YIELD AND PHYSIOLOGICAL ASPECTS OF 17 VARIETIES OF CORN GROWN IN RUNOFF FARMING

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF SOILS, WATER AND ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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To the oppressed and those who
suffer with them and fight at their side.

ACKNOWLEDGMENTS

The author wishes to thank Drs. Jack L. Stroehlein and Allan D. Matthias, the thesis directors, for their constructive recommendations, advice, and most of all, for their encouragement throughout the course of this study.

Thanks to Drs. G. R. Dutt, A. W. Warrick, K. Matsuda, A. K. Dobrenz and J. W. O'Leary for their useful suggestions and advice whenever they were needed. Appreciation is also extended to S. Musil and D. Ackley for their priceless help in the field.

And finally, the author would like to express his gratitude to Jacqueline A. Charette for her labor, moral and mental support, without which the completion of this work would have been more difficult.

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ABSTRACT

A micro-catchment water harvesting agrisystem in Ávra Valley, west of Tucson, Arizona, was utilized to grow 17 varieties of drought tolerant corn (Zea mays). The primary objective of this study was to isolate and evaluate the grain yield performance of these cultivars. Additional measurements were also taken on transpiration rate (TR), leaf water potential (ψ_l), stress degree day (SDD), and crop water stress index (CWSI), during the period 24 October to 2 November, between two irrigations, in search of possible physiological mechanisms of drought adaptability and their impact on production.

The system's performance in terms of economical crop growth is subject to further research. The analysis of grain yield indicates a significant varietal difference. Physiological parameters monitored also show trends of differences among cultivars. It was found that cultivars capable of maintaining a higher plant water content, by preserving their TR, ψ_l, CWSI, and SDD are not necessarily the better yielding cultivars. Possible justifications of this phenomena are discussed.

It is suggested that a distinction has to be made between crop adaptability to drought and preservation of a high grain yield since under limited moisture conditions, one might be attained through the suppression of the other.

INTRODUCTION

One of the fundamental problems of arid crop production is making sufficient water available to plants for normal growth. The arid regions of the world occupy 36% of the earth's land surface, engulfing some of the poorest nations plus parts of Australia and the North American desert (Buol, Hole and McCracken 1980). There is evidence that farmers have been utilizing the concept of water harvesting in arid regions of the world for 4000 years (Myers 1974).

Unfair distribution of agricultural goods in many parts of the world, ever increasing population density and higher demands for food, as well as the high cost of water, have made it important to maintain or increase the production potential of the arid and semi-arid regions of the world. Agricultural scientists have been carrying the burden of this task. Many of these scientists have recognized water harvesting agrisystems as a potentially viable alternative for use in crop production in otherwise costly and/or nonproductive areas. To grow plants under water harvesting systems, one must be concerned with the adverse environmental conditions, especially the extremes of the ranges of water and the temperature stresses. In determining the crop species and cultivars wqhich can be profitably grown under water harvesting systems, the adapted genotypes have to be studied not only in terms of yield, but also in terms of physiological, genetic, and biochemical reactions. In other words, a good understanding of the specific reactions of plants to low moisture during the critical stage(s) of growth is essential in order to be able to evaluate the performance of an adapted genotype. Crop yield improvement under conditions of drought stress, according to Blum (1979) requires dissociation from yield as a major genetic selection criterion. He suggests that additional physiological criteria are required. These criteria, together with yield response, may provide an even better explanation for the mechanism of adaptation to conditions of moisture stress under water harvesting agrisystems.

In this study, 17 cultivars of corn (Zea mays), a crop which is known to have an excellent potential for adaptation to low moisture conditions, were used (CIMMYT Report 1973). The overall purpose was to evaluate the grain yield productivity of these cultivars under a water harvesting agrisystem in Avra Valley, Arizona. Yield is a complex character, in large a function of quantitative genetics and in part a function of interactions of many physiological components, especially the limiting components which vary with variety.

It is suggested that the most adapted genotypes are those which can preserve a high water content. Therefore, to generate some information for a clearer understanding of the physiological basis of the differences in yield among cultivars of this project, it was decided to monitor some of the plant characteristics which are known to be strong indicators of the plant water status and yield. Therefore, between the two irrigations on 24 October and 2 November, transpiration rate (TR), leaf water potential (ψl), stress degree day (SDD), and crop water stress index (CWSI) were measured for all the cultivars and the rate of change of these parameters were compared.

LITERATURE REVIEW

Water Harvesting

According to Geddes (1963), the term water harvesting is defined as "the collection and storage of any form of water, either runoff or creek flow, for irrigation use." In recent years, this definition has been modified to describe the processes involved in water harvesting, including provisions for storage as an essential part of the design system (Cluff and Dutt 1975). Rauzi, Fairbourn and Landers (1973) concluded that runoff and storage are the indispensible parts of the water harvesting agrisystems. However, Currier's (in Myers 1974) definition of water harvesting as "the processes of collecting natural precipitation from prepared water sheds for beneficial use" has gained a great deal of acceptance among scientists.

Historically, runoff farming (water harvesting) is not new in agriculture. The remnants of the Negev Highland ancient desert agriculture, including the terraced wadis, date some 4000 years (Evanari, Shanan and Tadmor 1961). Excavations in Jawa (Jordan) have provided evidence that people there already used runoff farming around 3000 B.C., while the ruins of the Dam of Marib in South Arabia (North Yemen) indicate that water harnessing was being utilized between 750 B.C. and 500 A.D. for agricultural purposes (Evanari 1981). Also, according to Evanari, there are innumerable artifacts of ancient runoff agriculture in the desert of North Africa, especially in southern Algeria and Tunisia, which date back to the first millenium B.C.

The basic design of these systems involved the ":use of runoff collected from untreated hill slopes, water spreading and ponding by dikes built in the flood plains of ephemeral stream channels, and diversion of ephemeral stream flows to irrigated fields in the same or adjacent flood plains" (Evett 1983). Today, this is still the framework of water harvesting design, although the specific adjustments have changed the appearance of the system.

Modern day agriculture did not appreciate the potential of runoff farming as a viable alternative for crop and livestock production until the earlier part of this century. Burdass (1974) and Frasier (1974) discussed the potential of water harvesting for livestock production. Recently, a good number of papers have dealt with the means of improving the storage system (Boyer and Cluff 1972, Dedrick 1975, Cluff 1980). Some of these investigators have presented extensive data on evaporation suppression for conserving water supplies (Cluff 1980) and still others have concentrated their work on increasing runoff, decreasing soil erosion and cost effectiveness (Hillel, Rawitz and Steinhardt 1965; Cluff and Dutt 1966; Cluff et al. 1972; Dutt and McCreary 1975). The growing interest in water harvesting in recent years resulted in the creation of two international meetings to further discuss the improvements and problems of the field. These are the Proceedings of the Water Harvesting Symposium (Frasier 1975) and the Symposium on Rainfall Collection for Agriculture in

Arid and Semi-arid Regions (Dutt, Hutchinson and Garduno 1981 which provides ample literature on water harvesting.

The following sections, however, provide some insight into investigations related to plant physiological characteristics that pertain to this project. These physiological parameters are temperature (leaf and canopy), leaf water potential, and transpiration rate.

Physiological Parameters Affecting Yield

Temperature Dependent Indices as an Indicator of Crop Performance

Temperature and moisture are the two primary environmental determinants of crop yield. Heat stress is a major factor influencing the productivity and adaptation, especially when temperature extremes coincide with a critical stage of plant growth. The temperature of the aerial portion of the plant may rise above or remain below the environmental temperature depending on the plant's ability to transfer excess heat to the environment. The temperature of an individual leaf or plant canopy relative to ambient air temperature has long been recognized as an indicator of plant water stress (Gates 1964, Wiegand and Namken 1966). Tanner (1963) stated that plant temperature may be a valuable qualitative index to differences in plant water regime. Recently, Ehrler et al. (1978) and Jackson, Reginato and Idso (1977) indicated that wheat is not stressed for water unless leaf temperature exceeds air temperature.

Plant temperature is measured by different means. Monteith and Szeicz (1962) and Tanner (1963) were among the first to use infrared thermometry, while before that, thermocouples were the only means of plant temperature measurements (Ehrler 1973). Some of the earliest work using plant canopy temperature to detect crops under various degrees of water stress was that of Idso, Jackson and Reginato (1977) and Jackson et al. (1977). They developed the concept of the stress degree day (SDD). These workers defined SDD as the difference between the temperature of a plant canopy (T_c) and the temperature of the surrounding air (T_a).

$$SDD = (T_c - T_a) \qquad (1)$$

A positive value for SDD for wheat would indicate that the plants are stressed. The SDD is preferably taken at the time of maximum surface temperature (1 to 1.5 hours after solar noon) and it can be used for yield prediction as well (Idso et al. 1977).

In order to establish a relationship between crop temperature and the grain yield in corn, Gardner et al. (1981) developed the concept of temperature stress day (TSD) which, like the SDD concept, could be determined by infrared thermometry. They defined

$$TSD = T_f - T_{fl} \qquad (2)$$

where T_f is foliage temperature at mid-day (°C), and T_{fl} is foliage temperature of fully irrigated plant(s) at mid-day (°C). Jackson et al. (1981) developed the crop water stress index as a rapid means of assessing crop water stress by remote measurements. The crop water stress index (CWSI) is a more accurate temperature dependent index in which it takes into account the effects of atmospheric vapor pressure, net radiation, and wind speed on crop temperature. The CWSI is defined as

$$CWSI = 1 - (E/E_p) = [\gamma(1 + (r_c/r_a)) - \gamma^*) / (\Delta + (1 + (r_c/r_a))] \quad (3)$$

$$\text{where } \gamma^* = \gamma(1 + (r_{cp}/r_a)) \quad (4)$$

$$\text{and } r_c/r_a = \frac{\gamma r_a \, R_n/(\rho c_p) - (T_c - T_a)(\Delta + \gamma) - (e_a^* - e_a)}{\gamma[(T_c - T_a) - r_a R_n / (\rho c_p)]} \quad (5)$$

T_c = Canopy temperature at mid-day °C

T_a = Mid-day air temperature °C

E/E_p = Actual evapotranspiration/potential evapotranspiration

r_c = Canopy resistance to vapor transport (s m^{-1})

r_{cp} = Canopy resistance to vapor transport at potential evapotranspiration (s m^{-1})

r_a = Aerodynamic resistance to vapor transport (s m^{-1})

e_a^* = Air saturation vapor pressure (P_a)

e_a = Air vapor pressure (P_a)

Δ = Slope of saturation vapor pressure verses temperature curve (P_a/°C)

γ = Psychometric constant (P_a/°C)

R_n = Net radiation of crop during mid-day ($^m/_s$)

ρ = Air density≃1.2 (kg m^{-3}) in Tucson, AZ

C_p = Specific heat of air ≃ 1010 ($^J/_{kg}$ °C)

In their study, Jackson et al. (1981) concluded that CWSI is a promising tool for the quantification of crop water stress as well as being a useful indicator of irrigation needs for a variety of crops.

Diaz, Matthias and Hanks (1983) used all the indices mentioned here for the estimation of evapotranspiration and yield of spring wheat. Theeir results indicate that $\sum$SDD and yield data for combined planting dates were closely related (r^2 = 0.75). While grain yield versus $\sum$TSD was greatly influenced by the planting date, they found that the seasonal mean of CWSI, like $\sum$SDD, was also closely related to the relative yield decrease (r^2 = 0.78).

Effect of Leaf Water Potential and Its Components on Yield

In most plant organs, water constitutes more than 90 percent of the fresh weight (Turner and Burch 1983). Plant physiological and biochemical processes, including "photosynthesis, transpiration, cell division, progressive tissue initiation, and organ primordia, as well as crop productivity depends on the maintenance of a high water content" (Slatyer 1973). Traditionally, physiologists quantified the effect of water stress on plants and crops in terms of soil water potential; more recently plant water potential (ψ_{plant}) has been given a central role (Fischer 1980). During the last decade and a half, leaf water potential (ψ_l) has gained wide acceptance as a fundamental measure of plant status (Hsiao 1973). Many studies have been conducted to evaluate the effect of ψ_l on photosynthesis rate as well as dry matter production and grain yield (Boyer 1968, 1970; Turner and Burch 1983). A number of researchers have also dealt with ψ_l as an important tool in efficient use of irrigation water (Grimes and Yamada 1982, Clark and Hiler 1973, Bordovsky et al. 1974). Grimes and Yamada (1982) showed that leaf water potential of cotton declined linearly with time following irrigation. They found that the slope of these relationships varied for different soil textures.

