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Organo-mineral fertilization regimes trigger growth and stigma yield of temperate saffron (*Crocus sativus* L.)

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ABSTRACT: Integrated nutrient management (INM) is an environment friendly and ecologically adoptable approach of plant nutrition to sustain crop productivity and maintain soil fertility of fragile agricultural ecosystems. A three-year field experiment on saffron was conducted involving 12 fertilization regimes: control; urea (UN) = 100 kg·ha^{-1}; poultry manure (PM) = 100 kg·ha^{-1}; farmyard manure (FYM) = 100 kg·ha^{-1}; PM_{50} + FYM_{50}; UN_{75} + PM_{25}; UN_{50} + PM_{50}; UN_{25} + PM_{75}; UN_{75} + FYM_{25}; UN_{50} + FYM_{50}; UN_{25} + FYM_{75}; and UN_{50} + PM_{25}+ FYM_{25}. Results showed that PM alone and combined with 50% UN (UN_{50} + PM_{50}) were effective compared to the controls in increasing the number of flowers (58%), flower dry weight (59%), stigma length (70%), dry weight of stigma (40%), number of daughter corms plant^{-1} (35%), and corm diameter (71%) of saffron over years. In addition, the same treatment combination increased corm weight (96%), corm yield (96%), and stigma yield (35%) over controls across the years. This treatment combination was followed by UN_{50} + PM_{25} + FYM_{25}, while UN_{50} alone did not perform at par to the rest of the fertilization regimes. These results showed that UN_{50} + PM_{50} might be developed as potent strategy for boosting the growth and yield (stigma and daughter corms yield) of saffron in temperate climatic conditions.

Key words: synergistic fertilization, cash crop, poultry manure, farmyard manure, stigma yield, corm yield.

INTRODUCTION

Mineral fertilizers are a prime source of plant nutrition in conventional, commercially oriented and input intensive farming systems. Application of these fertilizers on a regular basis may create nutritional imbalances and adversely affect soil properties, crops, and human health (Bisht and Chauhan 2020, Pahalvi et al. 2021). As a result, it leads to concerns in term of soil health, environment, and saffron quality. There is a dire need of ecofriendly alternatives to improve growth, yield, and quality of saffron (Selim 2020).

Integrated nutrient management (INM) refers to the preservation of soil fertility and the provision of plant nutrients in order to maintain the desired crop production by maximizing the benefits from organic, inorganic, and biological potential sources of plant nutrients in an integrated manner. INM plays a pivotal role in the enhancement of crop production on a sustained basis (Kafle et al. 2019). Organic amendments such as farmyard manure (FYM) and poultry manure (PM) improve crop growth by supplying essential plant nutrients and by improving the physicochemical and biological properties of the soil (Mengistu and Mekonnen 2012). In addition, PM contains high amounts of macronutrients compared to other animal sources (Duncan 2005). It also helps to improve the soil water holding capacity, aeration, and fertility (Khatri et al. 2019).

Thus, PM provides essential nutrients for crop production and improves the fertility status of soils on a sustainable basis (Dikinya and Mufwanzala 2010, Zydelis et al. 2019). In another field trail, Ashworth et al. (2020) reported that PM enhanced the N supply, the ion exchange capacity, and the water holding capacity of soils on long-term basis. While PM may have relatively low mineralization rates to meet timely crop N uptake demand (Adeyeye et al. 2017), urea applications may lead to N leaching and to environmental losses. Therefore, the application of INM such as integrated use of PM along with urea N might be useful for improving crop production and the quality of soil on a sustainable basis (Zahid et al. 2021).

