E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(12): 143-149
Received: 15-10-2024
Accepted: 19-11-2024

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Unraveling the influence of sowing dates, deficit irrigation levels and osmoregulators on dicoccum wheat: A regression approach to relate yield and associated parameters

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i12b.2110

Abstract
The study investigated the influenced of sowing date, irrigation levels and osmoregulators on dicoccum wheat during *rabi* 2022-23 and 2023-24 at Main Agricultural Research Station, University of Agricultural sciences, Dharwad. The experiment was laid in strip split plot design with Main plots *viz.*, D_1: November II fortnight sowing D_2: December I fortnight sowing and D_3: December II fortnight sowing, sub-sub plots *viz.*, I_1: Irrigation at 1.0 ETc and I_2: Irrigation at 0.5 ETc and sub-sub plots *viz,* O_1: Salicylic acid @ 200 ppm, O_2: Thiourea @ 400 ppm, O_3: Kaolin at 5% and O_4: Control (Water spray) at tillering and ear emergence stages. Among the sowing dates, November II fortnight sowing recorded significantly higher flag leaf area, test weight and grain yield over other sowing dates. The deficit irrigation at 1.0 ETc recorded 16.05, 5.17 and 24.30 per cent higher flag leaf area, test weight and grain yield over 0.5 ETc which recorded 54.78 per cent higher chaffy grains spike^{-1}. Among the osmoregulators, thiourea @ 400 ppm and salicylic acid @ 200 ppm at tillering and ear emergence stages recorded significantly higher grain yield and test weight. The chaffy grains were significantly higher in water spray (1.86). The interaction of November II fortnight sowing, irrigation at 1.0 ETc and foliar spray of thiourea @ 400 ppm recorded significantly higher flag leaf area, test weight and grain yield. The chaffy grains spike were significantly higher in December II fortnight sowing, irrigation at 0.5 ETc and water spray. Similar results were obtained with salicylic acid sprayed dicoccum wheat under November II fortnight sowing and 1.0 ETc irrigation. The regression analysis revealed a strong positive influence of flag leaf area and test weight on grain yield. In contrast, chaffy grains spike^{-1} showed a negative relationship emphasizing their detrimental impact on yield. Optimal sowing in November II fortnight, irrigation at 1.0 ETc, and foliar application of thiourea @ 400 ppm or salicylic acid @ 200 ppm significantly enhance flag leaf area, test weight, grain yield and decreased chaffy grains in dicoccum wheat which are strong determinants of grain yield.

Keywords: Chaffy grains, deficit irrigation, flag leaf area, osmoregulators, test weight

Introduction
Wheat is staple crop throughout world. Its productivity is increasingly threatened by abiotic stresses, especially heat and water paucity**.** Climate change have exacerbated these stresses, studies indicate that mere 1 °C increase in temperature could reduce wheat yields by up to 10% (Lobell *et al.,* 2011) [9]. Wheat is sensitive to heat and moisture stress during critical growth stages. As a crop that relies on irrigation, wheat cultivation faces increasing challenges due to the growing demand for water resources. In this context, deficit irrigation has emerged as a promising strategy, where water is applied below full evapotranspiration levels, aiming for "more crop per drop". This method not only helps conserve water but can still maintain reasonable yields under controlled water stress. The use of osmoregulators in conditions of abiotic stress *viz.,* heat and moisture stress is gaining importance. The osmoregulators help in anti-oxidation of ROS species produced in the system due to osmotic stress caused by high temperature and low moisture.

Key agronomic factors such as flag leaf area**,** test weight**,** and chaffy grains per spike are crucial determinants of wheat productivity. Flag leaf area plays a vital role in photosynthesis, particularly during the grain-filling stage, contributing up to 41 to 43% of the carbohydrates necessary for grain formation (Araus and Tapia, 1987) [2]. Similarly, test weight serves as an important indicator of grain quality, while chaffy grains are often a sign of incomplete grain filling, leading to yield loss. The application of osmoregulators**,** like salicylic acid and thiourea, can enhance wheat's ability to cope with abiotic stresses, improving grain filling and reducing sterility. Dicoccum wheat, a super food is gaining importance due to nutraceutical values and resilence. Hence, the study focused on improving productivity of dicoccum wheat under different sowing dates, deficit irrigation and application of osmoregulators. The research investigates how these factors influence crucial parameters like flag leaf area**,** test weight**,** grain yield, and chaffy grains spike^{-1} and enhance overall wheat productivity in the face of ongoing environmental challenges.

Material and Methods

A field experiment was conducted at Main Agricultural Research Station, University of Agricultural Science, Dharwad, which was geographically situated at 15°26' N latitude and 75°01' E longitude and at an altitude of 678 m above mean sea level. The experiment was laid in strip split plot design with three treatments in main plots *viz*., D_1: November II fortnight sowing D_2: December I fortnight sowing and D_3: December II fortnight sowing, sub-sub plots with two irrigation levels including I_1: Irrigation at 1.0 ETc and I_2: Irrigation at 0.5 ETc and sub-sub plots *viz*, O_1: Salicylic acid @ 200 ppm, O_2: Thiourea @ 400 ppm, O_3: Kaolin at 5% and O_4: Control (water spray) at tillering and ear emergence stages. The soil of experimental field was clay loam, almost neutral in reaction (pH 7.22), EC (0.31 dS m^{-1}), medium in nitrogen (308.61 kg ha^{-1}), medium in available phosphorus (33.5 kg ha^{-1}) and high in available potassium (397.10 kg ha^{-1}). The dicoccum wheat was sown at 22.5 cm row spacing and the recommended dose of 60:30:20 (N: P_2O_5: K_2O kgha^{-1}) and FYM of 6 t ha^{-1} was applied.

