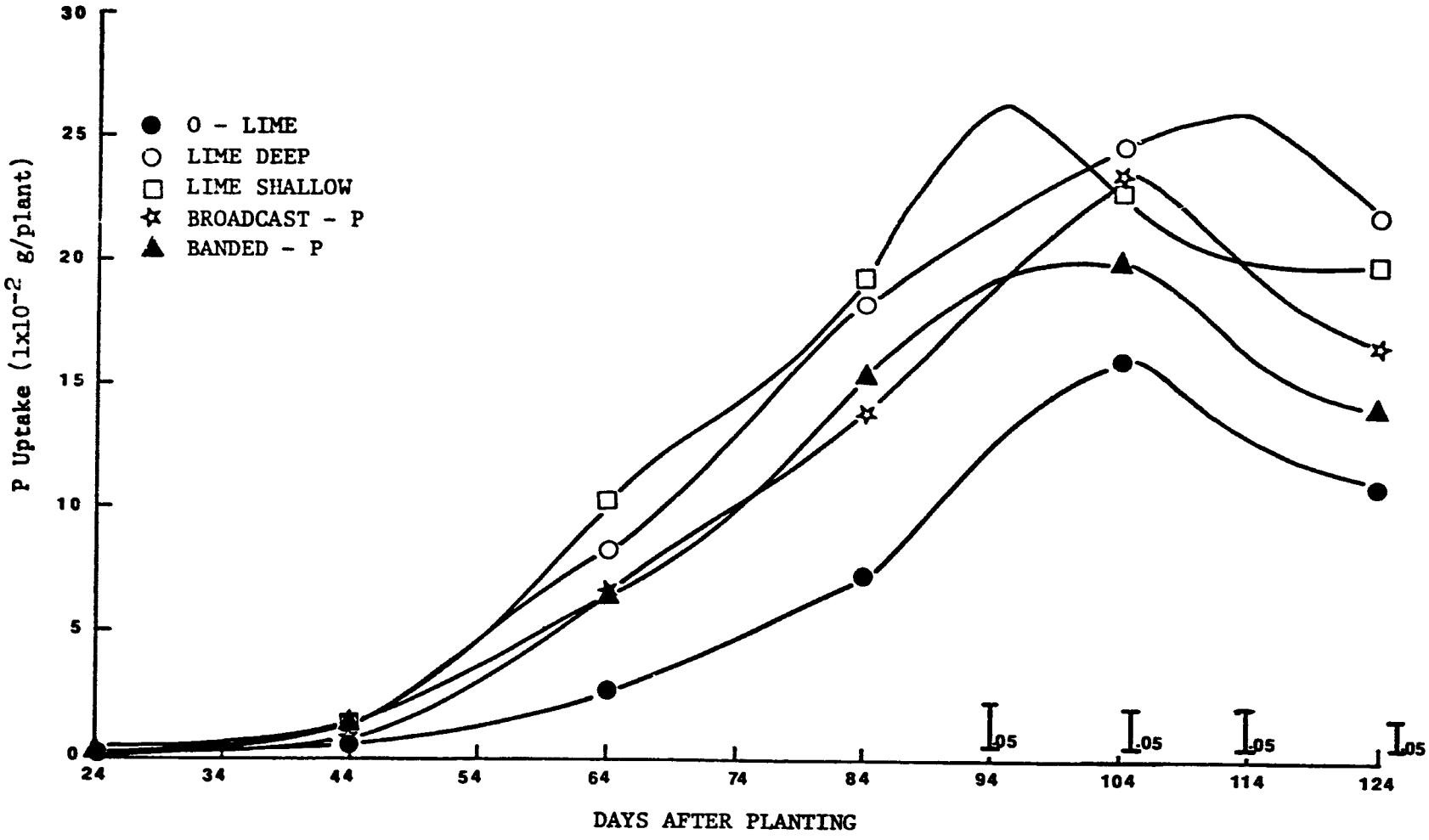


Fig. 32. Plant uptake of phosphorus throughout the growing season in relation to the five fertility treatments.

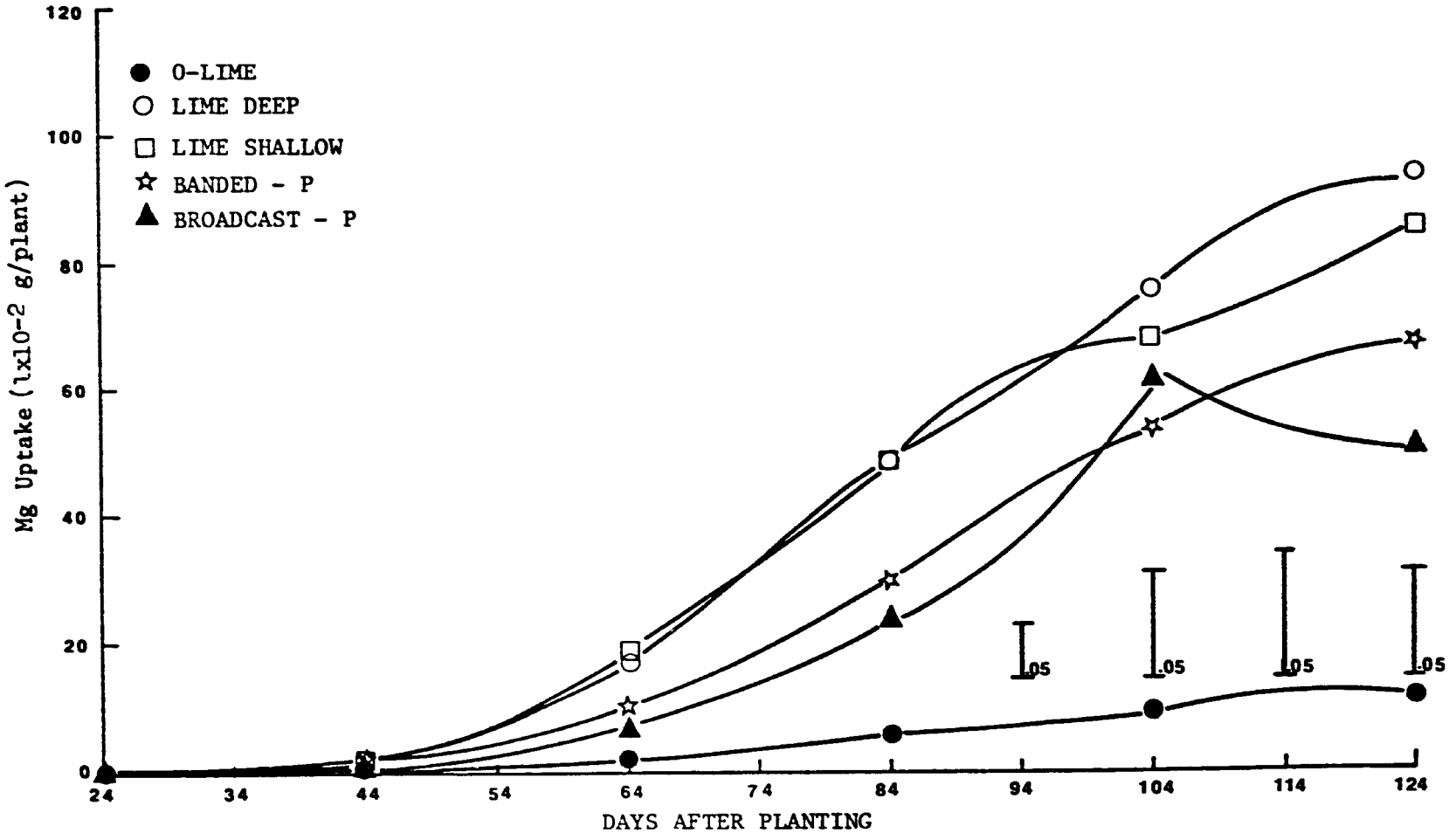


Fig. 33. Plant uptake of magnesium throughout the growing season in relation to the five fertility treatments.

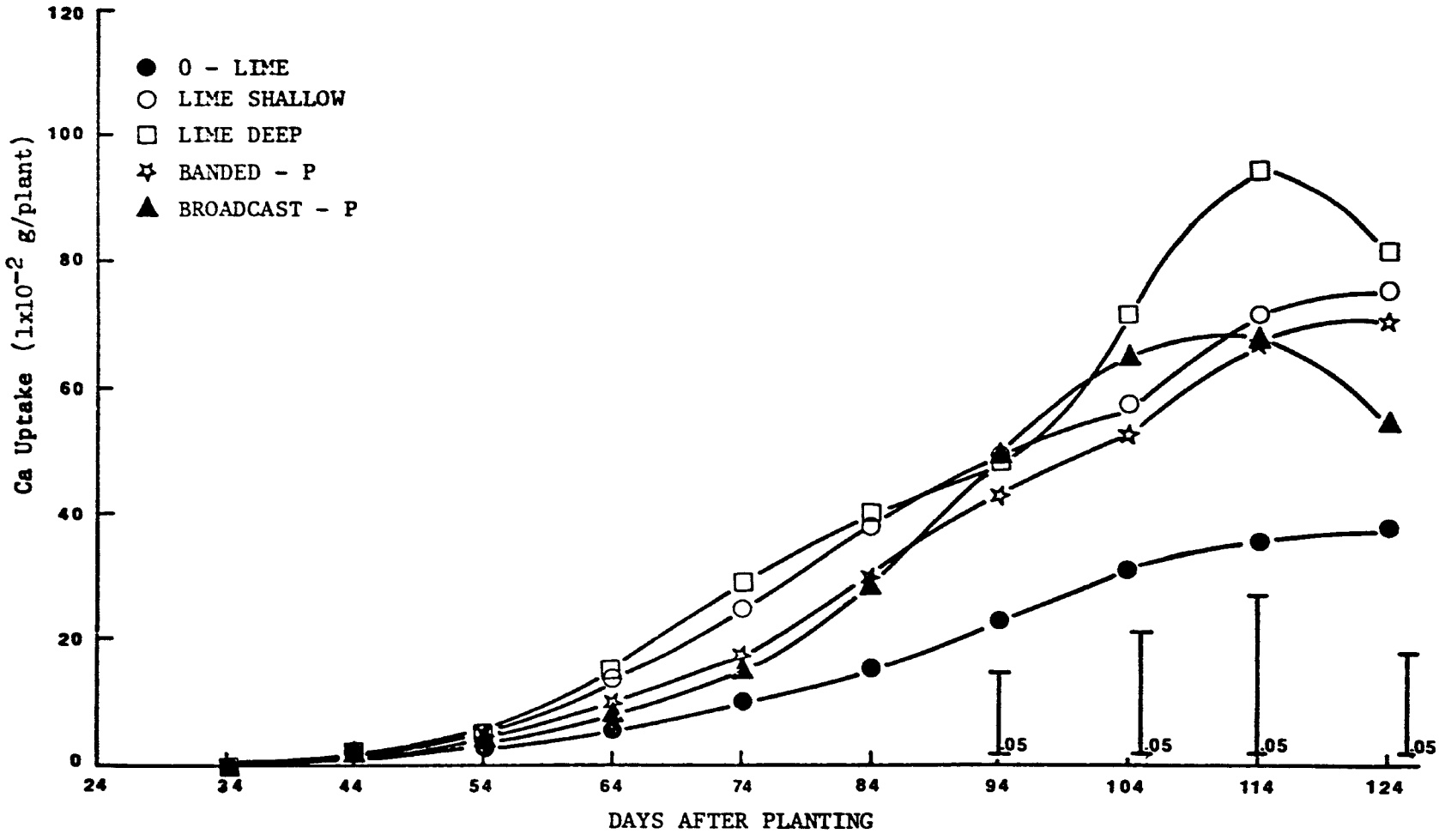


Fig. 34. Plant uptake of calcium throughout the growing season in relation to the five fertility treatments.

Table 34. Uptake of P, K, Ca, Mg, and Zn by corn grain and stover in relation to water stress and fertility. Results are expressed in kg/ha.

Treatment	Phosphorus		Magnesium		Calcium		Potassium		Zinc	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
					No Stress					
0-Lime	22.98	2.62	9.23	4.47	2.912	22.18	25.96	43.94	.17	.08
Lime-Shallow	34.11	4.25	15.01	33.47	2.933	27.50	36.56	74.60	.22	.07
Lime-Deep	38.44	4.67	16.45	28.65	2.907	26.13	40.20	75.58	.23	.06
Broadcast-P	35.04	3.89	14.98	23.91	2.769	27.57	35.75	66.22	.23	.07
Banded-P	27.00	3.87	12.16	26.21	2.975	26.98	28.75	62.09	.17	.05
					Late Stress					
0-Lime	20.53	2.49	7.80	3.39	2.208	18.18	20.14	47.42	.18	.06
Lime-Shallow	30.12	7.10	11.93	26.60	2.163	30.41	28.93	81.50	.18	.12
Lime-Deep	31.12	5.08	13.07	28.07	1.872	24.63	30.53	78.10	.19	.07
Broadcast-P	33.10	3.54	14.22	22.88	2.754	26.88	33.08	66.68	.23	.07
Banded-P	29.56	2.61	13.55	24.41	2.445	24.23	30.28	53.23	.23	.07
					Early Stress					
0-Lime	31.03	2.74	12.54	3.70	3.658	18.25	30.03	56.66	.24	.09
Lime-Shallow	40.40	3.98	16.86	28.02	2.926	23.66	40.68	58.57	.25	.07
Lime-Deep	35.96	4.09	15.63	29.49	2.236	28.47	36.75	68.19	.22	.07
Broadcast-P	34.18	3.53	14.94	22.77	2.647	25.38	36.12	66.25	.21	.06
Banded-P	31.74	2.99	15.30	23.72	2.879	21.62	33.79	58.63	.21	.06
F Test-Nut.	0.1 %	0.1 %	0.1 %	0.1 %	n.s.	5 %	0.1 %	0.1 %	n.s.	1 %
F Test-Stress	10 %	n.s.	10%	n.s.	n.s.	n.s.	10 %	n.s.	n.s.	1 %
F Test-S*N	n.s.	1 %	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	1 %
C.V. (%)	13.66	22.08	14.53	27.12	20.02	19.85	11.66	16.81	19.1	17.4

Table 35. Soil analysis results for two measurement periods during the 1975 dry season maize experiment.

Treatment	pH 1:1 H_2O Sept 8	pH 1:1 H_2O Nov 20	Ca + Mg meq/100ml Sept 8	Ca + Mg meq/100ml Nov 20	Al meq/100ml Sept 8	Al meq/100ml Nov 20	Al Sat. % Sept 8	Al Sat. % Nov 20	Phosphorus ppm Sept 8	Phosphorus ppm Nov 20
					0-15 cm					
0-Lime	4.43	4.59	.55	.57	1.14	1.25	67.5	68.7	23.5	21.5
Lime-Shallow	6.03	6.26	4.52	5.11	.00	.00	0.0	0.0	26.0	22.4
Lime-Deep	5.68	5.83	4.05	4.13	.02	.02	.5	.5	27.9	28.7
Broadcast-P	5.36	5.51	3.17	3.15	.13	.10	3.9	3.1	38.7	36.7
Banded-P	5.25	5.39	2.69	2.70	.16	.17	5.6	5.9	6.6	5.7
					15-30 cm					
0-Lime	4.23	4.62	.36	.33	1.12	1.14	75.7	77.6	3.6	2.6
Lime-Shallow	4.84	4.94	1.37	1.44	.56	.57	28.4	28.4	4.8	2.5
Lime-Deep	5.36	5.50	2.62	3.14	.18	.10	6.4	3.1	5.5	3.2
Broadcast-P	4.56	4.78	.76	1.00	.89	.87	53.9	46.5	4.8	3.1
Banded-P	4.53	4.74	.86	.80	.89	.93	50.9	53.8	2.3	1.5
					30-45 cm					
0-Lime	4.20	4.34	.27	.21	.88	1.04	76.5	83.2	1.8	0.9
Lime-Shallow	4.37	4.57	.44	.44	.81	.88	64.8	66.7	2.1	0.9
Lime-Deep	4.44	4.68	.59	.68	.71	.77	54.6	53.1	2.2	1.0
Broadcast-P	4.25	4.51	.40	.43	.87	.92	68.5	68.1	2.1	1.0
Banded-P	4.26	4.43	.39	.33	.85	.93	68.5	73.8	2.0	1.2

The second time was after the experiment had been harvested. The reason for the two sampling periods was to learn if there would be a decrease in soil acidity due to rainfall. Table 35 shows a slight decrease in soil acidity and % Al Sat. for all treatments but the differences are not very large. Phosphorus in solution was more than adequate. Banded-P results are low because soil sampling was done between the rows only, thus missing the band of P within the row. The deep liming treatment still has a 15-30 cm soil layer very conducive to root penetration.

CONCLUSION

The growth of the unlimed treatment was always inferior to the deep and shallow lime treatments. There were no significant growth differences between the deep and shallow lime treatments during the early part of vegetative growth with shallow lime at times giving better growth than deep. From about 50 % tasseling on, deep liming usually showed significant increases in leaf area, leaf dry weight, and total dry weight. The better growth seemed to be related to delayed leaf senescence.

Phosphorus applied in bands gave better seedling vigor than the broadcast application because the band of P was more easily utilized by the young corn root system. After the seedling stage, the broadcast-P treatments gave significantly superior growth for the first two crops. The amount of P applied in the bands was not sufficient to maintain optimum plant growth. However, after the third crop, the banded-P plants were able to grow at the same rate as the broadcast-P plants due to the reapplication of phosphorus in bands for each crop and the reducing residual effect of the one time only application of broadcast-P.

Water stress during the vegetative growth stage gave significant decreases in all growth parameters. The plants did not recover from the effects of the water stress period during the vegetative stage in the 1975 dry season crop for leaf area, leaf dry weight and plant height. Other growth parameters, such as stem dry weight, were not permanently affected. Nutrient treatments usually did not produce any differences in the initial water stress effect, but deep liming and broadcast-P plants recovered from

some of the stress effects earlier than the other treatments.

Water stress after tasseling enhanced leaf senescence and reduced leaf dry weight, stem dry weight, ear dry weight, and tassel dry weight. Net assimulation rates (NAR) and relative growth rates (RGR) were reduced by the early stress period but did not show a late stress effect. No significant differences between the five fertility practices were seen for NAR and RGR.

Regression analysis showed that periodic measurement of the total leaf area of the plant was sensitive enough to predict plant response to water stress and nutrient treatment up through Hanway stage 5.

Soil temperatures were found to fluctuate daily down to a 60 cm depth. The upper soil layer was cooler at night by 5 ^{o}C or more than deeper soil depths which could cause the upward movement of water due to the associated vapor pressure gradient.

Soil water use was shown to be influenced by depth of lime incorporation for all three experiments. Water use during the early stress period usually did not show a large deep lime effect. Late stress periods widened the differences between the nutrient treatments with the deep lime treatment always showing the greater soil water use, especially below the 22.5 cm soil depth. Deep limed plants used anywhere from 2-18 mm more soil water than all other treatments.

Daily water flux measurements under a mature corn field (LAI $\geq$ 3.0) showed that downward movement of water continued for only 2-3 days after soil saturation. Water was shown to move upward from deeper soil depths due to the large pressure head gradient developed from plant water use during the day and soil temperature differences at night. As much as

1.5 mm/day of soil water was noted to move upward. Water use by full grown corn plants was shown to be 5-6 mm/day under well watered conditions and decrease to 1-2 mm/day during severe plant stress. The soil water extraction pattern was dynamic with more water being extracted from deeper soil depths as the veranico continued.

The various soil management practices influenced plant water stress with deep limed plants usually showing less stress in comparison to the other four treatments. Deep limed plants became water stressed later on in the day and returned to less negative leaf water potentials earlier in the evening. For example, during the 1974-5 wet season veranico, shallow limed plants showed a -20 bar four days earlier than deep limed plants. In other stress periods, deep limed plants never became severely stressed while the shallow limed plants were near the permanent wilting point. Banded-P plants were less stressed during the first two experiments because they were much smaller plants. When the corn plants were equal in size for the two phosphorus application treatments, the broadcast-P treatment was superior, i.e. lower Ψ_L and higher RWC.

Stomatal resistance (R_s) and transpiration rate (E) results always showed that deep lime incorporation delayed and reduced plant water stress. Diurnal measurements showed that stomates were closing in the late morning for shallow limed plants as the veranico became more severe. The stomates never closed in the late morning due to plant water stress in the deep lime treatment. The transpiration rate (E) for plants in the deep limed plots was shown to average 68 % more than E for shallow limed plants during the 1974-5 veranico.

Leaf temperatures generally agreed very closely with stomatal

resistance and transpiration results. Plants with the least R_s and most E had the lowest leaf temperatures. This occurred in the deep limed plants.

Corn canopy microclimate was usually influenced by lime depth incorporation. Shallow limed plant canopies showed lower percent relative humidities than deep limed plant canopies.

Leaf chloropyll contents were found to be degraded with increasing plant water stress but no nutrient influence was noted.

Photosynthetic rate measurements were taken on one experiment only. The results showed that the deep limed plants averaged 10 mg CO_2 dm^{-2} hr^{-1} more than shallow limed plants during the stress period.

At final grain harvest, deep lime incorporation plots outyielded shallow limed plots in both water stressed and non-water stressed treatments. Non-limed treatments yielded less than limed plots. A 10-15 day water stress period during the vegetative growth stage permanently reduced plant size but it did not significantly reduce grain yield. A 10-15 day stress period during the grain formation stage decreased yields by 100-150 kg/ha/day.

With all other fertilizer treatments being equal, incorporation of lime 30 cm deep instead of the traditional 15 cm depth produced 1157 kg/ha more grain for the three crops under non-water stressed conditions and produced 2043 kg/ha more grain under the stressed conditions. On a three crop average, late stress reduced yields by 19 % for deep limed treatments and 27 % for shallow limed treatments.

The no lime treatment with adequate amounts of N, P, K, Zn, and Boron returned around 4,000 kg/ha of corn grain, thus showing that

Cargill-111 was somewhat tolerant to aluminum toxicity. But, by only adding lime to a 30 cm depth, yields were increased by 4800 kg/ha for the three seasons under non-water stressed conditions. Late period water stress reduced yields by 31 % in unlimed soils.

Broadcast application of phosphorus gave less reduction in yield in relation to plant water stress for two of the three seasons when compared to the banded application of phosphorus. Both treatments gave significant reductions in grain yields when water stress was imposed on the plants during the grain filling stage.

One of the effects of plant water stress during the grain filling stage was to reduce ear dry weight accumulation by one gram/day. Another effect was to change the source of carbohydrate for ear dry weight accumulation. Carbohydrate reserves in the culm were the main source for ear dry weight accumulation during the stress period. Under non-stress conditions, ear dry weight accumulation came directly from the leaves as the result of uninhibited photosynthesis.

A yield component analysis was conducted to determine what effect the soil management practices and what effect plant water stress had on the various yield components which influenced final grain yield. Deep limed plants outyielded shallow limed plants because they had longer ears, more kernels/row, more kernels/ear, more grain/plant, and a better grain-cob ratio. Late water stress reduced grain yield by producing fewer rows of kernels/ear and fewer kernels/ear.

Root distribution measurements showed that the depth of lime incorporation influenced the depth of root penetration. The quantity of root at various depths and lateral distances from the corn plant were

also influenced by the five fertility management practices.

Nutrient uptake by the plant and by the grain and stover showed that under low limed conditions magnesium was the most limiting factor to optimum plant growth and production. Under limed conditions, phosphorus was the most critical nutrient in limiting yields. Water stress in both early and late stress periods reduced nutrient uptake. Water stress during the grain filling stage reduced Ca and Mg uptake by 61 % & 52 % and reduced P-translocation from stover to grain by 48 %. Potassium uptake in both grain and stover was also negatively influenced by water stress.

Soil analysis results showed that the soil never stayed moist long enough to dissolve lime during the 1974 dry season crop even though it was irrigated every 4-7 days during the dry period. Once the rains came, the lime dissolved very rapidly. Lime residual effect through three cropping seasons was excellent for both the 4 ton and 8 ton/ha rates.

Phosphorus application rates of an initial 400 kg/ha P_2O_5 broadcast and a pre-plant band of 100 kg/ha P_2O_5 were more than sufficient to maintain a high level of available P in solution. The 640 kg/ha P_2O_5 broadcast treatment showed a loss of 25 ppm of P in solution for one season's growth. The third application of 160 kg/ha P_2O_5 in bands built up the phosphorus availability in the soil to where its P uptake in the grain plus stover was equal to that of the other four treatments.

CHAPTER II

1974-5 Wet Season Crop Management Experiment

Rainfall intensity and distribution are two very serious problems that have to be managed or controlled before any economically viable cropping system can be implemented in the Brazilian Cerrado. The short-term droughts during the rainy season "veranicos" can greatly reduce plant growth and productivity. Rainfall intensity is also a problem in that it can cause severe water and soil losses on clean-tilled land. This researcher has observed 3-hour rainfall periods produce 75 mm of rain. New cropping systems are needed to conserve the soil and water resources. Mulching with various plant residues and materials have been used extensively in areas where rainfall is limiting or the slope of the land is such that clean-tillage encourages excessive soil erosion.

In addition, there is the possibility of conserving soil water during a veranico by suppressing plant transpiration. Many materials have been used to reduce water loss, i.e. formulations of cetyl alcohol (Roberts, 1961); plastic films (Gale, 1961); and dilute concentrations of metabolic inhibitors (Zelitch, 1961; Zelitch and Waggoner, 1962).

The experiment was designed to utilize both crop and soil management technique to enhance conservation of soil moisture and/or improve water use efficiency. It was completely randomized with a factorial design. The treatments were; 1) two depths of lime incorporation (shallow, 0-15 cm and deep, 0-30 cm), 2) dry grass mulch 10 cm thick or no mulch, 3) two types of antitranspirants (Wilt Pruf and Phenyl Mercuric Acetate). Three

replications were included. The principal objective was to study how the various management techniques would reduce the negative effect of a veranico on crop growth and production; a veranico being a short drought period within the rainy season. All stress measurements, methods, and procedures were the same as described in the previous paper.

A 15-day veranico occurred 66 days after planting which coincided with the begining of the tasseling stage in corn. Water stress measurements were taken for six days (14/1/75 through 19/1/75). To learn if the plants were able to fully recover from the veranico, water stress measurements were taken for two days (29/1/75 and 30/1/75) after 47.3 mm of rain had occurred in the 10 day interim (Figure 35). Other meteorological data in figure 1 shows that Pan ET, maximum temperature, and solar radiation were quite high. Photosynthetically active radiation (PAR) was taken during the two stress measurements periods. PAR was very intense, even after the readings were averaged with the cloudiness effect (Figure 36).

The vegetative growth of the corn was periodically measured by using total leaf area and plant height (Figure 37, Table 36). Measurements began 26 days after planting and were taken every 14 days thereafter to 85 days after planting. The same 4 plants/plot were measured throughout the crop's growth by using a non-destructive technique for leaf area determination. Cargill-111 had a larger leaf area than Agroceres-152. Deep lime incorporation gave a small increase in leaf area over shallow lime incorporation . A 15 day veranico (drought) started 66 days after planting. Fifty percent tasseling occurred 77 days after planting. The effect of the veranico on leaf area, leaf number, and plant height was

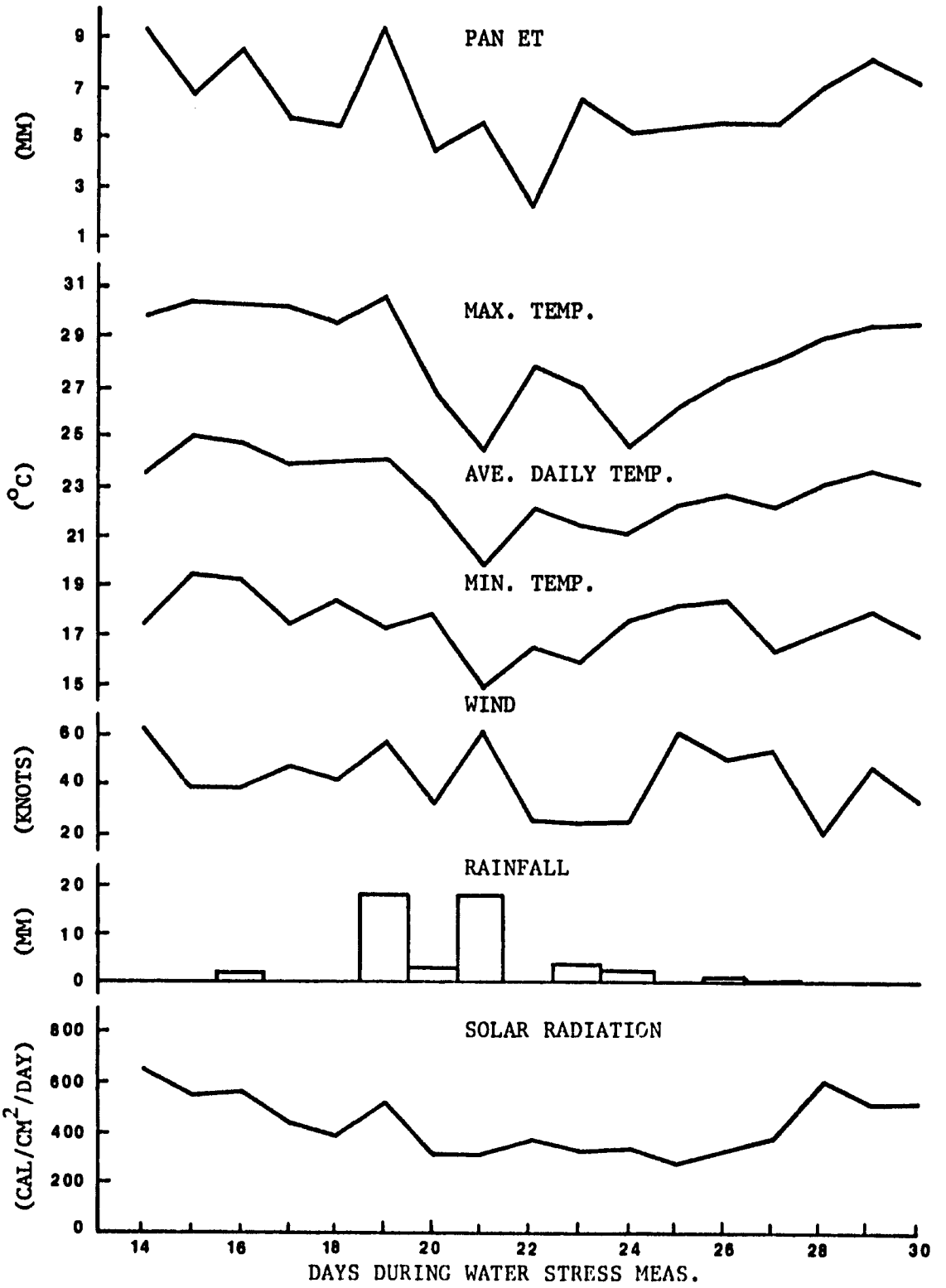


Fig. 35. Meteorological data for the 1974-5 wet season. Time period (days) corresponds to plant measurements taken during the veranico in January '75 and recovery period.

