Efficient use of water in four genotypes of cowpea (*Vigna unguiculata* L. walp) aiming to face water deficit

Amir David Vergara Carvajal,[1] Teobaldis Mercado Fernandez,[1] Hermes Aramendiz Tatis,[1] Alvaro Alberto López-Lambraño[2,3,4]

[1]Research Group on Tropical Crops in Warm Climates, University of Cordoba, Monteria, Colombia
[2]Faculty of Engineering, Architecture and Design, Universidad Autónoma de Baja California, Baja California, Mexico
[3]Hidrus S.A. de C.V., Ensenada, Mexico

Abstract

Cowpea (*Vigna unguiculata* L. walp*)* is grown in small areas without technology and with yields not exceeding 1,000kg ha^{-1}. Water management is paramount to address water deficit caused by rainfall variability. A complete block experimental design was implemented with two factors and four levels each, with a split plot arrangement with four repetitions to apply irrigation sheets of 2.0, 2.8, 3.6 and 4.4 mm day^{-1} to the LC-019, LC-005-016, LC-014-016 and CAUPICOR 50 cowpea genotypes. The research was carried out in Montería, Colombia, located at 8º 48' North Latitude and 75º 52' West Longitude. Total dry mass and leaf area variables were assessed 55 days after emergence (DAE). At the cycle end, weight of 100 seeds and yield were determined. The largest leaf area was recorded for LC-005-016 and LC-014-016 with 3,178.23 and 2,802.23 cm^2 plant^{-1} for 4.4 mm day^{-1}, respectively. The highest biomass was recorded for the LC-005-16 genotype, with 127.6g plant^{-1} for 4.4 mm day^{-1}. Yield of genotypes increased, when increasing irrigation sheet, being CAUPICOR 50 and LC-019 the ones with the highest yield, with 2,276.62 and 2,092 kg ha^{-1} for 4.4 mm day^{-1}. Similar water consumption was found between CAUPICOR 50 and LC-019 with Kc of 1.1 and LC-005-016 with LC-014-016 with Kc of 0.9. These Kc values allow us to know the consumptive use of each of these genotypes for any climatic zone by multiplying them by its evapotranspiration.

Correspondence: Alvaro López-Lambraño, Faculty of Engineering, Architecture and Design, Baja California 22860, Mexico.
E-mail: altoti@gmail.com

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Introduction

Cowpea (*Vigna unguiculata L.* walp) is a very important food legume in tropical and subtropical regions, considered of high nutritional value due to its high protein, iron and zinc content (Gerrano *et al*., 2019; Morales-Morales *et al*., 2019). Despite its great significance, average grain production is less than 1,000 kg ha^{-1}, due to deficient use of technological packages and water deficit caused by the irregular distribution of rainfall (Carvalho *et al*., 2012; Cardona-Ayala *et al*., 2013; Aramendiz and Espitia, 2017; Silva *et al*., 2017; Junior *et al*., 2017).

Irrigation in cowpea crops is essential in regions where there is an irregular rainfall distribution, favoring fluctuations in production. It is important to identify which development stages are most sensitive to water, aiming to define water saving strategies with low impact on productivity. In this sense, it is imperative to know the water needs of the crop in the different phenological stages (Souza *et al.,* 2011). Water deficit affects productive capacity of plants and as its intensity increases, various metabolic changes occur, causing a decrease in plant height, leaf number, leaf area, pod number per plant, weight of 100 seeds and yield, due to reduced absorption and transport of nutrients Merwad *et al*. (2018). Effects caused by water deficit in the plant are related to the alteration of the transpiration and absorption processes, and water availability in the soil, causing a decrease in productivity by affecting photosynthesis. As water availability in the soil decreases, plant transpiration rate decreases with the closure of the stomata. Consequently, CO_2 availability reaches extremely low levels, forcing the plant to use CO_2 that comes from respiration in order to maintain a minimum level of photosynthetic rate (Raven, 2001; Ribeiro *et al.,* 2008; Santana and Souto, 2011).

