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Soil test crop response (STCR) based primary nutrient management of gladiolus (*Gladiolus hybridus* hort.) in inceptisol

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ABSTRACT

Gladiolus production systems demand precise nutrient management to ensure high quality spikes and propagative-sized corms. However, conventional recommendations are generalised and often ignore the spatial and temporal heterogeneity of soils, adversely affecting nutrient availability and plant uptake. To address these issues and to refine the existing practices, A field study was conducted in gladiolus cv. Trader Horn to develop a site-specific nutrient management strategy using soil test crop response (STCR) approach. The experiment involved creating fertility gradients and applying various combinations of N, P, K, and FYM in a fractional factorial randomised block design. Results revealed that producing 100 kg of spikes required 0.96 kg N, 0.16 kg P, and 0.98 kg K, while 100 kg of corms requires 0.98 kg N, 0.16 kg P, and 1.00 kg K. Contributions from soil, fertilizer, and FYM were quantified as N (29.3%, 29.7%, 17.5%), P (56.4%, 16.9%, 9.6%), and K (31.6%, 74.6%, 17.1%). Fertilizer prescription equations and a ready reckoner were developed for different soil test values and yield targets enabling farmers to apply optimal nutrients based on soil capacity and crop needs. This approach promotes balanced fertilization, enhances environmental sustainability and ensures economic viability in gladiolus cultivation.

Keywords: *gladiolus, fertilizer prescription, soil test crop response, targeted yield model, NPK uptake, nutrient management, target yield.*

Introduction

Among the bulbous ornamentals, Gladiolus (*Gladiolus hybridus* Hort.) occupies a special position in the international cut flower trade for its wide array of hues and shades, markings and blends of elegant spikes. Nutrition is one of the utmost important aspects in gladiolus, which directly influences spike and corm yield, and the quality of flowers. Fertilizer requirements of gladiolus vary with variety, yield level, climatic conditions, irrigation method and soil type [1]. The crop is a heavy user of nutrients [2]; [3]; consequently, soil reserves must be supplemented through external sources. The present method of blanket fertilizer recommendations doesn't consider the yield target, crop requirement, soil nutrient status and on-farm available resources, and results in either excessive or inadequate nutrition [4]. The resulting problems include declining fertility and productivity, multi-nutrient deficiencies, and, on the other extreme, environmental contamination and low fertilizer use efficiency [5]. Soil health was found to be affected by the management practices adopted by the farmers and the extent of fertilizer used over a period of time.

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Under these circumstances, the adoption of 'Targeted yield model' [6], later elaborated as 'Inductive-cum-yield targeted model' [7] would help growers in assuring the real balance between soil-plant system [8]. Hence, development of a suitable nutrient management system using soil test crop response (STCR) correlation becomes crucial for the quality production of gladiolus to ensure agronomic, economic, social and environmental sustainability [9]. Thus, recognizing the lack of information available on STCR correlation-based fertilizer and manure recommendation in flower crops involving an integrated plant nutrient supply system (IPNSS), the present investigation was undertaken on gladiolus.

Materials and Methods

Two field experiments were conducted on the gladiolus cv. Trader Horn at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi, India, situated at a latitude of 28.4 °N, a longitude 77.1°E and an altitude of 250 m above mean sea level. The climate of the Delhi region is semi-arid and subtropical, characterized by dry summers and cold winters. On the basis of three years of meteorological data (2013-15), the mean maximum and minimum temperatures, relative humidity and rainfall were 30.8°C, 17.4°C, 68.4% and 1144.3 mm, respectively. The fluctuations in temperature and rainfall during crop growth (September to May) are depicted in Supplementary Figure 1.

Physical and chemical properties of experimental soil

The soil at the experimental site was sandy loam in texture and taxonomically categorized under the great group typic Haplustepts (old alluvium). The soil had $pH_{1:2.5}$ 8.13, $EC_{1:2.5}$ 0.32 dSm^{-1}[10], alkaline $KMnO_4$-N 179 kg ha^{-1} [11], Olsen's P 20.4 kg ha^{-1} [12], NH_4OAC-K 167 kg ha^{-1} [13] and 0.46% organic carbon [14]. DTPA-extractable Fe, Cu, Mn and Zn [15] were in a sufficient range.

Treatment structure

The field experiments *viz.*, fertility gradient experiment with fodder sorghum, test crop experiment with gladiolus were conducted based on "Inductive-cum-Targeted yield model" [7]. The major aim of inducing a fertility gradient was to create significant variability with respect to soil available N, P and K prior to test crop experiment [8]. Before conducting the experiment on test crop gladiolus, low (Strip I), medium (Strip II) and high (Strip III) soil fertility gradient Strips of equal size were deliberately created in the experimental field by applying graded doses of NPK as $N_0P_0K_0$ (no fertilizer), $N_{1/2}P_{1/2}K_{1/2}$ (half dose of $N_1P_1K_1$) and $N_1P_1K_1$ (400, 300, 300 kg ha^{-1} of N, P_2O_5 and K_2O, respectively) in the respective Strips. Similarly, three gradient levels of farmyard manure (FYM) (0, 5 and 10 t ha^{-1}) were applied across the fertilizer gradient of each Strip creating nine distinctly different fertility blocks (Supplementary Figure 2). The developed gradient was stabilized by growing exhaustive fodder sorghum during summer, 2013-14 using the technique of inductive methodology. Post-harvest soil samples were collected from each fertility Strip and analyzed for alkaline $KMnO_4$-N Olsen-P and NH_4OAC-K.