Flag leaf area

Ten representative primary tillers in the net plot rows from each plot were selected and the flag leaf, length (FLL) and flag leaf width (FLW) were calculated at peak flowering stage.

Flag leaf area = FLL × FLW × 0.75 (Gardner *et al*. 1985) [6]

Test weight (Thousand grain weight):
Thousand grains from each treatment were counted and weight were taken

Chaffy grains spike^{-1}

The ten ears were selected for computing filled grains and for recording chaffy grains *i.e*. number of unfilled grains spikelet^{-1}.

Results and discussion

The pooled data on flag leaf area**,** test weight, chaffy grains spike^{-1} and grain yield exhibited significant difference with sowing dates of dicoccum wheat (Table 1 to 4). Significantly higher flag leaf area (17.49 cm^2) and test weight (37.50 g) were recorded with November II fortnight sowing compared to other sowing dates. On the other hand, significantly higher chaffy grains spike^{-1} (2.28) was recorded with December II fortnight sowing followed by December I fortnight sowing (1.34). November II fortnight sowing recorded significantly lower chaffy grains panicle^{-1} (0.78). The flag leaf area was significantly higher in November II fortnight sowing by 9.52 per cent over December I fortnight and by 42.78 per cent over December II fortnight. Flag leaf area played an important role for trapping photosynthetically active radiation and therefore desirable under both early and late sowing conditions in wheat (Saxena *et al.* 2011) [15]. Further, contributed to enhanced source-sink relationship and there by the grain yield in wheat. December II fortnight sowing recorded 12.08 per cent decrease in test weight compared to November II fortnight sowing. High temperature during the later part of the reproductive stage of December II fortnight sowing caused forced maturity of the crop and resulted in development of less number of grains spike^{-1} which were small, shrivelled and of low weight as evident from its low test weight. This was primarily due to increase in temperature during the reproductive phase that affected the fertilization, deposition of carbohydrates, protein, seed setting. Thus affected the grain yield. These parameters influenced the grain yield. The grain yield was reduced by 38.90 per cent in December II fortnight sowing over November II fortnight sowing and by 30.06 per cent over December I fortnight sowing.

The flag leaf area, test weight and grain yield of dicoccum wheat differed significantly with irrigation levels. Significantly higher flag leaf area was recorded with irrigation at 1.0 ETc (16.57 cm^2) than at 0.5 ETc (13.91 cm^2). The decrease of 16.05 per cent in flag leaf area under irrigation at 0.5 ETc might be attributed to moisture deficit condition, reduced photosynthesis process due to decrease in leaf expansion, impaired photosynthetic machinery, premature leaf senescence and associated with reduction in yield parameters (Wahid *et al*. 2017) [13]. The test weight was decreased by 5.17 per cent in irrigation at 0.5 ETc over irrigation at 1.0 ETc. Contrarily, the chaffy grains spike^{-1} of dicoccum wheat were significantly higher with irrigation at 0.5 ETc (1.78) than at 1.0 ETc (1.15). The number of chaffy grains spike^{-1} were 54.78 per cent higher in 0.5 ETc irrigation (Table 3). Irrigation at 0.5 ETc led to relatively deficit moisture affected grain setting, protein and carbohydrate deposition, shriveled grains and low specific weight of wheat grains. Kumar *et al.* (2018) [8] also ascribed that stress condition decreased viability of pollen and stigma receptivity, which led to poor seed setting. Further increased chaffy grains, reduced seed weight and ultimately culminating in lower crop yields under stress. Similar results were reported by Razaq *et al.* (2016) [12], Rady *et al.* (2021) [11]. These overall parameters led to significantly lower grain yield with irrigation at 0.5 ETc (2645 kg ha^{-1}) over irrigation at 1.0 ETc (3288 kg ha^{-1}). The lower grain yield in lower moisture level were also reported by Asthir *et al.* (2015) [3] and Al-Molhem (2016) [6].