Globally, cash crops impart sustainability to modern cropping systems through improvement of farm available resources due to more cash inflows along with high economic returns to farmers. Among cash crops, saffron has attracted considerable attention owing to its utilization in beverages and numerous food and medicinal recipes (Hill 2004, Cardone et al. 2019). The dried stigma of saffron (commercial saffron) is considered as one of the world's most valuable and expensive spices because of its wide uses in food, medicines, cosmetics, perfumes and as dye in textile industries (Hill 2004). The dried stigma of saffron flowers is the source of numerous antioxidant, volatile and non-volatile compounds (Chen et al. 2008). Among these compounds, three secondary metabolites namely crocin, picrocrocin and safranal are of prime economic importance (Cardone et al. 2020). Saffron is also a unique herbal plant for the effective treatment of diseases like gastric disorder, cardiovascular disease (Haenen et al. 1997, Cardone et al. 2019), atherosclerosis (Kamalipour and Akhondzadeh 2011), stomach ulcer (Nabavizadeh et al. 2009), cancer therapy (Hassan-Beygy et al. 2010), memory enhancement (Schmidt et al. 2007), and sex stimulation (Husaini et al. 2009).

Under a changing climate, there is a dire need to bridge the research gap pertaining to integrated fertilizers dose and source optimization. Limited research has been conducted to determine the effect of manures and organic amendments on saffron growth and yields. Thus, it was hypothesized that a combination of PM and urea N may increase the yield of saffron, while optimizing the timely release of nutrients with crop uptake demands (Saeidi et al. 2022). A multi-year field trail was conducted with the aim of evaluating the comparative performance of organic manure and mineral fertilizer applied as sole source or in different combinations.

MATERIAL AND METHODS

Agrometrological features of the study area

Over three consecutive growing seasons (2018–21), a field study was carried out on a farmer's field on Khaigala, District Poonch Azad Jammu and Kashmir Pakistan, a sub-tropical humid region. At sowing, the metrological data included air temperature (27.6 °C), humidity (49.1%), heat index (26.4 °C), barometric pressure (827.2 hPa), located at longitude (73.831), latitude (33.844) and altitude (1,687 m). Weather data was recorded manually with a pocket weather tracker model (Nielsen-Kellerman, Kestrel 4500 SN 635611). The soil of the study area was classified as loamy soil. Rainfall data was obtained from a metrological station located in close vicinity of the study area (Table 1). The fields used for the experiments inherently contain low amounts of plant available nutrients and organic matter due to a difficult topography and prevailing erosion. For the last seven decades, the dominant crops, i.e., the wheat and maize, were grown in the study area before planting saffron. There was little use of costly chemical fertilizers because of limited access to the market and high transportation costs. Therefore, the farmers of the area have relied mostly on organic amendments for the past decades.

Table 1. The physicochemical characterization of soils used for field experimentation and rainfall pattern (mm) during the growing seasons (2018–21).

Soil characteristics	Soil depth (cm)		Month	Year		
	0-15	16-30		2018	2019	2020
				Rainfall pattern (mm)		
Clay (%)	22.1	24.7	Sept	97	165.6	100.6
Silt (%)	37.8	38.5	Oct	55.2	69.4	0
Sand (%)	40.1	36.8	Nov	52.4	144.2	67.9
Textural class	Loam	Loam	Dec	18	52.1	96.2
Soil pH (1:2 H_2O)	6.9	7.1	Jan	7.3	223.3	273.1
Organic matter ($g \cdot kg^{-1}$)	10.8	8.7	Feb	120.3	261.9	78
Total N ($g \cdot kg^{-1}$)	0.347	0.338	Mar	123.6	194.4	304.1
Available P ($mg \cdot kg^{-1}$)	7.4	5.9	Apr	166.5	110.3	220.9
Exchangeable K ($mg \cdot kg^{-1}$)	50.7	40.5	May	99.4	97.3	136.2
			Total	739.7	1,318.5	1,277

Collection and processing of pre-sowing soil samples

In order to determine the initial macro and micronutrients status of the soils, a total of 10 samples, five from 0–15-cm depth and five from 15–30-cm depth, was taken. Among them, five samples from each depth were mixed to make composite sample. The soil samples were air-dried under shade, ground, sieved and stored in tarred plastic jars. Soil particle size analysis was determined by the hydrometer method given by Day (1965). Soil pH was determined by preparing a soil water suspension of 1:2 (soil:water) by McLean (1982). Organic matter was estimated by the method described by Nelson and Sommers (1982). Total soil nitrogen was determined by digesting soil sample with a mixture of selenium and potassium (1:100) and 4 mL of concentrated H_2SO_4 described by Bremner and Mulvaney (1982), available P by AB-DTPA method using spectrophotometer at 880 nm wavelength given by Soltanpour and Workman (1979), and available K was determined by flame photometry at 767-nm wavelength after extracting soil samples by 1 N ammonium acetate solution (Richard 1954). Micronutrients (Cu, Fe, Mn, and Zn) concentration in soil were measured on atomic absorption spectrophotometer by DTPA method described by Lindsay and Norvell (1978) (Table 1).

