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Research paper

Biomass response of chickpea (*Cicer arietinum* L.) to different textured soils and irrigation levels

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Irrigation is required to supplement rainfall to enhance the productivity of chickpea in South Africa (SA). However, the dependence on irrigation can be problematic for SA and other countries with limited natural water resources and variable rainfall. Even though access to irrigation water has been identified as one of the challenges faced when planting chickpea in the winter season in SA, irrigation management strategies for chickpea grown on soils differing in texture have not gained considerable research attention. Hence, this study aimed to assess the effects of irrigation levels on dry matter production of chickpea grown on two soils differing in soil texture under greenhouse conditions. The experiment was arranged as a 3 × 2 factorial in a completely randomized design, with 3 irrigation levels (25%, 50% and 75% of the water-holding capacity of soil (WHC)) and 2 soils differing in soil textural class (Loamy sand (LS) soil and sandy loam (SL) soil), replicated thrice. Irrigation level, soil texture and their interaction significantly affected shoot biomass (SBM) and total plant biomass (TBM). Generally, SBM, TBM and root biomass decreased correspondingly with the reduction in irrigation. The 25% WHC significantly reduced the SBM by up to 60% and TBM by up to 56% compared to the 50% and 75% WHC. The SBM and TBM were higher in SL soil than in LS soil. A significantly higher root/shoot ratio (0.45) in the LS soil than in the SL soil (0.16) indicated that the conditions of LS soil encouraged plants to allocate higher proportions of biomass into roots, possibly due to increased competition for soil resources. In conclusion, maintaining soil moisture at 50% WHC ensures better chickpea dry matter production in SL soil.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop in production after dry bean and field pea (Siddique and Krishnamurthy, 2016; Merga and Haji, 2019) and is cultivated all over the world for its seeds (Yegrem 2021). It is grown primarily in developing and underdeveloped countries for household consumption and localized trade (Bell, 2014; Sharma et al., 2020). Chickpea is well known for contributing to soil fertility by fixing atmospheric nitrogen (N_2) into ammonia, which can be further transformed into various organic forms (Verma et al., 2015; Abd-Alla et al., 2023; Crop Trust, 2023) and thus minimizes the fertilizer costs for subsequent crops. It is a quality food source rich in protein (McDermott and Wyatt, 2017), minerals (calcium, magnesium, phosphorus and potassium), vitamins (riboflavin, niacin, thiamine, folate, and the vitamin A precursor β-carotene), and carbohydrates (Jukanti et al., 2012; Singh et al., 2021). The protein quality of chickpea seeds is better than that of other pulses (Jukanti et al., 2012). Chickpea seeds contain on average 23% proteins (Verma et al., 2015; Crop Trust, 2023). Chickpeas are reported to contain a low quantity of lipids, but are rich in nutritionally vital unsaturated fatty acids such as linoleic acid and oleic acid (Yegrem, 2021).

Although chickpea has a large economic potential in sub-Saharan Africa (Fikre et al., 2020), there is hardly any commercial production of chickpea in some sub-Saharan African countries such as South Africa (SA). Several research trials aiming to encourage the local production of chickpea have been conducted in the Limpopo and Mpumalanga Provinces of SA (Madzivhandila et al., 2012; Masowa et al., 2012; Ogola, 2015; Lusiba et al., 2017; Makonya, 2019; Leboho, 2020; Moloto et al., 2018; Ogola et al., 2021). Although these studies have demonstrated that chickpea can be grown in those parts of SA, access to irrigation water has been identified as one of the serious challenges that could be faced by South African smallholder crop farmers when cultivating chickpea during the winter season (Mpai and Maseko, 2018; Leboho, 2020). Against the previous context, investigations on appropriate water-saving irrigation management strategies that will ensure higher yields of chickpea with a limited amount of water are crucial. The need to use water efficiently is unquestionable in water-scarce countries such as SA (Stelli et al., 2018; Mahlare et al., 2023).

Chickpea is normally grown in semi-arid or arid tropical regions under rain-fed conditions and the crop can be harmed by a shortage of moisture in the soil (Mohammed et al., 2017). Shortage of soil moisture reduces grain and biological yields of crops (Fahad et al., 2017; Pour-Aboughadareh et al., 2019) through negative impacts on plant growth, physiology, and reproduction (Yordanov et al., 2000; Pour-Aboughadareh et al., 2019; Mustafa et al., 2021). Also, a shortage of moisture in the soil leads to difficulties in crop management with regards to pests and diseases and reduced nutrient availability and assimilation by plants (Al-Kaisi et al., 2013; Yetgin, 2023). Although plants cope with soil moisture shortages by evolving various complex resistance and adaptation mechanisms (Osakabe et al., 2014; Fahad et al., 2017; Seleiman et al., 2021), adding the required amount of water through irrigation may alleviate plant water stress.

Supplemental irrigation is used to overcome the reduction of chickpea yield caused by a shortage of soil moisture in some parts of the world (Singh et al., 2016; Zhao et al., 2020). However, the dependence on irrigation to supplement rainfall can be a problem for countries that have limited natural water resources and variable rainfall, such as SA (Stelli et al., 2018). This problem can be exacerbated by inappropriate irrigation management practices that not only waste water resources but also damage crop growth (Zhao et al., 2020). Therefore, studies to determine the amount of water to apply to provide the maximum useable soil moisture in a plant's root zone without inducing harmful stress to the crop are crucial. The use of suitable irrigation levels will ensure better water use efficiency of chickpea and reduced water wastage during irrigation (Zhao et al., 2020). However, such irrigation management trials should also evaluate the effects of soil properties on crop growth because soil properties such as soil texture can affect the soil available water capacity as well as the growth of plant roots, which are the main organs in water uptake (Duo et al., 2016). Hence, the objective of this study was to determine the effects of different irrigation levels and soil texture on dry matter production of chickpea grown under greenhouse conditions.