Boyer (1970) found that soybean photosynthetic rate was unaffected by dessication until leaf water potentials were below -11 bars, whereas the photosynthetic activities were greatly affected in corn as soon as the ψ_l dropped below -3.5. In a related study, McPherson and Boyer (1977) indicated that when maize was subjected to a water deficiency shortly after tasseling, the ψ_l decreased to -18 to -20 bars, where ψ_l remained until maturity. Apparent photosynthesis became virtually zero at such a low ψ_l, while the yield was 47 to 69 percent of the control. In a recent study, Gardner et al. (1981) showed that wheat and maize grain yields were reduced if water stress occurred at any time during the growing season. In their experiment, they examined the differences in mid-day leaf water potential ($\Delta\psi_l$) and crop temperature between stressed and non-stressed vegetation (ΔT). As ΔT increased to about 4°C, $\Delta\psi_l$ also increased, but beyond that point $\Delta\psi_l$ decreased while ΔT continued to increase.

The measurement of leaf water potential in the field has some drawbacks in terms of instrument portability and expenses. The means available for direct ψ_l determination include the pressure chamber (Boyer 1967) which is the most common way of ψ_l measurement in the field. However, the most accurate measurement of ψ_l is determined by thermocouple psychrometry (Turner and Burch 1983). The psychrometric method is based on the principle that the relative vapor pressure above a solution or piece of plant tissue is related to its water potential (ψ_l) according to the following equation.

$$\psi_l = \frac{RT}{V} \ln \left(\frac{e}{e_0}\right) \tag{6}$$

where R is gas constant, T is temperature in °K, V is partial molal volume, with e and e_0 being vapor pressure of water in the solution and at atmospheric pressure, respectively.

Bristow, Van Zyle and De Jager (1981) and Jones and Carabaly (1980) have discussed the possibility of using another instrument known as the J14 press or Campbell press for ψ_l measurements. Rhodes and Matsuda (1976) indicated that values obtained with the press were found to correlate well with estimates of relative water content of three-day-old pumpkin seedlings.

Transpiration Rate and Grain Yield

The major effect of environmental variation in water stress on the yield of a given crop is usually explained by variations in the total supply of water to the crop and is reflected in variations in crop evapotranspiration, or more precisely, crop transpiration. The models that are of interest to scientists as a means of predicting crop production generally relate the crop yield evapotranspiration (ET) or evapotranspiration deficit (EG_d). Hanks and Hill (1980) stated that models relating yield to transpiration are more accurate than those relating yield to evapotranspiration because they account for the water that goes through the plant.

Studies have shown that water loss due to transpiration can account for 50 to 70 percent of total water lost during peak use by corn (Waldren 1983). Waldren states that, "Any change in the water potential of the roots is reflected by a change in leaf water potential of a similar magnitude. This, in turn, will affect stomatal diffusive resistance and ultimately the rate of transpiration."

As DeWit (1958) indicated, a correlation existed between total dry matter yield and transpiration if water was the only limiting factor. He developed the following equations:

$$P = m\ W\ E_0^{-1} \quad (7)$$

$$P = n\ W \quad (8)$$

where P is total dry matter production, W is the total transpiration during growth of the plants, E_0 is the free water evaporation, and m and n are crop factors in (g dry matter mm)/(kg water day). Equation (7) is for climates with a large percentage of bright sunshine, and Equation (8) is for climates with a small percentage of bright sunshine.

Since the equation for yield prediction developed by DeWit (1958) needed measurements of transpiration rate, Hanks, Gardner and Florian (1969) and Hanks (1974) showed the evaporation (E) and transpiration (T) can be estimated from field measurements of ET, with T being the dominant mechanism through which water is lost. In another related study, Stewart and Hagan (1973) demonstrated that there is a linear relationship between evapotranspiration and corn grain yield with $r^2 = 0.98$.

Stewart and Hagan also found that yield response is closely correlated with transpiration if factors other than water are not limiting (Morey et al. 1980). They indicated that for soil moisture tensions less than 0.15 atm, it is assumed that transpiration is at the potential rate with no reduction due to soil moisture conditions. As soil moisture stress increases, predicted transpiration decreases. They observed that the transpiration ratio estimates (defined as the ratio of actual transpiration rate at a given soil moisture to the potential transpiration) were linearly correlated to the relative yield of corn with $r^2 = 0.9$.

The most common technique for <u>in situ</u> measurements of transpiration is done by an instrument known as the steady state porometer

(Beardsell, Jarvis and Davidson 1972). This instrument has the capability of measuring the leaf diffusive resistance, leaf and air temperature, and incoming solar radiation simultaneously.

Calculation of CWSI

Crop water stress index was calculated as described by Jackson et al. (1981) using Equation (3). However, there was a slight variation through which the aerodynamic resistance r_A was calculated using a buoyancy corrected formula given by Hatfield, Perrier and Jackson (1983).

$$r_A = ra' \, [1 - n(Z - d) \, g \, (T_c - T_A)/(T_A U^2)] \qquad (9)$$

where $ra' = Ln[(Z - d)/Z_0]^2 \, / \, (K^2 U) =$

$4.72 \, [Ln(Z - d)/Z_0]^2/1 + .54U$

and

U = The wind speed m s^{-1}

Z = The wind speed measurements at 3m above ground

d = Zero plane displacement = h x .67

Z_0 = Roughness length = h x .1

h = Height of the crop (average) = 1.5m

g = Acceleration due to gravity = 9.8 m s^{-2}

K^2 = Von Karman's constant = 0.38 (unitless)

T_A = The air temperature in °K

n = Emperical constant = 5

To calculate CWSI, values of vapor pressure deficit (e* - e), net radiation (Rn), and windspeed, were obtained from an automated weather station (Campbell Scientific, Inc.) in Avra Valley, Arizona, about 16 Km from the site (Table 1). Net radiation was calculated as being 75 percent of incoming solar radiation (Jackson et al. (1981) and the actual vapor pressure was calculated by utilizing the equation defined by Richards (1971). Table 1 also includes the values for Δ and γ which were obtained from Fritschen and Gay (1979).

Table 1. Environmental input for crop water stress index (CWSI) calculation.

DATE	Ave.Air Temp. °C	Rn wm^{-2}	e* Pa	RH	e Pa	(e*- e) Pa	Δ Pa/°C	γ Pa/°C	U m/s
24 Oct.	31.5*	308.30	4634.5	10.12	463.5	4171.0	262.50	66.55	1.196
	32.5**	308.30	4891.0	10.12	496.3	4394.7	275.25	66.50	1.196
26 Oct.	31.5	330.82	4634.5	11.84	548.7	4085.8	262.50	66.50	1.216
31 Oct.	28.0	483.75	3759.0	14.84	557.8	3201.2	219.90	66.40	3.314
2 Nov.	25.0	486.00	3176.0	20.20	635.0	2541.0	188.60	66.20	3.193

* Block 1

** Block 3

MATERIALS AND METHODS

Description of the Area

During the summer of 1982, a water harvesting agrisystem was developed by the University of Arizona College of Agriculture, Department of Soils, Water and Engineering in cooperation with the Office of Arid Land Studies and the City of Tucson. The site was in Avra Valley, Arizona, about 36 Km west of Tucson as depicted in Figures 1 and 2. The elevation at this site is 600 m and the average annual rainfall does not exceed 25 cm. Daytime air temperaturess as high as 44°C are typical during the summer (Sellers and Hill 1974).

The overall Avra Valley Water Harvesting System encompasses about 2 ha of land (Figure 3). A complete report on the dimensions of the Avra Valley Water Harvesting System as well as the slopes, soil texture, Na^+ treatment of the catchments and the type of crops planted is presented by Dutt et al. (1983). The dimensions of the cropping and catchment area where the corn was planted are shown in Figure 4.

Of the 17 varieties of corn studied, 14 were supplied by the International Mays and Wheat Improvement Center "CIMMYT" and 3 were obtained from local varieties (Papago, Chapalote and Hopi). The complete list of these varieties and their local habitat is given in Table 2. A randomized complete block design with four replications was chosen. Plots consisted of single rows which covered the

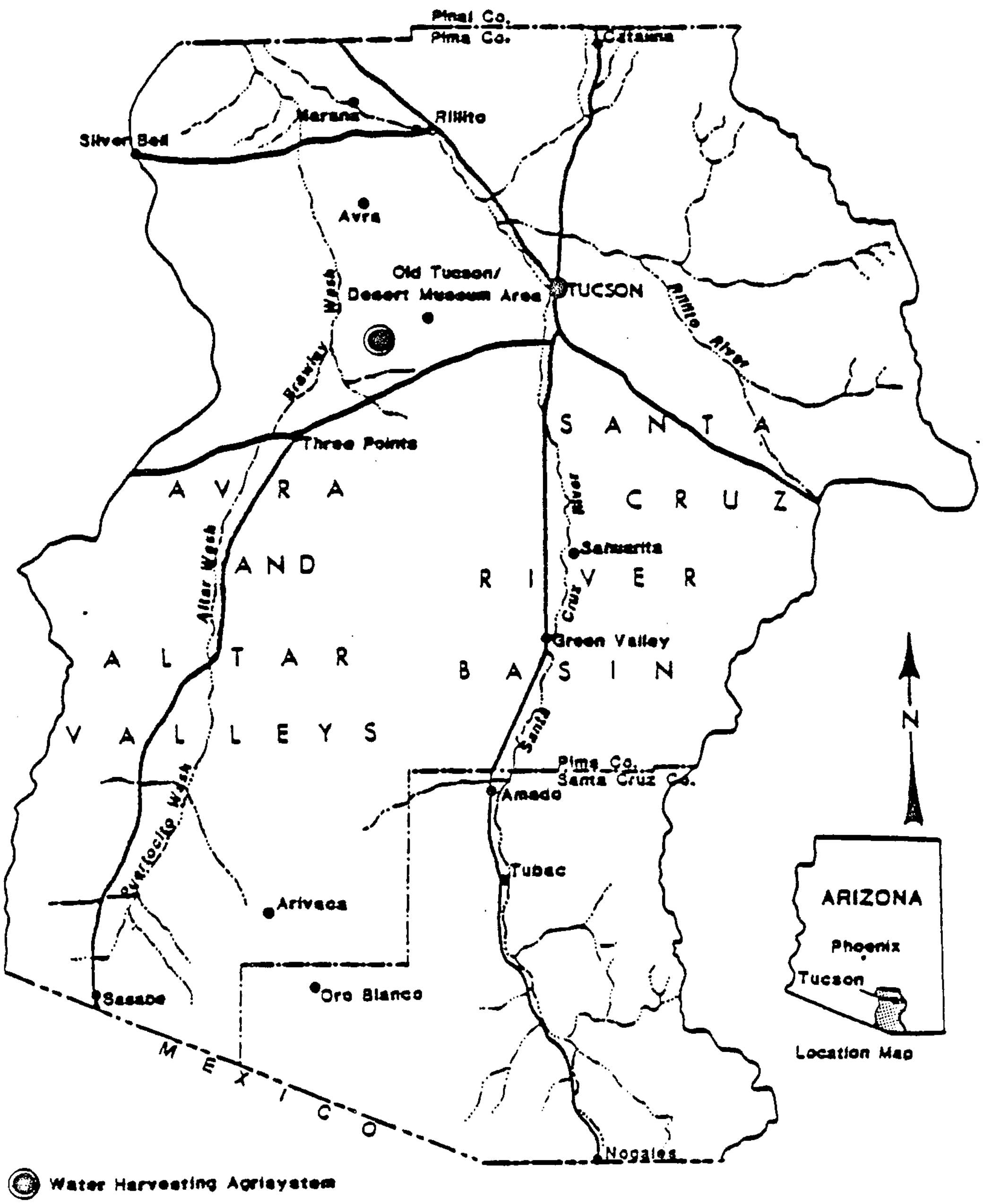

Figure 1. Santa Cruz Basin and Avra Valley. From Dutt et al. (1983).

