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Soil Test Crop Response Based Integrated Plant Nutrient Management System for Fennel (*Foeniculum vulgare* Mill.) in an Inceptisol

Y.V. Singh*, S.K. Singh, D.K. Srivastava[1], Pavan Singh and H.S. Jatav
Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, 221005, Uttar Pradesh

A field experiment was conducted on an Inceptisol of Agricultural Research Farm, Banaras Hindu University, Varanasi during *rabi* 2017-18 by using integrated plant nutrient management system (IPNMS) on the basis of STCR approach. The aim of study was to develop fertilizer recommendation equations for cultivation of fennel. Soil test data, grain yield and NPK uptake by fennel crop were used for achieving four important basic parameters, *viz*., nutrients required to produce one quintal of fennel grain (NR), contribution of nutrients from fertilizers (%CF), contribution of nutrients from soil (%CS) and contribution of nutrients from organic matter-FYM (%C-OM). It was found that 4.37, 1.13 and 3.91 kg of N, P_2O_5 and K_2O, respectively were required for producing one quintal fennel grain. The per cent contribution of nutrients from soil, fertilizer and FYM were 14.05, 50.30 and 10.38 for N; 62.65, 54.08 and 3.45 for P_2O_5, and 13.24, 169.63 and 12.24 for K_2O, respectively. By using these basic parameters, ready reckoner of fertilizer doses was prepared for varying soil test values and desired yield targets of fennel grain using NPK alone and NPK with FYM.

Key words: Fennel, nutrient, grain yield, STCR, fertilizer, basic parameter and FYM

Fennel (*Foeniculum vulgare* Mill.) is one of the popular seed spices in India mainly grown in *rabi* season, locally known as *saunf* belongs to the family Apiaceae (Umbelliferae). It is cultivated throughout the temperate and subtropical regions of the world for its aromatic seeds which are used for culinary and pharmaceutical purposes. Fennel is also recommended for the treatment of diabetes, bronchitis and chronic coughs, kidney stones, and is considered to have diuretic, stomachic and galactogogue properties. In India, it is mainly cultivated in the states of Gujarat and Rajasthan and to some extent in Uttar Pradesh, Bihar, Madhya Pradesh, Punjab and Haryana. In India, area under fennel was 41368 ha with production of 58265 tonnes and productivity of 1.40 t ha^{-1} in 2010-11 (SBI 2011). Farmyard manure (FYM) plays an important role in increasing crop yields by supplying nitrogen, phosphorus and potassium in available forms to the plants through biological decomposition. It improves physical properties of soil such as aggregation, permeability and water holding capacity. It contains all the essential elements which mitigate the ill effect of imbalanced use of fertilizers (Ray *et al*. 2000). Farmers are using excess chemical fertilizers to achieve higher yields but the decision on fertilizer use requires knowledge of the expected crop yield and response to nutrient application. It is a function of crop nutrient needs, supply of nutrients from indigenous sources and the short-term and long-term fate of the applied fertilizer nutrients (Dobermann *et al*. 2003). Hence, there is a scope to increase the production of fennel by soil test crop response (STCR) correlation method. In STCR, the fertilizer doses are recommended based on fertilizer adjustment equations which are developed after establishing significant relationship between soil test values and the added fertilizers. Fertilizer recommendations based on STCR concept are more quantitative, precise and meaningful because combined use of soil and plant analysis are involved in it. It gives a real balance between applied nutrients and the available nutrients already present in the soil.

*Corresponding author (Email: yvsingh59@rediffmail.com)
[1]Council of Science and Technology, Lucknow, 226018, Uttar Pradesh

Keeping the above facts in view and non-availability of STCR-IPNMS data for fennel in eastern Uttar Pradesh, this study was conducted.

The objective of this study was to evolve the sound basis of fertilizer prescriptions for fennel crop in alluvial soil (Inceptisol) at different soil fertility levels under the conditions of fertilizer scarcity and to ensure maximum fertilizer use efficiency. The study also intended to find the relationship between the nutrients supplied by the soil and added through organic and inorganic sources, their uptake and to develop a guideline for judicious application of fertilizers for desired yield target of field fennel by using STCR model.

