DOI: 10.13140/RG.2.1.4157.2080
http://dx.doi.org/10.13140/RG.2.1.4157.2080
Cultivos Tropicales, 2016, vol. 37, no. 3, pp. 94-102 July-September

ISSN print: 0258-5936
ISSN online: 1819-4087

Ministry of Higher Education. Cuba
National Institute of Agricultural Sciences
http://ediciones.inca.edu.cu

PHYSIOLOGICAL RESPONSE OF WHEAT (*Triticum aestivum* L.) CULTIVAR INCA TH 4 TO WATER DEFICIT

Respuesta fisiológica del trigo (*Triticum aestivum* L.) cultivar INCA TH 4 al déficit hídrico

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ABSTRACT. In areas of the National Institute of Agricultural Sciences (INCA) an experiment was conducted with crop wheat in order to assess their physiological response to water stress by default, for which the effect of two irrigation treatments on soil moisturecontent, development variables, water relations, yield and water use efficiency (WUE) in culturewere evaluated. The INCA TH 4 cultivar was grown at double row in concrete containers of 1,56 m^2. The two irrigation treatments T 100 and T 50, they consisted of applying 50 to 100 % of standard crop evapotranspiration (ETc.), respectively.Background fertilization was performed before planting with complete formula NPK (9-13-17) and urea (46-0-0) applied to each container 0,1 and 0,04 kg, respectively. Irrigation was applied using an automated system micro sprinkler and water delivery was controlled by valves placed in each treatment. The results showed a significant effect of treatments on soil water content and T 50 at 52 and 67 days after sowing (DDS) that dropped below 15 %, something that was confirmed with the values of potential deficit soil moisture (Dp) which was 178 in T 50 and 77 mm in T 100, respectively. Also the results of leaf water potential (Ψfoliar) showed that T 50 plants were exposed to severe water deficit at 41 and 62 DDS, with lower values of -1,5 MPa and T 100 at 62 DDS. Stomatal conductance (gs) showed greater sensitivity to water stress than the remaining variables of water relations. Studied treatments hardly exerted any effect on growth variables, mainly in the accumulation of dry matter and leaf area. In T 50 plants had a lower yield and water use efficiency (WUE) was slightly higher than the T 100.

Key words: growth, wheat, crop yield, irrigation, water use

RESUMEN. En áreas del Instituto Nacional de Ciencias Agrícolas (INCA) se realizó un experimento en el cultivo de trigo con el objetivo de evaluar su respuesta fisiológica al estrés hídrico por defecto, para lo cual, se evaluó el efecto de dos tratamientos de riego en el contenido de humedad del suelo, variables del desarrollo, las relaciones hídricas, el rendimiento y el uso eficiente del agua (WUE) en el cultivo. El cultivar empleado fue el INCA TH 4 cultivado en doble hilera en contenedores de hormigón de 1,56 m^2. Los dos tratamientos de riego T 100 y T 50, consistieron en aplicar el 50 y el 100 % de la evapotranspiración estándar del cultivo (ETc), respectivamente. Se realizó una fertilización de fondo antes de la siembra con fórmula completa NPK (9-13-17) y urea (46-0-0) aplicando a cada canaleta 0,1 y 0,04 kg, respectivamente. El riego se aplicó mediante un sistema automatizado de micro aspersión y la entrega del agua se controló mediante válvulas colocadas en cada tratamiento. Los resultados mostraron un efecto importante de los tratamientos en el contenido hídrico del suelo y en T 50 a los 52 y 67 días después de la siembra (DDS) este descendió por debajo del 15 %, aspecto que se corroboró con los valores del déficit potencial de humedad del suelo (Dp) que en T 50 fue de 178 y en T 100 de 77 mm, respectivamente. También los resultados del potencial hídrico foliar (Ψ_{foliar}) evidenciaron que las plantas de T 50 estuvieron expuestas a déficit hídrico severo a los 41 y 62 DDS, con valores menores de -1,5 MPa y las de T 100 a los 62 DDS. La conductancia estomática (gs) reflejó una sensibilidad mayor a la deficiencia hídrica que las restantes variables de las relaciones hídricas. Los tratamientos estudiados prácticamente no ejercieron efecto alguno en las variables del crecimiento, principalmente en la acumulación de materia seca y el área foliar. En T 50 las plantas tuvieron un rendimiento menor y su uso eficiente del agua (WUE) fue ligeramente mayor que las de T 100.

