Journal of Tropical Agriculture 60(2): 195-205, 2022

Precision farming techniques and Agro meteorological indices for African marigold cultivation in humid tropics of Kerala

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Received 02 March 2022; received in revised form 25 November 2022; accepted 03 December 2022

Abstract

The study could identify the best precision farming techniques,such as fertigation and drip irrigation, by utilizing two resistant marigold genotypes G_1 (Bhagwati –F_1 hybrid) and G_2 (KAU-M-1, Local collection) in three seasons *viz*., rainy, winter, and summer, under humid tropical plains of Kerala. Crop raised under drip fertigation recorded enhanced growth and yield compared to the control plot in all three seasons. In the rainy season, fertigation @ 75 % RDF (F_1) recorded a yield of 35.26 t/ha for G_1 and 13.00 t/ha for G_2 which is double the yield obtained in the control treatments of respective genotypes. In winter and summer seasons, irrigation @ 100 per cent Epan and fertigation @ 125% RDF recorded the highest yield in both the genotypes. The highest nutrient uptake was recorded in 75% RDF during the rainy season, whereas in winter and summer seasons, nutrient uptake was maximum in I_2F_3. Water use efficiency was the highest in the treatment I_2F_3 for G_1 and G_2 during the winter and summer seasons. Response of the genotypes varied concerning different meteorological indices like average temperature, average relative humidity, average rainfall, and average Epan in the three cropping seasons. In the rainy season, the majority of the vegetative, flowering (except days to initiation and fifty per cent flowering), as well as yield parameters, were positively correlated with temperature in both the genotypes, whereas in the case of relative humidity, only hybrid Bhagwati was showing positive correlation with a majority of the parameters. Due to cloudiness in the rainy season, the flowering phase was delayed in both genotypes up to an average of 13.45 days. Response of the two genotypes during summer was negative with average temperature and relative humidity whereas epan showed a positive response in both winter and summer.

Keywords: Drip irrigation, Fertigation, Relative humidity, *Tagetes erecta*, Temperature and Water use efficiency.

Introduction

Marigold (*Tagetes erecta)* is an important commercial loose flower crop grown in India. Major marigold growing tracts are West Bengal, Karnataka, Andhra Pradesh, Maharashtra, and Tamil Nadu. Recently, the cultivation of this crop is gaining popularity during festival seasons in Kerala. Usually, flower growers prefer F_1 hybrids due to their high-yielding nature with good quality attractive flowers. However, bacterial wilt has become a major threat to successful marigold cultivation in Kerala.

African marigold can be cultivated in Kerala throughout the year due to their free-flowering nature and short duration. But, the conventional farming system is highly labour intensive and uneconomical due to the high cost of labour prevailing in the state. Water and nutrient management are the two essential factors directly influencing crop yield. Precision farming is the best

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choice for commercial cultivation of any crop, wherever irrigation water is limited. Precision farming also reduces the labour required for the cultivation of the crop. Drip irrigation and fertigation not only save water but also improve the growth and yield of crops. Jawaharlal et al. (2013) reported improved vegetative growth, flower yield, and xanthophyll content in African marigold flowers with 75 per cent recommended dose of fertilizers along with humic acid 0.2 per cent through drip fertigation.

Seasonal assessment of the genotypes concerning performance in terms of quality and yield is quite important for successful cultivation. Kerala experiences a humid tropical climate, and there is a need to identify suitable genotypes for commercial cultivation. In this context, the present investigation was carried out with the objective of standardization of precision farming techniques using two marigold genotypes and to find out meteorological indices for African marigold cultivation in the humid tropics of Kerala. Responses of the two genotypes, in terms of vegetative, floral, and yield characters as well as nutrient uptake were correlated to weather parameters *viz.,* average temperature, average relative humidity, average rainfall, and average Epan in all three seasons. Weather parameters influence all stages of plant growth and thereby affect crop productivity. Each crop, particularly its hybrids/ varieties, has its own set of optimum and tolerable environmental conditions under which it can be grown efficiently. Knowledge about the relationships between crop growth stages and weather parameters is very important to maximize production by adjusting crop management practices. For a crop variety to be successful in a specific region, the sequences of its growth phases must fit in the climate of the region to ensure good growth and adequate production.

