Optimizing crop water use by deficit irrigation: A case study in South Brazil using Corn

Matthias Langensiepen[1], Homero Bergamaschi[2], Joao Ito Bergonci[2] and Luis Mauro Rosa[2]

[1]Crop Science, University of Kiel, Herman-Rodewald-Strasse 6, D-24118 Kiel, Germany;
[2]Agricultural Meteorology, Federal University of Rio Grande do Sul, P.O.Box 776, 91501.970 Porto Alegre, Brazil

Abstract

Irrigation applied at rates below the actual crop water demand is termed as deficit irrigation. It is particularly carried out when the crop is relatively insensitive to water stress. The practical application of the concept requires information on crop responses to water. We tested a number of methods to determine corresponding crop parameters. The study was carried out under the production conditions of the South Brazilian State of Rio Grande do Sul taking maize as an example. Infrared thermography proved to be the most suitable method for detecting plant water states.

Introduction

Irrigated agriculture is a major factor in determining the food security of mankind. As population growth increases, efficient use of water resources becomes critical in maintaining crop production. Timing and dosages of irrigation applications are often dictated by water availability and frequently do not coincide with actual crop water requirements. Inflexible water management, over-irrigation, poor maintenance of irrigation and drainage equipment and lacking hygiene often lead to situations, where soils loose their productivity and people are becoming sick. Optimizing water delivery and the introduction of modern irrigation methods will help to improve this situation. Experiences in more developed countries have shown that irrigation scheduling is the most important factor determining the efficiency of these systems. Provided that crop water requirements can be correctly estimated and be matched by frequent irrigation applications, deficit irrigation is a way to further optimize the use of water for production.

The study focuses on the question, how irrigation scheduling must be adapted to facilitate irrigation management aimed at conserving water. The trial was carried out under the production conditions of the Brazilian State of Rio Grande do Sul taking maize an example. Maize is the second important crop in this state where 400.000 farmers produce an average of five million tons per annum which comprises 45 percent of the total production in Brazil.

Material and Methods

The field study was carried out at the experimental farm of the Federal University of Rio Grande do Sul (Eldorado do Sul - $30^0$05' S, $51^0$39'W, 40m) covering four seasons (1993-1997). A 0.54ha field (90x60m) was prepared and sown manually each year at the beginning of spring time (October 25^{th} to November 4^{th} depending on weather conditions). Maize (var. Pioneer 3230) was planted in rows 0.75m apart and at a density of 67,000 plants per hectare. Crop management followed standard practice. Irrigation was carried out using a line source sprinkler design. The sprinkler line passed close to a weighing lysimeter (3.4 * 1.5 m^2 surface area, 0.9 m depth, 0.1 mm resolution) which was situated in the center of the experimental plot and was kept at field capacity I4. Irrigation treatments I3, I2, I1, and I0 were applied at both sides of the sprinkler line to reach corresponding field capacity levels of 75, 50, 25, and 0 percent. Subplots were distributed in a split plot fashion with five levels of water stress (I4 to I0) and 10 replications. Soil water potential was monitored by tensiometers, while irrigation was applied according to the evapotranspirative weight change of the lysimeter.

Crop samples were taken from one half of the field, while the other half served for measurements of crop water states. 20 plants were harvested per week and treatment. They served for the determination of dry matter accumulation, leaf area index, height and phenological stage. Diurnal measurements of leaf water potential (Scholander type pressure chamber), leaf to air temperature difference, incident photosynthetically active radiation and leaf conductance (1600M, LICOR, Li, Ne, USA) were performed each year at irregular intervals covering various conditions of growth, weather and stress. An automatic weather station (Campbell, Logan, UT, USA) was installed in an adjacent area to collect data of solar radiation, air temperature, relative humidity, precipitation, wind speed and direction

Results and Discussion

Average measured grain yield was 10 t/ha under conditons of none-limiting soil moisture supply. Rainfed conditions reduced yield by 40 percent. The effect of water stress was more pronounced in dry years than in wet years. Buildup of average dry matter in the I4 and I0 treatments were 25 t/ha and 15 t/ha, respectively. Highest irrigation efficiency was reached when water deficits occured during the tasseling and silking stages of the crop. Aerial biomass production was generally affected by irrigation, irrespective of the stage of growth.