Palabras clave: crecimiento, rendimiento, riego, trigo, uso del agua

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INTRODUCTION

Wheat is a species that has a wide range of adaptation; it grows and develops under very diverse environments and can be seeded both in winter and spring, which together with its great consumption, has allowed to be spread in many parts of the world (1).

In Cuba, wheat was introduced since the early years our island was conquered by Spaniards and it was grown until the beginning of the XIX century. Later on, this crop was prohibited by the metropolis, which feared for market competition (2). Thus, it is very important to provide knowledge about wheat sowing, investigation results and recommendations to students, researchers and producers under Cuban conditions (3).

Water competition among various sectors, such as agriculture, industry, hydropower, aquaculture, tourism and urban consumption demands a more efficient irrigation in agricultural production (4-6). Drought is one of the adversities that crops often confront during their growth and development. In recent years, droughts caused by global climatic change are each time more frequent (7), so that investigations on plant response to water deficit are essential. According to some authors, soil moisture has a significant impact on dry biomass accumulation and distribution in wheat plants, providing more than 70 % yield (8).

Other authors working on this crop have previously shown that water use efficiency (WUE) is a key physiological variable that indicates crop ability to preserve water in areas where it is limited, by combining drought resistance with high yield potential (9, 10).

In Cuba, there are a few research works regarding the effect of irrigation treatments on wheat development and yield; therefore, the main objective of this study consisted of evaluating the physiological response of cv. INCA TH 4 to soil water deficiency.

MATERIALS AND METHODS

This work was conducted at the central area of the National Institute of Agricultural Sciences (INCA) from November, 2013 to February, 2014, using six concrete containers 2,60 m long x 0,60 m wide (1,56 m^2) and 0,50 m deep with Lixiviated Red Ferralitic soil (11). Then, 30 g wheat seeds of cv. INCA TH 4 were seeded in two rows spaced 0,25 m between them in each container.

A basal dressing was applied before sowing with a complete formula of NPK (9-13-17) and urea (46-0-0), at a rate of 0,1 and 0,04 kg to each container, respectively. Irrigation was spread by an automated micro sprinkler system and water was delivered through valves placed on irrigation sides in each treatment.

Two irrigation treatments (three containers per treatment) were tested and arranged according to a randomized block experimental design with three replications, which were as follows:

T 100, watered at 100 % ETc (Standard crop evapotranspiration)

T 50, watered at 50 % Etc.

Crop evapotranspiration (ETo) was calculated by using data from a nearby meteorological station (about 200 m far from the experiment) and FAO Penman-Monteith method (12) under standard conditions (ETc) through this equation:

$$ETc= ETo*Kc. \quad [1]$$

where:

ETc: crop evapotranspiration [mm d^{-1}]
Kc: crop coefficient [dimensionless]
ETo: crop evapotranspiration [mm d^{-1}] of reference

The following crop coefficients were employed:
Initial Kc = 0,15; mid Kc= 1,10 and final Kc= 0,65

During a 14-day-period (November 27 to December 10), 3 mm water was daily irrigated to both treatments, in order to ensure a homogeneous early germination and growth. From December 11 upwards, irrigation was applied according to each treatment. Rainfall was considered effective when it exceeded 3 mm. Other cultural practices were also performed in both treatments.

Data of maximum and minimum temperatures as well as of solar radiation corresponded to values recorded within rainy days.

Soil moisture evaluation

Soil moisture (%) was weekly evaluated by a TDR (Time Domain Reflectometry) probe of Field Scout TDR 100 System, Spectrum Technologies, Inc. and 30 measurements were done in each treatment (10 per pipe) at 20 cm deep.

As a measure of crop moisture stress, the potential deficit of soil moisture (Dp, mm) was calculated (13). Dp is a measure of the amount by which atmospheric demand is higher than that provided by irrigation and rainfall (R+I), independently of available soil moisture. Dp was calculated according to the following formula:

$$Dp = \int PET\, dt - \Sigma (P+I) + Ds \quad [2]$$

where:

∫PET is standard evapotranspiration (mm) calculated in this case by FAO Penman-Monteith method from sowing (12)
Σ (P+I) (mm) is total rainfall and irrigation applied from sowing
Ds (mm) corresponds to soil moisture deficit at sowing time (PET-P)

If Dp increases, it will reach a maximum level of potential deficit, so that the crop will not be able to extract water. Thus, maximum Dp (mm) throughout developing period is a measure of the total amount of stress experienced by a crop.