Materials and Methods

The experiment was carried out in three seasons corresponding to summer (January to April 2019), rainy (June to September 2019), and winter (October 2019 to January 2020) using two marigold genotypes that showed better resistance to bacterial wilt, *viz.,* one F1 hybrid Bhagwati (G_1) and one local collection KAU -M-1(G_2). The seeds were raised in protrays in a medium comprised of coco peat, vermiculite, and perlite on a 3:1:1 v/v basis. One-month-old seedlings were transplanted to the experimental plots. All the treatment plots except the control plots were provided with inline drip irrigation with a dripping capacity of 2L/hour, drip spacing of 40 cm, and a facility for venturi mediated fertigation. All the treatments were mulched with 30µ silver black polythene sheet. Plots with conventional irrigation and fertilizer application, without mulching, were treated as control. The plot size was 4 m x 1m, and the spacing was adopted at 0.50 m x 0.50 m. A single pinching was given at 20 days after transplanting (DAT) in all the treatments, and plants were staked at 45 DAT. The fertilizer for precision farming recommended by IIHR in African marigold (90:90:75 NPK kg/ha) was followed for the experiment. Before the layout of the experiment, soil samples were collected and analyzed, and fertilizer doses were calculated based on the soil test data. Full P_2O_5 in the form of rock phosphate was applied as the basal dose. Even though P was in excess as per the soil test data, 25% of the recommended dose was applied to ensure nutrient availability. The doses of N and K_2O were fixed for the different fertigation levels *viz*., F_1- 75 %, F2-100 %, and F_3- 125% RDF. The sources of N and K were urea and potassium nitrate (13:0:45). Fertigation was given at three days intervals following the schedule *viz.,* 20% of N and K (6 doses) during the establishment stage (up to 21 DAT), 40% each of N and K (12 doses each) during the vegetative stage (21-55 DAT) and flowering stage (55 DAT to till complete flower harvests). Irrigation was given daily based on the pan evaporation, which was calculated taking into consideration the number of emitters present in the plot, the discharge capacity of emitters, and the daily pan evaporation (Epan). Irrigation was given at two levels *viz.*, I_1 (75 % Epan) and I_2 (100 % Epan) during winter and summer. No irrigation was given during the rainy season. In the control plots, each plot was given 20 mm of water twice a week at three days intervals. Observations were recorded on vegetative parameters (plant height, plant spread, number of primary branches, and dry matter production), flowering parameters (days to bud initiation, flower diameter, and flower weight), yield parameters (number of flowers/plants, flower yield/plant, and number of harvests/plant). The uptake of nutrients (NPK) and water use efficiency were also worked out. The data was analyzed statistically [Gomez and Gomez, (1984) and Sheoran et al. (1998)].

Results and Discussion

Vegetative parameters

During the rainy season, (Table 1) the plant height (131.86 cm), plant spread (61.81 cm), the number of primary branches (20.58), and dry matter production (120.14 g/plant) were maximum in treatment F_1 (75% RDF) in the G_1 genotype. Compared to G_1, all the vegetative parameters recorded lower values for G_2 in respective treatments. Greater plant height of 69.80 cm during the winter season was recorded in I_2F_3, which was on par with I_2F_2 (67.60 cm) in G_1. Plant spread was significantly highest in I_2F_3 in both the genotypes (38.90 cm and 36.50 cm) and were on par with the treatments, I_2F_2 (37.53 cm) and I_2F_2 (67.60 cm) in G_1 genotype. Significantly greater dry matter production was recorded in hybrid G_1 (78.61 g/plant), and G_2 (77.75 g/plant) under treatment I_2F_3, and they were on par with each other. During the summer season, the highest plant height (60.77 cm) was recorded in I_2F_2, which was on par with I_2F_2 (67.60 cm), I_2F_2 (67.60 cm) and I_2F_2 (67.60 cm) in G_1. Significantly greater plant spread (42.03 cm) was recorded in I_2F_3, which was on par with I_2F_2 (38.90 cm) in G_1. Plant spread in G_2 was less compared to G_1 and it ranged from 30.30 cm (I1F2) to 35.27 cm (I_2F_3). The greatest dry matter production (76.14 g/plant) was recorded in G_1 (hybrid) in I_2F_3. The more number of primary branches was recorded in genotype G1, I_2F_3 (8.27) and it was on par with I_2F_1 (7.90), I2F1 (7.90), and control (7.57) in genotype G_2. During the three seasons, control treatment in both genotypes recorded comparatively low vegetative growth. Better performance in drip fertigation treatments compared to control is attributed to the improved microclimate in the root zone, which in turn might have favoured enhanced photosynthesis and

Table 1. Effect of precision farming techniques in African marigold genotypes for vegetative parameters

Treatments		Rainy season: Plant height (cm)	Plant spread (cm)	Number of primary branches	Dry matter production (g/plant)
G_1	F_1	131.86	61.81	20.58	120.14
	F_2	115.77	53.74	18.22	117.50
	F_3	105.55	49.67	14.12	115.52
	C	86.10	33.52	8.40	65.77
G_2	F_1	61.57	54.80	16.81	91.99
	F_2	54.53	44.58	15.17	90.22
	F_3	48.60	37.17	11.57	87.37
	C	41.77	33.77	7.63	64.53
C.D.(0.05)		2.72	2.03	1.19	1.24
SEm±		0.89	0.66	0.39	0.41

