Soil –Plant– Water Status and Growth Development and Yield of Maize (*Zea Mays* L.)[1]

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ABSTRACT

Limitations of yield and dry matter production by water deficits on their enhancement through irrigation will depend on the degree, duration and timing of those deficits which, in turn, depend on the plant, atmospheric and soil conditions. The objective of this study was to investigate the relationship between soil-plant water status and nutrients and the growth, development and yield of maize under the soil and atmospheric conditions of the Guelph research station. Two levels of fertility were used under irrigated and non-irrigated conditions. Measurements of plant height, leaf area index (LAI) and silking were taken during the growing season, along with leaf and soil water potential and stomatal conductances. At the end of the season, grain yield and dry matter production data were collected. During the vegetative stage, irrigation caused significant differences in plant height in the high fertility treatments. Leaf area index increased more slowly in unirrigated than in irrigated treatments during dry periods in July. However, total LAI was not significantly influenced by irrigation at any stage of growth. Water supply caused significant differences in leaf water potentials during July and August. Nevertheless, the stomatal conductances were largely insensitive to irrigation and the stomates seemed to respond mostly to daily fluctuations in solar irradiance. Grain yield and dry matter production were significantly different between low and high fertility but not between irrigated and non-irrigated treatments, in spite of the large differences in soil water content.

COMPENDIO

Las deficiencias hídricas en las plantas causan generalmente decrementos en la producción de grano y materia seca, debido a esto se evaluaron las relaciones hídricas suelo-planta en el cultivo de maíz bajo las condiciones climáticas de la estación experimental de la Universidad de Guelph, Ontario, Canadá. Los factores estudiados fueron riego y fertilización a dos niveles cada uno. El efecto de irrigación sobre rendimiento no fue estadísticamente significativo a pesar de la gran diferencia en humedad de suelo registrada del 8 al 15 de julio, etapa de prefloración, donde los tratamientos no irrigados alcanzaron valores de –1.50 MPa y –1.70 MPa en los primeros 30 cm de suelo. Los potenciales hídricos de las hojas tuvieron una respuesta más directa a las diferencias en presión de vapor del aire que a la diferencia en humedad del suelo. Los valores más bajos de potencial hídrico fueron –1.50 MPa y –1.70 MPa para los tratamientos no irrigados. Las diferencias en conductancia estomatal sólo fueron significativas el 15 de julio para el tratamiento de alta fertilidad no irrigado, registrándose valores de 0.3 cm seg^{-1} comparados con 1.0 y 1.2 cm seg^{-1} de los tratamientos irrigados. El cierre estomatal se observó entre valores de –1.65 MPa y 1.70 MPa de potencial hídrico.

INTRODUCTION

Soil and climatic conditions usually restrict growth and development of crop canopies in the field in such a way that the genetic potential is seldom achieved. Climate factors such as radiation, relative humidity, air temperature and CO_2 concentration cannot be modified by any feasible management practices. They limit and determine the maximum yield that can be obtained in a given region.

Limitation to yield imposed by soil factors such as nutrient status, soil structure or soil moisture may be eliminated to some extent by tillage, fertilizer application, and irrigation. However, the extent to which these factors and the interaction among them, are limiting maximum dry matter production is still not very well understood. For instance, it is not clear how dry a soil can become before yield is decreased in any given climatic environment.

Plants usually withstand moderate water stress without a decline in their physiological functions. Stomatal closure in maize has been observed after leaf water potentials reached values about –1.7 MPa (10). However, leaf enlargment, in the same crop, declined rapidly at leaf water potentials below –0.2 MPa and ceased at potentials of –0.7 to –0.9 MPa (2, 4). Under field conditions, leaf expansion seems to be less sensitive to low water potentials. Watts (11) found that there was no reduction in maize leaf extension until leaf water potentials were below –0.8 MPa. Nevertheless, the sensitivity of cell elongation to water deficits may cause a marked reduction in leaf area. A decrease in leaf area may result in incomplete interception of irradiance or a delay in achieving full light interception by the crop

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canopy. The time at which full light interception is achieved may be of particular importance to yield under the seasonal incoming radiation in this area (Guelph, Ontario, Canada). On the other hand, under prolonged dry conditions a reduction in leaf area may be beneficial to the plant because of reduced water losses.

