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Original article

Effect of deficit irrigation controlled in maize plant development

Efecto del riego deficitario controlado en el desarrollo de plantas de maíz

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ABSTRACT: Maize is considered one of the main crops that contribute to food and nutritional security for a large part of the world population and drought represents one of the phenomena that most negatively impacts agri-food production and therefore the yield of this cereal. The research was carried out under semi-controlled conditions in concrete containers planted with the maize P7928 cultivar and three controlled deficit irrigation (CDI) treatments were studied, with irrigation suspensions for 15 days in three stages of crop development (SC, SF and SLL)) and a control treatment irrigated at 100 % of the ETc. At the end of the irrigation suspension periods, evaluations of soil moisture, physiological and yield indicators were carried out. The statistical analysis of the data was carried out using the IBM SPSS Statistics 19 program. The results showed that the suspension of irrigation for 15 days in the three stages (SC), (SF) and (SLL) to plants of the maize cultivar P7928 caused significant decreases in soil moisture and RWC. In addition, in SC it reduced the aerial dry mass, considerably the 100 grains mass and the grams per plant. In SF, it reduced stem length, RCC, severely 100grains mass, and yield in grams per plant, and in SLL, only RCC.

Key words: water stress, soil moisture, growth, yield.

RESUMEN: El maíz es considerado uno de los principales cultivos que contribuyen a la seguridad alimentaria y nutricional de gran parte de la población mundial y la sequía representa uno de los fenómenos que más negativamente impacta en la producción agroalimentaria y por tanto en el rendimiento de este cereal. La investigación se realizó con el objetivo de estudiar el efecto de tres tratamientos de riego deficitario controlado (RDC) en el desarrollo del cultivo. El trabajo se diseñó en condiciones semi-controladas, en canaletas de hormigón, sembradas con el cultivar de maíz P7928 y se estudiaron tres tratamientos de RDC, con suspensiones del riego por 15 días en tres etapas del desarrollo del cultivo (SC, SF y SLL) y un tratamiento control regado al 100 % de la ETc. Al término de los periodos de suspensión del riego, se realizaron evaluaciones de la humedad del suelo, indicadores fisiológicos y del rendimiento. El análisis estadístico de los datos se realizó mediante el programa IBM SPSS Statistics 19. Los resultados mostraron que la suspensión del riego por 15 días en las tres etapas (SC, SF y SLL) provocó a las plantas de maíz disminuciones importantes en la humedad del suelo y en CRA. Además, en SC redujo la masa seca aérea, considerablemente la masa de 100 granos y los gramos por planta. En SF, redujo la longitud del tallo, el CRC, severamente la masa de 100 granos y el rendimiento en gramos por planta y en SLL, solamente el CRC.

Palabras clave: estrés hídrico, humedad del suelo, crecimiento, rendimiento.

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INTRODUCTION

Maize (*Zea mays* L.) ranks eighth on the list of the world's most important agricultural products with a production of around 1.1 billion tons in 2020 (1).

This cereal belongs to the Poaceae family, is considered one of the main crops that contribute to food and nutritional security, is a very important source of protein for most of the rural population in Central America, and is also the most important fodder crop worldwide (2-4).

Climate change is one of the most important and studied phenomena of our era and can have a profound impact on agriculture, mainly due to the occurrence of low rainfall (5).

Historically, the Central American region has been affected by extreme hydro-meteorological events. Among these, drought is one of the phenomena that most negatively impacts agrifood production (6). For the coming years, climate models project an increase in temperatures, more erratic rainfall and increased evapotranspiration, factors that could intensify the impact of climate variability on family agriculture (7,8) and its effects on food and nutritional security on a larger scale (9).

Irrigated agriculture is more frequently practiced in a restricted and uncertain water resource environment, due to the intensification of climate variability and increased water competition from non-agricultural users (10).

In Cuba, the general problem of water use for agriculture and its particularity is based fundamentally on the great demand for water per unit of production that agricultural products have and the global efficiencies of irrigation (11). Agriculture, as the main consumer of freshwater, is working to reduce water consumption and one of the fundamental ways to achieve this is to increase efficiency in the use of irrigation water and to increase productivity.

The volume of water demanded per ton of agricultural product, as well as the efficiency in the use of water during irrigation, are the main factors that condition its consumption. Corn is considered one of the priority crops in the grain production program for import substitution carried out by the Cuban government (12). Maize is highly sensitive to drought, extreme temperatures, salinity and heavy metal toxicity (13).