Treatments		Winter season: Plant height (cm)	Plant spread (cm)	Number of primary branches	Dry matter production (g/plant)	Summer season: Plant height (cm)	Plant spread (cm)	Number of primary branches	Dry matter production (g/plant)
G_1	I_1F_1	53.67	25.73	8.07	61.94	55.40	34.47	6.70	58.41
	I_1F_2	51.53	31.23	8.33	62.21	50.50	35.73	6.72	60.75
	I_1F_3	54.87	31.97	9.33	66.43	51.83	36.77	6.97	65.25
	I_2F_1	61.67	37.00	10.40	68.55	59.53	37.37	7.90	68.36
	I_2F_2	67.60	37.53	9.87	75.55	60.77	38.90	7.77	70.52
	I_2F_3	69.80	38.90	11.40	78.61	59.60	42.03	7.17	76.14
	C	45.73	23.43	5.93	39.12	46.10	28.90	7.57	35.49
G_2	I_1F_1	41.30	25.47	6.70	63.34	39.47	31.17	5.63	54.77
	I_1F_2	41.97	29.35	6.60	63.93	39.10	30.30	5.40	51.42
	I_1F_3	43.80	28.73	6.60	66.08	39.93	32.77	5.90	53.33
	I_2F_1	44.13	28.92	7.53	68.14	41.40	31.73	6.70	58.37
	I_2F_2	49.17	32.77	6.87	72.09	40.10	30.67	6.73	60.36
	I_2F_3	55.17	36.50	7.60	77.75	45.53	35.27	8.27	63.38
	C	36.67	23.97	6.40	43.19	40.17	33.33	6.10	36.61
C.D.(0.05)		3.46	2.60	1.09	1.17	5.80	3.19	0.76	0.32
SEm±		1.18	0.89	0.37	0.40	1.98	1.09	0.26	0.11

Table 2. Effect of precision farming techniques in African marigold genotypes for flowering and floral parameters

Treatments		Rainy season: Days to bud initiation	Rainy season: Flower diameter (cm)	Rainy season: Flower weight (g)
G_1	F_1	30.20	10.27	28.10
	F_2	35.60	9.33	25.20
	F_3	38.30	8.68	24.80
	C	46.27	4.82	14.80
G_2	F_1	63.53	6.10	10.78
	F_2	67.90	5.18	10.07
	F_3	72.40	4.37	8.20
	C	81.30	3.22	6.80
	C.D.(0.05)	1.15	0.38	2.19
	SEm±	0.38	0.12	0.72

Treatments		Winter season: Days to bud initiation	Winter season: Flower diameter (cm)	Winter season: Flower weight (g)	Summer season: Days to bud initiation	Summer season: Flower diameter (cm)	Summer season: Flower weight (g)
G_1	I_1F_1	24.67	4.06	4.92	24.60	6.13	4.73
	I_1F_2	24.70	3.53	3.91	26.50	6.01	4.80
	I_1F_3	24.50	3.45	4.12	26.97	6.67	5.70
	I_2F_1	25.33	4.06	4.22	27.47	7.07	6.72
	I_2F_2	28.50	4.59	5.87	27.53	7.93	8.88
	I_2F_3	27.33	4.49	6.87	27.67	6.70	9.23
	C	22.17	3.80	3.77	25.93	4.85	4.45
G_2	I_1F_1	28.07	3.68	5.37	35.13	5.20	7.47
	I_1F_2	29.33	3.73	5.17	35.17	5.30	6.62
	I_1F_3	24.97	3.73	5.10	35.83	5.08	6.45
	I_2F_1	25.13	3.23	4.92	35.30	5.33	5.73
	I_2F_2	23.30	4.68	7.57	36.17	5.43	7.52
	I_2F_3	22.17	4.87	7.45	36.80	5.82	7.83
	C	40.17	3.59	4.18	39.73	4.52	4.57
	C.D.(0.05)	1.29	0.41	0.79	2.51	0.66	0.36
	SEm±	0.44	0.14	0.27	0.86	0.23	0.12

metabolic activities, less leaching of nutrients, less compaction of soil, and low competition from weeds as reported by Bhatt et al. (2011) and Parmar et al. (2013). Divya et al. (2017) and Vashista et al. (2020) reported enhanced vegetative growth and flowering under drip irrigation in African marigold. Optimum nutrient uptake through drip fertigation could lead to superior growth thereby enhancing the biomass of the plant and this might have resulted in increased dry matter production in these treatments.

It could also be observed that in the rainy season, fertigation with 75% RDF showed superior performance compared to the other two fertilizer levels, while during the winter and summer season, drip irrigation @ 100% Epan along with fertigation @ 125% RDF showed better performance for vegetative and floral parameters. This might be due to the soil nutrient status before each crop and evapotranspiration prevailing during the cropping seasons. The nutrient status of the soil and plants could be a reminder of the response of the plant to fertilizers, and the internal content of the nutrients determine the fertilizer requirement (Sumangala et al. 2018).