The objective of this study was to investigate the relationship between nutrient-soil-plant water status and the growth, development and yield of maize under the temperature, rainfall and irradiance conditions of the University of Guelph Research Station.

MATERIALS AND METHODS

The field research was conducted on the Guelph Research Station (43°38'N, 80°39'W). The edafic characteristics of the experimental site are described within two series, the Guelph Loam and the London Loam.

Treatments used were (1), low fertility treatment: phosphorus 30 kg/ha, potassium 58 kg/ha, and 100 kg/ha of nitrogen (LFNI); (2), fertility conditions as in (1), but the plot was irrigated (LFI); (3), fertilizer rate considerably in excees of those recommended; phosphorus 425 kg/ha, potassium 810 kg/ha and 325 kg/ha of nitrogen (HFNI); (4), the same high fertility levels were applied as in (3), but plots were irrigated (HFI).

The corn hybrid PAG SX-111 was used because of its strong stalks and its relatively high yield for short growing seasons. The seed was treated and planted on May 7. Plant population was thinned to 80 000/ha.

Water was applied periodically through a trickle irrigation system at the time when water deficit (evaporation from a class A pan less rainfall) exceeded 2 cm. Water was supplied at an approximate rate of 0.3 cm per hour, keeping the irrigated plots close to field capacity. Neutron scattering technique was used to determine changes in moisture content of the soil profile every 15 cm depth (15-90 cm), during the growing season. This technique was replaced by a gravimetric method to determine the water content in the top 15 cm of soil. Soil water characteristics curves were used to estimate the soil water potential.

Measurements of stomatal conductance were taken with a LI 1 600 steady state porometer on the upper leaves of the canopy, which were completely exposed to direct sunlight. Readings were done in the adaxial and abaxial surface of the leaf. An average of two leaves per plot and four replicates were considered as the sample size to estimate effects of treatment on stomatal conductance.

Leaf water potential was measured on the same days as stomatal conductance using a pressure chamber on the design of Scholander *et al.* (7). Tips of fully sunlit leaves were placed between two wooden boards lined with soft foam rubber and covered with polythylene film to minimize water loss. A narrow strip, 2 or 3 cm wide and about 15 cm long, was torn off each leaf and immediately inserted through the slot into the pressure chamber to determine leaf water potential. Sample size was two leaves per plot and four replicates. Leaf area index (LAI) was determined by periodically measuring the maximum width (W) and length (L) of each leaf on six plants per plot. The linear regression equation for estimating LAI was $LAI = 0.75 (L \times W)$.

Final yield was obtained from the ears collected in the inner three meters of the two centers rows in each plot. The same sample was used to determine dry matter production.

RESULTS AND DISCUSSION

There were two main periods of low rainfall during the growing season. The longest period was from June 23 to July 16, in which only 14.8 mm of rainfall were recorded. This period corresponded to the time of rapid growth in the vegetative stage. The second dry period was monitored from August 15 to 26, with a total rainfall at 7.2 mm.

Plant heights are shown in Fig. 1. The effect of high fertility on plant height was significant as early as June 25. The response of plant height to irrigation was different for the high and low fertility treatments. For instance, during the dry period between July 7 and July 15, and that between July 16 and July 23, treatment 3 had a significantly lesser increment of plant height than treatment 4, whereas the increment in treatment 1 was not significantly lower than that of treatment 2 (Fig. 2). In fact, differences in plant height caused by irrigation in the low fertility treatments were significant only at the end of the growing season.