Although maize seedlings require less water than plants of subsequent phenological stages, in the early stages, it is very sensitive to environmental stresses such as drought, which can cause total crop loss (14). In irrigated agriculture, irrigation practice is one of the most complex processes to be carried out by the farmer due to the large number of factors involved in water management, requiring technical information for precise knowledge between applied water and crop yield (15).

Some authors have reported the evaluation of growth parameters under stress conditions to evaluate drought tolerant genotypes, but, on few occasions, early physiological responses to water stress are evaluated simultaneously (16).

There are irrigation strategies that allow reducing the frequency and amount of irrigation in crops with minimal effects on conventional yields if validated on a local scale, such as the application of deficit irrigation according to phenological development (17). Sometimes, the comparison of results is extremely complex, because independently of the fact that there is a great amount of information of works carried out in this subject and in the corn cultivation, the conditions in which the researches are carried out are very different, mainly in the conception and application of the treatments of hydric stress.

Considering the problems of corn in relation to its water requirements, the objective of this work was to study the effect of three controlled deficit irrigation (CDI) treatments on the development of the crop.

MATERIALS AND METHODS

The work was carried out under semi-controlled conditions in the central area of the National Institute of Agricultural Sciences (INCA) geographically located at 22º58′00″N and 82°09′00″O at 130 m a.s.l. On April 20, 2021, 12 concrete containers 2.60 m long by 0.60 m wide (1.56 m^2) were sown containing Ferrallitic Red Leached soil from the Mayabeque province (18) area that is part of the Havana-Matanzas karst plain (8). In each container were sown corn seeds cultivar P7928 arranged in two rows and with a separation between them of 0.4 m and 0.2 m between plants (26 plants per container).

Four irrigation treatments were tested as shown in Table 1 and were distributed following a randomized block experimental design with three replications.

Irrigation was applied by an automated micro-sprinkler system and water delivery was controlled by valves conveniently placed on the irrigation laterals of each treatment. The pH and electrical conductivity (E.C. dS m^{-1}) values of the water applied to the crop during the experiment were 7.8 and 0.58, respectively.

Irrigations consisted of replenishing the daily standard crop evapotranspiration (ETc) three times per week (Monday, Wednesday and Friday). Plants before and after irrigation suspension (SR) received 100 % of ETc.

Table 1. Description of the deficit irrigation treatments studied

Treatments	Description
100 %	Control irrigated at 100 % of the crop standard evapotranspiration (ETc) during the whole cycle
SC	Suspension of irrigation for 15 days in the growth stage (between 20-35 DAS).
SF	Suspension of irrigation for 15 days at flowering stage (between 40-55 DAS).
SLL	Suspend irrigation for 15 days at grain filling stage (between 60-75 DAS).

DAS= days after planting. During periods when irrigation was suspended, the concrete containers were covered with a transparent polyethylene roof to prevent rain

The reference evapotranspiration ETo (mm), standard crop evapotranspiration ETc (mm) and irrigation requirements (ETc= ETo*Kc) were obtained using the CropWat.8 Program; this was updated with a historical series of meteorological data for 31 years (1990- 2021) corresponding to Tapaste meteorological station which belongs to the National Institute of Meteorology and it is located approximately 200 m from the experimental site and for the calculation of ETo and ETc the monthly mean values were used.

Crop coefficients (Kc) used were: initial Kc = 0.62, average Kc= 1.00 and final Kc= 0.93, proposed for the region by FAO (19).

Evaluations carried out

All evaluations were carried out at 35, 55 and 75 days after sowing (DAS), coinciding with the culmination of the irrigation suspension periods in the growth (SC), flowering (SF) and grain filling (SLL) phases.

Soil moisture was measured at 20 cm depth using a HD2 Precise Moisture Measurement equipment equipped with a Moisture Sensor TRIME®- PICO TDR Technology, Germany calibrated with internal calibration No. 2 of the probe itself and 15 replicates per treatment were performed.

Growth evaluations:

Stem length cm (graduated ruler).

Stem diameter (cm) (caliper)

No. of leaves, Leaf area (cm^2) = (Length*Mean leaf width)*0.75 (20)

Aerial dry mass (g) on technical balance.