The osmoregulators spray influenced flag leaf area, test weight and grain yield of dicoccum wheat. The flag leaf area was higher by 21.27 per cent with thiourea @ 400 ppm (16.42 cm^2) and by 16.47 per cent with salicylic acid @ 200 ppm (15.77 cm^2) compared to water spray (13.54 cm^2). These results were also in agreement with El-Saadony *et al.* (2021) [5] and El Sherbiny *et al.* (2022) [4]. In the study, notably higher test weight was recorded with foliar spray of thiourea @ 400 ppm (36.97 g) and salicylic acid @ 200 ppm (36.25 g) than kaolin at 5% (35.03 g) and water spray (33.36 g) at tillering and ear emergence stages. The chaffy grain spike^{-1} were higher with water spray (1.86) at tillering and ear emergence stage and significantly lower with foliar spray of thiourea @ 400 ppm at tillering and ear emergence stages (1.20). The increase in grain weight with thiourea application was because of better photosynthesis and translocation of starch towards the developing kernel. This resulted in significantly higher grain yield in foliar spray of thiourea @ 400 ppm (3170 kg ha^{-1}) and salicylic acid @ 200 ppm (3068 kg ha^{-1}) at tillering and ear emergence stages compared to kaolin at 5% (2895 kg ha^{-1}) and water spray (2735 kg ha^{-1}). This improved grain yield in foliar spray of thiourea @ 400 ppm and salicylic acid @ 200 ppm was also reported by Yadav *et al.* (2023) [14]. The interaction of sowing dates, deficit irrigation and osmoregulators differed significantly. November II fortnight sowing at 1.0 ETc irrigation and foliar spray of thiourea @ 400 ppm at tillering and ear emergence stages recorded significantly higher flag leaf area (21.20 cm^2) than the rest of the interactions (D×I×O). Significantly lower flag leaf area (10.00 cm^2) was recorded with December II fortnight sowing, irrigation level at 0.5 ETc and water spray. It was on par with December II fortnight sowing, irrigation at 0.5 ETc and kaolin at 5% (10.89 cm^2). The interaction of November II fortnight sowing at 1.0 ETc irrigation level and foliar spray of thiourea @ 400 ppm at tillering and ear emergence stages recorded significantly higher test weight (40.27 g) and grain yield (4191 kg ha^{-1}) than the rest of the interactions (D×I×O). Similarly higher test weight and grain yield were also recorded with foliar spray of salicylic acid @ 200 ppm at tillering and ear emergence stages (38.71 g and 4149 kg ha^{-1} respectively). December II fortnight sowing at 0.5 ETc irrigation level and foliar spray of water spray at tillering and ear emergence stages recorded significantly higher chaffy grains $spike^{-1}$ (3.13), lower test weight (29.82 g) and grain yield (1784 kg ha^{-1}) than the rest of the interactions (D×I×O). Significantly lower number of chaffy grains $spike^{-1}$ was observed with November II fortnight sowing, irrigation at 1.0 ETc and foliar spray of thiourea at 400 ppm (0.50), salicylic acid @ 200 ppm (0.53), and kaolin at 5% (0.60) over rest of the interactions. The regression analysis of interaction of sowing dates, irrigation levels and osmoregulators on dicoccum wheat highlighted strong positive relationships of flag leaf area and test weight with grain yield. These relationships are evident through high R^2 values of which indicate the reliability of these traits as predictors of yield. The regression equation underscores the significant contribution of flag leaf area ($y=0.004x+3.4028$) to grain yield. The high R^2 value of 0.9435 demonstrated that 94.35% of the variability in grain yield was explicated by changes in flag leaf area. This was in agreement with findings of Hashim and Hanaa (2012) [7]. Similarly, the regression equation, ($y=0.0034x+25.385$), also exposed a positive correlation between test weight and grain yield, explaining 85.04% of the variability in yield. The favorable conditions provided by early sowing (November II fortnight), optimum irrigation (1.0 ETc) and abiotic stress mitigation by osmoregulators enhanced flag leaf area and test weight. This aligns with findings that heat and moisture stress during grain filling reduces test weight due to incomplete grain development and poor starch deposition (Prajapat *et al.*, 2022) [10]. A significantly negative relationship was observed between chaffy grains per spike and grain yield, represented by the equation ($y= -0.001x+4.5424$) value indicates that 89.32% of the variability in grain yield is explained by changes in the number of chaffy grains. This highlights the detrimental effect of increased chaffy grains on overall yield potential.

Table 1: Effect of sowing dates, deficit irrigation and osmoregulators on flag leaf area of dicoccum wheat