Test crop experiment

After ensuring the establishment of a fertility gradient, 24 treatments (eight within each block containing one untreated control) were assigned in each Strip, thus making the total of 72 plots in three Strips. Initial soil samples were collected from each plot and analysed for available N, P and K. The test crop experiment on gladiolus was conducted in a fractional factorial randomized block design (Supplementary Figure 3). The treatments consisted of various selected combinations of four levels of N (0, 100, 200 and 300 kg ha^{-1}), P_2O_5 (0, 40, 80 and 120 kg ha^{-1}), K_2O (0 40, 80 and 120 kg ha^{-1}), and three levels of FYM (0, 5 and 10 t FYM ha^{-1}). Treatments were randomized in each Strip in such a way that all the 24 treatments (21 treated + 3 untreated control) were present in all three Strips in either direction.

Sizeable corms (3.8 - 4.5 cm diameter) were dibbled at a spacing of 50 x 15 cm. The crop received one-third of N and a full dose of P_2O_5, K_2O and FYM (at moisture content 30%, total N - 0.4%, total P - 0.2% and total K - 0.5%) as basal. The remaining two-thirds N dose was top-dressed at the third leaf and spike emergence stages in equal amounts, respectively. Recommended agronomic package of practices was followed throughout the crop period [16]. Oven dried (60±2°C) samples of foliage plus spike and corms were di-acid (HNO_3:$HClO_4$, 9:4 v/v) digested for nutrient analysis of P and K. Total P in the di-acid digest was determined by vanadomolybdate phosphoric acid yellow colour method and total K was estimated flame photometrically [10]. Total N was analysed using the modified micro-Kjeldahls' method [10]. Total N, P and K uptake (kg ha^{-1}) was computed by multiplying crop nutrient concentration and dry weight.

Basic parameters for fertiliser recommendation equations

Using data on gladiolus spike yield, corm yield, nutrient uptake, initial soil available nutrient status, fertiliser and FYM doses applied, basic parameters *viz.,* nutrient required (NR) for production of 100 kg spike and corm, and contribution efficiencies (%) of soil available nutrient (C_S), fertilizer (C_F) and FYM (C_{FYM}) were computed [7]. These parameters were used for developing fertilizer prescription equations and a ready reckoner of NPK fertilizer doses alone and in combination with FYM for a range of soil test values with desired yield targets (±5-10% of potential yield) of gladiolus spike and corm.

(i) Nutrient requirement (NR)

$$\text{kg of N, P or K per 100 kg spike} = \frac{\text{Total (spike +corm) uptake of N, P or K (kg ha}^{-1}\text{)}}{\text{Gladiolus spike yield (100 kg ha}^{-1}\text{)}}$$

$$\text{kg of N, P or K per 100 kg corm} = \frac{\text{Total (spike +corm) uptake of N, P or K (kg ha}^{-1}\text{)}}{\text{Gladiolus corm yield (100 kg ha}^{-1}\text{)}}$$

(ii) Contribution of nutrients from soil to total uptake (%)

$$\text{Contribution of N, P or K from soil } (C_S) = \frac{\text{Total uptake of N, P or K in control plot (kg ha}^{-1}\text{)}}{\text{Soil test values of available N, P or K in control plots (kg ha}^{-1}\text{)}} \times 100$$

(iii) Contribution of nutrients from fertilizer to total uptake (%)

$$\text{Contribution of N, P or K from fertilizer } (C_F) = \frac{\text{Total uptake of N, P or K in fertilized plot (kg ha-1)} - \text{(Soil test value of N, P or K in fertilized plot (kg ha}^{-1}\text{) x mean } C_S\text{)}}{\text{Fertilizer N, P and K applied (kg ha}^{-1}\text{)}} \times 100$$

(iv) Contribution of FYM to total uptake (%)

$$\text{Contribution of N, P or K from FYM } (C_{FYM}) = \frac{\text{Total uptake of N, P or K in FYM treated plot (kg ha}^{-1}\text{)} - \text{(Soil test value of N, P or K in farmyard treated plot (kg ha}^{-1}\text{) x mean } C_S\text{)}}{\text{N, P and K applied through FYM (kg ha}^{-1}\text{)}} \times 100$$

(v) Fertilizer recommendation equations

Utilizing the basic parameters, fertilizer prescription equations were derived using the following formulae.

Fertilizer nitrogen (FN)

$$FN = \frac{NR}{CF/100} T - \frac{C_S}{C_F} STVN \quad \text{...without FYM}$$

$$FN = \frac{NR}{CF/100} T - \frac{C_S}{C_F} STVN - \frac{C_{FYM}}{C_F} FYMN \quad \text{...with FYM}$$

Fertilizer phosphorus (FP)

$$FP = \frac{NR}{CF/100} T - \frac{C_S}{C_F} STVP \quad \text{...without FYM}$$

where, FN, FP, and FK - fertilizer N, P and K (kg ha^{-1}), respectively; NR - nutrient requirement

of N, P, and K (kg ha^{-1}); Cs, C_F and C_{FYM} - percent contribution of nutrients from soil, fertilizer, and farmyard manure, respectively; STVN, STVP and STVK - soil test value of available N, P and K (kg ha^{-1}), respectively; FYMN, FYMP and FYMK - amount of N, P and K applied through farmyard manure (FYM), respectively; T- Targeted yield (kg ha^{-1}) of gladiolus spike or corm.

Statistical analysis

Descriptive statistics across three gradient Strips with all treatment combinations of N, P, K and FYM were carried out using Statistical Analysis System version 9.3. Graphs and figures were plotted with GraphPad Prism version 5.00 (GraphPad Software, La Jolla, CA, USA) and Microsoft Excel 2007 (Microsoft Corp., Redmond, CA, USA).