Water relation evaluation

After 22, 41, 62 and 77 days of seeding, water potential (Ψ_{foliar}), solute potential (Ψ_{solute}) and solute potential at maximum saturation ($\Psi_{solute\ Sat.}$) were evaluated in leaves of two plants per replicate (six observations per treatment).

Ψ_{foliar} was measured between 10:00 and 11:00 am by a Scholander pressure chamber, Soil Moisture Model P80 L08. Randomly selected leaves were taken out of the upper third portion of plants, which were fully developed and well exposed to the sun. Immediately after evaluating Ψ_{foliar}, samples were covered with aluminum foil, frozen in liquid nitrogen and stored in a freezer at -80 °C. To determine $\Psi_{solute\ Sat.}$, leaves surrounding those selected were taken out for measuring Ψ_{foliar} and placed in hydration chambers with distilled water at darkness between 6 and 8 °C for 24 hours. Afterwards, they were wrapped with aluminum foil for freezing in liquid nitrogen and stored in a freezer at -80 °C.

Subsequently, all samples were thawed at room temperature and leaf cell juice was obtained by centrifuging to 3000 rpm for three minutes. Starting from 100 uL aliquots, Ψ_{solute} and $\Psi_{solute\ Sat.}$ were determined in leaves through a Vapro 5520 vapor pressure osmometer. Leaf pressure potential (Ψp) was calculated by the difference between Ψ_{foliar} and Ψ_{solute} through the formula:

$$\Psi p = \Psi_{foliar} - \Psi_{solute} \quad [3]$$

Likewise, stomatal conductance was measured using an SC-1diffusion porometer. All assessments corresponding to 41, 62 and 77 days after sowing were performed on the flag leaf. Water stress evaluated in plants was based on Y_{foliar} values. A slight water stress was considered when Ψ_{foliar} was higher than -1,0 MPa, a moderate stress when Ψ_{foliar} value was between -1,0 and -1,5 MPa whereas a severe water stress when Ψ_{foliar} was lower than 1, 5 MPa (11).

Growth and development evaluations

Growth and development variables: the aerial part and root length (cm), the aerial part and root dry mass (g) and leaf area (cm^2) were evaluated 21, 40, 61 and 76 days after seeding (DAS). Leaf area was measured through an AMP-300 integrator and dry masses were obtained by shot forced oven drying at 80 °C up to constant weight.

Yield evaluation

For evaluating yield and its components at 90 DAS, 10 plants (spikes) were randomly harvested in each container (30 plants per treatment), measuring their grain number, grain mass and empty grains per spike, as well as total yield of each container (g m^{-2}). Concerning data of yield and water applied (ET) to each treatment, water use efficiency (WUE, kg m^{-3}) was calculated using the formula:

$$WUE = \frac{Y}{ET} \quad [4]$$

where:

WUE is water use efficiency, Y is yield (kg m^{-2}) and ET (mm) is the actual crop evapotranspiration in each treatment (9).

In this experiment, ET was calculated using the following equation:

$$ET = I + P - R - D - SW \quad [5]$$

where:
ET (mm) is evapotranspiration
I (mm) is the amount of water applied by irrigation
P (mm) is rainfall
R (mm) is runoff (it was not considered in this case according to growing conditions)
D is drainage (it was negligible in this case)
SW is soil moisture content change in the profile exploited by roots (14).

For processing data, means were compared and the confidence interval was calculated through SPSS 19.0 statistical program for Windows (15). Results were plotted using Sigma Plot 11.0 program.

RESULTS AND DISCUSSION

Temperature and rainfall data make evident that the experimental period was relatively warm and dry, as it can be seen in Figure 1A and C, mainly because minimum and maximum temperatures had a little variation and their averages were of 17 and 27 °C respectively, whereas accumulated rainfall was only of 68 mm, equivalent to 6 mm per week.

Moreover, solar radiation was relatively high (Figure 1B), with an average value of 19,62 Mj m^{-2} d^{-1} compared to similar periods with values between 15 and 16 Mj m^{-2} d^{-1}. Higher radiation values were presented at experimental beginning (the first 17 days), reaching up to 22 Mj m^{-2} d^{-1} at 52 DAS. Climatic water demand (ETo) accumulated within the period was of 306 mm, representing a mean daily evapotranspiration of 4 mm.