Flag leaf area (cm^2)													
		2022-23				2023-24				Pooled			
D×I×O		D_1	D_2	D_3	I×O	D_1	D_2	D_3	I×O	D_1	D_2	D_3	I×O
I_1	O_1	19.62^{ab}	18.17^{a-d}	13.59^{f-i}	17.13^{a}	18.74^{b}	17.65^{bc}	13.70^{e-g}	16.69^{ab}	19.18^{b}	17.91^{bc}	13.64^{f-i}	16.91^{b}
	O_2	20.78^{a}	19.26^{a-c}	14.1^{e-i}	18.04^{a}	21.63^{a}	18.76^{b}	13.28^{e-h}	17.89^{a}	21.20^{a}	19.01^{b}	13.69^{f-i}	17.97^{a}
	O_3	19.4^{a-c}	17.84^{b-d}	13.31^{g-j}	16.85^{ab}	18.6^{b}	16.11^{b-e}	13.30^{e-h}	16.01^{bc}	19.00^{b}	16.98^{cd}	13.31^{g-i}	16.43^{b}
	O_4	16.66^{c-e}	15.63^{d-g}	12.67^{h-j}	14.99^{c}	16.83^{b-d}	15.5^{c-f}	12.49^{f-h}	14.94^{cd}	16.74^{c-e}	15.57^{d-f}	12.58^{h-j}	14.96^{c}
I_2	O_1	16.98^{b-d}	15.58^{d-g}	12.16^{ij}	14.91^{c}	16.88^{b-d}	14.19^{d-g}	11.97^{g-i}	14.35^{d}	16.93^{cd}	14.88^{e-g}	12.07^{hij}	14.63^{c}
	O_2	17.07^{b-d}	17.03^{b-d}	12.63^{ij}	15.58^{bc}	16.20^{b-e}	15.27^{c-f}	11.08^{jkl}	14.18^{d}	16.63^{c-e}	16.15^{c-e}	11.85^{h-j}	14.88^{c}
	O_3	16.36^{d-f}	15.53^{d-h}	11.32^{ij}	14.41^{c}	16.30^{b-e}	14.12^{d-g}	10.46^{hi}	13.63^{d}	16.33^{c-e}	14.82^{ef}	10.89^{jk}	14.02^{c}
	O_4	13.96^{e-i}	12.79^{g-j}	10.58^{j}	12.44^{d}	13.80^{d-g}	12.14^{g-i}	9.43^{i}	11.79^{e}	13.88^{f-h}	12.46^{h-j}	10.00^{k}	12.12^{d}
D		17.6^{a}	16.48^{b}	12.55^{c}	I	17.37^{a}	15.47^{b}	11.96^{c}	I	17.49^{a}	15.97^{b}	12.25^{c}	I
	D×I					D×I				D×I			
I	I_1	19.12^{a}	17.73^{b}	13.42^{d}	16.75^{a}	18.95^{a}	17.01^{b}	13.19^{c}	16.38^{a}	19.03^{a}	17.37^{b}	13.30^{e}	16.57^{a}
	I_2	16.09^{c}	15.23^{c}	11.68^{e}	14.33^{b}	15.80^{b}	13.93^{c}	10.73^{d}	13.49^{b}	15.94^{c}	14.58^{d}	11.21^{f}	13.91^{b}
	D×O				O	D×O			O	D×O			O
O	O_1	18.3^{ab}	16.87^{bc}	12.88^{ef}	16.02^{ab}	17.81^{ab}	15.92^{bc}	12.84^{ef}	15.52^{ab}	18.05^{a}	16.4^{bc}	12.86^{de}	15.77^{ab}
	O_2	18.92^{a}	18.14^{ab}	13.36^{ef}	16.81^{a}	18.92^{a}	17.01^{a-c}	12.18^{ef}	16.04^{a}	18.92^{a}	17.58^{ab}	12.77^{de}	16.42^{a}
	O_3	17.88^{ab}	16.69^{bc}	12.32^{ef}	15.63^{b}	17.45^{ab}	15.12^{cd}	11.88^{ef}	14.82^{b}	17.67^{ab}	15.90^{c}	12.10^{ef}	15.22^{b}
	O_4	15.31^{cd}	14.21^{de}	11.63^{f}	13.72^{c}	15.31^{cd}	13.82^{de}	10.96^{f}	13.36^{c}	15.31^{c}	14.02^{d}	11.29^{f}	13.54^{c}
Sources	S.Em±					S.Em±				S.Em±			
D	0.26					0.43				0.20			
I	0.08					0.11				0.07			
O	0.37					0.37				0.26			
D×I	0.40					0.39				0.29			
D×O	0.64					0.65				0.44			
I×O	0.53					0.53				0.36			
D ×I×O	0.91					0.92				0.63			

Treatment details Sowing dates (D) Irrigation levels (I) Osmoregulators (O)
D_1: November II fortnight I_1: Irrigation at 1.0 ETc O_1: Salicylic acid @ 200 ppm at tillering and ear emergence stages
D_2: December I fortnight I_2: Irrigation at 0.5 ETc O_2: Thiourea @ 400 ppm at tillering and ear emergence stages
D_3: December II fortnight O_3: Kaolin at 5% as antitranspirant spray at tillering and ear emergence stages
O_4: Control (water spray)

Table 2: Effect of sowing dates, deficit irrigation and osmoregulators on test weight (thousand grain weight) of dicoccum wheat

