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Effect of water stress on growth and yield of selected cowpea (*Vigna unguiculata* L.) varieties

Ghadeer Ali Fatalawi [1*], Mundher kh. Jabbar [2]

[1]Crops Sciences Department, College of Agriculture Engineering Sciences, University of Karbala, Karbala, Iraq.
[2]Crops Sciences Department, College of Agriculture Engineering Sciences, University of Al-Qasim Green , Babylon, Iraq.
*Corresponding author e-mail: ghadeer.a@uokerbala.edu.iq
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Abstract

The study aimed to evaluate the effect of water stress on the growth and yield of selected cowpea (*Vigna unguiculata* L.) varieties. The experiment included two factors: the first factor was irrigation levels, The secondry factor was three cowpea varieties. Harvesting was done after the pods reached the drying stage, 90 days after planting. The results were analyzed according to the statistical design used, and comparisons between means were made using the Least Significant Difference. The results showed a significant effect of using different irrigation levels on The characteristics of plant height, number of leaves, leaf area, biological yield, and percentage of protein, where the irrigation level exceeded 100% of the field capacity, giving the highest averages, reached (142.1 cm, 52.8 leaves.plant-1, 2188 cm2, 72.86 g, 14.71 tons.ha-1, 26.062%). Furthermore, the results showed the superiority of the ROTTRDAM variety in the traits of plant height and number of leaves, reaching (155 cm and 50.2 leaves.plant^{-1}, respectively). The Ramshorn variety excelled in the traits of leaf area and biological yield, recording (1924 cm^2 and 15.62 ton.ha^{-1}, respectively). The Yunanda variety was superior in the traits of 300-seed weight and percentage of protein, reaching (74.47 g and 27.987%, respectively). A significant interaction was observed between the two study factors. The interaction between the 100% irrigation level and the ROTTRDAM variety recorded the highest plant height and number of leaves (171.4 cm and 54.5 leaves.plant^{-1}, respectively). The interaction between the 100% irrigation level and the Ramshorn variety recorded the highest leaf area and biological yield (2679 cm^2 and 15.92 ton.ha^{-1}, respectively). The interaction between the 100% irrigation level and the Yunanda variety recorded the highest 300-seed weight and percentage of protein (75.82 g and 29.586%, respectively).

Keywords: Water stress , Cowpea , Varieties, Growth, Yield

Introduction

Cowpea (*Vigna unguiculata L.*) is considered a vital and strategic legume crop of utmost importance on both the agricultural and nutritional fronts, especially in tropical and semi-arid regions. It serves as a primary and low-cost source of plant protein for millions of people [1]. In addition to its high nutritional value, the agricultural importance of cowpea is highlighted by its vital role in sustainable agriculture, owing to its distinct and effective ability to fix atmospheric nitrogen biologically in the soil, which enhances soil fertility and reduces reliance on chemical nitrogen fertilizers. This contributes to the sustainability of agricultural productivity and the improvement of soil quality [2].

The significant variation in performance among cowpea varieties under conditions of water scarcity underscores the urgent need to select and evaluate genetically superior varieties. The plant's response to drought is not limited to a single trait but is a complex outcome of morphological, physiological, and molecular mechanisms. Some varieties are able to maintain osmotic pressure, increase Water Use Efficiency (WUE), and direct resources toward root growth and subsequent yield formation.

Numerous scientific studies have confirmed the existence of wide genetic variation among cowpea varieties. Some varieties have shown clear superiority in growth and yield traits when exposed to water stress conditions. A study on four cowpea varieties showed that the 'Ma'rifa' variety outperformed the local variety in several important morphological traits, such as plant height and leaf area (recording 7840.23 cm^2 compared to 4499.75 cm^2 for the local variety). This superiority, in addition to its yield, suggests its better ability to adapt and convert resources to yield, supporting the idea of the existence of genetically superior varieties [3].

Water is considered the primary determinant and a crucial factor for the growth and productivity of the cowpea plant, especially in dry environments that suffer from water resource scarcity or fluctuating rainfall. Water stress negatively affects morphological characteristics (such as plant height and leaf area) and physiological processes (such as the efficiency of photosynthesis), which ultimately reflects on the final crop traits in terms of seed weight, and protein percentage [4]. The severity of this stress is particularly evident during sensitive reproductive stages (flowering and pod formation), where it can cause severe losses in crop yield, potentially exceeding 50% [5].