In general, except temperatures that were relatively warm, rainfall and ETo values are typical of the experimental months.

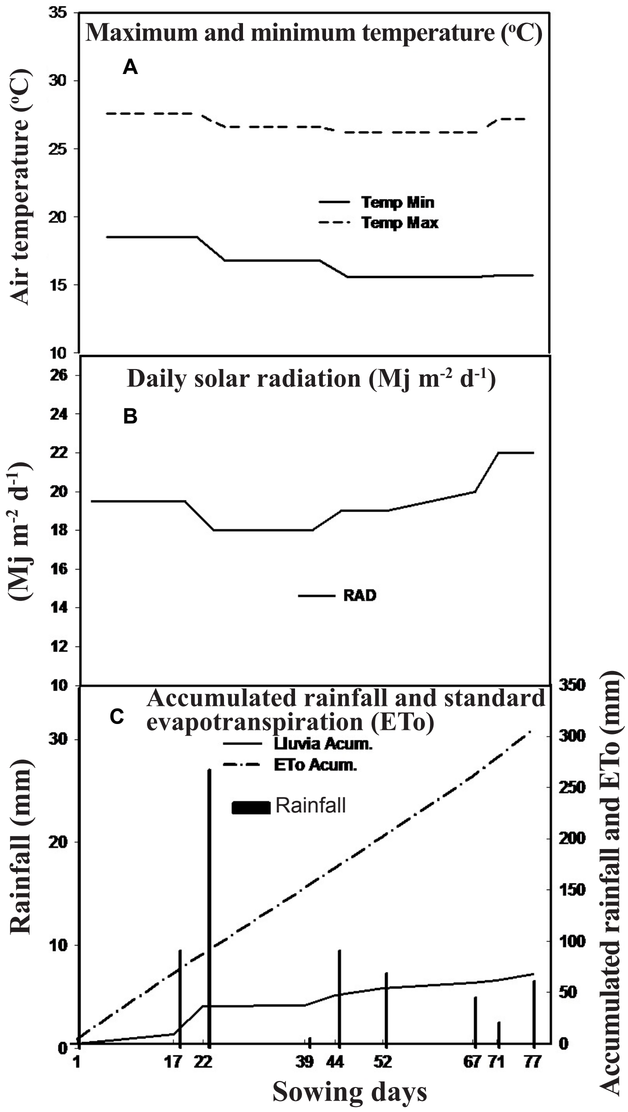
Figure 2A shows soil moisture content variations, since in both irrigation treatments its values were about 40 % at 22 DAS, due to the occurrence of 25 mm rainfall and from that date on, there was a sharp moisture decrease in treatment T 50, whereas at 52 and 71 DAS, it could reach values of about 13 % water content. However, in T 100, soil water contents ranged between 30 and 45 % during the whole experimental period. These results prove the remarkable effect of treatments applied to the crop.

The fact that accumulated Dp values in irrigation treatments were lower than cumulative ETo indicates that plants in both treatments were exposed to some degree of water stress and Dp value was of 178 mm for T 50, whereas of 77 mm for T 100, representing a difference of 101 mm.

These results suggest that perhaps irrigation scheduling resulted to be practice for establishing and applying treatments, they did not allow providing the necessary water amount to meet crop demands, mainly for T 100 plants. Some works conducted on sweet corn (*Zea mays* L.) found a similar trend to Dp values, with a difference of 83 mm between treatments (13).