Before application, organic manure was also analyzed for NPK by the procedure earlier adopted for soil analysis. Poultry manure contained (19.3, 9.5, and 14.1 $g{\cdot}kg^{-1}$ NPK), and FYM contained N (7.3 kg^{-1}), P (3.5 kg^{-1}), and K (15.2 $g{\cdot}kg^{-1}$), whereas C/N ratio was 13.1 and 20.3 for PM and FYM, respectively. The initial soil analysis revealed that these soils are deficient in total soil N and organic matter, while potassium is marginal. However, there is no problem of phosphorus availability.

The experiment consisted of a randomized complete block design with three replications per treatment. In each plot (4 m^{-2} area), 160 corms were planted with a distance of 50 cm from plot to plot and eight rows per plot. A single corm was planted in each planting hole or hill at a depth of 8 cm. During each of the three years (i.e., 2018, 2019, and 2020), the saffron corms were planted in the last week of September, and flower harvesting was completed between 15–25 December, while the daughter corms were uplifted from the start to mid of May. The post-harvest soil analysis showed N (0.5 $g{\cdot}kg^{-1}$), P (9.7 $mg{\cdot}kg^{-1}$), and K (60.1 $mg{\cdot}kg^{-1}$). A standard local commercial variety obtained from Iran (Khorasan province) was used as planting material.

Field preparation

The fields were ploughed manually to a depth of 30 cm two to three times to ensure uniform soil mixing. Raised beds of 2 × 2 m dimensions (4^2 size) were prepared, levelled, and ridges of 25–30-cm height were prepared for planting. Twelve nutrient treatments consisting of three N sources (urea, poultry manure, and farmyard manure) were applied at each site during the three years. Well-rotten poultry and farmyard manures were broadcasted and well incorporated at 8–10-cm depth in on the ridges in the respective treatment plots at least 20 days before planting the crop. A half dose of N through urea was applied at sowing time and the remaining half after first flower picking. Phosphorus and potassium were applied as a basal dose at the rate of 60 kg P_2O_5 and 40 kg K_2O ha^{-1} to all experimental units including control from single super phosphate [$Ca(H_2PO_4)_2$, 18% P_2O_5] and sulfate of potash (K_2SO_4, 60% K_2O), respectively at the time of sowing.

Treatment descriptions

These experiments were conducted on a permanent layout over the three years and comprised of the following 12 treatments. Two- to three-year-old aged farmyard and poultry manure were applied on dry weight basis:

- T_1 = control (no amendment);
- T_2 = full recommended nitrogen (i.e., urea fertilizer @ equivalent to 100 kg $N{\cdot}ha^{-1}$; UN_{100});
- T_3 = PM = 100 kg total $N{\cdot}ha^{-1}$ (PM_{100});
- T_4 = FYM =100 kg total $N{\cdot}ha^{-1}$ (FYM_{100});
- T_5 = PM_{50} + FYM_{50};

- $T_6 = UN_{75} + PM_{25}$;
- $T_7 = UN_{50} + PM_{50}$;
- $T_8 = UN_{25} + PM_{75}$;
- $T_9 = UN_{75} + FYM_{25}$;
- $T_{10} = UN_{50} + FYM_{50}$;
- $T_{11} = UN_{25} + FYM_{75}$;
- $T_{12} = UN_{50} + PM_{25} + FYM_{25}$.

Recording of response variables

Healthy corms of 3–5-cm diameter and greater than 8-g weight were planted on raised ridges (15–20-cm deep) by maintaining a plant to plant and row to row spacing of 10 and 20 cm, respectively. During the whole crop cycle, no irrigation was practiced, but cultural practices like hoeing and wedding were carried out when required. The growth and yield data, collected from the two inner rows, included the number of flowers (m^{-2}), flower dry weight ($mg·m^{-2}$), stigma length (cm), stigma dry weight ($mg·m^{-2}$), number of daughter corms $plant^{-1}$, corm diameter (mm), corm yield ($kg·ha^{-1}$), and stigma dry yield ($g·ha^{-1}$).

