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ORIGINAL RESEARCH PAPER

Responses of sunflower biomass subjected to different water replacements and NPK sources

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Abstract: Sunflower is an important agricultural crop with high water demand for optimal development. This study aimed to evaluate the physiological responses of sunflower plants subjected to different irrigation levels and NPK fertilizer sources under protected conditions. The experiment was conducted in pots placed in a greenhouse, with controlled water deficit via lysimeters and application of various doses of NPK fertilizers, in both mineral and organomineral forms. The variables analyzed were fresh mass, dry mass, and water content of the floral capitulum. Results showed that irrigation levels between 103% and 125% led to greater accumulation of dry matter in the leaves and stems. In contrast, increasing NPK doses reduced leaf and stem dry mass, possibly due to toxic effects at doses exceeding crop recommendations. Organomineral fertilization demonstrated a positive effect on the development of leaf and stem biomass. Further studies are recommended to explore the use of alternative natural fertilization strategies in sunflower cultivation.

Keywords: *Helianthus* genus; Minerals; Phosphorus; Potassium; Agronomic parameters.

1. Introduction

Sunflower (*Helianthus annuus* L.) is a crop recognized for its high tolerance to adverse conditions such as drought, cold, and heat, also demonstrating a broad capacity to adapt to different soil types (Yankov; Drumeva, 2021). Another crucial factor for achieving good agricultural production in sunflower cultivation is water availability. Several studies indicate that adequate water supply significantly increases productivity, oil content in the seeds, and dry biomass of the plant (Gomes et al., 2012), while water deficit negatively affects production in terms of yield (Bashir et al., 2021). As described by Hussain et al. (2009), water from rainfall alone is often insufficient or irregular, especially in semi-arid regions or areas with uneven water distribution throughout the year, which does not guarantee satisfactory yields.

Another essential factor for the development of sunflower cultivation is fertilization. The primary nutrients required in greater amounts by plants are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) (Coelho, 2006). Although mineral fertilizers supply the necessary nutrients for growth, they do not improve the physical properties of the soil (Rabelo, 2015). Conversely, soil organic matter (OM) dynamics can be influenced by the addition of both mineral fertilizers and organic materials, which positively affect soil quality (Leite et al., 2003).

In recent years, the use of organomineral fertilizers has grown significantly, driven by cost reductions compared to conventional mineral fertilizers, high nutrient concentrations, and the benefits that organic matter provides to the soil. These fertilizers have been applied to replace or complement mineral fertilization in agricultural systems (Timossi et al., 2016; Malaquias; Sousa, 2017).

Given this context, the present study aimed to evaluate biomass production and water content in sunflower crops under different levels of water deficit and with mineral and organomineral NPK fertilization applied at sowing.

2. Material and Methods

2.1. Experimental site

The experiment was conducted in 2025 in the experimental area of the Federal Institute of Goiás – Rio Verde Campus, located in the municipality of Rio Verde, state of Goiás, Brazil.

2.2. Climate type and experimental design

The regional climate is classified as Aw, according to Köppen and Geiger (1928), characterized by dry winters and rainy summers, with an average annual temperature ranging from 20 to 25 °C and annual rainfall exceeding 1500 mm.

The experimental design used was a randomized block design (RBD), arranged in a 4 × 4 × 2 factorial scheme with three replications. The evaluated factors were: four irrigation replacement levels (50, 75, 100, and 125% of the available soil water capacity), four doses of NPK fertilizer (4:14:8 formulation) at 50, 100, 150, and 200% of the recommended rate (according to Sousa and Lobato, 2003), and two fertilizer sources (mineral and organomineral).

2.3. Irrigation control

Irrigation depth was controlled using four electronic weighing lysimeters. The irrigation system was surface drip, using pressure-compensating emitters (iDrop PC-PCDS model, Irritec®), with a flow rate of 2.2 L h^{-1}, installed in low-density polyethylene tubing (16 mm), spaced 0.5 m apart and pressurized by a motor-pump assembly.

2.4. Soil type and planting soil analysis

The soil used was classified as dystroferric Red Latosol (LVdf), clay-textured, Cerrado phase (Santos et al., 2018), collected from an area with a 10-year history of cultivation with pastures or annual crops (Table 1). Soil samples were collected from the 0–20 cm and 20–40 cm depth layers.

Table 1. Physicochemical characterization of the soil used in the experiment, Rio Verde, GO, Brazil.