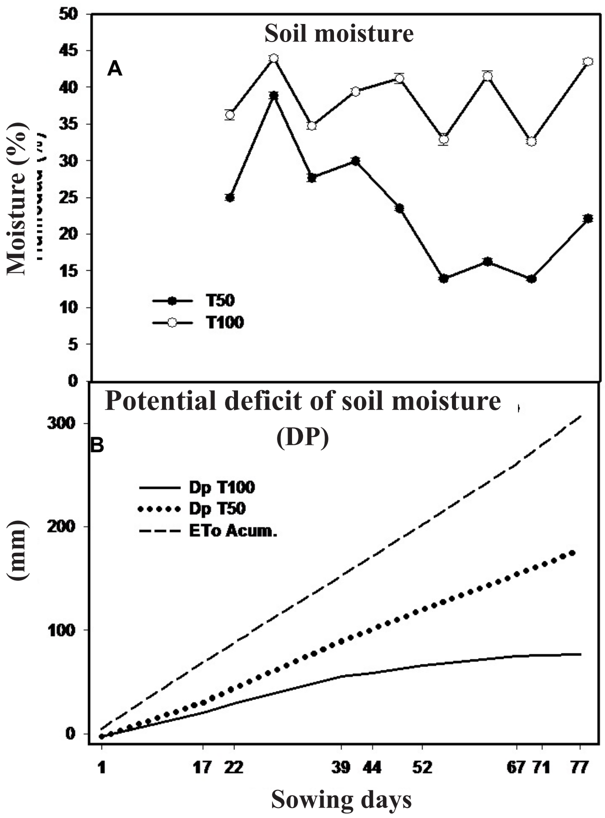
With regard to Ψ_{foliar} values in T 50 and T 100 (Figure 3A), it was evident that T 50 plants at 41 and 62 DAS were subjected to a severe water stress with average values of -1,6 and -1,83 MPa, respectively, meanwhile T 100 plants were in this condition only at 62 DAS with Ψ_{foliar} values of -1,62 MPa. Moreover, increased values of this variable in plants of both treatments at the end of the experiment were due to higher soil moisture contents caused by rainfall.

Ψ_{solute} in both treatments followed the same behavior as Ψ_{foliar} (Figure 3B), although obviously with more negative values and differences between plants of both treatments were practically appreciated at 41 DAS.



Air temperature (A), solar radiation (B), Accumulated rainfall and standard evapotranspiration (ETo) (C)

Figure 1. Environmental conditions during the experimental period at INCA, San José de las Lajas, Mayabeque



Bars on average values of (A) represent the confidence interval of means, α= 0,5

Figure 2. Seasonal variation of soil water content in both treatments T 50 and T 100 (A) at 20 cm deep and potential deficit of soil moisture and climatic water demand (ETO) (B)

On the other hand, $\Psi_{solute\ Sat.}$ values showed differences between plants of both treatments at 41 (-0.30) and 62 (-0.19 MPa) DAS (Figure 3D), whereas more negative values corresponded to T 50 plants.

These results suggest the possibility of occurring an osmotic adjustment process in T 50 plants, which has allowed to keep positive turgor levels (Figure 3C), even though plants were affected by a severe water stress in both evaluation times.

Similar results regarding Ψ_{foliar} behavior in plants of both treatments have been reported in this crop when studying the physiological mechanisms that enable to increase water use efficiency in winter wheat with irrigation deficit (16), as well as when assessing differences in root functions of two wheat genotypes for a long period of drought adaptation (17).

When analyzing stomatal conductance (Figure 4), its behavior was very similar to soil moisture, observing remarkable differences at 22, 41 and 62 DAS, with reductions in T 50 plants of 16, 72 and 77 %, respectively, compared to T 100 plants. Plant values were similar in both treatments only at the end of the experiment.