Immediately following the separation of the stigmas from the flowers, the flower heads were dried in an oven for four to seven hours at 50 °C to ensure quality. The dried saffron stigmas were stored in airtight glass jars at appropriate moisture content (8%) around 10 °C. At the end of each experiment, the digging of experimental area was carried out carefully during mid to end of April to remove the daughter corms.

Statistical analysis

Analysis of variance (ANOVA) on the data for each individual year and over the three years was conducted by using software Statistix 8.1, and differences among treatment means evaluated at 5 percent probability level by applying Tukey's HSD test.

RESULTS

Keeping in view the market importance of saffron, only key growth and yield parameter like number of flowers, flower dry weight, stigma length, stigma dry weight, number of daughter corms, corm diameter, corm yield, and stigma dry yield were studied.

Number of flowers per plant

The different organic-inorganic nutrient treatments combinations significantly increased the number of flowers (NF) between 37.4 to 47.1, compared to the minimum of 29.8 recorded for the controls (Table 2). The relative increase (over control) was 25.3–57.8%. The combined treatment $UN_{50} + PM_{50}$ recorded the highest numerical NF followed by $UN_{25} + PM_{75}$, but no actual significant differences were detected between these two treatments.

Dry weight of saffron flowers

Averaged over three years, application of organic amendments (FYM and PM), either alone or in combination with UN, significantly increased the dry flower weight (DFW) of saffron between 23.3 to 59% (from 73–94.1 $mg·m^{-2}$) compared to 59.2 $mg·m^{-2}$ in case of the controls (Table 2). The maximum numerical DFW (94.1 $mg·m^{-2}$) was recorded for $UN_{50} + PM_{50}$, which was statistically equivalent with $UN_{50} + PM_{25} + FYM_{25}$ and $UN_{75} + PM_{25}$.

Table 2. Effect of urea, poultry manure, farmyard manure and their combinations on number of flowers, dry flower weight, and stigma length of saffron.

Treatments	Number of flowers (m^{-2})				Dry flower weight of saffron ($mg \cdot m^{-2}$)				Stigma length of saffron (cm)			
	Years 2018–19	2019–20	2020–21	Mean	Years 2018–19	2019–20	2020–21	Mean	Years 2018–19	2019–20	2020–21	Mean
Control	26.2 e	31.9 g	31.3 d	29.8 E	50.5 f	64.9 g	62.3 f	59.2 F	1.7 f	1.8 f	1.8 f	1.8 E
UN @ 100 $kg \cdot ha^{-1}$ (UN_{100})	34.8 bcd	37.2 f	39.6 c	37.5 D	59.8 e	78.8 ef	80.4 de	73.0 E	1.8 f	2.1 de	2.2 de	2.0 D
Poultry manure (PM_{100})	33.8 bcd	41.5 bcd	44.9 bc	39.7 BCD	76.3 bcd	79.2 ef	87.8 bcde	81.1 CD	1.8 f	2.2 d	2.2 d	2.1 D
Farmyard manure (FYM_{100})	31.7 d	39.3 def	41.2 bc	37.4 D	71.0 d	91.0 abc	93.5 abc	85.2 BC	1.7 f	2.1 e	2.1 e	2.0 D
$PM_{50} + FYM_{50}$	33.5 cd	40.6 cde	42.2 bc	38.9 BCD	75.6 bcd	75.6 f	78.7 e	76.7 DE	2.4 d	2.2 d	2.2 d	2.7 C
$UN_{75} + PM_{25}$	35.9 bcd	38.4 def	40.3 c	38.2 CD	80.2 abc	89.6 bc	91.6 abc	87.1 ABC	2.6 ab	2.4 c	2.4 c	2.5 B
$UN_{50} + PM_{50}$	40.8 a	46.4 a	53.4 a	47.1 A	86.9 a	96.1 a	99.3 a	94.1 A	2.8 a	3.1 a	3.1 a	3.0 A
$UN_{25} + PM_{75}$	37.4 abc	44.7 ab	47.6 ab	43.1 AB	78.0 bcd	85.4 cd	89.3 bcd	84.3 BCD	2.5 cd	2.5 bc	2.5 bc	2.5 B
$UN_{75} + FYM_{25}$	34.9 bcd	39.2 def	39.5 c	37.6 CD	80.7 abc	81.6 def	84.9 cde	82.4 BCD	2.5 cd	2.2 d	2.2 d	2.3 C
$UN_{50} + FYM_{50}$	36.8 abcd	38.0 ef	39.3 c	38.0 CD	72.1 d	77.2 ef	80.7 de	76.7 DE	2.0 e	2.4 c	2.4 c	2.3 C
$UN_{25} + FYM_{75}$	33.1 cd	39.7 cdef	40.2 c	37.7 CD	74.1 cd	82.1 de	85.2 cde	80.5 CDE	2.1 e	2.4 bc	2.4 c	2.3 C
$UN_{50} + PM_{25} + FYM_{25}$	38.9 ab	42.8 bc	45.5 bc	42.4 ABC	82.1 ab	91.7 ab	95.5 ab	90.0 AB	2.6 bc	2.5 b	2.5 b	2.6 B
LSD ($P \leq 0.05$)	5.2	3.4	6.7	4.8	7.24	6.1	9.7	7.6	0.2	0.1	0.1	0.1