To address this challenge, research focuses on two main strategies: developing drought-tolerant varieties and improving irrigation management efficiency. Studies have shown clear genetic variation in the response of cowpea varieties to water stress, leading to the identification of promising varieties such as 'IT98K-131-2' and 'IT98K-205-8', which have the ability to maintain osmotic pressure and functional stability under water scarcity conditions [6].

In parallel with variety improvement, studies investigate improving Water Use Efficiency through irrigation systems. Results indicate that applying deficit or supplemental irrigation at a level of 60-80% of the total water requirement can achieve an effective balance between rationalizing water consumption and maintaining acceptable economic productivity [7]

These combined efforts highlight the importance of adapting to the escalating challenges resulting from climate change and water scarcity. This makes the development of drought-tolerant varieties and the improvement of water resource management two fundamental pillars for ensuring the sustainability of cowpea production [9].

Therefore, this study aims to analyze and evaluate the effect of water stress on a selected group of cowpea varieties, focusing on morphological, physiological, and yield traits. This is to identify the most drought-tolerant and water-efficient varieties, which will contribute to finding sustainable solutions for cowpea cultivation in regions suffering from water scarcity.

Materials and Methods

A field experiment was conducted during the summer season of 2024 (15/3/2024) in the field belonging to the Department of Field Crops, College of Agriculture, Al-Qasim Green University in Babylon Governorate. A Split-Plot Design with three replications was used. The experiment included two factors: the first factor was irrigation levels, which comprised three levels: 100% of Field Capacity (FC), 75% of Field Capacity (FC), and 50% of Field Capacity (FC). The second factor was three cowpea varieties: Rottrdam, Ramshorn, and Yunanda. Harvesting was done after the pods reached the drying stage, 90 days after planting. The results were analyzed according to the statistical design used, and comparisons between means were made using the Least Significant Difference (L.S.D.) test at a 0.05 probability level. The measurement was performed using a Kjeldal apparatus.

The experimental unit consisted of 4 rows with a length of 3 m. Planting was done on one side of the row, with 50 cm between rows and 25 cm between plants (one plant/furrow) after thinning, at a plant density of 53333 plants.ha^{-1}

Fertilization was applied by adding DAP fertilizer (18% N – 46% P_2O_5) as a source of phosphorus at 75 kg P_2O_5.ha^{-1} and nitrogen at 40 kg N.ha^{-1} in two batches: the first with phosphorus before planting, and the second batch 20 days after planting with Potassium Sulphate fertilizer (50% K_2O) at 75 kg K_2O.ha^{-1} [10].

The physical and chemical properties of the soil at a depth of (0-30) cm before planting were taken (Table 1).

Vegetative Growth Traits

Plant Height (cm)

Ten random plants were selected from the two central rows of each experimental unit. The height was measured using a measuring tape, starting from the base of the stem near the soil surface up to the end of the main stem. The average for each experimental unit was calculated.

Number of Leaves (leaf.plant^{-1})

The number of leaves was counted for the ten plants selected for calculating the traits in each experimental unit. The average for each experimental unit was taken.

Leaf Area (cm²)

The leaf area for each treatment was calculated by measuring the leaf area of three leaves (upper, middle, lower) for five randomly selected plants from the two central rows. The average was extracted using the following equation:

$$\text{Leaf Area} = \text{Maximum Length} \times \text{Maximum Width} \times 0.68[11]$$

Total Leaf Area = Leaf Area*Number of Leaves

Seed Weight (g)

The seeds were weighed after complete drying

Biological Yield (ton.ha^{-1})

Calculated based on the yield of the ten plants from the two central rows, plus the yield of the two central rows.

Percentage of Protein (%)

The measurement was performed using a Kjeldal apparatus.

$\text{Percentage of Protein} = N \times 6.25[12]$

*I_1=100% FC I_2=75%FC I_3=50%FC

*V_1=Yunanda V_2= Ramshorn V_3=Rottrdam

Table (1): Some Physical and Chemical Properties of Field Soil

Soil Separators%			OM%	Available Elements (mg/kg)			Ec (ds.m^{-1})	pH
Sand	SILT	CLAY		K	P	N		
285	482	233	1.73	314	9.33	38.62	3.8	7.2
Clay Silty				Soil Texture				

Results and Discussion

Table (2): Effect of Irrigation Levels on Growth and Yield Traits.