Cowpea water requirement varies according to its developmental stage and increases from a minimum value in germination to a maximum value in flowering and pod formation, decreasing from the start of the maturation (Lima *et al*., 2006; Bastos *et al*., 2012). On the other hand, Perez *et al*, 2021 point out that this crop requires more water in the phase of floral differentiation, fruiting, and grain filling. Similarly, it can be considered that beans are a susceptible crop, both to excess moisture and to its deficit during its development cycle, for which it is necessary to know its water requirements (Chavarria *et al.*, 2020). Thus, the objective of this research work was to evaluate the effect of four irrigation sheets on the total biomass along with the production indicators in four cowpea genotypes in order to know the water requirement of the crop.

Materials and Methods

This research was carried out between January and April 2014, in the crop area of University of Cordoba in Montería, Colombia, located at 8° 48' north latitude and 75° 52' west longitude (Figure 1), with an elevation point of 15 m asl, a mean annual precipitation of 1,200 mm, average temperature of 28°C, solar brightness of 1,800 light-h year^{-1}, and 84% relative humidity (Palencia *et al.*, 2006). A complete block experimental design was used with two factors (A and B) and four levels for each factor, with a split plot arrangement with four replicates, for a total of 64 experimental units. Factor A corresponded to four irrigation sheets equivalent to 2.0, 2.8, 3.6, and 4.4 mm day^{-1}, resulting from the maximum mean evapotranspiration product for the period between 1998 and 2017 for the months of January to March, in the study area, equivalent to 4.0 mm day^{-1} and proposed crop coefficients (Kc) of 0.5, 0.7, 0.9 and 1.1. These sheets were applied through a drip irrigation system up to 50 days after emergency (DAE), making the respective water balance, due to the occurrence of 17mm rainfall during the study period. Factor B corresponded to the cowpea genotypes LC-019, LC-005-016, LC-014-016 and CAUPICOR 50, planted at a distance of 0.4 m between plants and 0.7 m between rows, in 14 m^2 experimental units. During the development of the crop, a standard phytosanitary management was carried out. At 55 DAE, in two plants of each replicate per treatment, total dry mass (TOTDM) was measured in *g* plant^{-1} and leaf area (LA) in cm^2 plant^{-1}. For the TOTDM, each organ was separated for its respective drying at 80ºC for 48 h, with an MF-2006 electric muffle with a 20-liter capacity and subsequent weight. LA was measured with an image scanner, processed with Image J-NIH Software. Yield indicators were measured at the end of the crop cycle between 62 and 78 DAE, depending on the earliness of each genotype. For the weight of one hundred seeds (W100S), 100 grains were counted and weighed on an analytical balance with a precision of 0.1mg in the first, second and third harvest passes, to obtain its mean value. Yield was obtained after harvesting two central rows three times in each treatment, expressed in kg ha^{-1} and adjusted to 14% humidity.

Results and Discussion

Total dry biomass and leaf area

According to the results of ANOVA (Table 1), the applied irrigation sheets generated a highly significant effect ($p\leq0.01$) on the total dry mass and leaf area variables. Regarding the genotypes, significant ($p\leq0.05$) and highly significant ($p\leq0.01$) differences were found, respectively, in said variables, evidencing an independent effect for each factor, since the interaction was not significant for TOTDM and highly significant for LA, a fact that agrees with Junior *et al*. (2017). The effect of the irrigation sheets on the four cowpea bean genotypes (Table 2) indicated that the higher the irrigation sheet, the average total dry mass (MSTOT) values increased. Nonetheless, no statistical differences were found

Table 1. Mean squares for total dry mass and leaf area of Cowpea genotypes at 55 days after emergency.

Source	df	TOTDM (g plant^{-1})	LA (cm^2 plant^{-1})
Block	3	1016.4	367,557.6
Sheet (A)	3	3353.0**	2,920,465.9 *
Error (a)	9	326.7	221,268.5
Genotype (B)	3	1079.8*	2,979,228.1**
Interaction A x B	9	470.3 ns	670,746.1**
Error (b)	36	354.4	199,734.6
R^2		0.65	0.79
CV (%)		15.7	21.9

df, degrees of freedom; TOTDM, total dry matter; LA, leaf area; *significant differences ($p\leq0.05$); **highly significant differences ($p\leq0.01$); ns, no significant differences ($p>0.05$); R2, coefficient of determination; CV, coefficient of variation.