LSD: least significant difference.

Stigma length of saffron

Stigma length (SL) of saffron increased by 9.2 to 69.7% (from 2–3 cm) by the individual application of FYM and PM alone or with UN combinations (Table 2) compared to 1.8-cm length recorded for the control. Comparing the effect of individual applications (UN, FYM, PM), revealed that the sole application of FYM amendments and PM did not show significant increase in SL of saffron over UN alone. However, when these two organic nutrient sources were combined together as FYM + PM, they showed a significant increase over UN alone. Similarly, the co-application of UN with FYM or PM showed higher SL compared to either nutrient source alone.

Dry stigma weight of saffron

Over the three years (2018–21), the sole and combined use of organic-inorganic treatments significantly increased the dry stigma weight (DSW) of saffron between 6.3 to 8.1 $mg \cdot m^{-2}$ compared to a minimum of 5.8 $mg \cdot m^{-2}$ recorded in the control (Table 3). The relative increase (over control) in DSW due to the added organic-inorganic amendments varied between 9.3–40.2%. The average over three years also indicated that the maximum numerical DSW (8.1 $mg \cdot m^{-2}$) was obtained by combining urea N with PM in $UN_{50} + PM_{50}$ combination, which was statistically equivalent with both $UN_{25} + PM_{75}$ and $UN_{50} + PM_{25} + FYM_{25}$.

Table 3. Effect of urea, poultry manure, farmyard manure and their combinations on dry stigma weight, number of daughter corms plant^{-1} and corm diameter of bulbs of saffron.