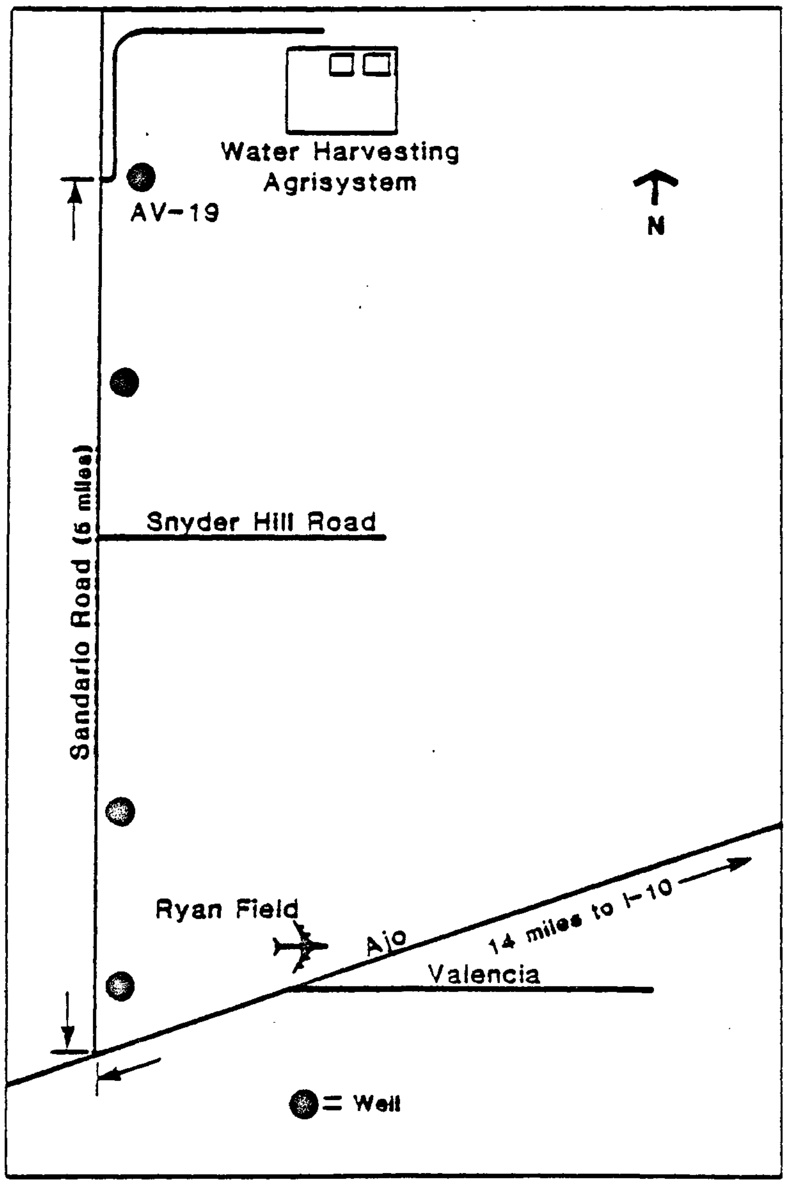

Figure 2. Location of the Water Harvesting Agri-system. From Dutt et al. (1983).

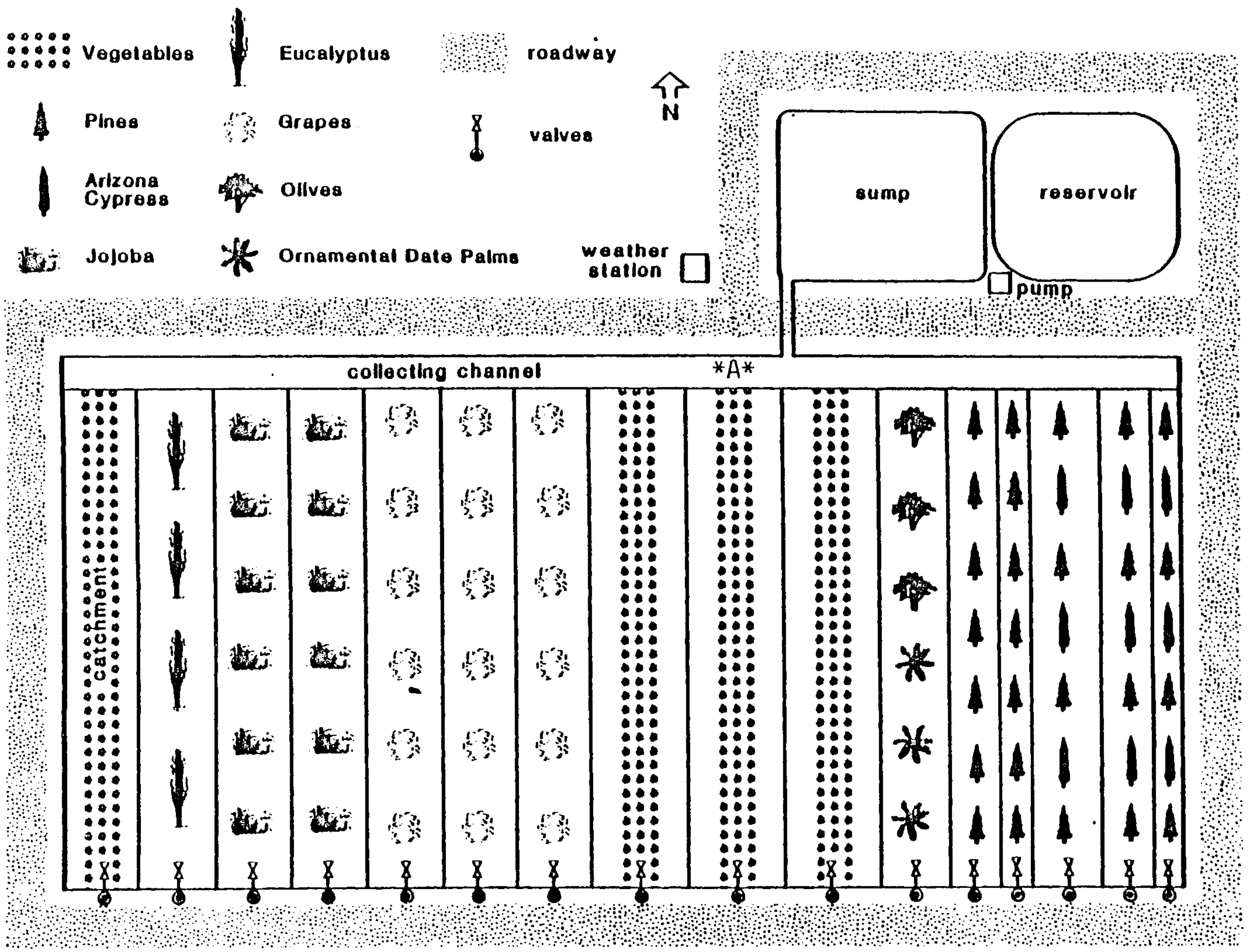

Figure 3. City of Tucson Water Harvesting Agri-system. From Dutt et al. (1983).

A = Corn

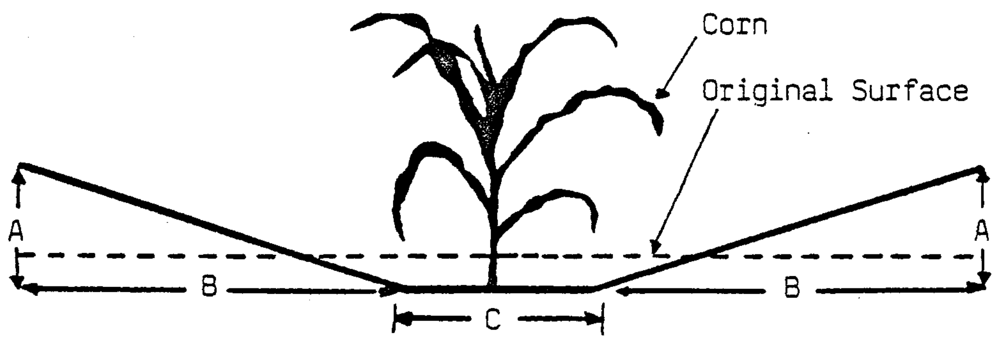

Figure 4. Catchment configuration. From Dutt et al. (1983).

A/B x's 100 = slope of catchment (%) = 4.

C = cropping area width = 4m.

Length of the cropping area is 90m.

Table 2. International Experimental Variety Trial, 1982 Intermediate Tropical Normal Yellow Varieties, used at the Avra Valley Water Harvesting site.

Variety No.	Variety Name	Country	Origin	Replication			
				1	2	3	4
				Row Number			
1.	Piura (1) 7926	Peru	TL81A - 1074	16	23	48	68
2.	Islamabad (1) 7926	Pakistan	TL81A - 1071	4	25	41	55
3.	Saavedra 7926	Bolivia	TL81A - 1075	1	31	40	52
4.	Across 7926	Across Locations	TL81A - 1078	3	32	39	65
5.	Sete Lagoas 7931	Brazil	TL81A - 1067	8	34	43	63
6.	Pichilingue 7931	Ecuador	TL81A - 1072	11	18	49	56
7.	Satipo (1) 7931	Peru	TL81A - 1070	5	24	38	61
8.	Satipo (2) 7931	Peru	TL81A - 1061	15	26	51	54
9.	Across 7931	Across Locations	TL81A - 1073	14	29	44	59
10.	Islamabad 8035	Pakistan	TL81B - 1547	13	19	50	62
11.	Poza Rica 8035	Mexico	TL81B - 1548	17	20	35	64
12.	Suwan 8035	Thailand	TL81B - 1582	2	30	47	57
13.	Across 7726 RE	Across Locations	TL81B - 1100u	9	28	42	67
14.	Across 7635 RE	Across Locations	PR78A - 21A	12	21	45	66
15.	Hopi*	United States	— — — —	7	22	37	53
16.	Chapalote*	United States	— — — —	10	27	46	58
17.	Papago*	United States	— — — —	6	33	36	60

* Local Varieties

entire 4 m-width of the cropped area. Row spacing was 75 cm with the hill-to-hill spacing within a row being 50 cm. Two seeds were planted per hill giving a plant density of about 48,000 per hectare.

The soil was originally mapped as Vėkol silty clay loam and classified as fine, mixed thermic, Typic Haplargid (Gelderman 1972). However, the actual particle size analysis after leveling of the site indicates a sandy clay loam soil (Dutt et al. 1983). The site is located between Sandario Road and the drainage canal in Section 27T 14S R11 E. A representative sample from the same area indicates that this soil is non-saline with the $EC_e = 0.75 \times 10^3$ d S m^{-1} and pH = 7.45. Ammonium phosphate was added to the soil at a rate of 100 Kg/ha (cropping area only) one week before the planting date, 31 July. The late planting date was chosen so that the growing season would closely coincide with the normal summer rainy season. However, Figure 5 indicates that in the summer of 1982, the precipitation was unexpectedly low in the region, especially during the early stage of the growing season. Although by 20 August, three weeks after planting, well above 50 percent of the seeds were germinated and emerged, and the lack of moisture was causing severe wilting of the plants. It was therefore vital to bring supplementary water to the plants in order to reduce the effects of extreme moisture stress during the reproductive and grain filling stage, which has the greatest impact on the yield of corn (Waldren 1983). Therefore, it was decided to pump water from the reservoir to flood irrigate the cropping area. The first flood irrigation was done on 1 September, while

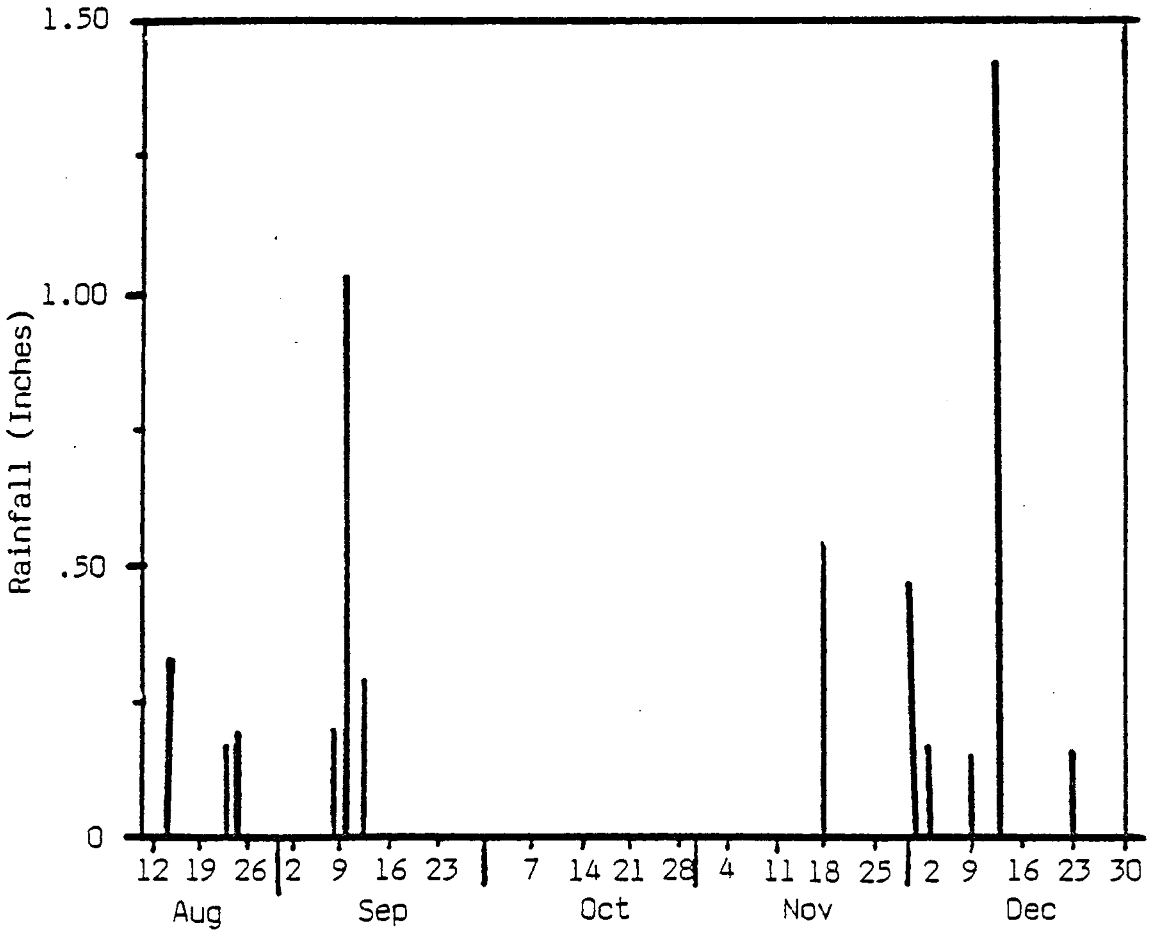

Figure 5. Measurable rainfall at Avra Valley Water Harvesting Agri-system in 1982. From Dutt et al. (1983).

other floodings followed on 9, 20, 27 September; 12, 21 October; and 4 November.