Table 2. Total dry mass for four sheets and four cowpea bean genotypes at 55 days after emergency.

Irrigation sheets (mm day^{-1})	TOTDM (g plant^{-1})
2.0	98.7b
2.8	124.3^{a}
3.6	125.1^{a}
4.4	131.4^{a}
Genotypes	
LC-019	108.3^{b}
LC-005-16	127.6^{a}
LC-014-016	121.2b^{a}
CAUPICOR 50	122.5b^{a}

TOTDM, total dry matter; ^{a,b,ba}equal letters do not statistically differ Tukey (α=0.05).

between sheets 2.8, 3.6, and 4.4 mm dia^{-1}, which presented the highest mean values with 124.3, 125.1, and 131.4 g plant^{-1}, respectively. Regarding the genotypes, LC-005-16 presented the highest average value of TOTDM with 127.6 g plant^{-1}, although statistically equal to LC-014-016 and CAUPICOR 50, with a lower value in LC-019, which is possibly due to its greater root capacity to explore the soil rhizosphere and extract nutrients to transport them to form branches and leaves (Waters and Sankaran, 2011).

Bastos *et al*. (2012) and de Andrade *et al*. (2014), in independent studies, found the highest accumulations of dry mass in cowpea bean cultivars of Brazilian origin with the application of irrigation sheets ranging from 401.9 mm to 473.4 mm. These results are contrary to those from this research, since an accumulated sheet of 140 mm cycle^{-1}, statistically presented the same effect as one of 220 mm cycle^{-1}, which allows us to infer that TOTDM, depending on the irrigation sheet, depends on the genetics of each genotype as well as on the soil moisture states as Oliveira *et al*. (2011). In this sense, Colombian cultivars are very early compared to those from other environments, because they flower before 34 days and are classified as insensitive to the photoperiod according to Ishiyaku *et al*. (2005).

As seen from Figure 2, leaf area tends to increase in all genotypes when irrigation sheet increases. Nonetheless, the highest values of leaf area are recorded in LC-005-016 for all applied sheets due to possible differences in the phyllochron, especially in the stage in which the cowpea emits a greater number of leaves (Hissene *et al*., 2016); while the lowest values were found in LC-019 and CAUPICOR 50, related to the lower dry mass of leaves that these genotypes presented. The plants in this phase were at the start of maturation in such a way that senescence of the leaves occurred, mainly in CAUPICOR 50 and LC-019, since they were much earlier. These results are similar to those from Filho *et al*. (2017), who recorded the highest mean value of leaf area with an irrigation sheet equivalent to 100% of potential evapotranspiration, exceeding by 24.72% the value found under a 50% lower water regime, and consistent with previous studies from Nascimento *et al*. (2011) and Bastos *et al*. (2012), when they verified a reduction in the leaf area in cowpea bean cultivars, given the stop of emission of new leaves in the treatments subjected to water stress, as a mechanism to escape water stress and reduce water loss due to transpiration. This behavior possibly occurred with the application of water sheets of 2.0 and 2.8 mm dia^{-1}.

Weight of 100 seeds and yield

According to Table 3, the used irrigation sheets generated a highly significant effect ($p \leq 0.01$) on yield in kg ha^{-1} and not significant for the weight of 100 seeds, results that agree with Oliveira *et al*. (2011), for the yield. When observing the effects between genotypes, the existence of highly significant differences for W100S and yield is evidenced, as a result of their genetic differences, coinciding with preliminary studies by Morales-Morales *et al*. (2019). The highest W100S was recorded for CAUPICOR 50 with a value of 20.4g, followed by LC-019 with 14.72 g. Genotypes LC-005-016 and LC-014-016 were statistically the same and presented the lowest averages with 14.12 and 13.97 g, respectively, classifying the seeds of CAUPICOR 50 as large and the other genotypes small according, to Ogle *et al*. (1987), with comparative advantages for the first market, especially internationally. Regarding the LC-019 genotype, similar results were obtained by Aramendiz *et al.* (2017) evaluating the adaptability and phenotypic stability in cowpea bean cultivars in the Colombian Humid Caribbean, reporting values of 15.92 g for this genotype. Figure 3