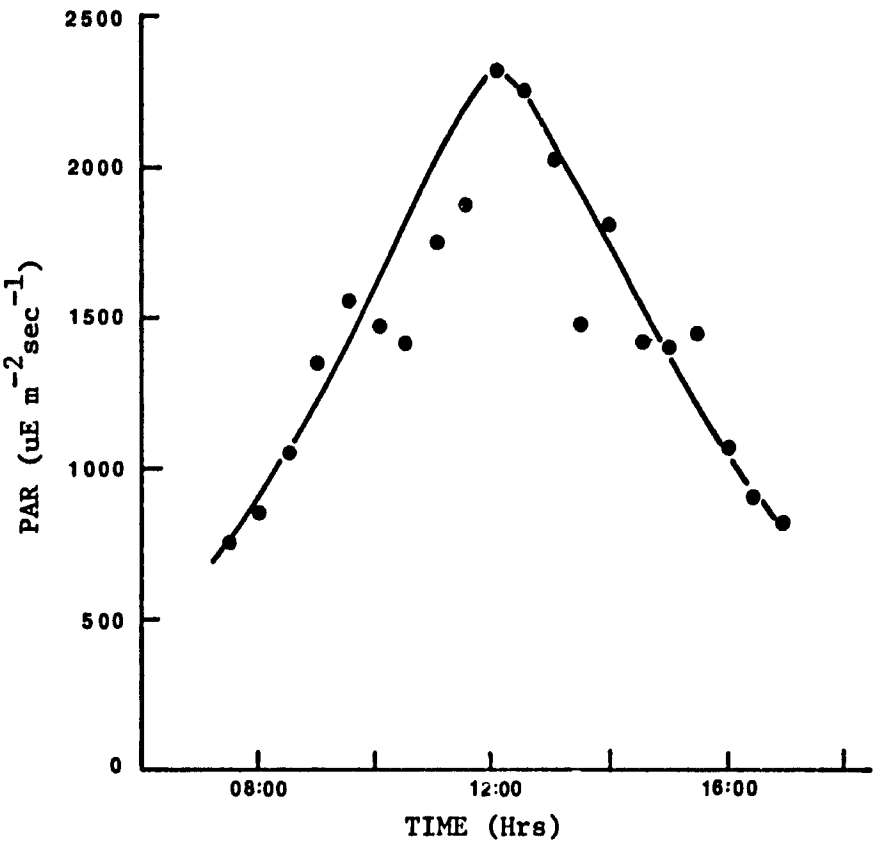


Fig. 36. Photosynthetic active radiation measurements taken daily during the 8 days of water stress measurements. (14/1 - 19/1/75 and 29/1 - 30/1/75).

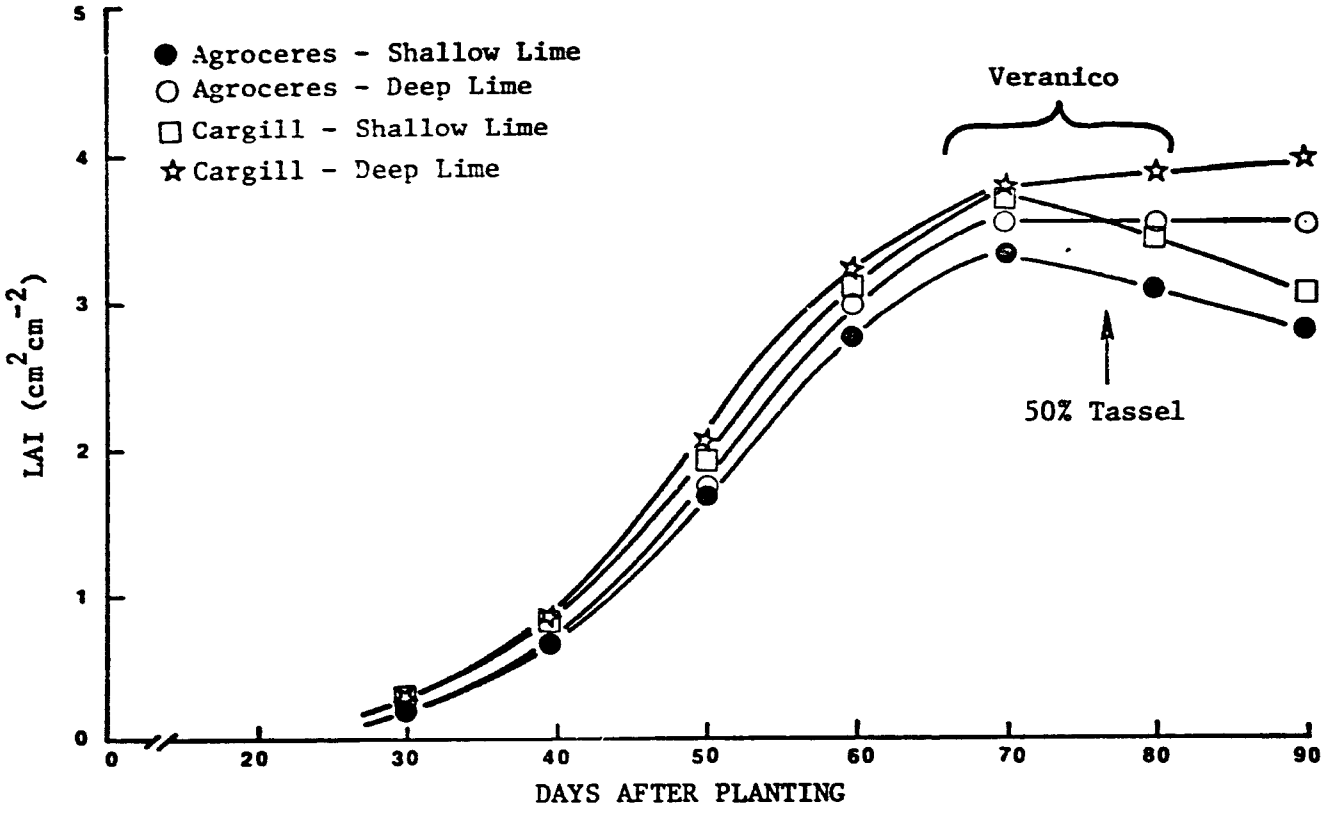


Fig. 37. Leaf area index (LAI) for maize grown during the 1974-5 wet season at Planaltina, Brazil. Shallow lime refers to 0-15 cm depth of lime incorporation and deep lime refers to 0-30 cm depth of lime incorporation.

Table 36. Leaf area index (LAI), plant height (Ht), and number of leaves for corn grown during the 1974-5 wet season at Planaltina, Brazil. Results for LAI and Ht are expressed in cm^2/cm^2 and cm respectively.

Treatment	Days after Planting										
	27 days		40 days		54 days		68 days		85 days		No. of Leaves
	LAI	Ht	LAI	Ht	LAI	Ht	LAI	Ht	LAI	Ht	
Agroceres-Shallow	.130	16.5	.657	44.2	2.17	118.0	3.34	193	2.931	222	11.2
Agroceres-Deep	.126	16.4	.652	42.6	2.27	119.6	3.50	197	3.480	236	12.6
Cargill-Shallow	.157	20.3	.759	53.5	2.54	136.2	3.68	195	3.317	213	11.1
Cargill-Deep	.157	20.3	.754	54.6	2.59	140.5	3.70	209	3.830	232	12.3

Table 37. Average percent soil water content for six days of measurements (14/1 through 19/1/75) during a 15 day veranico (5/1-19/1/75) at five soil depths of a 0-45 cm soil profile.

	Treatments	Soil Depth				
		0-15 cm	15-22.5 cm	22.5-30 cm	30-37.5 cm	37.5-45 cm
		g/100g				
(9)	Cargill-Deep-Mulch	20.6	21.1	20.8	22.5	23.2
(29)	Cargill-Deep-No Mulch	17.6	18.9	20.5	20.9	21.7
	ave. of Deep Lime Tr't.	(19.1)	(20.0)	(20.7)	(21.7)	(22.5)
(23)	Cargill-Shallow-Mulch	19.9	21.1	22.1	22.8	24.8
(10)	Cargill-Shallow-No Mulch	18.6	20.7	23.7	24.6	25.0
	ave. of Shallow Lime Tr't.	(.9.3)	(20.9)	(23.0)	(23.7)	(24.9)
(28)	Cargill-No Mulch-Anti transpirants	16.4	19.0	21.0	23.2	24.8

clearly demonstrated. Leaf area decreased in the shallow lime treatments for both varieties, due to enhanced leaf senescence caused by water stress.

A mulch of molasses grass was used as one method of conserving soil water. The mulch decreased soil temperatures by approximately 3 ^{o}C in the top 5 cm of soil depth and it continued having an effect of decreasing soil temperature to an 18 cm soil depth. Soil temperature measurements were taken daily at 15:00 hours during the 6 days of water stress measurements (14/1 through 19/1/75) (Fig. 38).

Air temperature and percent relative humidity were measured daily within the corn canopy at 12:30 and 14:30 hours during the 6 day period of water stress measurements. The measurements were taken with a sling synchrometer approximately 30 cm above ground level but below active or green corn leaves. Average results from 6 days of measurements are shown in Figure 39 . The mulched plots gave a lower % RH and higher air temperature than the plots having no mulch. The results suggest decreased soil water evaporation with mulching. This also means that the corn plants were called upon to transpire more to meet ET demand. A larger vapor pressure deficit of approximately four mbars was placed upon the mulched plants. The daily canopy % RH and air temperature results are presented in Figure 40. Note the large increase in % RH on 17/1/75 which was due to a 2.5 mm rainfall the night before.

Soil moisture content was measured throughout the crop growing season with tensionmeters and gypsom blocks. During the six day water stress measurement period, soil moisture content was determined at five depths by gravimetric sampling. The results in Table 37 show that the

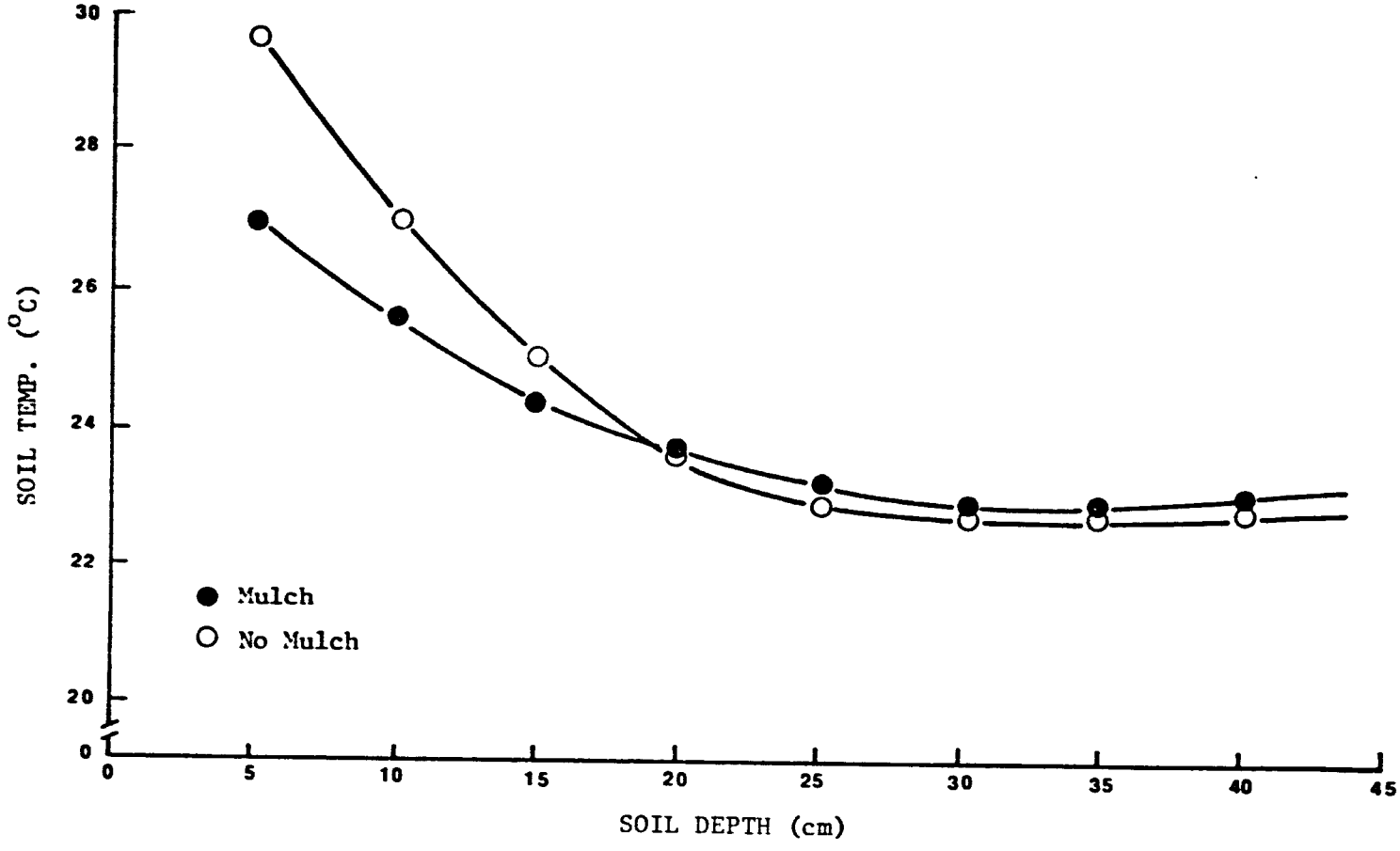


Fig. 38. Soil temperatures for mulched and unmulched corn plots. Measurements were taken at six soil depths daily for 8 days at 15:00 hours. Time period corresponds to water stress measurement period.

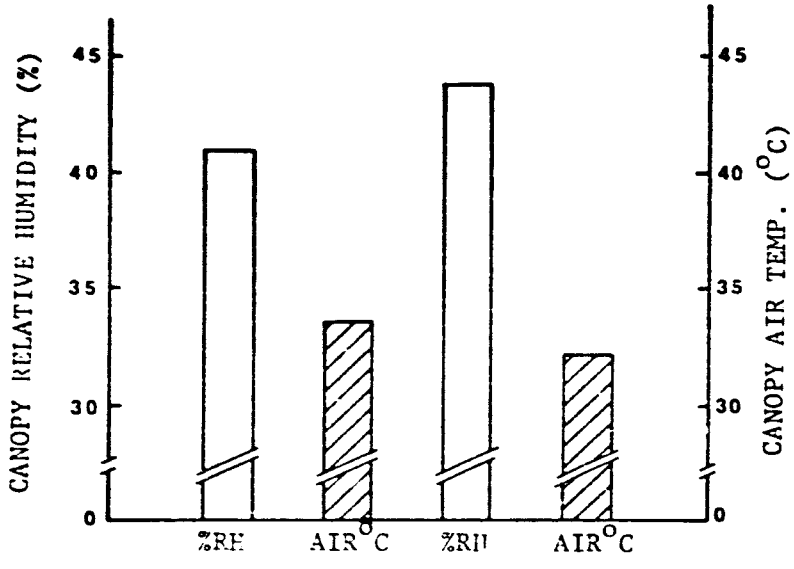


Fig. 39. Air temperature and % relative humidity within a corn canopy of mulched and unmulched plots. Data was collected at 12:30 hours daily for six days during the veranico (14/1 - 19/1/75).

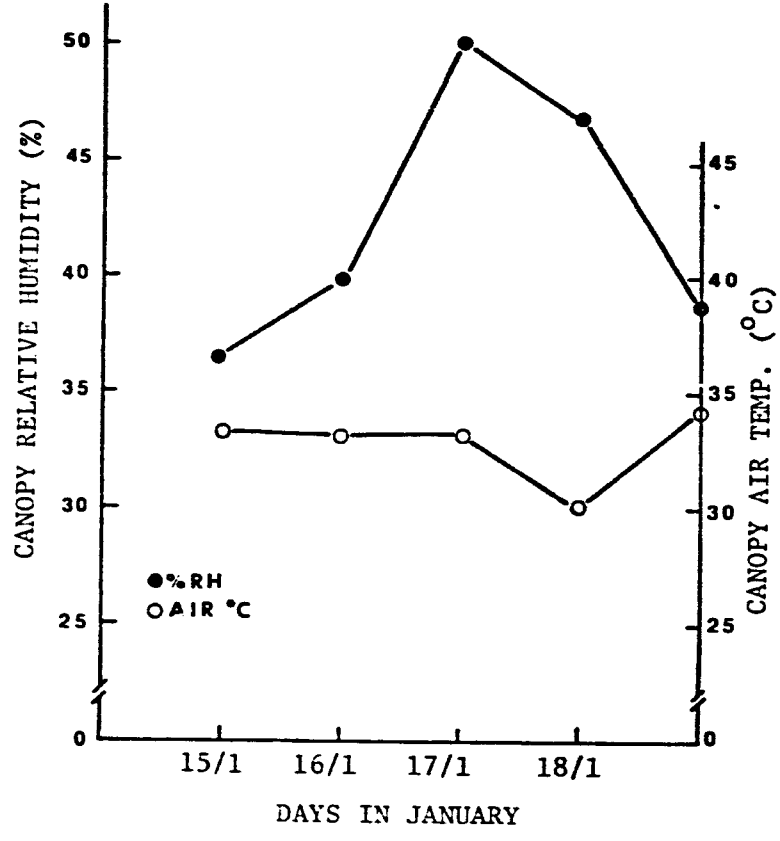


Fig. 40. Daily air temperature and % relative humidity in the corn canopy. Measurements were taken at 12:30 hours.

deep lime treatment increased water availability and use by the corn plants. There was 8.2 mm more soil water used by the deep limed plants or, in other words, deep liming delayed plant water stress by 3 to 4 days if the same ET rates can be used that were shown in the 1974-5 wet season maize experiment. Mulching increased soil water content by 4.5 mm in the top 20 cm of the soil profile. This larger soil water content near the soil surface was probably due to the decreased soil water evaporation shown above.

Leaf water potential (Ψ_L) was measured on 5 plants/plot for six treatments during the 8 days of measurements. All Ψ_L , relative water content (RWC), stomatal resistance (S_R), and leaf temperature (T_L) measurements were taken on the same leaf; third leaf down from the top and in direct sunlight. One-half of the leaf blade lengthwise, excluding midvein, was used for Ψ_L . The other half of the same leaf blade was used for RWC, S_R, and T_L. Leaf water potential during the veranico was greatly influenced by depth of liming, by grass mulch, and by their combinations (Fig. 41). The Ψ_L for the deep lime with mulch treatment averaged - 13.5 bars whereas shallow lime with no mulch averaged - 15.7 bars. Note that Ψ_L became more negative as the plants grew older but the respective differences in relation to treatment were still shown (Appendix 19). Two antitranspirants, Wilt Pruf and phenyl mercuric acetate were applied on their respective plots 13/1/75, one day before water stress measurements began. It was expected that the antitranspirants would reduce transpiration, thus leaf water potential. The results suggest that they were of no benefit in terms of Ψ_L . Their leaf water potentials were the same as those shown for the shallow lime-no mulch

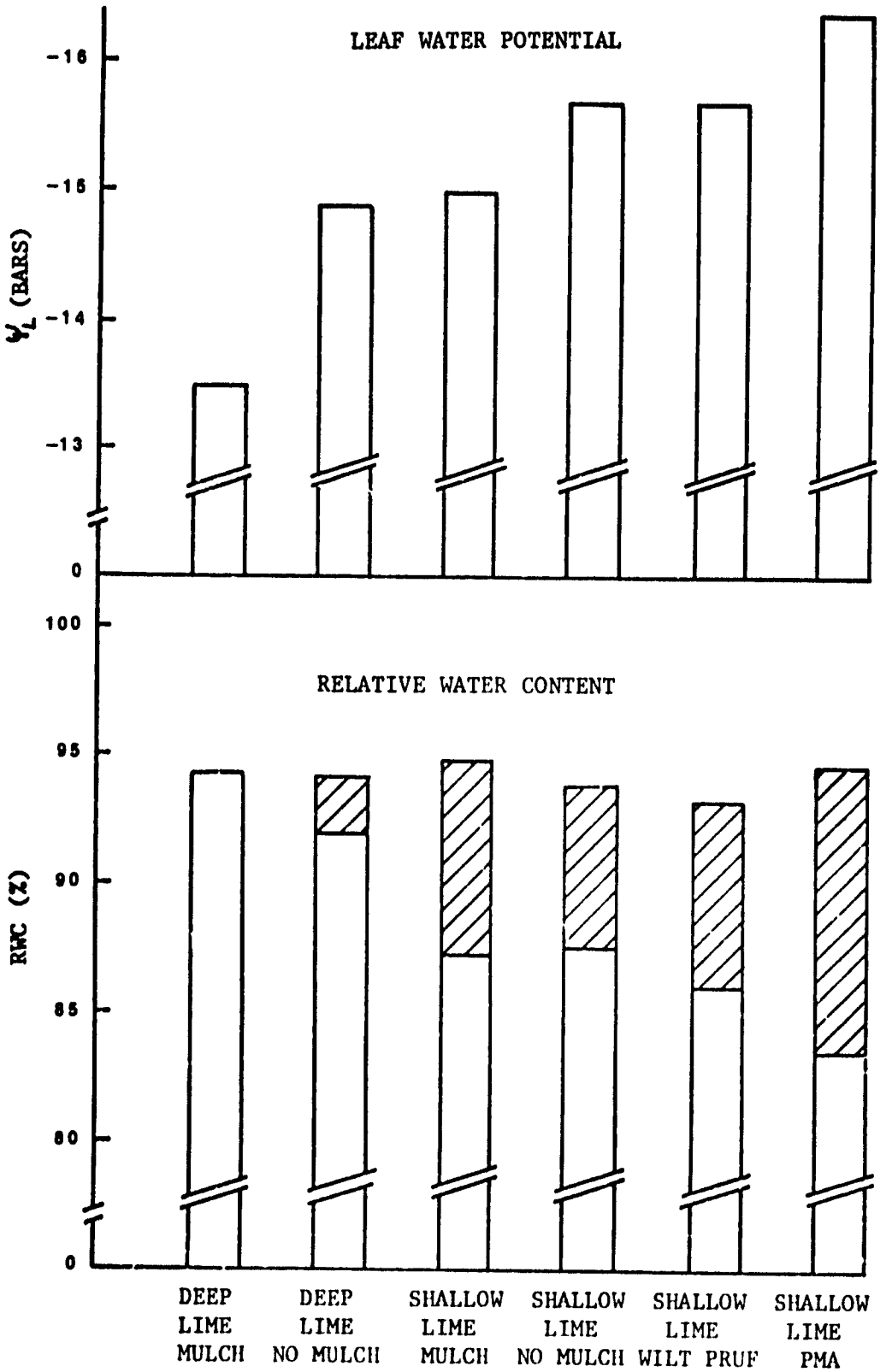


Fig. 41. Leaf water potential and relative water content for corn plants under water stress as a result of a 15 day veranico during the 1974-5 wet season. Measurements were taken daily at 14:30-15:30 hours for six days.

treatment.

Relative water content (RWC) reflected a soil water-plant water interaction equal to Ψ_L during the water stress measurements (Figure 41). Appendix table 20). Leaves were more turgid for deep lime and mulch treatments. RWC in the deep lime-mulch plots did not change during the veranico in comparison to RWC after 47 mm of rain. Note that in all the plots the leaves were able to return to normal leaf turgidity once the veranico was terminated by rains. Since the leaf cells were able to return to optimum RWC or turgidity, the veranico was not serious enough to cause permanent leaf cellular damage. The antitranspirants show that they were causing more leaf water stress than any other treatment.

Stomatal resistance (R_s) results continued to show the advantage of mulching, depth of liming, and their combinations in reducing plant water stress during a veranico (Table 38). Deep liming with mulch reduced R_s by 86.7 % compared to the shallow lime no mulch treatment. Note that after the rains the plants returned to normal R_s values of less than 5 sec cm^{-1}, thus the plants suffered no permanent damage from the veranico. The antitranspirants were expected to increase R_s by their respective modes of action. Wilt Pruf is a chemical spray which suppresses transpiration by covering the leaves with a thin film of plastic. Phenyl mercuric acetate (PMA) is a metabolic inhibitor which suppresses transpiration by affecting the guard cells of the stomates. The results suggest that the application of Wilt Pruf was poor in its coverage of the total leaf surface. PMA molar concentration (10^{-7}) was probably too low to induce proper stomatal closure, thus no PMA effect was shown in any of the plant stress results (Slatyer, et-al, 1964).

Table 38. Stomatal resistance for the top and bottom side of corn leaves under water stress conditions.

Plot. No.		Sampling Days During Water Stress						Sampling Days after rains		
		15/1	16/1	17/1	18/1	19/1	X	29/1	30/1	X
		Sec cm^{-1}								
10	1/	104.3	35.7	53.6	29.0	82.2	61.02	3.8	3.3	3.60
	2/	76.4	35.7	45.4	32.5	75.8	53.18	1.8	2.1	1.97
23		80.6	56.3	37.8	18.4	90.6	56.78	3.7	3.8	3.83
		8.17	42.5	26.5	23.8	65.8	48.09	1.7	1.4	1.61
29		22.8	27.3	17.3	20.3	57.2	29.02	6.2	5.9	6.10
		7.9	15.0	11.7	9.7	49.4	18.79	3.2	2.2	2.76
9		11.7	6.2	5.2	5.5	18.3	9.44	5.8	3.2	4.54
		4.9	3.3	2.1	4.6	20.3	7.09	2.3	1.7	2.08
28_1		54.4	41.6	20.0	48.6	121.1	57.16	4.0	12.5	8.30
		52.4	32.8	17.3	40.3	73.9	43.40	1.5	3.3	2.43
28_2		33.9	44.7	16.2	17.1	56.6	33.74	10.9	10.0	10.48
		48.3	43.0	9.9	19.4	50.8	34.32	2.5	3.9	3.26

Average R_s during 5 days of water stress measurements.

Plot No.	Treatment Identification	1/ Top	2/ Bottom
(9)	Deep-Lime-Mulch	9.44	7.09
(29)	Deep-Lime-No Mulch	29.02	18.79
(23)	Shallow-Lime-Mulch	56.78	48.09
(10)	Shallow-Lime-No Mulch	61.02	53.18
(28_1)	Shallow-Lime-No Mulch-Wilt Pruf	57.16	43.40
(28_2)	Shallow-Lime-No Mulch-PMA	33.74	34.32

Transpiration results also show that the antitranspirants did not diminish water loss (Table 39). Transpiration rates for the deep lime-mulch treatment didn't show any big decrease due to plant stress until the last day of the veranico.

Leaf temperatures were taken on the top and bottom sides of the third leaf down from the top at the same time stomatal resistance measurements were taken. Higher leaf temperatures should result when leaf transpiration rates are slowed down or stopped because the cooling effect caused by evaporating water would be less or stopped completely. The shallow lime-no mulch treatment gave higher leaf temperatures than the other lime or mulch treatments (Fig. 42). The antitranspirant leaf temperatures were very cool compared to the other treatments. Cool leaf temperatures suggest high transpiration rates.

High leaf temperatures should result in leaf senescence. Table 40 shows that the shallow lime-no mulch treatment had the least number of leaves at the end of the veranico. That same treatment had the highest leaf temperature. The antitranspirant treatments were at odds again. Very low leaf temperatures were noted above but the number of leaves were reduced more in those treatments than in any lime depth or mulch treatment.

Corn grain yield reflects the soil water-plant water relationship with the veranico (Table 41). The results show that the negative effect of the veranico can be controlled to some degree by proper soil and plant management techniques. Both corn varieties gave increased yields with deep liming, mulching, and their combined effect. Lime depth incorporation of 0-30 cms gave around 1200 kg/ha of corn grain (15.5 %

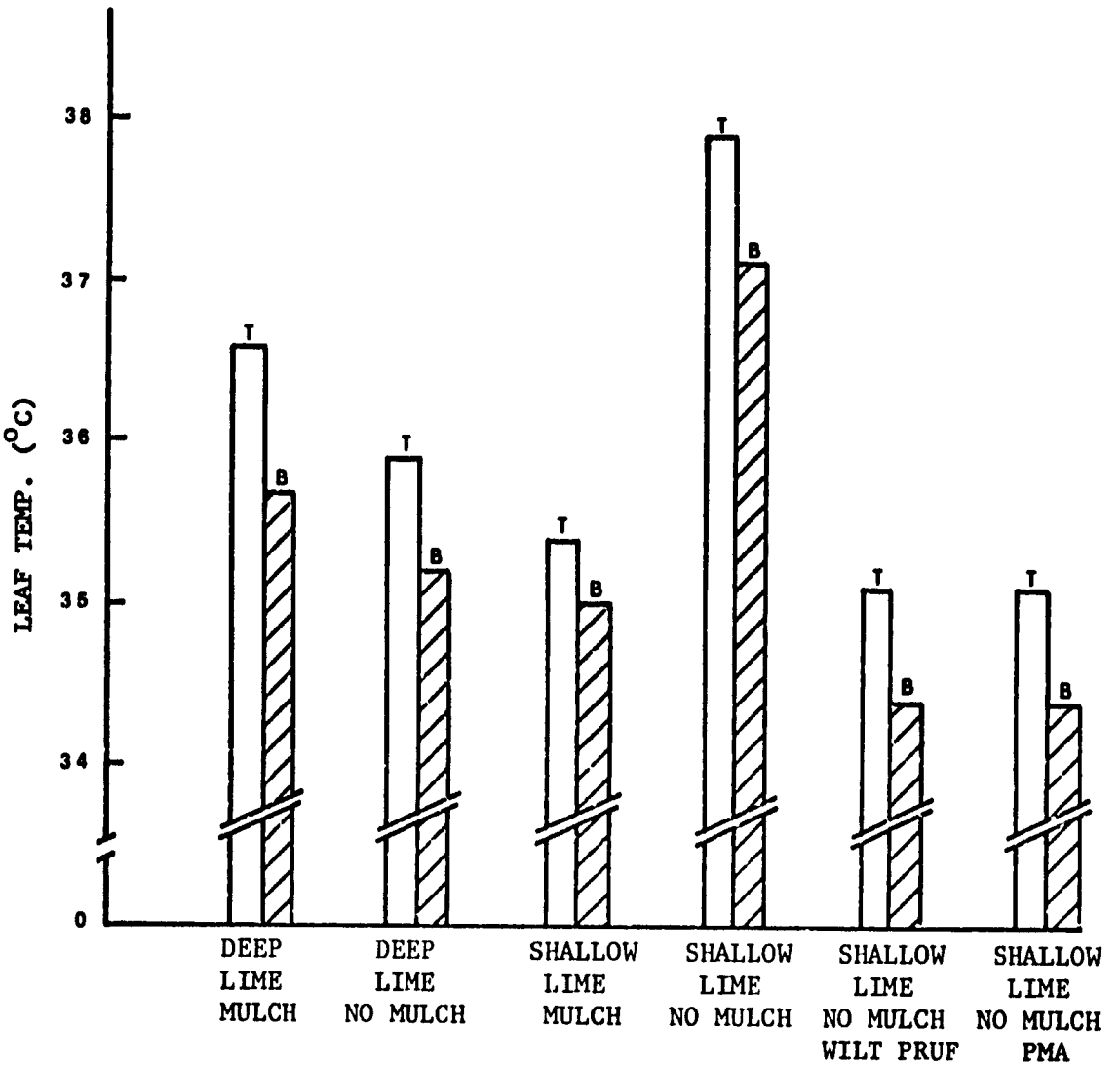


Fig. 42. Leaf temperatures for corn plants in relation to various treatment effects. Measurements were taken for six days of a 15 day veranico. T= Top of the leaf; B= Bottom of the leaf.

Table 39. Transpiration rates for the top and bottom side of the corn leaves as influenced by mulching and antitranspirants.

Treatment		Sampling Days During Water Stress					
		15/1	16/1	17/1	18/1	19/1	$\bar{X}$
		$\mu g\ H_2O\ cm^{-2}\ sec^{-1}$					
Deep-Mulch	1/	2.64	4.96	5.56	4.38	1.64	3.84
	2/	5.61	8.35	11.00	5.11	1.49	6.31
Deep-No Mulch		1.51	1.20	1.43	1.37	.58	1.21
		4.02	2.11	2.06	2.71	.67	2.31
Shallow-Mulch		.44	.58	.79	1.42	.38	.72
		.43	.76	1.11	1.15	.52	.79
Shallow-No Mulch		.35	.96	.67	1.05	.42	.69
		.47	.96	.79	.94	.47	.73
Shallow-Wilt Pruf		.57	.84	1.29	.53	.30	.71
		.60	1.06	1.47	.63	.49	.85
Shallow-PMA		.97	.76	1.46	1.45	.57	1.04
		.69	.79	2.30	1.29	.63	1.14

1/ Top

2/ Bottom

Table 40. The effect of plant water stress on number of corn leaves that remain active in relation to plant and soil management practices.