Taking various sets of yield responses to soil water yielded a relation which can be used to match irrigation with targeted production. Maximum water use efficiency was reached when soil water content was kept at around 70 percent field capacity (Fig.1).

Consumptive water use was low at plant emergence and substantially increased towards the stage of tasseling reaching maximum values of 9 mm / day. Rapidly changing weather conditions at the sub-tropical location produced high variations in crop water uptake and make frequent determinations of actual evapotranspiration necessary.
Crop water requirements are often determined by models. They vary in their degrees of complexity and applicability, but most of them either assume optimal or constant soil moisture supply. The application of deficit irrigation requires, however, that a scheduling model is also able to cope with fluctuating soil moisture supply conditions. This particular applies to situations where irrigation is applied at irregular intervals on

the soil surface, which is the common practice in the less developed areas.

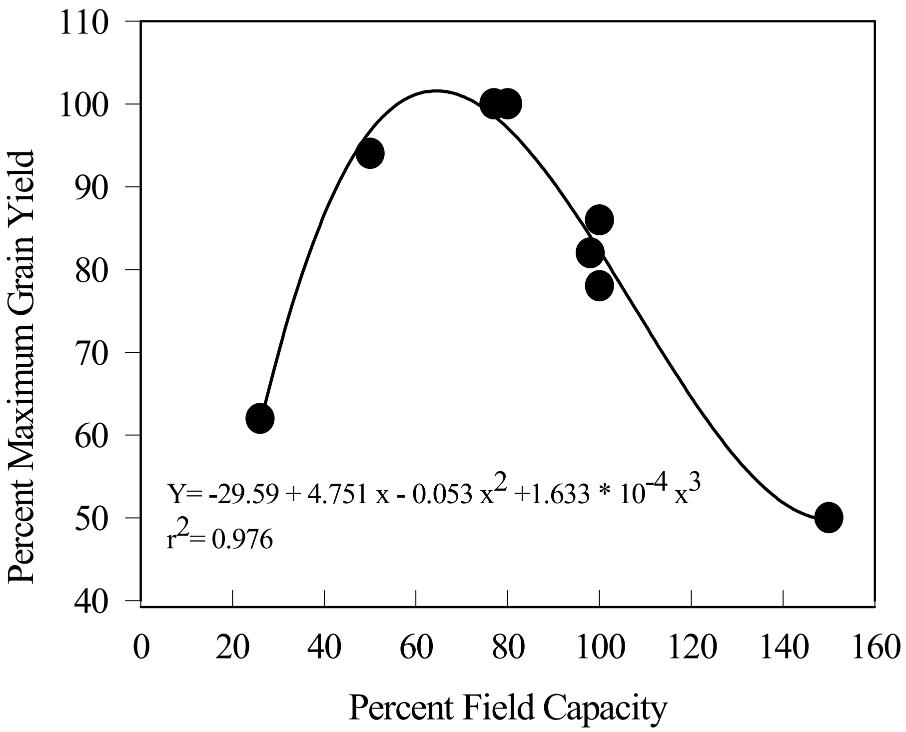

Fig. 1 Relation between average Root Zone Soil Water Content and Maximum atainable Yield (All seasons). Eldorado do Sul, Brazil

The crop water transport regime is very much influenced by the current state of water stress. Both can be determined by various methods. Some of them are evaluated in the following :

It is a common practice to relate crop water requirements to soil water availability. We therefore tested the effect of soil water potential on minimum leaf water potential (e.g. maximum stress condition), but found a loose relation between both determinations (Fig. 2). Since the plant hydraulic system also responds to other environmental factors like atmospheric vapor demand or impigning photosynthetically active radiation, we suspect that the data scattering was caused by additional regulative mechanisms. Measurements of soil water availability thus need to be accompanied by additional determinations of plant water states.