Uniformity of moisture and fertility is the underlying assumption of this project, otherwise any differences in yield could be attributed to such non-varietal causes.

Measurements and Instrumentation

Corn grown in arid regions are known to have a shallow root depth which hardly penetrates below 0.5 m. Moisture measurements were taken by a neutron meter at 19 sites throughout the cropping area. These measurements were taken at 20 and 40-cm depths as an indicator of irrigation uniformity. Soon after 50 percent of the plants had silked, height measurements were taken on 5 October. Transpiration rate was measured by a steady state porometer Li-cor model Li-1600 (as described by Beardsell et al. 1972). Leaf and ambient temperatures were also simultaneously measured with the porometer from the flag leaf. Data were collected on 24 and 31 October for blocks 1 and 3, and on 26 October and 2 November for blocks 2 and 4. Measurements were taken at 1300 hours at the time of maximum solar radiation. A minimum of three readings were taken for each replication.

Using a Model J-14 Campbell press (Jones and Carabaly 1980), the leaf potentials were also taken on the same plants simultaneously. Measurements were consistently taken on the same locations in order to eliminate the variation in the water status of different parts of the plants. Harvesting was done on 19 November, a few days earlier than desirable, due to a light frost. The ears were the only part of the plant that were harvested. These were later oven dried and weighed.

RESULTS AND DISCUSSION

Data were analyzed in two parts to provide sufficient information to meet the objectives of this project. In the first part, the oven dried weight of ears were compared for all the varieties using an analysis of variance. The presence of significant differences between the yields would have then provided the basis for the second part, the analysis of variance of comparing the rates of change of SDD, CWSI, TR, and ψ_1. Programs of statistical analysis for computer use were adopted from the Statistical Package for Social Sciences (SPSS) (Nie et al. 1975).

Yield

The oven dry weights of the ears are presented in Table 3, as the average harvested yield per plot ($3m^2$) per cultivar. This table also presents the average height of the cultivars at the stage of 50 percent silking. Table 4 shows the results of analysis of variance on yields. This table indicates that there is a significant difference among the cultivar's yields. Cultivar TL81A-1073 was the highest yielding variety with a per hectare yield of about 1533 kg. Cultivars TL81B-1547, TL81B-1548, TL81A-1061 and TL81A-1070 all produced above one ton per ha. The conspicuous low yielding cultivar was the local check, the Chapolate, with a yield of about

Table 3. Multiple comparison of yields and the height of respective cultivars.

ENT‡ #	YIELD kg/3m²	HEIGHT*(m) at 50% silking
1	.26 b c d f**	.83
2	.19 a b c d e	.74
3	.10 a b	.68
4	.10 a b	.70
5	.29 b c d e f	.74
6	.29 b c d e f	.81
7	.32 c d e f	.76
8	.35 d e f	.75
9	.46 f	.83
10	.40 e f	.78
11	.36 d e f	.80
12	.17 a b c d	.60
13	.13 a b c	.74
14	.23 b c d e	.69
15	.17 a b c d	.50
16	.08 a	.76
17	.13 a b c	.79

* Height values are average of at least 10 readings per cultivar.

** Values followed by the same letter within a column are not significantly different at the 0.05 level according to least significant difference (LSD). Calculated LSD = 2.84.

‡ ENT = Entry.

Table 4. Analysis of variance related to the yield x's 10.

Source of Variation	SS	DF	MS	F
Main Effects	104.483	19	5.499	2.455
ENT	94.355	16	5.897	2.633
REP	10.127	3	3.376	1.507
Explained	104.483	19	5.499	2.455
Residual	107.513	48	2.240	
Total	211.996	67	3.164	

α Level = 5%

$F_{critical} = F^{16}_{48} = 1.85$

SS = Sum of Squares

DF = Degrees of Freedom

MS = Mean Square

267 kg/ha. Under irrigated conditions, many of these cultivars can produce as high as 10^6 kg/ha (CIIMYT 1982). However, according to another CIMMYT (1973) report, the estimates of the mean yield of maize grown in the tropical regions is only 10^3 kg/ha. The cultivars in this project are identified as intermediate tropical normal yellow varieties. Since there are no data available in terms of potential yield of these varieties, an evaluation of relative yield performance of these cultivars is impossible. The analysis of absolute grain yield without a knowledge of the cultivar's potential yield could be misleading.

It has been also suggested that the smaller size of various plant organs and cells constitutes a drought adaptive attribute (smaller cells are better adjusted osmotically) (Blum 1979). However, since yield is in itself a manifestation of a larger organ size, the potential yield might be undermined by a genetic shift toward smaller cells and meristem size to improve drought adaptation. The complexity of size, yield, and drought adaptation points, however, to a probable balance in the integrated plant system, with greater yield not necessarily constituting a greater adaptability. It is therefore possible that a further improvement of yield will involve a corresponding decrease in drought resistance and vice versa.

Some of the variations in grain yield can also be attributed to the differences among cultivars in attaining maturity after silking. In other words, some cultivars would perhaps require a shorter interval after silking to mature than others. If this were true, then the forced early harvest was done at a time when some cultivars did not attain maturity. If all the cultivars were mature, one would perhaps have obtained less variation among the grain yields. Nonetheless, if total dry matter production can be estimated from the above ground height of the plants, it is apparent in Table 3 that cultivars such as Chapolate have produced little grain while diverting more photosynthetic assimilate for production of vegetative tissues. It is also possible that low yielding cultivars have avoided drought stress by extending their root system. An extended root system would therefore deprive the grain by becoming the primary sink of carbohydrate produced through photosynthesis . This also indicates that adaptive response could be expressed not only in terms of grain yield, but also in terms of growth and survival of vegetative organs. In the following sections, the physiological parameters were analyzed in search of relevant information concerning drought adaptation mechanisms.

Stress Degree Day and Crop Water Stress Index

Leaf and ambient temperatures are given in Table 5, while the calculated SDD values are presented in Table 6. The rate of change of SDD ($\Delta SDD/\Delta t$) over the period 24 October and 2 November were statistically analyzed with the analysis of variance showing no significant differences in the $\Delta SDD/\Delta t$ (Table 7). However, when the changes in SDD over time are shown in Figure 6 for cultivars TL81A-1071, TL81A-1070, TL81A-1061 and PR788A-21A, it is obvious

Table 5. Measured leaf and air temperature over the period 24 Oct to 2 Nov.

Row #	Variety #	Block #	DATE 24 Oct. Leaf	 Air	 26 Oct. Leaf	 Air	 31 Oct. Leaf	 Air	 2 Nov. Leaf	 Air
						°C				
1	3	1	36.0	31.5	—	—	29.4	28.0	—	—
2	12	"	31.3	31.5	—	—	30.3	28.0	—	—
3	4	"	30.2	31.5	—	—	31.8	28.0	—	—
4	2	"	30.8	31.5	—	—	30.8	28.0	—	—
5	7	"	30.3	31.5	—	—	32.3	28.0	—	—
6	17	"	30.2	31.5	—	—	30.1	28.0	—	—
7	15	"	28.5	31.5	—	—	29.0	28.0	—	—
8	5	"	29.3	31.5	—	—	30.5	28.0	—	—
9	13	"	30.5	31.5	—	—	28.5	28.0	—	—
10	16	"	missing data		—	—	28.6	28.0	—	—
11	6	"	30.3	31.5	—	—	29.5	28.0	—	—
12	14	"	29.7	31.5	—	—	28.9	28.0	—	—
13	10	"	29.6	31.5	—	—	27.4	28.0	—	—
14	9	"	28.8	31.5	—	—	28.0	28.0	—	—
15	8	"	30.0	31.5	—	—	27.7	28.0	—	—
16	1	"	30.6	31.5	—	—	29.5	28.0	—	—
17	11	"	29.6	31.5	—	—	29.0	28.0	—	—
18	6	2	—	—	30.6	31.5	—	—	28.9	25.0
19	10	"	—	—	32.3	31.5	—	—	28.2	25.0
20	11	"	—	—	32.7	31.5	—	—	27.5	25.0
21	14	"	—	—	32.7	31.5	—	—	27.2	25.0
22	15	"	—	—	32.4	31.5	—	—	27.0	25.0
23	1	"	—	—	33.8	31.5	—	—	26.8	25.0
24	7	"	—	—	32.4	31.5	—	—	28.6	25.0
25	2	"	—	—	31.3	31.5	—	—	26.6	25.0
26	8	"	—	—	31.1	31.5	—	—	26.8	25.0
27	16	"	—	—	32.4	31.5	—	—	28.3	25.0
28	13	"	—	—	32.4	31.5	—	—	28.0	25.0
29	9	"	—	—	32.0	31.5	—	—	28.0	25.0
30	12	"	—	—	33.0	31.5	—	—	26.2	25.0
31	3	"	—	—	32.2	31.5	—	—	28.8	25.0
32	4	"	—	—	33.0	31.5	—	—	27.4	25.0
33	17	"	—	—	33.0	31.5	—	—	27.8	25.0
34	5	"	—	—	31.9	31.5	—	—	28.0	25.0

Table 5 (cont.). Measured leaf and air temperature over the period 24 Oct to 2 Nov.

Row #	Variety #	Block #	24 Oct. Leaf	24 Oct. Air	26 Oct. Leaf	26 Oct. Air	31 Oct. Leaf	31 Oct. Air	2 Nov. Leaf	2 Nov. Air
					°C					
35	11	3	30.2	32.5	----	----	30.4	28.0	----	----
36	17	"	30.4	32.5	----	----	29.1	28.0	----	----
37	15	"	30.5	32.5	----	----	28.6	28.0	----	----
38	7	"	30.6	32.5	----	----	28.8	28.0	----	----
39	4	"	30.9	32.5	----	----	32.1	28.0	----	----
40	3	"	30.7	32.5	----	----	29.8	28.0	----	----
41	2	"	32.7	42.5	----	----	25.2	28.0	----	----
42	13	"	31.1	32.5	----	----	31.5	28.0	----	----
43	5	"	31.2	32.5	----	----	27.2	28.0	----	----
44	9	"	31.2	32.5	----	----	30.7	28.0	----	----
45	14	"	30.8	32.5	----	----	28.9	28.0	----	----
46	16	"	29.7	32.5	----	----	28.5	28.0	----	----
47	12	"	29.8	32.5	----	----	30.0	28.0	----	----
48	1	"	30.6	32.5	----	----	27.4	28.0	----	----
49	6	"	30.9	32.5	----	----	28.3	28.0	----	----
50	10	"	30.6	32.5	----	----	30.0	28.0	----	----
51	8	"	30.2	32.5	----	----	30.7	28.0	----	----
52	3	4	----	----	32.7	31.5	----	----	25.8	25.
53	15	"	----	----	31.9	31.5	----	----	26.2	25.
54	18	"	----	----	32.0	31.5	----	----	26.9	25.
55	2	"	----	----	33.0	31.5	----	----	26.5	25.
56	6	"	----	----	34.2	31.5	----	----	26.6	25.
57	12	"	----	----	33.0	31.5	----	----	25.5	25.
58	16	"	----	----	32.4	31.5	----	----	26.9	25.
59	9	"	----	----	32.8	31.5	----	----	24.6	25.
60	17	"	----	----	32.5	31.5	----	----	25.7	25.
61	7	"	----	----	32.3	31.5	----	----	26.3	25.
62	10	"	----	----	32.6	31.5	----	----	25.9	25.
63	5	"	----	----	32.7	31.5	----	----	27.7	25.
64	11	"	----	----	32.5	31.5	----	----	25.6	25.
65	4	"	----	----	33.5	31.5	----	----	28.2	25.
66	14	"	----	----	33.9	31.5	----	----	25.9	25.
67	13	"	----	----	34.1	31.5	----	----	27.5	25.
68	1	"	----	----	33.1	31.5	----	----	25.6	25.