Plot No.	Sampling Days During Water Stress							Sampling Days after rains		
	14/1	15/1	16/1	17/1	18/1	19/1	X	29/1	30/1	X
9	15.2	14.8	14.2	14.4	14.0	13.2	14.3	13.2	13.4	13.3
10	14.4	13.6	14.4	11.8	11.6	12.2	13.0	12.2	11.2	11.7
23	14.6	13.2	14.0	11.8	13.2	12.0	13.1	11.6	11.2	11.4
28_1	14.2	12.8	13.0	12.0	11.6	10.4	12.3	11.0	13.6	12.3
28_2	13.2	12.4	11.2	10.2	9.4	8.4	10.8	9.2	9.8	9.5
29	15.8	15.2	14.6	11.8	12.8	13.2	13.9	12.4	12.4	12.4

Plot No.	Treatment Identification	No. of leaves (Ave. of 30 samples)
9	Cargill-Deep-Mulch	14.3
29	Cargill-Deep-No Mulch	13.9
23	Cargill-Shallow-Mulch	13.1
10	Cargill-Shallow-No Mulch	13.0
28_1	Cargill-Shallow-No Mulch-Wilt Pruf	12.3
28_2	Cargill-Shallow-No Mulch-PMA	10.8

LIME DEPTH EFFECT	No. of Leaves
Deep (0-30 cm)	14.1
Shallow (0-15 cm)	13.1

Table 41. Grain Yields for corn grown during the 1974-5 wet season at Plananltina, Brazil. All yield results are based on 15.5% moisture content. Deep lime refers to a 0-30 cm depth of lime incorporation and shallow lime refers to a 0-15 cm depth incorporation.

Treatment Identification	Grain Yield (kg/ha)	Lime depth Effect (kg/ha)	Mulch Effect (kg/ha)
Cargill-Deep lime-Mulch	7795	Deep = 7348***	Mulch = 7050**
Cargill-Deep lime-No Mulch	6901		
Cargill-Shallow lime-Mulch	6304		
Cargill-Shallow lime-No Mulch	6420	Shallow = 6362	No Mulch = 6661
Agroceres-Deep lime-Mulch	6348	Deep = 6502***	Mulch = 6023
Agroceres-Deep lime-No Mulch	6656		
Agroceres-Shallow lime-Mulch	5698	Shallow = 5198	No Mulch = 5677
Agroceres-Shallow lime-No Mulch	4698		
Cargill-Shallow lime-No Mulch-Wilt Pruf 1/	5843		
Cargill-Shallow lime-No Mulch-PMA 2/	5278		

1/ Antitranspirant

2/ Phenyl Mercuric Acetate Antitranspirant

*** = 0.1 % Level of Sign.

** = 1.0 % Level of Sign.

C.V. (%) = 4.51

Table 42. Stover yields for corn grown during the 1974-5 wet season at Planaltina, Brazil. All yield results are based on oven-dry weights. Deep lime refers to a 0-30 cm depth of lime incorporation and shallow lime refers to a 0-15 cm depth of lime incorporation.

Treatment Identification	Stover Yield (kg/ha)	Lime depth Effect (kg/ha)	Mulch Effect (kg/ha)
Cargill-Deep lime-Mulch	7609	Deep = 7662**	Mulch = 6788
Cargill-Deep lime-No Mulch	7714		
Cargill-Shallow lime-Mulch	5966	Shallow = 6590	No Mulch = 7464*
Cargill-Shallow lime-No Mulch	7214		
Agroceres-Deep lime-Mulch	6118	Deep = 6285**	Mulch = 5766
Agroceres-Deep lime-No Mulch	6451		
Agroceres-Shallow lime-Mulch	5413	Shallow = 5743	No Mulch = 6262*
Agroceres-Shallow lime-No Mulch	6072		
Cargill-Shallow lime-No Mulch-Wilt Pruf 1/	6223		
Cargill-Shallow lime-No Mulch-PMA 2/	5874		

1/ Antitranspirant

2/ Phenyl Mercuric Acetate Antitranspirant

** = 1.0 % Level of Sign.

* = 5.0 % Level of Sign.

C.V. (%) = 10.59

moisture) more than the 0-15 cm lime depth incorporation treatment. Mulching increased grain yields by 400 kg over no mulch treatments. Cargill significantly outyielded Agroceres by more than 1000 kg/ha.

Corn stover yields also show the advantage of deep liming, around 800 kg/ha more stover than shallow liming (Table 42). Cargill produced 1100 kg/ha more stover than Agroceres. Note the significant mulch effect; non-mulched treatments yielded more stover than the mulched treatments. A probable explanation was that mulching had a negative effect on plant vegetative growth due to cooler soil temperatures (Fig. 37).

The following table substantiates the assumption that mulching reduced plant growth (Table 43). Leaf area for the non-mulched plants was superior to the mulched plant's leaf area at the 1 % level of significance, 68 days after planting. Eighty-five days after planting, which was after the veranico, there wasn't any superiority in leaf area for non-mulched plants. Leaf area was reduced by premature leaf senescence due to plant water stress. Mulching was significantly superior to no-mulch plants in terms of having less leaf senescence.

Table 43. Growth measurements before and after the veranico in relation to mulching and variety.

Treatment	LAI		Pl. Ht.		# Leaves
	68 day	85 day	68 day	85 day	85 day
	cm^2 cm^{-2}		cm		no.
Cargill-Mulch	3.56	3.51	202	226	12.0
Cargill-No Mulch	3.81	3.64	204	219	11.4
Agroceres-Mulch	3.22	3.17	197	231	12.1
Agroceres-No Mulch	3.63	3.24	194	227	11.7

In conclusion, the veranico reversed the negative effect of the

mulch to a positive one because of soil water conservation which in turn reduced plant water stress.

Plant nutrient levels were more or less sufficient for corn growth and production. Ear leaf nutrient concentrations and stover nutrient uptake were closely correlated in relation to the treatments (Table 44 & 45). Phosphorus levels were sufficient with no differences seen between mulches or varieties. Magnesium and calcium results show a mulch and a varietal effect. The vegetative growth of Agroceres was always less than Cargill's and its resultant grain yield was substantually less. The reason for slow growth could be its less efficient uptake of Ca and Mg. Another reason could be the availability of Calcium and Magnesium in the soil . Reduced Ca and Mg uptake in mulched plots could be related to the cooler soil temperatures which reduced uptake. Shallow liming increased leaf concentrations of Ca and Mg while it decreased potassium. Potassium ear-leaf concentrations in the deep limed plants were in the nutrient sufficient range but the shallow limed plants were defficient in potassium. Deep liming probably enabled plants to be more efficient in extracting leached potassium from deeper soil depths. There weren't any problems noted with zinc.

Table 46 demonstrates the mulch effect on Mg and Ca uptake. Correlation coefficients show that stover yield was more dependent on Ca & Mg uptake in the mulch treatment. The near defficient levels of potassium, noted in Table 44 show how closely stover yield depended on K in all treatments.

Soil analysis results show why Calcium and Magnesium uptake were greater in shallow limed treatments (Table 47). Phosphorus in the soil

Table 44. Ear leaf nutrient concentration of P, Mg, Ca, K, and Zn as influenced by corn variety, depth of lime incorporation and mulching.

Treatment	Phosphorus %		Magnesium %		Calcium %		Potassium%		Zinc (ppm)	
	Cargill	Agro*	Cargill	Agro*	Cargill	Agro*	Cargill	Agro*	Cargill	Agro*
Deep-Lime-Mulch	.25	.24	.08	.10	.60	.49	2.0	1.8	35	31
Deep-Lime-No Mulch	.25	.23	.07	.11	.70	.53	1.9	2.1	29	31
Shallow-Lime-Mulch	.23	.24	.12	.14	.70	.60	1.9	1.4	31	30
Shallow-Lime-No Mulch	.23	.22	.17	.17	.82	.58	1.7	1.7	31	29

* = Agroceres.

Table 45 Uptake of P, Mg, Ca, and K by the stover. Resutls are expressed in kg/ha.

Treatment	Phosphorus		Magnesium		Calcium		Potassium	
	Cargill	Agro*	Cargill	Agro*	Cargill	Agro*	Cargill	Agro*
Deep-Lime-Mulch	3.34	3.46	9.14	6.32	19.88	10.21	96.66	69.28
Deep-Lime-No Mulch	4.88	3.11	8.57	6.33	22.24	15.13	96.48	75.28
Shallow-Lime-Mulch	2.98	3.64	6.76	5.49	12.43	10.51	67.72	68.11
Shallow-Lime-No Mulch	3.60	4.06	10.81	7.86	24.27	10.43	74.61	55.41
Mulch F Test	n.s.		5 %		10 %		n.s.	
Lime F Test	n.s.		n.s.		n.s.		5 %	
Variety F Test	n.s.		1 %		1 %		5 %	
C.V. (%)	26.48		20.91		38.11		22.83	

* = Agroceres.

Table 46. Correlation of nutrient uptake by the stover and stover yield in relation to mulching and maize variety.

Nutrient	Mulch	No Mulch	Cargill	Agroceres
P-Stover	.23	.65**	.46	.67**
Mg-Stover	.65**	.43	.31	.49*
Ca-Stover	.71***	.32	.25	.44
K-Stover	.90****	.87****	.86****	.75***

**** = 0.1 %; *** = 5 %; ** = 10 %.

Table 47. Soil analysis results taken at harvest time of the 1974-5 wet season mulch experiment. Results are for the 0-15 cm soil layer only.

Treatment	pH 1:1 H_2O	P (ppm)	Ca + Mg meq/100ml	Al meq/100ml	Al Sat. (%)
Cargill-Deep-Mulch	5.35	8.33	2.30	.40	14.8
Cargill-Deep-No Mulch	5.13	15.07	1.38	.73	34.6
Cargill-Shallow-Mulch	5.55	13.00	2.74	.25	8.4
Cargill-Shallow-No Mulch	5.35	8.07	2.16	.42	16.3
Agroceres-Deep-Mulch	5.13	8.33	1.51	.53	26.0
Agroceres-Deep-No Mulch	5.28	7.27	1.40	.72	34.0
Agroceres-Shallow-Mulch	5.42	8.73	2.53	.33	11.5
Agroceres-Shallow-No Mulch	5.32	8.53	2.58	.28	9.8

solution was low but close to the required 10 ppm for optimum corn growth. The 4 metric tons/ha of lime applied in September 1973 seems to be losing its ability to neutralize the acid soil and reduce the toxicity of aluminum, especially the 4 tons incorporated to the 30 cm depth whereas some lime was left in the plot that got 4 tons/ha in 0-15 cm. One more cropping season will probably deplete the last residual effect of lime to where soil acidity and % Al Sat. will become detrimental to crop growth and production.

1975 Dry Season Crop Management Experiment

This is a continuation of the mulching experiment that was initiated in the 1974-5 wet season. Some modifications were made to verify whether the grass mulch had a negative effect on corn growth. A black plastic mulch was installed along with a continuation of the grass mulch treatment. The black plastic should increase soil temperature and at the same time conserve soil moisture equal to the grass mulch. Two lime depth incorporations and two antitranspirants were used again. To accomodate the plastic mulch treatment, the Agroceres-152 comparison was not continued. Six plots of Agroceres corn were planted on shallow limed plots only to allow for a general comparison of the two varieties growing during the dry season.

Methods and procedures for the measurement of plant growth and production and for the measurements taken during the plant water stress period were the same as was explained in the companion maize papers. A completely randomized design was used. Three replications were included. To simulate a veranico, water stress was imposed on the plants by withholding irrigation water. The principle objective of this experiment was the same as in the 1974-5 wet season crop management experiment; to study various soil and plant management techniques which may reduce the harmful effects of a veranico.

The experiment was planted on 9/6/75 and harvested 141 days later. The plastic mulch was installed eleven days after planting. The total area of the plot was covered with 20 mil black plastic. Ten cm^2 holes

were cut in the plastic, 25 cm apart within the row to allow correct spacing for the 50,000 plant/ha population. A ten cm thick rice straw mulch was applied 46 days after planting. The simulated veranico commenced 112 days after planting and was terminated 11 days later by rainfall. The two antitranspirants were applied on the evening before the stress measurements began.

The stress period was of short duration due to the closeness of the start of the rainy season. The first five days of the stress period were quite warm with low percent relative humidities and high solar radiation and Pan ET rates (Fig. 43). The rains began during the night of October 4th and lasted for four days. Two days after the rains had stopped, stress measurements were started again but for only one day due to continued rains. Photosynthetically active radiation (PAR) was measured every half-hour during the stress periods. The average PAR results for the first five days of stress measurements are shown in Fig. 44.

Non-destructive leaf area and plant height measurements were made on four plants/plot. Measurements began 23 days after planting and were taken every 10-12 days thereafter until 134 days after planting. Leaf area index and plant height in relation to mulching are shown in Figures 45 and 46. The black plastic mulch treatment showed the fastest plant growth and development which was probably due to warmer soil temperatures. The grass mulch decreased plant growth during the coolest part of the dry season, i.e. July and August. The warmer air temperatures during the end of the dry season negated the cooler soil effect of the grass mulch, thus allowing for a faster growth rate during the latter part of the growing season. Soil water conservation probably also influenced

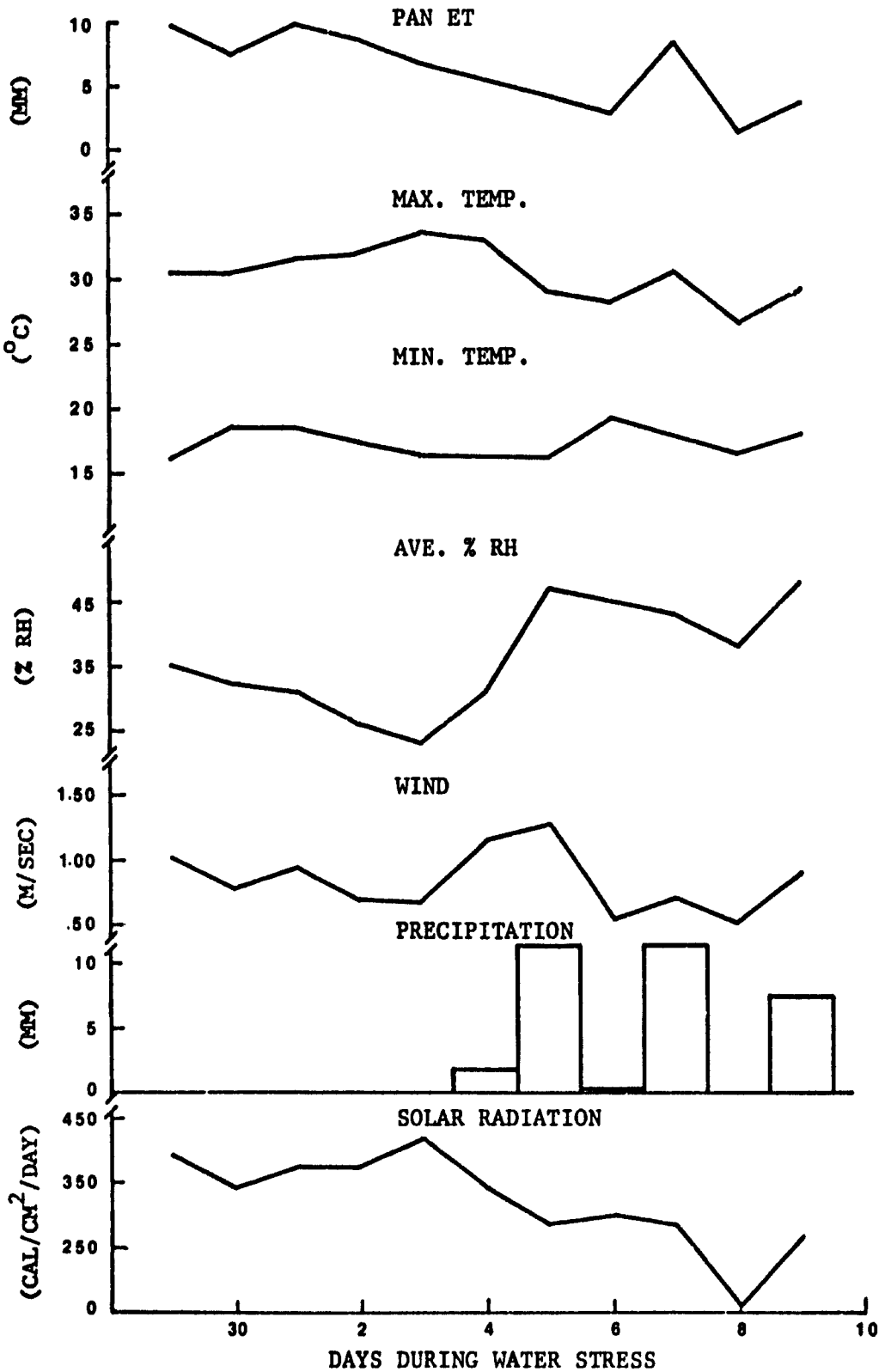


Fig. 43. General meteorological data corresponding to the water stress period of measurements at CPAC, Planaltina, Brazil.

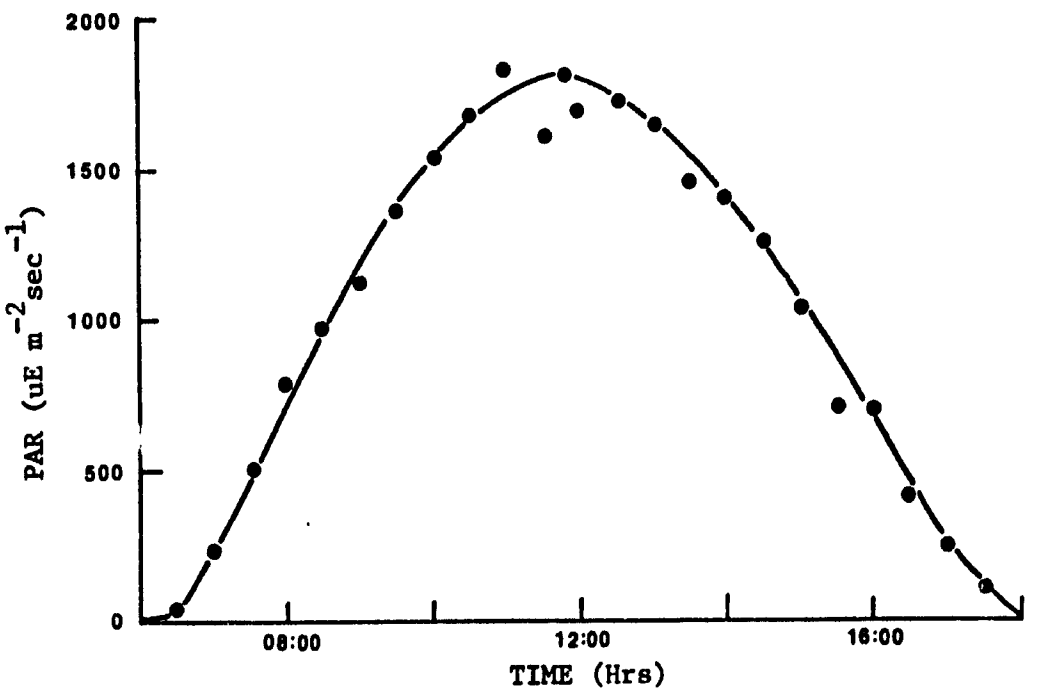


Fig. 44. Photosynthetic active radiation curve during the first five days of the water stress period in the corn mulching experiment.

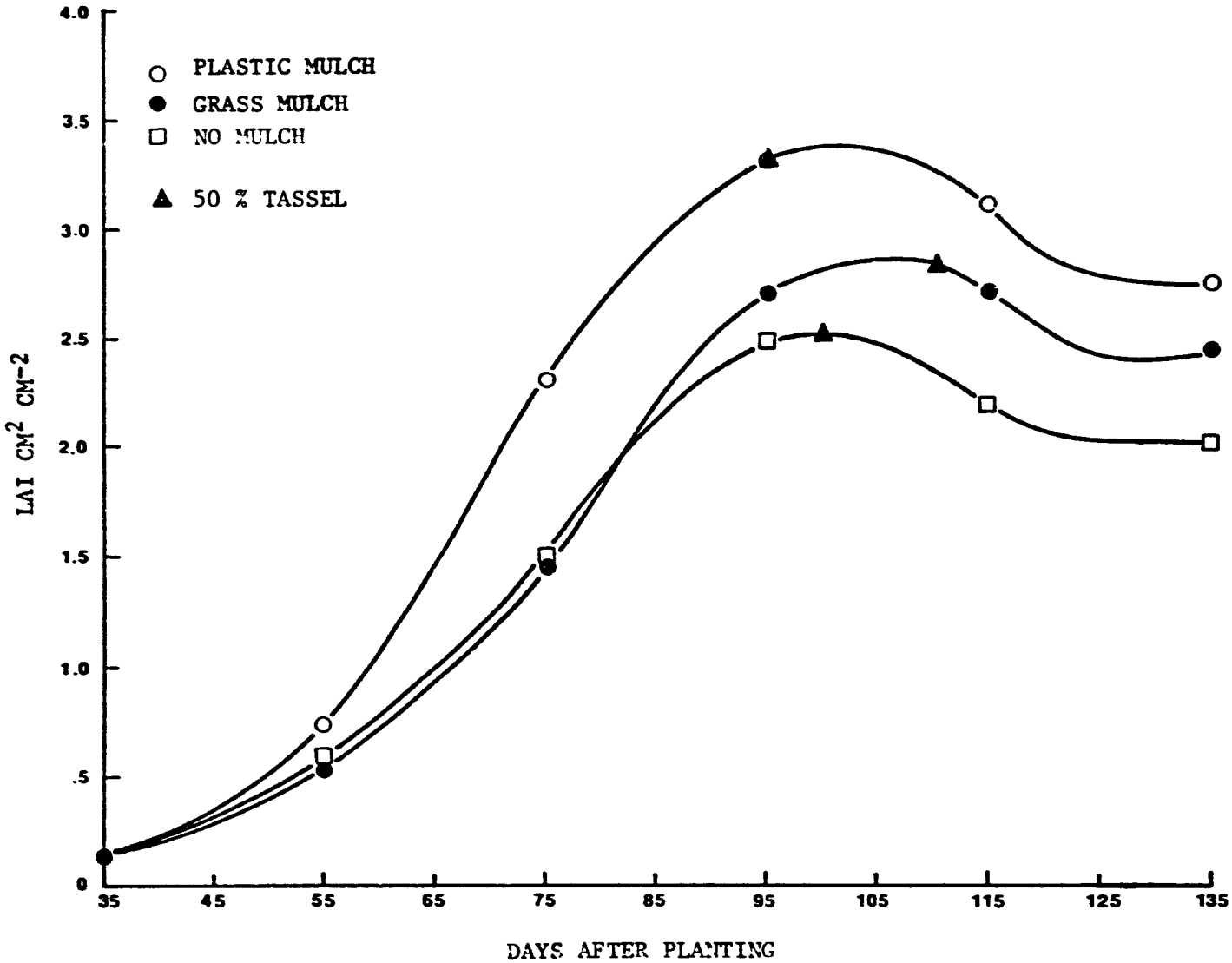


Fig. 45. Leaf area index (LAI) for corn in relation to the three mulch treatments.

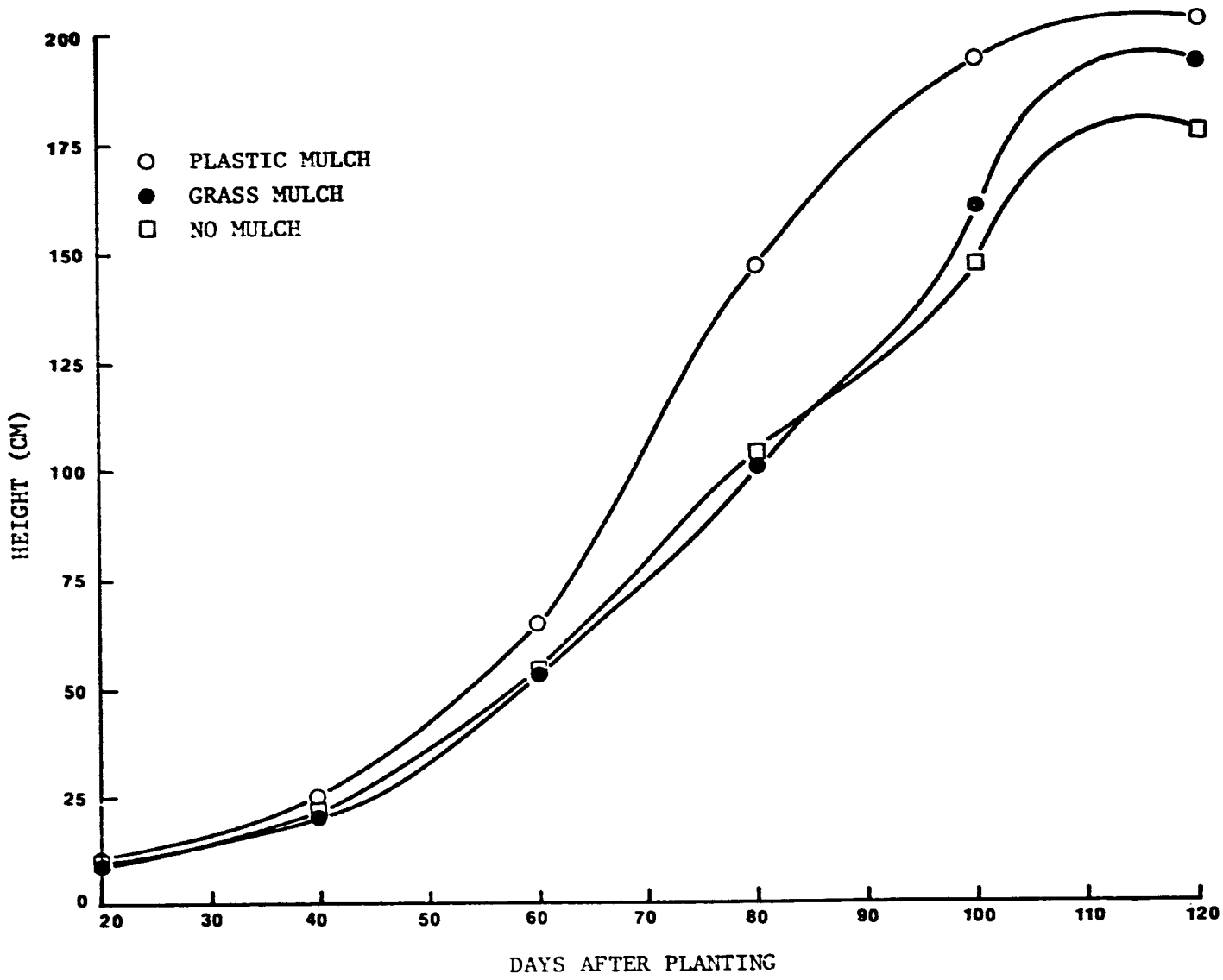


Fig. 46. Influence of mulches on corn plant height.

plant growth in favor of the mulch treatment over the bare soil treatment.

The mulches, lime depth incorporation and their combinations influenced the development of the corn plant. Table 48 shows the number of days after planting to 50 % tasseling. The warmer soil temperature allowed for quicker plant development while mulching by grass delayed tassel emergence. Note that deep liming consistently delayed plant development in all treatments.

Table 48. Number of days to 50 % tasseling.

Treatment	No. of days
Cargill-Shallow Lime-Plastic Mulch	95
Cargill-Deep Lime-Plastic Mulch	101
Cargill-Shallow Lime-Grass Mulch	110
Cargill-Deep Lime-Grass Mulch	111
Cargill-Shallow Lime-No Mulch	100
Cargill-Deep Lime-No Mulch	110
Agroceres-Shallow Lime-No Mulch	109

In order to quantitatively determine how much soil temperatures influenced corn plant growth, development, and production, soil temperatures were taken at 08:00 and 15:00 hours every 3-4 days during the growing season at six depths in the 0-45 cm soil layer. Morning and afternoon soil temperatures at five cm soil depth in relation to the mulch treatments are shown in Fig. 47. The results confirm the previous wet season's findings in that grass mulch cooled soil temperatures by 2-3 ^{o}C. Note that the grass mulch gave a warmer temperature in the morning which would be beneficial during the cool, dry season's nights that averaged around 14 ^{o}C in July and August, 1975. The black plastic mulch increased soil temperatures both during the day and during the

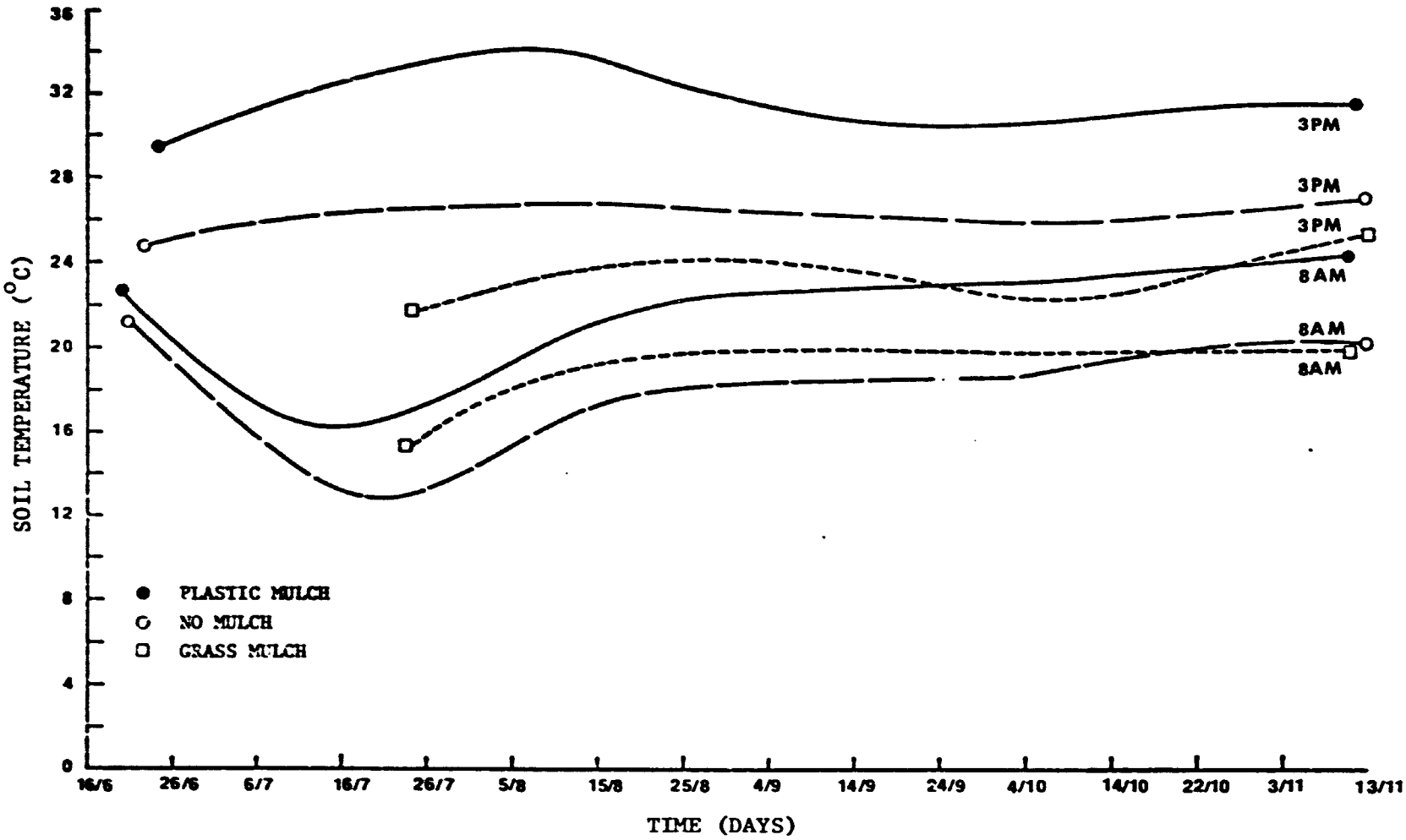


Fig. 47. Morning and afternoon soil temperatures at 5 cm depth in relation to mulching.

cool nights. Table 49 shows that the black plastic mulch maintained a 3-4 ^{o}C warmer soil temperature throughout the growing season. Grass mulch reduced soil temperatures by 0.5-1.0 ^{o}C for the 0-45 cm soil layer. The previously shown increased plant growth and development in relation to the black plastic mulch treatment was definitely because of the warmer soil temperatures. For example, the corn increased in leaf area by 54 cm^2 $plant^{-1}$ day^{-1} for the 5.2 ^{o}C difference in soil temperature during the month of August. The comparison was made between the no-mulch treatment and the plastic mulch treatment.