MATERIALS AND METHODS

Study site description, design and treatments

A pot experiment was conducted for 50 days in the greenhouse at the Green Biotechnologies Research Centre of Excellence (GBRCE) of the University of Limpopo (23° 53' 10" S, 29° 44' 15" E; 1327 m) in South Africa between February and March 2021. The ambient day/night greenhouse temperatures averaged 28/21°C, with maximum temperatures controlled using thermostatically activated fans. The experiment was arranged as a 3 × 2 factorial in a completely randomized design, with 3 irrigation levels (25%, 50% and 75% of the water-holding capacity (WHC) of the soil (maximum amount of water a soil can retain)) and 2 different textured soils (greyish-brown sandy loam and reddish-brown loamy sand textured soils), replicated thrice.

Soil collection, preparation, and characterization

The loamy sand textured soil was obtained from the GBRCE, while the sandy loam textured soil was collected from the University of Limpopo Experimental Farm (ULEF; 23° 50' 42.86" S; 29° 42' 44.35" E). The ULEF and GBRCE soils were previously classified as Hutton soils following the South African soil classification system (Phefadu and Kutu, 2016; Pofu and Mashela, 2022). For the purposes of this paper, the loamy sand textured soil and sandy loam textured soil will hereafter be referred to as LS soil and SL soil, respectively. Both soils were collected from the surface (0–25 cm), air-dried, homogenized and sieved (4 mm sieve) to remove stones and plant roots.

Selected physico-chemical properties (Table 1) of the soils used in this study were analysed following standard laboratory procedures. Soil particle size was determined using a hydrometer procedure as described by Sheldrick and Wang (1993). Soil pH was measured in a 1:2.5 soil: water extract (Non-Affiliated Soil Analyses Work Committee, 1990) while soil organic carbon (C) was determined using the Walkley-Black method (Walkley and Black, 1934). The contents of nitrate and ammonium in the soil were determined colorimetrically following the extraction with 0.5 M KCl solution (Okalebo et al., 2002). The total mineral N content was calculated as the sum of the contents of ammonium and nitrate. Available phosphorus (P) was determined using the Bray-1 method (Bray and Kurtz, 1945). The WHC of the soil was determined using a method described by Mahajan et al. (2018) with slight modifications. Six pots (25 cm diameter and 20 cm height) filled with 6 kg of air-dried soil were saturated with tap water (3 pots for LS soil and 3 pots for SL soil). The surface of the pot was covered with a plastic sheet and then left to drain for 48 h. Following this, a soil sample was taken from the middle of each pot. These samples were weighed (wet weight of soil, A), oven-dried at 105°C for 72 h and re-weighed (dry weight of soil, B). Following this, the WHC was calculated using the following formula (Mahajan et al., 2018):

$$\text{WHC} = [(\text{A}-\text{B}) \times 100]/\text{B} \qquad (1)$$

Crop husbandry

Prior to planting, pots (25 cm diameter and 20 cm height) were filled with 6 kg of air-dried soil. Limestone ammonium nitrate (LAN; 28%) and single superphosphate fertilizers (SSP; 10.5%) were applied before planting to supply N and P at the rates of 20 and 40 kg/ha, respectively. These fertilizers were applied based on the calculated weight of soil used per pot and an assumption of 2 million kg/ha weight of soil from the furrow slice (Masowa et al., 2022). Based on the recommended rates and percentage of N and P content in the fertilizers, the quantities of LAN and SSP fertilizers were 214.28 and 1 142.86 mg/pot, respectively. Three seeds of kabuli-type chickpea were planted in each pot and one seedling was thinned after 2 weeks of planting. Pots were watered to achieve 100% of the WHC of the soil before subjecting the plants to the different irrigation levels 28 days after planting. To subject the plants to water deficit treatments, pots were watered to achieve 25%, 50% and 75% of WHC (Table 2). The amount of water lost from each pot was measured every 7 days by weighing each pot before re-watering to 25%, 50%, 75% and 100% of WHC. The mass of water added was considered to be equal to the volume of water added, assuming that the density of water is 1 g/cm^3 (Mulidzi et al., 2016; Imakumbili et al., 2021).

Table 1. Physico-chemical properties of soils used in this study

Soil property	Loamy sand soil	Sandy loam soil
Particle size (%):		
Sand	80.88	73.33
Silt	10.29	10.00
Clay	8.83	16.67
Bulk density (kg/m^3)	1.53	1.58
Porosity (%)	42.0	40.22
WHC (kg H_2O/kg soil)	0.19	0.27
pH (H_2O)	5.06	6.29
Soil organic C (%)	1.56	0.70
NO_3-N (mg/kg)	4.42	3.53
NH_4-N (mg/kg)	1.40	1.80
Available P (mg/kg)	27.0	63.0
Exchangeable K (mg/kg)	158.0	370.0

WHC = water-holding capacity

Table 2. The amount of water applied to achieve 25%, 50%, 75% and 100% of soil water-holding capacity

Soil texture	Irrigation water (mL/pot)			
	25% WHC	50% WHC	75% WHC	100% WHC
Loamy sand soil	285	570	855	1140
Sandy loam soil	405	810	1215	1620

WHC = water-holding capacity

Data collection

Plants were harvested 50 days after sowing (R_1: flowering stage) for the determination of shoot biomass (SBM), root biomass (RBM), total plant biomass (TBM; SBM + RBM) and root/shoot ratio (RSR; root dry weight/shoot dry weight). After harvesting the plants, shoots and roots were separated, washed with tap water to remove dirt, placed in separate labelled paper bags, oven-dried to a constant mass at 65°C, and the mass recorded as dry matter (g dry matter/plant).