Results and Discussion

Soil fertility gradient establishment

The statistical analysis of mean soil test values revealed the existence of a significant difference ($P \leqslant 0.001$) in the distribution of soil available N, P and K content between the Strips (Figure 1a-c). Before test crop experiment on gladiolus, mean alkaline $KMnO_4$-N content in experimental plots were 171.9, 213.4 and 235.2 kg ha^{-1} in the year 2013-14 and 173.2, 216.7 and 241.0 kg ha^{-1} in 2014-15 in Strips I, II and III, respectively (Figure 1a). Concerning Olsen's P, the mean values in Strips I, II and III were 16.7, 26.5 and 31.3 kg ha^{-1}, respectively in the year 2013-14 while it was 18.1, 26.6 and 32.1 kg ha^{-1} in 2014-15 (Figure 1b). Similarly, mean NH_4OAC-K was highest in Strip III (274.7, 309.0 kg ha^{-1}) followed by Strip II (247.8, 263.9 kg ha^{-1}) and Strip I (166.2, 176.9 kg ha^{-1}) in both years (Figure 1c). From soil nutrient analysis data, it is apparent that alkaline $KMnO_4$-N, Olsen 's-P and NH_4OAC-K increased significantly from Strip I to Strip III. The spread of whiskers on box plots indicated a considerable increase in range and median values of soil N, P and K in parallel to the increment in fertility gradient. Within the Strip, a fertility gradient was built up by the application of FYM across the plots which is evident from the coefficient of variation (CV). Variability among soil available nutrients was observed in the order of P> K> N. Higher values of the coefficient of variation for Olsen's-P indicated larger variation in P content as compared to N and K in the experimental plots. This could be attributed to the substantial accumulation of applied P as residual due to low (10-20%) P uptake efficiency [17]. Existence of such a magnitude of fertility gradients was also reported earlier under fodder sorghum and maize in Inceptisols and oat in mollisols [18]; [19];[20]. Development of a sufficient soil fertility gradient of N, P and K in the same field was the primary aim of fertility gradient experiment [21] which developed an operational range of variability in soil fertility in the same agro-climatic and edaphological conditions [22].

Yield and nutrient uptake

Significant variation was observed among Strips with respect to spike and corm yield, and total N, P and K uptake. Mean spike yield was highest in Strip III (11.4, 13.1 t ha^{-1}), ranging from 8.9-13.8 t ha^{-1} in the year 2013-14 and 9.9-15.7 t ha^{-1} in 2014-15 (Figure 2a). This was closely followed by Strip II (10.8, 12.3 t ha^{-1}) with a variability of 8.0-13.4 t ha^{-1} and 8.9-14.8 t ha^{-1} during the two experimental years, respectively. Least spike yield was obtained from Strip I with a mean production of 9.5 t ha^{-1}, ranging from 6.6-12.1 t ha^{-1} during 2013-14 while it was 10.7 t ha^{-1} with a range between 7.3-13.5 t ha^{-1} during 2014-15. Fresh corm yield was in the order of Strip III >Strip II >Strip I. The mean yield of corm recorded was 11.4, 10.8, 10.3 t ha^{-1} in 2013-14 and 12.0, 11.3 and 10.5 t ha^{-1} in 2014-15 concerning to Strip III, II and I, respectively (Figure 2b). High fertility gradient (Strip III) benefited consistently with the highest median spike (Figure 2a, b) and corm yield when compared to medium and low gradient Strips. The extent of variability in the yield of spike and corm within the Strip was mentioned in terms of % CV which was relatively higher in the 2014-15 experiment.

These results suggest that gladiolus is responsive to soil fertility levels, fertilizer doses and FYM application. In general, the total uptake of N, P and K by the gladiolus crop followed a similar trend as the soil available status in both years (Figure 3a, b, c). The total plant N uptake significantly varied from 45.4 to 128.4 kg ha^{-1} (Figure 3a), P uptake ranged from 7.1 to 29.4 kg ha^{-1} (Figure 3b), and K uptake was recorded in between 55.6 to 125.8 kg ha^{-1} (Figure 3c) considering two years in response to variation in nutrient dose and fertility gradient. Among nutrients, uptake of N and K was higher compared to P (Figure 3a, b, c). This result is in agreement with an earlier report that gladiolus requires P only $1/10^{th}$ of N and K [23]. The combined effect of organic and inorganic fertilizers on increased nutrient availability in Strip III resulted in better nutrient absorption and growth of crop [24]. This indicates the beneficial effects of higher doses of fertiliser to obtain the best quality of spike and corm [25]. Moreover, it showed efficient utilization of applied fertilizer nutrients due to synergistic and residual effects of FYM [26].

Better yield performance and the highest nutrient availability of the second year's gladiolus experiment was attributed to congenial climatic conditions during the crop growth period. A significant amount of rainfall was received during February and March (Supplementary Figure 1) resulted in efficient acquisition and translocation of soil available nutrients. Moreover, residual nutrients in soil from first crop boosted the second crop growth, thus accumulating more biomass leading to production of graded quality spike and corms. Similar findings were reported by [3]; [27].