Many researchers have shown the influence of soil temperature on corn growth and yield. Fairbourn (1973) in Colorado, using a variety of mulches, showed that warmer soil temperatures increased corn growth and yield. For some areas in the tropics, decreasing the soil temperatures increased corn yield. Lal (1975) in Nigeria has shown that mulching not only increased corn yields by reducing soil temperatures but had the added benefits of increasing soil moisture conservation, reduced water run-off and soil loss, increased the activity of micro flora and fauna and reduced weed control problems. Van Doren and Triplett (1973) showed that mulching during a cool summer season in Ohio reduced soil temperatures too much resulting in a loss of grain yield. But, during a hot summer in Ohio, the cooler soil temperatures under the mulch increased grain yield. In conclusion, the selection of mulch material and the climatic condition during the growing season need to be studied in order to determine whether a mulch or no-till system will be beneficial.

Soil water use and conservation during the stress period in relation

Table 49. Influence of mulching on soil temperatures throughout the 0–45 cm soil layer.

Month	Mulch Tr't	Soil Depth 5cm 08:00	5cm 15:00	10 cm 08:00	10 cm 15:00	15 cm 08:00	15 cm 15:00	22.5 cm 08:00	22.5 cm 15:00	30 cm 08:00	30 cm 15:00	45 cm 08:00	45 cm 15:00	$\bar{X}$ 08:00	$\bar{X}$ 15:00
June	Soil	17.9	22.2	18.6	20.6	18.4	21.2	19.0	19.8	19.6	21.0	21.1	22.2	19.1	21.2
	Grass	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Plastic	20.1	27.8	20.3	25.6	20.0	23.9	21.5	22.5	22.3	22.2	22.7	23.0	21.2	24.2
July	Soil	14.3	25.5	14.7	23.0	15.4	20.2	16.5	19.3	18.0	19.0	19.3	19.4	16.4	21.1
	Grass	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Plastic	16.9	30.0	17.2	27.4	18.6	24.3	18.4	22.1	20.6	21.4	21.6	22.0	19.1	24.5
August	Soil	17.0	27.5	15.9	24.1	16.7	21.5	16.9	20.0	18.6	18.8	19.5	19.0	17.4	21.8
	Grass	18.2	25.0	17.1	23.0	16.4	21.4	17.1	19.8	17.0	19.4	18.3	19.7	17.4	21.3
	Plastic	22.5	33.4	21.7	29.4	21.8	26.1	22.3	23.6	23.3	23.4	23.5	23.3	22.5	26.5
September	Soil	18.3	25.5	19.0	23.5	19.5	21.9	20.1	20.6	21.0	20.0	21.6	21.0	19.9	22.1
	Grass	18.0	22.9	18.0	22.1	18.6	21.0	18.8	20.2	18.6	20.5	19.2	20.8	18.4	21.2
	Plastic	22.5	28.6	22.7	26.2	23.8	24.0	24.3	22.6	23.7	22.4	23.9	22.8	23.5	24.4
October	Soil	19.7	26.7	19.1	24.7	19.9	22.3	20.2	20.4	20.6	19.4	20.9	19.7	20.1	22.2
	Grass	19.7	23.6	19.5	22.4	19.8	21.8	20.3	20.3	20.4	20.1	20.4	20.3	20.0	21.4
	Plastic	22.1	31.5	22.2	29.5	22.3	26.4	23.0	24.3	22.8	24.0	23.3	23.9	22.6	26.6

to the mulches is shown in Table 50. The mulches conserved approximately 4-7 mm of soil water in the 0-22.5 cm soil layer which was due to reducing soil surface evaporation of soil water. The grass mulch plots showed less water use than the plastic mulch plots which was due to less transpiration demand because of smaller leaf areas. The plastic mulch plants had about 0.5 cm^2 cm^{-2} more leaf area index at that time. No difference in soil water use was noted in relation to the antitranspirant plots.

Table 50. Soil water content at five soil depths in relation to the crop management practices. Results are averaged over the six-day stress period.

Treatment	Soil Depth 15 cm	22.5 cm	30 cm	37.5 cm	45 cm
	(g/100 g)				
Bare Soil Shallow	20.9	23.8	24.0	24.5	24.5
Bare Soil Deep	22.2	23.8	24.7	24.0	24.3
Straw Mulch Shallow	24.5	25.4	24.6	24.6	24.9
Straw Mulch Deep	25.6	25.0	27.4	26.6	26.7
Plastic Mulch Shallow	23.1	24.2	25.9	24.3	25.4
Plastic Mulch Deep	23.7	24.2	24.8	23.5	25.4
Antitranspirant Shallow	21.8	22.5	24.1	22.8	25.0
Antitranspirant Deep	21.8	22.8	23.8	23.9	25.1

Plant water stress measurements were taken for six days. Plant stress was just starting to cause leaf rolling when the stress period was terminated by the first rainfall of the season (5/10/75). Measurements were continued four days later for one day only because of more rainfall. Since the simulated veranico was so short, the stress measurements really don't show how the mulch treatments might have influenced plant stress under more severe water stress conditions.

Leaf water potential (Ψ_L) results show that grass mulching decreased plant stress. The reason for more negative Ψ_L 's with the plastic mulch treatment was related to the plant's age. As was shown in the previous experiments, increasing corn plant age caused a more negative Ψ_L . The plants in the black plastic mulch treatment developed 10 days or more earlier than the other treatments. The 10 day older plants could easily account for the difference in Ψ_L results shown in Table 51. In addition, relative water contents (RWC) were shown in previous experiments that they were not influenced by the plant's age. Table 52 shows that RWC values for both mulch treatments were equal and that both treatments had more cell turgor pressure than the bare soil treatment did.

Wilt Pruf and phenyl mercuric acetate (PMA) antitranspirants were applied on the evening of the 29th of September. The following day stress measurements were taken on those plants and on the bare soil plants for comparison. PMA supressed transpiration which in turn reduced plant water stress. Ψ_L was reduced by 5 bars. Wilt Pruf also reduced plant water stress but not as much as PMA did (1.6 bars). RWC results were not influenced by the antitranspirants. The duration of the stress period was really too short to where any real measurable difference could be detected.

If the transpiration suppressants were working, stomatal resistance measurements (R_s) would show that the resistance to water vapor passing out of the leaf was greater. The results in Table 53 show that PMA increased R_s 10 times and Wilt Pruf increased R_s 5 times over plants that did not receive an application of either antitranspirant, but were

Table 51. Leaf water potential (Ψ_L) for corn in relation to mulches and antitranspirants. Mulch and antitranspirant measurements were made on alternate days during the stress period.

Treatment	Ψ_L (Bars)
No Mulch	-17.0
Grass Mulch	-16.2
Plastic Mulch	-17.7
No Antitranspirant	-16.4
PMA	-11.3
Wilt Pruf	-14.8

Table 52. Relative water contents (RWC) for corn in relation to mulches and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.

Treatment	RWC (%)
No Mulch	94.8
Grass Mulch	95.1
Plastic Mulch	95.1
No Antitranspirant	95.8
PMA	96.0
Witl Pruf	95.8

Table 53. Maize leaf stomatal resistance (R_s) as influenced by mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.

Treatment	R_s (sec cm^{-1})	
	adaxial	abaxial
No Mulch	6.53	4.66
Grass Mulch	6.25	4.03
Plastic Mulch	6.13	4.58
No Antitranspirant	4.66	2.97
PMA	25.76	19.10
Wilt Pruf	7.72	12.80

Table 54. Corn leaf temperatures taken during the stress period in relation to mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.

Treatment	Leaf Temperature (^oC)	
	adaxial	abaxial
No Mulch	35.1	34.6
Grass Mulch	35.8	35.3
Plastic Mulch	36.0	35.5
No Antitranspirant	34.6	34.0
PMA	36.4	36.2
Wilt Pruf	35.7	35.6

subjected to the same water stress conditions. The measurements were taken on the same day and within 30 minutes of each other. A mulch effect for R_s was also realized but since the simulated veranico never caused severe plant water stress, due to the rains, all R_s results were still less than 5 sec cm^{-1} , thus differences were small. A depth of lime effect on R_s was shown in all mulch and antitranspirant treatments.

PMA reduced plant water stress but perhaps too severely. Table 55 shows that the PMA effect became very detrimental to plant survival.

Table 55. Effect of the antitranspirants on leaf area and leaf number before and after water stress period.

Treatment	106 days	119 days	134 days
		LAI cm^2 cm^{-2}	
Plastic Mulch	3.37	2.94	2.79
Grass Mulch	2.88	2.47	2.50
No Mulch	2.45	2.08	2.06
PMA	2.79	0.42	0.39
Wilt Pruf	2.55	2.61	2.53
		Leaf No.	
Plastic Mulch	--	11.7	11.2
Grass Mulch	--	11.2	10.8
No Mulch	--	11.1	10.4
PMA	--	3.5	3.3
Wilt Pruf	--	11.0	11.0

Measurements of leaf area on day 106 was six days before water stress started to become severe and 6 days before antitranspirants were applied. The antitranspirant plots were the same as the no mulch plots before their application of antitranspirant.

Day 119 was 7 days into water stress and 7 days after PMA and Wilt Pruf were applied. Plants on which PMA was applied decreased in leaf area

by 85 % and leaf no. reduced by 7.5-9.0 leaves, whereas, Wilt Pruf showed no loss in leaf area or leaf number. PMA's negative effect was due to its almost complete closure of the leaf stomates which in turn caused a high amount of leaf senescence due to leaf burning.

A 2 ^{o}C difference in leaf temperatures (Table 54) plus a 70 % reduction in transpiration (Appendix table 21) added up to enhanced leaf senescence. For example, an estimate of the leaf-air temperature differences needed to dissipate solar radiation by sensible heat transfer processes can be made from the work of Raschke (1960). Assuming a solar radiation level of 1.0 cal cm^{-2} min^{-1} (Fig. 44) and a 70 % reduction in transpiration (Appendix table 21) it can than be assumed that about 0.7 cal cm^{-2} min^{-1} will have to be dissipated by sensible heat transfer processes. Assuming also a wind speed of 1 m sec^{-1} (Fig. 44) and a leaf width of 10 cm, the heat transfer coefficient is 0.6 cal cm^{-2} min^{-1} $degC^{-1}$ for both leaf surfaces, the leaf-air temperature difference would need to be approximately 12 ^{o}C to dissipate the 1.0 cal cm^{-2} min^{-1} solar radiation energy. Only a 5 ^{o}C difference was noted (Table 54 & 56) thus the reason for enhanced leaf senescence. The no-antitranspirant leaf-air temperature differences were great enough to dissipate that amount of energy.

PMA also reduced leaf chlorophyll content by 42.9 % when compared to plants that received no application of an antitranspirant.

Wet and dry bulb temperatures were taken two times daily during the stress period in each plot with a sling psychrometer. Measurements were also taken outside the corn plots over a bare soil area. The readings were made approximately one meter above the soil or mulch surface with

two replications per plot. The results show that the microclimate within the corn canopy was influenced by the various crop management practices (Table 56). Both mulches and the antitranspiran· treatment reduced canopy evaportranspiration and increased air temperature. Note that Ψ_L ,

Table 56. Corn canopy air temperature and percent relative humidity during the stress period in relation to the crop management practices.

	12:30 Hours		14:30 Hours	
	% RH	Air Temp. (^oC)	% RH	Air Temp. (^oC)
No Mulch	26.5	31.9	24.3	32.3
Grass Mulch	24.9	32.3	23.4	32.2
Plastic Mulch	26.6	31.8	23.4	31.9
Clear area	23.7	32.3	19.8	33.4
No Antitranspirant	26.3	32.0	29.0	30.3
Antitranspirant	26.0	32.9	23.6	31.6
Clear area	22.5	33.4	20.0	32.2

RWC, R_s, E, T_L, and microclimate measurements were taken on alternate days, thus a comparison of mulch against antitranspirant results can not be made without taking into account the day to day macroclimatic influence on the measurements.

Final grain and stover yields produced some interesting results (Table 57). Shallow limed plants tended to produce more dry matter and yielded more grain than the deep limed plants. A second fact was that the plastic mulch treatment significantly yielded more grain and stover than the no mulch, bare soil treatment. Since the simulated veranico was not long and severe enough to really stress the plants, the plastic mulch's higher yields may be partially attributed to the warmer soil temperatures throughout the growing season.

Phenyl mercuric acetate's negative effect on final grain yield was

Table 57. Final grain and stover yields for the 1975 dry season mulching experiment. Grain yield is expressed at 15.5 % moisture. Stover yield is on an over-dry weight basis.

Treatment	Grain kg/ha	Stover kg/ha	Grain:Stover Ratio
Cargill-Shallow-Plastic Mulch	7054	7319	.97
Cargill-Deep-Plastic Mulch	6440	6053	1.07
Cargill-Shallow-Grass Mulch	6593	6850	.97
Cargill-Deep-Grass Mulch	5391	5186	1.04
Cargill-Shallow-No Mulch	6090	5964	1.02
Cargill-Deep-No Mulch	5770	5189	1.12
Cargill-Shallow-PMA	1737	5231	.34
Cargill-Deep-PMA	2082	5798	.35
Cargill-Shallow-Wilt Pruf	6323	5971	1.06
Cargill-Deep-Wilt Pruf	6443	6142	1.05
Agroceres-Shallow-No Mulch	5675	6285	.91
$LSD._{05}$	951	1045	.18
C.V. (%)	9.97	10.23	11.63

very serious. PMA not only caused a reduction in plant leaf area due to leaf senescence but it must have also closed the stomates to CO_2 uptake since grain yield were so low. The 4-5 leaves/plant should have been enough leaf area to provide adequate photosynthate production if CO_2 uptake was not limited. Wil Pruf reduced plant water stress as was shown earlier but it did not improve final grain yield. CO_2 uptake must not have been inhibited by the thin layer of plastic film applied to both sides of the corn leaf.

Note that the yields/ha were not as high as might have been expected, especially with the deep lime treatments. Ear leaf nutrient concentrations show that the deep-lime plants had less phosphorus, magnesium and calcium concentrations than the ear leaves of shallow limed plots (Table 58). Not only were the three nutrients taken up less by deep limed plants, but the values were well below the critical value for optimum corn growth. The critical value is that concentration below which grain yields will decrease. The more deficient the nutrient, as in deep limed plots, the larger decreased in grain yield. The critical values for P, K, Ca, Mg, and Zn are 0.25 %, 1.9-2 %, 0.4 %, 0.25 %, and 15-17 ppm respectively (Jones and Eck, 1973). The results of the ear leaf analysis show that the plants were below or near the critical level for P, Mg, K, and Zn. Only calcium was above the critical concentration and within the normal sufficiency range for corn (0.21-1.00 %) (Jones and Eck, 1973).

Nutrient uptake by the grain and stover correlate well with the ear leaf analysis results (Table 59). Magnesium uptake by the stover was very low which suggests that Mg was not available in the soil or that its uptake was limited by some other factor or factors. In addition, uptake results show that deep liming had less nutrient uptake in both grain and

Table 58. Ear leaf nutrient analysis in relation to the crop management practices.

Treatment	Phosphorus (%)	Magnesium (%)	Calcium (%)	Potassium (%)	Zinc ppm
Cargill-Shallow-Plastic	.19	.15	.88	1.49	17
Cargill-Deep-Plastic	.18	.13	.86	1.62	18
Cargill-Shallow-Grass	.19	.14	.92	1.77	19
Cargill-Deep-Grass	.16	.11	.72	1.73	18
Cargill-Shallow-PMA	.16	.15	1.07	1.46	17
Cargill-Shallow-Wilt Pruf	.17	.17	.98	1.41	19
Cargill-Deep-PMA	.16	.17	.90	1.45	15
Cargill-Deep-Wilt Pruf	.18	.13	.90	1.49	20
Cargill-Shallow-No Mulch	.16	.16	1.00	1.49	14
Cargill-Deep-No Mulch	.16	.14	.82	1.62	16
Agroceres-Shallow-No Mulch	.16	.14	.70	1.63	15

Table 59. Uptake of P, Mg, Ca, K, and Zn in the grain and stover. Results are expressed in kg/ha.

Treatment	Phosphorus	Magnesium	Calcium	Potassium	Zinc
			Grain		
Cargill-Shallow-Plastic	32.33	13.65	4.7	38.82	.22
Cargill-Deep-Plastic	29.38	14.16	4.5	36.94	.23
Cargill-Shallow-Grass	29.94	13.24	5.1	35.43	.23
Cargill-Deep-Grass	18.43	7.76	3.5	21.34	.14
Cargill-Shallow-PMA	7.61	3.03	1.6	8.70	.06
Cargill-Shallow-Wilt Pruf	27.72	11.47	4.8	31.49	.23
Cargill-Deep-PMA	7.70	3.19	1.6	8.81	.06
Cargill-Deep-Wilt Pruf	26.92	11.23	4.2	30.79	.20
Cargill-Shallow-No Mulch	20.24	8.71	4.3	26.53	.16
Cargill-Deep-No Mulch	16.70	8.14	3.6	21.84	.15
Agroceres-Shallow-No Mulch	20.90	9.03	4.5	26.91	.16
			Stover		
Cargill-Shallow-Plastic	3.19	9.10	40.26	37.45	.06
Cargill-Deep-Plastic	2.43	7.11	27.86	45.90	.05
Cargill-Shallow-Grass	3.14	9.39	35.75	69.49	.08
Cargill-Deep-Grass	2.59	7.27	26.20	73.32	.06
Cargill-Shallow-PMA	3.14	5.52	23.54	29.96	.09
Cargill-Shallow-Wilt Pruf	2.01	8.11	36.20	45.95	.08
Cargill-Deep-PMA	4.06	6.65	24.56	40.63	.09
Cargill-Deep-Wilt Pruf	4.01	9.25	37.07	46.72	.08
Cargill-Shallow-No Mulch	2.55	7.14	33.40	36.33	.06
Cargill-Deep-No Mulch	1.67	5.94	28.60	42.62	.05
Agroceres-Shallow-No Mulch	2.49	6.61	31.20	46.63	.06

stover than shallow liming did.

Soil analysis results also show that phosphorus, calcium, and magnesium availabilities were very low (Table 60). The deep limed soils were more acidic and with less Ca + Mg and P available in the 0-15 cm soil layer than the shallow limed plots. The lower grain yields in the deep limed plots were the result of the combined effect of low pH, high Al, and low availability of P, Ca, and Mg. The 15-30 cm soil layer in the deep limed plots had lost almost all the neutralization effect of the lime. Soil acidity and aluminium concentrations were quite high.

Table 60. Soil analysis for the 1975 Dry Season Mulching Experiment. Comparison made between deep and shallow lime incorporation.

Lime Depths	pH 1:1 H_2O	Al meq/100ml	Ca + Mg meq/100ml	P ppm	Al Sat. %
		0-15 cm			
Shallow	5.33	.21	2.50	14.3	7.7
Deep	5.13	.46	1.74	9.8	20.9
		15-30 cm			
Shallow	4.63	1.00	.91	1.41	52.4
Deep	5.03	.50	1.74	1.27	22.3
		30-45 cm			
Shallow	4.51	.85	.63	.87	57.4
Deep	5.52	.67	.96	.87	41.1

Root measurements were taken by the Newman technique just before the corn plants had started to tassel. The results shown in Table 61 agree with the deep and shallow liming results explained earlier. The plastic mulch treatment showed the best root distribution while the grass mulch treatment had the highest concentration of roots near the soil surface. The results suggest that root penetration was related to soil

temperature. The cooler soil temperatures had roots near the surface and the warmer soil had deeper roots. The grass mulch effect of increasing root growth near the soil surface was also found by Onderdonk and Ketcheson (1973). They attributed the increased root growth to a higher soil water content near the soil surface. In addition, they found that mulching tripled phosphorus uptake by the tasseling stage. Table 58 shows that the phosphorus concentrations in the ear leaf for the mulched plants were slightly larger, but due to the already P deficient levels it is difficult to determine if mulching would have increased P uptake.

Table 61. Corn root length (cm cm^{-3}) for three soil depth as influenced by depth of lime incorporation and mulching.

	Soil Depth (cm)		
Treatment	0-15 cm	15-30 cm	30-45 cm
Shallow Lime	434	153	58
Deep Lime	459	132	116
No Mulch	404	147	61
Grass Mulch	533	99	60
Plastic Mulch	403	183	141

CONCLUSION

Mulching was shown to influence corn growth and development in both seasons. Grass mulch decreased plant growth and development while black plastic mulch increased plant growth and development in relation to the non-mulched plots. Black plastic mulched plants reached 50 % tasseling 10-15 days earlier than the grass mulched plants did.

During the natural veranico in 1974-5 wet season, leaf area decreased in the shallow limed plots for both Cargill and Agroceres. No decrease in leaf area was noted for either variety in the deep limed plots. In addition, deep limed plants showed a slightly superior leaf area over shallow liming during the growing season.

Cargill's leaf area was larger than Agroceres but both varieties reacted equally to mulching and depth of lime incorporation in relation to water stress.

Grass mulch was shown to reduce soil temperatures by 2-3 ^{o}C in the top 20 cm soil layer in both seasons. Black plastic increased soil temperatures substantially. During the 1975 dry season the 0-45 cm soil layer under the black plastic was on the average 3-4 ^{o}C warmer. Warmer soils were responsible for increased plant growth. For example, in August, 1975, leaf area increased by 54 $cm^2 plant^{-1} day^{-1}$ for the plastic mulched plants over the non-mulched plants in relation to an average difference in soil temperature of 5.2 ^{o}C.

Both mulches reduced soil surface evaporation of soil water by 4-7 mm in the top 20 cm of the soil during the stress periods. In the

wet season crop, deep limed plants used 8.2 mm more water than the shallow limed plants. During the dry season crop, grass mulched plants used less soil water during the simulated veranico than the other treatments because of poorer growth.

No severe plant water stress was imposed on the 1975 dry season experiment, thus the stress results were not too meangingful. The natural occurring veranico in the 1974-5 wet season was quite severe. During that veranico, plant water stress was greatly influenced by depth of liming, mulching, and their combinations. For example, the deep lime with mulch treatment had a six day leaf water potential average of -13.5 bars. Shallow liming without mulch averaged -15.7 bars. Relative water content results reflected the Ψ_L findings. Deep lime-mulched plants showed no loss in cell turgidity while shallow lime-non-mulched plants averaged 87 % RWC. Stress measurements taken after substantial rains showed that the plants in all treatments returned to their normal plant-water relationship, thus no permanent demage was caused by the veranico in terms of an internal plant-water balance.

The antitranspirants showed no effect on the wet season crop which was probably due to application errors. The dry season's results showed that both Wilt Pruf and phenyl mercuric acetate (PMA) reduced plant water stress by supressing transpiration. For example, PMA reduced Ψ_L by 5 bars and Wilt Pruf reduced Ψ_L by 1.6 bars in comparison to plants that received no antitranspirant. In addition, stomatal resistance was reduced 10 fold by PMA and 5 fold by Wilt Pruf.

PMA had side effects that were quite severe on the plant's continued growth and production. It caused severe leaf senescence. Leaf area

decreased by 85 % seven days after the application of PMA. It was noted that PMA plants decreased in leaf number faster than any other treatment for the wet season crop. Perhaps PMA has certain toxic effects which kill the corn leaves regardless of whether or not it was reducing transpiration.

Leaf temperature was also part of the reason for premature leaf senescence. Both experiments showed higher leaf temperatures were related to the leaves of plants which had higher stomatal resistance and lower transpiration rates. Those same plants had the greatest loss of leaf area. PMA leaf temperatures averaged 1-2 ^{o}C higher than Wilt Pruf plants or plants which had no antitranspirant.

Mulching had a significant effect on grain yield in both seasons. Plastic mulch increased yields by 1000 kg/ha. Grass mulch increased grain yields by 400-500 kg/ha in both season despite its negative effect on plant growth during the vegetative stage. Grass mulch reduced stover dry weights by 500-700 kg/ha.

Deep lime incorporation increased yields over shallow liming by 1000 kg/ha during the wet season. Dry season's results showed that deep liming reduced yields. Soil analysis and nutrient uptake results showed that the low yields were the result of the combined effect of acid soils, high aluminum concentration, and low availability of phosphorus, calcium, and magnesium.

The antitranspirant effect on yield was both good and bad. PMA reduced grain yield by 4000 kg/ha. Wilt Pruf increased grain yield by 450 kg/ha in comparison to the no mulch, no antitranspirant treatment.

Agroceres 152, like Cargill-111, gave increased yields with deep liming, mulching, and their combinations. Cargill outyielded Agroceres

by 1000 kg/ha in the wet season and by 425 kg/ha in the dry season.

Nutrient uptake results in both ear leaf and stover showed that calcium and magnesium were effected by mulching and variety during the wet season. Agroceres took up less Ca and Mg which suggests it was less efficient in extracting Ca + Mg from the soil or in its translocation and utilization within the plant. Mulching may have decreased Ca + Mg uptake because of the cooler soil temperatures. Potassium uptake showed a variety and lime effect. Cargill and deep lime plants took up more K than Agroceres and shallow limed plants respectively.

The dry season's nutrient concentration in the ear leaf showed that the plants were deficient or near the deficiency level for P, K, Mg, and Zn. Mg was the most limiting nutrient.

Soil analysis results showed that the residual effect of the 4 ton/ha of lime applied in September, 1973 was about all used up, especially in the deep lime incorporation plots where the lime had to neutralize 30 cms of the soil layer.

Root distribution measurements reflected the soil analysis results. Deep limed plots showed only a slight advantage of having more roots at deeper depths. The plastic mulch treatment gave the best root distribution at all depths. Grass mulched plots showed a high concentration of roots near the soil surface. The root results suggest that they were quite closely related to the soil temperature regime.

CHAPTER III

1974-5 Wet Season Rice Experiment

Upland rice is grown on a large scale in Brazil, probably the largest hectarage of any country in the world. The traditional method for planting upland rice is to use a 45-60 cm row spacing with a planting rate of 50 kg/ha. The general justification for the wide row spacing is to reduce water stress effects when veranicos occur and to permit weeding by hand.

The principle objective of this experiment was to study the row width effect on plant water stress in relation to veranicos. A secondary objective was to study whether deep and shallow lime incorporation would have any influence on rice growth and yield.

The rice experiment was planted on 20/12/74. The experiment was completely randomized with a factorial design. Three row widths (15, 30, & 45 cm); two lime depths (0-15 & 0-30 cm); and two varieties, Pratao Precoce a early maturing variety and IAC-1246 a medium maturing variety, were used. Three replications were included. A broadcast treatment, on shallow lime plots only,was planted for observation with each variety. A 50 kg/ha seed rate was used for all treatments. All stress measurements, methods, and procedures, were the same as described in the companion paper for maize.

Fig. 48 shows the general meteorological data for the time period corresponding to water stress measurements (5/4-13/4/75). Overall, the climatic effect on plant growth was not too severe. Maximum temperature,

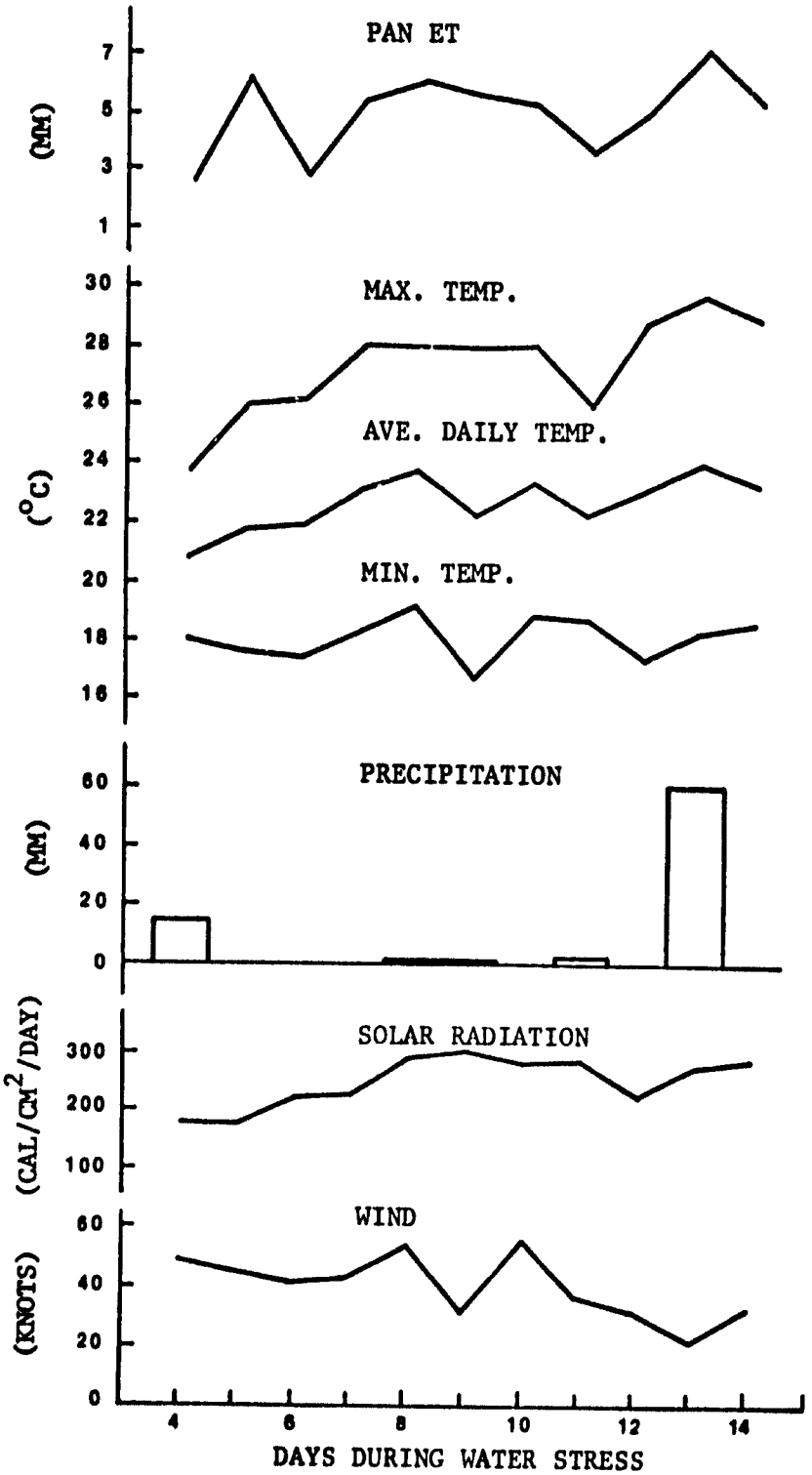


Fig. 48. Meteorological data for rice '74-5 wet season. Time period (days) corresponds to period of plant measurements (7/4-13/4/75).

wind, and a light rain were all instrumental in reducing the effect of the veranico. Photosynthetically active radiation intensity was quite high, even with the partially cloudy weather (Figure 49).

Two veranicos occurred during the growth of the rice crop. The first veranico occurred only two weeks after the experiment had been planted (4/1-19/1/75). The second veranico (26/2-17/3/75) corresponds to period of water stress measurements for the wet season maize experiment. Rice plant water-stress became quite severe, thus the experiment was irrigated on the 13th and 17th of March. Rains began the night of the 17th. The rice variety Pratao Precoce was at 50 % flowering (11/3/75) during the second veranico and IAC-1246 had just entered the flower initiation stage (9/3/75). Pratao Precoce started flower initiation around the 20th of February. The following table shows row width and depth of liming effect on percent flowering. For Pratao Precoce,

Table 62. Fifty percent flowering response of two rice varieties in relation to 3 row spacings and 2 lime depth incorporation.