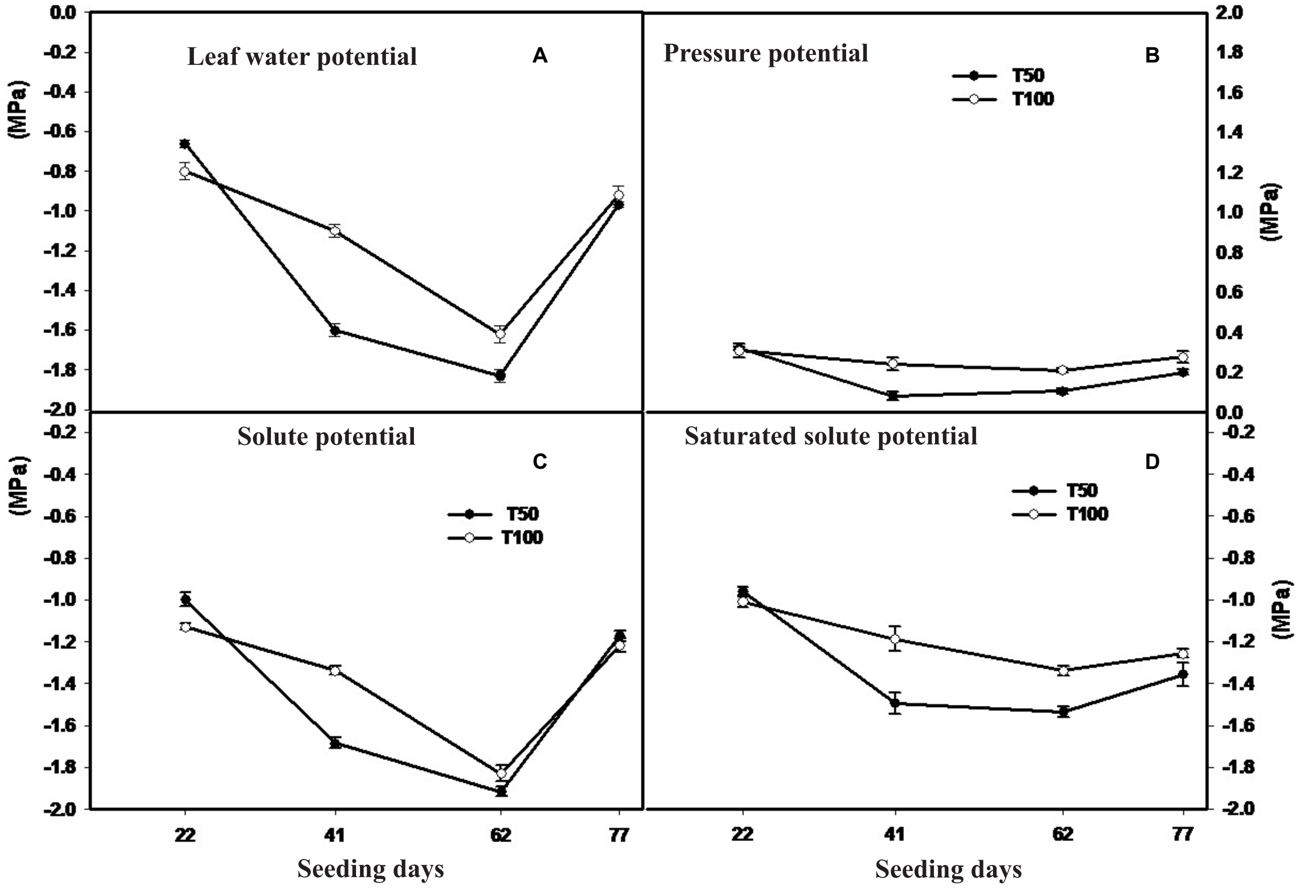
It is notable that among all water relation variables evaluated, stomatal conductance was the most sensitive to crop water limitations.

Some research works were performed on barley (*Hordeum vulgare* L.) crop with reductions of up to 43 % stomatal conductance in plants affected by water stress and compared to its corresponding well-watered controls (18).

Several growth indicators evaluated at different crop cycle times are presented in Table I, without significant differences in any variable between plants of both treatments at 22 and 77 DAS. However, statistically significant differences were recorded in stem length of T 100 plants at 41 DAS and in root length of T 100 plants at 62 DAS. In contrast to what was observed at 41 DAS, other indicator values tended to be slightly higher in T 100 plants.

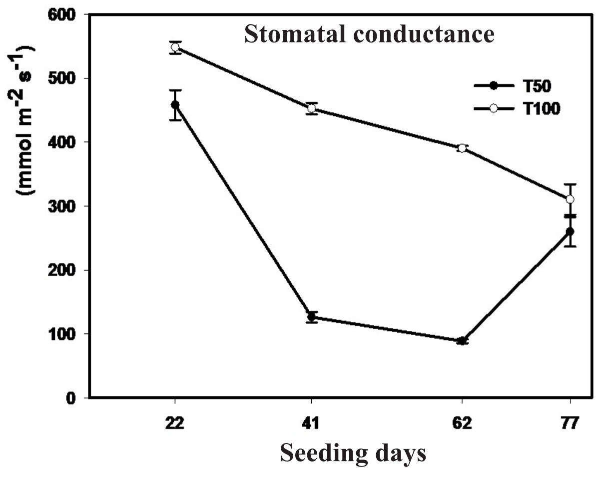
In general, it can be summarized that irrigation treatments had practically no effect on plant growth variables, as there were always significant differences in stem length at 41 DAS and root length at 62 DAS of T 100 plants, respectively. On the other hand, dry biomass accumulated in the aerial part, root and leaf area did not present any statistically significant differences at the evaluated times, which may be associated to the fact that plants of both treatments had an appropriate water supply almost until the first 22 DAS and it was enough to allow them keep adequate levels of leaf growth and dry biomass accumulation.