Irrigation Level	Plant Height (cm)	Number of Leaves (leaf.plant^{-1})	Leaf Area (cm^2)	Biological Yield (ton.ha^{-1})	300-Seed Weight (g)	Protein Percentage (%)
I_1	142.1	52.8	2188	14.71	72.86	26.062
I_2	135.7	48.4	1666	14.09	71.95	23.289
I_3	115.5	35.5	1317	12.65	71.29	21.953
L.S.D. (0.05)	32.87	12.72	813.9	1.426	3.795	0.8598

The analysis indicated that the 100% Field Capacity (FC) irrigation level significantly outperformed the others, providing optimal water potential to ensure the continuity of vital physiological processes, such as the necessary turgor pressure for cell elongation and growth. Crucially, there was no significant difference between the 100% and 75% FC irrigation treatments, suggesting the latter lies above the critical threshold for initiating water stress. Therefore, providing 75% of the water was sufficient to maintain physiological performance near its maximum potential. This similar performance implies that increasing water from 75% to 100% only provided marginal, non-significant gains, highlighting high Water Use Efficiency (WUE) at the 75% level and avoiding wasteful luxury consumption.

Table (3): Effect of Varieties on Growth and Yield Traits

Variety	Plant Height (cm)	Number of Leaves (leaf.plant⁻¹)	Leaf Area (cm²)	Biological Yield (ton.ha⁻¹)	300-Seed Weight (g)	Protein Percentage (%)
V_1	97.5	41.0	1563	12.98	74.47	27.987
V_2	140	45.5	1924	15.62	69.95	21.438
V_3	155.8	50.2	1685	12.86	71.69	21.881
L.S.D. (0.05)	13.99	6.58	608.3	1.162	4.363	0.5097

The results in Table 3 show the superiority of the ROTTRDAM variety in the traits of plant height and number of leaves, reaching (155.8 cm and 50.2 leaves.plant^{-1}, respectively). The remarkable superiority of the [ROTTRDAM] variety in plant height and number of leaves is attributed to its possession of a genetically superior trait characterized by high vegetative growth vigor. This superiority at the physiological level is interpreted as higher efficiency in net photosynthesis, which increases the production of dry matter and directs it towards building vegetative parts. Furthermore, the increase in plant height and number of leaves indicates the variety's efficiency in utilizing growth hormones such as auxins and gibberellins, which support cell elongation and increase the distance between nodes, delaying entry into the reproductive stage. This allows for greater resource accumulation, which directly reflects on the increase in the total height and number of leaves of the plant [13].

The Ramshorn variety excelled in the traits of leaf area and biological yield, recording (1924 cm² and 15.62 ton.ha^{-1}, respectively).

Superiority in Leaf Area (Leaf Area) The leaf area is the "factory" responsible for food production in the plant. This variety possesses a genetic trait that allows for a high density of chlorophyll in the leaves, which increases its ability to absorb solar energy. Larger and more numerous leaves contribute to increasing the leaf area. This increase means intercepting a larger amount of solar radiation, which translates into a higher net photosynthetic rate compared to other varieties. The variety shows an effective response to growth hormones, such as auxins, which support the rapid expansion of epidermal and mesophyll cells, increasing the size of the leaves and the length of the internodes.

Relationship between Leaf Area and Biological Yield Biological yield is the total dry mass produced by the plant (roots, stems, leaves, pods, and seeds). It is directly linked to the accumulation of dry matter. Since leaves are the primary source of carbohydrates, increasing their quantity (leaf area) and efficiency (photosynthesis) inevitably leads to a greater accumulation of dry matter throughout the season. This dry matter constitutes the biological yield. The superior variety is characterized by an effective balance in the allocation of resources, where it allocates a large portion to vegetative growth initially, and then efficiently directs it later to the reproductive organs (pods and seeds), which keeps the biological yield high even in the later stages [14].