	Pratao Precoce Date: 11/3/75		IAC-1246 Date: 6/4/75	
Row Space (cm)	Shallow (%)	Deep (%)	Shallow (%)	Deep (%)
Broadcast	25.0	--	20.0	--
15	13.0	43.0	24.3	36.7
30	23.0	50.0	60.0	46.7
45	20.0	50.0	53.3	60.7

a depth of liming effect occurred, whereas, IAC-1246 demonstrates a row spacing effect on % flowering.

Because of the time sequence of veranicos and plant growth, water stress measurements were taken on IAC-1246 for five days in april but the

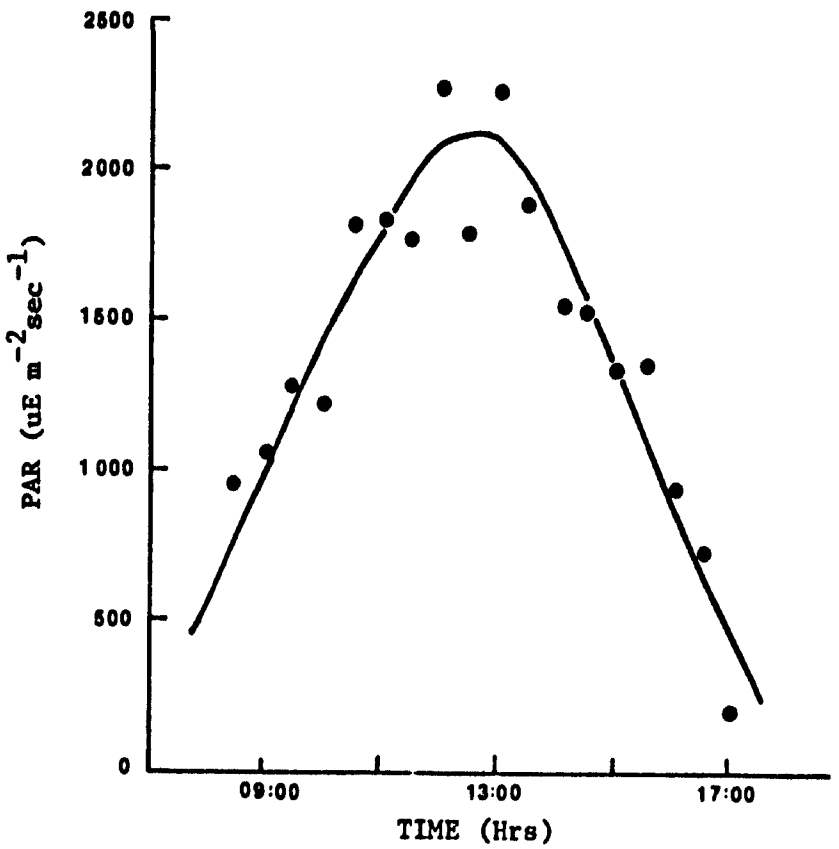


Fig. 49. Photosynthetic active radiation (PAR) during the period of water stress measurements on the rice variety IAC-1246 at Planaltina, Brazil. Measurements were taken every one-half hour during the day for 5 days (7-9 and 12-13/4/75).

veranico was only nine days long (5/4-13/4/75). There were light showers during four days of the veranico (Figure 49). During the five days of measurements, 5 plants/plot/treatment were selected daily for water stress measurements. Growth measurements were also made on 5 plants/plot/treatment (Table 63). The flag leaf was the only leaf used for water stress measurements. Shallow lime treatments gave significantly better plant growth in terms of leaf area of flag leaf, total leaf area of plant, leaf number and plant height. Forty-five cm row spacing produced the largest leaf areas.

Soil water content was measured daily for 6 days at 5 soil depths in the 0-45 cm soil profile (Table 64). Due to the shortness of the veranico, soil water contents did not reach very low values, thus a depth of liming and row spacing effect averaged over the five days were not clear. The rice plants in the deep liming treatment used 4.77 mm of water more than the shallow limed plants for the 0-45 cm soil profile. The 30 cm row spacing-deep lime treatment used the most water of all treatments in the 0-45 cm profile, whereas, the 30 cm row spacing-shallow lime treatment gave the least water use by the rice plants.

Leaf sampling for leaf water potential (Ψ_L) and relative water content (RWC) were conducted on 5 plants/plot/treatment. Only the flag leaf was used. One half of the flag leaf split lengthwise and without midrib was used for Ψ_L and the other half of leaf, without midrib, was used for RWC. RWC and Ψ_L sampling was done simultaneously. Table 65 shows the average results of 3 days of measurements for RWC and Ψ_L in relation to lime depth and row spacing. The results tend to show the opposite of the soil moisture content results. Shallow liming shows

Table 63. Growth measurements for the rice variety IAC-1246 taken during the 5 days of water stress measurements (7-9 & 12-13/4/75).

Row Spacing (cm)	Lime Depth (cm)	Leaf area of flag leaf (cm^2)	Leaf area of total plant (cm^2)	No. of leaves (no.)	Plant height (cm)
15	0-15	38.1	209.3	4.6	96.9
30	0-15	42.2	201.8	4.5	100.3
45	0-15	41.0	230.2	4.5	98.0
15	0-30	38.1	156.2	4.4	92.5
30	0-30	33.7	168.4	4.3	92.7
45	0-30	37.4	204.2	4.3	93.8
		LIME DEPTH EFFECT			
--	0-15	40.4	213.7	4.6	98.4
--	0-30	36.4	176.3	4.4	93.0
		ROW SPACE EFFECT			
15	--	38.1	182.8	4.5	94.7
30	--	37.9	185.1	4.4	96.5
45	--	39.2	217.2	4.4	95.0
Row $LSD._{05}$		n.s.	18.29	n.s.	n.s.
Lime $LSD._{05}$		2.79	14.93	.19	2.98
Lime*Row $LSD._{05}$		4.86	n.s.	n.s.	n.s.
C.V. (%)		27.70	19.53	12.22	8.46

Table 64. Soil water content (%) for IAC-1246 in relation to 2 lime depths and 3 row spacings. Measurements were taken for six days (7-10 and 12-13/4/75).

Treatment	Soil Depth 0-15	15-22.5	22.5-30	30-37.5	37.5-45	$\bar{X}$
	(g/100 g)					
15 cm-Shallow	23.4	24.6	25.0	25.5	26.7	25.0
15 cm-Deep	23.9	24.4	24.8	25.4	26.7	25.0
30 cm-Shallow	23.2	24.6	25.4	26.4	27.0	25.3
30 cm-Deep	21.8	22.9	24.6	25.5	26.0	24.2
45 cm-Shallow	22.4	24.1	25.1	25.8	26.8	24.8
45 cm-Deep	22.7	23.1	24.5	25.6	27.0	24.6
LIME DEPTH EFFECT						
Shallow	23.0	24.4	25.2	25.9	26.8	25.1
Deep	22.8	23.5	24.6	25.5	26.6	24.6
ROW SPACE EFFECT						
15 cm	23.7	24.5	24.9	25.5	26.7	25.1
30 cm	22.5	23.8	25.0	26.1	26.5	24.8
45 cm	22.6	23.6	24.8	25.7	26.9	24.7

Table 65. Leaf water potential (ψ_L) and relative water content (RWC) for rice as influenced by depth of lime incorporation and row spacing.

LIME DEPTH EFFECT		
Lime Depth	ψ_L (Bars)	RWC (%)
Shallow	-14.0	95.0
Deep	-14.5	94.6
ROW SPACING EFFECT		
Row Spacing	ψ_L (Bars)	RWC (%)
15 cm	-14.6	94.4
30 cm	-14.5	94.4
45 cm	-13.6	95.6

less plant water stress than deep liming. The row spacing effect seems to hold true. Soil moisture content for 45 cm rows showed the most plant water use which corresponds to less plant water stress. Differences in soil moisture, RWC and ψ_L were very small which was a reflection of the short veranico. It did not place the plants under severe water stress which may have enlarged the differences.

Photosynthetic rate (Pn) measurements were taken daily for five days between 12:30-14:30 hours. The flag leaf of 5 plants/plot/treatment were used. The same leaf was used for stomatal resistance measurements. The Pn results shown in Table 66 do not directly correlate with ψ_L and RWC. The 30 cm row spacing-deep liming treatment had the highest Pn and deep liming was better than shallow liming. These results correlate very well with the soil moisture content results and stomatal resistance measurements.

Stomatal resistance measurements showed that deep liming and the 45 cm row spacing were superior treatments in reducing water stress (Table 67). Note that the deep-lime-30 cm row spacing treatment gave the lowest R_s which was the same treatment that showed the most water extracted from the soil.

Transpiration was inhibited the most by 15 cm row spacing and by

Table 66. Photosynthetic rate (Pn) measurements for IAC-1246 as influenced by 2 lime depths and 3 plant-row spacing. Measurements were taken for 5 days (7-9 and 12-13/4/75). Results are expressed in mg $CO_2/dm^2/hr$.

Treatments	Days of Measurements					
	7/4	8/4	9/4	12/4	13/4	$\bar{X}$
15 cm-Shallow	18.6	22 4	12.4	17.7	17.2	17.7
15 cm-Deep	15.3	28.0	13.7	17.6	18.2	18.6
30 cm-Shallow	13.6	16.1	21.3	20.9	16.9	17.8
30 cm-Deep	23.9	20.0	23.3	18.2	15.1	20.1
45 cm-Shallow	16.6	21.0	14.8	16.2	18.7	17.5
45 cm-Deep	18.5	12.5	12.2	25.8	16.0	17.0
Daily average	17.8	20.0	16.3	19.4	17.0	--

LIME DEPTH EFFECT

Lime depth	Pn
Shallow	17.7
Deep	18.6

ROW SPACE EFFECT

Row space	Pn
15 cm	18.2
30 cm	19.0
45 cm	17.3

Table 67. Influence of two lime depths and three row spacings on the stomatal resistance for the rice variety IAC-1246.

Treatment		Sampling Days During Water Stress 7/4	8/4	9/4	12/4	13/4	$\bar{X}$
		sec cm^{-1}					
15 cm-Shallow	1/	1.47	2.47	2.50	1.86	2.74	2.21
	2/	1.36	2.70	2.69	3.17	2.72	2.53
15 cm-Deep		1.86	2.82	2.45	3.40	3.18	2.74
		1.63	2.55	2.72	4.75	2.93	2.92
30 cm-Shallow		2.13	6.67	1.06	2.95	2.86	3.13
		2.22	4.73	1.66	1.91	4.31	2.97
30 cm-Deep		1.45	1.58	0.83	1.58	2.18	1.52
		1.10	1.33	0.87	1.37	3.27	1.59
45 cm-Shallow		2.10	3.78	1.34	3.62	4.04	2.98
		2.10	2.41	1.19	3.42	5.20	2.86
45 cm-Deep		1.17	1.85	1.18	1.42	2.45	1.61
		1.10	2.50	1.10	0.93	2.65	1.66

ROW SPACE EFFECT

(cm)	1/ TOP	2/ BOTTOM
	sec/cm	
15	2.48	2.73
30	2.33	2.28
45	2.30	2.26

LIME DEPTH EFFECT

	1/ TOP	2/ BOTTOM
	sec/cm	
Shallow	2.77	2.79
Deep	1.96	2.06

shallow lime incorporation (Table 68). The 30 cm deep lime treatment continued to show the least plant water stress of all treatments.

Growth and yield parameters were measured in a square meter area in each plot one day before the total plot area was harvested for grain yield. Yield parameters were measured on 5 plants/meter^2 while number of plants, grain yield, and stover yield were taken from the total square meter area. Pratao Precoce was harvested on 19/4/75. IAC-1246 was harvested on 10/5/75.

There was not any statistical significance shown for the growth and yield parameters between deep and shallow liming for Pratao Precoce (Table 69). Row spacing did have an influence on the growth and yield of Pratao Precoce (Table 70). Narrow row spacing resulted in greater grain sterility and lighter grain weight which in turn influenced a lower grain:straw ratio and a lower grain yield/plant.

The statistical analysis for the growth and yield parameters demonstrate very clearly that row spacing did not influence IAC-1246 production in any form (Table 71). The principle reason for shallow liming significantly outyielding deep liming was greater panicle weight which in turn produced more grain/plant. The grain yields for IAC-1246 are shown in Table 72. The 15 cm and 45 cm row spacing with shallow lime yielded almost the same and were the highest yielding treatments. The 45 cm row spacing with deep lime was the lowest yielder, over 600 kg/ha less. Shallow lime treatments yielded 439 kg/ha over the deep lime treatments.

A comparison between the two varieties show that IAC-1246 was significantly superior for the growth parameters taller plants, fewer unproductive tillers, and more stover dry weight. In addition, IAC-1246 was superior for the yield components, heavier grain weight and less flower

Table 68. Transpiration rate for IAC-1246 in relation to depth of lime incorporation and row spacing.

Treatment		Sampling Days During the Water Stress 7/4	8/4	9/4	12/4	13/4	$\bar{X}$
		$\mu g\ H_2O\ cm^{-2}\ sec^{-1}$					
15 cm-Shallow	1/	12.2	7.9	7.8	11.1	8.9	9.6
	2/	12.8	7.4	7.4	7.6	8.9	8.8
15 cm-Deep		10.7	7.5	7.3	6.9	7.9	8.1
		11.7	8.1	6.7	5.3	8.4	8.0
30 cm-Shallow		9.7	4.1	12.5	8.0	8.4	8.5
		9.4	5.5	9.7	10.8	6.1	8.3
30 cm-Deep		10.2	11.0	14.6	10.2	9.8	11.2
		11.9	12.2	14.2	11.1	7.3	11.3
45 cm-Shallow		9.2	6.5	10.8	6.7	6.4	7.9
		9.2	9.1	11.5	7.0	5.2	8.4
45 cm-Deep		11.2	10.0	13.1	11.5	9.0	11.0
		11.5	8.1	13.6	14.5	8.5	11.2

ROW SPACE EFFECT

(cm)	1/ TOP	2/ BOTTOM
	$\mu g\ H_2O\ cm^{-2}\ sec^{-1}$	
15	8.9	8.4
30	9.9	9.8
45	9.5	9.8

LIME DEPTH EFFECT

	1/ TOP	2/ BOTTOM
	$\mu g\ H_2O\ cm^{-2}\ sec^{-1}$	
Shallow	8.7	8.5
Deep	10.1	10.2

Table 69. Row spacing and depth of liming effect on growth and yield parameters for Pratao Precoce. Measurements were taken from a square meter area on 19/4/75.

Measurement Parameter	Broadcast		15 cm		30 cm		45 cm		$\bar{X}$	$\bar{X}$	Row
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	$LSD_{.05}$
No. of plants	284	--	228	276	215	203	196	220	231	233	28.1
No. of Pl. w/o panicle	5.7	--	4.0	7.0	7 3	.3	2.7	6.0	4.9	6.1	n.s.
Pl. Height (cm)	72.8	--	76.5	76.8	79.2	77.7	82.7	76.7	77.8	77.1	n.s.
Panicle length (cm)	20.7	--	21.3	19.7	20.2	22.1	22.6	21.1	21.2	21.0	n.s.
Panicle weight (g)	12.8	--	12.4	9.8	13.2	12.9	15.6	13.5	13.5	12.1	n.s.
% Unfilled grain	27.0	--	44.4	45.4	33.5	36.0	24.7	33.6	32.4	38.3	8.6
100 grain weight (g)	2.56	--	2.57	2.25	2.59	2.72	2.90	2.73	2.66	2.57	.25
Grain yield (g)	427	--	309	311	330	336	422	345	372	331	n.s.
Stover yield (g)	576	--	516	583	548	494	516	485	539	521	n.s.
Grain Stover ratio	.74	--	.60	.53	.60	.68	.82	.71	.69	.64	.13
Grain wt. per pl. (g)	1.50	--	.35	1.13	1.54	1.65	2.15	1.57	1.64	1.45	.34

Table 70. Grain yield for Pratao Precoce grown during the '74-5 wet season at Planaltina, Brazil. Results are expressed in kg/ha at 14 % moisture.

Row Spacing (cm)	Lime Depth Shallow (kg/ha)	Lime Depth Deep (kg/ha)	Row $\bar{X}$ (kg/ha)
Broadcast	2939	--	2939
15	2577	2244	2411
30	2597	2776	2687
45	2956	2666	2811
Depth $\bar{X}$	2710	2562	--
Depth $LSD_{.05}$	n.s.	Row $LSD_{.05}$	n.s.

Table 71. Row spacing and depth of liming effect on growth and yield parameters for IAC-1246. Measurements were taken from a square meter area on10/15/75.

Measurement Parameter	Broadcast		15 cm		30 cm		45 cm		$\bar{X}$	$\bar{X}$	Row
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	$LSD_{.05}$
No.of plants	277	--	237	258	252	228	200	230	242	239	n.s.
Plant Height (cm)	103	--	101	98	105	96	110	98	105**	97	n.s.
Panicle Weight (g)	14.0	--	13.6	10.8	14.4	13.8	15.7	12.7	14.4*	12.4	2.1
Panicle Length (cm)	20.6	--	21.5	21.6	20.5	20.9	22.2	20.8	21.5	21.1	n.s.
% Unfilled grain	21.3	--	19.8	30.1	28.6	25.1	26.0	24.4	23.9	26.5	n.s.
100 grain weight (g)	3.07	--	2.72	2.84	2.91	2.82	2.89	2.94	2.90	2.87	n.s.
Grain yield (g)	421	--	391	321	354	335	342	310	377	322	n.s.
Stover yield (g)	864	--	767	792	778	708	741	740	788	747	n.s.
Grain Stover ratio	.49	--	.51	.41	.46	.47	.46	.42	.48	.43	n.s.
Grain wt. per pl. (g)	1.50	--	1.65	1.24	1.40	1.47	1.71	1.35	1.57*	1.35	n.s.

*= 5 %; **= 1 % Level of sign.

Table 72. Grain yield for IAC-1246 grown during the '74-5 wet season at Planaltina, Brazil. Results are expressed in kg/ha at 14% moisture.

Row Spacing (cm)	Lime Depth Shallow (kg/ha)	Deep (kg/ha)	Row $\bar{X}$ (kg/ha)
Broadcast	3438	--	3438
15	3574	3188	3381
30	3460	3095	3278
45	3516	2952	3234
Depth $\bar{X}$	3517***	3078	--

*** = 0.1 % Level of sign. Row $LSD_{.05}$ n.s.

sterility. All of these factors contributed to IAC-1246 significantly out-yielding Pratao Precoce by over 660 kg/ha.

This researcher does not understand why most of the physiological stress measurements showed deep liming superior to shallow liming during the veranico but the final grain yield was the exact opposite for IAC-1246. Since row spacing did not significantly effect either the growth and yield parameters or final grain yield, it can be assumed that water stress was not a determining factor for the growth and production of IAC-1246. The next question is, why did the shallow limed plants produce larger panicles which resulted in a significantly greater yield?

Nutrient uptake (Table 73) and soil analysis results (Table 74) do not convincingly show that shallow liming had an advantage of any kind over deep liming. Magnesium uptake by the stover and phosphorus uptake by the grain were greater in the shallow limed treatments. In addition, soil analysis data show that calcium and magnesium were in greater quantity in the shallow limed soils. Whether those nutrient influences were significant enough to influence panicle size is debatable.

This researcher believes that the veranico which occurred during the panicle initiation stage for IAC-1246 had more of an influence on panicle size than soil fertility did. The selectivity between the lime depths could have been related to the timing of panicle initiation in relation to the duration of the veranico.

Table 73. Uptake of P, K, Ca, and Mg by the grain and stover of two rice varieties, IAC-1246 and Pratao Precoce.

Treatment	Phosphorus IAC 1246	Phosphorus Pratao Precoce	Potassium IAC 1246	Potassium Pratao Precoce	Calcium IAC 1246	Calcium Pratao Precoce	Magnesium IAC 1246	Magnesium Pratao Precoce
Grain	$1x10^{-2}$ g/m^2		g/m^2		$1x10^{-2}$ g/m^2		$1x10^{-2}$ g/m^2	
15 cm-Shallow	82.1	71.1	1.17	.93	35.2	24.7	39.1	34.0
15 cm-Deep	61.0	65.3	.96	.62	22.5	24.9	25.7	34.2
30 cm-Shallow	70.8	72.6	1.06	.66	28.3	26.4	24.8	36.3
30 cm-Deep	80.4	70.6	1.34	.67	30.2	20.2	40.2	33.6
45 cm-Shallow	75.2	88.6	1.02	.84	20.5	33.8	30.8	46.4
45 cm-Deep	68.2	72.5	1.24	.69	24.8	27.6	31.0	34.5
Broadcast-Shallow	88.4	72.6	1.68	.85	37.9	38.4	42.1	34.2
Stover	g/m^2							
15 cm-Shallow	.38	.52	17.6	13.4	3.84	3.92	1.84	1.29
15 cm-Deep	.48	..47	19.0	12.2	4.59	4.08	1.74	1.28
30 cm-Shallow	.47	.38	18.7	12.6	4.51	3.95	1.95	1.26
30 cm-Deep	.42	.30	14.9	11.4	3.82	3.26	1.70	1.04
45 cm-Shallow	.44	.36	18.5	12.4	4.59	3.61	1.78	1.19
45 cm-Deep	.44	.34	16.3	10.7	4.74	3.98	1.63	1.02
Broadcast-Shallow	.43	.46	19.9	13.3	4.66	3.92	2.33	1.23

Table 74. Post harvest soil analysis data for the rice experiment.

Treatment	pH 1:1 H_2O	Al meq/100ml	Ca + Mg meq/100ml	P ppm	Al Sat. %
IAC-1246					
15 cm-Shallow	5.25	.13	2.8	16.7	4.4
15 cm-Deep	5.22	.37	1.7	16.7	17.9
30 cm-Shallow	5.10	.50	2.2	9.0	18.5
30 cm-Deep	5.40	.20	2.4	29.7	7.7
45 cm-Shallow	5.30	.37	2.5	17.7	12.9
45 cm-Deep	5.28	.30	1.6	18.3	15.8
Broadcast-Shallow	5.10	.45	2.4	17.5	15.8
Pratao Precoce					
15 cm-Shallow	5.25	.33	2.7	19.0	10.9
15 cm-Deep	5.43	.20	2.2	15.0	8.3
30 cm-Shallow	5.23	.33	2.8	15.7	10.5
30 cm-Deep	5.35	.27	2.5	16.7	9.7
45 cm-Shallow	5.43	.20	3.2	20.0	5.9
45 cm-Deep	5.48	.20	2.3	11.7	8.0
Broadcast-Shallow	5.40	.20	2.7	11.5	6.9

CONCLUSION

The growth and development of the two rice varieties, Pratao Precoce and IAC-1246, in relation to row spacing and lime depth acted independently. Pratao Precoce showed a preference for deep liming at 50 % flowering but that could have been related to a veranico which occurred at the same time. Date of 50 % flowering for IAC-1246 was influenced by row spacing but plant growth was influenced more by depth of liming. Shallow limed plants gave superior growth for total leaf area, number of leaves, and plant height.

Water stress measurements on IAC-1246 showed that shallow liming was slightly superior in reducing internal plant water stress in terms of leaf water potential and cell turgidity. Deep limed plants showed less water stress in terms of stomatal resistance, transpiration, and photosynthetic rate. The duration of the veranico was not long, thus the rice plants never became severely stressed. All the stress measurement differences were very small, thus they are not indisputable.

An analysis of growth and yield parameters showed that Pratao Precoce was more influenced by row spacing than lime depth incorporation. The 15 cm row spacing showed more grain sterility and lighter grain weights which influenced a lower grain:straw ratio and a lower grain yield/plant. Final yield results showed that narrow row spacing produced 400 kg/ha less than the 45 cm row spacing.

IAC-1246 growth and yield parameters were not influenced by row spacing. Lime depth did have a significant effect with shallow liming being superior. Principle reason for shallow liming outyielding deep

liming was that it produced greater panicle weights which in turn produced more grain/plant. Shallow limed treatments yielded 440 kg/ha more rice than deep limed treatments.

IAC-1246 significantly outyielded Pratao Precoce because it produced fewer unproductive tillers, produced heavier grain weights, and had a lower percentage of flower sterility. Those factors contributed to a 660 kg/ha yield difference.

No final statement can be made as to why shallow limed plants yielded more grain than the deep limed plants in the IAC-1246 variety even though stress measurements during the veranico showed that deep limed plants were under less stress. Nutrient uptake and soil analysis results suggested that phosphorus, calcium, and magnesium were either more available or were taken up more by the shallow limed plants. In addition, it was shown that shallow limed plants gave superior growth, thus a larger panicle seems logical. If there were no serious water stress effects at the panicle initiation stage or during the grain filling stage, then a larger sized panicle would direclty relate to a greater grain yield. In conclusion it can be stated that IAC-1246 showed no row spacing effect and that deep liming inhibited plant growth and yield. Pratao Precoce showed that narrow row spacing was detrimental to plant growth and yield whereas depth of lime incorporation showed no effect on final grain yield.

GENEPAL CONCLUSIONS

The central cerrado of Brazil is like many other areas in the tropics that have a marked wet and dry season. The total quantity of rainfall per year is sufficient to grow almost any crop but the crops are subjected to droughts (veranicos) almost every year due to the poor distribution of rain. Another factor which contributes to the drought problem is the low water holding capacity of the soil, i.e. 51 mm in the 0-45 cm soil layer. In addition, most economic plants are not able to put down an adequate root system to tap the available soil water when a veranico occurs because of the 80 % aluminum saturation in the top-soil and subsoil. Along with the small amount of soil water available to the plants is the high evaporative demand that can occur during a veranico, 6-8 mm per day ET rate is normal.

With the above problems in mind, experiments were conducted for two years near Brasilia, Brazil to study the effect of a veranico on the soil water-plant water relationship. The experiments were designed to facilitate drought avoidance. In one experiment, soil management techniques were used to allow a crop to tap a greater quantity of the water stored in the soil. A second experiment used crop management techniques to increase water use efficiency by decreasing water loss from the soil surface and from the corn leaf surface.

The soil management experiment consisted basically of lime rates and depth of lime incorporation, i.e. 0-lime, 8T/ha lime incorporated to a 15 cm depth and 8 T/ha lime incorporated to a 30 cm depth, and a

broadcast verses banding application of phosphorus.

Without plant water stress, no depth of lime effect was noted to the tasseling stage. From silking to grain maturity, the deep limed plants maintained a longer period of active plant growth by delaying leaf senescence. The unlimed corn plants were always inferior to the limed plants with the dry-cool season crop showing a more pronounced decrease in plant growth.

Measurements taken during an actual veranico or a simulated veranico showed that deep liming had a large effect in providing a drought avoidance mechanism for the corn plants. Corn roots were able to penetrate to deeper soil depths to extract water which in turn reduced the plant's internal water stress, i.e. leaf water potential and relative water content, and reduced stomatal resistance thus allowing the plant to continue to transpire and take up CO_2.

At final grain harvest, deep lime incorporation plots outyielded shallow limed plots in both water stressed and non-water stressed treatments. Non-limed treatments yielded less than limed plots. A 10-15 day water stress period during the vegetative growth stage permanently reduced plant size but it did not significantly reduce grain yield. A 10-15 day stress period during the grain formation stage decreased yields by 100-150 kg/ha/day.

With all other fertilizer treatments being equal, incorporation of lime 30 cm deep instead of the traditional 15 cm depth produced 1157 kg/ha more grain for the three crops under non-water stressed conditions and produced 2043 kg/ha more grain under the stressed conditions. On a three crop average, late stress reduced yields by 19 % for deep limed treatments

and 27 % for shallow limed treatments.

The no-lime treatment with adequate amounts of N, P, K, Zn, and Boron returned around 4,000 kg/ha of corn grain, thus showing that Cargill-111 was somewhat tolerant to aluminum toxicity. But, by only adding lime to a 30 cm depth, yields were increased by 4800 kg/ha for the three seasons under non-water stressed conditions. Late period water stress reduced yields by 31 % in unlimed soils.

Broadcast application of phosphorus gave less reduction in yield in relation to plant water stress for two of the three seasons when compared to the banded application of phosphorus. Both treatments gave significant reductions in grain yields when water stress was imposed on the plants during the grain filling stage.

Mulching was shown to influence corn growth and development. Grass mulch decreased plant growth and development due to cooler soil temperatures (2-3 ^{o}C) while black plastic mulch increased plant growth and development due to warmer soil temperatures (3-4 ^{o}C) in relation to the non-mulched plots.

Both mulches reduced soil surface evaporation of soil water by 4-7 mm in the top 20 cm of the soil during the stress periods. During a veranico plant water stress was greatly influenced by depth of liming, mulching, and their combinations. Deep liming with mulch reduced leaf water potential and showed no loss in cell turgidity. Transpiration suppressants reduced internal plant water stress by over 30 % but one of the antitranspirants caused a serious reduction in plant growth and yield. It caused severe premature leaf senescence and had a permanent effect on the plant's ability to continue to function normally.

Mulching had a significant effect on grain yield. Plastic mulch increased yields by 1000 kg/ha. Grass mulch increased grain yields by 400-500 kg/ha despite its negative effect on plant growth during the vegetative stage. The PMA antitranspirant reduced yield by 4000 kg/ha while Wilt Pruf had no significant effect on yield.

An upland rice experiment was conducted to study the depth of lime incorporation and row spacing effect on the rice plant's internal water balance and final grain yield with two rice varieties.

An analysis of growth and yield parameters showed that Pratao Precoce was more influenced by row spacing than lime depth incorporation. The 15 cm row spacing showed more grain sterility and lighter grain weights which influenced a lower grain:straw ratio and a lower grain yield/plant. Final yield results showed that narrow row spacing produced 400 kg/ha less than the 45 cm row spacing.

IAC-1246 growth and yield parameters were not influenced by row spacing. Lime depth did have a significant effect with shallow liming being superior. Principle reason for shallow liming outyielding deep liming was that it produced greater panicle weights which in turn produced more grain/plant. Shallow limed treatments yielded 440 kg/ha more rice than deep lime treatments.

IAC-1246 significantly outyielded Pratao Precoce because it produced fewer unproductive tillers, produced heavier grain weights, and had a lower percentage of flower sterility. Those factors contributed to a 660 kg/ha yield difference.

BIBLIOGRAPHY

Arens, K. 1963. As plantas lenhosas dos campos cerrados como flora adaptadas as deficiencias minerais do solo. In: Ferri, M.G. Coord. I Simposio sobre o cerrado. Editora E. Blucher Ltda. Sao Paulo 249-265.

Barrs, H.D. and P.E. Weatherly. 1962. A re-examination of the relative turgidity technique for estimating water deficits in leaves. Aust. J. Biol. Sci. 15:413-428.

_____ 1968. Determination of water deficits in plant tissues. In: T.T. Kozlowski, ed., Water Deficits and Plant Growth, Vol. 1. Academic Press. New York. pp. 235-368.

Bravdo, Ben-Ami. 1972. Photosynthesis, transpiration, leaf stomatal and mesophyll resistance measurements by the use of a ventilated diffusion porometer. Physiol. Plant. 27:209-215.

Bidinger, F.R. 1976. Unpublished Ph.D. Thesis. Cornell University. Ithaca, N. Y.

Boyer, J.S. and B.Bowen. 1970. Inhibition of Oxygen Evolution in Chloroplasts Isolated from Leaves with Low Water Potentials. Plant Physiol. 45:612-615.

_____ and H. G. McPherson. 1975. Physiology of Water Deficits in Cereal Crops. Advances in Agronomy. 27:1-24.

Byrne, C.F., C.W. Rose and R.O. Slayter. 1970. An aspirated diffusion porometer. Agr. Meteorol. 7: pp. 19-28.

Claassen, M.M. and R.H. Shaw. 1970. Water Deficit Effects on Corn. II Grain Components. Agron. Jour. 62:652-655.

Cline, M.G. and S.W. Buol. 1973. Soils of the Central Plateau of Brazil and Extension of Results of Field Research Conducted near Planaltina, Federal District to Them. Agronomy Mimeo 73-13. Cornell University. Ithaca, N.Y.

Cornell University. 1973. Annual Report. Soil fertility requirements to attain efficient production of food crops on the extensive, deep, well-drained but relatively infertile acid soils of the humic tropics. Agronomy Department, Cornell University, Ithaca, N.Y. 14850.