Treatments	Years			Mean	Years			Mean	Years			Mean
	2018–19	2019–20	2020–21		2018–19	2019–20	2020–21		2018–19	2019–20	2020–21	
	Dry stigma weight of saffron (mg·m^{-2})				Number of daughter corms plant^{-1} of saffron				Corm diameter of saffron bulbs (mm)			
Control	4.6 b	6.5 e	6.3 j	5.8 E	2.7 f	3.1 f	3.1 g	3.0 E	7.3 f	10 c	9.9 e	9.1 E
UN @ 100 kg·ha^{-1} (UN_{100})	5.0 ab	6.6 de	7.4 i	6.3 DE	3.3 bcde	3.2 ef	3.2 fg	3.2 DE	7.7 f	10.6 c	10.6 de	9.5 DE
Poultry manure (PM_{100})	5.3 ab	7.0 cde	8.3 e	6.9 CD	3.3 cde	3.4 def	3.5 cde	3.4 CD	9.2 def	12.6 bc	12.7 cde	11.5 CDE
Farmyard manure (FYM_{100})	5.2 ab	6.9 cde	7.3 i	6.5 D	3.4 bcd	3.4 cde	3.5 def	3.5 CD	8.1 ef	11.4 c	11.4 cde	10.3 CDE
PM_{50} + FYM_{50}	5.4 ab	7.2 bcde	7.6 hi	6.7 CD	3.1 def	3.8 ab	3.9 ab	3.6 ABC	9.5 cdef	13.4 abc	13.4 cde	12.1 BCDE
UN_{75} + PM_{25}	5.4 ab	7.2 bcde	8.0 f	6.9 CD	3.2 de	3.7 abc	3.7 bcd	3.5 BC	10.1 bcde	13.1 abc	13.1 cd	12.1 BCDE
UN_{50} + PM_{50}	6.4 a	8.2 a	9.9 a	8.1 A	3.7 ab	3.9 a	4.0 a	3.9 A	12.5 a	17.1 a	17.1 a	15.6 A
UN_{25} + PM_{75}	5.8 ab	7.8 ab	9.2 b	7.6 AB	3.4 bcd	3.6 cd	3.4 efg	3.4 CD	11.6 abc	14.2 abc	14.3 abc	13.4 ABC
UN_{75} + FYM_{25}	6.0 a	7.3 bcd	8.7 d	7.3 BC	3.0 ef	3.6 bcd	3.7 bcd	3.4 CD	10.7 abcd	14.4 abc	14.5 abc	13.2 ABC
UN_{50} + FYM_{50}	5.7 ab	7.1 bcde	7.9 fg	6.9 CD	3.7 abc	3.5 cd	3.8 abcd	3.6 ABC	10.7 abcd	14.1 abc	14.1 abc	13.0 ABC
UN_{25} + FYM_{75}	5.7 ab	7.6 abc	7.7 gh	7.0 BCD	4.0 a	3.9 abc	3.7 bcd	3.8 AB	9.8 cde	13.8 abc	13.9 bc	12.5 ABCD
UN_{50} + PM_{25} + FYM_{25}	6.2 a	7.7 abc	8.9 c	7.6 AB	3.4 bcd	3.6 cd	3.8 abc	3.6 ABC	12.1 a	12.6 ab	16.6 ab	15.1 AB
LSD ($P \leq 0.05$)	1.4	0.8	0.3	0.7	0.4	0.3	0.3	0.3	2.2	4.5	3.1	3.2

LSD: least significant difference.

Number of daughter corms plant^{-1} of saffron

Averaged over three years, the application of different organic-inorganic nutrient treatments significantly boosted the number of daughter corms (NDC) of saffron from 3.2 to 3.9 compared to the minimum of 3 for the control (Table 3). The relative increase (over control) was 8–28.8%. However, UN_{50} + PM_{50} showed maximum NDC followed by UN_{50} + PM_{25} + FYM_{25} and UN_{25} + PM_{75}, and the latter two were at statistically par with each other.

Corm diameter of saffron bulbs

The corm diameter (CD) of saffron bulbs ranged from 9.5 to 15.9 mm compared to 9.1 mm for the control (Table 3). Among the organic nutrient treatments (FYM, PM and FYM + PM), PM_{50} + FYM_{50} performed better when applied in combination compared to their sole applications. Among the UN+ organic combined treatments, the UN_{50} + PM_{50} produced saffron corms with greatest diameter followed by UN_{25} + PM_{75} and UN_{50} + PM_{25} + FYM_{25} treatments, which were statistically equivalent with one another. The CD in case of UN_{50} + PM_{50} was 71.4% greater over the control.

Corm yield of saffron

The corm yield (CY) of saffron varied between 6,004.5–8,924.5 kg·ha^{-1} compared to 4,562.5 kg·ha^{-1} recorded for the control (Table 4). Averaged across the years, the single or combined application of amendments increased CY by 31.6–95.6% over the control. Whereas in case of the combined treatments, the maximum numerical CY was recorded for

UN_{50} + PM_{50} followed by UN_{50} + PM_{25} + FYM_{25} with both treatments being statistically equivalent, while the lowest value was recorded in the control.

Table 4. Effect of urea, poultry manure, farmyard manure and their combinations on corm yield and stigma yield of saffron.