Leaf development was greatly stimulated by high fertility treatments in the early stages of growth (Fig. 3). At this time, the irrigation imposed on treatments 2 and 4 did not cause any significant differences from treatments 1 and 3, respectively. The effect of water supply was more evident from July 7 to July 15; both treatments 2 and 4 reached signifi-

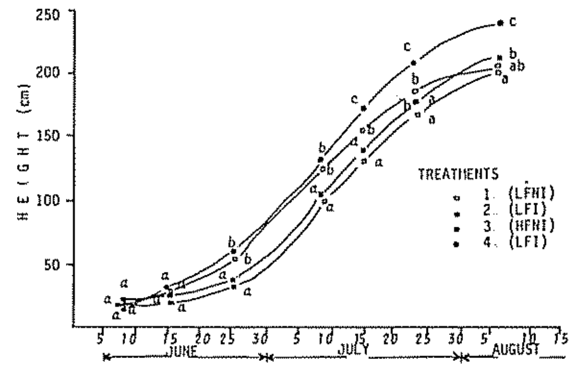

Fig. 1. Effect of water and nutrients on height of maize (PAG SX-111) Guelph Research Station. (The same letter are not significantly different, $\alpha = 0.05$)

cantly ($\alpha = 0.05$) higher LAI increments than treatments 1 and 3, respectively (Fig 4) The effects of dry conditions were more severe for treatment 3, which achieved the lowest increment of leaf area index during the July 7-15 period However, after a partial release of stress by a 17 mm rainfall received from July 17 to July 22, treatment 3 had a more rapid rate of leaf enlargement than treatment 4 (Fig. 4). This may indicate a "storage growth" phase, where most of the metabolic events continued unabated and leaf growth was only prevented by the lack of turgor required for cell expansion Acevedo *et al.* (1), also working with maize, found a rapid phase of growth after release of stress under mild and severe water stress conditions.

Silking began just at the end of the critical dry period of July During silking, from July 23 to August 7, an accumulated rainfall of 48.4 mm was received, so that water stress was not a major restriction at this stage. High fertility resulted in a more rapid plant development, and hence in an earlier silking for treatments 3 and 4 (Table 1) For these treatments, the 75% silking stage was reached 5 and 7 days earlier than for treatments 1 and 2, respectively Irrigation did not alter the time of silking. The final grain yield, dry matter production and harvest index are shown in Table 2 The high fertility treatments resulted in significantly ($\alpha = 0.05$) higher yield than the low fertility treatments Irrigation imposed on treatments 2 and 4 did not cause significant differences in either grain yield or in dry matter production when compared to treatments 1 and 3, respectively Harvest index is higher for the non-irrigated treatments, which could mean a greater reproductive effort under water stress (6)

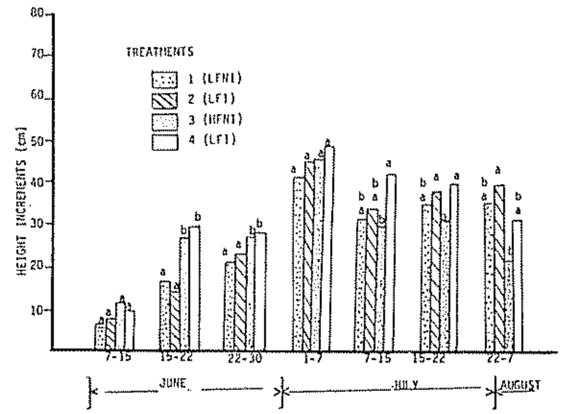

Fig. 2. Effect of water and nutrients on height increments of maize (PAG SX 111) Guelph Research Station (same letters are not significantly different, $\alpha = 0.05$).

Soil water potentials (ψ Soil). At the initial stage of rapid growth on June 19, irrigation kept high soil water potential for treatment 2 and 4 Meanwhile, lower ψ soil developed for treatments 1 and 3 in the upper 15 cm (Fig. 5) During the dry period from July 7 to 15, soil water in the top 30 cm was largely depleted in treatments 1 and 3 and the water potentials reached values between −1.5 MPa and −1.7 MPa (Fig 6) Precipitation in the first two weeks of August (88.9 mm) was sufficient to replace much of the water lost during July in the unirrigated treatments Soil water potentials had recovered for treatments 1 and 3 down to the 50 cm depth (Fig. 7).