Test weight (g)													
Treatment		2022-23				2023-24				Pooled			
		D×I×O			I×O	D×I×O			I×O	D×I×O			I×O
		D_1	D_2	D_3		D_1	D_2	D_3		D_1	D_2	D_3	
I_1	O_1	39.19^{ab}	37.54^{b-e}	35.23^{d-j}	37.32^{ab}	38.22^{a-c}	37.88^{a-d}	34.59^{c-g}	36.90^{ab}	38.71^{ab}	37.71^{b-e}	34.91^{d-g}	37.11^{ab}
	O_2	41.09^{a}	38.20^{bc}	36.03^{c-i}	38.44^{a}	39.45^{a}	38.70^{ab}	35.30^{b-f}	37.82^{a}	40.27^{a}	38.45^{a-c}	35.67^{c-f}	38.13^{a}
	O_3	38.04^{b-d}	37.30^{b-f}	33.61^{h-k}	36.32^{bc}	37.41^{a-d}	36.11^{a-e}	32.80^{e-h}	35.44^{bc}	37.72^{bc}	36.71^{b-d}	33.20^{f-i}	35.88^{bc}
	O_4	36.8^{c-g}	35.44^{c-j}	32.09^{kl}	34.78^{cd}	36.28^{a-e}	34.77^{b-g}	30.04^{h}	33.70^{cd}	36.54^{b-d}	35.10^{d-g}	31.06^{ij}	34.24^{d}
I_2	O_1	37.67^{b-d}	34.57^{f-k}	33.90^{g-k}	35.38^{cd}	37.68^{a-d}	35.50^{b-f}	33.03^{h}	35.41^{ab}	37.68^{b-e}	35.04^{d-g}	33.47^{i-k}	35.39^{cd}
	O_2	37.98^{b-d}	35.75^{c-i}	34.69^{e-k}	36.14^{bc}	37.83^{a-d}	35.90^{a-f}	32.65^{eh}	35.46^{ab}	37.91^{bc}	35.83^{c-e}	33.67^{e-h}	35.8^{bc}
	O_3	36.35^{b-h}	34.41^{f-kl}	32.7^{j-k}	34.49^{d}	36.31^{a-e}	34.08^{d-g}	31.20^{gh}	33.86^{cd}	36.33^{b-d}	34.24^{d-h}	31.95^{h-j}	34.17^{d}
	O_4	35.10^{d-j}	33.38^{i-k}	30.03^{l}	32.84^{e}	34.6^{c-g}	32.16^{f-h}	29.60^{h}	32.12^{d}	34.85^{d-g}	32.77^{g-i}	29.82^{j}	32.48^{e}
D		37.78^{a}	35.82^{b}	33.54^{c}	I	37.22^{a}	35.64^{b}	32.4^{c}	I	37.50^{a}	35.73^{b}	32.97^{c}	I
		D×I				D×I				D×I			
I	I_1	38.8^{a}	37.1^{b}	34.2^{c}	36.71^{a}	37.84^{a}	36.87^{a}	33.18^{bc}	35.96^{a}	38.31^{a}	36.99^{b}	33.71^{c}	36.34^{a}
	I_2	36.8^{b}	34.5^{c}	32.8^{d}	34.71^{b}	36.61^{a}	34.41^{b}	31.62^{c}	34.21^{b}	36.69^{b}	34.47^{c}	32.23^{c}	34.46^{b}
		D×O			O	D×O			O	D×O			O
O	O_1	38.43^{ab}	36.06^{cd}	34.57^{de}	36.35^{ab}	37.95^{ab}	36.69^{a-c}	33.81^{de}	36.15^{a}	38.19^{ab}	36.37^{c}	34.19^{d-f}	36.25^{a}
	O_2	39.54^{a}	36.98^{bc}	35.36^{de}	37.29^{a}	38.64^{a}	37.3^{a-c}	33.98^{de}	36.64^{a}	39.09^{a}	37.14^{bc}	34.67^{de}	36.97^{a}
	O_3	37.19^{bc}	35.86^{cd}	33.15^{e}	35.4^{b}	36.86^{a-c}	35.09^{cd}	32^{ef}	34.65^{b}	37.03^{bc}	35.48^{c-e}	32.58^{f}	35.03^{b}
	O_4	35.95^{cd}	34.41^{de}	31.06^{f}	33.81^{c}	35.44^{b-d}	33.47^{de}	29.82^{f}	32.91^{c}	35.69^{c-e}	33.94^{ef}	30.44^{g}	33.36^{c}
SV		S.Em±				S.Em±				S.Em±			
D		0.47				0.30				0.33			
I		0.26				0.22				0.14			
O		0.33				0.49				0.29			
D × I		0.47				0.57				0.44			
D×O		0.57				0.85				0.51			
I×O		0.46				0.69				0.42			
D ×I × O		0.81				1.20				0.72			

Means followed by the same letter(s) within column and row are not significantly differed by DMRT (p=0.05); SV-Sources of variation
Treatment details sowing dates (D) Irrigation levels (I) Osmoregulators (O)
D_1: November II fortnight I_1: Irrigation at 1.0 ETc O_1: Salicylic acid @ 200 ppm at tillering and ear emergence stages
D_2: December I fortnight I_2: Irrigation at 0.5 ETc O_2: Thiourea @ 400 ppm at tillering and ear emergence stages
D_3: December II fortnight O_3: Kaolin at 5% as antitranspirant spray at tillering and ear emergence stages
O_4: Control (water spray)

Table 3: Effect of sowing dates, deficit irrigation and osmoregulators on chaffy grains per spike of dicoccum wheat