Treatments	Years			Mean	Years			Mean
	2018–19	2019–20	2020–21		2018–19	2019–20	2020–21	
	Corm yield of saffron (kg·ha^{-1})				Stigma yield of saffron (g·ha^{-1})			
Control	4,008.2 c	4,882.1 f	4,797.1 f	4,562.5 E	46.0 b	64.7 e	61.0 e	57.2 D
UN @ 100 kg·ha^{-1} (UN_{100})	5,507.9 bc	6,101.8 ef	6,403.8 ef	6,004.5 DE	56.0 ab	65.5 de	66.3 de	60.6 CD
Poultry manure (PM_{100})	6,869.2 ab	6,748.6 de	7,104.8 bcde	6,907.5 BCD	53.3 ab	69.5 cde	74.8 bcd	65.9 BCD
Farmyard manure (FYM_{100})	6,156.3 ab	6,320.0 ef	6,628.0 def	6,368.1 CD	52.2 ab	69.2 cde	72.9 cd	64.8 BCD
PM_{50} + FYM_{50}	7,010.9 ab	6,611.1 def	6,906.7 cde	6,842.9 BCD	54.4 ab	71.6 bcde	75.7 bcd	67.2 ABCD
UN_{75} + PM_{25}	6,022.1 ab	6,901.2 cde	7,058.1 bcde	6,660.5 CD	54.2 ab	72.1 bcde	73.5 cd	66.6 BCD
UN_{50} + PM_{50}	7,957.4 a	9,152.7 a	9,662.5 a	8,924.2 A	63.6 a	81.5 a	86.2 a	77.1 A
UN_{25} + PM_{75}	5,096.6 bc	7,711.7 abcde	8,041.1 abcde	6,949.8 BCD	57.7 ab	78.2 ab	83.9 ab	73.2 AB
UN_{75} + FYM_{25}	7,048.5 ab	8,143.6 abcd	9,461.6 abcd	7,884.6 ABC	60.3 a	73.0 bcd	74.9 bcd	69.4 ABC
UN_{50} + FYM_{50}	6,021.4 ab	8,537.4 abc	8,736.8 abc	7,765.2 ABCD	56.8 ab	71.0 bcde	71.7 cd	66.5 BCD
UN_{25} + FYM_{75}	6,441.7 ab	7,285.2 bcde	7,717.0 abcde	7,148.0 BCD	56.6 ab	75.7 abc	77.8 ab	70.0 ABC
UN_{50} + PM_{25} + FYM_{25}	7,875.4 a	8,780.8 ab	9,102.6 ab	8,586.3 AB	62.2 a	76.8 abc	78.5 abc	72.5 AB
LSD ($P \leq 0.05$)	1,954.5	1,763.8	2,047.7	1,763.1	14.0	7.6	9.9	10.1

LSD: least significant difference.

Stigma yield of saffron

Application of different organic-inorganic nutrient sources over the three years significantly increased the stigma yield (SY) of saffron ranging from 60.6 to 77.1 g·ha^{-1} compared to 57.2 g·ha^{-1} recorded for the control (Table 4). The relative increase (over control) was 5.9–34.7%. For all years, the maximum SY of saffron was recorded for UN_{50} + PM_{50} followed by UN_{25} + PM_{75} and UN_{50} + PM_{25} + FYM_{25}, while the difference between the latter two treatments was non-significant.

DISCUSSION

The findings showed that the application of organic amendments alone or in combination with urea N especially boosted the NF (58%), DFW (59%), SL (70%), DSW (40%), number of daughter corms plant^{-1} (35%), CD (71%), CY (96%) and SY (35%). The regular supply of nutrients during the cropping period, close synchronization between nutrient release/crop demand and improvements in the important properties of amended soils could be possible causes for the considerable increase in growth and yield obtained with saffron under UN + PM treatment, as observed by Ghanbarian et al. (2008). Other studies (Enujeke 2013, Adeyeye et al. 2107, Zydelis et al. 2019) also showed that the soil application of organic materials, particularly PM, has the potential to sustain crop yields and improve soil properties and fertility. Moreover, Koocheki et al. (2019) discussed the positive effects of organic matter amendments or content on stigma and daughter corm yield of saffron. The maximum number of flowers in treatment combinations (UN_{50} + PM_{50}) might be due to the improved nutrients supply provided gradually during the whole cropping season by the poultry manure and urea nitrogen combination. Farmyard manure is also rich in various micro and macronutrients, although it could not perform at par to UN_{50} + PM_{50}. However, it performed better then UN_{100} alone application.