Similar results were recorded when studying the effects of supplementary irrigation on dry matter accumulation and distribution, as well as water use efficiency in winter wheat (19). Nevertheless, it should be stated that important effects of treatments were recorded when dry matter distribution was destined to yield formation, an aspect that will be addressed below.



Bars on average values represent the confidence interval of means, α= 0,5

Figure 3. Variations of leaf water potential (A) and its components of solute (B), pressure (C) and saturated solute (D) in plants of both treatments, T 50 and T 100



Bars on average values represent the confidence interval of means, α= 0,5

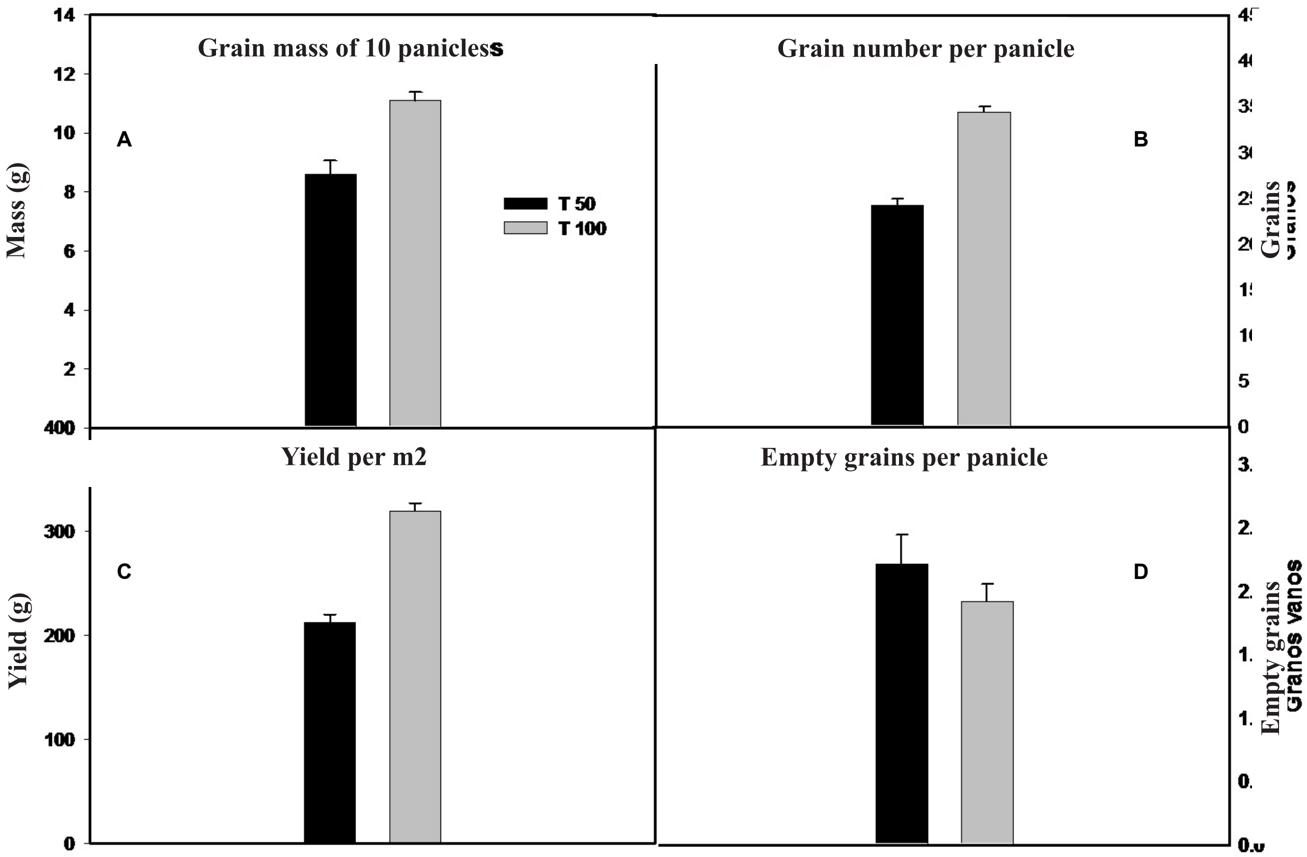
Figure 4. Behavior of stomatal conductance (gs) in wheat plants grown with different irrigation treatments

When analyzing the effect of irrigation treatments on yield variables, it was found that the highest values of grain number per panicle, grain mass of ten panicles and yield (g m^{-2}) at 90 DAS corresponded to T 100 plants (Figure 5A, B and C, respectively). Meanwhile the largest number of empty grains per panicle was recorded in T 50 plants (Figure 5D).