Ellis, F.B. and B.T. Barnes. 1973. Estimation of the distribution of living roots of plants under field conditions. Plant and Soil 39:81-91.

Fairbourn, M.L. 1973. Effect of gravel mulch on Crop Yields. Agron. Jour. 65:925-928.

Foy, C.D. 1972. Effects of aluminum on plant growth. In: E.W. Carson (ed.). The plant root and its environment. University Press of Va. Charlottesville, Va.

Gale, J. 1961. Studies on plant antitranspirants. Physiol. Plant. 14:777-786.

Gonzalez, E.E. 1974. Soil Fertility in the Humid Tropics. Annual Progress Report for the period July 1, 1972 to June 30, 1973. Cornell University. Ithaca, N.Y.

_____ 1976. Unplished Ph.D. Thesis. North Carolina State University. Raleigh, N.C.

Goodland, R. 1970. The Savanna Controversy: Background Information on the Brasilian Cerrado Vegetation. Savanna Research Series No. 15. McGill University, Montreal, Canada.

_____ and R. Pollard. 1973. The Brazilain cerrado vegetation: A fertility gradient. Ecology. 61 (1) :219-225.

Hansen, D.L. and Bush, E.T. 1967. Improved solubilization procedures for liquid scintillation counting of Biological Materials. Analytical Biochem 18: pp. 320-332.

Hanway, J. H. 1966. How a Corn Plant Developes. Special Report No. 48. Iowa State University. Ames, Iowa.

Incoll, L.D. 1969. A convenient assay for ^{14}Carbon in leaf tissue. Plant Physiol. 44: Suplement p. 42.

Jones, Jr, J.B. and H.V. Eck. 1973. Plant Analysis as an Aid in Fertilizing Corn and Grain Sorghum. L.M. Walsh and J.D. Beaton. (ed). Soil Testing and Plant Analysis. Soil Science Society of America, Inc. pp 349-364.

Kanemasu, E.T. G.W. Thurtell, and C.B. Tanner. 1969. Design, calibration and field use of a stomatal diffusion porometer. Plant Physiol. 44:881-885.

Keck, R.W. and J.S. Boyer 1974. Chloroplast Response to Low Leaf Water Potentials. II Differing Inhibition of Electron Transport adn Photophosphorylation. Plant Physyol. 53:474-479.

Kramer, P.J. 1969. Plant and soil water relationships: A modern synthesis. Mc Graw - Hill Book Co. New York.

Lal. R. 1975. Role of Mulching Techniques in Tropical Soil and Water Management. IITA Tech. Bull No. 1. pp. 1-38.

McWilliam, J.R., P.J. Phillips, and R.R. Parks. 1973. Measurement of photosynthetic rate using labelled carbon dioxide. CSIRO Aust. Div. Pl. Ind. Tech. Pap. No. 31, 1-12.

Newman, E.I. 1966. Method of Estimating the total Lenght of Root in a Sample. Appl. Ecal. 3: pp. 139-145.

North Carolina State University. 1973. Annual Report. Agronomic-Economic Research in Tropical Soils. Soil Science Department, North Carolina State University, Raleigh, North Carolina, 27607.

Onderdouk, J.J. and J.W. Ketcheson. 1973. Effect of Stover Mulch on Soil Temperature, Corn Root Weight, and Phosphorus Fertilizer Uptake. Soil Sci. Soc. Amer. Proc. 37:904-906.

Plaut, Z. and B. Bravdo. 1973. Response of Carbon Dioxids Fixation to Water Stress. Parallel Measurements on Isolated Chloroplasts and Intact Spinach Leaves. Plant Physiol. 52:28-32.

Pruntel, J. 1975. Water Availability and Soil Suitability for Irrigation Water Impoundments in the Federal District of Brazil. M.S. Thesis. Cornell University, Ithaca, N. Y.

Raschke, K. 1960. Heat transfer between the plant and the environment. Annu. Rev. Pl. Physiol. 11:111-126.

Roberts, W.J. 1961. Reducing transpiration from plants. J. Geophys. Res. 66:3309-3312.

Scholander, P. F., H.T. Hammel, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Slatyer, R.O. and J.F. Bierhuizen. 1964. The Influence of Several Transpiration Suppressants on Transpiration, Photosynthesis, and Water-Use Efficiency of Cotton Leaves. Aust. J. Biol. Sci. 17:131-146.

_____ 1969. Physiological significance of internal water relations to crop yield. In. A.C. Dinaur. (ed.). Physiological Aspects of Yield. Pub. ASA, CSSA. Madison, Wis. USA. pp. 53-88.

Stigter, C.J. and B. Lammers. 1974. Leaf Diffusion Resistance to Water Vapor and Its Direct Measurement III. Mededelinger Londbouwhogeschool Wageningen, Nederland 74-21.

Turner, N.C. and Jean-Yves Parlauge. 1970. Analysis of Operation and Calibration of a Ventilated Diffusion Porometer. Plant Physiol. 46:pp. 175-177.

van Bavel, C.H.M. 1964. Measuring Transpiration Resistance of Leaves. W C L Report 2. A R S, USDA. Temple, Arizona.

_____, M.F.S. Nakayama, and W.L. Ehrler. 1965. Measuring transpiration resistance of leaves. Plant Physiol. 40:535-540.

Van Doren, Jr., D.M. and G.B. Triplitt, Jr. 1973. Mulch and Tillage Relationships in Corn Culture. Soil Sci. Soc. Amer. Proc. 37:766-769.

Wallikam, Ellis.F. 1964. Modification and use of an eletric hygrometer for estimating relative stomatal apertures. Plant Physiol. 39: pp. 86-90.

Wardlaw, I.F. 1969. The Effect of Water Stress on Translocation in Relation to Photosynthesis and Growth. II. Effect during leaf development in Lolium Temulentum L. Aust. J. Biol. Sci. 22:1-16.

Wolf, J.M. 1975. Water Constraints to Corn Production in Central Brazil. Ph.D. Thesis. Cornell University. Ithaca,New York.

Yost, R.S. 1974. Soil Fertility in the Humid Tropics. Annual Progress Report for the period July 1, 1972 to June 30, 1973. Cornell University. Ithaca, New York.

Zelitch.I. 1961. Biochemical control of stomatal opening in leaves. Proc. Nat. Acad. Sci., Wash. 47:1423-1433.

_____, and P.E. Waggoner. 1962. Effect of chemical control of stomata on transpiration and photosynthesis. Proc. Nat. Acad. Sci., Wash. 48:1101-1108.

Appendix

Table 1. Growth analysis for corn grown during the 1974 dry season. Measurements were taken approximately every 10-12 days.

Treatment	Height	LAI	Leaf Dry Wt.	Stem Dry Wt.	Total Dry Wt.	NAR	RGR
	cm	$cm^2\ cm^{-2}$	g/plant	g/plant	g/plant	$g\ m^{-2}\ w^{-1}$	w^{-1}
		29 Days after Planting					
0-Lime	12.1	.047	.30	.16	.46	—	—
Lime-Shallow	14.5	.081	.48	.26	.74	—	—
Lime -Deep	16.1	.093	.55	.30	.85	—	—
Broadcast-P	12.8	.057	.33	.15	.45	—	—
Banded-P	16.2	.092	.65	.39	1.04	—	—
$LSD._{.05}$	2.6	.026	.18	.14	.31	—	—
C.V. (%)	18.5	36.6	40.0	55.7	45.3	—	—
		39 Days after Planting					
0-Lime	15.2	.111	1.51	.91	2.42	91.25	1.17
Lime-Shallow	15.4	.155	2.15	1.17	3.31	80.85	1.09
Lime-Deep	15.6	.155	2.08	1.13	3.23	67.58	.94
Broadcast-P	13.8	.114	1.49	.68	2.17	72.73	1.09
Banded-P	16.1	.145	2.09	1.27	3.36	78.48	.93
$LSD._{.05}$	n.s.	.039	.61	.43	1.04	n.s.	n.s.
C.V. (%)	13.2	29.5	33.5	43.3	36.8	38.21	33.69
		50 Days after Planting					
0-Lime	20.9	.173	3.02	1.90	4.92	54.24	.42
Lime-Shallow	26.8	.275	4.60	3.11	7.71	66.01	.52
Lime-Deep	27.2	.332	5.93	4.02	9.95	87.77	.68
Broadcast-P	19.9	.170	2.80	1.19	3.99	43.33	.42
Banded-P	22.3	.224	3.77	2.50	6.27	43.84	.32
$LSD._{.05}$	4.6	.081	1.56	1.48	3.00	n.s.	n.s.
C.V. (%)	20.1	35.3	40.4	57.4	46.50	74.64	69.96

Appendix
Table 1. (cont.)

		61 Days after Planting					
0-Lime	28.6	.353	6.88	5.23	12.11	78.99	.50
Lime-Shallow	31.7	.429	7.66	5.01	12.70	46.36	.33
Lime-Deep	30.5	.429	7.12	4.57	11.70	15.01	.11
Broadcast-P	25.5	.285	5.34	3.63	8.97	58.58	.40
Banded-P	26.9	.359	6.13	4.18	10.31	47.46	.37
$LSD_{.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	.43	n.s.
C.V. (%)	25.7	44.7	49.4	65.8	55.5	90.03	88.36
		71 Days after Planting					
0-Lime	43.0	.587	11.76	11.90	23.66	91.94	.51
Lime-Shallow	46.9	.783	14.38	12.79	27.17	75.75	.48
Lime-Deep	46.5	.803	15.45	14.21	29.66	103.76	.66
Broadcast-P	50.7	.814	16.86	18.43	35.29	189.91	1.02
Banded-P	40.9	.584	10.47	8.62	19.09	67.52	.44
$LSD_{.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	.81	n.s.
C.V. (%)	20.5	35.3	38.2	48.2	43.8	79.01	80.72
		81 Days after Planting					
0-Lime	54.0	.853	18.81	21.92	40.73	78.87	.35
Lime-Shallow	52.7	.894	18.40	17.20	35.60	43.30	.23
Lime-Deep	55.3	.959	20.02	18.56	38.58	36.56	.20
Broadcast-P	54.7	.877	18.18	17.99	36.17	-1.38	-.01
Banded-P	44.7	.672	15.46	14.00	29.46	49.74	.25
$LSD_{.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V. (%)	25.9	40.6	42.9	71.3	56.4	217.34	208.30

Appendix
Table 1. (cont.)

		92 Days after Planting					
0-Lime	75.2	1.165	29.85	43.07	72.92	106.52	.39
Lime-Shallow	59.8	.843	20.33	21.96	42.29	19.27	.09
Lime-Deep	68.7	1.177	26.84	31.51	58.35	50.88	.21
Broadcast-P	90.4	1.552	39.46	57.81	97.27	144.97	.56
Banded-P	45.7	.603	15.10	12.72	27.82	1.42	.02
$LSD._{05}$	15.1	.347	9.78	22.01	30.86	106.46	.44
C.V. (%)	22.8	33.3	38.0	67.7	53.0	169.33	178.59
		106 Days after Planting (No Stress)					
0-Lime	120.4	1.560	55.8	108.9	164.7	199.48	.44
Lime-Shallow	105.6	1.489	48.8	94.6	143.4	320.14	.62
Lime-Deep	120.0	1.711	61.5	73.7	135.2	168.85	.53
Broadcast-P	129.6	1.999	63.0	115.9	178.9	135.15	.41
Banded-P	67.4	.774	23.8	25.7	49.5	86.04	.30
$LSD._{05}$	14.0	.220	9.9	36.8	45.2	n.s.	n.s.
C.V. (%)	13.9	16.1	21.5	47.3	36.5	86.12	82.17
		106 Days after Planting (Stress)					
0-Lime	95.3	1.277	50.3	68.3	118.6	124.27	.34
Lime-Shallow	91.2	1.270	41.0	51.6	92.6	152.72	.52
Lime-Deep	116.2	1.503	50.2	89.8	140.0	152.82	.44
Broadcast-P	108.7	1.387	51.7	87.6	139.3	81.67	.21
Banded-P	59.3	.596	23.0	22.8	45.8	79.45	.20
Nutrient $LSD._{05}$	14.0	.220	9.86	36.8	45.2	n.s.	n.s.
Stress $LSD._{05}$	15.3	.223	n.s.	14.7	15.5	n.s.	n.s.
Stress*Nutrient $LSD._{05}$	27.1	.425	19.0	71.3	87.5	n.s.	n.s.
C.V. (%)	13.9	16.1	21.5	47.3	36.5	86.12	82.17

Appendix
Table 1. (cont.)

		119 Days after Planting (No Stress)					
0-Lime	126.1	1.405	38.4	83.0	168.4	-40.65	-.06
Lime-Shallow	137.7	1.623	40.5	76.4	156.1	52.17	.08
Lime-Deep	138.1	1.654	38.3	70.1	127.2	-11.13	-.02
Broadcast-P	136.5	1.480	39.7	80.8	145.5	-55.30	-.24
Banded-P	101.1	.870	23.2	40.3	68.7	71.25	.20
Nutrient $LSD._{05}$	17.9	.378	11.5	28.7	54.9	n.s.	n.s.
C.V. (%)	14.8	27.7	32.9	43.3	43.6	1584.38	869.79
		119 Days after Planting (Stress)					
0-Lime	120.0	1.420	34.7	64.4	116.4	-8.45	-.03
Lime-Shallow	106.0	1.440	37.2	62.0	132.0	79.68	.18
Lime-Deep	128.3	1.436	38.5	60.7	110.3	-54.67	-.14
Broadcast-P	143.3	1.743	52.2	103.2	190.9	86.23	.19
Banded-P	90.7	.930	20.5	30.3	60.3	55.28	.16
Nutrient $LSD._{05}$	17.9	.378	11.5	28.7	54.9	n.s.	n.s.
Stress $LSD._{05}$	10.7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V. (%)	14.8	27.7	32.9	43.3	43.6	1584.38	869.79

Appendix
Table 2. Morning and afternoon soil temperatures at six depths in the 0-45 cm soil profile.

	Average Soil Temperatures (°C) Inside Plots					
	Soil Depth (cm)					
Date	5	10	15	22.5	30	45
			(08:00 hrs)			
12/7	21.1	18.1	17.8	17.9	18.5	19.4
22/7	19.2	17.9	17.6	18.8	18.7	16.6
24/7	18.2	17.8	18.1	19.3	18.3	20.8
26/7	18.0	16.9	18.2	18.9	18.8	21.4
30/7	16.6	16.8	17.6	18.7	19.0	20.3
2/8	16.2	15.5	15.9	17.5	18.2	19.0
5/8	16.6	16.5	17.3	19.1	19.5	21.3
7/8	17.7	17.3	17.5	19.5	18.7	21.0
9/8	17.3	18.3	19.3	19.8	20.6	21.4
15/8	18.5	19.0	19.7	20.9	21.5	21.3
19/8	19.5	18.0	19.2	20.3	20.7	20.6
23/8	17.1	19.4	18.8	20.4	21.0	22.3
25/8	18.4	18.0	19.1	19.6	20.5	21.3
$\bar{X}$	18.0	17.7	18.2	19.3	19.5	20.5
			(15:00 hrs)			
22/6	22.7	19.3	19.0	19.4	19.3	21.2
12/7	25.9	23.7	20.5	19.2	19.9	20.1
22/7	28.4	26.7	24.4	21.2	20.4	21.0
30/7	28.2	25.6	22.5	20.1	19.5	20.0
2/8	32.7	25.1	21.9	20.0	19.6	20.2
7/8	26.5	23.6	21.3	19.7	19.4	23.6
9/8	28.7	26.0	24.1	19.5	19.2	19.9
15/8	25.8	24.8	24.0	22.3	21.9	22.3
19/8	30.6	28.4	24.3	21.3	20.9	20.6
$\bar{X}$	27.7	24.8	22.4	20.3	20.0	21.0

Appendix

Table 3a. Stomatal resistance for both adaxial and abaxial sides of the corn leaf taken four times daily during the first stress period; (a) 08:30-09:30 hrs, (b) 10:30-11:30 hrs, (c) 13:30-14:30 hrs and (d)15:30-16:30 hrs.

Treatment		Sampling Days During Water Stress									*
		30/8	31/8	1/9	2/9	3/9	5/9	6/9	7/9	Av.	10/9
		sec/cm									
0-Lime	1/	9.47	13.95	11.38	11.82	19.40	11.32	14.93	19.22	13.94	24.75
	2/	4.57	6.67	6.59	6.69	6.81	7.29	7.52	11.69	7.23	6.26
Lime-Shallow		7.47	10.41	7.71	9.83	12.09	11.20	19.92	22.48	12.64	15.86
		5.67	7.50	7.07	8.96	7.91	8.51	10.87	9.22	8.21	5.40
Lime-Deep		12.96	9.70	8.46	10.53	11.15	10.98	19.39	13.91	12.10	23.12
		5.66	8.53	5.37	6.06	6.45	7.12	9.09	10.45	7.34	6.23
Broadcast-P		6.93	8.33	7.64	16.79	12.07	14.92	16.54	18.63	12.74	19.26
		3.93	6.90	4.82	10.35	6.01	11.49	12.54	11.04	8.39	9.72
Banded-P		11.26	11.52	12.29	11.93	11.17	18.33	19.39	20.37	14.53	19.14
		8.06	9.03	10.58	11.84	9.99	10.43	12.34	14.45	10.84	8.42

* One day after irrigation

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix
Table 3 b. 10:30-11:30 hours.

Treatment		Sampling Days During Water Stress									*
		30/8	31/8	1/9	2/9	3/9	5/9	6/9	7/9	Av.	10/9
		sec/cm									
0-Lime	1/	—	16.90	12.61	71.21	73.72	83.49	167.38	74.38	71.38	17.05
	2/	—	7.10	7.07	57.40	75.95	63.96	151.05	73.59	62.30	6.08
Lime-Shallow		—	20.06	24.79	46.32	36.10	25.84	121.66	89.13	51.99	14.02
		—	13.39	9.13	77.67	36.85	48.56	160.22	102.02	63.98	6.69
Lime-Deep		—	13.95	11.31	25.86	15.83	25.40	59.88	28.38	25.80	17.89
		—	6.07	9.77	15.64	15.23	21.04	20.13	16.92	14.74	7.19
Broadcast-P		—	20.47	16.43	69.29	51.58	140.56	258.26	83.13	91.39	12.90
		—	31.86	12.82	45.99	30.53	29.11	230.72	61.78	63.26	6.70
Banded-P		—	15.02	11.97	25.47	14.68	24.78	87.30	33.33	30.36	15.67
		—	10.67	9.62	15.54	14.12	13.09	26.82	19.75	15.66	7.11

* One day after irrigation

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix
Table 3 c. 13:30-14:30 hours.

Treatment		Sampling Days During Water Stress									*
		30/8	31/8	1/9	2/9	3/9	5/9	6/9	7/9	Av.	10/9
		sec/cm									
0-Lime	1/	16.05	16.75	57.90	69.64	63.80	64.90	84.36	87.83	57.65	15.16
	2/	6.39	6.95	15.77	22.88	51.22	43.05	58.16	26.59	28.88	4.91
Lime-Shallow		11.92	32.19	45.77	74.01	84.04	67.18	121.99	90.43	65.94	15.31
		8.37	17.35	49.32	74.25	57.13	66.03	146.20	73.78	61.55	4.60
Lime-Deep		11.86	26.97	12.82	22.08	30.70	37.45	38.34	22.63	25.36	13.98
		6.83	6.78	11.58	14.02	40.64	16.37	43.04	18.14	19.68	9.15
Broadcast-P		9.49	26.08	25.26	90.02	55.13	81.88	80.33	108.79	119.25	17.42
		7.25	17.54	16.27	102.84	47.80	69.34	43.27	91.89	49.53	6.61
Banded-P		16.60	15.24	17.60	20.82	23.22	25.21	35.55	28.96	22.90	15.91
		9.14	13.94	11.21	40.19	26.26	31.16	35.27	23.79	23.87	6.05

* One day after irrigation

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix
Table 3 d. 15:30-16:30

Treatment		Sampling Days During Water Stress									*
		30/8	31/8	1/9	2/9	3/9	5/9	6/9	7/9	Av.	10/9
		sec/cm									
0-Lime	1/	20.19	15.16	41.89	27.64	107.00	69.91	33.20	35.69	43.84	27.90
	2/	11.64	16.88	13.96	16.49	66.31	58.98	24.76	31.99	30.13	11.29
Lime-Shallow		13.49	19.39	47.69	27.63	51.02	59.21	67.09	46.25	41.47	30.34
		12.61	26.55	38.37	22.66	37.16	74.17	42.35	28.21	35.26	18.74
Lime-Deep		13.55	16.95	16.59	19.53	25.07	28.81	26.95	26.25	21.71	19.64
		10.33	29.47	17.55	24.80	42.04	19.36	20.52	18.03	22.76	11.19
Broadcast-P		11.57	28.31	32.11	23.07	44.30	43.59	74.99	54.65	39.07	37.02
		12.02	33.86	32.65	19.10	39.04	61.49	57.78	34.57	36.31	13.15
Banded-P		21.91	67.65	43.56	31.99	55.07	57.15	41.52	44.53	45.42	44.52
		12.73	23.16	23.86	21.24	23.38	80.89	53.33	48.49	35.89	7.20

* One day after irrigation

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix

Table 4a. Stomatal resistance for both adaxial and abaxial sides of the corn leaf taken four times daily during the second stress period; (a) 08:30-09:30 hrs, (b) 10:30-11:30 hrs, (c) 13:30-14:30 hrs, and (d) 15:30-16:30 hrs.

Treatment		Sampling Days During Water Stress											
		21/9	22/9	23/9	25/9	26/9	27/9	28/9	29/9	30/9	1/10	2/10	Av.
		sec/cm											
0-Lime	1/	10.7	9.2	10.4	10.1	7.9	7.2	12.9	13.5	12.9	13.2	11.6	10.91
	2/	3.3	4.4	3.2	4.2	4.7	4.4	7.1	9.6	8.1	10.6	6.8	6.07
Lime-Shallow		9.3	7.4	9.8	11.2	8.8	7.9	10.3	12.4	11.5	11.8	9.5	10.03
		3.8	3.6	4.0	7.4	5.2	4.1	6.3	6.6	8.5	8.0	6.5	5.85
Lime-Deep		6.7	5.4	6.4	7.1	4.5	5.6	7.7	7.3	8.5	10.2	7.1	7.01
		3.1	3.3	3.9	3.8	3.0	3.1	3.6	4.7	5.4	5.8	5.1	4.13
Broadcast-P		8.6	8.5	7.7	8.0	8.3	6.6	15.6	19.2	12.3	14.6	7.8	10.70
		4.4	4.4	4.1	7.6	6.6	6.7	18.3	23.0	8.3	10.7	9.5	9.46
Banded-P		12.4	12.3	10.2	11.2	7.7	9.6	11.1	14.9	7.7	18.5	10.5	11.52
		3.6	4.7	3.3	4.4	4.3	4.4	5.1	5.7	7.7	6.5	6.3	5.13

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix
Table 4 b. 10:30-11:30 hours.

Treatment		Sampling Days During Water Stress											
		21/9	22/9	23/9	25/9	26/9	27/9	28/9	29/9	30/9	1/10	2/10	Av.
		sec/cm											
0-Lime	1/	7.0	9.8	11.5	7.9	8.8	9.1	25.4	45.1	35.7	30.3	20.3	19.23
	2/	3.0	4.1	4.6	4.5	4.6	5.7	15.9	21.3	24.9	26.3	17.2	12.06
Lime-Shallow		6.2	8.0	6.9	7.3	6.1	7.1	24.3	27.9	32.6	14.9	27.6	15.39
		2.6	3.0	3.6	3.7	4.0	3.0	11.6	30.9	28.6	19.8	13.4	11.35
Lime-Deep		5.1	7.0	6.3	5.5	4.8	5.5	7.2	11.1	12.8	11.0	11.1	7.99
		2.9	3.3	3.4	3.3	2.6	2.6	4.5	6.2	7.6	6.1	9.1	4.75
Broadcast-P		6.7	7.7	7.2	8.6	8.3	11.6	23.8	25.5	49.1	22.6	16.4	17.09
		3.9	6.6	6.4	6.7	7.6	8.0	60.3	69.2	42.3	52.4	27.9	26.52
Banded-P		7.8	10.7	9.3	10.6	6.8	9.7	15.4	18.6	23.5	18.6	17.9	13.58
		3.0	4.6	3.4	3.8	3.5	4.5	6.7	6.3	13.1	8.1	9.0	6.05

1/ adaxial side of leaf

2/ abaxialside of leaf

Appendix
Table 4 c. 13:30-14:30 hours.

Treatment		Sampling Days During Water Stress											
		21/9	22/9	23/9	25/9	26/9	27/9	28/9	29/9	30/9	1/10	2/10	Av.
		sec/cm											
0-Lime	1/	9.6	10.2	7.6	12.9	13.5	18.6	26.4	55.3	73.5	43.1	53.9	29.54
	2/	5.4	4.0	3.1	5.9	8.2	12.0	17.9	39.9	46.9	40.8	48.0	21.15
Lime-Shallow		8.5	9.8	7.2	9.8	8.9	12.5	24.4	42.6	57.0	33.6	38.6	23.03
		5.1	3.2	2.7	7.4	7.0	8.3	17.0	23.0	82.5	20.4	55.6	21.15
Lime-Deep		9.3	8.1	6.7	11.5	8.3	9.3	12.2	17.6	14.5	16.6	20.3	12.26
		5.8	4.4	3.2	7.1	6.1	6.7	6.3	18.8	11.5	16.9	20.1	9.76
Broadcast-P		10.1	13.5	10.4	14.0	15.0	13.2	31.9	52.9	36.2	21.1	39.6	23.48
		7.7	5.7	9.5	12.2	16.6	19.8	53.0	45.5	42.0	47.9	26.2	26.06
Banded-P		11.9	17.0	12.4	17.1	12.0	12.1	19.8	21.1	23.1	28.0	40.8	19.62
		5.8	5.2	3.5	7.6	5.1	5.4	8.3	14.7	19.8	22.4	12.6	10.09

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix
Table 4 d. 15:30-16:30 hours.

Treatment		Sampling Days During Water Stress											
		21/9	22/9	23/9	25/9	26/9	27/9	28/9	29/9	30/9	1/10	2/10	Av.
		sec/cm											
0-Lime	1/	12.1	13.2	10.9	13.9	26.1	14.7	23.9	31.1	83.8	34.3	22.7	26.09
	2/	7.1	7.3	4.8	13.8	19.7	13.3	24.7	41.0	36.2	31.6	13.0	19.35
Lime-Shallow		13.7	12.2	13.3	11.4	31.2	12.5	25.6	30.8	45.9	28.7	29.3	23.19
		12.2	5.6	7.5	9.5	27.3	11.7	27.5	39.0	45.8	22.2	22.4	21.01
Lime-Deep		9.6	13.3	15.6	19.8	18.0	13.3	15.4	13.9	20.6	20.6	16.4	16.11
		7.7	6.4	10.7	21.5	34.6	20.1	21.5	19.3	37.2	25.7	22.3	20.72
Broadcast-P		13.4	12.7	13.4	17.0	21.7	17.4	26.3	27.3	61.3	31.5	25.4	24.36
		9.0	20.0	7.4	47.0	36.5	18.9	36.0	46.6	63.8	26.2	23.0	30.43
Banded-P		16.5	23.6	19.9	24.7	34.3	15.0	24.3	33.4	25.0	37.9	24.0	25.38

1/ adaxial side of leaf

2/ abaxial side of leaf

Appendix

Table 5. Vapor pressure deficit within the corn canopy at four time periods during the day for both stress periods.

First Water Stress Period

Hours	Sampling Days During Water Stress									
	30/8	31/8	1/9	2/9	3/9	4/9	5/9	6/9	7/9	Av.
	Vapor Pressure Deficit (mbars)									
08:30–09:30	22.8	24.8	17.7	25.3	18.1	15.9	17.7	16.2	21.8	20.0
10:30–11:30	32.2	30.2	25.3	36.2	31.3	23.5	26.4	32.8	28.3	29.6
13:30–14:30	35.6	35.8	34.3	38.7	38.5	33.6	34.8	36.9	33.8	35.8
15:30–16:30	33.4	--	29.8	38.1	37.2	33.4	33.0	33.7	27.4	33.3

Second Water Stress Period

Hours	Sampling Days During Water Stress											
	21/9	22/9	23/9	25/9	26/9	27/9	28/9	29/9	30/9	1/10	2/10	Av.
	Vapor Pressure Deficit (mbars)											
08:30–09:30	9.5	15.5	8.6	16.3	16.8	12.5	26.9	20.6	15.4	20.1	14.3	16.0
10:30–11:30	18.9	24.7	17.4	24.7	27.1	21.6	30.7	30.9	39.5	26.9	26.5	26.3
13:30–14:30	19.4	26.5	27.0	32.0	27.1	30.0	36.6	38.5	39.8	35.2	34.8	31.5
15:30–16:30	21.8	24.4	21.7	28.2	24.0	28.1	31.6	32.9	34.5	30.1	27.4	27.7

Appendix

Table 6. Percent concentration of P, K, Ca and Mg in the stover for the 1974 dryseason experiment.

Treatment	Phosphorus	Potassium	Calcium	Magnesium
		No Stress		
0-Lime	.05	7.47	.31	.43
Lime-Shallow	.06	7.56	.32	.59
Lime-Deep	.05	8.80	.34	.53
Broadcast-P	.05	8.70	.33	.61
Banded-P	.05	7.90	.35	.54
		Late Stress		
0-Lime	.07	6.90	.26	.20
Lime-Shallow	.08	7.37	.35	.61
Lime-Deep	.06	7.37	.32	.52
Broadcast-P	.06	9.27	.29	.47
Banded-P	.07	5.50	.30	.50
		Early Stress		
0-Lime	.05	8.37	.27	.21
Lime-Shallow	.06	8.73	.48	.70
Lime-Deep	.04	8.73	.38	.65
Broadcast-P	.05	7.83	.39	.50
Banded-P	.06	6.43	.33	.56
F Test-Nutrient	n.s.	10 %	5 %	0.1 %
F Test-Stress	n.s.	n.s.	n.s.	n.s.

Appendix
Table 7. Growth analysis results for the 1974-5 wet season maize experiment in relation to plant water stress and five soil management practices.

Treatment	Height	LAI	Leaf Dry Wt.	Stem Dry Wt.	Total Dry Wt.	NAR	RGR
	cm	$cm^2\ cm^{-2}$	g/2 plants			$g\ m^{-2}\ w^{-1}$	w^{-1}
			27 Days after Planting				
0-Lime	34.5	.310	3.30	1.47	4.77	—	—
Lime-Shallow	41.3	.468	5.40	2.26	7.66	—	—
Lime-Deep	40.6	.451	5.24	2.28	7.52	—	—
Broadcast-P	32.5	.328	3.64	1.48	5.12	—	—
Banded-P	36.8	.390	4.09	1.84	5.93	—	—
$LSD_{.05}$	4.29	.08	.93	.49	1.36	—	—
C.V. (%)	11.88	20.04	21.97	26.88	22.51		
			39 Days after Planting				
0-Lime	55.7	.93	10.01	4.53	14.54	51.31	.666
Lime-Shallow	81.4	1.52	16.21	10.43	26.62	61.94	.729
Lime-Deep	28.2	1.35	14.93	8.28	23.21	53.62	.635
Broadcast-P	76.1	1.38	16.19	8.92	25.11	81.39	.952
Banded-P	61.1	.95	10.06	5.13	15.19	42.09	.536
$LSD_{.05}$	8.08	.23	3.18	2.40	5.45	15.30	.171
C.V. (%)	11.78	19.18	24.26	33.10	26.76	27.08	24.11
			51 Days after Planting				
0-Lime	108.3	1.84	25.12	19.06	44.17	64.68	.641
Lime-Shallow	148.6	2.80	35.99	35.78	71.77	62.86	.583
Lime-Deep	154.2	2.90	34.82	35.36	70.18	68.77	.664
Broadcast-P	141.3	2.53	34.18	34.95	69.13	68.34	.606
Banded-P	111.5	1.94	25.72	23.40	49.12	71.25	.684
$LSD_{.05}$	13.31	.27	5.06	6.01	10.55	n.s.	n.s.
C.V. (%)	10.31	11.75	16.68	20.78	17.80	28.44	26.34

Appendix
Table 7. (cont.)