Nutrient requirement and contribution of nutrients from different sources

Nutrient required for production of 100 kg gladiolus spike was computed to be 0.97 and 0.95 kg of N, 0.16 and 0.16 kg of P, 1.0 and 0.96 kg of K and for corms, it was 0.96 and 1.01 kg of N, 0.16 and 0.17 kg of P, 0.97 and 1.03 kg of K, in the years 2013-14 and 2014-15, respectively (Figure 4a). It indicated that the nutrient required for producing spike or corm did not change significantly over the two growing seasons. However, the percent contribution of N, P and K to the total uptake of nutrients by the gladiolus crop from different sources varied significantly in both years (Figure 4b). Contribution of N from soil available nutrient pool (CS), fertilizer (CF) and farmyard manure (CFYM) were 27.4, 29.6 and 20.5% in the year 2013-14 and 31.1, 29.8 and 13.5%, respectively in 2014-15. Contribution of P in 2013-14 was 52.5, 17.5 and 10.1% and in year 2014-15 it was 60.5, 15.8 and 10.5% from CS, CF and CFYM, respectively. Likewise, the contribution of K from different sources CS, CF and CFYM, was found to be 31.1, 73.0 and 15.0% in 2013-14 and 32.1, 75.4 and 17.7% in 2014-15, respectively. The relative contribution of nutrients from various sources *viz.* CS, CF and CFYM showed that N was contributed equally from CS and CF due to sufficient available soil pool and split application of nitrogen fertilizer, respectively, as evidenced by [28]. Among nutrients, P and K were contributed from soil and fertilizer, respectively (Figure 4b). The favourable effect of FYM was highest for N, which might have provided enough carbon for build-up of bacterial population to enhance N availability and the findings conform with Ahmed *et al*. (2015).

Fertilizer prescription equations and fertilizer recommendations for yield targets

Table 1 represents soil test-based fertilizer prescription equations formulated by using basic parameters for desired yield targets of gladiolus spike and corm, based on the guidelines of [29]. An estimate of fertilizer dose was prepared based on the fertilizer prescription equations for a range of soil test values and a yield target of 10 t ha^{-1} each of spike and corm. For achieving the targeted spike yield in a field having soil test values of 100 kg $KMnO_4$-N, 5 kg Olsen 's-P and100 kg NH_4OAc-K ha^{-1}, the fertilizer N, P_2O_5 and K_2O required were 225.0, 77.5 and

88.7 kg ha^{-1}, respectively, without integration of FYM (Figure 5a, b, c).

Agricultural production systems using chemical fertilizers solely are suffering from problems such as low fertilizer use efficiency, multi-nutrient deficiency, decrease in soil quality and environmental deterioration [30]. Therefore, we developed an integrated equation of STCR involving FYM, which quantitatively curtails the fertiliser quantity to be applied thereby saving prices incurred on costly fertilisers [31]. FYM has the ability to increase nutrient availability and improve the efficiency of applied nutrients [30]. Moreover, soils having high nutrient status need a lesser amount of fertilizer and manure to produce specific yield targets [32]. With the addition of FYM at the rate of 10 t ha^{-1} (containing 0.4, 0.2 and 0.5% of N, P and K, respectively) with NPK, the fertilizer requirement was reduced to 201.4 N, 66.2 P_2O_5 and 77.2 K_2O kg ha^{-1}(Figure 5a,5b,5c). Similarly, for a targeted yield of corm at similar soil test values as for spikes, the fertilizer requirement was found to be 231.6 kg N, 79.5 kg P_2O_5 and 91.1 kg K_2O ha^{-1} without FYM while it was reduced to 208.0, 68.1 and 79.7kg ha^{-1} of N, P_2O_5 and K_2O, respectively with addition of FYM (Figure 6a, 6b, 6c). It is evident from Figures 5 and 6 that fertilizer N, P_2O_5 and K_2O requirements decreased with an increase in soil test values. In horticultural crops such as beetroot (*Beta vulgaris*), potato (*Solanum tuberosum*) and onion (*Alium cepa*), a decrease in fertilizer use with an increase in soil test status of the nutrients have been reported [33]; [34]. [35] also reported 25% reduction in the recommended dose of chemical fertilizer for gladiolus upon integration with FYM @ 10 t ha^{-1}.

In conclusion, a STCR-based integrated fertilizer recommendation was developed for targeted yield (10 t ha^{-1}) of gladiolus spike and corm considering the total NPK requirement of crop, percent NPK contribution from soil, chemical fertiliser, and manure in relation to total nutrient uptake. This approach provides more quantitative, precise and site-specific balanced fertilisation of crops for obtaining higher productivity and profitability on per unit fertiliser investment. The prescription equations developed in this study could be used for a similar kind of soil and climatic conditions. To meet the future demand of flowers it is imperative to increase production per unit area, time and space by adopting soil test crop response-based integrated plant nutrient supply system.

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Conflict of interest statement

Authors declare no conflicts of interest regarding this manuscript

Table 1. Soil test based fertilizer prescription equations for targeted yield of 10 t ha-1 of gladiolus spike and corm