Chaffy grains spike^{-1}													
Treatment		2022-23				2023-24				Pooled			
		D×I×O			I×O	D×I×O			I×O	D×I×O			I×O
		D_1	D_2	D_3		D_1	D_2	D_3		D_1	D_2	D_3	
I_1	O_1	0.30^{gh}	0.53^{f-h}	1.50^{cd}	0.78^{d}	0.77^{kl}	1.08^{h-l}	1.60^{d-g}	1.15^{d}	0.53^{k}	0.81^{i-k}	1.55^{ef}	0.96^{f}
	O_2	0.27^{h}	0.48^{f-h}	1.43^{cd}	0.73^{d}	0.73^{l}	1.06^{h-l}	1.47^{d-h}	1.09^{d}	0.50^{k}	0.77^{i-k}	1.45^{f}	0.91^{f}
	O_3	0.33^{gh}	0.70^{fg}	1.75^{c}	0.93^{d}	0.87^{j-l}	1.33^{f-j}	1.80^{def}	1.33^{d}	0.60^{k}	1.01^{hi}	1.78^{e}	1.13^{e}
	O_4	0.44^{gh}	1.30^{d}	2.53^{ab}	1.42^{bc}	0.95^{i-l}	1.76^{d-f}	2.56^{bc}	1.76^{c}	0.69^{jk}	1.53^{ef}	2.55^{bc}	1.59^{cd}
I_2	O_1	0.59^{f-h}	1.22^{de}	2.50^{ab}	1.44^{bc}	1.25^{g-k}	1.87^{de}	2.70^{bc}	1.94^{bc}	0.92^{h-j}	1.55^{ef}	2.60^{bc}	1.69^{bc}
	O_2	0.42^{gh}	1.18^{de}	2.30^{b}	1.30^{c}	1.15^{g-l}	1.48^{d-h}	2.40^{c}	1.68^{c}	0.78^{i-k}	1.33^{fg}	2.35^{cd}	1.49^{d}
	O_3	0.71^{fg}	1.29^{d}	2.7^{a}	1.57^{b}	1.38^{e-i}	1.92^{d}	2.94^{b}	2.08^{b}	1.04^{g-i}	1.60^{ef}	2.82^{b}	1.82^{b}
	O_4	0.89^{ef}	1.76^{c}	2.85^{a}	1.84^{a}	1.42^{d-i}	2.43^{c}	3.40^{a}	2.42^{a}	1.15^{gh}	2.1^{d}	3.13^{a}	2.13^{a}
D		0.49^{c}	1.06^{b}	2.20^{a}	I	1.06^{c}	1.62^{b}	2.36^{a}	I	0.78^{c}	1.34^{b}	2.28^{a}	I
		D×I				D×I				D×I			
I	I_1	0.33^{e}	0.75^{d}	1.80^{b}	0.96^{b}	0.83^{d}	1.31^{c}	1.86^{b}	1.33^{b}	0.58^{e}	1.03^{d}	1.83^{b}	1.15^{b}
	I_2	0.65^{d}	1.36^{c}	2.59^{a}	1.53^{a}	1.30^{c}	1.92^{b}	2.86^{a}	2.03^{a}	0.98^{d}	1.64^{c}	2.72^{a}	1.78^{a}
		D×O			O	D×O			O	D×O			O
O	O_1	0.45^{gh}	0.88^{ef}	2.00^{bc}	1.11^{bc}	1.01^{f}	1.47^{de}	2.15^{bc}	1.54^{bc}	0.73^{hi}	1.18^{ef}	2.07^{c}	1.33^{c}
	O_2	0.34^{h}	0.83^{ef}	1.87^{c}	1.01^{c}	0.94^{f}	1.27^{ef}	1.94^{c}	1.38^{c}	0.64^{i}	1.05^{fg}	1.90^{cd}	1.20^{d}
	O_3	0.52^{gh}	0.99^{e}	2.23^{b}	1.25^{b}	1.12^{f}	1.62^{d}	2.37^{b}	1.71^{b}	0.82^{hi}	1.31^{e}	2.30^{b}	1.48^{b}
	O_4	0.66^{fg}	1.53^{d}	2.69^{a}	1.63^{a}	1.18^{ef}	2.10^{bc}	2.98^{a}	2.09^{a}	0.92^{gh}	1.81^{d}	2.84^{a}	1.86^{a}
SV		S.Em±				S.Em±				S.Em±			
D		0.031				0.024				0.020			
I		0.018				0.018				0.017			
D × I		0.053				0.057				0.045			
O		0.055				0.068				0.042			
D×O		0.096				0.118				0.074			
I×O		0.078				0.096				0.060			
D×I×O		0.135				0.166				0.104			

Means followed by the same letter(s) within column and row are not significantly differed by DMRT (p=0.05); SV-Sources of variation
Treatment details sowing dates (D) Irrigation levels (I) Osmoregulators (O)
D_1: November II fortnight I_1: Irrigation at 1.0 ETc O_1: Salicylic acid @ 200 ppm at tillering and ear emergence stages
D_2: December I fortnight I_2: Irrigation at 0.5 ETc O_2: Thiourea @ 400 ppm at tillering and ear emergence stages
D_3: December II fortnight O_3: Kaolin at 5% as antitranspirant spray at tillering and ear emergence stages
O_4: Control (water spray)

Table 4: Effect of sowing dates, deficit irrigation and osmoregulators on grain yield of dicoccum wheat