63 Days after Planting (No Stress)

0-Lime	175.7	3.12	88.90	113.40	202.30	190.93	.90
Lime-Shallow	246.0	4.24	118.77	198.87	317.63	205.94	.86
Lime-Deep	246.0	4.15	107.27	134.23	241.50	157.65	.85
Broadcast-P	234.0	3.93	99.07	139.73	238.80	159.60	.76
Banded-P	211.0	3.56	90.40	147.17	237.57	186.12	.85

63 Days after Planting (Stress)

0-Lime	197.0	3.18	83.23	109.33	192.56	173.41	.84
Lime-Shallow	234.0	3.61	105.80	147.07	252.87	163.21	.72
Lime-Deep	251.3	3.65	99.90	157.80	257.70	163.10	.70
Broadcast-P	226.0	3.72	109.57	149.60	259.27	182.24	.75
Banded-P	178.3	2.67	70.[illegible]0	87.00	157.40	144.07	.72
Nutrient $LSD_{.05}$	16.39	.36	12.96	21.71	32.19	n.s.	n.s.
Stress $LSD_{.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Stress*Nut $LSD_{.05}$	n.s.	n.s.	n.s.	37.64	55.74	n.s.	n.s.
C.V. (%)	7.63	10.18	13.64	15.74	13.82	20.55	18.89

Appendix

Table 7. (cont.)

				90 Days after Planting (Early Stress)						
0-Lime	239.3	2.04	89.4	176.2	436.0	12.0	160.6	9.8	121.7	.21
Lime-Shallow	259.3	1.87	105.4	241.7	514.6	12.7	155.0	12.5	102.6	.17
Lime-Deep	269.3	2.28	123.8	226.0	605.4	13.3	204.3	11.3	145.0	.25
Broadcast-P	250.0	3.23	91.2	230.0	468.3	11.8	137.3	10.0	46.2	.07
Banded-P	225.3	2.79	85.9	157.1	355.6	11.5	103.4	9.1	91.5	.17
Nutrient $LSD_{.05}$	15.7	.39	17.19	25.87	72.03	n.s.	41.69	n.s.	52.58	.08
Stress $LSD_{.05}$	n.s.	.25	13.37	n.s.	91.13	.70	25.42	2.88	n.s.	n.s.
Stress*Nut. $LSD_{.05}$	n.s.	n.s.	n.s.	44.82	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V. (%)	6.43	13.89	18.36	13.12	16.86	11.75	30.79	40.69	86.42	79.28
				105 Days after Planting (No Stress)						
0-Lime	207.7	2.66	78.7	173.8	508.4	10.0	245.9	9.9	73.[illegible]	.08
Lime-Shallow	247.0	2.67	97.2	229.9	661.9	10.0	327.4	7.3	177.5	.18
Lime-Deep	249.3	2.70	97.7	172.0	532.3	9.5	253.0	9.4	-29.4	-.03
Broadcast-P	253.6	2.92	87.0	213.7	609.4	9.7	297.4	11.2	153.7	.17
Banded-P	237.0	2.01	75.1	169.0	511.1	8.3	260.5	6.4	71.0	.07
				105 Days after Planting (Late Stress)						
0-Lime	217.8	2.45	77.6	178.3	435.9	7.5	170.0	10.0	93.1	.08
Lime-Shallow	238.3	2.35	79.7	189.2	474.3	7.8	196.4	9.0	76.8	.05
Lime-Deep	244.7	2.63	87.7	228.4	564.7	8.3	239.4	9.2	117.2	.09
Broadcast-P	246.0	1.93	77.3	197.7	557.0	8.3	275.4	6.5	221.5	.21
Banded-P	199.3	1.45	59.6	135.3	352.2	7.2	150.7	6.5	48.2	.05
				105 Days after Planting (Early Stress)						
0-Lime	216.0	1.81	70.2	159.8	448.8	9.2	207.6	11.1	9.4	.00
Lime-Dhallow	248.8	1.96	88.9	210.0	612.0	8.8	301.8	11.2	77.9	.07
Lime-Deep	257.7	1.99	89.3	198.2	594.8	10.0	296.9	10.5	-7.9	.00
Broadcast-P	248.0	2.35	76.0	192.5	535.5	9.0	257.2	9.6	57.0	.06
Banded-P	237.7	2.23	81.7	139.3	455.2	9.3	223.0	11.1	88.8	.11
Nutrient $LSD_{.05}$	20.32	.33	8.81	36.38	79.39	n.s.	56.44	n.s.	n.s.	n.s.
Stress $LSD_{.05}$	n.s.	.41	n.s.	n.s.	n.s.	.93	n.s.	n.s.	n.s.	n.s.
Stress*Nut. $LSD_{.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V. (%)	8.84	14.80	11.10	20.12	15.58	8.9	23.50	23.26	145.1	143.4

Appendix
Table 7. (cont.)

Treatment	Height	LAI	Leaf Dry Wt.	Stem Dry Wt.	Total Dry Wt.	Leaf No.	EAR Dry Wt.	Tassel Dry Wt.	NAR	RGR
	cm	$cm^2 cm^{-2}$	—— g/2 plants	——		No.	g/2 plants		$gm^{-2} w^{-1}$	w^{-1}
				76 Days after Planting						
0-Lime	226.9	3.45	81.9	162.1	289.5	13.8	31.7	13.7	81.9	.21
Lime-Shallow	258.0	4.14	96.5	224.7	387.8	14.2	53.8	12.7	66.8	.16
Lime-Deep	255.4	4.34	103.5	226.3	393.9	14.6	50.3	13.8	81.7	.20
Broadcast-P	261.1	4.42	105.2	243.1	413.1	14.4	52.8	13.1	99.2	.25
Banded-P	219.9	3.27	78.8	157.6	279.1	13.5	31.4	11.3	78.8	.21
Nutrient $LSD._{.05}$	16.79	.49	11.52	31.40	44.26	.78	14.5	n.s.	n.s.	n.s.
Stress $LSD._{.10}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	.97	n.s.	n.s.
C.V. (%)	7.07	12.79	12.70	15.91	12.90	5.70	33.77	16.38	56.88	56.83
				90 Days after Planting (No Stress)						
0-Lime	222.2	2.97	87.7	176.3	415.0	11.7	140.6	11.1	112.5	.22
Lime-Shallow	270.3	2.93	100.4	205.7	452.6	10.8	133.5	13.0	35.7	.06
Lime-Deep	272.0	3.86	126.6	229.8	579.0	12.7	210.6	12.0	89.8	.13
Broadcast-P	267.0	3.01	91.6	185.2	414.9	10.8	123.0	15.1	-0.5	.0
Banded-P	238.7	3.23	102.3	218.5	423.4	11.7	152.1	13.0	69.8	.13
				90 Days after Planting (Late Stress)						
0-Lime	238.3	2.96	77.1	168.5	362.1	8.2	107.2	9.2	47.9	.07
Lime-Shallow	275.0	3.63	94.2	201.2	420.6	7.7	116.7	8.5	13.6	.02
Lime-Deep	275.3	4.37	106.1	246.9	471.2	8.5	148.1	10.0	67.6	.09
Broadcast-P	264.3	2.11	91.0	195.3	356.2	8.3	106.2	11.3	-53.6	-.1
Banded-P	208.7	1.90	71.6	142.8	310.7	7.8	89.0	7.3	47.5	.08

Appendix

Table 8. Transpiration rates for maize during the veranico in relation to five fertility treatments; (a) Transpiration rates calculated from modified van Bavel formula; (b) Transpiration rates using the weight method.

(a)

Treatment		Sampling Days During Water Stress								
		6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	Av.
		$\mu g\ H_2O/cm^2/sec$								
0-Lime	1/	3.1	.93	.80	.42	.60	.38	.57	.76	.95
	2/	3.2	1.13	1.15	.63	.87	.38	.61	.71	1.09
Lime-Shallow		2.1	2.00	1.32	.60	1.44	.52	.55	.74	1.16
		3.8	2.60	1.40	.81	1.42	.60	.68	.82	1.52
Lime-Deep		7.8	5.61	8.94	4.02	2.77	2.17	3.03	2.86	4.65
		7.0	5.75	12.95	3.17	1.94	2.08	3.21	2.08	4.77
Broadcast-P		2.9	1.42	1.29	.71	.80	.39	.59	.42	1.07
		2.4	1.64	.97	.97	1.67	.34	.53	.57	1.14
Banded-P		2.1	1.62	1.14	.49	.58	.55	.84	.52	.98
		2.9	3.22	2.71	1.55	.77	.61	1.19	.52	1.68

1/ adaxial side of the leaf.

2/ abaxial side of the leaf.

Appendix
Table 8 cont. (b)

Treatment		Sampling Days During Water Stress								
		6/3	7/3	8/3	9/3	10/3	11/3	12/3	13/3	Av.
		$\mu g\ H_2O\ cm^{-2}\ s^{-1}$								
O-Lime	1/	6.22	2.18	2.76	.94	1.44	.76	1.44	1.39	2.14
	2/	5.99	3.67	3.54	1.22	2.50	1.45	2.19	1.34	2.74
Lime-Shallow		6.97	3.72	2.94	1.71	4.01	1.04	1.06	1.23	2.94
		8.21	4.82	2.48	1.45	4.27	1.12	1.60	1.84	3.22
Lime-Deep		13.76	8.45	11.73	6.24	5.36	4.51	4.81	5.01	7.48
		13.43	8.23	17.28	5.92	4.06	4.93	4.70	4.56	7.89
Broadcast-P		5.52	4.72	2.72	1.99	2.25	.76	1.29	1.61	2.61
		5.88	4.25	3.33	2.46	3.99	.63	1.21	1.26	2.88
Banded-P		7.39	3.88	4.06	2.05	1.28	.95	2.43	1.26	2.91
		9.44	5.30	5.84	3.47	2.62	1.05	2.23	1.59	3.94

1/ adaxial side of the leaf.

2/ abaxial side of the leaf.

Appendix
Table 9. Plant uptake of P, K, Ca, and Mg throughout the season in relation to the five fertility treatments and late stress period.

Treatment	Phosphorus	Magnesium	Calcium	Potassium
	$1x10^{-2}$ g/plant			
		27 Days after Planting		
0-Lime	1.4	1.8	1.4	22
Lime-Shallow	2.0	2.7	2.2	36
Lime-Deep	2.1	2.4	2.0	35
Broadcast-P	1.1	1.8	1.6	22
Banded-P	1.4	1.3	1.8	26
		39 Days after Planting		
0-Lime	2.1	1.0	2.6	36
Lime-Shallow	4.1	5.5	4.5	69
Lime-Deep	3.4	4.9	3.2	54
Broadcast-P	4.1	4.2	4.5	65
Banded-P	1.5	3.0	3.4	36
		51 Days after Planting		
0-Lime	9.1	7.2	10.9	161
Lime-Shallow	15.0	27.8	16.1	278
Lime-Deep	13.7	26.0	17.0	258
Broadcast-P	14.6	17.9	14.4	240
Banded-P	9.3	16.0	13.9	194
		63 Days after Planting		
0-Lime	21.1	10.5	17.2	254
Lime-Shallow	35.8	41.9	31.2	358
Lime-Deep	35.2	39.3	31.2	346
Broadcast-P	32.7	30.7	27.4	327
Banded-P	19.1	25.2	19.6	264
		76 Days after Planting		
0-Lime	23.5	8.0	22.2	204
Lime-Shallow	35.3	46.8	31.2	279
Lime-Deep	32.5	43.6	34.2	299
Broadcast-P	36.8	39.5	34.1	332
Banded-P	15.4	30.1	22.1	203

Appendix
Table 9 (cont.)

	90 Days after Planting (No Stress)			
0-Lime	22.3	13.1	37.2	237
Lime-Shallow	24.5	58.2	55.2	230
Lime-Deep	33.9	51.7	57.1	321
Broadcast-P	22.2	34.7	36.0	360
Banded-P	18.8	38.9	51.6	258
	90 Days after Planting (Late Stress)			
0-Lime	18.4	17.3	27.0	184
Lime-Shallow	22.2	42.8	53.2	251
Lime-Deep	28.5	58.8	57.0	303
Broadcast-P	21.2	39.5	33.8	212
Banded-P	10.7	31.1	25.8	214
	105 Days after Planting (No Stress)			
0-Lime	13.8	15.2	37.9	177
Lime-Shallow	18.0	52.4	49.1	245
Lime-Deep	14.8	47.2	43.2	189
Broadcast-P	12.0	39.1	48.2	181
Banded-P	7.3	31.7	29.3	110
	105 Days after Planting (Late Stress)			
0-Lime	14.1	12.8	46.1	141
Lime-Shallow	17.5	51.1	53.8	135
Lime-Deep	15.8	45.8	53.7	237
Broadcast-P	18.3	26.7	33.8	155
Banded-P	7.2	33.2	28.9	116

Appendix

Table 10. Percent concentration of P, K, Ca, and Mg in corn grain and stover from the 1974-5 wet season experiment.

Treatment	Phosphorus		Potassium		Calcium		Magnesium	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
			No Stress					
0-Lime	.42	.03	.40	1.00	.03	.19	.17	.13
Lime-Shallow	.37	.05	.40	1.03	.03	.16	.14	.23
Lime-Deep	.40	.06	.47	1.13	.03	.17	.16	.27
Broadcast-P	.33	.07	.40	1.20	.02	.19	.15	.22
Banded-P	.28	.05	.37	1.10	.04	.23	.12	.26
			Late Stress					
0-Lime	.34	.05	.40	1.07	.04	.18	.13	.06
Lime-Shallow	.27	.05	.30	1.13	.03	.17	.12	.23
Lime-Deep	.33	.05	.37	1.13	.04	.16	.13	.21
Broadcast-P	.35	.04	.37	1.00	.04	.16	.13	.16
Banded-P	.25	.03	.30	0.93	.04	.17	.10	.23
			Early Stress					
0-Lime	.30	.05	.33	1.10	.04	.19	.13	.10
Lime-Shallow	.45	.04	.47	1.23	.02	.17	.17	.22
Lime-Deep	.38	.04	.40	0.97	.02	.17	.15	.24
Broadcast-P	.34	.05	.40	1.07	.03	.17	.13	.21
Banded-P	.35	.03	.40	1.03	.03	.19	.14	.26
F Test-Nutrient	n.s.	n.s.	n.s.	n.s.	n.s.	10 %	n.s.	0.1 %
F Test-Stress	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	5 %

Appendix

Table 11. Growth analysis results for corn grown during the 1975 dry season in relation to plant water stress and to five fertility management practices.

Treatment	Height	LAI	Leaf Dry Wt.	Stem Dry Wt.	Total Dry Wt.	Leaf	NAR	RGR
	cm	$cm^2 cm^{-2}$	———	$g/plant^{-1}$	———	No.	$gm^{-2} w^{-1}$	w^{-1}
				24 Days after Planting				
0-Lime	10.8	.023	.322	.150	.472	2.7	—	—
Lime-Shallow	14.1	.034	.394	.200	.594	3.1	—	—
Lime-Deep	12.1	.028	.406	.205	.606	3.1	—	—
Broadcast-P	11.4	.018	.317	.183	.500	2.6	—	—
Banded-P	13.8	.033	.417	.183	.500	3.0	—	—
$LSD._{05}$	n.s.	.009	n.s.	n.s.	n.s.	.22	—	—
C.V. (%)	27.75	32.46	27.59	41.61	29.87	7.95	—	—
				35 Days after Planting				
0-Lime	16.4	.083	.95	.256	1.20	4.9	50.72	.59
Lime-Shallow	23.2	.147	1.44	.461	1.89	6.1	53.08	.75
Lime-Deep	24.0	.160	1.67	.600	2.72	5.9	69.22	.84
Broadcast-P	18.6	.111	1.13	.372	1.50	5.4	62.22	.69
Banded-P	24.1	.152	1.54	.606	2.14	5.5	62.30	.83
$LSD._{05}$	3.18	.027	.287	.157	.426	.53	n.s.	n.s.
C.V. (%)	15.34	21.46	21.89	35.10	24.27	9.76	35.28	36.64
				46 Days after Planting				
0-Lime	24.2	.197	2.23	.79	3.02	13.8	38.79	.51
Lime-Shallow	34.5	.417	4.99	2.16	7.15	11.8	63.72	.83
Lime-Deep	34.0	.387	4.54	2.02	6.56	11.9	54.29	.69
Broadcast-P	26.7	.262	2.99	1.08	3.96	14.0	43.07	.60
Banded-P	33.0	.349	4.17	1.84	6.05	11.6	52.55	.66
$LSD._{05}$	4.8	.084	1.05	.60	1.64	.66	18.27	.21
C.V. (%)	16.19	26.67	28.48	39.12	31.55	10.37	37.19	33.36

Appendix

Table 11. (cont.)

				59 Days after Planting				
0-Lime	40.0	.46	6.04	3.06	9.09	10.4	56.35	.66
Lime-Shallow	69.4	1.19	15.56	10.08	25.64	9.3	68.59	.70
Lime-Deep	69.8	1.20	14.46	9.71	24.17	10.0	66.45	.71
Broadcast-P	60.2	.89	12.04	6.68	18.72	9.7	78.43	.86
Banded-P	65.9	1.13	14.97	10.02	24.99	9.1	77.10	.77
$LSD._{.05}$	4.99	.15	2.17	1.79	3.86	.73	n.s.	n.s.
C.V. (%)	8.40	15.67	17.67	23.34	19.34	9.58	31.85	33.55
				69 Days after Planting				
0-Lime	60.1	.90	14.27	7.23	21.55	7.1	64.32	.56
Lime-Shallow	111.8	2.24	31.32	29.14	60.47	9.9	72.26	.59
Lime-Deep	110.4	1.99	28.08	23.77	51.85	9.3	60.13	.52
Broadcast-P	93.1	1.56	21.13	17.71	38.83	8.4	57.71	.50
Banded-P	99.6	1.77	23.09	21.18	44.27	8.9	45.74	.39
$LSD._{.05}$	12.7	.34	5.57	6.54	11.41	.68	n.s.	n.s.
C.V. (%)	13.79	20.48	24.30	33.95	27.01	8.00	61.81	57.80
				82 Days after Planting (No Stress)				
0-Lime	95.7	1.88	27.83	23.77	51.60	8.7	64.26	.50
Lime-Shallow	187.3	3.36	52.60	65.97	118.57	11.5	67.14	.44
Lime-Deep	190.3	3.20	48.50	66.63	115.13	12.2	67.48	.42
Broadcast-P	154.7	2.90	47.37	54.83	102.10	11.2	88.19	.56
Banded-P	170.7	2.97	48.63	64.23	112.87	11.7	71.26	.45
				82 Days after Planting (Early Stress)				
0-Lime	81.5	1.30	21.57	16.67	38.23	7.2	48.35	.38
Lime-Shallow	142.5	2.71	45.30	51.10	96.40	8.8	48.12	.32
Lime-Deep	151.7	2.75	45.73	58.63	104.37	9.2	41.31	.25
Broadcast-P	114.7	2.04	32.17	32.60	64.77	8.2	33.59	.24
Banded-P	126.0	2.32	38.50	39.03	77.53	8.0	49.22	.34
Nutrient $LSD._{.05}$	10.68	.28	5.53	8.79	13.71	.58	n.s.	n.s.
Stress $LSD._{.05}$	3.54	.19	3.86	5.36	9.05	.56	17.31	.11
C.V. (%)	7.59	11.28	14.16	19.11	16.12	5.93	50.30	52.34

Appendix

Table 11. (cont.)

			95 Days after Planting (No Stress)					
0-Lime	147.8	1.80	36.87	36.27	73.13	13.0	25.66	.15
Lime-Shallow	205.8	3.35	59.93	113.13	173.07	15.2	43.85	.21
Lime-Deep	216.7	3.27	56.20	101.17	157.36	14.5	34.04	.16
Broadcast-P	197.5	2.76	49.93	68.57	118.50	13.3	15.60	.08
Banded-P	204.2	3.46	52.53	99.93	152.47	14.7	33.09	.16
			95 Days after Planting (Early Stress)					
0-Lime	119.2	1.26	31.07	27.90	58.97	11.5	48.96	.24
Lime-Shallow	200.7	3.63	58.73	95.30	154.04	13.5	49.40	.25
Lime-Deep	197.3	3.24	47.27	75.87	123.13	13.8	17.66	.09
Broadcast-P	195.3	3.17	51.53	90.10	131.63	13.0	71.28	.38
Banded-P	165.5	2.48	46.50	64.13	110.63	12.8	35.75	.18
Nutrient $LSD._{05}$	13.8	.44	5.41	16.88	20.50	.82	23.30	.12
Stress $LSD._{05}$	14.9	n.s.	n.s.	20.76	n.s.	.93	n.s.	n.s.
C.V. (%)	7.59	15.47	11.28	21.53	16.23	6.19	56.15	56.37

	Height	LAI	Leaf Dry Wt.	Stem Dry Wt.	Total Dry Wt.	Leaf	EAR Dry Wt.	Tassel Dry Wt.	NAR	RGR
	cm	$cm^2 cm^{-2}$	g/plant^{-1}			No.	g/plant^{-1}		$gm^{-2} w^{-1}$	w^{-1}
				105 Days after Planting (No Stress)						
0-Lime	173.3	2.55	35.12	62.60	108.42	10.9	4.53	6.23	61.05	.30
Lime-Shallow	240.0	3.13	49.42	106.32	199.37	13.8	37.60	6.03	28.05	.10
Lime-Deep	235.8	3.81	59.45	135.95	247.56	14.5	44.53	7.63	90.23	.33
Broadcast-P	200.0	3.27	53.60	126.00	219.53	14.2	32.00	7.93	117.21	.43
Banded-P	209.2	3.05	49.30	114.78	203.75	14.3	35.63	5.50	56.55	.20
				105 Days after Planting (Late Stress)						
0-Lime	162.5	2.05	33.07	63.68	106.48	10.7	5.07	4.73	42.67	.19
Lime-Shallow	246.2	3.12	48.80	112.75	205.82	14.0	37.20	7.03	.53	.00
Lime-Deep	197.2	3.39	49.72	118.05	200.06	14.5	24.90	7.40	36.26	.13
Broadcast-p	227.5	3.21	51.02	124.27	202.69	12.8	18.50	8.93	84.85	.31
Banded-P	219.2	2.95	46.60	101.23	189.75	12.7	36.03	5.83	85.35	.32

Appendix

Table 11. (cont.)

				105 Days after Planting (Early Stress)						
0-Lime	167.2	2.00	33.72	55.77	101.15	11.7	5.27	6.47	96.33	.38
Lime-Shallow	215.2	3.23	47.55	102.13	187.08	14.3	31.70	5.03	32.63	.12
Lime-Deep	206.8	2.97	44.50	90.67	166.53	14.7	26.73	4.63	49.43	.22
Broadcast-P	195.8	3.65	58.15	118.15	228.30	15.2	45.00	7.00	98.67	.39
Banded-P	187.8	2.53	38.10	74.32	141.45	14.2	24.73	4.30	43.39	.18
Nutrient $LSD._{.05}$	27.5	.41	7.31	21.56	32.42	1.33	.99	1.44	34.04	.12
Stress $LSD._{.05}$	14.9	n.s.	n.s.	11.69	21.84	.-6	n.s.	n.s.	n.s.	n.s.
C.V. (%)	13.74	13.98	16.15	22.06	18.46	10.15	37.13	23.50	56.84	51.9
				114 Days after Planting (No Stress)						
0-Lime	176.0	1.95	34.23	62.37	149.30	11.5	47.30	5.40	68.09	.27
Lime-Shallow	225.0	3.54	61.20	124.00	288.13	13.0	96.27	6.67	99.99	.27
Lime-Deep	238.7	3.89	65.84	138.43	299.60	15.2	87.43	7.90	52.77	.15
Broadcast-P	223.7	3.09	57.60	111.60	257.30	12.7	81.08	7.04	44.39	.11
Banded-P	212.7	2.76	49.90	109.53	238.60	12.3	74.27	4.90	40.48	.10
				114 Days after Planting (Late Stress)						
0-Lime	163.7	2.10	35.90	85.60	156.73	10.7	30.33	4.90	109.79	.33
Lime-Shallow	232.0	2.61	51.56	118.03	238.77	10.2	63.13	6.03	45.82	.11
Lime-Deep	231.0	2.90	55.37	122.87	250.63	12.0	66.27	6.13	66.01	.18
Broadcast-P	209.7	2.34	43.73	91.57	186.47	10.5	45.53	5.63	-20.92	-.05
Banded-P	203.7	2.41	50.50	100.67	217.70	10.0	60.27	6.27	31.37	.09
				114 Days after Planting (Early Stress)						
0-Lime	176.3	2.25	34.60	64.67	139.37	12.7	34.53	5.57	74.01	.25
Lime-Shallow	204.3	2.84	47.70	80.00	190.70	14.2	58.20	4.90	5.19	.01
Lime-Deep	227.7	3.41	61.30	116.50	263.33	14.7	79.20	6.33	118.12	.36
Broadcast-P	204.3	2.98	47.60	90.30	212.10	15.0	69.00	5.20	-18.48	-.06
Banded-P	200.0	3.05	45.20	94.56	211.93	14.2	65.80	6.03	99.05	.32
Nutrient $LSD._{.05}$	15.1	.41	8.47	19.25	37.28	1.05	16.88	n.s.	n.s.	.22
Stress $LSD._{.05}$	12.0	.41	6.06	n.s.	n.s.	1.40	21.06	n.s.	n.s.	n.s.
C.V. (%)	7.44	15.12	17.60	19.65	17.41	8.57	27.14	24.68	127.9	122

Appendix

Table 11. (cont.)

			127 Days after Planting (No Stress)							
O-Lime	178.3	2.13	37.23	66.23	185.26	11.8	76.20	5.63	48.34	.12
Lime-Shallow	228.3	3.31	61.73	132.10	390.23	11.3	188.77	7.66	84.01	.18
Lime-Deep	238.3	3.62	64.43	128.50	356.16	13.0	155.90	7.33	40.36	.09
Broadcast-P	225.8	3.22	60.63	129.50	328.90	12.2	131.37	7.40	63.78	.14
Banded-P	244.2	2.87	53.63	103.60	281.36	11.8	136.56	7.57	52.97	.11
			127 Days after Planting (Late Stress)							
O-Lime	165.0	1.97	32.03	55.60	132.83	10.0	46.73	5.13	-36.56	-.11
Lime-Shallow	256.7	2.48	61.90	136.20	315.80	9.3	110.60	7.10	77.32	.15
Lime-Deep	239.6	2.83	59.66	121.66	284.33	10.7	94.37	8.53	31.08	.07
Broadcast-P	221.7	2.74	50.17	107.13	281.16	11.2	117.37	6.50	101.19	.22
Banded-P	222.5	2.41	49.00	100.13	257.33	10.2	103.03	5.17	48.18	.10
			127 Days after Planting (Early Stress)							
O-Lime	186.7	1.99	32.97	62.20	159.90	12.7	60.63	4.10	25.42	.07
Lime-Shallow	208.3	3.12	51.63	89.53	271.83	13.0	126.13	4.53	73.51	.20
Lime-Deep	212.5	3.38	58.03	111.57	312.27	13.3	136.27	6.40	41.26	.09
Broadcast-P	210.8	3.20	52.93	103.07	291.00	13.7	145.13	5.53	70.90	.17
Banded-P	183.3	2.62	46.17	86.80	246.20	12.8	107.63	5.60	32.34	.08
Nutrient $LSD._{05}$	18.5	.37	7.25	16.53	35.98	.92	2.05	1.34	49.26	.12
Stress $LSD._{05}$	6.3	.16	3.26	7.51	28.37	.77	2.01	.90	n.s.	n.s.
C.V. (%)	8.87	13.46	14.47	16.62	13.55	8.05	18.20	21.90	100.57	110.5

Appendix

Table 12. Leaf water potential and relative water content results for the early stress period.

Treatment	Sampling Days During Water Stress													
	5/8	7/8	9/8	11/8	12/8	13/8	14/8	15/8	16/8	17/8	18/8	19/8	21/8	Av.
	R W C (%)													
0-Lime	96.4	96.7	94.8	94.9	96.8	93.3	94.3	93.5	91.6	91.5	91.2	87.9	83.4	92.84
Lime-Shallow	97.3	96.0	95.6	95.3	94.1	94.7	91.8	89.9	92.9	90.1	87.3	87.4	81.1	91.86
Lime-Deep	98.2	95.9	95.3	96.2	97.2	94.8	95.2	92.6	94.1	90.8	90.6	87.8	83.7	93.32
Banded-P	98.3	95.8	96.4	95.2	96.4	88.1	89.1	89.3	91.6	88.4	87.3	86.9	84.1	91.36
Broadcast-P	95.0	96.4	95.2	92.7	97.4	91.5	93.6	89.9	90.3	87.7	88.0	84.8	83.6	91.29
	Leaf Water Potential (Bars)													
0-Lime	-12.2	-12.5	-12.1	-13.1	-10.8	-13.4	-13.8	-14.4	-13.7	-15.1	-14.0	-15.7	-14.9	-13.5
Lime-Shallow	-13.0	-13.4	-11.6	-12.2	-13.9	-12.8	-14.8	-14.6	-14.7	-14.8	-15.5	-14.4	-16.4	-14.0
Lime-Deep	-12.0	-13.8	-11.9	-11.9	-11.2	-13.1	-13.2	-14.5	-13.3	-14.4	-14.4	-14.5	-15.2	-13.3
Broadcast-P	-13.4	-13.2	-12.0	-13.3	-11.8	-14.2	-14.2	-14.8	-13.6	-15.6	-15.0	-14.7	-15.4	-13.9
Banded-P	-11.4	-11.7	-11.1	-13.7	-12.2	-14.1	-14.3	-15.4	-14.7	-15.2	-15.6	-15.7	-15.6	-13.9

Appendix
Table 13. Leaf water potential and relative water content results for the late stress period.

Treatment	Sampling Days During Water Stress							
	10/9	12/9	14/9	16/9	17/9	18/9	19/9	Av.
	R W C (%)							
0-Lime	98.4	95.9	92.3	90.5	88.2	88.1	85.5	91.3
Lime-Shallow	97.1	95.4	94.3	90.5	81.4	83.1	85.7	89.6
Lime-Deep	98.2	96.7	96.3	90.4	85.8	84.2	87.7	91.3
Broadcast-P	96.1	97.4	93.9	89.4	85.4	87.8	89.1	91.4
Banded-P	98.1	96.3	95.2	90.4	87.6	86.7	87.1	91.6
	Leaf Water Potential (Bars)							
0-Lime	-14.9	-14.7	-15.3	-16.0	-15.9	-16.8	-16.4	-15.7
Lime-Shallow	-16.9	-15.7	-16.5	-17.5	-20.4	-19.4	-20.1	-18.1
Lime-Deep	-16.3	-14.5	-16.2	-17.1	-17.7	-19.4	-18.3	-17.1
Broadcast-P	-15.0	-15.6	-15.4	-17.0	-16.8	-17.2	-17.4	-16.3
Banded-P	-16.2	-16.3	-16.1	-18.1	-17.8	-20.7	-18.4	-17.7

Appendix
Table 14. Stomatal resistance for corn leaves during the first stress period in relation to the fertility treatments.