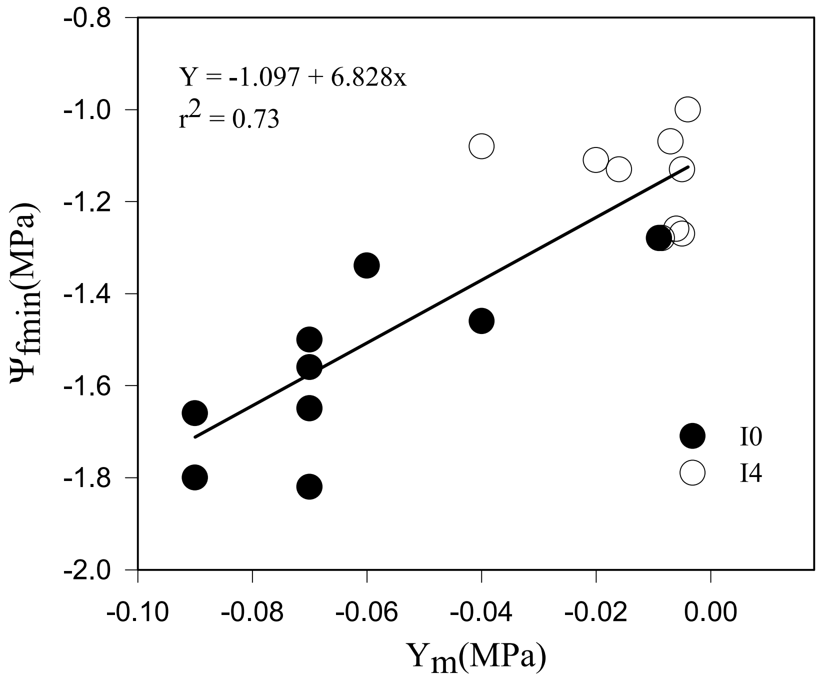

Fig. 2 Relation between Soil and Minimum Leaf Water Potential. Date ? Eldorado do Sul, Brazil

Light can be measured by automatic weather stations. Using empirical information on leaf area distribution and stomatal responses to light, this data can be taken as a scaling variable to determine canopy vapor conductance. However, despite usually finding close relations between both determinations (e.g. light and stomatal conductance) the method requires an additional indicator of stress. Figure 3 shows different stomatal responses to light which are mediated by water supply conditions (I4 and I0). Since the different responses are related to other environmental factors, the method does not seem practically applicable, despite being costly as well. Combined measurements of light, canopy geometry, stomatal conductance and one or more indicators of water stress are well suitable, however, for deeper understanding crop water relations and may lead to the development of robust empirical relations.