Materials and Methods

A field experiment was conducted using fennel as test crop during *rabi* 2017-18 on alluvial soil (Inceptisol) at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to develop targeted yield equations following the procedure of Ramamoorthy *et al.* (1967). In 2017, selected site of 1245.6 m^2 area was divided into three strips of equal size and in each strip, different fertilizer doses, low 0, 0, 0, medium 120, 60, 60 and high 240, 120, 120 kg ha^{-1} of N, P_2O_5 and K_2O, respectively were applied to develop a fertility gradient. Sorghum (variety Deshi Chari) was grown as an exhaust crop during *kharif* 2017 for stabilizing fertility gradient. The crop was harvested at maturity in the succeeding season. Fennel (variety - RF-125) was grown as test crop during *rabi* 2017-18 in the same field in which the fertility gradient stabilizing experiment was conducted. Each strip (made in the fertility gradient stabilizing experiment in the previous season) was divided into 24 (21 treated and 3 control plots) equal sized (2 m × 2 m) plots resulting in a total of 72 (24 × 3) plots. Three blocks (A, B, C) comprising 8 treatments were made within each strip randomized with FYM levels. Treatments of N, P_2O_5, K_2O and FYM were used as shown in table 1. The fertilizers used were urea, single superphosphate and muriate of potash. Full doses of P_2O_5 and K_2O were applied as basal while N was applied in two equal splits, half as basal and remaining half at 30 days after sowing. Plot-wise nutrient levels were tested before applying FYM and NPK. Soil samples (0-20 cm) from all the 72 plots were collected and analyzed for available N, by the alkaline permanganate method (Subbiah and Asija 1956); available P by Olsen *et al*. (1954) and available K by ammonium acetate method (Hanway and Heidal 1952) as described by Jackson (1973). Fennel crop was sown in lines 45 cm apart; having 7 lines in a plot and recommended package of practices were followed. Fennel grain and straw yields were recorded separately and plant samples were taken for estimation of N, P, and K contents for working out uptake by the crop. Plot-wise soil test data, fertilizer doses, yield and uptake were used for obtaining NR (nutrient required to produce one quintal fennel grain yield), %CS (per cent contribution of nutrients from soil), %CF (per cent contribution of nutrients from fertilizers) and %C-OM (per cent contribution of nutrients from organic manure), as per method described by Ramamoorthy *et al.*(1967).

Table 1. Levels of nitrogen, phosphorus, potassium and FYM used in experiment

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	FYM (t ha^{-1})
0	0	0	0
40	20	15	5
80	40	30	10
120	60	45	-

1. Nutrient requirement in kg q^{-1} of grain (NR)

$$= \frac{\text{Total uptake of nutrient (kg ha}^{-1}\text{)}}{\text{Grain yield (q ha}^{-1}\text{) in plot}}$$

2. Per cent contribution of nutrients from soil (%CS)

$$= \frac{\text{Total uptake of nutrient in the control plot (kg ha}^{-1}\text{)}}{\text{Soil test values of nutrient in control plot (kg ha}^{-1}\text{)}} \times 100$$

3. Per cent contribution of nutrients from fertilizer without FYM (%CF)

$$= \frac{\left(\begin{array}{c}\text{Total uptake of}\\ \text{nutrient (kg ha}^{-1}\text{) in}\\ \text{fertilizer treated}\\ \text{plot}\end{array}\right) - \left(\begin{array}{c}\text{Soil test values}\\ \text{(kg ha}^{-1}\text{) of nutrient}\\ \text{in fertilizer treated}\\ \text{plot} \times \%CS/100\end{array}\right)}{\text{Nutrient dose applied through fertilizer (kg ha}^{-1}\text{)}} \times 100$$

4. Per cent contribution of nutrients from organic manure (%CFYM)

$$= \frac{\left(\begin{array}{c}\text{Total uptake of}\\ \text{nutrient (kg ha}^{-1}\text{)}\\ \text{in organic manure}\\ \text{treated plot}\end{array}\right) - \left(\begin{array}{c}\text{Soil test values}\\ \text{(kg ha}^{-1}\text{) of nutrient}\\ \text{in organic plot}\\ \times \%CS/100\end{array}\right)}{\text{Dose of nutrient added through FYM (kg ha}^{-1}\text{)}} \times 100$$

These parameters were used to develop equations for soil test based fertilizer recommendations for desired yield targets of fennel under NPK alone as well as NPK plus FYM.

Table 2. Available nutrients in pre-sowing surface soil and yield of fennel

Parameters	NPK treated plots		Control plots	
	Range	Mean SEm±	Range	Mean SEm±
$KMnO_4$-N (kg ha^{-1})	213.1 – 265.4	239.3 ± 26.1	200.4 – 231.2	215.8 ± 15.4
Olsen-P_2O_5 (kg ha^{-1})	13.0 – 25.0	19.0 ± 6.0	12.3 – 15.1	13.7 ± 1.4
NH_4OAc-K_2O (kg ha^{-1})	205.1 – 240.3	222.7 ± 17.6	184.5 – 216.0	200.3 ± 15.8
Yield (q ha^{-1})	11.17 – 16.15	13.93 ± 2.23	6.70 – 11.30	9.00 ± 2.30

Results and Discussion

Soil available nutrients and grain yield

The range and mean values of soil available nutrients and grain yield of fennel in treated and control plots are presented in table 2. In the NPK treated plots (plots that received NPK alone or NPK plus FYM), $KMnO_4$-N increased from 213.1 kg ha^{-1} in strip I to 265.4 kg ha^{-1} in strip III with a mean value of 239.3 kg ha^{-1}. The Olsen-P_2O_5 ranged from 13.0 kg ha^{-1} in strip I to 25.0 kg ha^{-1} in strip III with a mean value of 19.0 kg ha^{-1}, while the NH_4OAc–K_2O status varied from 205.1 kg ha^{-1} in strip I to 240.3 kg ha^{-1} in strip III with a mean value of 222.7 kg ha^{-1}.