Treatments		2022-23 D×I×O D1	2022-23 D×I×O D2	2022-23 D×I×O D3	2022-23 I×O	2023-24 D×I×O D1	2023-24 D×I×O D2	2023-24 D×I×O D3	2023-24 I×O	Pooled D×I×O D1	Pooled D×I×O D2	Pooled D×I×O D3	Pooled I×O
I1	O1	4307^{ab}	4072^{a-c}	2790^{i-l}	3723^{a}	3991^{a}	3134de	2114^{ij}	3079^{ab}	4149^{a}	3603^{bc}	2452^{i-k}	3401^{a}
	O2	4380^{a}	4190^{a-c}	2850^{h-l}	3807^{a}	4001^{a}	3269de	2296^{h-j}	3189^{a}	4191^{a}	3730^{b}	2573^{ij}	3498^{a}
	O3	3947^{a-c}	3784^{c-e}	2675^{j-m}	3468^{b}	3707^{ab}	3021^{d-f}	2143^{ij}	2957^{bc}	3827^{b}	3402^{c-e}	2409^{jk}	3213^{b}
	O4	3880^{b-d}	3500^{d-f}	2495^{k-n}	3292^{bc}	3604^{bc}	2750^{fg}	2022^{jk}	2792^{cd}	3742^{b}	3125^{e-g}	2259^{kl}	3042^{c}
I2	O1	3357^{e-g}	3180^{f-i}	2248^{mn}	2928de	3231^{cd}	2650^{f-h}	1739^{kl}	2540^{ef}	3294^{d-f}	2915^{gh}	1993^{l-n}	2734^{d}
	O2	3490^{d-f}	3253^{f-h}	2460^{k-m}	3068^{cd}	3361^{cd}	2740^{gh}	1746^{kl}	2616de	3426^{cd}	2996^{f}	2103^{lm}	2842^{d}
	O3	3170^{f-i}	2960^{g-j}	2200^{n}	2777^{e}	3001^{e-g}	2463^{g-i}	1670^{l}	2378^{f}	3085^{fg}	2711^{hi}	1935^{mn}	2577^{e}
	O4	3090^{f-j}	2908^{g-k}	2138^{n}	2712^{e}	2803^{e-g}	2204^{ij}	1430^{l}	2146^{g}	2946^{gh}	2556^{ij}	1784^{n}	2429^{f}
D		3703^{a}	3481^{b}	2482^{c}	I	3462^{a}	2779^{b}	1895^{c}	I	3583^{a}	3130^{b}	2189^{c}	I
	D×I					D×I				D×I			
I	I1	4129^{a}	3886^{b}	2703^{e}	3573^{a}	3826^{a}	3044^{b}	2144^{d}	3004^{a}	3977^{a}	3465^{b}	2423^{e}	3288^{a}
	I2	3277^{c}	3075^{d}	2261^{f}	2871^{b}	3099^{b}	2514^{c}	1646^{e}	2420^{b}	3188^{c}	2795^{d}	1954^{f}	2645^{b}
O	D×O				O	D×O			O	D×O			O
	O1	3832^{ab}	3626^{b-d}	2519^{fg}	3326^{a}	3611^{a}	2892^{cd}	1926^{f}	2810^{ab}	3721^{a}	3259^{b}	2223^{ef}	3068^{a}
	O2	3935^{a}	3722^{a-c}	2655^{f}	3437^{a}	3681^{a}	3004^{c}	2021^{f}	2902^{a}	3808^{a}	3363^{b}	2338^{e}	3170^{a}
	O3	3558^{b-d}	3372de	2437^{fg}	3123^{b}	3354^{b}	2742^{d}	1907^{f}	2667^{b}	3456^{b}	3057^{c}	2172^{ef}	2895^{b}
	O4	3485^{c-e}	3204^{e}	2316^{g}	3002^{b}	3204^{b}	2477^{e}	1726^{g}	2469^{c}	3344^{b}	2841^{d}	2021^{f}	2735^{c}
SV	S.Em±					S.Em±				S.Em±			
D	54					29				39			
I	29					29				20			
O	57					52				37			
D×I	67					59				49			
D×O	99					90				64			
I×O	81					73				52			
D×I×O	140					127				91			

Means followed by the same letter(s) within column and row are not significantly differed by DMRT (p=0.05); SV-Sources of variation

Treatment details

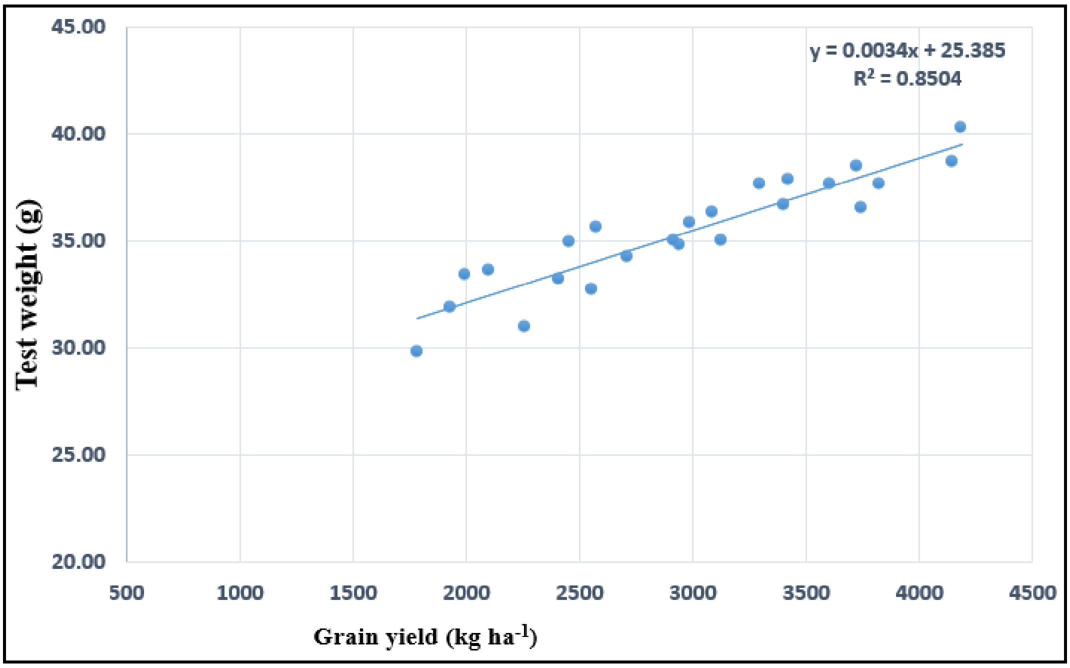
Sowing dates (D) Irrigation levels (I) Osmoregulators (O)