These results indicate that severe water stress mainly affected T 50 plants, causing less grain formation and more empty grains than in T 100 plants. Concerning these results, which are linked to the effects of different irrigation treatments (20), climatic conditions (19), soil moisture (21) and rainfall (22) on wheat yield, there is enough updated information and, in general, it is said that wheat yield is adversely affected when plants are exposed to severe water stress, either by deficiency (20) or excess (21).

Table. Effect of irrigation treatments on plant growth variables at 22, 41, 62 and 77 DAS

Treatment	Stem length (cm)	Root length (cm)	Dry mass of aerial part (g)	Dry mass of root (g)	Leaf area (cm^2)
22 DAS					
T 50	38,20	13,400	0,233	0,035	69,37
T 100	38,68	13,483	0,275	0,042	74,33
Significance	0,762	0,070	0,114	0,305	0,626
41 DAS					
T 50	57,92	12,55	1,211	0,131	170,60
T 100	59,55	12,19	0,985	0,123	154,35
Significance	0,012 *	0,260	0,574	0,321	0,943
62 DAS					
T 50	86,27	11,57	1,926	0,228	90,05
T 100	100,65	13,33	1,934	0,293	98,92
Significance	0,240	0,030 *	0,079	0,610	0,244
77 DAS					
T 50	66,37	11,82	1,975	0,313	23,90
T 100	83,33	14,67	2,184	0,253	30,77
Significance	0,147	0,417	0,471	0,106	0,199

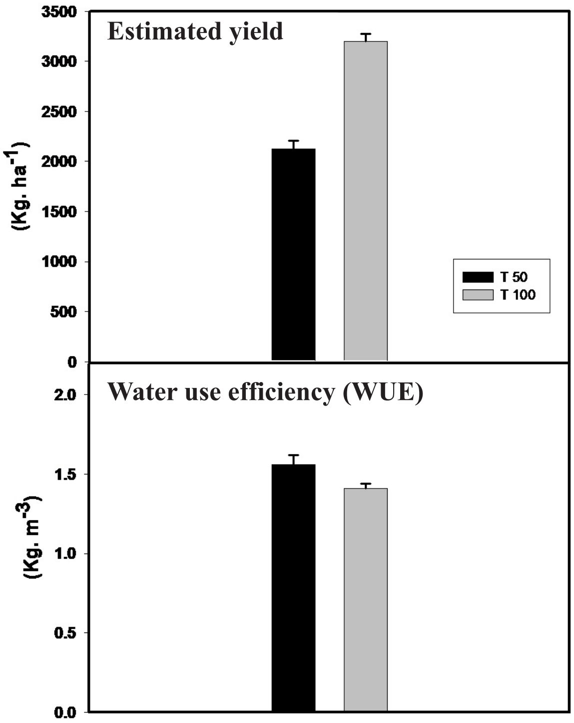


Average grain mass of 30 panicles (A) Grain number per panicle (B) Yield per m^2 (C) Average empty grains per panicle (D)

Bars on average values represent the confidence interval of means, α= 0,5

Figure 5. Yield variables of wheat plants with different irrigation treatments at 90 DAS

Figure 6 shows the results of estimated yield and water use efficiency in plants of both treatments, where the highest yield logically corresponded to T 100 plants, whereas water use efficiency was slightly higher in T 50 plants.



Bars on average values represent the confidence interval of means, α= 0,5

Figure 6. Effect of irrigation treatments T 50 and T 100 on estimated yield A (kg ha^{-1}) and water use efficiency (WUE) B (kg m^{-3})

Some experiments were conducted on wheat cultivars, so as to evaluate water use efficiency associated to agronomic and physiological traits in two groups of cultivars: a first group with 16 and a second one with ten cultivars. It was found that most cultivars in both groups had a similar response to water supply, since water use efficiency was higher in less irrigated plants, while yield was higher in plants subjected to a slight water stress (10). Simultaneous increases in yields and water use efficiency were recorded when efficiently combining irrigation with appropriate cultivars (23, 24).

CONCLUSIONS

In general, it can be concluded that wheat plants of cv. INCA TH 4 do not necessarily require an excessive water supply but an efficient irrigation management, to be able to reach an adequate development and yield, as well as an efficient water use.

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Received: December 12, 2014
Accepted: July 27, 2015