In the NPK treated plots that received NPK alone or NPK plus FYM, the yield of fennel ranged from 11.17-16.15 q ha^{-1} with a mean value 13.93 q ha^{-1}. In the overall control plots, the yield ranged from 6.70-11.30 q ha^{-1} with a mean value of 9.00 q ha^{-1}. In the overall control plot of three fertility gradients (Table 2), the $KMnO_4$-N ranged from 200.4 to 231.2 kg ha^{-1} with a mean of 215.8 kg ha^{-1}, Olsen-P_2O_5 ranged from 12.3 to 15.1 kg ha^{-1} with a mean value of 13.7 kg ha^{-1}, and the NH_4OAc-K_2O varied from 184.5-216.0 kg ha^{-1} with a mean value of 200.3 kg ha^{-1}. Though these soils are considered as fertile, they are low in N and organic carbon and medium in P_2O_5 and K_2O. Almost similar results were found by Bera *et al.* (2006) and Dwivedi *et al.* (2009) for on-farm evaluation of soil test based site specific nutrient management in fennel-millet-based cropping systems on alluvial soils.

The above data clearly indicate the existence of operational range of soil test values for available N, P and K and yield of treated and control plots, which is a prerequisite for calculating the basic parameters and fertilizer prescription equations for calibrating the fertilizer doses for specific yield targets. The equations are:

NPK Alone

$$FN = 8.68T - 0.28SN$$
$$FP_2O_5 = 2.08T - 1.16SP_2O_5$$
$$FK_2O = 2.32T - 0.08SK_2O$$

NPK + FYM

$$FN = 8.68T - 0.28SN - 0.21ON$$
$$FP_2O_5 = 2.08T - 1.16SP_2O_5 - 0.06OP_2O_5$$
$$FK_2O = 2.32T - 0.08SK_2O - 0.07OK_2O$$

FN = Fertilizer N (kg ha^{-1})

FP_2O_5 = Fertilizer P_2O_5 (kg ha^{-1})

FK_2O = Fertilizer K_2O (kg ha^{-1})

T = Yield target (q ha^{-1})

where, SN, SP_2O_5 and SK_2O, respectively are alkaline $KMnO_4$-N, Olsen-P_2O_5 and NH_4OAc-K_2O in kg ha^{-1} and ON, OP_2O_5 and OK_2O are the quantities of N, P_2O_5 and K_2O in kg ha^{-1} supplied through FYM, respectively.

Basic parameters

The basic data *viz*., nutrient requirement for producing one quintal grain of fennel, per cent contribution of nutrients from soil (%CS), fertilizer (%CF) and FYM (%CFYM) have been calculated (Table 3). These basic parameters were used for developing the fertilizer prescription equations under NPK alone and NPK plus FYM. The nutrient requirement of N, P_2O_5 and K_2O were 4.37, 1.13 and 3.91 kg q^{-1} of grain, respectively. The %CS and %CF were found to be 14.05 and 50.30 for N, 62.65 and 54.08 for P_2O_5, and 13.24 and 169.63 for K_2O. Similarly, the per cent contribution of N, P_2O_5 and K_2O from FYM was 10.38, 3.45 and 12.24, respectively. It was noted that contribution of K from fertilizer for fennel was higher in comparison to soil. This high value of K could be due to the interaction effect of higher doses of N and P coupled with priming effect of starter K doses in the treated plots, which might have caused the release of soil K,

Table 3. Basic data and fertilizer adjustment equations of fennel (*var.* RF-125) in Inceptisol

Basic data	N	P_2O_5	K_2O
Nutrient requirement (kg q^{-1})	4.37	1.13	3.91
Per cent soil efficiency (%CS)	14.05	62.65	13.24
Per cent fertilizer efficiency (%CF)	50.30	54.08	169.63
Per cent organic efficiency (%CFYM)	10.38	3.45	12.24

Table 4. Estimation of soil test based fertilizer recommendation for 15 q ha^{-1} grain yield target of fennel