Ca	Mg	Ca+Mg	Al	H+Al	K	K	S	P	$CaCl_2$
----------------- $cmol_c$ dm^{-3} -----------------						--------- mg dm^{-3} ---------			pH
0.94	0.86	1.8	0.03	2.39	0.32	126	5.0	1.09	5.2
Na	Fe	Mn	Cu	Zn	B	CTC	SB	V%	m%
-------- Micronutrients (mg dm^{-3}) -------						$cmol_c$ dm^{-3}		Base sat.	Al Sat.
1.0	21.4	22.52	4.25	1.13	0.09	4.51	2.12	47	1.4
Texture (%)			M.O.	Ca/Mg	Ca/K	Mg/K	Ca/CEC	Mg/CEC	K/CEC
Clay	Silt	Sand	g dm^{-3}	----------------- Bases Ratio -----------------					
45	8	47	36.3	1.1	2.9	2.7	20.84	19.07	7.10

Note: P (Mel), K, Na, Cu, Fe, Mn, and Zn = extraction by Melich[1] method, Ca, Mg, and Al = extraction with 1N KCl, S = extraction with $Ca(H_2PO_4)_2$ in acetic acid (HOAc), Organic Matter (O.M.) = Colorimetric method, B = extraction with $BaCl_2$. CEC = Soil Cation Exchange Capacity. Source: Authors, 2025.

2.5. Experiment setup

The experiment was conducted in black plastic pots with a capacity of 30 L. Eight sunflower seeds, cultivar Aguará 6, were sown per pot/lysimeter after soil moisture was adjusted to field capacity to ensure ideal conditions for germination. At 12 days after sowing (DAS), with a germination rate above 80%, thinning was performed to maintain a single plant per experimental unit, ensuring uniform development. Irrigation replacement treatments were applied until 80 DAS, after which they were discontinued to allow natural physiological maturation of the achenes.

2.6. Morphological parameters evaluated

Fresh and dry masses of the leaves (FLM and DLM), stem (FSM and DSM), and capitulum (FMSC and DMSC) were measured, as well as the water content of the leaves (TWC), stem (SWC), and capitulum (WCCS). After selection, the plants were carefully separated into leaf with petiole, stem, and capitulum. Each part was oven-dried at 65 °C for 72 h. After drying, each plant fraction was weighed using an analytical balance with a precision of 0.001 g, ensuring reliable data for subsequent analyses.

2.4. Statistical analysis

Data analysis was performed using SISVAR® software (Ferreira, 2019). Main effects and interactions between factors were assessed by the *F-test* at a 5% significance level ($p < 0.05$). When statistical significance was detected, *Tukey's* test was applied for mean comparisons. For quantitative factors, irrigation replacement and NPK fertilizer doses, regression analysis was conducted.

3. Results

The irrigation replacement factor (IR) significantly influenced the dry weight of the leaves (FLM), fresh weight of the stem (FSM), and dry weight of the stem (DLM), while the NPK dose factor (D) affected the fresh weight of the stem (DSM). Additionally, there was a significant interaction effect between doses and fertilizer sources (D × F) for DWL and FWS (Table 2).

The irrigation replacement (IR) factor significantly influenced leaf fresh mass (FLM), stem fresh mass (FSM), and stem dry mass (DSM), while the NPK dose (D) affected only FSM. Additionally, a significant interaction effect between fertilizer doses and sources (D × F) was observed for FLM and FSM (Table 2).

Table 2. Analysis of variance for fresh weight (FLM) and dry weight (DLM) of leaves, fresh weight (FSM) and dry weight (DSM) of the stem, and fresh weight (FMSC) and dry weight (DMSC) of the sunflower capitulum at harvest, as affected by irrigation replacement, NPK doses, and fertilizer sources, Rio Verde, GO, Brazil.