Statistical analysis

The data collected were subjected to a factorial analysis of variance using SAS software version 9.4. The treatment means were separated using Fisher's protected least significant difference (LSD) test at the 5% level of significance. Regression analysis was performed to establish the relationship between the measured crop parameters and the irrigation levels, regardless of the soil textural class.

RESULTS AND DISCUSSION

The assessment of SBM and plant weight is of primary importance when quantifying the accumulation of biomass (Souza et al., 2016), which is used when evaluating the crop performance (Ogola et al., 2021; Wang et al., 2021; Meiyan et al., 2022). In this study, the performance of chickpea subjected to different irrigation levels and soils with different textures was assessed by measuring the crop's dry biomass. Shoot biomass and the TBM were significantly influenced by the soil texture, irrigation level and their interaction, while RSR was significantly affected by the soil texture and irrigation level (Table 3). The 25% WHC treatment reduced SBM by up to 60% and TBM by up to 56% as compared to the 50% and 75% WHC treatments, which were statistically on par with each other (Figs 1A and 1C). Previous studies also reported a decrease in the SBM of various plants under reduced irrigation (Moosavi et al., 2015; Imakumbili et al., 2021; Mehak et al., 2021). The non-significant effect of irrigation level on RBM (Fig. 1C) indicated that subjecting chickpea plants to reduced irrigation (25% and 50% WHC) does not compromise chickpea root growth. Root biomass adjustment is one of the strategies that plants use to avoid and tolerate water deficit (Brunner et al., 2015). The 50% and 75% WHC treatments gave significantly lower RSR values as compared to the 25% WHC treatment (Fig. 1D), indicating that the 25% WHC reduced the growth of shoots more than that of roots. A study by Saidi et al. (2010) also showed a decrease in RSR under reduced irrigation treatment as compared to that observed under full irrigation. This finding confirms that the reduction of root growth in response to low water availability due to a decreased amount of irrigation

Table 3. Results of analysis of variance conducted to determine the effects of soil texture, irrigation level and their interaction on shoot biomass, root biomass, root/shoot ratio and total plant biomass of chickpea

Source	df	*p*-value			
		Root biomass	Shoot biomass	Root/shoot ratio	Total plant biomass
Model	7	0.5649	0.0006	<0.0001	0.0035
Factors:					
Soil texture (S)	1	0.2215	0.0001	<0.0001	0.0013
Irrigation level (I)	2	0.2881	0.0014	0.0052	0.0041
S x I	2	0.6649	0.0182	0.7380	0.0453
CV (%)		37.67	27.86	16.49	29.10
R^2 value		0.38	0.88	0.95	0.83

df = degrees of freedom; CV = coefficient of variation

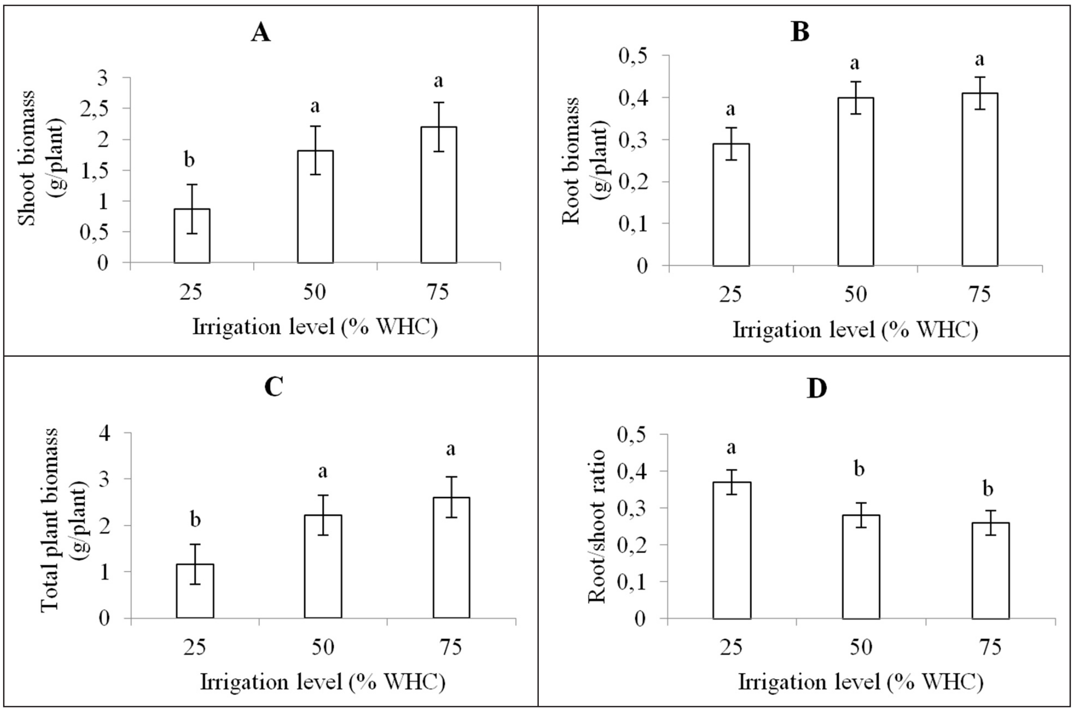

Figure 1. Effect of irrigation level on (A) shoot biomass, (B) root biomass (C) total plant biomass, and (D) root/shoot ratio of chickpea. Means with the same letter are not significantly different at the 5% probability level. WHC = water-holding capacity of soil.

is lower than the accompanying reduction in shoot growth (Hsiao and Liu-Kang, 2000; Saidi et al., 2010).