Flowering parameters

During the rainy season, the G_1 genotype applied with 75% RDF showed earlier flower bud initiation (30.20 DAT), higher flower diameter (10.27 cm), and flower weight (28.10 g) which was significantly superior among all other treatments. The G_2 genotype recorded very late flower bud initiation ranging from 63 to 72 DAT, flower diameter from 4.37 to 6.10 cm, flower weight (g) from 8.20 to 10.78 in fertigation treatments, and 81 DAT, 3.22 cm and 6.80 g in control. The differential response in flowering parameters of the two genotypes under the same treatments was attributed to their genetic makeup. Among the fertigation levels tried, delayed bud initiation and lower values for flowering parameters were observed in higher doses of fertilizers like 100% and 125% RDF compared to the lower dose of 75% RDF in both genotypes. In this context, the high available nitrogen in the soil before the rainy season crop was considered as the reason for earlier flower initiation even at lower doses of fertigation. Plants under this condition might have completed sufficient vegetative growth and put forth the floral primordial earlier. Delayed flowering at a higher level of fertigation has been reported by Divya et al. (2017) in African marigold. During the winter season, drip fertigation treatments showed delayed bud initiation ranging from 24.50 (I_1F_3) to 28.50 (I_2F_2) DAT compared to control (22.17 DAT) in G_1, whereas in G_2 the reverse trend was observed. About flower diameter, significantly greater values ranging from 4.49 cm to 4.87 cm were observed in I_2F_3 and I_2F_2 in both genotypes. Flower weight was significantly higher in I2F3 (6.87 g) inG_1 and I_2F_2 (7.57 g), I_2F_3(7.45 g) in the G_2 genotypes.

During the summer season, G_1 showed early bud initiation in all treatments except I_1F_1 (24.60 days), ranging from 24.60 to 27.67 DAT. Compared to G_1, G_2 showed delayed bud initiation that ranged from 35.13 (I_1F_1) to 36.80 (I_2F_3) DAT in drip fertigated treatments, while it was further delayed in control (39.73 DAT). This differential response in flowering during the winter and summer seasons could be attributed to their genetic makeup.

During the summer season, flower diameter and weight were significantly high in G_1 under a higher level of irrigation (I_2). The highest flower diameter (7.93 cm) was observed in G1 in treatment I_2F_2, followed by I_2F_1 (7.07 cm) and I_2F_3 (6.70 cm). Significantly greater flower weight was recorded in I_2F_3 and I_2F_2 (9.23 g and 8.88 g, respectively) in the same genotype.

Yield parameters

During the rainy season (Table 3), G_1 recorded significantly more flowers per plant (55.67) and greater flower yield (1101.97 g/plant) in the treatment F_1 (75 % RDF). During the winter and summer seasons, the treatment I_2F_3 showed better performance for the yield parameters in both genotypes. In the winter season, the number of flowers per plant was significantly greater and on par in treatment I_2F_3 in both the genotypes (65.33 and 63.67 in G_1 and G_2, respectively). The greater flower yield of 403.70 g/plant was recorded in I_2F_3 of G_2 and this was followed by the same treatment of G_1 (382.46 g/plant). The number of harvests per plant was significantly more in I_2F_3 (6.67) and I_2F_2 (6.33) in G_2, and these were on par also.

During the summer season also, the number of flowers per plant was significantly more in I_2F_3 for both G_1 and G_2 (74.87 and 70.90, respectively). The treatment I_2F_3 recorded significantly greater flower yield (334.63 g/plant) in G_2, which was on par with the same treatment of G_1 (314.50 g/ plant). The number of harvests per plant was more in I_2F_3(7.67), and were on par with I_1F_2, :I_1F_3: I_2F_2 (7.33) and I_2F_1 (7.00) in G_1 (hybrid) compared to G_2, and it ranged from 3.87 (control) to 5.53 (I_2F_3).

Table 3. Effect of precision farming techniques in African marigold genotypes for Yield parameters

Treatments		Rainy season: No. of flowers/ plant	Flower yield / plant (g)	No. of harvests/ plant
G_1	F_1	55.67	1101.97	9.67
	F_2	53.60	975.40	8.69
	F_3	51.53	842.90	8.65
	C	41.80	489.67	5.67
G_2	F_1	44.93	461.73	6.33
	F_2	39.80	397.93	5.67
	F_3	38.07	354.53	5.33
	C	31.00	243.60	4.67
C.D.(0.05)		2.02	74.20	1.03
SEm±		0.66	24.23	0.34