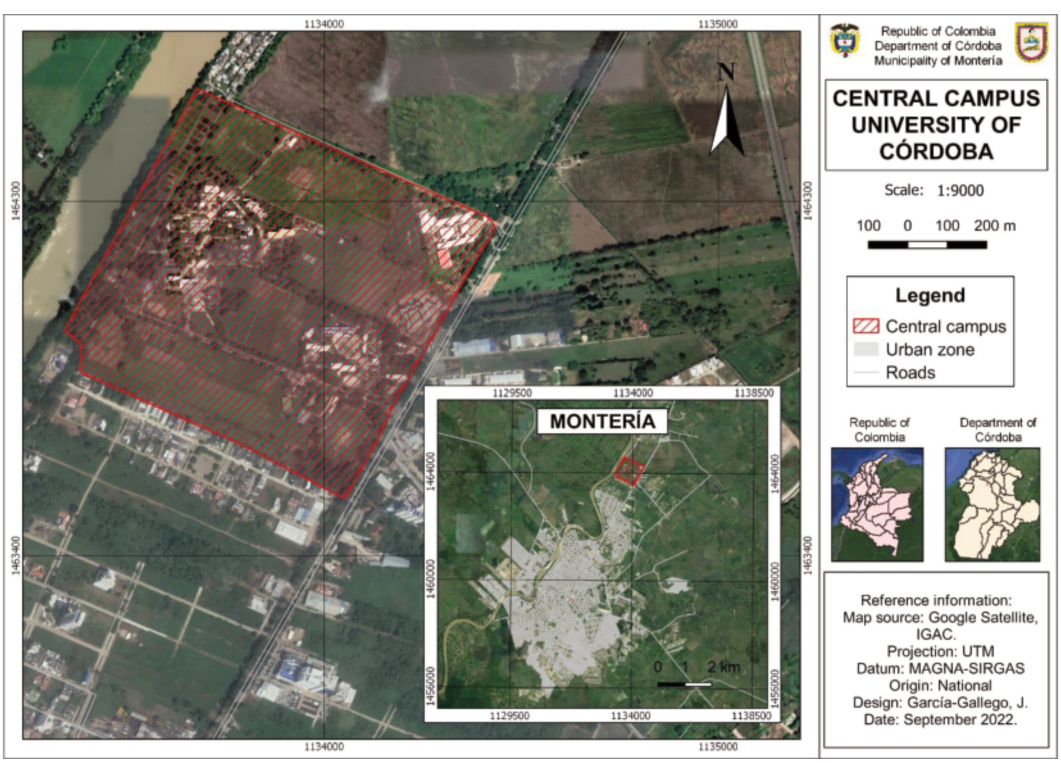

Figure 1. Research study location.

shows the interaction between genotypes and irrigation sheets, noting that the highest yield was obtained by CAUPICOR 50, with an increasing trend with the largest irrigation sheets, highlighting that with 4.4 mm day^{-1}, CAUPICOR 50 and LC-019 registered their highest yield with 2,279.62 and 2,092.36 kg ha^{-1}, respectively, possibly due to a greater capacity to form pods per plant, which is the main yield component. On the other hand, the LC-014-016 and LC-005-016 genotypes achieved higher yields with the irrigation sheet of 3.6 mm dia^{-1}, with values of 2,024.57 and 1,438.54kg ha^{-1} respectively. Silva *et al*. (2016), evaluating dry grain yield and cowpea production, observed increases of 30.4%, with values ranging from 886.72 to 1,274.06kg ha^{-1} when applying a 360 mm irrigation sheet under a conventional production system. Oliveira *et al* (2015), evaluating the interaction between water sheets and plant densities on cowpea growth and yield, and using a conventional production system, observed a seed yield of 1,668.86kg ha^{-1}, using 390.88 mm sheet and density of 24.1 plants m^{-2}, for the BRS Itaim cultivar.