Fertilization approach	Fertilizer prescription equations for gladiolus spike		
	2014	2015	Mean
NPK alone	FN = 3.30 T – 0.93 SN	FN = 3.18 T – 1.04 SN	FN = 3.24 T – 0.99 SN
	FP = 0.91 T – 3.00 SP	FP = 1.00 T – 3.83 SP	FP =0.94 T – 3.35 SP
	FK =1.36 T – 0.43 SK	FK =1.28 T – 0.43 SK	FK =1.31 T – 0.42 SK
NPK + FYM	FN = 3.30T – 0.93 SN – 0.69 FYMN	FN = 3.18 T – 1.04 SN – 0.45 FYMN	FN = 3.24 T – 0.99 SN – 0.59 FYMN
	FP = 0.91 T – 3.00 SP – 0.58 FYMP	FP = 1.00 T – 3.83 SP – 0.67 FYMP	FP = 0.94 T – 3.35 SP – 0.51 FYMP
	FK = 1.36 T - 0.43 SK - 0.21 FYMK	FK = 1.28 T – 0.43 SK – 0.23 FYMK	FK = 1.31 T – 0.42 SK – 0.23 FYMK
Fertilization approach	Fertilizer prescription equations for gladiolus corm		
	2014	2015	Mean
NPK alone	FN = 3.23 T – 0.93 SN	FN = 3.39 T –1.04 SN	FN = 3.30 T – 0.99 SN
	FP = 0.89 T – 3.00 SP	FP = 1.07 T –3.83 SP	FP = 0.96 T – 3.35 SP
	FK = 1.33 T – 0.43 SK	FK = 1.36 T – 0.43 SK	FK = 1.33 T – 0.42 SK
NPK + FYM	FN = 3.23 T – 0.93 SN - 0.69 FYMN	FN =3.39 T –1.04 SN – 0.45 FYMN	FN = 3.30 T – 0.99 SN – 0.59 FYMN
	FP = 0.89 T – 3.00 SP - 0.58 FYMP	FP =1.07 T –3.83 SP – 0.67 FYMP	FP = 0.96 T – 3.35 SP – 0.62 FYMP
	FK = 1.33 T - 0.43 SK - 0.21 FYMK	FK = 1.36 T – 0.43 SK –0.23 FYMK	FK = 1.34 T – 0.43 SK – 0.22 FYMK

FN, FP and FK - fertilizer N, P and K (kg ha^{-1}), respectively; SN, SP and SK - soil test value of available N, P and K (kg ha^{-1}), respectively; FYMN, FYMP and FYMK - amount of N, P and K applied through farmyard manure (tonne ha^{-1}), respectively; T- Targeted yield (kg ha^{-1}) of gladiolus spike or corm.

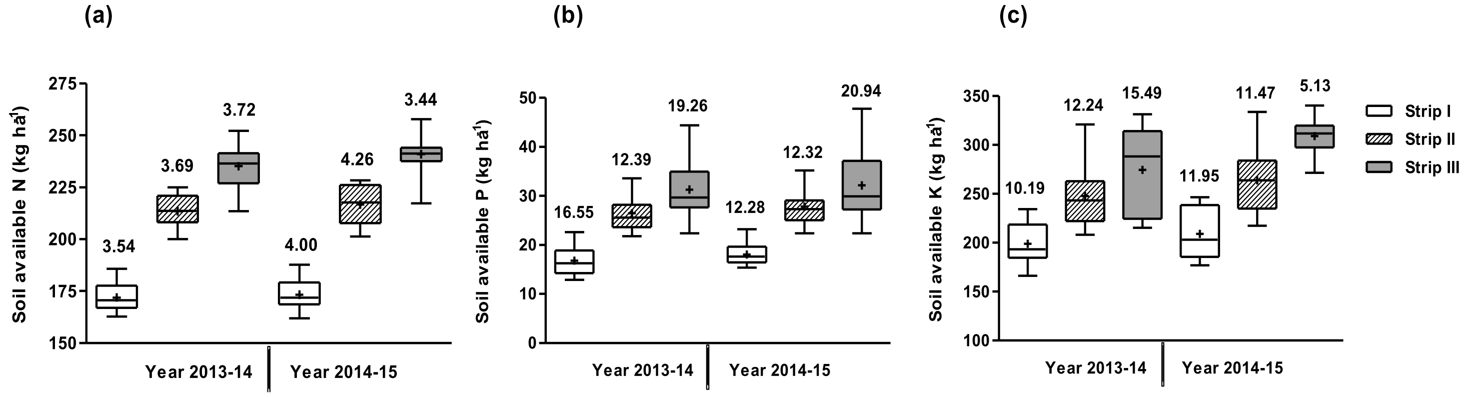


Fig 1. Nutrient status of field soil collected at 0-15 cm from three Strips. (a) Available N, (b) Available P and, (c) Available K.

Box and whisker plot showing variation in three fertility gradient Strips with respect to soil available Alkaline $KMnO_4$-N, Olsen's-P and NH_4OAc-K. Horizontal line inside boxes, median; +, mean; box hinges, first and third quartiles; whiskers, range of data; data labels, coefficient of variation (CV).