Plant water status. Leaf water potentials (ψ leaf) measured on July 8 were not significantly different among treatments (Fig. 8a.) Early in the morning the water potential readings ranged from −0.2 MPa to −0.4 MPa and reached minimum values of −1.1 MPa and −1.3 MPa (14:00 Eastern Standard Time). The soil water potential apparently had little effect on the leaf water potential. Measurements of root growth by Stypa (8) indicated that roots were already growing down to 35 cm, where soil moisture was more available. This may account, at least in part,

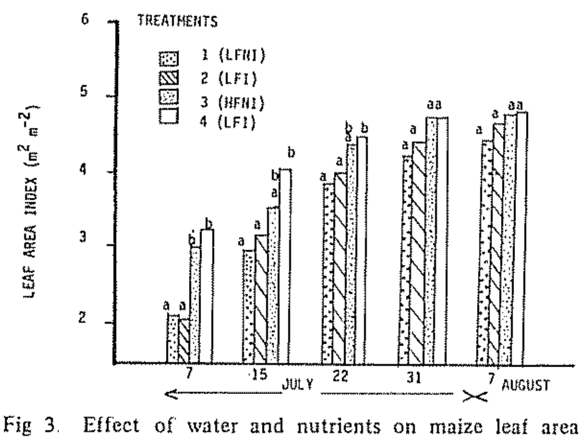

Fig 3. Effect of water and nutrients on maize leaf area index (LAI) (the same letters are not significantly different, $\alpha = 0.05$).

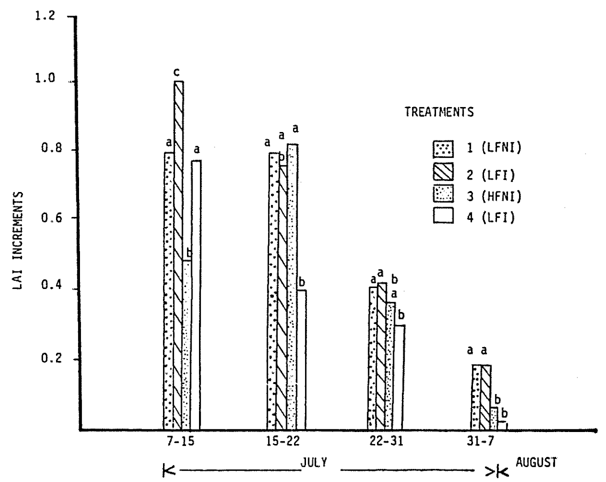

Fig. 4. Effect of water and nutrients on the increment of maize leaf area index (same letters are not significantly different, $\alpha = 0.05$).

for the lack of differences in leaf water potential between irrigated and non-irrigated treatments.

There was no apparent pattern in stomatal conductance among treatments (Fig. 8b). However, stomates seemed to respond more to diurnal changes in solar irradiance than to differences in soil moisture. A decrease in solar irradiance between 09:30 and 10:30 EST (not shown) in likely to be the cause of the lower stomatal conductance monitored at this time. This variation in conductance had no apparent effect on leaf water potential for any of the treatments.

Table 1. Percentage of maize plants silked at different dates. Guelph Research Station.

Treatment	July 23	July 29	July 31	Aug. 5	Aug. 7
1 (LFNI)	0.0	4.2	13.2	77.0	
2 (LFI)	0.0	2.8	11.8	60.4	78.5
3 (HFNI)	6.9	44.4	68.8		
4 (HFI)	15.6	59.7	75.4		

July 15 was one of the driest days on which measurements were taken. The soil water potentials for the unirrigated treatments had reached values less than −1.5 MPa in the top 15 cm (Fig. 6). Leaf water potential showed a clear response to these stress conditions (Fig. 9a). The potentials on treatment 1 and 3 reached values less than 1.4 MPa as early as 08:30 EST in the morning and remained below that level until 13:30 EST. For treatments under irrigation, the leaf water potentials were also low, reaching values between −1.2 MPa and −1.4 MPa. The differences among treatments were not significant ($\alpha = 0.05$) in the morning, despite large differences in soil water potentials (Fig. 6). In the afternoon, the leaf water potential of plants in treatment 3 became significantly lower than those of the irrigated treatments. However, the leaf water potential in treatment 1 was not significantly lower than those in treatments 2 and 4.