These results differ from this study, where with smaller sheets per cycle equivalent to 220 and 180 mm, higher yields were obtained in the assessed genotypes with the exception of LC-005-016. Nascimento *et al.* (2011) obtained a reduction in the productivity of different cowpea cultivars by reducing the water supply from 300 to 190 mm in the Northeast of Brazil, these results being similar to this study, evidencing that the least irrigation sheet generated the least yield. The results of the present research corroborate that it is possible to increase the yield of this species and with it, minimize the possibilities of importation to Colombia as it has been occurring from Peru, with a type of cream-colored grain and weight desired by the national market.

Determination of the crop coefficient

The choice of Kc was established considering the highest yield in each genotype with the irrigation sheets. A global or unique Kc was selected for a 50-day irrigation cycle (Table 4). The same consumption was found for LC-019 and CAUPICOR 50 with Kc of 1.1 and requirements of 220 mm cycle^{-1} and for LC-005-1 and LC-014-016 with Kc of 0.9 and a requirement of 180 mm cycle^{-1}. These results are similar to those presented by Leon *et al*. (2022) for the similar species *pahseolus vulgaris* who report for the phase of greatest demand a Kc of 1.06 and 1.05, determined by means of lysimeters and empirical equations from the FAO, respectively. Similarly, Pérez *et al*. (2021) reported a 1.19 Kc for the phase of greatest water demand. On the other hand, it was evidenced that these results are not similar to those of Chavarría *et al*. (2020), who obtained a 215 mm sheet for a 90-day cycle during the dry period. Likewise, because they do not coincide with the same irrigation cycle, these results differ from the studies by Souza *et al*. (2011), who observed a yield of 1,376.9kg ha^{-1} in cowpea with 449 mm. Oliveira *et al*. (2015), assessing the interaction between the irrigation sheets and planting densities in BRS Itaim Cowpeas, obtained a yield of 1,668.86 kg ha^{-1} using 390.8 mm. In general, it can be inferred that sheet per cycle in the cowpea crop is different for each genotype. In total agreement, Oliveira *et al*. (2011) states that the amount of water necessary for crops depends on the genotype, stage of phonological development, planting season, productivity, type of soil, and climatic conditions.

In has been shown in legumes that in the early stages, the water requirement is lower, and this tends to increase until it reaches its maximum requirement when the plant is in the formation stage of reproductive organs because in that stage the crop generates a greater demand for water to carry out this process (Chavarría *et al.*, 2020; León *et al.*, 2022).

Conclusions

The applied irrigation sheets generated a highly significant effect on the total dry mass and leaf area variables; and on the genotypes, significant and highly significant differences, respectively, on said variables as a reflection of their genetic differences. The yield in each of the genotypes increased with increasing irrigation sheet, highlighting that with 4.4 mm day^{-1}, CAUPICOR 50

Table 3. Mean squares of W100S and yield in four cowpea genotypes.

Source	df	W100S (g)	Yield (kg ha^{-1})
Block	3	67.4	228,197.4
Sheet (A)	3	8.9 ns	1,478,453.4**
Error (a)	9	54.1	171.001.2
Genotype (B)	3	15,163.0**	1,377,019.4**
Interaction A:B	9	19.7 ns	158,610.6**
Error (b)	36	28.3	47,127.6
R^2		0.98	0.88
CV%		5.3	13.9

df, degrees of freedom; **highly significant differences (p≤0.01); ns, no significant differences (p>0.05); R^2, coefficient of determination; CV, coefficient of variation.

Table 4. Crop coefficients for four cowpea bean genotypes.