Relative water content % (RWC) and chlorophyll content (SPAD), as well as growth evaluations, were carried out in nine replicates per treatment.

For RWC, leaf apices from the upper third of the plants were taken at 7:00 a.m., fully developed, weighed (fresh mass) and placed in a hydration chamber for 24 hours in the dark and at 8 ºC, then their turgid mass was measured and they were placed in a forced draught oven at 65 ºC for 72 hours until constant dry mass. RWC was calculated using the equation [1].

$$RWC = [(fresh\ \ mass - dry\ \ mass) / (turgid\ \ mass - dry\ \ mass)] \text{ x } 100\ \ (\%) \tag{1}$$

To measure the relative chlorophyll content (RCC), a MINOLTA Portable Chlorophyll Meter was used. SPAD 502 Plus was used.

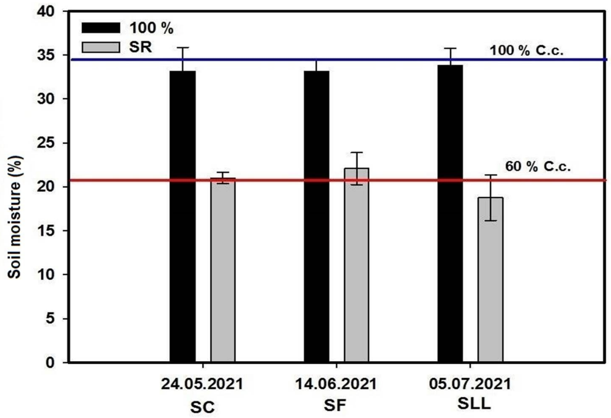
In the evaluations of yield and its components, the following variables were measured in 10 ears per treatment: rows per ear, grains per row, grains per cob and per plant, mass of 100 grains, and grams per plant.

The calculation of the confidence intervals of the means and their comparison was carried out using IBM SPSS Statistics 19 and the results were plotted using Sigma Plot 11.0.

RESULTS AND DISCUSSION

Figure 1 shows the variations of soil moisture content in the different treatments, where it was found that, in this variable, when irrigation was suspended in the growth stage (SC), it decreased or decreased by 36.6 % with respect to the control treatment (100 % of ETc); by 33.45 % in the flowering stage (SF) and by 44.45 % in the grain filling stage (SLL).

These results suggest that the irrigation schedule used was adequate for the establishment and application of the treatments in the different phases of the crop, achieving with the suspension of irrigation at each stage soil moisture values that are around 60 % of the field capacity, so it can be considered as a moderate water stress.



Bars above the mean values represent the confidence interval of the means, α= 0.05

Figure 1. Variation of soil moisture percentage in the treatments studied at 20 cm depth. SC= suspension of irrigation at growth stage, SF= suspension of irrigation at flowering stage and SLL= suspension of irrigation at grain filling stage

Effects of soil water deficiency resulting from the suspension of irrigation in the three crop stages studied are shown in Table 2, where it was found that in stem length growth, the suspension of irrigation in the growth stage (SC) did not negatively affect this indicator in the plants, even the mean value was slightly higher than in plants that received 100 % of their water requirements, although without statistically significant differences.

Water stress induced at the flowering stage (SF) produced significant decreases in growth in terms of stem length and diameter.

At SLL, the mean values of the three variables in plants were higher, although with significant differences only in stem diameter. However, this behavior of the plants in both treatments (SLL and 100 % ETc) is basically associated with the fact that at this stage there is practically no growth supremacy.

The values of leaf area and dry mass of the aerial part of the corn plants with irrigation suspension at different stages of their development are shown in Figure 2, in which it was observed that the suspension of irrigation for 15 days in the three stages did not negatively affect leaf area. On the other hand, the dry mass of the aerial part only decreased slightly with the suspension of irrigation in the growth stage (SC).