Table 6. Calculated stress degree day (SDD) over the period 24 Oct. to 2 Nov.

Row #	Var. #	Blk. #	DATE 24 Oct.	31 Oct.	Row #	Var. #	Blk. #	DATE 24 Oct.	31 Oct.
			°C					°C	
1	3	1	4.5	1.5	35	11	3	-0.8	2.4
2	12	"	-0.2	2.3	36	17	"	-2.1	1.1
3	4	"	-1.3	3.8	37	15	"	-2.0	0.6
4	2	"	-0.7	2.8	38	7	"	-1.9	0.8
5	7	"	-1.2	4.8	39	4	"	-1.6	2.1
6	17	"	-1.3	2.1	40	3	"	-1.8	1.8
7	15	"	-3.0	1.0	41	2	"	0.2	-2.8
8	5	"	-2.2	2.5	42	13	"	-1.4	3.5
9	13	"	-1.0	0.5	43	5	"	-1.3	-0.8
10	16	"	missing	0.6	44	9	"	-1.3	2.7
11	6	"	-1.2	1.5	45	14	"	-1.7	2.9
12	14	"	-1.8	0.9	46	16	"	-2.8	2.5
13	10	"	-1.9	-0.6	47	12	"	-2.7	2.0
14	9	"	-2.7	0.0	48	1	"	-1.9	-0.6
15	8	"	-1.5	-0.3	49	6	"	-1.6	0.3
16	1	"	-0.9	1.5	50	10	"	-1.6	2.0
17	11	"	-1.9	1.0	51	8	"	-1.3	2.7
			26 Oct.	2 Nov.				26 Oct.	2 Nov.
18	16	2	-0.9	3.9	52	3	4	1.2	0.8
19	10	"	-0.8	3.2	53	15	"	0.4	1.2
20	11	"	1.2	2.5	54	8	"	0.5	1.9
21	14	"	1.2	2.2	55	2	"	1.5	1.5
22	15	"	0.4	2.0	56	6	"	2.7	1.6
23	1	"	2.3	1.8	57	12	"	1.5	1.5
24	7	"	-0.9	3.6	58	16	"	0.9	1.9
25	2	"	-0.2	1.6	59	9	"	1.3	0.4
26	8	"	-0.4	1.8	60	17	"	1.0	0.7
27	16	"	0.9	3.3	61	7	"	0.8	1.3
28	13	"	0.9	2.0	62	10	"	1.1	0.9
29	9	"	0.5	3.0	63	5	"	1.2	2.7
30	12	"	1.5	1.2	64	11	"	1.0	0.6
31	3	"	0.8	3.8	65	4	"	2.0	3.2
32	4	"	1.5	2.4	66	14	"	2.4	0.9
33	17	"	1.5	2.8	67	13	"	2.6	2.5
34	5	"	1.1	4.0	68	1	"	1.6	0.6

Table 7. Analysis of variance related to the SDD x's 1000.

Source of Variation	SS	DF	MS	F
Main Effects	4354.200	19	229.168	2.142
ENT	1228.408	16	76.776	.718
REP	3125.792	3	1041.931	9.740
Explained	4354.200	19	229.168	2.142
Residual	5134.554	48	106.970	
Total	9488.754	67	141.623	

α Level = 5%

$F_{critical}$ = 1.85

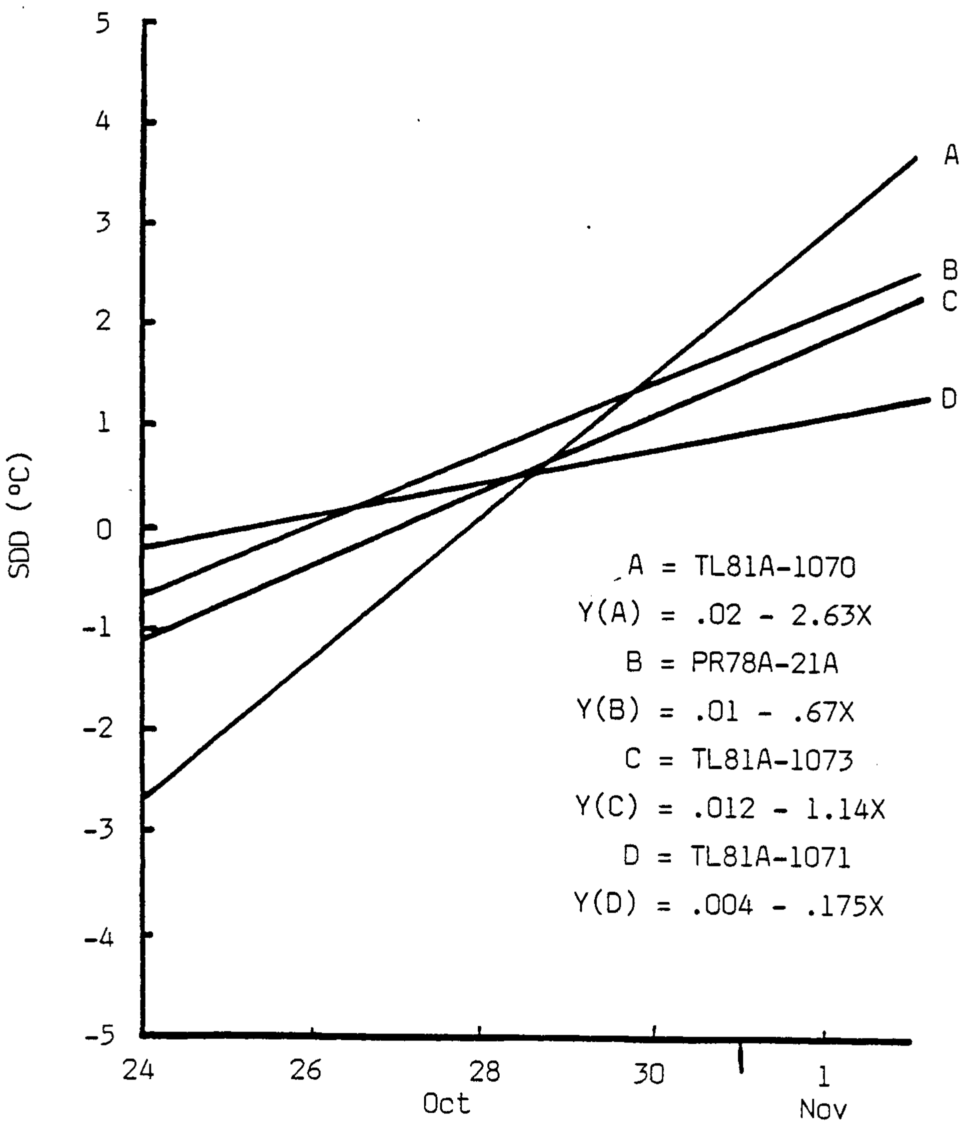

Figure 6. Rate of SDD change over the period 24 Oct. to 2 Nov for 4 selected cultivars. Y( ) is the equation of the line.

that at least some of the cultivars adapt differently from others by maintaining a lower leaf temperature. But $\Delta SDD/\Delta t$ does not seem to be the determining factor of grain yield. For example, cultivar TL81A-1071 is the lowest yielding, and it also has the smallest change in SDD over this two-week interval. Cultivars TL81A-1061 and PR78A-21A have a similar rate of change in SDD with the former having a twofold higher yield than the latter (Table 8). Table 8 shows the grain yield ranked from highest to lowest, with the corresponding changes in the physiological parameters.

Since the development of SDD in 1977 by Jackson et al., there have been studies which have indicated a positive correlation between seasonal SDD and yield, but recent investigations have demonstrated that foliage-air temperature differential is, by itself, too simple a parameter to adequately characterize the effects of significant environmental variations (Idso et al. 1981a, 1981b; Jackson et al. 1981) on drought stress. Recently, Walker and Hatfield (1983) found that yield is linearly related to foliage-air temperature difference if an energy balance equation is used to obtain the SDD. Hsiao (1973) stated that the temperature increase in the plant leaf has to be considered along with the sensitivity of the process in question. For a given reduction in transpiration, the increase in leaf temperature would strongly depend on factors such as radiation load on the leaf and heat transfer coefficient of the air. Barrs (1973) has also shown that leaf temperature changes of up to 3°C do not affect the net photosynthesis. Based on leaf temperature values presented

Table 8. Ranked yield data and the corresponding rates of changes of the related physiological parameters.*

ENT #	Yield Kg/ha	$\frac{\Delta TR}{\Delta t}$	$\frac{\Delta \psi_l}{\Delta t}$	$\frac{\Delta CWSI}{\Delta t}$	$\frac{\Delta SDD}{\Delta t}$
9	1533	-0.02	0.04	0.0000	0.001
10	1333	-0.02	0.31	0.0006	0.001
11	1210	-0.04	0.27	0.0007	0.001
8	1156	-0.02	0.10	0.0005	0.001
7	1067	-0.01	0.20	0.0010	0.002
5	950	-0.02	0.07	0.0006	0.001
1	877	-0.01	0.15	-0.0003	0.003
14	777	-0.03	0.40	-0.0007	0.001
6	760	-0.03	0.27	0.0006	0.001
2	633	-0.01	0.16	-0.0000	0.003
12	577	-0.03	0.23	0.0002	0.001
15	557	-0.001	0.09	0.0008	0.001
13	430	-0.02	0.04	0.0004	0.001
17	423	-0.02	0.18	0.0005	0.001
4	353	-0.03	0.15	0.0010	0.002
3	340	-0.01	0.22	-0.0005	0.004
16	267	-0.01	0.19	0.0010	0.001
Mean ($\bar{X}$)	779	-0.02	0.16	0.0006	0.0015
Std. Dev.(σ)	380.90	-0.01	0.099	0.0003	0.0009

*ΔTR is the change in transpiration rate; $\Delta\psi_l$ is the change in leaf water potential; ΔCWSI is the change in crop water stress index; ΔSDD is the change in stress degree day; and Δt is the time between the two irrigations (288 hrs). TR is in μg $cm^{-2}s^{-1}$; ψ_l is in -bar; and SDD is in °C.

in Table 5, it is obvious that during this two-week interval the mid-day leaf temperature changes very little over time, thus causing an even smaller change in SDD which cannot be related to the grain productivity.

However, the calculated values of CWSI (Table 9) also shows no significant difference between cultivars when analyzed in the same manner (Table 10). Also as shown in Table 8, there is no relationship between rates of change of CWSI and yield. Figure 7 further indicates graphically that the changes in CWSI for some selected cultivars seem to vary significantly. Cultivars TL81A-1070 and TL81A-1061 have produced the same relatively high yield (Table 8), but PR78A-21A, one of the lower yielding plants, showed to be less stressed during the two-week period than the higher yielding cultivars. Therefore, the rate of change of CWSI over the time of these measurements appears to be unrelated to yield. Nonetheless, the combination of CWSI and ψ_1 data, indicate that even a few days after irrigation, the plants are under moisture stress.

The lack of a positive correlation between the change in CWSI over time with the grain yield have come about because of the following factors. In Equations (9) and (4), the parameters h, d, Z, and r_{cp} are all estimations. The height dependent functions used in our calculation was an estimated value which could be a gross overestimation for the height of the dwarf varieties. The value of r_{cp} is adapted from Jackson et al. (1981) for wheat which could be different from that expected for corn crop. Also, presently it is not

Table 9. Calculated crop water stress index (CWSI) over the period 24 Oct. to 2 Nov.