The Yunanda variety was superior in the traits of 300-seed weight and percentage of protein, reaching (74.47 g and 27.987%, respectively). The superiority of this variety in the traits of 300-seed weight and percentage of protein is due to the synergy of genetically physiological mechanisms that focus on the efficiency of filling and the quality of the yield. Seed weight is considered an important morphological indicator for yield components. The superiority of the variety in this is due to the efficiency of the seed-filling period. The superior variety possesses a genetic trait that ensures the continuation of the process of transporting and accumulating nutritional materials (carbohydrates and fats) to the seeds for a longer period and at a faster rate. This prevents premature cessation of material accumulation in the seeds. The allocation of nitrogen: This variety possesses superior physiological mechanisms in recycling nitrogen from the vegetative organs (leaves that have begun senescence) and transporting it efficiently, storing it in the internal cytoplasm of the seed cells in the form of storage proteins [15].

Table (4): Effect of Interaction between Irrigation Levels and Varieties on Growth and Yield Traits.

Irrigation Level	Variety	Plant Height (cm)	Number of Leaves ($leaf.plant^{-1}$)	Leaf Area (cm^2)	Biological Yield ($ton.ha^{-1}$)	300-Seed Weight (g)	Protein Percentage (%)
I_1	V_1	112.3	52.3	2033	13.84	75.82	29.586
I_1	V_2	142.7	51.6	2679	15.92	70.34	23.309
I_1	V_3	171.4	54.5	1852	14.39	72.44	25.293
I_2	V_1	107.2	46.6	1520	12.78	74.06	28.149
I_2	V_2	141.5	49.2	1832	15.72	70.32	21.327
I_2	V_3	158.3	49.4	1647	13.78	71.48	20.392
I_3	V_1	73	24.0	1137	12.32	73.54	26.225
I_3	V_2	135.9	35.7	1260	15.23	69.2	19.678
I_3	V_3	137.5	46.8	1555	10.42	71.14	19.958
L.S.D.(0.05)		33.7	13.76	1047.6	1.938	6.678	0.9807

A significant interaction was observed between the two study factors. The interaction between the 100% irrigation level and the ROTTRDAM variety recorded the highest plant height and number of leaves (171.4 cm and 54.5 $leaves.plant^{-1}$,) respectively. Optimal Genetic Response to Water: The Rotterdam cultivar possesses a genetic makeup that allows it to maximize benefit from the full availability of its water requirements (100% irrigation). Enhanced Cell Division and Elongation: Optimal water availability acts as a fundamental factor in increasing photosynthetic rates and augmenting the Turgor Pressure in the cells. This, in turn, accelerates cell elongation processes in the stem and leaves, leading to a significant increase in plant height and number of leaves.

Active Vegetative Growth: These results indicate that this combination (Rotterdam + 100% irrigation) primarily directs the plant's energy towards vegetative growth. The interaction between the 100% irrigation level and the Ramshorn variety recorded the highest leaf area and biological yield (2679 cm^2 and 15.92 $ton.ha^{-1}$), respectively Radiation Interception Efficiency: When optimal irrigation (100%) is provided, the Ramshorn cultivar exhibits a genetic ability to form a larger leaf area. A large leaf area is the crucial factor in intercepting and absorbing the maximum amount of solar radiation.Increased Photosynthetic Efficiency: This maximal light absorption translates into the highest rate of Dry Matter production throughout the season, which is reflected in the very high Biological Yield. The Biological Yield represents the total dry weight of the above-ground part of the plant (vegetative and reproductive components).Resource Allocation: This cultivar allocates its resources with high efficiency toward forming a large biomass under ideal water conditions. . The interaction between the 100% irrigation level and the Yunanda variety recorded the highest 300-seed weight and percentage of protein (75.82 g and 29.586%), respectively. Focus on Quality Components: The Yonanda cultivar excels in the transport and storage of photosynthetic products (carbohydrates) and nitrogen into the seeds during the Grain Filling Stage, especially in the absence of water stress. Increased Individual Seed Weight: Full water availability ensures the continuation of carbohydrate synthesis and their flow to the seeds until maturity, which increases the weight of the individual seed (known as the 1000-seed weight, here the 300-seed weight). Nitrogen Utilization Efficiency: The high protein percentage suggests that the combination (Yonanda + 100% irrigation) has enhanced the plant's efficiency in uptake, translocation, and synthesis of proteins within the seeds. Protein is primarily composed of nitrogen, and water availability is essential for the processes of nitrogen absorption from the soil and its conversion into proteins (amino acids). This indicates that Yonanda is a high-quality cultivar under optimal conditions.

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