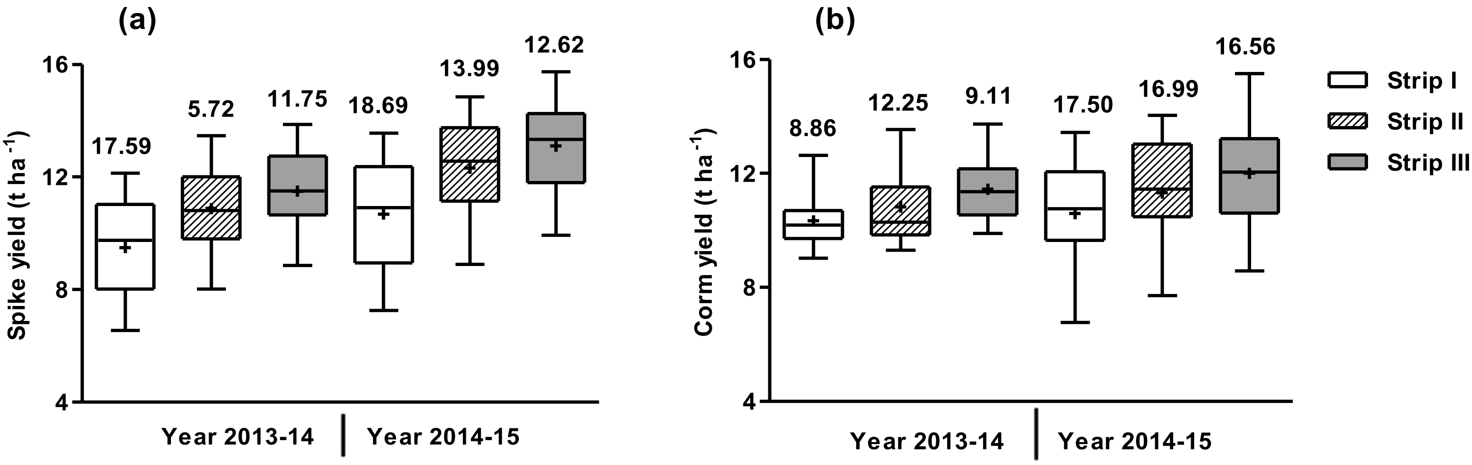


Fig 2. Effect of different fertility status in Strips on yield of gladiolus (a) spike and (b) corm.

Box and whisker plot showing variation in three fertility gradient Strips with respect to yield. Horizontal line inside boxes, median; +, mean; box hinges, first and third quartiles; whiskers, full range of the data; data labels, coefficient of variation (CV).

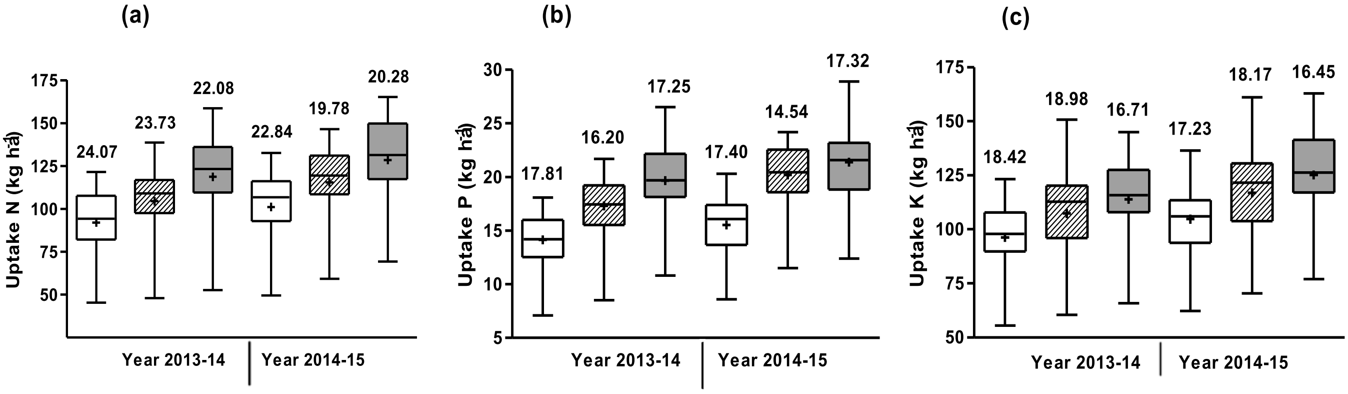


Fig 3. Effect of different fertility status in Strips on total uptake of nutrients by gladiolus crop (a) total uptake of N, (b) total uptake of P and (c) total uptake of K.

Box and whisker plot showing variation in three fertility gradient Strips with respect to total nutrient uptake from field. Horizontal line inside boxes, median; +, mean; box hinges, first and third quartiles; whiskers, full range of the data; data labels, coefficient of variation (CV).

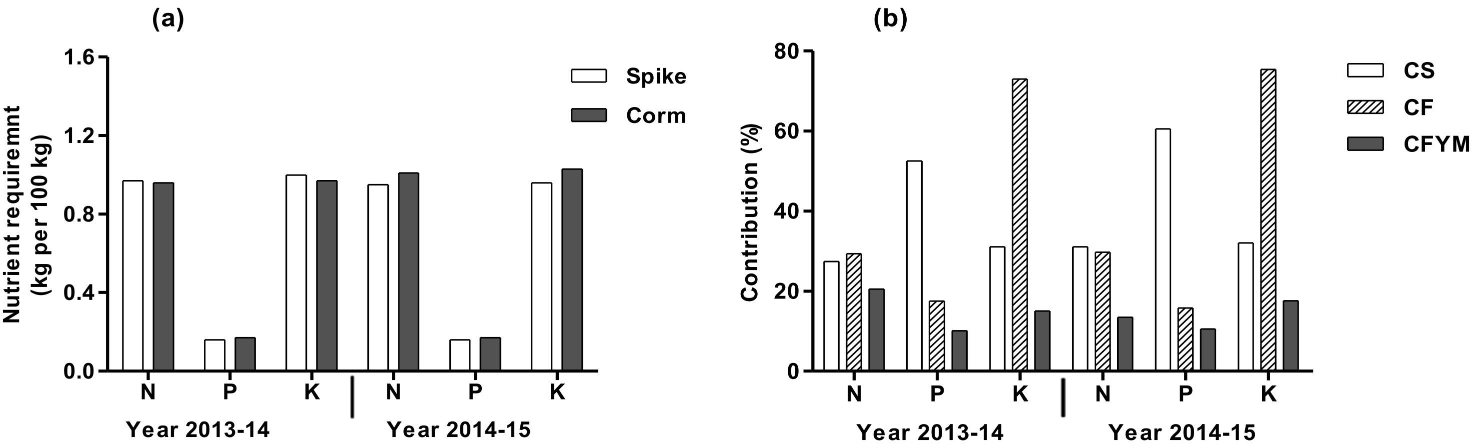


Fig 4. Effect of different soil fertility status on (a) nutrient requirement (NR) of gladiolus crop to produce spike and corm and (b) percent contribution of NPK from soil (CS), fertilizer (CF) and farmyard manure (CFYM).