Variation Source	DF	Mean Square					
		FLM[1]	DLM	FSM[1]	DSM[1]	FMSC[1]	DMSC[1]
Fluid Replacement (FH)	3	28.22^{ns}	1578.34**	68.04*	18.48*	18.80^{ns}	6.88^{ns}
Block	2	7.83^{ns}	158.17^{ns}	10.82^{ns}	1.53^{ns}	14.39^{ns}	1.27^{ns}
Residue (a)	6	7.73	142.28	8.80	1.93	10.35	2.48
Dose (D)	3	8.55^{ns}	126.32^{ns}	14.22*	1.41^{ns}	81.83^{ns}	4.02^{ns}
FR x D	9	2.33^{ns}	47.40^{ns}	2.77^{ns}	0.54^{ns}	17.27^{ns}	1.25
Residue (b)	6	2.47	40.73	2.36	1.46	24.22	2.53
Source (F)	1	4.60^{ns}	214.20^{ns}	13.47^{ns}	0.62^{ns}	6.67^{ns}	0.84
RF x F Interaction	3	6.85^{ns}	35.14^{ns}	3.28^{ns}	1.95^{ns}	11.45^{ns}	1.92
D x F Interaction	3	5.26^{ns}	519.37**	12.79*	2.17^{ns}	20.57^{ns}	0.95
RF x D x F Interaction	9	3.53^{ns}	34.81^{ns}	2.61^{ns}	0.66^{ns}	14.73^{ns}	0.68
Residue (c)	50	2.67	104.82	3.29	0.89	11.85	1.98
CV a (%)		29.12	28.28	25.96	20.10	28.12	24.86
CV b (%)		16.47	15.13	13.44	17.54	43.00	25.12
CV c (%)		17.15	24.28	15.89	13.72	30.08	22.20

Note: ¹ Data transformed using the square root of X. ns: not significant; * and **: significant at 5% and 1% probability levels, respectively, according to the *F-test*. DF – Degrees of freedom; CV – Coefficient of variation. DF = Degrees of Freedom. Source: Authors, 2025.

For each 25% increase in irrigation replacement (IR), there was a 15.59% and 25.14% increase in DLM and FSM, respectively, corresponding to 6.1 g and 30.5 g. When comparing the IR extremes of 50% and 125%, DLM increased by 35.62% and SFM by 50.18%. The DSM showed a second-degree polynomial response to IR, with the maximum value of 55.38 g obtained at 103.87% IR.

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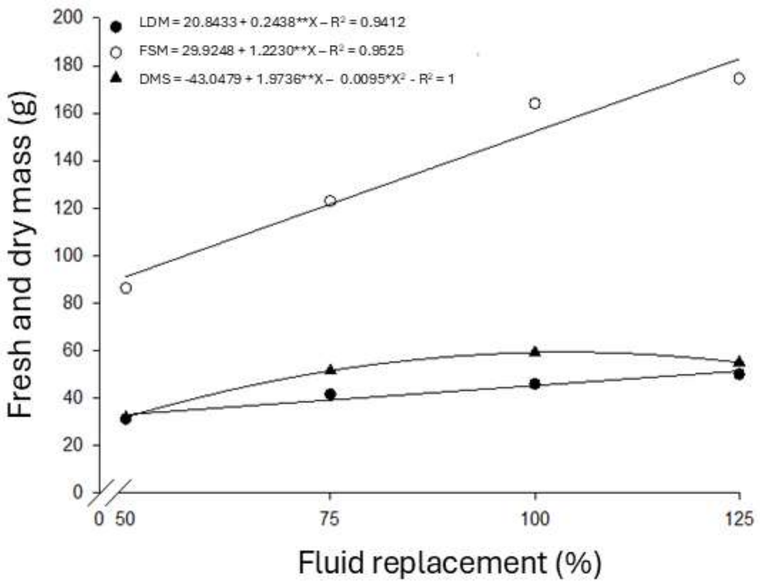

Figure 1. Leaf dry weight and stem fresh and dry weight as a function of irrigation replacement, Rio Verde, GO, Brazil. Source: Authors, 2025.

In Figure 2A, for the organomineral (OM) fertilizer source, the variable DLM fit a second-degree polynomial equation, with the 158.75% dose resulting in the lowest DLM value, equivalent to 37.9 g. Increasing the OM doses led to a reduction in stem fresh mass FSM, with an average decrease of 26.5 g for every 50% increment in dose.

When comparing the 50% and 200% doses, a 73.75% reduction in FSM was observed. Statistically significant differences were found only at the 50% dose between the fertilizer sources (Figure 2B), where the OM source increased DLM by 30.9% and FSM by 38.34% compared to the mineral (M) source.