Although RBM was not significantly increased by an increase in the amount of irrigation water applied, a linear (R^2 = 0.81) effect on RBM was observed, regardless of soil texture (Fig. 2A). The SBM (R^2 = 0.94; Fig. 2B) and TBM (R^2 = 0.93; Fig. 2C) were linearly increased regardless of the soil texture. The RSR decreased linearly (R^2 = 0.88) with irrigation level (Fig. 2D).

Shoot biomass and TBM were significantly higher in SL with high clay content (16.67% clay) and high WHC than in LS soil with low clay content (8.83% clay) and low WHC (Table 4). The greater SBM and TBM observed in SL soil than in LS soil may be ascribed to the higher WHC of this soil (Souza et al., 2016). This finding is in line with that of Ogola et al. (2021), who reported that the above-ground biomass and grain yield of chickpea were quantitatively higher in high clay content soil (clay-textured soil) than in soil with low clay content (loamy sand–textured soil). On the contrary, Moloto et al. (2018) found that 4 out of 5 desi-type chickpea genotypes had greater plant growth in sandy loam–textured soil than in the clay-textured soil. High values of SBM and TBM in SL soil may be attributed to the sandy loam soil's good water retention capacity (Purushothaman et al., 2017), nutrient retention and permeability, as well as its higher clay content, which provide good soil structure and fertility (Molepo et al., 2017). Conversely, the dry roots of plants from pots with LS soil were generally (24.24%) heavier than the dry roots of plants from pots with SL soil (Table 4). A study by Ahmadi et al. (2011) also showed a significantly higher potato root dry matter in loamy sand soil compared to sandy loam soil. Significantly higher RSR (Table 4) in the LS soil than in the SL soil indicated that the conditions of LS soil allowed plants to allocate higher proportions of biomass into roots, possibly due to increased competition for soil resources (Qi et al., 2019). Soils with high clay content, such as the SL-textured soil used in this study, may also have a temporary mechanical impedance that limits root growth when the soil dries out (Cairns et al., 2004; Whitmore and Whalley, 2009; Ahmadi et al., 2011; Bengough et al., 2011). The loamy sand–textured soil on the other hand has a high permeability due to its coarser texture (Molepo et al., 2017), which has been shown to promote root growth (Ahmadi et al., 2011).

The 25% WHC treatment reduced SBM by up to 68% as compared to the 50% and 75% WHC treatments in SL soil (Fig. 3A). Even though the differences in RBM amongst the different irrigation levels were insignificant, the RBM increased correspondingly with the irrigation level in SL soil (Fig. 3B). The TBM obtained from the 25% WHC treatment was 65% lower than that recorded from the 75% WHC treatment in SL soil (Fig. 3C). The RSRs obtained from the irrigation treatments in LS soil were significantly higher than those from irrigation treatments in SL soil (Fig. 3D), indicating that irrigation treatments favoured root growth over shoot growth more under LS soil than SL soil. This result is different from that reported by Souza et al. (2016), who showed that irrigation promotes greater growth of plants in soils of a medium texture with high clay content compared to sandy soils with low clay content.

Table 4. Effect of soil texture on root biomass, shoot biomass, root/shoot ratio and total plant biomass

Soil texture	Root biomass (g/plant)	Shoot biomass (g/plant)	Root/shoot ratio	Total plant biomass (g/plant)
Loamy sand soil	0.41a	0.98b	0.45a	1.39b
Sandy loam soil	0.33a	2.28a	0.16b	2.60a

Means with the same letter in each column are not significantly different at the 5% probability level