These findings also indicate that integrated use of organo-mineral fertilizer was effective in increasing the yield attributes likely due to the increased concentration of macro and micronutrients and their utilization throughout the entire plant growth period. Furthermore, integrated nutrition including the use organic and inorganic constituents results in significant stimulation of various physiological and metabolic processes that lead to improved plant growth and floral attributes (Singh et al. 2013). Moreover, Kabir et al. (2011) and Eifediyi et al. (2017) also documented that floral characteristics improved when organic fertilizers were combined with mineral fertilizers compared to the sole application of mineral fertilizers.

The yield attributes serve as reliable indicators of saffron yield, and our findings were in line with those of Ewulo et al. (2008) and Koocheki et al. (2019), who opined that crop yields were increased through PM application because of its leading role in enhancing nutrient content and uptake. Increased growth and yield attributes (SY and CY) in the combined N and PM treatments could be the result of microbial N mineralization from the PM providing N during the whole growing period in proportion to crop requirement (Zydelis et al. 2019).

Along with SY, fertilization regimes remained effective in influencing the CY during all seasons. The increased number of cormlets plant^{-1} and other corm yield parameters might be attributed in part to improved soil texture by and water holding capacity. Similarly, Sisodia and Singh (2015) documented maximum weight of corms plant^{-1} and corm diameter with the use of organic and mineral nutrients in Gladiolus.

Likewise, in this study, the UN_{50} + PM_{50} combination recorded a maximum number of daughter corms plant^{-1}, CY kg·ha^{-1}, and SY g·ha^{-1}. Poultry manure takes a relatively short time to decompose, and nutrients are mineralized over the entire period of crop growth likely resulting in the increased observed yields. Olasekan et al. (2019) and Ashworth et al. (2020) also observed that PM improves soil physicochemical properties, which result in improved yield parameters. Different manures behave differently under different agroclimatic and soil conditions. Even they can perform differently under tropical or subtropical and temperate conditions. So, these finding provide a base line for conducting further in-depth studies to determine the response of various organic manures of animal origin for boosting the productivity of saffron.

CONCLUSION

The findings of this multi-year field investigation are in line with postulated hypothesis whereby fertilization regimes remained significantly divergent in their influence on growth and yield of saffron. Based on recorded data, it might be inferred that combination of PM with UN might serve as a biologically probable and potent strategy for boosting saffron productivity under fragile ecosystems.

Among employed treatment combinations, combined application of UN_{50} + PM_{50} was more affective for boosting growth and yield parameters of saffron. Consequently, the combination of organic manure with inorganic fertilizers could be recommended to growers in the region and other areas having similar agroclimatic conditions. Additionally, the sole and combined use of organic amendments hold bright prospects for improving flower production, SY and CY of saffron grown on degraded small landholdings of the study regions and other soils having similar physicochemical characteristics. However, the grower's technical know-how, local availability of organic manures, technical expertise to calculate and optimize doses of organic and synthetic fertilizers, composting of organic manures and cost related factors might pose a challenge for implementing the research findings for small landholders. These encouraging results must conduct further in-depth studies for optimizing different sources and doses of the organic amendments.

AUTHORS' CONTRIBUTION

Conceptualization: Sarfraz, M. and Khaliq, A.; **Methodology:** Sarfraz, M., Khaliq, A. and Tahir, M. M.; **Investigation:** Sarfraz, M., Khaliq, A., Tahir, M. M. and Sarwar, S.; **Writing – Original Draft:** Sarfraz, M. and Khaliq, A.; **Writing – Review and Editing:** Sarfraz, M., Khaliq, A., Sarwar, S. and Tahir, M.; **Funding Acquisition:** Khaliq, A.; **Supervision:** Khaliq, A.

DATA AVAILABILITY STATEMENT

Data will be available upon request.

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