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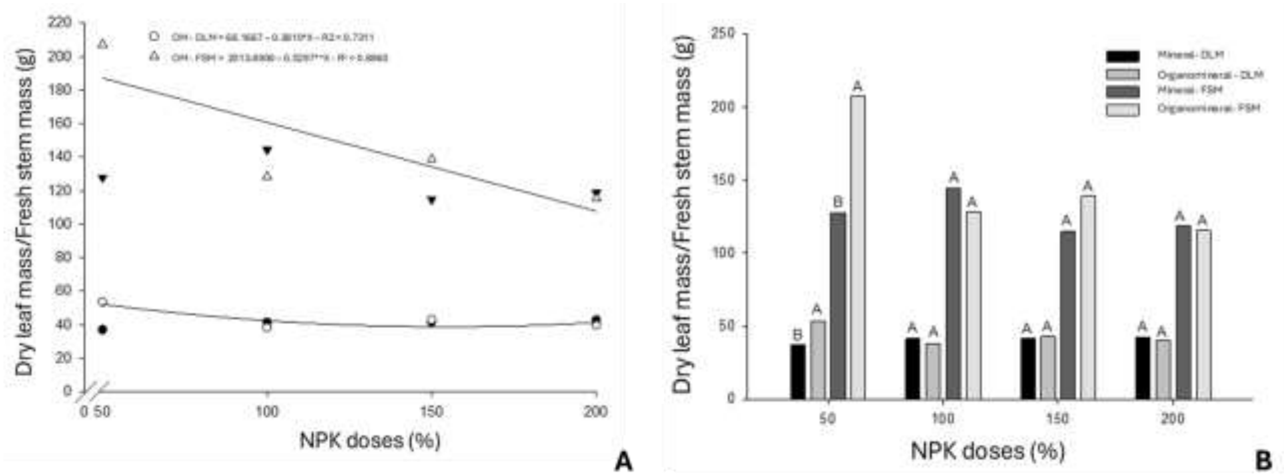

Figure 2. Breakdown of the significant interaction between NPK doses (A) and fertilizer sources (B) — mineral (M) and organomineral (OM) — on sunflower leaf dry weight and stem fresh weight. Rio Verde – GO.

No significant differences were observed in the LWC, SWC, and WCSC for any of the evaluated factors (Table 3).

Table 3. Analysis of variance for water content in leaves, stem, and capitulum of sunflower at harvest, as affected by irrigation replacement, NPK doses, and fertilizer sources. Rio Verde – GO.

Variation Source	DF	Mean Square		
		LWC[1]	SWC	WCSC[1]
Fluid Replacement (RF)	3	1.60	332.31	1.30
Block	2	1.65	862.24	3.37
Residue (a)	6	1.04	123.20	4.00
Dose (D)	3	1.53	197.26	8.50
RF x D Interaction	9	0.40	222.08	4.59
Residue (b)	6	1.45	201.05	4.62
Source (F)	1	0.03	75.70	10.29
RF x F Interaction	3	1.42	429.41	5.54
D x F Interaction	3	0.15	35.75	0.45
RF x D x F Interaction	9	1.44	208.69	5.46
Residue (c)	50	0.68	180.21	3.22
CV a (%)		14.31	18.23	26.57
CV b (%)		16.92	23.29	28.57
CV c (%)		11.61	22.05	23.85

Note: [1] Data transformed using the square root of X. DF = Degrees Freedom. Source: Authors, 2025

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4. Discussion

Helianthus annuus is known for its adaptability to various edaphoclimatic conditions, including semi-arid environments. However, despite its relative tolerance, water deficit during critical growth stages can significantly compromise crop productivity. Water scarcity affects essential physiological processes such as photosynthesis, stomatal conductance, nutrient transport, and cell expansion, directly reducing plant biomass and grain yield (Hussain et al., 2009; Gomes et al., 2012).

According to Ahmad et al. (2022), moderate to severe water stress, particularly during flowering and grain filling, reduces water content in plant tissues and dry matter accumulation, negatively impacting capitulum formation and oil yield. Similarly, Soares et al. (2015) observed a 19.56% reduction in stem dry mass in plants subjected to water limitation, demonstrating that even resilient species like sunflower are sensitive to water shortages at certain growth stages.

In this study, irrigation levels exceeding 100% of the reference evapotranspiration resulted in greater accumulation of dry matter in leaves and stems, indicating that adequate water supply is essential for optimal vegetative growth. These findings are consistent with Farooq et al. (2014), who highlighted the importance of supplemental irrigation in maintaining productivity under water deficit conditions.