Treatments		Winter season			Summer season		
		No. of flowers/ plant	Flower yield / plant (g)	No. of harvests/ plant	No. of flowers/ plant	Flower yield / plant (g)	No. of harvests/ plant
G_1	I_1F_1	43.60	197.08	4.00	46.17	182.73	6.00
	I_1F_2	46.20	208.24	4.00	55.30	209.67	7.33
	I_1F_3	47.53	221.67	4.00	55.97	206.77	7.33
	I_2F_1	40.93	185.07	4.00	54.83	192.43	7.00
	I_2F_2	54.73	318.66	4.33	65.13	240.80	7.33
	I_2F_3	65.33	382.46	6.00	74.87	314.50	7.67
	C	33.33	150.07	4.33	37.33	131.70	5.33
G_2	I_1F_1	47.93	238.93	5.00	50.60	214.97	5.07
	I_1F_2	51.53	264.73	5.00	45.53	185.47	4.73
	I_1F_3	55.23	282.93	5.00	44.27	181.97	4.67
	I_2F_1	38.43	194.03	5.00	54.83	232.70	5.53
	I_2F_2	58.07	354.63	6.33	59.87	294.77	4.63
	I_2F_3	63.67	403.70	6.67	70.90	334.63	5.33
	C	38.07	189.27	5.00	39.10	176.33	3.87
C.D.(0.05)		2.10	11.96	0.54	4.44	21.83	1.29
SEm±		0.72	4.09	0.18	1.52	7.47	0.44

The floral and yield parameters, such as flower diameter, weight, number of flowers, flower yield, and number of harvests, were significantly greater in 75% RDF during the rainy season. This might be due to the fulfillment of the optimum fertilizer requirement of the crop in already rich available nutrients in the soil during the rainy season. Fertilizer doses higher than 75% RDF harmed all the floral parameters and flower yield in marigold during the rainy season. During winter and summer, the treatment I_2F_3 (irrigation @100 Epan along with 125% RDF) recorded a better performance in terms of floral parameters *viz.,* flower diameter, stalk length, flower weight, petal weight, as well as yield parameters *viz.,* number of flowers, flower yield and number of harvests in both the genotypes. The requirement of increased fertilizer doses and irrigation at 100% Epan could be attributed to the soil nutrient status and prevailing weather conditions like evapotranspiration and temperature. The higher doses of nutrients, along with sufficient irrigation, might have increased the uptake of nutrients that might have contributed to enhanced photosynthesis and metabolic activities, and this, in turn, resulted in high dry matter production and translocation of phytohormones to the shoots. The high dry matter, as well as the hormonal activity, was assigned as the reasons for enhanced floral parameters as well as flower yield. This conformed to the findings of Jawaharlal et al. (2013), Divya et al. (2017), and Babu et al. (2018) in African marigold and Salma et al. (2014) in gerbera.

Nutrient uptake

During the rainy season (Table 4), a significantly higher uptake of nitrogen (73.82 kg/ha) was recorded in F1 (75% RDF), which was on par with F_2 (71.81 kg/ha). Phosphorous uptake was highest (19.86 kg/ha) in F_1 (75% RDF). Treatments F_1, F_2 and F_3 were on par with respect to potassium uptake (60.22 kg/ha, 58.55 kg/ha, and 57.20 kg/ha respectively). Compared to G_1, G_2 showed lower nutrient uptake during the season, and this could be attributed to the differential response of these genotypes.

During winter, the treatment I_2F_3 recorded the highest nitrogen, phosphorous, and potassium uptake (71.77 kg/ha, 17.24 kg/ha, and 36.98 kg/ha, respectively) in G_1. In G_2, the nitrogen uptake under I_2F_3 was on par with the same treatment of G_1. However, uptake of both phosphorous (14.60 kg/ha) and potassium (35.99 kg/ha) was lower compared to I_2F_3(17.24 and 36.97 kg/ha respectively) of G_1. A similar trend was noticed in the summer season also.

Table 4. Effect of precision farming techniques in African marigold genotypes for nutrient uptake

Treatments		Rainy season			Treatments		Winter season			Summer season		
		N uptake	P uptake	K uptake			N uptake	P uptake	K uptake	N uptake	P uptake	K uptake
G_1	F_1	73.82	19.86	60.22	G_1	I_1F_1	56.10	11.78	28.01	47.85	8.72	25.23
	F_2	71.81	18.30	58.55		I_1F_2	56.14	12.74	28.28	49.57	9.91	25.72
	F_3	66.28	17.37	57.20		I_1F_3	59.87	13.25	30.17	53.17	10.44	28.39
	Control	33.04	8.49	28.08		I_2F_1	62.23	13.89	31.82	56.14	11.01	30.33
G_2	F_1	56.52	15.21	46.10		I_2F_2	68.50	16.76	35.31	57.85	12.64	31.52
	F_2	55.14	14.05	44.94		I_2F_3	71.77	17.24	36.98	62.94	13.56	34.27
	F_3	50.15	13.14	43.24		C	35.43	7.07	17.16	29.08	4.96	14.84
	Control	32.42	8.33	27.44	G_2	I_1F_1	56.93	13.51	27.90	44.52	9.47	23.03
	C.D.(0.05)	5.22	0.30	9.15		I_1F_2	57.00	13.43	28.37	41.41	8.72	21.78
	SEm±	1.70	0.10	2.99		I_1F_3	59.77	13.81	28.98	43.63	8.99	22.30
					I_2F_1	61.63	12.93	30.24	47.75	8.72	24.72	
					I_2F_2	65.63	13.84	32.61	49.77	9.14	26.08	
					I_2F_3	71.27	14.60	35.99	52.60	9.33	28.06	
					C	39.20	7.74	18.43	30.03	5.08	14.88	
				C.D.(0.05)	1.13	0.64	0.72	0.45	0.60	0.75		
				SEm±	0.39	0.22	0.25	0.16	0.21	0.26		