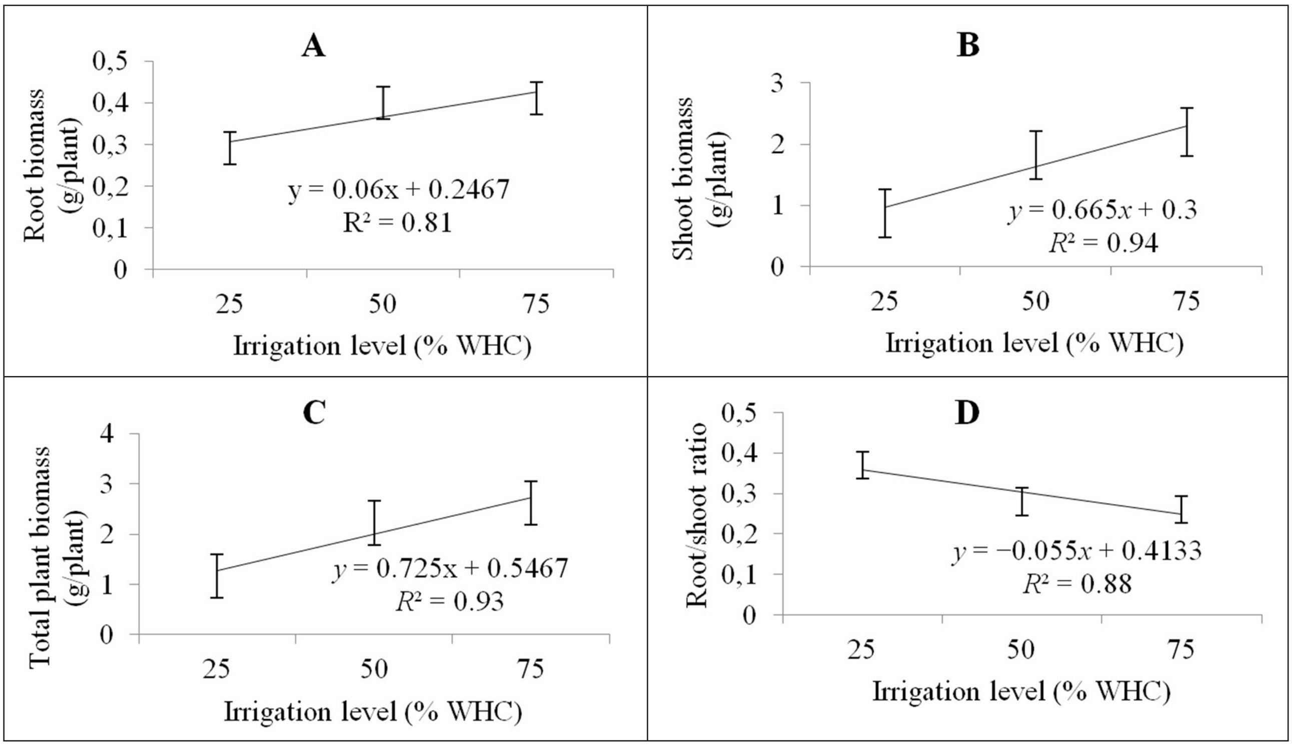

Figure 2. Linear regression of (A) root biomass, (B) shoot biomass, (C) total plant biomass and (D) root/shoot ratio for different irrigation levels across the different soils.

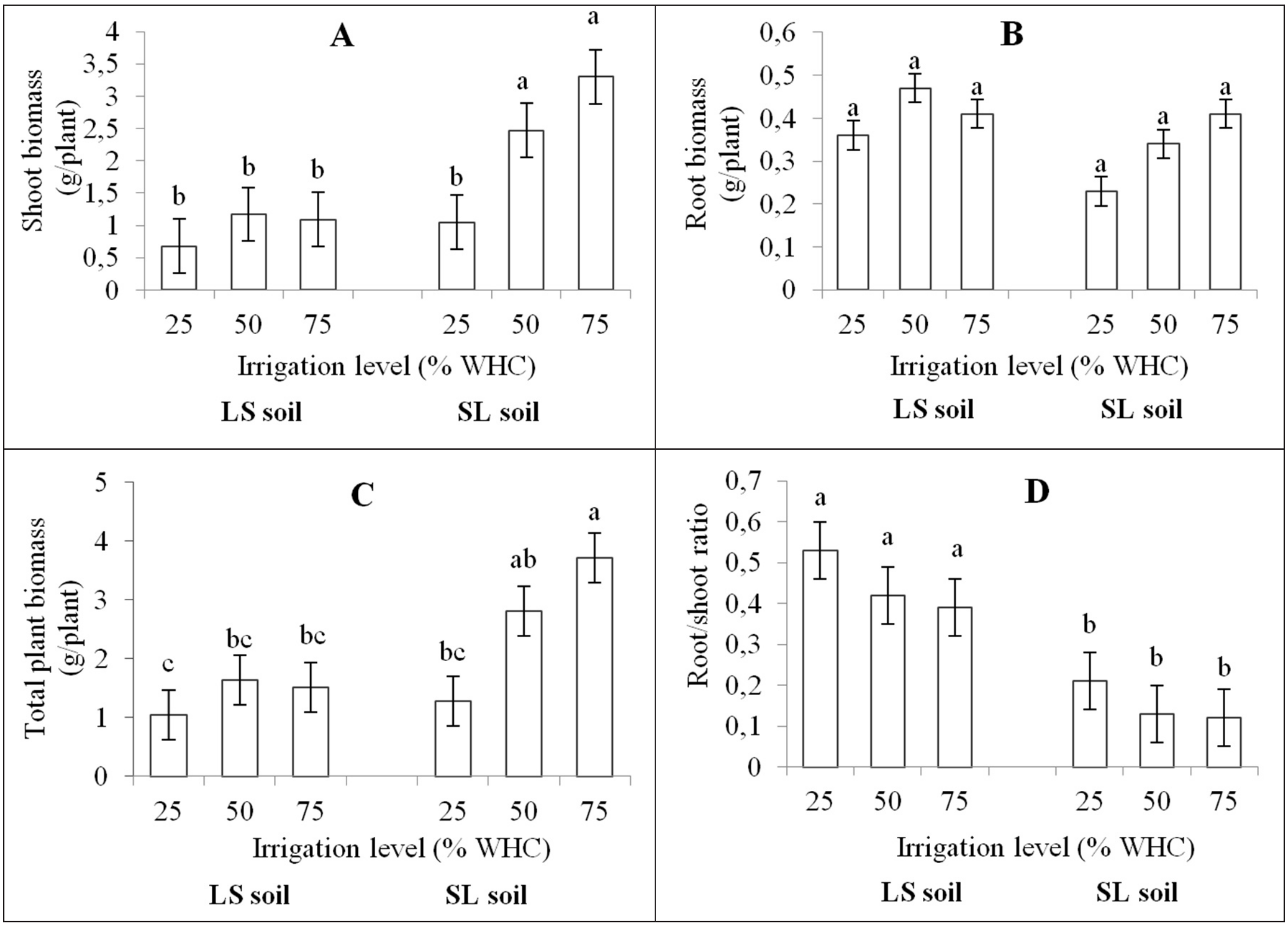

Figure 3. Interaction effect of irrigation level and soil texture on (A) shoot biomass, (B) root biomass, (C) total plant biomass, and (D) root/shoot ratio of chickpea. Means with the same letter are not significantly different at the 5% probability level. WHC = water holding capacity of soil, LS = loamy sand, SL = sandy loam.