Stomatal conductances on July 15 were significantly ($\alpha = 0.05$) lower for plants in treatments 1 and 3 than for 2 and 4 (Fig. 9b) during both the morning and afternoon. There was also some indication that the low leaf water potential may have induced stomatal closure in the afternoon (12:30 EST). In one of the plots of treatment 3, stomatal conductances of 0.042 and 0.045 cm sec^{-1} were measured in adaxial and abaxial surfaces respectively. Leaf water potential monitored in the same plot within a few minutes of the stomatal conductance measurements gave values of −1.65 MPa. This is in fairly close agreement with observations of Turner (10), who found a "critical potential" of −1.7 MPa in maize, at which stomates began to close. However, not all the plants in that plot reached such low stomatal conductances. Readings in a nearby plant gave values of 0.33 and 0.25 cm sec^{-1} (adaxial-abaxial surfaces), even though the plant showed the same leaf rolling symptoms as that with the lower conductances. Suggestions that stomates close abruptly when the critical potential is reached (4, 5) might account for these differences.

The leaf water potential of plants in the unirrigated treatments apparently was not influenced by the low soil water content in the top 15 cm of the profile in spite of the fact that a large proportion of the root length was in that layer (8). The water potential gradient between the soil (top 15 cm) and the leaves of plants in treatment 3 was very small (approx. 0.2 MPa) compared to that of the irrigated treatments (approx. 1.2 MPa). Although the stomatal conduc-

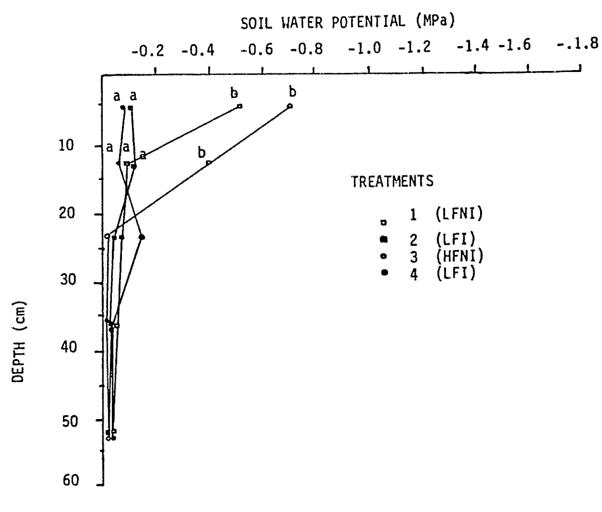

Fig. 5. Soil water potential of treatments at different depths in the soil profile, June 19. Guelph, Research Station (same letters are not significantly different $\alpha = 0.05$).

Table 2. Final grain yield, total dry matter production and harvest index of maize. Guelph Research Station.

Treatment	Grain* (kg ha⁻¹)	Dry matter (kg ha⁻¹)	Harvest Index
1 100 N + 30 P + 58 K (LFNI)	6 276 a**	10 766 a	0.682 a
2 100 N + 30 P + 58 K (LFI)	6 357 a	11 616 ab	0.556 b
3 325 N + 425 P + 810 K (HFNI)	7 443 b	12 199 cb	0.612 a
4 325 N + 425 P + 810 K (HFI)	7 543 b	13 072 c	0.576 b

* 15.5% Moisture
** (same letters are not significantly different, $\alpha = 0.05$).

tance was lower in treatment 3 than in the irrigated treatments, the difference was not sufficient to reduce transpiration to the extent suggested in the water potential gradient. This indicates that in the unirrigated treatments water was being absorbed from deeper layers in the soil profile to meet the transpiration demand and to keep nearly the same leaf water potentials as those in the irrigated treatments. It also suggests that relatively low densities of root system (5% of total), growing under favorable soil water conditions, may largely satisfy the transpiration demand and mantain plant hydration. In this research, a large amount of the root length (approx. 90%) was measured on the top 30 cm (8). The rest of the root system was growing in deeper layers where soil wetness was more available for non-irrigated treatments.