In general, better uptake of nutrients was observed in drip fertigation treatments. This was due to the high nutrient contents and dry matter production in these treatments, which was facilitated by the judicious application of water and water-soluble nutrients through drip irrigation in the root zone, that leads to minimum leaching losses under plastic mulching. Nitrogen is a highly mobile element in plant tissues. Its efficient translocation under optimum moisture and nutrient supply from root to leaves could have added to its enhanced accumulation in the leaves (Smith, 1962). Similar results have been observed by Qasim et al. (2008) in rose, Jeevan et al. (2016) in tuberose, and Prabu et al. (2016) in chilli. High uptake of potassium could be attributed to the fact that the treatments which recorded higher nitrogen and phosphorous improve the potassium (K) nutrition by synergistic effect and enhanced the uptake of K by the plants, as reported by Polara et al. (2014) in marigold.

Water use efficiency: During the winter season (Table 5), the highest WUE (10.92 kg/ha mm^{-1}) was recorded in I_2F_3 in G_1 (hybrid), which was followed by I_2F_3 in G_2. In the summer season also, a similar trend was noticed; the WUE being 7.02 kg/ha mm^{-1} in G_2 and 6.79 kg/ha mm^{-1} in G_1 in the treatment (I_2F_3). The lowest WUE was recorded in control treatments of the two genotypes in both seasons.

It is evident from the study that WUE was significantly greater in all drip fertigation treatments compared to control in both the genotypes during winter and summer. It could also be observed that among the drip fertigation treatments, WUE was the highest for the treatment I_2F_3 in both genotypes during both seasons. This might be because the higher irrigation and fertigation levels, along with black polythene mulching, promoted greater uptake of nutrients, thereby enhancing yield, which led to the remarkable WUE in this treatment. There were also seasonal differences observed in WUE between the winter and summer seasons. At the same irrigation and fertigation levels, WUE was more during winter than summer. This could be due to the increased evapotranspiration during summer, increasing the total water used during summer coupled with low flower yield. Improved WUE in drip fertigation treatments over control has been reported by Vashista et al. (2020) in African marigold, Narayanankutty et al. (2017) in Okra, and Navyashree et al. (2019) in tomato.

Table 5. Effect of precision farming techniques in African marigold genotypes for water use efficiency

Treatments		Winter season			Summer season		
		Flower yield/ ha	Water applied (mm)	WUE (Kg/ ha/mm)	Flower yield/ ha	Water applied (mm)	WUE (Kg/ ha/mm)
G_1	I_1F_1	6335	840.1	7.51	5847	1112	5.26
	I_1F_2	6644	840.1	7.93	6709	1112	6.04
	I_1F_3	7100	840.1	8.44	6617	1112	5.95
	I_2F_1	5896	1121.3	5.28	6158	1483	4.15
	I_2F_2	9951	1121.3	9.09	7706	1483	5.20
	I_2F_3	12281	1121.3	10.92	10064	1483	6.79
	C	4809	1600.0	3.00	4214	2160	1.95
G_2	I_1F_1	7691	957.1	7.99	6879	1145	6.01
	I_1F_2	8394	957.1	8.85	5935	1145	5.18
	I_1F_3	9031	957.1	9.46	5823	1145	5.08
	I_2F_1	6219	1277.3	4.86	7446	1525	4.88
	I_2F_2	11344	1277.3	8.88	9433	1525	6.18
	I_2F_3	12963	1277.3	10.11	10708	1525	7.02
	C	6040	1800.1	3.36	5643	2640	2.14
C.D.(0.05)				0.36			0.55
SEm±				0.12			0.19

Correlation of weather parameters on vegetative, flowering, yield, and nutrient uptake in African marigold genotypes

Average temperature: In the rainy season, the average temperature was 26.5° C (Fig.1 a). Vegetative parameters like plant height, spread, and the number of primary branches showed a positive correlation with the average temperature in both genotypes during the season. However, flowering parameters like days to floral bud initiation and 50 per cent flowering were negatively correlated with the temperature. Other parameters, *viz.,* floral and yield parameters, were positively correlated with temperature. The uptake of major nutrients also showed a positive correlation with the temperature.