Genotypes	Kc	ETo (mm day^{-1})	Irrigation sheet (mm day^{-1})	Total sheet (mm cycle^{-1})	Yield (kg ha^{-1})
LC-019	1.1	4	4.4	220	2092.36
LC-005-16	0.9	4	3.6	180	1438.54
LC-014-016	0.9	4	3.6	180	2024.57
CAUPICOR 50	1.1	4	4.4	220	2279.62

Kc, crop coefficients; ETo, maximum potential evapotranspiration.

and LC-019 presented the highest yields with 2,276.62 and 2,092 kg ha^{-1}, respectively; while an irrigation sheet of 3.6 mm day^{-1}, allowed the cultivars LC-005-016 and LC-014-016, yields of 1438.54 and 2024.57 kg ha^{-1} each These results show that the application of irrigation in the different genotypes of cowpea beans can enhance their yields. In the same way, knowing the Kc values, allows to estimate the irrigation sheets for a certain area when its evapotranspiration is known, and at the same time, irrigation planning can be done contributing to the efficient use of water.

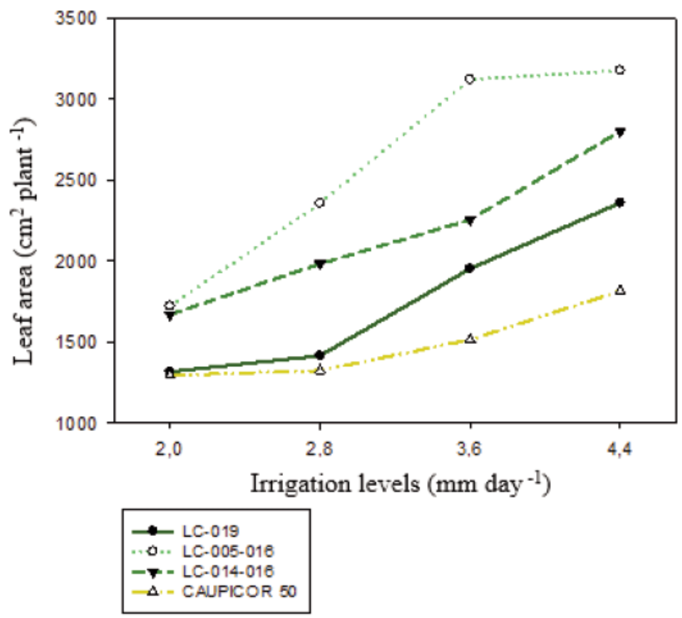

Figure 2. Behavior of the leaf area for four cowpea genotypes and four irrigation sheets at 55 days after emergency.

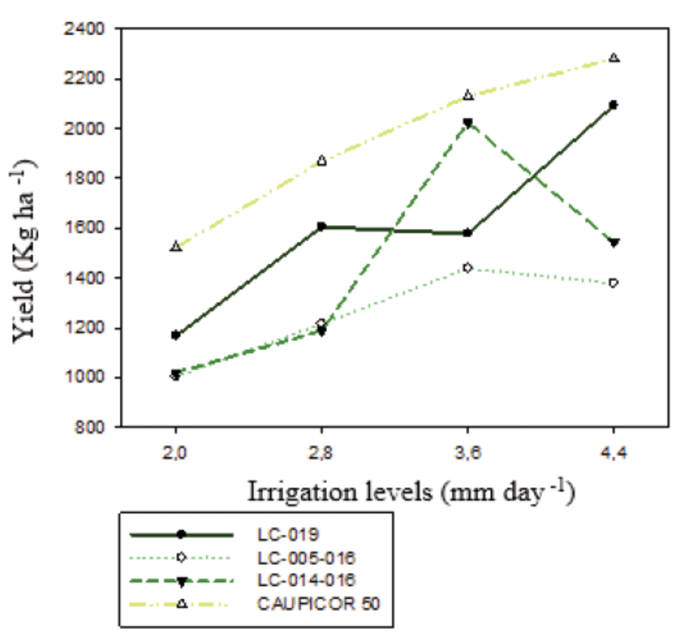

Figure 3. Yield of four cowpea genotypes under the effect of four irrigation sheets.

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