On August 26, plants in all treatments had reached full vegetative growth and were into the maturity phase. The rainfall in the first two weeks of August was abundant, replacing, to a large extent, the soil

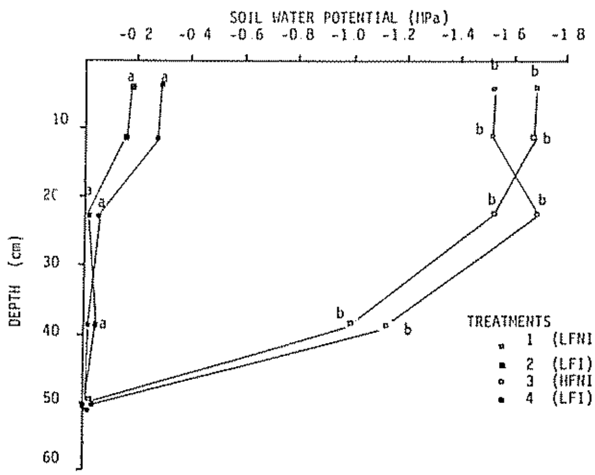

Fig 6. Soil water potential of treatments at different depth in the soil profile, July 15 (Same letters are not sigficantly different, $\alpha = 0.05$).

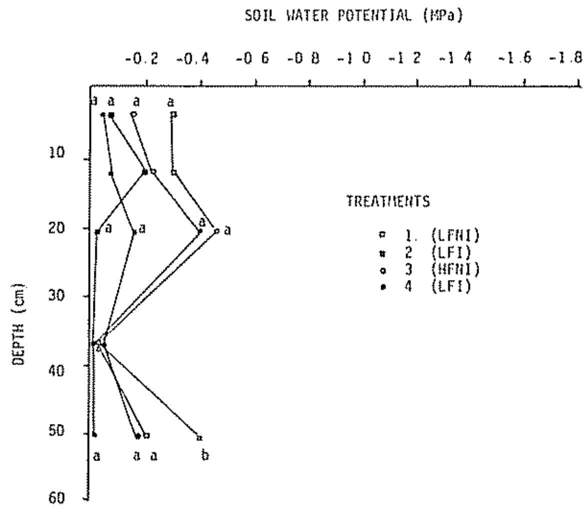

Fig 7. Soil water potential of treatments at different depths in the soil profile August 23. Guelph Research Station. (Same letters are not significantly different, $\alpha = 0.05$).

water lost in July (Fig 7). After this rainfall, there was a dry period of about 10 days, from August 16 to 26.

GENERAL DISCUSSION

The effect of irrigation on plant growth was not significant during the early vegetative stage. Soil moisture at this stage was enough to satisfy the actual demand for water without causing major stress in plants. No significant differences were observed in either leaf water potential or stomatal resistance between irrigated and non-irrigated treatments on July 8 (Fig 8).

As the soil dried out in treatments 1 and 3, the water absorbed from deeper layers was not enough to keep the same plant growth rate as that of treatments 2 and 4. Between July 7 and 15, the unirrigated treatments had lower increments in terms of plant height and leaf area index. On July 15, the leaf water potential reached the lowest values measured during the season. However, the stomatal conductance

(Fig. 9b) seems not to have changed compared to other days. This could indicate that some of the physiological events necessary for growth, such as CO_2 absorption and indirect photosynthesis, continued unabated during the dry period, and the decrement of plant height and leaf area index in treatment 1 and 3 was mainly caused by the lack of physical turgor required for cell expansion.

The high fertility conditions of treatments 3 and 4 produced a rapid growth and leaf expansion during the earlier stages.