			DATE					DATE	
Row #	Var. #	Blk. #	24 Oct.	31 Oct.	Row #	Var. #	Blk. #	24 Oct.	31 Oct.
1	3	1	1.28	0.66	35	11	3	0.36	0.73
2	12	"	0.56	0.73	36	17	"	0.38	0.63
3	4	"	0.44	0.85	37	15	"	0.38	0.59
4	2	"	0.50	0.77	38	7	"	0.39	0.61
5	7	"	0.45	0.89	39	4	"	0.42	0.87
6	17	"	0.44	0.71	40	3	"	0.41	0.69
7	15	"	0.29	0.63	41	2	"	0.62	0.35
8	5	"	0.36	0.74	42	13	"	0.44	0.82
9	13	"	0.47	0.56	43	5	"	0.45	0.49
10	16	"	missing	0.59	44	9	"	0.45	0.38
11	6	"	0.45	0.66	45	14	"	0.40	0.62
12	14	"	0.39	0.62	46	16	"	0.32	0.58
13	10	"	0.38	0.51	47	12	"	0.33	0.71
14	9	"	0.32	0.55	48	1	"	0.38	0.51
15	8	"	0.42	0.53	49	6	"	0.42	0.57
16	1	"	0.48	0.66	50	10	"	0.38	0.41
17	11	"	0.38	0.63	51	8	"	0.36	0.38
			26 Oct.	2 Nov.				26 Oct.	2 Nov.
18	6	2	0.46	0.83	52	3	4	0.72	0.56
19	10	"	0.70	0.77	53	15	"	0.61	0.60
20	11	"	0.72	0.71	54	8	"	0.62	0.66
21	14	"	0.72	0.68	55	2	"	0.77	0.62
22	15	"	0.68	0.66	56	6	"	0.99	0.63
23	1	"	0.91	0.65	57	12	"	0.77	0.54
24	7	"	0.68	0.81	58	16	"	0.68	0.66
25	2	"	0.54	0.63	59	9	"	0.74	0.46
26	8	"	0.51	0.65	60	17	"	0.69	0.56
27	16	"	0.68	0.78	61	7	"	0.67	0.60
28	13	"	0.68	0.75	62	10	"	0.70	0.57
29	9	"	0.62	0.75	63	5	"	0.72	0.73
30	12	"	0.77	0.60	64	11	"	0.69	0.55
31	3	"	0.65	0.83	65	4	"	0.85	0.77
32	4	"	0.77	0.70	66	14	"	0.93	0.57
33	17	"	0.77	0.73	67	13	"	0.97	0.71
34	5	"	0.75	0.75	68	1	"	0.77	0.55

Table 10. Analysis of variance related to the CWSI x's 1000.

Source of Variation	SS	DF	MS	F
Main Effects	69.787	19	3.673	3.673
ENT	20.496	16	1.281	1.281
REP	49.546	3	16.515	12.584
Explained	69.787	19	3.673	2.799
Residual	61.685	47	1.312	
Total	131.472	66	1.992	

α Level = 5%

$F_{critical}$ = 1.85

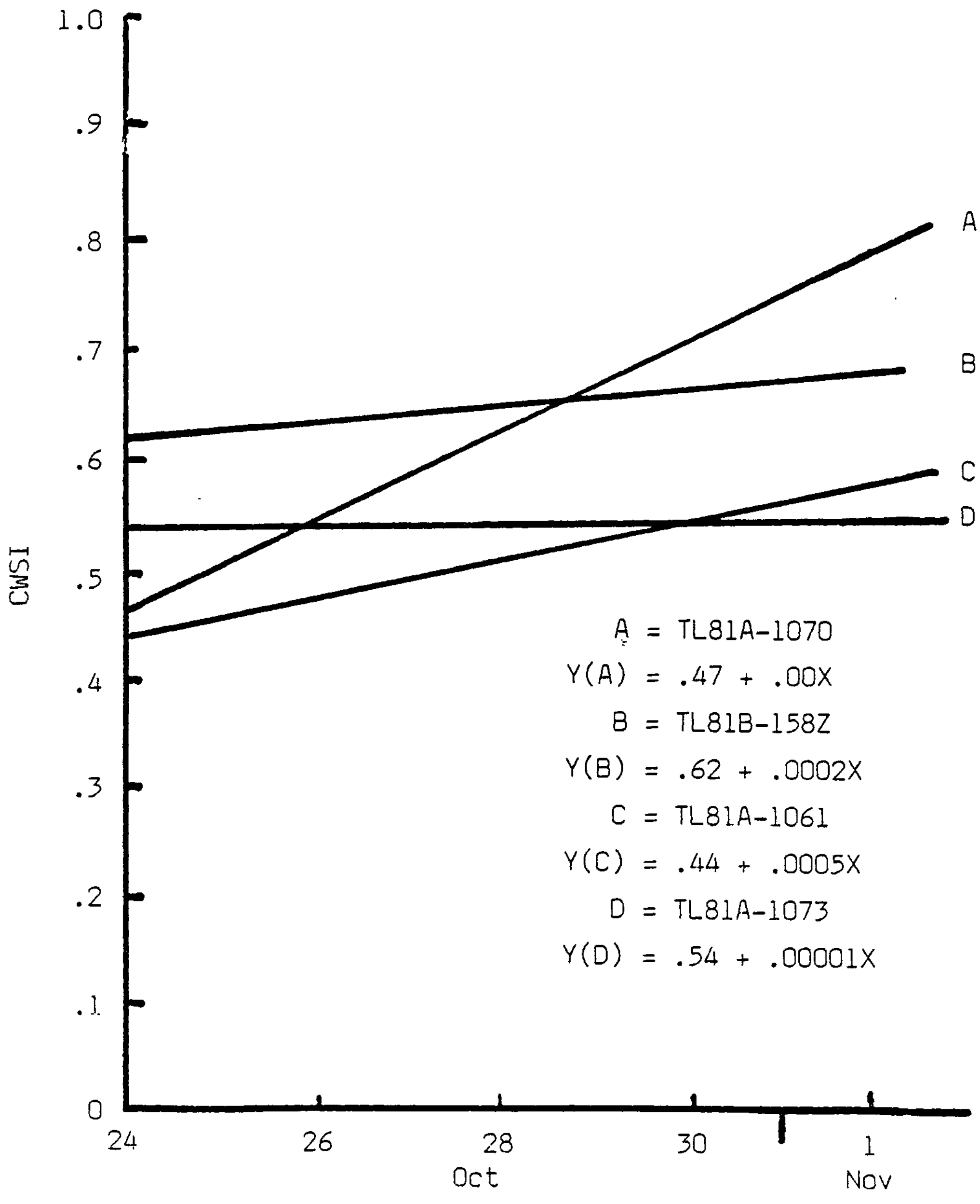

Figure 7. Rate of change of CWSI of 4 selected cultivars between 24 Oct. to 2 Nov. Y( ) is the equation of the line.

known whether CWSI has any limitation in terms of environmental variabilities.

Transpiration Rate and Leaf Water Potential

Table 11 shows the measured transpiration rates of all the 17 varieties between 24 October and 2 November. To analyze these values statistically, the differences of the transpiration rates (ψTR) over time (Δt) were used to obtain their slopes. Table 12 shows the analysis of variance for these slopes with the level of significance .05. This table indicates that the rate of change of transpiration rate is not significantly different between some of the varieties. In Figure 8, a graphical presentation of four selected cultivars shows some trends that at least some of the cultivars are significantly different from the others in the rates of change of transpiration rate. However, the results of this experiment show that the highest yielding plants are not necessarily those which could maintain a constant and high transpiration rate (Table 8). For example, in Figure 8, the local check Hopi shows the lowest rate of change in TR during the two-week interval while being one of the lowest yielding cultivars.

Transpiration is a process through which water is lost from the transpiring surfaces of the plant in exchange for CO_2. The CO_2 is in turn converted to chemically useable energy sources through photosynthesis. Thus, if the water loss to the atmosphere is reduced or prevented, one would expect a reduction of CO_2 uptake by the plant. Therefore, the well-adapted plant to drought might exhibit a lower

Table 11. Measured transpiration rates (TR) over the period 24 Oct. to 2 Nov.

Row #	Var. #	Blk. #	DATE 24 Oct.	DATE 31 Oct.	Row #	Var. #	Blk. #	DATE 24 Oct.	DATE 31 Oct.
			$\mu g\ cm^{-2}s^{-1}$					$\mu g\ cm^{-2}s^{-1}$	
1	3	1	3.9	3.1	35	11	3	11.9	2.5
2	12	"	7.5	4.7	36	17	"	9.9	4.7
3	4	"	7.2	3.5	37	15	"	8.5	9.3
4	2	"	7.2	6.2	38	7	"	8.0	7.3
5	7	"	7.9	5.3	39	4	"	8.4	3.6
6	17	"	7.3	7.5	40	3	"	8.1	6.7
7	15	"	8.7	10.6	41	2	"	9.3	8.1
8	5	"	8.9	6.2	42	13	"	9.7	3.7
9	13	"	7.0	9.0	43	5	"	8.5	2.2
10	16	"	missing	5.8	44	9	"	6.3	6.2
11	6	"	9.5	5.3	45	14	"	10.0	6.6
12	14	"	11.1	3.8	46	16	"	10.7	5.8
13	10	"	9.0	7.5	47	12	"	11.5	4.1
14	9	"	6.3	3.3	48	1	"	10.8	9.6
15	8	"	4.4	3.3	49	6	"	9.6	8.9
16	1	"	7.3	2.3	50	10	"	8.6	8.1
17	11	"	7.7	4.0	51	8	"	9.0	3.0
			26 Oct.	2 Nov.				26 Oct.	2 Nov.
18	6	2	12.3	5.9	52	3	4	7.9	6.1
19	10	"	10.8	5.3	53	15	"	6.8	6.1
20	11	"	12.5	4.9	54	8	"	9.3	4.9
21	14	"	10.2	7.7	55	2	"	8.4	3.7
22	15	"	9.9	8.9	56	6	"	10.3	3.9
23	1	"	8.9	4.5	57	12	"	9.7	5.9
24	7	"	8.0	5.7	58	16	"	11.3	5.1
25	2	"	6.1	5.5	59	9	"	9.7	5.0
26	8	"	6.8	6.3	60	17	"	9.6	4.2
27	16	"	6.0	2.5	61	7	"	8.8	6.2
28	13	"	8.3	1.5	62	10	"	8.4	4.3
29	9	"	6.1	2.5	63	5	"	8.0	4.7
30	12	"	5.1	2.2	64	11	"	10.7	4.9
31	3	"	7.7	1.8	65	4	"	6.0	1.8
32	4	"	7.5	3.3	66	14	"	8.1	3.1
33	17	"	8.2	5.4	67	13	"	6.7	3.0
34	5	"	7.5	3.8	68	1	"	7.1	2.9

Table 12. Analysis of variance related to the TR x's 1000.

Source of Variation	SS	DF	MS	F
Main Effects	7087.004	19	373.000	1.966
ENT	4924.305	16	307.769	1.622
REP	2162.699	3	720.900	3.800
Explained	7087.004	19	373.000	1.966
Residual	9105.927	48	189.707	
Total	16192.931	67	241.686	