Therefore, proper water management is crucial to maximize the physiological and productive performance of sunflower. Technologies for monitoring soil moisture and the rational use of irrigation are recommended, especially in regions with irregular rainfall distribution throughout the crop cycle (Azevedo et al., 2016).

These results further indicate that the fertilization recommendation adopted under the experimental conditions exceeded the nutritional requirements of sunflower, which may explain the reduction in fresh biomass. Furtado et al. (2017) reported that the 50% NPK recommendation dose resulted in the highest phytomass production of leaves and capitulum in sunflower plants, a finding similar to that observed in the present study (Figure 2A).

Several studies have confirmed that applying NPK doses above agronomic recommendations can have toxic effects, negatively impacting plant development. Although these macro- and micronutrients are essential in adequate amounts, their excess may lead to nutritional imbalances, reduced productivity, and adverse physiological changes. Mineral fertilization, especially with macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), is essential to ensure crop growth and productivity. However, excessive or unbalanced use of these nutrients can lead to toxic effects or nutritional imbalances that negatively affect plant metabolism and yield (Malavolta et al., 1997; Marschner, 2012).

In the present study, increasing NPK doses—particularly in the organomineral form—significantly reduced the dry mass of sunflower leaves and stems, especially at doses above 150% of the standard recommendation (Sousa; Lobato, 2004). The 200% dose led to reductions of up to 35% in shoot dry mass compared to the 50% dose, suggesting a possible toxic or suppressive effect due to nutrient excess.

According to Timossi et al. (2016), nitrogen toxicity may result from nitrate accumulation in plant tissues, leading to inhibited chlorophyll synthesis, osmotic imbalance, and reduced photosynthetic efficiency. Similarly, excessive potassium can interfere with calcium and magnesium uptake—nutrients essential for ionic balance and membrane stability (Epstein; Bloom, 2005). While phosphorus toxicity is less common, it can cause micronutrient deficiencies, such as zinc and iron, due to the formation of insoluble complexes (Alloway, 2008).

Studies specifically on sunflower also indicate a sensitivity of the crop to nutrient excess. Furtado et al. (2017) found that a 50% NPK recommendation yielded the highest biomass production in both leaves and capitulum, while higher doses did not result in additional gains, confirming the risk of over-fertilization toxicity. Similar results were reported by Shafiq et al. (2021), who observed decreased photosynthetic efficiency and total dry mass in sunflower plants subjected to excess nitrogen.

Therefore, determining appropriate NPK doses should consider not only the crop's productive potential but also its nutrient uptake capacity and the balance among nutrients. This helps to avoid economic losses and environmental impacts associated with excessive fertilizer use.

5. Conclusion

The application of irrigation levels exceeding 100% of the reference evapotranspiration, particularly at 103% and 125%, promoted greater dry matter accumulation in sunflower leaves and stems, highlighting the importance of efficient and precisely adjusted water management for the crop.

On the other hand, increasing NPK doses via organomineral fertilizer resulted in reductions in leaf dry weight and stem fresh weight, suggesting that excessive nutrient supply may surpass the crop's nutritional demands and compromise shoot development.

Notably, organomineral fertilization at 50% of the conventional recommendation provided the highest leaf dry mass and stem fresh mass compared to mineral fertilization alone, indicating its agronomic and economic viability.

Furthermore, no significant effects were observed for irrigation levels, fertilization doses, or fertilizer sources on water content in plant tissues or on fresh and dry biomass of the capitulum, indicating that these variables were less responsive under the conditions tested in this study.

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Author’s Contributions

Rafael Borges de Assis: Conceptualization, Investigation, Data curation, Writing – original draft. Fernando Rodrigues Cabral Filho: Co-supervision, Investigation, Data curation, Writing – original draft, Writing – review & editing. Matheus Vinícius Abadia Ventura: Supervision, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition, Publication. Gustavo Quereza de Freitas: Data curation, Writing – original draft, Writing – review & editing. Marconi Batista Teixeira: Writing – original draft, Writing – review & editing, Funding acquisition. Nelmício Furtado da Silva: Data curation, Writing – original draft, Writing – review & editing. Fernando Nobre Cunha: Data curation, Writing – original draft, Writing – review & editing. Christiano Lima Lobo de Andrade: Supervision, Writing – original draft, Writing – review & editing, Publication.

Ethics

The authors declare that there are no discrepancies in the publication.