As a consequence, duration of nearly complete light interception was a week longer than that of the comparative low fertility treatments. Tollenaar and Daynard (9) suggested that the duration of complete light interception is an important factor in dry matter production under the seasonal solar irradiance at Guelph, Ontario. High fertility caused also an earlier silking (July 30) and hence an extended period of grain filling. This, along with the effect of complete

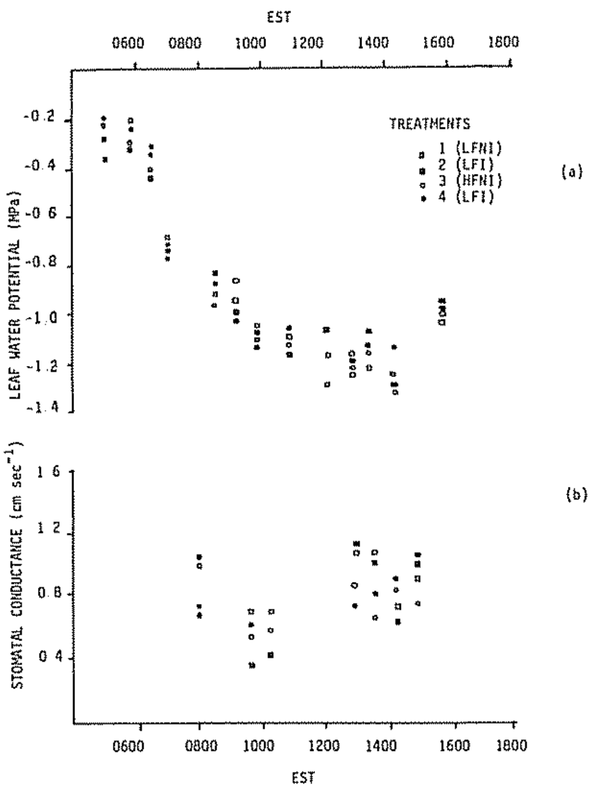

Fig. 8. Diurnal trends of leaf water potential (a) and stomatal conductance (b) of maize July 8.

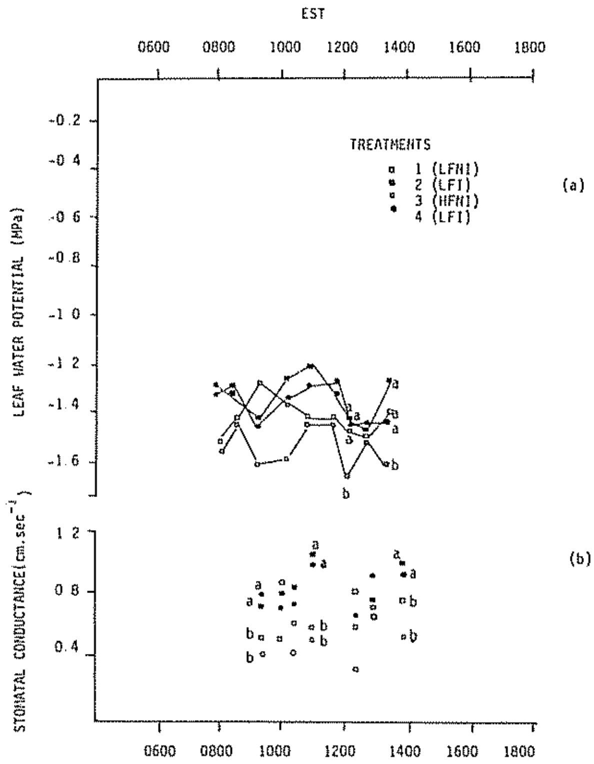

Fig. 9. Diurnal trends of leaf water potential (a) and stomatal conductance (b) of maize July 15. Guelph Research Station.

light interception, may largely explain the differences in grain and dry matter production between the high and low fertility treatments. There was no effect of irrigation on silking date.

During anthesis, available water was increased due to the high precipitation between July 23 and August 7, so no water stress was observed in this period. Finally, the stomatal conductances, which are inherently linked to plant biomass production, were significantly lower in the non-irrigated treatments only when the water potential in the upper 30 cm of soil was at or below −1.0 MPa. Despite differences in soil water content during the vegetative stage, the irrigation imposed on treatments 2 and 4 did not cause significant differences in grain yield and dry matter production when compared to treatments 1 and 3. This means that, under the existing atmospheric conditions at Guelph Research Station, plants could withstand the stress imposed by the soil water conditions without decreasing dry matter production or grain yield.

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