CONCLUSION

Chickpea productivity was studied under varying irrigation levels (25%, 50% and 75% of soil WHC and soils (sandy loam soil (SL) and loamy sand (LS) soil). The results revealed that shoot biomass (SBM), total plant biomass (TBM) and root/shoot ratio are affected by irrigation level, soil texture and their interaction. However, further studies that assess the influence of irrigation level, soil texture and their interaction on chickpea performance up to the point of grain harvest are needed. The use of 25% irrigation level is discouraged as it leads to SBM and TBM losses compared to 75% irrigation level in SL. The SL soil gave higher SBM and TBM as compared to the LS soil; therefore, soil texture should be considered when selecting a production site for chickpea. Lastly, the results showed that maintaining the soil moisture at 50% WHC may ensure better production of chickpea dry matter under the SL soil.

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AUTHOR CONTRIBUTION

Manare M Masowa – conceptualisation and methodology of the study, data collection and analysis, writing the initial draft manuscript and revising the manuscript, revision after review; Phesheya Dlamini – supervised the research and played a role of revising the final manuscript; Zenzile P Khetsha – methodology review, interpretation of results, redaction of review. All authors read and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

ABD-ALLA MH, AL-AMRI SM and EL-ENANY A-WE (2023) Enhancing rhizobium-legume symbiosis and reducing nitrogen fertilizer use are potential options for mitigating climate change. *Agriculture* **13** 2092. https://doi.org/10.3390/agriculture13112092

AHMADI SH, PLAUBORG F, ANDERSEN MN, SEPASKHAH AR, JENSEN CR and HANSEN S (2011) Effects of irrigation strategies and soils on field grown potatoes: root distribution. *Agric. Water Manage.* **98** 1280–1290. https://doi.org/10.1016/j.agwat.2011.03.013

AL-KAISI MM, ELMORE RW, GUZMAN JG, HANNA HM, HART CE, HELMERS MJ, HODGSON EW, LENSSEN AW, MALLARINO AP, ROBERTSON AE and SAWYER JE (2013) Drought impact on crop production and the soil environment: 2012 experiences from Iowa. *J. Soil Water Conserv.* **68** 19–24. https://doi.org/10.2489/jswc.68.1.19A

BELL S (2014) The small but mighty chickpea. URL: https://news.usc.edu/61008/the-small-but-mighty-chickpea/ (Accessed 4 April 2023).

BENGOUGH AG, MCKENZIE BM, HALLETT PD and VALENTINE TA (2011) Root elongation, water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. *J. Exp. Bot.* **62** 59–68. https://doi.org/10.1093/jxb/erq350

BRAY RH and KURTZ LT (1945) Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* **59** 39–45. https://doi.org/10.1097/00010694-194501000-00006

BRUNNER I, HERZOG C, DAWES MA, AREND M and SPERISEN C (2015) How tree roots respond to drought. *Front. Plant Sci.* **6** 1–16. https://doi.org/10.3389/fpls.2015.00547

CAIRNS JE, AUDEBERT A, PRICE AH and MULLINS CE (2004) Effect of soil mechanical impedance on root growth of two rice varieties under drought. In: Proceedings of the First Day of the Scientific Meetings of IFR 127 (Genomics and Integrative Biology of Plants) on the theme “the root”, 30 April 2004, Montpellier, France.

CROP TRUST (2023) Chickpea. URL: https://www.croptrust.org/ (Accessed 25 April 2023).

DOU F, SORIANO J, TABIEN RE and CHEN K (2016) Soil texture and cultivar effects on rice (*Oryza sativa* L.) grain yield, yield components and water productivity in three water regimes. *PLOS ONE* **11** e0150549. https://doi.org/10.1371/journal.pone.0150549

FAHAD S, BAJWA AA, NAZIR U, ANJUM SA, FAROOQ A, ZOHAIB A, SADIA S, NASIM W, ADKINS S, SAUD S, IHSAN MZ, ALHARBY H, WU C, WANG D and HUANG J (2017) Crop production under drought and heat stress: plant responses and management options. *Front. Plant Sci.* **8** 1–16. https://doi.org/10.3389/fpls.2017.01147

FIKRE A, DESMAE H and AHMED S (2020) Tapping the economic potential of chickpea in sub-Saharan Africa. *Agronomy* **10** 1707. https://doi.org/10.3390/agronomy10111707

HSIAO TC and LIU-KANG X (2000) Sensitivity of growth of roots versus leaves to water stress: biophysical analysis and relation to water transport. *J. Exp. Bot.* **51** 1595–1616. https://doi.org/10.1093/jexbot/51.350.1595

IMAKUMBILI MLE, SEMU E, SEMOKA JMR, ABASS A and MKAMILO G (2021) Managing cassava growth on nutrient poor soils under different water stress conditions. *Heliyon* **7** 1–10. https://doi.org/10.1016/j.heliyon.2021.e07331

JUKANTI AK, GAUR PM, GOWDA C and CHIBBAR R (2012) Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): a review. *Br. J. Nutr.* **108** 11–26. https://doi.org/10.1017/S0007114512000797

LEBOHO TM (2020) The effect of planting density on water use efficiency, growth and yield of four chickpea (*Cicer arietinum* L.) genotypes having contrasting growth patterns. Master’s dissertation, University of Limpopo.