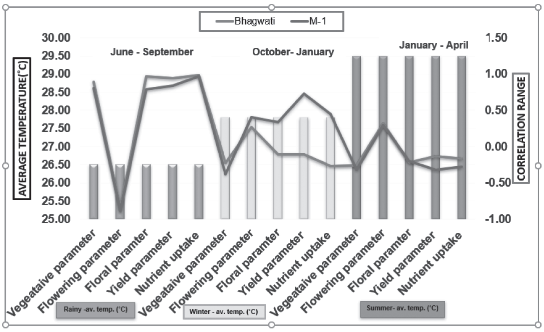

Fig a. Average Temperature

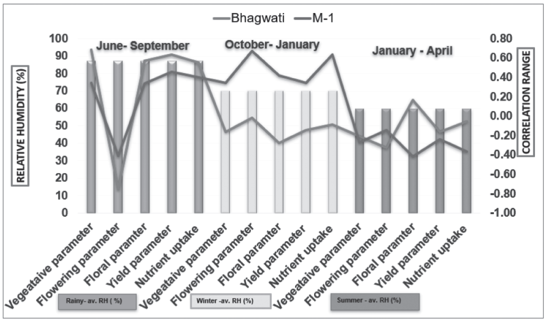

Fig b. Average Relative Humidity

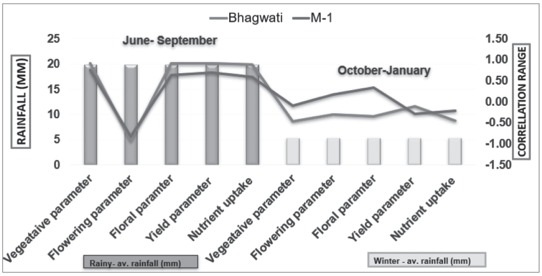

Fig c. Average Rainfall

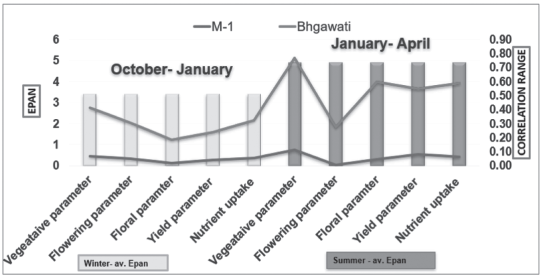

Fig d. Average Epan

Figure 1. Response of marigold genotypes to Agro meteorological indices during the cropping period

The average temperature during the winter season was 27.80° C (Fig1. a). Vegetative parameters showed a negative correlation with temperature in both the genotypes. However, days to bud initiation showed a positive correlation. Flower diameter in Bhagwati showed a negative correlation with average temperature, whereas KAU M-1 showed a positive correlation. Other floral and yield parameters were positively correlated with temperature in KAU M-1, whereas Bhagwati showed a negative correlation with temperature in these parameters. Nutrient uptake also showed the same trend.

During the summer season, the average temperature was 29.50° C (Fig.1 a). The majority of the parameters in both genotypes were negatively correlated with temperature during the summer season.

Average relative humidity

Average relative humidity was the maximum (87.00%) (Fig b) during the rainy season. Vegetative, floral, yield parameters, and nutrient uptake showed a positive correlation with relative humidity during the rainy season, whereas flowering parameters showed a negative correlation, and this correlation was significant in hybrid Bhagwati.

The average relative humidity during winter (Fig.1 b) was 69.85%. F_1 hybrid Bhagwati did not show any correlation with humidity during the winter season, whereas the genotype KAU-M-1 showed a significant positive correlation with humidity in most parameters except the flowering parameters, *viz.,* days to bud initiation and 50 per cent flowering.

The average relative humidity was very low (59.49%) during the summer (Fig.1 b). During this season, the parameters such as vegetative, yield, and nutrient uptake showed a significant negative correlation with humidity except for flowering and floral parameters.

Average rainfall

During the rainy season, both the genotypes had a strong correlation (Fig.1 c) with rainfall, whereas during winter, no significant correlation could be observed in the parameters such as vegetative, floral, flowering, yield and nutrient uptake.

Average Epan

The majority of the parameters in both the genotypes were positively correlated with average Epan during the winter season (3.4) and summer (4.9) season (Fig.1 d).

Seasonal response of the African marigold genotypes to the weather parameters

During the rainy season, (Fig.1 a,b,c,d) the hybrid Bhagwati showed better growth and flower yield than KAU-M-1. The hybrid Bhagwati showed a positive correlation with average temperature, average relative humidity, and rainfall during this season. Perhaps the high relative humidity might have contributed to adequate vegetative growth acquired by hybrid Bhagwati at an earlier stage, higher nutrient uptake, and high dry matter production compared to KAU-M-1. The reason for better growth and yield could also be due to the vigour of the hybrid Bhagwati. One of the flowering parameters, *viz.,* days to flower bud initiation, was very much delayed in KAU-M-1 compared to Bhagwati during the rainy season compared to the winter and summer seasons. This was attributed to the short-day requirement of the genotype KAU-M-1 for flowering. This also might have contributed to the differential response of the genotypes during the rainy season.