Table 2. Effect of CDI treatments in the three developmental stages of maize plants on different indicators of their morphology

Variables	100 %	SC	E.s.X	100 %	SF	E.s.X	100 %	SLL	E.s.X
Stem length (cm)	71.75	83.00	4.49 ns	138.87	124.25	3.67*	121.75	136.00	9.90ns
Stem diameter (cm)	1.37	1.32	0.056 ns	1.69	1.31	0.1109*	1.19	1.67	0.125*
Nº of leaves	7.5	7..25	0.375 ns	11.25	11.25	0.619 ns	10.50	12.00	0.75 ns

SC= suspension of irrigation at growth stage, SF= suspension of irrigation at flowering stage and SLL= suspension of irrigation at grain filling stage

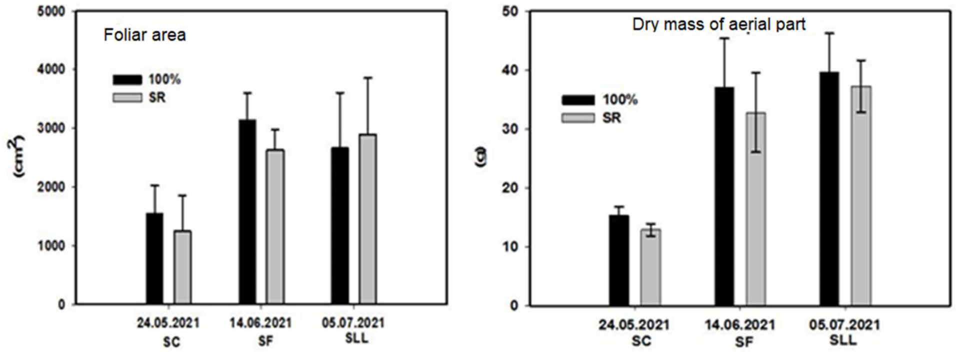


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Figure 2. Effect of irrigation suspension (SR) at different developmental stages of maize seedlings on leaf area and aerial dry mass. SC= suspension of irrigation at growth stage, SF= suspension of irrigation at flowering stage and SLL= suspension of irrigation at grain filling stage

These results suggest that the application of moderate stress (60 % of the C.c.) at the developmental stages studied only caused reductions in growth as a function of stem length and diameter in SF plants and aerial dry mass in SC. However, leaf number and leaf area were not negatively affected.

There is some correspondence of these results with those reported by some authors who worked with three maize genotypes and five irrigation treatments, and found that, in the most tolerant genotype (21), the lowest growth in stalk length corresponded to plants receiving 100 % of irrigation water and suggested that maize genotypes can grow with the application of 60 % of water requirements. Other researchers found greater dry mass of the stem when they applied 50 and 25 % of irrigation water and greater dry mass of green leaves when they applied 25 % and in rainfed conditions (5). In this sense, researchers found that biomass growth was directly influenced by leaf area, while soil moisture had no significant direct effect on total biomass production (22).

On the other hand, (23) found that growth in dry mass of the aerial part (stem and leaf) was lower in plants of extreme treatments in terms of water endowments, that is, when water stress was strong in the vegetative stage and at maturity with only two irrigations and when stress was light at the beginning and moderate at maturity with four irrigations.

RWC and RCC values of the plants in the different treatments are presented in Figure 3, where a certain correspondence between RWC and soil moisture can be appreciated (Figure 1).

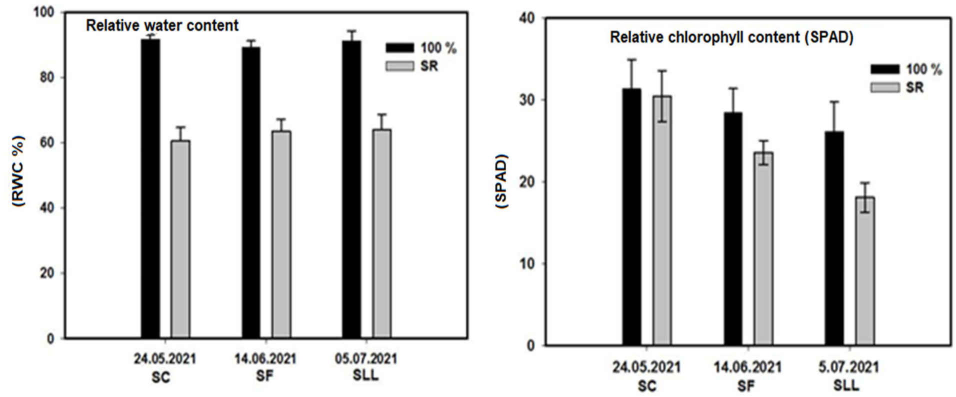
Plants in the three CDI treatments presented relative water contents around 60 %, while those receiving 100 % ETc presented values close to 90 %. CDI is an indicator of plant water status and is closely linked to root water uptake and transpiration loss. Under drought stress conditions, RWC decreases, but it can be rapidly increased by replenishment irrigations (2).