LUSIBA S, ODHIAMBO J and OGOLA J (2017) Growth, yield and water use efficiency of chickpea (*Cicer arietinum*): response to biochar and phosphorus fertilizer application. *Arch. Agron. Soil Sci.* **64** 819–833. https://doi.org/10.1080/03650340.2017.1407027

MADZIVHANDILA T, OGOLA JBO and ODHIAMBO JJO (2012) Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. *J. Food Agric. Environ.* **10** 451–455.

MAHAJAN G, GEORGE-JAEGGLI B, WALSH M and CHAUHAN BS (2018) Effect of soil moisture regimes on growth and seed production of two Australian biotypes of *Sisymbrium thellungii* O. E. Schulz. *Front. Plant Sci.* **9** 1241. https://doi.org/10.3389/fpls.2018.01241

MAHLARE MS, LEWU MN, LEWU FB and BESTER C (2023) *Cyclopia subternata* growth, yield, proline and relative water content in response to water deficit stress. *Water SA* **49** 64–72. https://doi.org/10.17159/wsa/2023.v49.i1.3988

MAKONYA GM (2019) Thermo and drought tolerance markers and regulation of heat stress proteins for chickpea (*Cicer arietinum* L.; Fabaceae) production in NE South Africa. Doctoral thesis, University of Cape Town.

MASOWA MM, KUTU FR, BABALOLA OO and MULIDZI AR (2022) Optimizing application rate of winery solid waste compost for improving the performance of maize (*Zea mays* L.) grown on Luvisol and Cambisol. *Appl. Ecol. Environ. Res.* **20** 815–828. https://doi.org/10.15666/aeer/2001_815828

MASOWA MM, ODHIAMBO JJO and OGOLA JBO (2012) Effect of Rhizobium inoculation on growth and yield of chickpea (*Cicer arietinum L.*) in semi-arid Limpopo Province. In: Proceedings of the Combined Congress of SSSSA, SASCP, SAWSS & SASHS, 16–19 January 2012, Potchefstroom, South Africa.

MCDERMOTT J and WYATT AJ (2017) The role of pulses in sustainable and healthy food systems. *Ann. N. Y. Acad. Sci.* **1392** 30–42. https://doi.org/10.1111/nyas.13319

MEHAK G, AKRAM NA, ASHRAF M, KAUSHIK P, EL-SHEIKH MA and AHMAD P (2021) Methionine-induced regulation of growth, secondary metabolites and oxidative defense system in sunflower (*Helianthus annuus* L.) plants subjected to water deficit stress. *PLOS ONE* **16** 1–16. https://doi.org/10.1371/journal.pone.0259585

MEIYAN S, MENGYUAN S, QIZHOU D, XIAOHONG Y, BAOGUO L and YUNTAO M (2022) Estimating the maize above-ground biomass by constructing the tridimensional concept model based on UAV-based digital and multi-spectral images. *Field Crops Res.* **282** 108491. https://doi.org/10.1016/j.fcr.2022.108491

MERGA B and HAJI J (2019) Economic importance of chickpea: production, value, and world trade. *Cogent Food Agric.* **5** 1615718. https://doi.org/10.1080/23311932.2019.1615718

MOHAMMED A, TANA T, SINGH P, KORECHA D and MOLLA A (2017) Management options for rainfed chickpea (*Cicer arietinum* L.) in northeast Ethiopia under climate change condition. *Clim. Risk Manage.* **16** 222–233. https://doi.org/10.1016/j.crm.2016.12.003

MOLEPO KJ, EKOSSE GIE and NGOLE-JEME VM (2017) Physicochemical, geochemical and mineralogical aspects of agricultural Soils in Limpopo Province, South Africa. *J. Hum. Ecol.* **58** 108–117.

MOLOTO RM, LENGWATI MD, SOUNDY P, DAKORA FD and MASEKO ST (2018) Effect of soil type and biostimulants on growth parameters of chickpea. *S. Afr. J. Bot.* **115** 300. https://doi.org/10.1016/j.sajb.2018.02.088

MOOSAVI AA, MANSOURI S and ZAHEDIFAR M (2015) Effect of soil water stress and nickel application on micronutrient status of canola grown on two calcareous soils. *Plant Prod. Sci.* **18** 377–387. https://doi.org/10.1626/pps.18.377

MPAI T and MASEKO ST (2018) Possible benefits and challenges associated with production of chickpea in inland South Africa. *Acta Agric. Scand. – B. Soil Plant Sci.* **68** 479–488. https://doi.org/10.1080/09064710.2018.1437926

MULIDZI AR, CLARKE CE and MYBURGH PA (2016) Design of a pot experiment to study the effect of irrigation with diluted winery wastewater on four differently textured soils. *Water SA* **42** 20–25. https://doi.org/10.4314/wsa.v42i1.03

MUSTAFA AA, ABASS MH and AWAD KM (2021) Responses of tomato to *Rhizoctonia solani* infection under the salinity stress. *Int. J. Agric. Biol.* **26** 707–716.

NON-AFFILIATED SOIL ANALYSES WORK COMMITTEE (1990) *Handbook of Standard Soil Testing Methods for Advisory Purposes.* Soil Science Society of South Africa, Pretoria.

OGOLA JBO (2015) Growth and yield response of chickpea to rhizobium inoculation: productivity in relation to interception of radiation. *Legume Res.* **38** 837–843. https://doi.org/10.18805/lr.v38i6.6733

OGOLA JBO, MACIL PJ and ODHIAMBO JJO (2021) Biochar application and *Rhizobium* inoculation increased intercepted radiation and yield of chickpea in contrasting soil types. *Int. J. Plant Prod.* **15** 219–229. https://doi.org/10.1007/s42106-021-00141-9

OKALEBO JR, GATHUA KW and WOOMER PL (2002) Laboratory methods of soil and water analysis: a working manual. TSBF-CIAT and SACRED – Africa, Kenya.