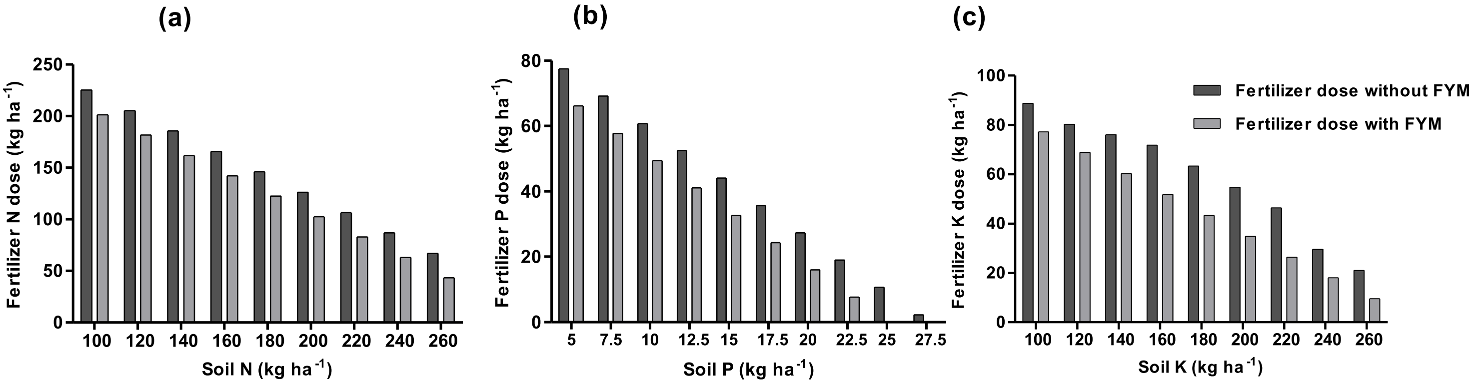


Fig 5. Soil test based fertilizer prescription of nutrients (a) N, (b) P and (c) K for a targeted yield 10 t ha^{-1} of gladiolus spikes supplied with and without FYM.

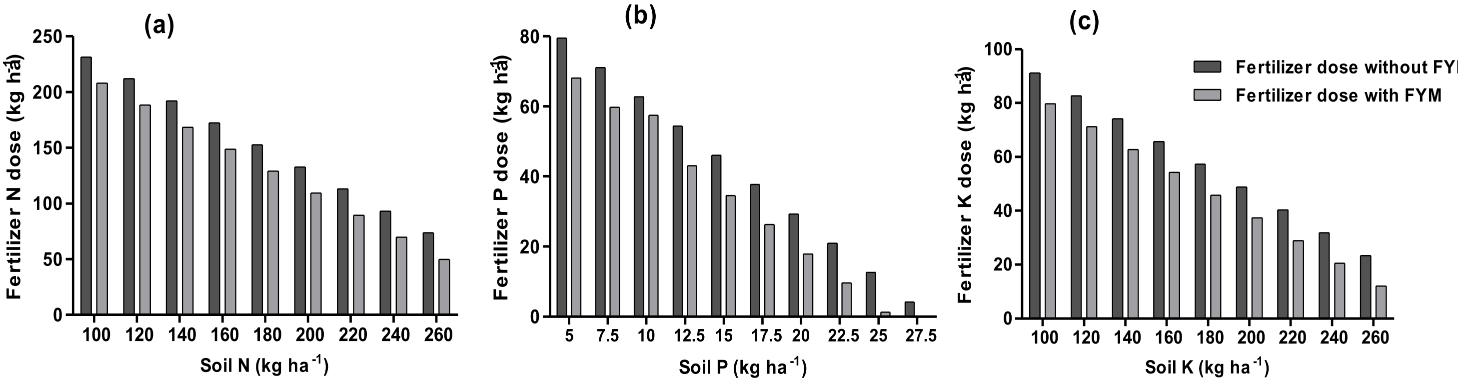
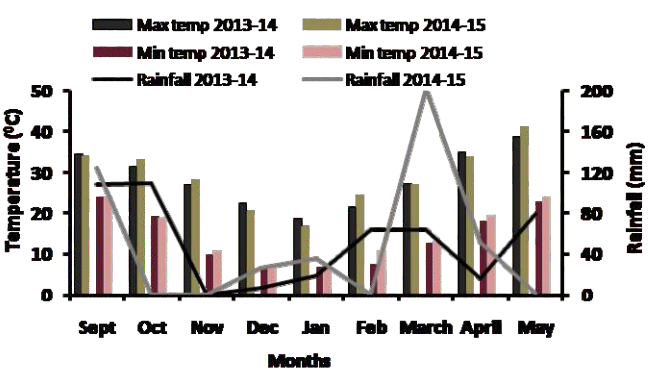
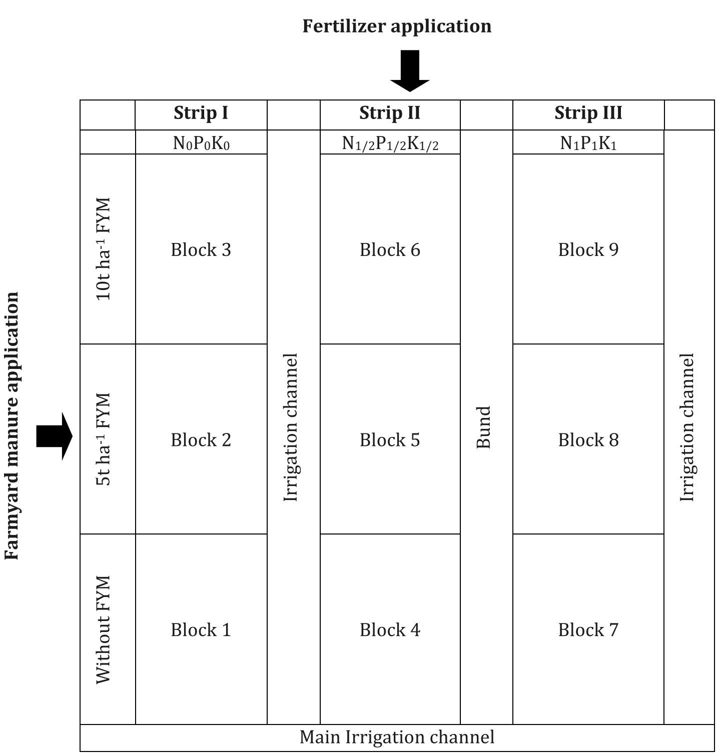