Chlorophyll is one of the main components of the chloroplast, a key organelle for photosynthesis; therefore, RCC has a positive relationship with photosynthetic rate. In this case, RCC in plants corresponding to SC did not decrease its values; in those of SF it slightly reduced and in SLL it presented the lowest values of this indicator; therefore, it could be inferred that water stress in plants at the grain filling stage, although no differences were found in the leaf area of plants in SLL, was the most detrimental treatment in RCC.

This behavior is apparently associated with the fact that in SLL the suspension of irrigation caused the greatest decrease in soil moisture and according to (24) the decrease in chlorophyll content under drought stress conditions has been considered a typical symptom of oxidative stress and may be the result of pigment photooxidation and pigment degradation.

Other authors applied a water stress treatment at four phenological stages of the crop reported (20), that severe and prolonged water stress during the seedling stage and extended to maturity can damage the photosynthetic membrane structure causing a lower chlorophyll content and therefore, a less efficient use of solar radiation.

When analyzing the values of the yield indicators and their components (Table 3), it was found that in the variables rows per ear, grains per ear, grains per ear and grains per plant, there were no statistically significant differences among the plants of the treatments under study.



Bars above the mean values represent the confidence interval of the means, α= 0.05

Figure 3. Effect of suspension of irrigation (SR) at different stages of maize plantain development in the RWC and RCC. SC= suspension of irrigation at growth stage, SF= suspension of irrigation at flowering stage and SLL= suspension of irrigation at grain filling stage

Table 3. Yield indicator values of maize plants treated with different CDI strategies

Variables	100 %	S C	SF	SLL	Es X
Rows-cob	12	13	13	13	0,746 ns.
Grains- row	23	18	18	20	2,220ns.
Grains -cob	279	249	239	259	12.70 ns.
Mass of 100 grains	17, 77 a	14, 78 c	14, 14 d	16, 51 b	0, 163*
Grains plant	282	250	240	273	31,274ns.
Grains plant	50,08 a	37,05 b	33,90 b	45,14 ab	2,26*

SC= suspension of irrigation at growth stage, SF= suspension of irrigation at flowering stage and SLL= suspension of irrigation at grain filling stage

Reductions with significant differences were only appreciated in the mass of 100 grains and in the grams per plant when irrigation suspension took place in SC and SF and the lowest values of mass of 100 grains corresponded to the plants of the SC treatment with significant differences with the plants of the rest of the treatments; while the lowest values of grains per plant corresponded to those of the SF treatment with significant differences only with the plants that received 100 % of the ETc.

This behavior in the plants of both treatments may indicate that the stress induced by the suspension of irrigation at the vegetative growth stage and at flowering causes considerable reductions in grain mass and crop yield.

Maize grain fill is significantly altered due to the timing and intensity of water deficits. This variation can limit leaf productivity (source), translocation of assimilated sugars (flux), and yield formation (sink) (25,26).

It was noted that severe water stress at the vegetative growth stage could severely inhibit growth and leaf area in maize plants (23,27). However, with a light water stress during the vegetative growth and grain filling stages, plants showed a certain level of tolerance to stress due to the low water requirement of the crop at these stages.

Other authors state that corn plants that received severe and prolonged water stress during the seedling stage did not show significant recovery even when irrigation levels during the rest of the growing season were the same as those applied to plants that were not subjected to such stress and suggest that unrecoverable yield loss could occur if corn were exposed to severe and prolonged water stress events during the seedling stage (20).

These results suggest that, if irrigation water savings are to be achieved without significantly affecting yield with this cultivar, the recommendation is to apply 100 % of ETc during the vegetative growth and flowering stages and to suspend irrigation during the grain filling stage.

CONCLUSIONS

It can be noted that the suspension of irrigation for 15 days in the three stages (SC), (SF) and SLL) to plants of corn cultivar P7928 caused significant decreases in soil moisture and RWC. In addition, in SC, it significantly reduced aerial dry mass, 100-grain mass and grams per plant. In SF, it reduced stalk length, RCC, 100-grain mass and yield in grams per plant, and in SLL, only RCC.

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