α Level = 5%

$F_{critical}$ = 1.85

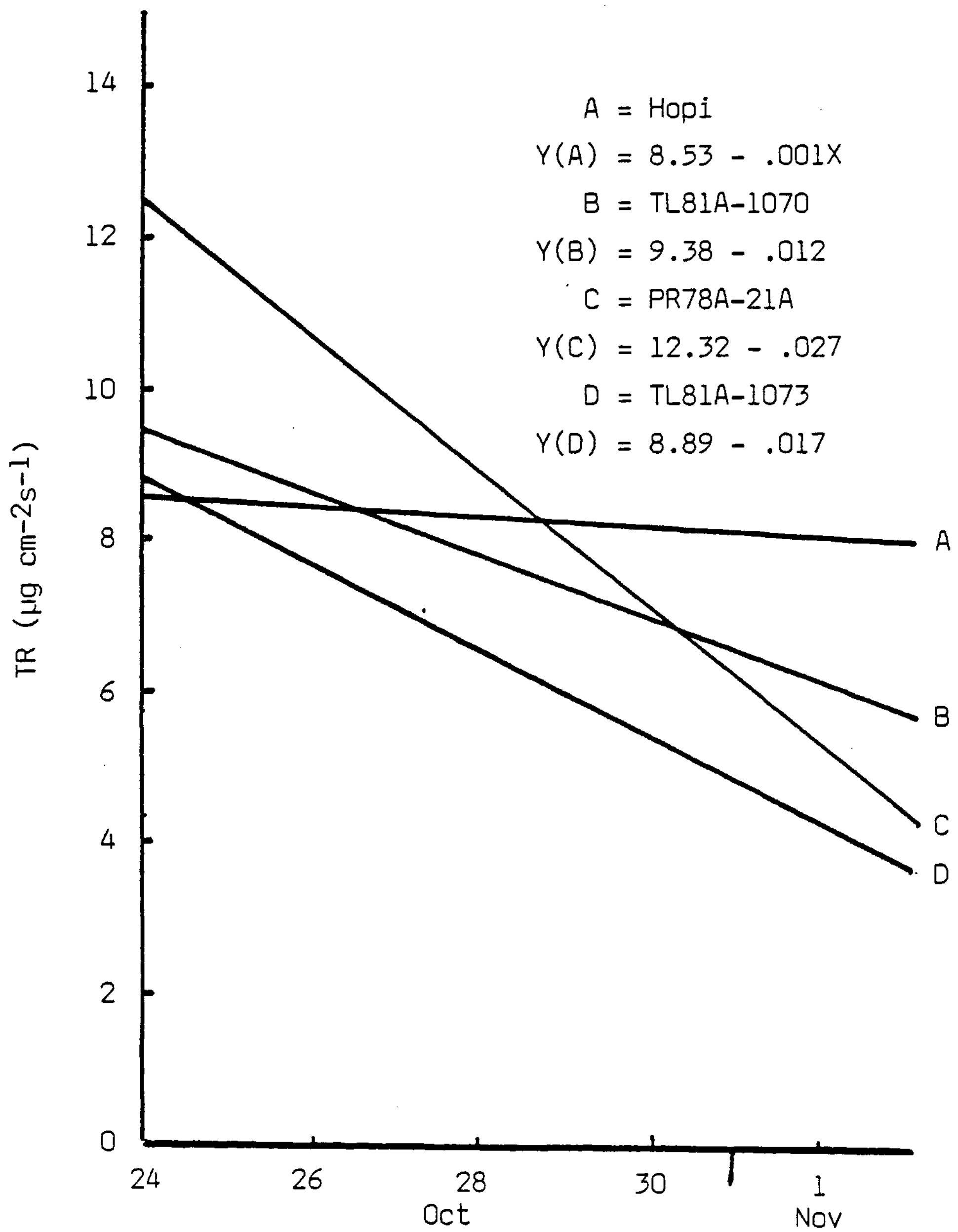

Figure 8. The changes of TR over the period 24 Oct. to 2 Nov for 4 selected cultivars. Y( ) is the equation of the line.

grain production due to an impairment in photosynthesis. However, some workers have indicated that the rate of photosynthesis is unaffected by the CO_2 supply under drought conditions (Boyer 1971, Wardlaw 1967).

When water is the only limiting factor for crop growth, there is a strong relationship between the amount of water transpired and the production (Taylor 1960, DeWit 1958, Hanks and Hill 1980, Stewart and Hagan 1969). Many of these and other similar works have related an estimated transpiration rate obtained from the measured or estimated evapotranspiration to yield. Black et al. (1960) reported that transpiration in snap beans can account for 60 percent of evapotranspiration. Therefore, a direct measurement of water flow from a transpiring leaf surface could in fact be debatable as far as the instrumentation accuracy is concerned. Also, Stegman (1982) has indicated that timing of stress has a great impact on the grain yield of corn. He observed that the greatest yield reduction was obtained when drought stress was imposed on corn during the period from 12th leaf to blister kernel period. It is possible that due to late and inadequate irrigation, all 17 varieties were stressed at this critical stage.

Even under improved irrigation manageement, hgigh leaf water potentials and CWSI values indicated that plants were stressed. Under such conditions, it is possible that a plant's stomatal resistance and TR are not the determining factors of grain yield since even under irrigation conditions it has been shown (Barrs 1973) that a drastic change in transpiration due to changes in relative humidity is unrelated to the net photosynthesis.

Using a similar statistical procedure, the values of leaf water potential (Table 13) were analyzed. High ψ_l, even three days after irrigation (24 October), are indicative of moisture stress and a strong indicator of impairment of photosynthate production. The results (Table 14) indicated that the slope of leaf water potential over time is significantly different between the cultivars. Figure 9 depicts the slopes of ψ_l over time of four representative varieties. Nonetheless, there was no indication to support the idea that the variety(ies) with a constant rate of leaf water potential change would out-yield variety(ies) with a rapid rate of change or vice versa (Table 8). Here again the local check Hopi shows a great ability to maintain its internal water status, but not being able to produce favorable yield.

However, when a plant is under drought stress, two distinct physiological processes could be impaired, namely, photosynthesis and translocation. There is some evidence as presented by Boyer and McPherson (1975) that under drought, in spite of a significant reduction in net photosynthesis during the grain-filling stage, grain production could remain unaffected. This is because some plants can mobilize photosynthate produced before the grain-filling period and use it to fill the grain when photosynthate production is impaired. At limited moisture, the ability of some of the cultivars to mobilize reserves for grain filling when current photosynthate

Table 13. Measured leaf water potential (ψ_l) over the period 24 Oct to 2 Nov.

Row #	Var. #	Blk. #	DATE 24 Oct.	31 Oct.	Row #	Var. #	Blk. #	DATE 24 Oct.	31 Oct.
			(- BAR)					(- BAR)	
1	3	1	9.0	13.3	35	11	3	11.0	15.4
2	12	"	10.0	13.2	36	17	"	12.4	13.7
3	4	"	9.0	14.7	37	15	"	6.9	8.6
4	2	"	9.2	12.8	38	7	"	10.3	12.8
5	7	"	9.7	12.0	39	4	"	11.3	12.0
6	17	"	7.4	11.5	40	3	"	9.7	12.0
7	15	"	7.5	8.0	41	2	"	12.8	15.2
8	5	"	10.7	12.9	42	13	"	14.0	14.5
9	13	"	10.3	11.6	43	5	"	14.7	15.2
10	16	"	9.0	12.0	44	9	"	13.5	12.9
11	6	"	10.0	13.3	45	14	"	10.9	16.3
12	14	"	9.8	15.0	46	16	"	11.6	14.1
13	10	"	8.8	13.7	47	12	"	7.4	11.6
14	9	"	12.0	13.1	48	1	"	7.2	11.0
15	8	"	10.9	13.6	49	6	"	8.2	10.8
16	1	"	12.5	15.5	50	10	"	10.5	13.7
17	11	"	11.4	13.6	51	8	"	12.1	12.6
			26 Oct.	2 Nov.				26 Oct.	2 Nov.
18	6	2	8.2	11.4	52	3	4	11.3	12.9
19	10	"	6.2	12.3	53	15	"	7.4	9.0
20	11	"	7.5	11.8	54	8	"	12.8	12.5
21	14	"	7.7	11.7	55	2	"	12.3	13.5
22	15	"	7.4	7.2	56	6	"	9.9	13.3
23	1	"	11.2	11.6	57	12	"	10.3	11.8
24	7	"	10.9	13.1	58	16	"	10.2	12.2
25	2	"	10.5	10.9	59	9	"	10.6	13.4
26	8	"	10.2	11.7	60	17	"	11.0	13.5
27	16	"	11.2	12.2	61	7	"	11.0	13.1
28	13	"	12.4	12.1	62	10	"	11.5	12.3
29	9	"	12.0	10.7	63	5	"	13.8	14.5
30	12	"	12.4	14.0	64	11	"	11.2	12.8
31	3	"	13.1	15.1	65	4	"	14.0	15.2
32	4	"	13.5	12.9	66	14	"	10.3	14.1
33	17	"	12.2	12.6	67	13	"	12.5	13.1
34	5	"	13.5	13.9	68	1	"	13.7	13.9

Table 14. Analysis of variance related to the ψ_1.

Source of Variation	SS	DF	MS	F
Main Effects	.844	19	.044	3.945
ENT	.613	16	.038	3.404
REP	.231	3	.077	6.832
Explained	.844	19	.044	3.945
Residual	.540	48	.011	
Total	1.384	67	.021	

α Level = 5%

$F_{critical}$ = 1.85

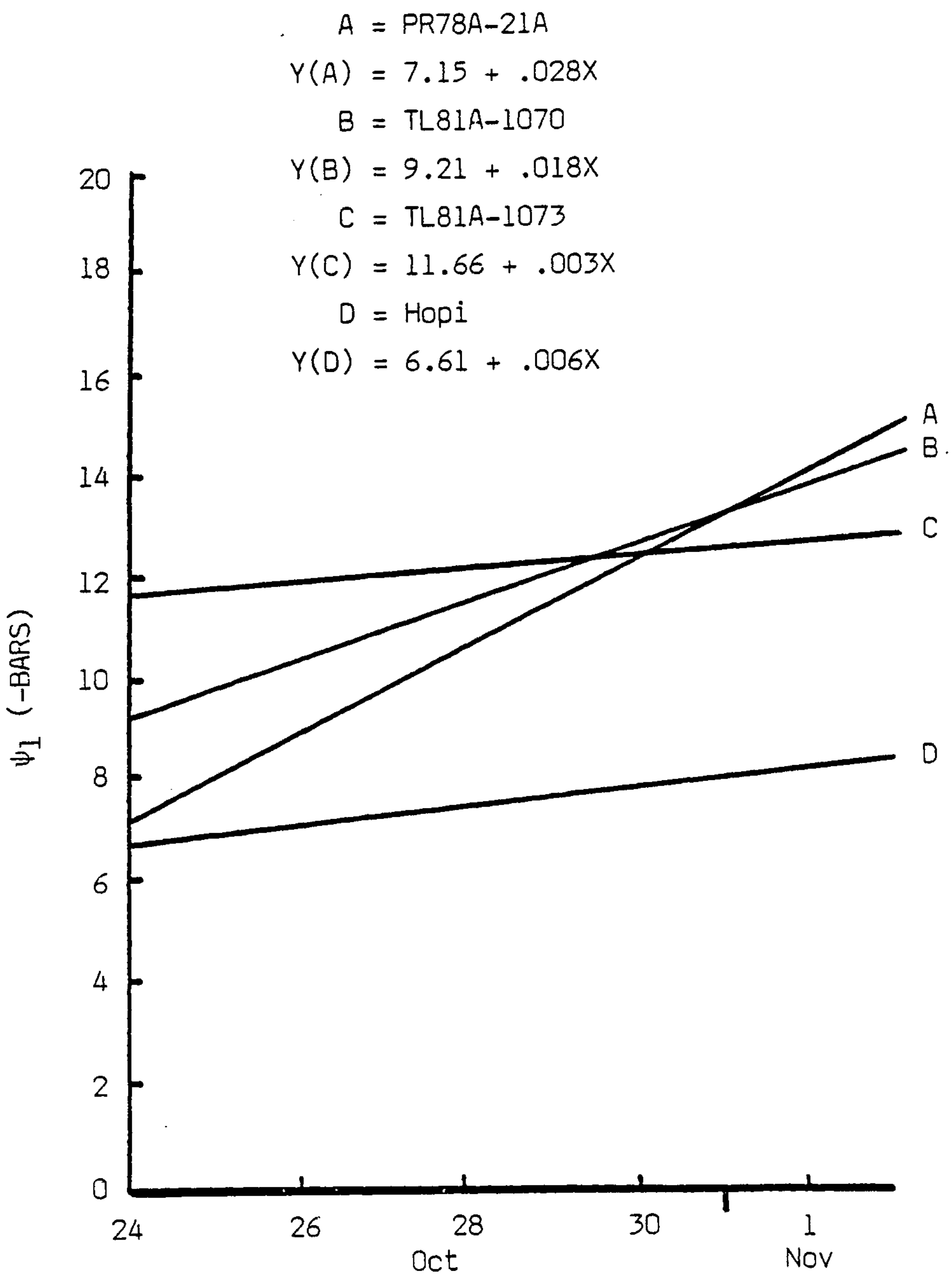

Figure 9. Rate of change of ψ_1 over the period 24 Oct to 2 Nov for 4 selected cultivars. Y( ) is the equation of the line.

became unavailable, is perhaps the underlying factor for the lack of a correlation between the changes of ψ_l and grain yield. Water stress at anthesis can markedly reduce fertilization and grain-set in most cereals. According to Slatyer (1973), corn is one of the most sensitive crops to water stress at this stage. He indicated that reductions of over 50 percent in yield can be caused by a relatively brief wilting at this stage. In this study, although irrigated, the plants received water far below their requirements, thus being forced to survive under stress conditions. These conditions seem to have masked a positive correlation that one might have expected between ψ_l and yield. Furthermore, it is shown that under irrigated conditions, a 300 percent change in corn transpiration rate was accompanied by no change in leaf water potential (Barrs 1973). Under these conditions, Barrs suggested that internal water status could remain unaffected by the drastic changes in the aerial evaporative demand on the plant, concomitantly reducing its flow of liquid flow rate through the stomatae.

These cultivars show drastic changes in the ψ_l between 24 October and 2 November, but the rate of the change of their internal water status as expressed by ψ_l is unrelated to the production of the grain. Leaf water potential is composed of osmotic pressure (π) and turgor pressure (P). Some plants have the ability to maintain their ψ_l by osmotic adjustment. The process of osmotic adjustment is an active mechanism through which energy is utilized. It is therefore apparent that assimilate partitioning, in such conditions, would favor plant survival rather than higher yield.