In the winter season (Fig.1 a,b,c,d), the genotype KAU-M-1 performed better than hybrid Bhagwati for flower yield. KAU-M-1 also showed almost on par performance with Bhagwati in many other floral as well as vegetative parameters. In this context, the differences in correlation pattern between the two genotypes with average temperature (27.80^{o}C), average relative humidity (69.85%), average rainfall (5.22 mm), and average Epan (3.4) should be considered. During the winter season, the genotype KAU-M-1 showed a positive and significant correlation between temperature and parameters *viz.,* days to bud initiation, flower diameter, flower weight, number of flowers per plant, and flower yield while Bhagwati showed a negative and significant correlation between temperature and parameters *viz.,* flower diameter, number of flowers per plant and flower yield. The differential behaviour of the genotypes was also attributed to their correlation pattern in temperature with the uptake of nutrients. KAU-M-1 showed a positive correlation between temperature and dry matter production, uptake of the three major nutrients, whereas, in Bhagwati, a negative correlation was observed between temperature and uptake of nutrients. The better performance of KAU-M-1 might be attributed to its adaptability to comparatively high temperature and short-day conditions during the winter season. Most F_1 hybrids are bred for rainy season cultivation; hence, Bhagwati, when cultivated during the winter season, did not perform well compared to the rainy season. The low performance of Bhagwati was attributed to the high temperature (Fig.1 a) and low relative humidity (Fig.1 b) during the winter season.

During the summer season (Fig.1 a,b,c,d), the majority of the growth, floral, and yield parameters showed a significant negative correlation by both the genotypes with temperature and relative humidity. Perhaps the temperature was too high and relative humidity was too low, so both the genotypes could not perform well during the summer season. The correlation pattern of temperature (29.50^{o} C) (Fig.1 a) with many parameters such as plant height, spread, number of primary branches, flower diameter, flower weight, petal weight, number of flowers per plant, dry matter production, yield as well as uptake of nutrients were showing a negative correlation in both the genotypes. About the effect of relative humidity (59.49%), in Bhagwati, many of the vegetative (plant spread), floral, and yield parameters (flower diameter, number of flowers/ plants, number of harvests/plant, and flower yield) were not showing any correlation with relative humidity while in KAU-M-1, majority of these parameters were negatively correlated with relative humidity. This might be the reason for the slight differential response between Bhagwati and KAU-M-1 during the summer season. Likewise, in the winter season, the average Epan (4.9) showed a significant positive correlation with the majority of the growth, floral, and yield parameters in both genotypes. This might be due to differential responses of marigold genotypes due to seasonal effects and photoperiodic responses [Joshna and Pal, (2015) and Prakash et al. (2016)].

Genotypic behaviour with weather parameters
Hybrid Bhagwati: under mild temperature (Fig.1 a) with high relative humidity (Fig.1 b), along with more rainfall, excelled in growth and quality along with yield attributes except for flowering phase (Fig.1 c). When the temperature increases and relative humidity decreases slightly during winter and summer, the performance becomes less compared to the rainy season. However, the flowering phase was earlier. Because of the hybrid vigour, Bhagwati excelled with more yield than KAU- M -1.

KAU-M-1: Performance of the genotype, a local collection of Kerala, was better over the F_1 hybrid Bhagwati during winter compared to rainy and summer seasons. From the figures, it could be inferred that the differential response of the two genotypes in terms of growth, flowering, and yield parameters was more during winter compared to the rainy and summer season. Among the weather parameters, relative humidity plays a key role in influencing the response of marigold genotypes. Differential responses of marigold genotypes due to seasonal effects and photoperiodic responses have been reported by Meena et al. (2015) and Devi et al. (2017).

For marigold cultivation in the humid tropical plains of Kerala, fertigation @ 75% RDF (NPK 90:90:75 kg/ha) was the best for the yield and quality of flowers during rainy season. I_2F_3 (100% Epan and 125% RDF) was found to be the best treatment for enhanced flower production during winter and summer. Hybrid Bhagwati excelled under mild climatic conditions during the rainy season. An increase in temperature and a sharp fall in relative humidity resulted in the poor performance of genotypes in terms of quality and yield in the humid tropics of Kerala during summer season. Despite the wide range of weather variations faced in all three seasons, KAU-M-1 was stable regarding growth and yield.

Acknowledgement

The Authors hereby acknowledge the financial assistance rendered by Kerala Agricultural University for the smooth conduct of the experiment.

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