OSAKABE Y, OSAKABE K, SHINOZAKI K and TRAN L-SP (2014) Response of plants to water stress. *Front. Plant Sci.* **5** 1–9. https://doi.org/10.3389/fpls.2014.00086

PHEFADU KC and KUTU FR (2016) Evaluation of spatial variability of soil physico-chemical characteristics on Rhodic Ferralsol at the Syferkuil Experimental Farm of University of Limpopo, South Africa. *J. Agric. Sci.* **8** 92–106. https://doi.org/10.5539/jas.v8n10p92

POFU KM and MASHELA PW (2022) Interactive effects of filamentous fungi and cucurbitacin phytonematicide on growth of cowpea and suppression of *Meloidogyne enterolobii*. *Front. Microbiol.* **13** 765051. https://doi.org/10.3389/fmicb.2022.765051

POUR-ABOUGHADAREH A, OMIDI M, NAGHAVI MR, ETMINAN A, MEHRABI AA, POCZAI P and BAYAT H (2019) Effect of water deficit stress on seedling biomass and physio-chemical characteristics in different species of wheat possessing the D genome. *Agronomy* **9** 1–20. https://doi.org/10.3390/agronomy9090522

PURUSHOTHAMAN R, KRISHNAMURTHY L and UPADHYAYA HD (2017) Genotypic variation in soil water use and root distribution and their implications for drought tolerance in chickpea. *Funct. Plant Biol.* **44** 235–252. https://doi.org/10.1071/FP16154

QI Y, WEI W, CHEN C and CHEN L (2019) Plant root-shoot biomass allocation over diverse biomes: a global synthesis. *Glob. Ecol. Conserv.* **18** 1–14. https://doi.org/10.1016/j.gecco.2019.e00606

SAIDI A, TAIICHIRO O and HIRASAWA T (2010) Responses of root growth to moderate soil water deficit in wheat seedlings. *Plant Prod. Sci.* **13** 261–268. https://doi.org/10.1626/pps.13.261

SELEIMAN MF, AL-SUHAIBANI N, ALI N, AKMAL M, ALOTAIBI M, REFAY Y, DINDAROGLU T, ABDUL-WAJID HH and BATTAGLIA ML (2021) Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants* **10** 259. https://doi.org/10.3390/plants10020259

SHARMA KM, SURINDER SC and RAJEEV R (2020) Molecular markers and marker trait associations. In: Singh M (ed.) *Chickpea: Crop Wild Relatives for Enhancing Genetic Gains.* Academic Press, United States. https://doi.org/10.1016/B978-0-12-818299-4.00007-5

SHELDRICK BH and WANG C (1993) Particle-size distribution. In: Carter MR (ed.) *Soil Sampling and Methods of Analysis.* Canadian Society of Soil Science/Lewis Publishers, Ann Arbor.

SIDDIQUE KHM and KRISHNAMURTHY L (2016) Chickpea: agronomy. In: Wrigley C, Corke H, Seetharaman K and Faubion J (eds) *Encyclopedia of Food Grains.* Academic Press, Oxford. https://doi.org/10.1016/B978-0-12-394437-5.00192-3

SINGH V, CHAUHAN Y, DALAL R and SCHMIDT S (2021) Chickpea. In: Pratap A and Gupta S (eds) *The Beans and the Peas.* Woodhead Publishing, United Kingdom. https://doi.org/10.1016/B978-0-12-821450-3.00003-2

SOUZA AJJ, GUIMARÃES RJ, COLOMBO A, SANT'ANA JAV and CASTANHEIRA DT (2016) Quantitative analysis of growth in coffee plants cultivated with a water-retaining polymer in an irrigated system. *Rev. Ciênc. Agron.* **47** 162–171.

STELLI S, HOY L, HENDRICK R and TAYLOR M (2018) Effects of different mulch types on soil moisture content in potted shrubs. *Water SA* **44** 1816–7950. https://doi.org/10.4314/wsa.v44i3.17

VERMA N, SINGH S, KHAN YJ, KUMAR S and SINGH AK (2015) Chickpea genetic resources to enhance production in changing climatic scenario. *Legume Res.* **38** 710–713.

WALKLEY A and BLACK IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37** 29–38. https://doi.org/10.1097/00010694-193401000-00003

WANG T, LIU Y, WANG M, FAN Q, TIAN H, QIAO X and LI Y (2021) Applications of UAS in crop biomass monitoring: a review. *Front. Plant Sci.* **12** 616689. https://doi.org/10.3389/fpls.2021.616689

WHITMORE AP and WHALLEY WR (2009) Physical effects of soil drying on roots and crop growth. *J. Exp. Bot.* **60** 2845–2857. https://doi.org/10.1093/jxb/erp200

YEGREM L (2021) Nutritional composition, antinutritional factors, and utilization trends of Ethiopian chickpea (*Cicer arietinum* L.). *Int. J. Food Sci.* **2021** 5570753. https://doi.org/10.1155/2021/5570753

YETGIN A (2023) Uncovering the role of microbes in plant health using soil database insights. *Authorea* April 19 2023. https://doi.org/10.22541/au.168188984.42212144/v1

YORDANOV I, VELIKOVA V and TSONEV T (2000) Plant responses to drought, acclimation, and stress tolerance. *Photosynthetica* **38** 171–186. https://doi.org/10.1023/A:1007201411474

ZHAO W, LIU L, SHEN Q, YANG J, HAN X, TIAN F and WU J (2020) Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. *Water* **12** 1–19. https://doi.org/10.3390/w12082127