Waldren (1983) stated that ψ_l after tasseling is lower than before under the same environmental conditions and is apparently associated with physiological changes in the plant. Therefore, it is also possible that we have looked into leaf water potential during the reproductive stage which is in fact a weak indicator of water stress in comparison to ψ_l of the vegetative stage.

In Table 15, the cultivar yields are presented with their corresponding average instantaneous values for ψ_l, TR, and CWSI. It was believed that the instantaneous values of these characteristics would probably provide a better explanation for the differences in yields. According to Figure 10, when the rate of change is considered, the differences in the magnitude of the rate of the change per plot can be neglected. As shown in Figure 10, changes in TR/Δt of cultivar TL81A-1075 from 24 to 31 October is similar for the same cultivar in the 1st and 3rd blocks, but the two rates are in fact about 3 μg $cm^{-2}s^{-1}$ apart. Thus, the difference in magnitude of transpiration rate is primarily caused by the differential age of plants of the same cultivar during the measurements. The heavy crustation of the soil surface earlier in the experiment caused some of the plants to emerge a few days before the others. Nonetheless, the instantaneous readings of ψ_l, TR, and CWSI during the period 24 October and 2 November show to vary very little or not at all among the cultivars, indicating that fluctuations in yield is not affected by the changes of these parameters for such a short period of time during the growing season.

Table 15. Yield and the corresponding average* instantaneous valaes of CWSI, ψ_l, and TR.

ENT #	Yield Kg/3m^2	CWSI	ψ_l (-bar)	TR (μg cm^{-2}s^{-1})
1	0.26	0.61	11.63	6.59
2	0.19	0.64	12.15	6.81
3	0.10	0.72	12.05	5.66
4	0.10	0.71	12.80	5.16
5	0.29	0.62	13.65	6.22
6	0.29	0.63	10.64	6.90
7	0.32	0.64	11.61	7.15
8	0.35	0.52	12.05	6.80
9	0.46	0.53	12.28	5.68
10	0.40	0.55	11.13	7.75
11	0.36	0.61	11.84	7.34
12	0.17	0.63	11.34	6.25
13	0.13	0.68	12.56	6.11
14	0.23	0.60	11.98	7.58
15	0.08	0.61	11.56	6.74
16	0.13	0.59	11.79	7.10
Mean ($\bar{X}$)	0.23	0.60	11.70	6.60
Std Dev.(σ)	0.12	0.10	1.20	0.70

* Average of 8 readings.

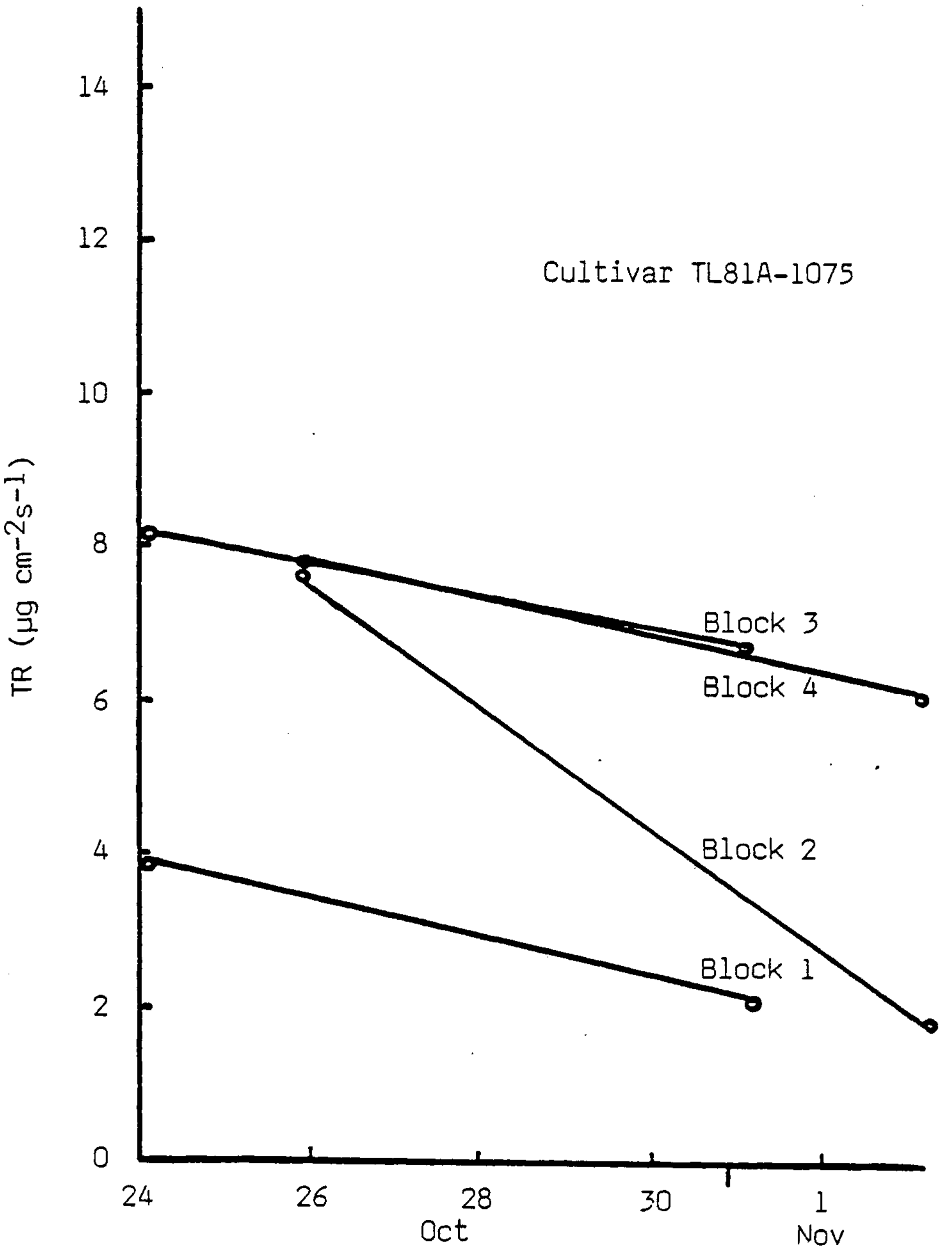

Figure 10. The changes of TR over the period 24 Oct. to 2 Nov. for cultivar RL81A-1075 in different blocks.

RECOMMENDATIONS

During the course of this study, a few relevant procedural failures were encountered which the author thinks are worth mentioning here so that they may be used as a guide for further research.

One of the earliest problems encountered in this project was that of obtaining a uniform emergence. A scattered emergence was noticed a few days after planting, primarily being caused by the heavy crustation of the cropping area after a light rain, thus causing the seedlings to emerge only from the cracked areas. Although an attempt was made to physically break the crust, the non-uniformity of emergence remained a factor in the experiment, leaving some of the plants (even within the same cultivar) at a more advanced stage than others. This age differential could have contributed considerably to the lack of correlations between the physiological parameters measured and the grain yield. The differential age of the plants also became important at the time of harvesting. As it was mentioned in the earlier sections, ears had to be harvested a few days earlier than planned due to a light frost (this being another failure of the procedure). However, when harvested, some plants were in the early stages of grain filling, some were in the milk stage, while others were ripe enough to be harvested.

The initial objective of this project was to rely only on precipitation as a source of water, but being just developed, the Avra Valley Water Harvesting System did not yet have the means of delivering supplementary water to the crop during the early stages of plant growth. Since the early stages of plant development coincided with virtually no rainfall on the site, plants experienced a prolonged stress that lasted up to the flowering stage. Although water stress is more effective in reducing yield during grain filling, there is some evidence that indicates any stress during ontogeny can also cause the yields of vegetative mass and grain to decrease (Volodarskii and Zinevich 1960). Further investigations have to insure availability of water if the drought period is to persist.

The light frost of mid-November should have been expected and the planting date should have been planned so as to avoid both the early harvesting and any chilling injury during the ripening period. It is therefore recommended that the planting date be adjusted to avoid the overlapping of any stages of the plant growth with the low temperatures that might be destructive to the plant. Another possibility is to select cultivars that require shorter time to mature. It is also recommended that, whenever potential or maximum yield is not available for the studied cultivars, the biological yield (total dry matter production) be obtained.

Furthermore, it is extremely desirable to take measurements of interest more often and over a longer period of time (or even throughout) during the growth if instrumentation are available and if the location of the experiment is not too remote. The interval between 24 October and 2 November, although a sensitive stage to water stress, might not have been representative of plant performance throughout the growing season.

The final observation made during the course of this study was regarding the occurrence of cross pollination. It is not clearly understood whether the cross fertilization of these various cultivars can affect the potential yield of the F_1 generation. If so, one might conclude that the physiological factors monitored in this experiment have been undermined by a genotypic shift. Therefore, to obtain reliable results, cross pollination must be avoided.

SUMMARY AND CONCLUSIONS

Water Harvesting and Corn Production

Like other micro-catchment systems, the Avra Valley Water Harvesting System utilizes a technique where the cropping area is an integral part of and immediately adjacent to the catchment area. If the annual average rainfall is below 300mm and extremely scattered, such as that in Avra Valley, the probability of rainfall collection by the micro-catchment may be marginal for the profitable production of crops such as corn.

During the early stages of growth, the author had observed that in some instances, rain can be falling all around the vicinity of the water harvesting agrisystem, but not on the site itself. It is therefore believed that in such crop production systems, one should rely on water spreading from a larger watershed. With a larger watershed, the probability of intercepting the scattered rainfall is significantly greater, thus insuring the delivery of water to the cropping area when it rains.

The feasibility of the type of crop and economic consideration of the Avra Valley Water Harvesting System is still subject to further research. Therefore, evaluation of the system based on its performance during the first year of operation could be both misleading and premature, especially since the precipitation during the growing season was unexpectedly low in the entire region.

Yield and Physiological Characteristics

Grain yield of the cultivars studied in this project showed a wide range of variations when grown in minimal moisture conditions of the Avra Valley Water Harvesting System. It is concluded that some cultivars, such as TL81A-1073, TL81A-1061, TL81A-1070, TL81A-1067, TL81B-1547 and TL81V-1548 can perform better or near the average yield of their local habitat, while others such as TL81A-1078, TL81A-1075, and Chapalote are conspicuously low yielding cultivars. This evaluation is primarily based on the relative comparison of the grain yield among these cultivars.

It is believed that the grain yield, by itself, is too simple of an indicator of varietal response to low moisture conditions, since cultivars showing signs of physiological adaptation did so at the expense of reducing their yield. There is also no doubt that the potential yield among these cultivars can be significantly different. These variations in yield could only be a manifestation of genotypic differences rather than plant response to drought. Analysis made on the relative yield (actual yield/potential yield) thus may be more relevant for the selection of cultivar(s) which are better adapted to drought conditions.

The original purpose of this study was to isolate and evaluate the grain yield response of drought tolerant corn to conditions of the Avra Valley Water Harvesting Agrisystem. But the evaluation of a number of physiological processes which are known to be effective in grain production were found to be unrelated to grain yield.

The results of this study indicate that as soil moisture becomes progressively limiting, conservation of plant water status as reflected in leaf temperature, water potential, and transpiration rate during the two-week interval at the grain-filling stage, is not an indicator of the varietal grain productivity.

This lack of correlation is partly explained by a number of undesirable procedural shortcomings, such as early harvesting and non-uniform emergence, and partly by a number of other complex physiological adaptations which require further investigations. It was found that the same cultivars, such as Hopi, could adapt to moisture stress by preserving their ψ_l and TR longer, but not necessarily be the best yielding cultivars.

It is postulated that at a lower water content, as reflected in the physiological parameters monitored, photosynthesis could be affected without an impact on the yield. Provided that this postulation is correct, during the grain-filling stage in the absence of adequate photosynthesis, some cultivars might be capable of mobilizing and translocating carbohydrates to compensate the grain from pre-stored sugar. Therefore, the changes in the TR, ψ_l, SDD, and CWSI in these cultivars can become ineffective in grain production.

It is also possible that the cultivars capable of preserving their water status by maintaining ψ_l, TR, SDD, and CWSI, do so at the expense of reducing the CO_2 uptake which in turn reduces photosynthate production. This mechanism, although logical, does not seem to be the reason for the lack of a trend between grain yield and the physiological characteristics measured in this study. For example, there is little doubt that stomatal closure is a means of preserving plant water while restricting the entry of CO_2 into the leaf, but the supply of CO_2 may or may not control the rate of photosynthesis.

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