D_1: November II fortnight I_1: Irrigation at 1.0 ETc O_1: Salicylic acid @ 200 ppm at tillering and ear emergence stages

D_2: December I fortnight I_2: Irrigation at 0.5 ETc O_2: Thiourea @ 400 ppm at tillering and ear emergence stages

D_3: December II fortnight O_3: Kaolin at 5% as antitranspirant spray at tillering and ear emergence stages

O_4: Control (water spray)



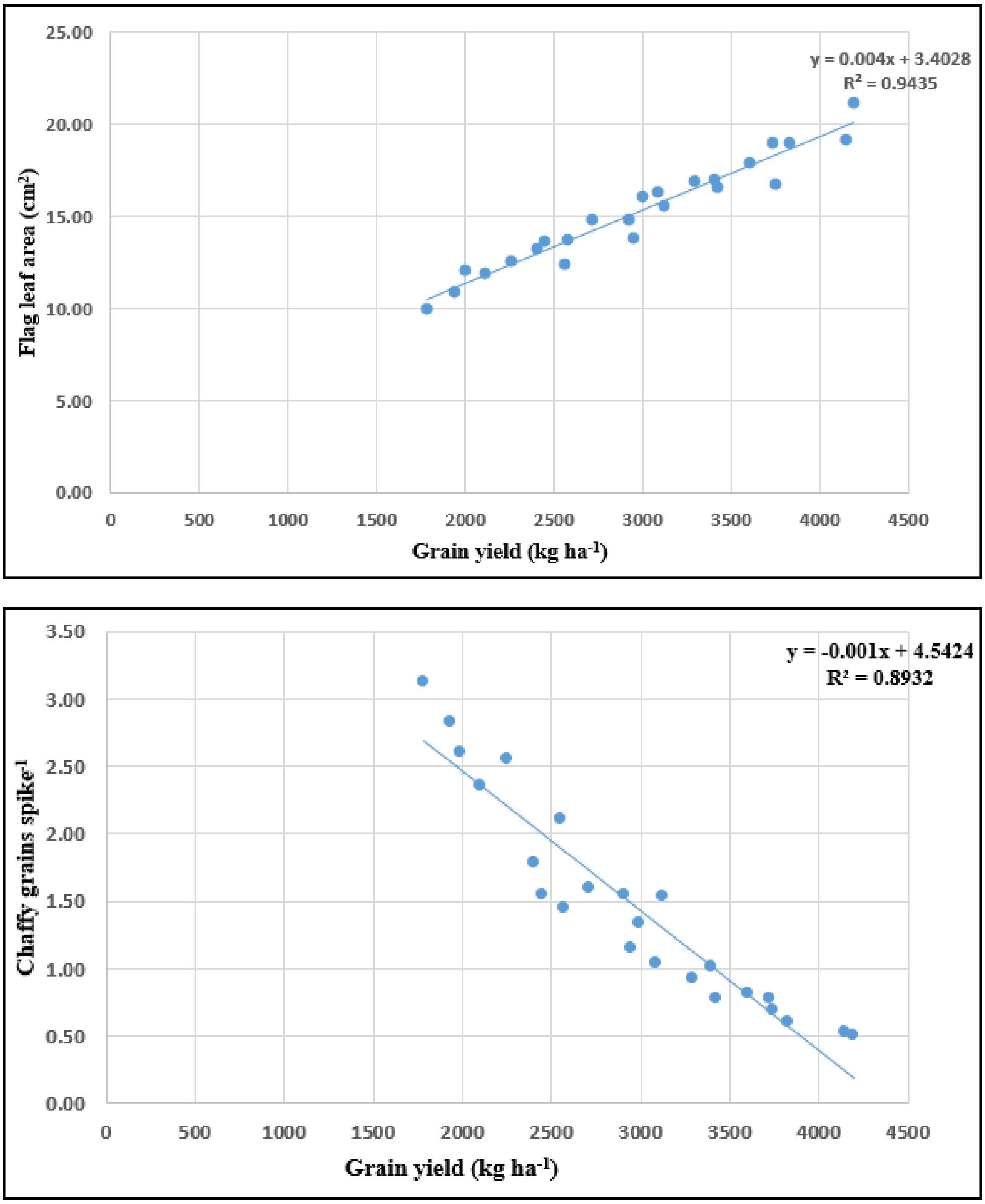


Fig 1: Regression analysis of grain yield with a. flag leaf area b. test weight and c. chaffy grains spike-1

Conclusion

The November II fortnight sowing, irrigation at 1.0 ETc and foliar spray of thiourea @ 400 ppm improved productivity of dicoccum wheat. Similar results were obtained with foliar spray of salicylic acid @ 200 ppm under November II fortnight sowing and irrigation at 1.0 ETc.

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