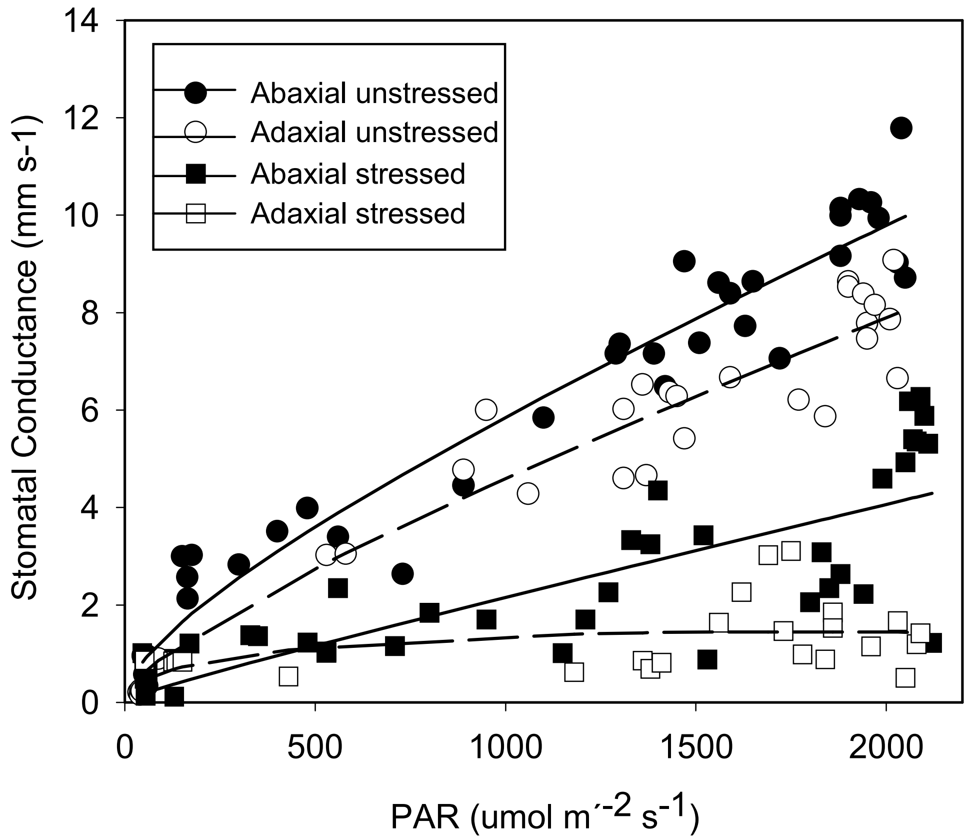

Fig. 3 Relation between intercepted photosynthetically active radiation and stomatal conductance. Dec. 19th, 1996. Eldorado do Sul, Brazil

Stomatal conductance is affected by plant internal water availability and is closely related to leaf water potential, which can be easily assessed by pressure bomb readings. Our results indicate good agreement between both determinations (Fig. 4b) and confirm results previously being reported in literature. Despite, it can be also shown that stomatal conductance affects leaf to air temperature differences in turn (Fig. 4a).