Fig 6. Soil test based fertilizer prescription of nutrients (a) N, (b) P and (c) K for a targeted yield 10 t ha^{-1} of gladiolus corms supplied with and without FYM.



Supplementary Figure 1. Meteorological data during the crop growth period of gladiolus for two years, 2013-14 and 2014-15



Supplementary Figure 2. Layout for creating fertility gradient in the experimental field

$N_0P_0K_0$, $N_{1/2}P_{1/2}K_{1/2}$ and $N_1P_1K_1$ represents zero, medium and high dose of fertilizer NPK applied to strip I, strip II and strip III, respectively. $N_1P_1K_1$ represents 400, 300 and 300 kg of N, P_2O_5 and K_2O ha^{-1}.

	Strip I		Strip II		Strip III	
FYM 10t ha^{-1}	1 $N_2P_2K_0$	Irrigation channel	25 $N_2P_0K_2$	Bund	49 $N_3P_3K_3$	Irrigation Channel
	2 $N_1P_2K_1$		26 $N_1P_1K_2$		50 $N_2P_1K_2$	
	3 $N_0P_0K_0$		27 $N_2P_2K_2$		51 $N_2P_3K_2$	
	4 $N_3P_3K_1$		28 $N_2P_1K_1$		52 $N_0P_2K_2$	
	5 $N_3P_3K_2$ A		29 $N_2P_2K_3$ B		53 $N_3P_2K_3$ C	
	6 $N_2P_2K_1$		30 $N_1P_1K_1$		54 $N_0P_0K_0$	
	7 $N_1P_2K_2$		31 $N_0P_0K_0$		55 $N_3P_1K_1$	
	8 $N_2P_3K_3$		32 $N_3P_2K_1$		56 $N_3P_2K_2$	
FYM 5t ha^{-1}	9 $N_2P_0K_2$		33 $N_3P_3K_3$		57 $N_3P_3K_1$	
	10 $N_1P_1K_2$		34 $N_0P_2K_2$		58 $N_0P_0K_0$	
	11 $N_3P_2K_1$		35 $N_3P_2K_2$		59 $N_2P_2K_1$	
	12 $N_0P_0K_0$		36 $N_3P_1K_1$		60 $N_1P_2K_1$	
	13 $N_2P_2K_3$ B		37 $N_0P_0K_0$ C		61 $N_3P_3K_2$ A	
	14 $N_1P_1K_1$		38 $N_3P_2K_3$		62 $N_2P_2K_0$	
	15 $N_2P_2K_2$		39 $N_2P_1K_2$		63 $N_2P_3K_3$	
	16 $N_2P_1K_1$		40 $N_2P_3K_2$		64 $N_1P_2K_2$	
WITHOUT FYM	17 $N_3P_3K_3$		41 $N_2P_3K_3$		65 $N_2P_0K_2$	
	18 $N_0P_2K_2$		42 $N_2P_2K_0$		66 $N_3P_2K_1$	
	19 $N_2P_3K_2$		43 $N_3P_3K_1$		67 $N_2P_1K_1$	
	20 $N_3P_2K_2$		44 $N_0P_0K_0$ A		68 $N_2P_2K_3$ B	
	21 $N_3P_2K_3$ C		45 $N_3P_3K_2$		69 $N_0P_0K_0$	
	22 $N_0P_0K_0$		46 $N_2P_2K_1$		70 $N_1P_1K_1$	
	23 $N_3P_1K_1$		47 $N_1P_2K_2$		71 $N_2P_2K_2$	
	24 $N_2P_1K_2$		48 $N_1P_2K_1$		72 $N_1P_1K_2$	
Main irrigation channel						

Supplementary Figure 3. Layout of soil test crop response experiment on gladiolus

Numbers 0, 1, 2 and 3 in treatment combination represents four levels of applied N, P and K;where (1) N_0, N_1, N_2 and N_3 represents 0, 100, 200 and 300 kg N ha^{-1}, (2) P_0, P_1, P_2 and P_3 represents 0, 40, 80 and 120 kg P_2O_5 ha^{-1}, and (3) K_0, K_1, K_2 and K_3 represents 0, 40, 80 and 120 kg K_2O ha^{-1} respectively. Three different blocks of eight treatments A, B and C were randomized in three different strips.

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