Treatment	Sampling Days During Water Stress													
	5/8	7/8	9/8	11/8	12/8	13/8	14/8	15/8	16/8	17/8	18/8	19/8	21/8	Av.
	sec/cm													
0-Lime 1/	5.88	10.90	3.67	5.55	3.54	5.06	4.38	8.00	9.51	12.86	19.47	39.31	103.7	17.83
2/	5.49	3.91	2.08	2.71	3.14	3.03	4.96	3.69	5.77	7.90	15.91	50.21	135.1	18.76
Lime-Shallow	5.39	4.78	4.62	6.07	4.74	6.91	11.31	9.33	12.78	39.67	38.65	95.51	92.81	25.58
	3.53	2.90	2.86	6.70	4.81	5.40	9.84	7.84	11.98	52.03	28.46	99.06	165.9	30.87
Lime-Deep	7.61	3.84	4.07	5.29	5.83	9.99	8.17	16.11	13.81	17.65	51.16	129.2	111.4	29.55
	4.95	1.96	3.64	4.16	3.26	12.87	3.69	20.13	18.34	34.30	78.67	142.9	154.9	37.22
Broadcast-P	3.96	3.73	4.64	12.28	4.01	13.56	17.24	19.85	13.85	23.27	86.60	95.29	96.64	30.38
	2.12	2.36	2.96	7.16	4.54	9.78	18.63	16.58	10.79	23.60	137.6	114.9	139.4	37.74
Banded-P	3.52	3.85	4.09	3.52	3.22	5.87	5.79	9.24	11.47	25.66	17.87	43.15	62.87	15.39
	2.63	3.38	2.43	2.55	2.80	8.35	3.51	6.16	5.75	15.63	18.71	50.90	44.21	12.85

1/ adaxial side of the leaf.

2/ abaxial side of the leaf.

Appendix

Table 15. Chlorophyll content of corn leaves as effected by water stress duration. Results are in mg chlorophyll/gram leaf fresh weight.

Date	0-Lime	Shallow-Lime	Deep-Lime	Broadcast-P	Banded-P
			First Water Stress Period		
7/8	2.90	3.62	3.91	4.06	3.33
9/8	2.52	3.33	3.19	3.91	3.10
11/8	2.00	3.48	3.33	2.75	3.01
18/8	2.65	2.96	2.97	2.88	2.88
21/8	2.46	2.75	2.61	3.01	2.88
			Second Water Stress Period		
10/9	4.13	4.06	3.99	4.06	3.30
16/9	2.75	4.17	3.62	4.17	3.19
17/9	2.75	4.28	3.77	4.17	3.19
19/9	2.00	3.52	3.30	2.68	2.74

Appendix

Table 16. Sample leaf area, plant height, and number of leaves on the sample plants during the early stress period.

Treatment	Sampling Days During Water Stress													
	5/8	7/8	9/8	11/8	12/8	13/8	14/8	15/8	16/8	17/8	18/8	19/8	21/8	Av.
	Leaf Area of Sample Leaf (cm^2)													
0-Lime	246	240	473	382	273	382	343	383	334	411	348	399	382	354.1
Lime-Shallow	522	585	594	701	635	654	643	598	736	762	581	667	484	628.3
Lime-Deep	573	478	563	662	693	686	614	654	669	660	685	627	653	632.4
Broadcast-P	434	498	407	642	584	628	586	505	649	619	650	534	582	563.4
Banded-P	424	463	447	636	526	631	497	542	539	664	470	575	454	528.7
	Height of Sample Plant (cm)													
0-Lime	48	55	93	65	52	69	57	73	63	75	63	77	68	66.0
Lime-Shallow	91	115	131	134	125	134	137	146	139	142	136	145	143	132.2
Lime-Deep	100	106	112	121	122	127	132	131	135	122	140	134	140	124.8
Broadcast-P	81	85	107	96	113	112	101	101	114	111	109	109	121	104.6
Banded-P	65	92	82	101	96	110	90	118	94	110	105	113	100	98.3
	No. of Leaves of Sample Plant													
0-Lime	7.2	7.4	7.0	7.2	6.6	7.6	7.2	8.6	7.0	7.6	6.0	6.8	7.6	7.2
Lime-Shallow	9.8	9.8	11.8	10.2	10.0	9.8	10.0	10.8	8.4	9.6	9.6	9.2	9.8	9.9
Lime-Deep	9.6	9.4	10.4	10.6	9.8	9.8	10.4	9.6	9.6	9.8	10.0	9.0	10.4	9.9
Broadcast-P	9.6	8.8	9.4	9.4	10.0	9.6	9.6	9.0	8.6	9.4	9.0	8.8	9.2	9.3
Banded-P	9.0	10.0	10.0	10.4	9.4	9.8	8.8	10.6	8.2	8.8	8.8	8.6	9.4	9.4

Appendix

Table 17. Sample leaf area, plant height, and number of leaves on sample plant during the second stress period.

Treatment	Sampling Days During Water Stress							Av.
	10/9	12/9	14/9	16/9	17/9	18/9	19/9	
	Leaf Area of Sample Leaf (cm^2)							
0-Lime	398.9	344.6	420.1	370.6	342.4	400.8	480.8	394.08
Lime-Shallow	443.2	530.7	429.2	438.0	515.6	486.2	547.2	484.33
Lime-Deep	444.5	466.4	432.7	497.7	474.6	448.9	444.8	458.53
Broadcast-P	448.2	387.4	400.0	414.0	371.1	453.8	498.6	424.79
Banded-P	468.4	380.7	352.7	342.4	424.1	425.9	448.0	406.06
	Height of Sample Plant (cm)							
0-Lime	156	128	169	140	172	140	167	153
Lime-Shallow	261	245	259	271	262	252	255	258
Lime-Deep	215	253	234	267	247	261	247	246
Broadcast-P	187	205	208	217	211	198	203	204
Banded-P	181	189	199	190	194	193	201	192
	No. of Leaves of Sample Plant							
0-Lime	11	12	10	8	12	10	8	10.1
Lime-Shallow	15	16	15	14	13	11	8	13.1
Lime-Deep	16	16	16	15	13	12	10	14.0
Broadcast-P	14	15	14	14	13	12	10	13.1
Banded-P	14	14	14	14	13	12	10	13.0

Appendix

Table 18. Uptake of P, K, Ca, Mg, and Zn by the corn plant in relation to plant water stress and fertility management practices.

Treatment	Magnesium	Calcium	Zinc	Potassium	Phosphorus
	$1x10^{-2}$ g/plant	$1x10^{-2}$ g/plant	ppm	$1x10^{-2}$ g/plant	$1x10^{-2}$ g/plant
		24 Days after Planting (No Stress)			
0-Lime	.07	.22	20.21	2.06	.20
Lime-Shallow	.25	.29	15.64	2.92	.28
Lime-Deep	.18	.24	11.96	2.29	.17
Broadcast-P	.20	.30	23.40	2.64	.37
Banded-P	.18	.23	13.78	2.33	.26
		24 Days after Planting (Late Stress)			
0-Lime	.12	.27	25.85	2.63	.28
Lime-Shallow	.19	.22	11.04	2.21	.23
Lime-Deep	.21	.26	14.30	2.73	.26
Broadcast-P	.14	.16	9.12	1.62	.10
Banded-P	.20	.31	13.87	3.21	.36
		24 Days after Planting (Early Stress)			
0-Lime	.07	.21	15.60	1.64	.19
Lime-Shallow	.21	.25	12.40	2.79	.22
Lime-Deep	.22	.27	13.00	2.73	.38
Broadcast-P	.22	.24	11.44	2.27	.10
Banded-P	.20	.25	13.25	2.44	.27
		35 Days after Planting (No Stress)			
0-Lime	.10	.63	27.60	6.35	.50
Lime-Shallow	.85	.69	46.32	9.65	.51
Lime-Deep	.74	.70	40.70	9.25	.61
Broadcast-P	.53	.59	34.10	6.82	.49
Banded-P	.74	.78	54.25	9.77	.69
		35 Days after Planting (Late Stress)			
0-Lime	.07	.42	33.93	5.50	.43
Lime-Shallow	.76	.61	41.80	8.93	.67
Lime-Deep	.70	.56	31.50	8.40	.56
Broadcast-P	.53	.54	44.02	6.67	.47
Banded-P	.57	.53	26.72	8.35	.48

Appendix
Table 18. (cont.)

		35 Days after Planting (Early Stress)			
0-Lime	.09	.47	21.40	4.60	.45
Lime-Shallow	.68	.59	65.88	9.52	.64
Lime-Deep	1.29	1.03	54.74	15.45	1.06
Broadcast-P	.61	.52	50.49	7.19	.50
Banded-P	.88	.78	39.00	11.96	.96
		46 Days after Planting (No Stress)			
0-Lime	.23	1.09	43.05	10.26	.69
Lime-Shallow	2.59	2.24	140.00	28.70	1.82
Lime-Deep	2.31	2.08	127.16	23.12	1.68
Broadcast-P	1.02	1.17	88.32	14.72	.96
Banded-P	1.54	1.68	84.24	17.60	1.22
		46 Days after Planting (Late Stress)			
0-Lime	0.25	1.16	83.00	16.35	.87
Lime-Shallow	2.79	2.26	128.01	28.92	1.96
Lime-Deep	2.46	2.13	106.40	26.60	1.46
Broadcast-P	1.76	1.86	124.08	20.68	1.24
Banded-P	2.24	2.50	85.54	26.32	1.58
		46 Days after Planting (Early Stress)			
0-Lime	.20	.77	30.45	6.60	.53
Lime-Shallow	2.77	2.35	103.80	31.14	1.73
Lime-Deep	2.90	2.32	108.75	31.18	1.89
Broadcast-P	1.23	1.17	73.68	11.54	.74
Banded-P	2.20	2.06	89.44	27.11	1.44
		59 Days after Planting (No Stress)			
0-Lime	.69	2.70	208.44	27.84	1.39
Lime-Shallow	12.83	8.98	589.95	98.50	6.67
Lime-Deep	8.01	7.01	480.72	92.14	4.61
Broadcast-P	6.43	5.88	441.12	77.20	4.41
Banded-P	7.92	6.99	442.70	89.47	5.36
		59 Days after Planting (Late Stress)			
0-Lime	1.14	3.72	180.88	32.75	1.71
Lime-Shallow	13.77	10.84	673.90	112.51	7.62
Lime-Deep	12.98	10.12	519.00	105.10	5.97
Broadcast-P	6.50	4.67	399.12	76.64	3.66
Banded-P	9.37	7.69	552.69	104.77	5.05

Appendix

Table 18. (cont.)

		59 Days after Planting (Early Stress)			
0-Lime	1.21	3.22	321.60	35.18	2.21
Lime-Shallow	9.45	7.02	571.22	90.96	5.71
Lime-Deep	13.26	9.83	556.92	111.55	6.36
Broadcast-P	6.98	6.35	549.90	87.56	5.50
Banded-P	9.68	8.85	635.95	114.47	5.53
		69 Days after Planting (No Stress)			
0-Lime	1.77	7.06	529.68	69.74	4.19
Lime-Shallow	24.56	18.29	992.75	177.65	10.45
Lime-Deep	21.39	17.11	1016.12	183.97	10.70
Broadcast-P	14.33	10.84	890.56	135.52	8.13
Banded-P	16.74	13.79	886.50	159.57	9.38
		69 Days after Planting (Late Stress)			
0-Lime	2.98	8.18	545.48	69.23	3.57
Lime-Shallow	35.02	23.85	--	271.25	17.14
Lime-Deep	17.59	11.97	673.56	151.55	6.73
Broadcast-P	11.99	10.90	762.93	137.33	7.99
Banded-P	15.12	13.08	776.53	151.22	7.77
		69 Days after Planting (Early Stress)			
0-Lime	2.16	6.91	626.40	66.96	3.67
Lime-Shallow	23.49	16.39	983.34	194.48	11.47
Lime-Deep	30.39	22.63	1293.00	226.28	12.93
Broadcast-P	14.09	11.61	1077.70	167.87	9.53
Banded-P	21.35	13.66	683.20	106.75	6.41
		82 Days after Planting (No Stress)			
0-Lime	6.19	18.06	1341	113.52	7.74
Lime-Shallow	55.81	35.63	1896	261.21	17.79
Lime-Deep	42.60	36.84	2072	300.49	19.57
Broadcast-P	30.63	28.59	1939	311.41	17.35
Banded-P	37.25	31.60	1578	248.31	18.06
		82 Days after Planting (Late Stress)			
0-Lime	5.44	11.66	971	93.29	5.83
Lime-Shallow	39.75	36.61	1778	234.40	19.87
Lime-Deep	50.12	40.80	1748	319.37	19.82
Broadcast-P	26.16	22.53	1380	203.48	10.90
Banded-P	30.08	27.17	1552	203.76	13.58

Appendix
Table 18. (cont.)

		82 Days after Planting (Early Stress)			
0-Lime	4.59	12.33	1185	87.16	7.26
Lime-Shallow	36.62	33.74	1446	206.30	14.46
Lime-Deep	44.99	36.53	1565	244.20	14.61
Broadcast-P	20.73	20.72	1165	165.81	9.72
Banded-P	27.14	23.26	1163	176.79	10.85
		95 Days after Planting (No Stress)			
0-Lime	6.47	23.56	2072	136.97	13.78
Lime-Shallow	66.30	50.75	2537	231.09	25.96
Lime-Deep	58.58	47.38	2020	252.11	22.09
Broadcast-P	38.61	34.07	1729	231.12	16.06
Banded-P	63.36	59.75	1948	206.22	22.87
		95 Days after Planting (Late Stress)			
0-Lime	7.11	27.02	2264	152.84	14.96
Lime-Shallow	--	--	--	--	--
Lime-Deep	60.37	48.91	2326	278.21	25.58
Broadcast-P	36.17	36.63	2129	261.57	20.01
Banded-P	39.60	34.45	1836	214.91	16.08
		95 Days after Planting (Early Stress)			
0-Lime	5.49	18.46	1682	146.49	10.71
Lime-Shallow	61.83	50.20	2637	316.26	27.00
Lime-Deep	53.66	36.95	1647	220.19	17.43
Broadcast-P	43.39	40.72	2432	265.59	21.81
Banded-P	40.42	40.64	1544	209.34	20.01
		105 Days after Planting (No Stress)			
0-Lime	8.33	38.29	1963	166.17	17.31
Lime-Shallow	66.79	60.66	1890	249.16	22.73
Lime-Deep	90.48	93.56	2864	271.00	28.78
Broadcast-P	64.20	78.17	2949	293.40	26.95
Banded-P	56.48	53.01	1772	201.29	18.87
		105 Days after Planting (Late Stress)			
0-Lime	9.39	29.53	2032	153.74	14.86
Lime-Shallow	72.35	54.79	2067	236.82	23.27
Lime-Deep	74.37	81.15	2668	301.05	26.02
Broadcast-P	63.40	69.05	2586	312.46	24.10
Banded-P	56.00	51.75	1942	211.16	15.53

Appendix
Table 18. (cont.)

		105 Days after Planting (Early Stress)			
0-Lime	7.51	30.19	1797	164.64	16.46
Lime-Shallow	64.84	51.21	1888	204.34	20.96
Lime-Deep	63.96	52.95	1856	215.21	19.42
Broadcast-P	63.87	51.49	1912	203.00	19.66
Banded-P	39.86	37.22	1471	165.62	13.37
		114 Days after Planting (No Stress)			
0-Lime	9.10	37.47	1429	110.92	11.37
Lime-Shallow	85.95	87.49	1730	228.06	21.06
Lime-Deep	89.13	93.52	2708	295.81	28.97
Broadcast-P	62.60	54.23	1358	195.55	15.82
Banded-P	58.84	67.79	1551	200.59	17.05
		114 Days after Planting (Late Stress)			
0-Lime	16.62	38.05	1624	143.84	13.68
Lime-Shallow	84.92	83.62	2028	225.80	24.65
Lime-Deep	103.13	118.01	2643	245.42	28.58
Broadcast-P	45.57	49.69	1722	201.22	14.04
Banded-P	76.83	80.60	1977	233.96	19.12
		114 Days after Planting (Early Stress)			
0-Lime	10.00	3162	1761	143.26	13.54
Lime-Shallow	56.87	49.64	1287	151.53	15.22
Lime-Deep	72.84	71.84	1601	244.91	20.86
Broadcast-P	40.95	47.05	1556	184.65	15.57
Banded-P	61.84	63.02	1669	200.11	16.77
		127 Days after Planting (No Stress)			
0-Lime	8.94	45.25	1539	100.78	11.44
Lime-Shallow	95.69	86.19	1684	213.24	18.82
Lime-Deep	93.69	77.83	1883	242.44	23.42
Broadcast-P	61.03	74.25	2071	249.93	18.94
Banded-P	94.66	99.19	1386	161.56	16.01
		127 Days after Planting (Late Stress)			
0-Lime	6.76	32.37	1343	109.95	9.44
Lime-Shallow	99.17	82.48	2140	195.34	26.86
Lime-Deep	81.41	68.94	1835	199.86	21.42
Broadcast-P	54.46	61.18	1827	218.06	16.50
Banded-P	62.60	63.23	1404	188.68	12.39
		127 Days after Planting (Early Stress)			
0-Lime	8.48	35.24	1615	131.96	11.97
Lime-Shallow	65.88	58.25	1541	213.27	18.20
Lime-Deep	101.61	76.95	1725	221.75	20.83
Broadcast-P	60.48	66.67	1600	230.54	17.06
Banded-P	52.92	54.37	1112	167.61	12.57

Appendix

Table 19. Corn leaf water potential (Ψ_L) in relation to water stress and certain crop and soil management practices. Results expressed in bars (14.5 psi = 1 bar).

	Sampling Days During Water Stress							Sampling Days after rains		
Plot No.	14/1	15/1	16/1	17/1	18/1	19/1	X	29/1	30/1	X
9	-15.2	-12.0	-16.3	-10.8	-11.2	-14.7	-13.5	-16.7	-15.1	-15.9
10	-16.0	-14.3	-16.0	-14.2	-15.5	-18.3	-15.7	-17.0	-17.6	-17.3
23	-14.8	-14.5	-16.5	-13.0	-14.7	-16.7	-15.0	-14.9	-17.0	-16.0
28_1	-15.3	-15.2	-15.7	-15.4	-15.1	-17.5	-15.7	-16.8	-15.6	-16.2
28_2	-14.4	-16.5	-16.6	-15.5	-17.1	-18.3	-16.4	-13.0	-16.2	-14.6
29	16.5	-15.8	-15.6	-12.3	-14.0	-15.4	-14.9	-11.1	-18.9	-15.0

Treatment Identification	Average Ψ_L during six days of water stress measurements (ave. of 30 samples)
(9) Cargill-Deep-Mulch	-13.5
(29) Cargill-Deep-No Mulch	-14.9
(23) Cargill-Shallow-Mulch	-15.0
(10) Cargill-Shallow-No Mulch	-15.7
(28_1) Cargill-Shallow No Mulch-Wilt Pruf Antitranspirant	-15.7
(28_2) Cargill-Shallow-No Mulch-Phenyl Mercuric Acetate Antitranspirant	-16.4

Appendix

Table 20. Relative water content (RWC) of corn leaves as affected by water stress and RWC after 47.3 mm of rainfall during a 10 day period.

	Sampling Days During Water Stress							Sampling Days after rains		
Plot No.	14/1	15/1	16/1	17/1	18/1	19/1	X	29/1	30/1	X
9	94.7	96.1	90.9	96.7	97.9	89.3	94.3	93.9	94.7	94.3
10	88.7	89.5	85.8	92.6	88.4	80.5	87.6	94.2	93.6	93.9
23	88.2	88.3	82.3	95.3	90.6	79.2	87.3	94.4	95.2	94.9
28_1	85.8	86.1	84.1	94.7	86.2	79.7	86.1	93.9	92.6	93.3
28_2	85.5	88.2	80.1	94.2	80.9	72.9	83.6	94.7	94.6	94.7
29	91.5	93.3	90.0	94.7	95.6	86.6	92.0	94.0	94.2	94.1

Plot No	Treatment Identification	Average RWC during 6 days of water stress measurements (Ave. of 30 samplings)
(9)	Cargill-Deep-Mulch	94.3
(29)	Cargill-Deep-No Mulch	92.0
(23)	Cargill-Shallow-Mulch	87.3
(10)	Cargill-Shallow-No Mulch	87.6
(28_1)	Cargill-Shallow-No Mulch-Wilt Pruf*	86.1
(28_2)	Cargill-Shallow -No Mulch-PMA**	83.6

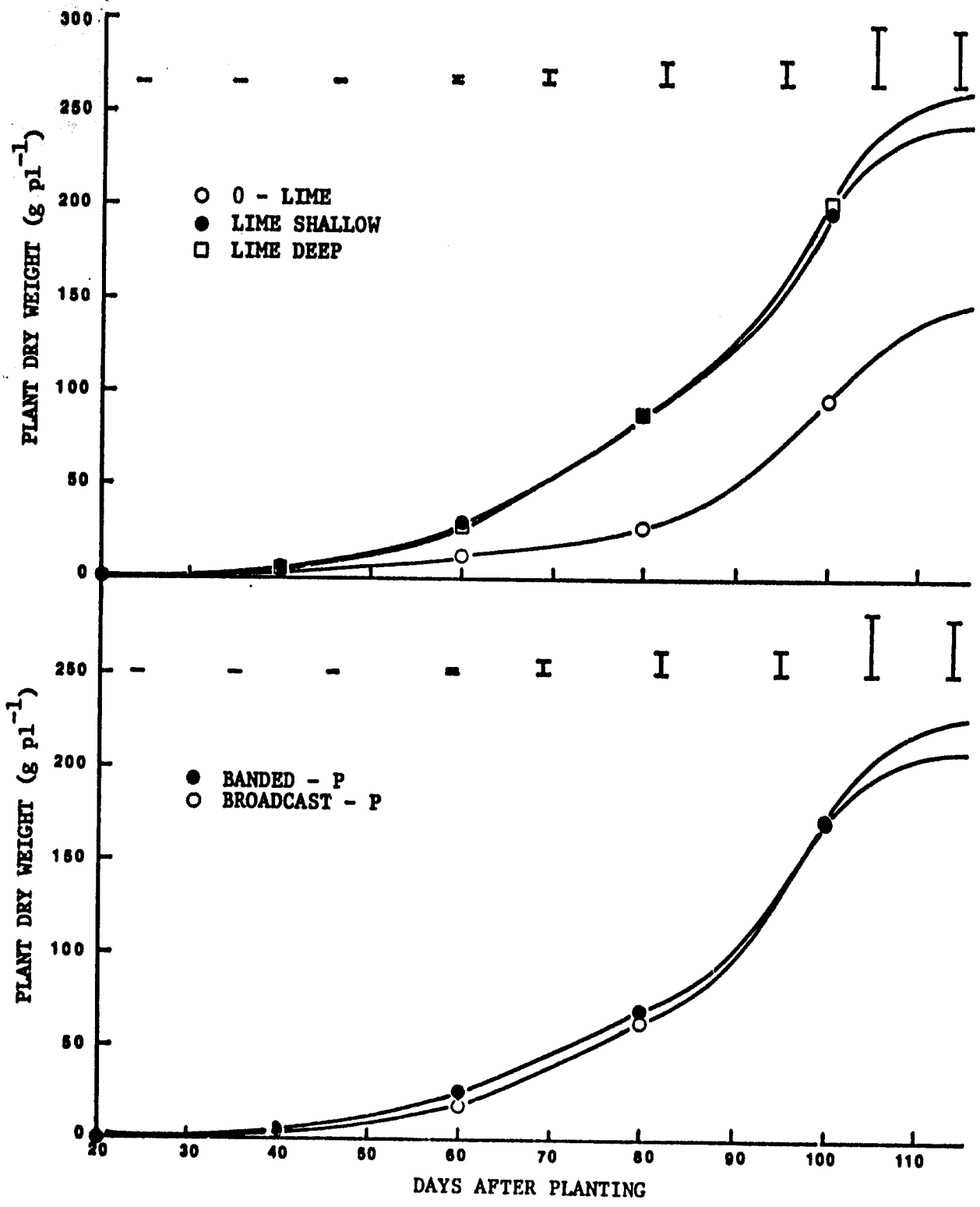
* Wilt Pruf Antitranspirant.

** Phenyl Mercuric Acetate Antitranspirant.

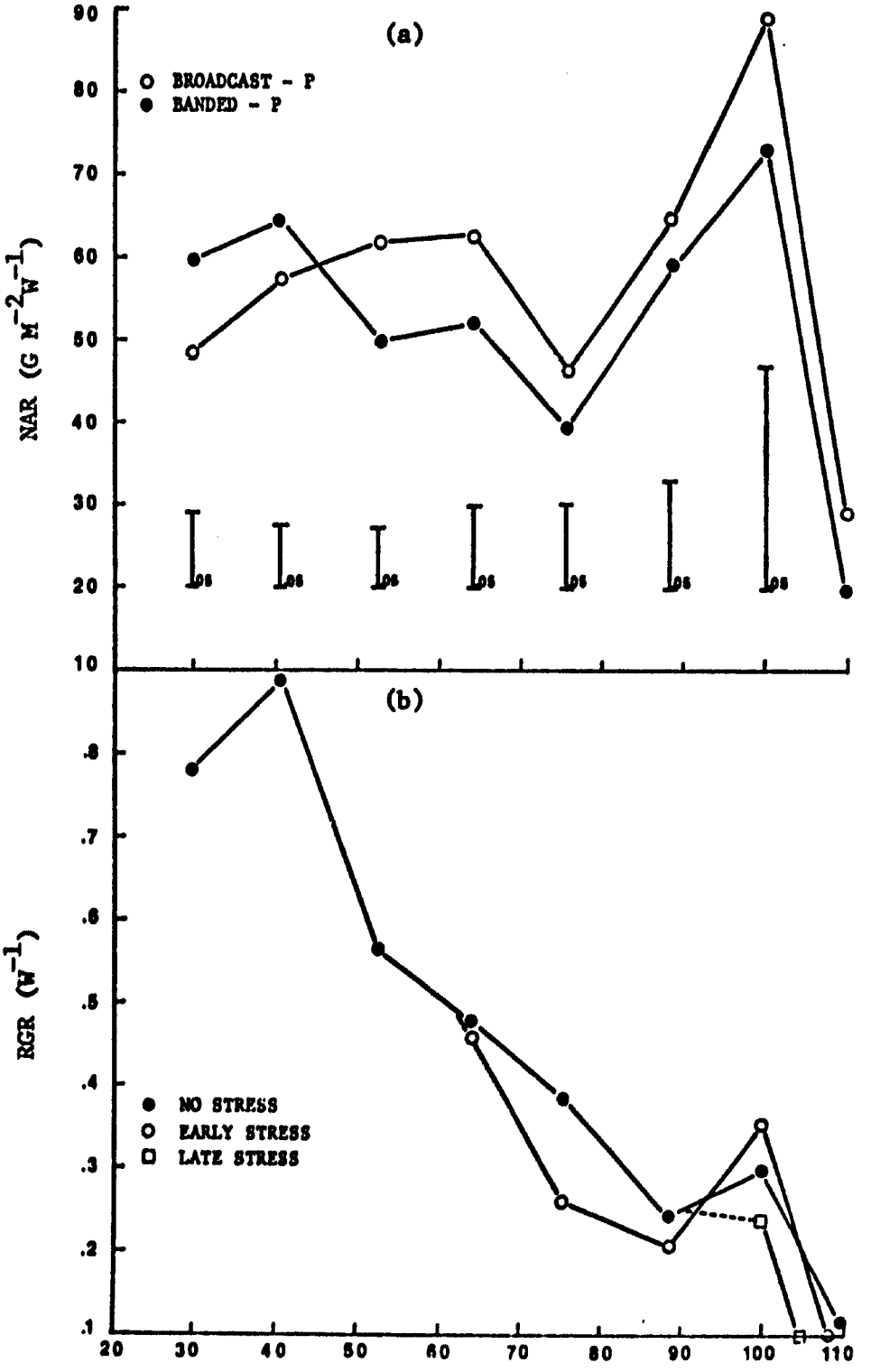
Appendix

Table 21. Transpiration rate for corn leaves in relation to mulching and antitranspirants. Mulch and antitranspirant measurements were taken on alternate days during the stress period.

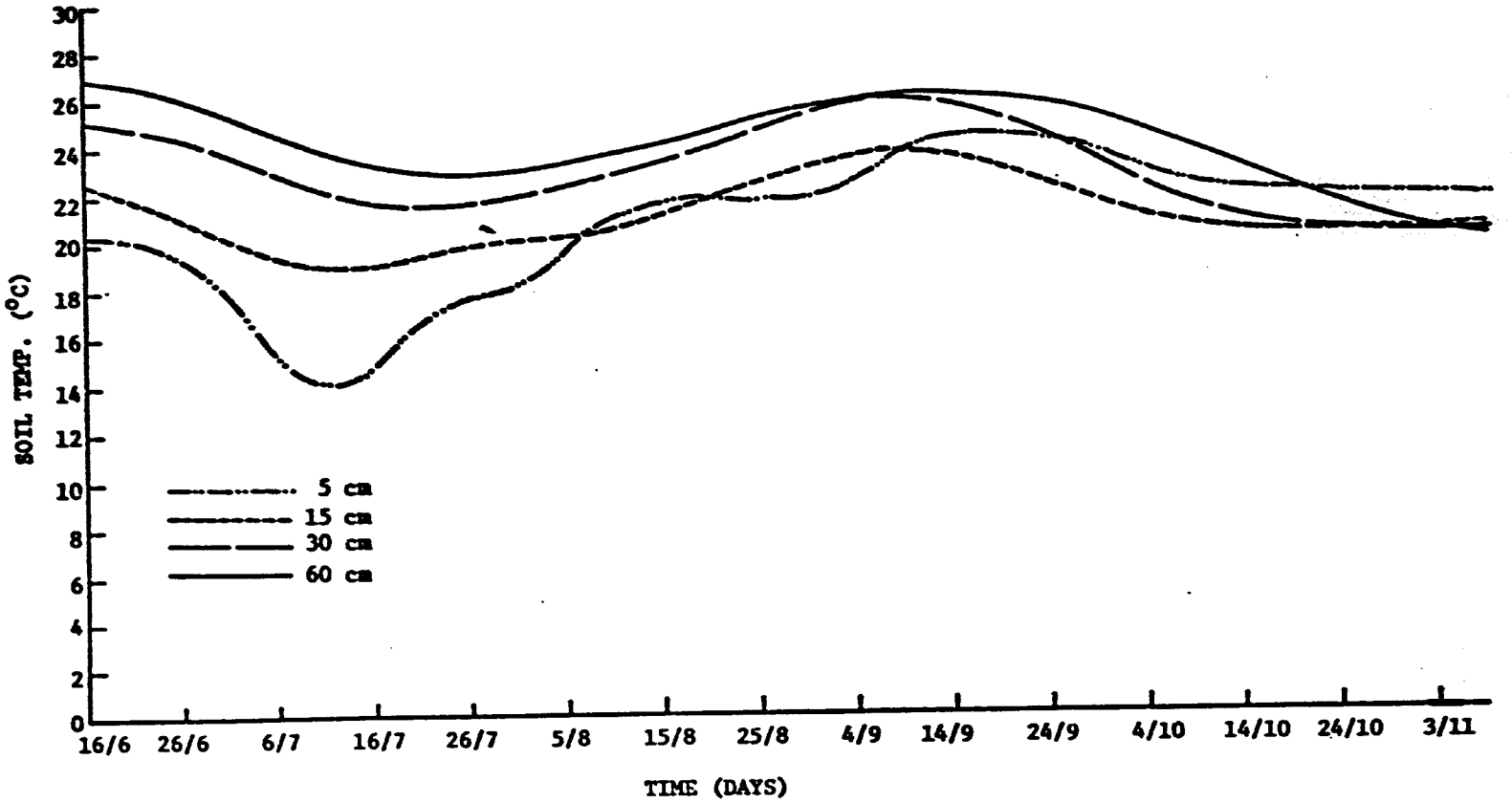
Treatment	Transpiration Rate	
	Adaxial	Abaxial
	$\mu g\ H_2O\ cm^{-2}\ sec^{-1}$	
No Mulch	5.12	6.53
Grass Mulch	4.77	7.02
Plastic Mulch	4.78	6.09
No Antitranspirant	4.93	6.69
PMA	1.52	2.13
Wilt Pruf	4.26	2.93



Appendix Fig. 1. Dry weight accumulation of corn in relation to five soil management practices; (a) Comparison of the 3 lime treatments; (b) Comparison of the 2 phosphorus treatments. LSD is at a 5 % level of sign.



Appendix Fig. 2. Comparison of the net assimulation rate between the banded and broadcast-P treatments (a). Influence of plant water stress on the relative growth rate of corn (b).



Appendix Fig. 3. Soil temperatures at four depths, 5, 15, 30 & 60 cm, during the 1975 dry season's crop grow period at Planaltina, Brazil.