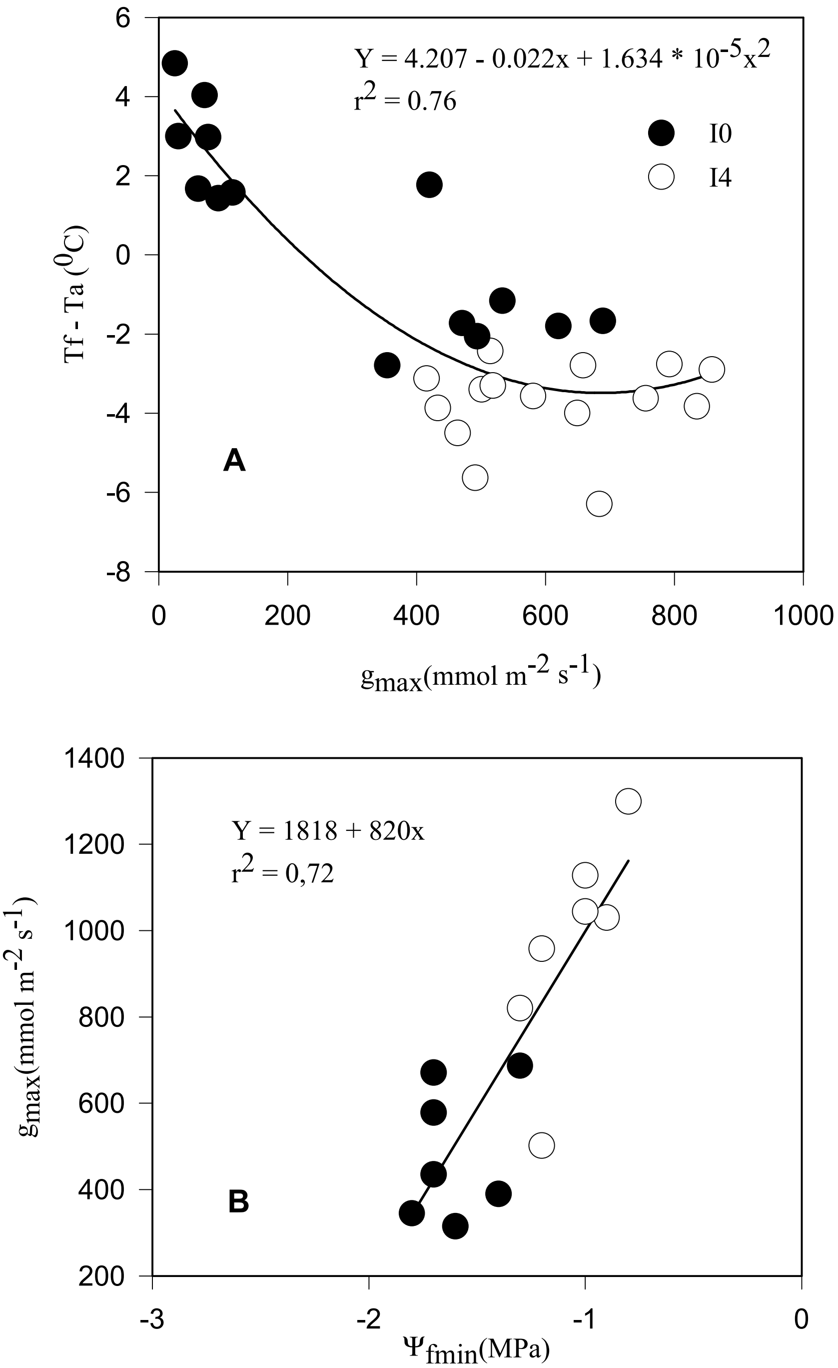

Fig. 4 Relation between maximum leaf conductance and leaf to air temperature difference (A) and between minimum leaf water potential and maximum leaf conductance (B). Eldorado do Sul, Brazil

Leaf temperature is a state variable resulting from all energy transfer processes and affects a large number of physiological processes. Leaf to air temperature differences commonly scales with water supply. This is the reason, why leaf water potential can be correlated with leaf to air temperature difference, as shown in Fig. 5.