Soil test value (kg ha^{-1})			Fertilizer dose (kg ha^{-1}) under NPK alone			Fertilizer dose (kg ha^{-1}) under NPK+ FYM @ 10 t ha^{-1}		
SN	S P_2O_5	SK_2O	FN	FP_2O_5	FK_2O	FN	FP_2O_5	FK_2O
180	10.0	140	79.80	19.60	23.60	69.30	17.80	20.80
200	15.0	160	74.20	13.80	22.00	63.70	12.00	19.20
220	20.0	180	68.60	8.00	20.40	58.10	6.20	17.60
240	25.0	200	63.00	2.20	18.80	52.50	0.40	16.00
260	30.0	220	57.40	0.00	17.20	46.90	0.00	14.40

resulting in the higher uptake from the native soil sources by the crop (Ray *et al*. 2000). Previously, higher efficiency of K-fertilizer was also reported for rice by Ahmed *et al*. (2002). Contribution of nutrients from FYM is low which might be due to lower mineralization rate of FYM (Singh and Singh 2014). However, in the case of P_2O_5, the contribution was more from soil than from fertilizer.

An assessment of fertilizer doses were prepared based on these equations for a range of soil test values and for yield target of 15 q ha^{-1} of fennel (Table 4). For achieving this target with soil test values of 180:10:140 kg ha^{-1} of $KMnO_4$-N, Olsen-P and NH_4OAc-K, the fertilizer N, P_2O_5 and K_2O doses required were 79.80, 19.60 and 23.60 kg ha^{-1}, respectively. When FYM (0.5, 0.3 and 0.5 per cent of N, P and K, respectively) was applied @ 10 t ha^{-1} along with NPK, the required fertilizer N, P_2O_5 and K_2O doses were 63.30, 17.80 and 20.80 kg ha^{-1}, respectively. Under IPNMS the required dose of fertilizer was low due to nutrient availability increased by FYM through mineralization. Singh *et al.* (2017) also reported that under integrated plant nutrient system, required dose of fertilizer to achieve desired yield target are reduced significantly.

Fertilizer prescription equations were transformed into ready reckoner for obtaining requirements of fertilizer, say for yield target of 15 q ha^{-1} of fennel on soils with varying soil test values for both NPK applied with and without FYM. From these findings, it is obvious that with varying soil test values, the fertilizer recommendation varies for the same level of crop production. Hence, balanced fertilization through soil testing becomes essential for increasing crop production. Similar results were also found by various workers in different crops: Avtari *et al*. (2010) for 2 t ha^{-1} yield of yellow mustard, Singh *et al.* (2014) for wheat, Regar and Singh (2014) for rice, and Singh *et al.* (2015) for maize. It was obvious from these findings that there was a net saving of fertilizers in each target and ultimately the reduction in cost of cultivation of crops.

Prediction of post-harvest soil available nutrients (N, P and K)

A post-harvest prediction equation of soil test value can be used to make a fertilizer recommendation for entire cropping sequence. This is very useful because the soil of farmers' fields under intensive farming cannot be tested for each crop for practical reasons. The interactions among the post-harvest soil test values, fertilizer applied doses, initial soil test values and grain yield from the treated plots for fennel crop are obtained through multiple regression analysis (Table 5).

It is evident that large R^2 values (significant at 1%) were obtained for these equations (Table 5). This suggests that such regression equations can be applied with confidence for the prediction of available N, P and K after harvest of fennel for making soil test based fertilizer recommendation for the succeeding crops. Similar predictions of post-harvest soil test values for N, P and K were also made by Verma and Singh (1991) and Bera *et al.* (2006).

Table 5. Prediction equations for post-harvest soil test value for fennel

Nutrient	R^2	Multiple regression equation
N	0.80**	PHN = 115.61 + 1.1530 RY** + 0.404691 SN** + 0.404691 FN
P	0.76**	PHP = 2.295719 + 0.281983 RY + 1.01767 SP** + 0.038626 FP**
K	0.85**	PHK = 66.55525 + 0.505582 RY** + 0.656008 SK** - 0.0211229 FK

*Significant at 5% level; ** Significant at 1% level: Here PHN, PHP and PHK stand for the post-harvest soil test values of N, P and K (kg ha^{-1}); RY is the yield of crop (q ha^{-1}), SN, SP and SK represent the initial soil test values of N, P and K (kg ha^{-1}) and FN, FP and FK represent the fertilizer doses of N, P_2O_5 and K_2O kg ha^{-1} applied, respectively.

Conclusions

Equations developed could be used for making fertilizer recommendation for seeking targeted yields of fennel in Inceptisols of eastern Uttar Pradesh. It is also advocated that the trends observed in this study may hold true for broad generalization in the larger parts of Gangetic Plains of eastern Uttar Pradesh having similar soil and climatic conditions.

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