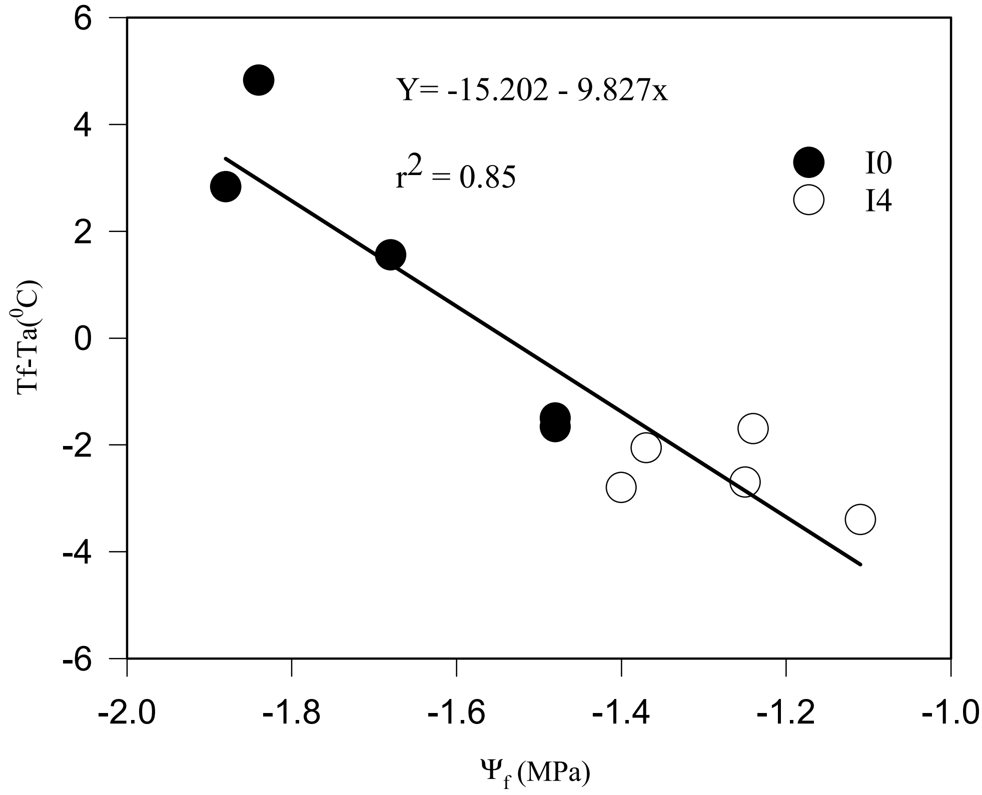

Fig. 5 Relation between Minimum Leaf Water Potential and Midday Leaf to Air Temperature Difference.

It is tempting to omit determinations of water potential since leaf to air temperature can be also directly related to stomatal conductance (Fig. 4a). However, such correlations are only valid for steady state flux conditions and cannot be applied to a variable flux regime, as it is the common case in deficit irrigation.

Conclusion and Summary

Scheduling is the major factor determining the efficiency of irrigation (Hillel 1988). Timing and dosages of irrigation applications are commonly estimated with simulation models. They are commonly feed with standard meteorological and agronomic data. Additional information on the current state of water stress is required, however, to make them applicable to the conditions of deficit irrigation.

Results from our test series show that leaf temperature is probably the most suitable indicator of stress. It can be effectively determined by means of infrared thermography and correlates with leaf water potential. Large scale application is also possible through the use of remote sensing methods (e.g. satellite pictures in the infrared-red spectrum).

Advanced evapotranspiration models require additional information on canopy conductance. When soil water potential is kept at a constant level this variable can be correlated with standard weather observations such as light of vapor-pressure-deficit (Langensiepen 1997). Conditions of constant soil moisture supplies can be achieved by using high frequency irrigation (e.g drip, LEPA and others). Nevertheless, 80 percent of world irrigation is carried out with surface methods where such conditions can hardly be meet. It is a challenge to extend irrigation scheduling to account for these conditions.

Limited literature on the topic shows that there is a growing need for studies of crop responses to water deficit aimed at conserving water (Fereres 1996).

Literature

Fereres E. (1996) Irrigation Scheduling and ist Impact on the 21st Century in Camp C.R., Sadler E.J. and R.E. Yoder (eds.): Int. Conf. Evapotranspiration and Irrigation Scheduling Nov. 3-6, 1996 San Antonio, Texas; Proceedings. ASAE, St. Joseph, MI, USA

Hillel D. (1988) The Role of Irrigation in Agricultural Systems. In: "Irrigation of Agricultural Crops." Monog. American Society of Agronomy, Madison, Wisconsin.

Langensiepen M. (1997) Using meteorological network data for improved agrosystem management: Case studies in Brazil, Germany and Israel. 164 p. Journal of Agriculture in the Tropics and the Subtropics. "Der Tropenlandwirt". Beiheft 59. ISBN 3-88122-928-0. Selbstverlag des Verbandes der Tropenlandwirte Witzenhausen (in German)

Acknowledgement

This research was carried out within the framework of the German Israeli Agricultural Research Agreement for the Benefit of Third World Countries (GIARA Project 94-1)