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Research article

BALANCED NUTRIENT MANAGEMENT OF MUSTARD *(Brassica juncea* L.) IN RICE-MUSTARD-SESAME CROPPING SYSTEM IN RED AND LATERITIC SOIL

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ABSTRACT: An experiment was conducted during the *Rabi* season to study the effect of balanced fertilization on mustard yield (var. RW-351; Bhagirathi) in rice-mustard-sesame cropping system in low productive multi nutrient stressed red and lateritic soil. After comprehensive soil test report, yield target based recommendations for applications of different plant nutrients (N, P, K, S and B) were also obtained for the crop. Based on these recommendations, fourteen numbers of fertilizer treatments were prepared. With these, two more treatments were added are the state fertilizer recommendation and the fertilization practice commonly used in the area by the farmers. Among different treatments, the soil test based recommendation of N, K, S and B along with 25% higher level of P (N_{140} $P_2O_{5\ 175}$ $K2O_{112}$B S) appeared to be the most effective in improving various growth attributes, yield attributes and highest seed yield (1.65 t ha^{-1}) of mustard.
Keywords: Red and lateritic soil, Nutrient stress, *mustard*, Balance fertilization

INTRODUCTION

Red and lateritic soils constitute an important soil group in India occupying about 70 million hectares of land area of the country [1]. These soils are usually low productive owing to occurrence of various soil related constraints like coarse texture, low water holding capacity, acidity, poor availability of nitrogen and phosphorus, restricted occurrence of K, low organic carbon status and toxic as well as inadequate occurrence of several secondary and trace elements [2]. Oilseeds contribute the second largest agricultural commodity after cereals in India sharing about 14% of the country's gross cropped area and accounting for nearly 5% of the gross national product and 10% of all national products [3]. Although the per capita availability of edible oils has increased from 4.0 kg per year in 1960-61 to 9.5-10.0 kg per year in 2000-2001 in India, the consumption is still well behind the world average of 16.0 kg ha^{-1} [4]. India's resounding success from its past green revolution has been followed by stagnating or declining agricultural productivity, even with increased total fertiliser use in the country over the years. This declining factor of productivity is largely due to imbalanced fertiliser use. The productivity of oilseeds in the country is only 840 kg ha^{-1} [5], much lower when compared with the major oilseed producing countries of the world. The farmer's of red and lateritic soil area seldom cultivates mustard and productivity of the crop is very low. This situation has been aggravated further due to indiscriminate use of N dependent imbalanced fertilization in these soil zones. Soils are inherently poor in bases and other plant nutrients. However, they are responsive to agronomic management. The continuous downward trend in crop production has been a matter of serious concern. Improving and maintaining soil fertility for productivity enhancement is of paramount importance in sustaining crop production to maximize the yield levels in such soils. It is necessary to adopt balanced fertilization schedules taking into consideration of all the deficient nutrient elements. In the present study, therefore, an attempt has been made to assess the possibilities of increasing the yield potentials in a rice-mustard-sesame cropping system in red and lateritic soils through soil test based balanced use of different nutrients. The objective of nutrient management in agricultural soils is to achieve the required crop yield in an efficient, economical and sustainable manner through removal of constraints including nutrient deficiencies [6,7].

It also stated that soil test effectively distinguished soils with low and high profitability of crop response for most nutrients [8], while reporting several case studies on balanced nutrient management, also emphasized the changes in soil nutrient management strategies by estimating the system level nutrient use efficiency. With the escalating population in the country, therefore, more and more emphasis is being given to reduce the gap between supply and demand of oilseeds in the country by increasing the productivity levels of these crops. Adoption of proper nutrient management practices forms an important component of such effort.

MATERIALS AND METHODS

The experiment was conducted during the *Rabi* season of 2002-03, 2003-04 and 2004-05 in a farmer's field of village Kendradangal of Birbhum district of West Bengal, India representing a typical red and lateritic soil. The field is situated at 23°39' N latitude and 87°42' E longitude with an average altitude of 58.9 m above the mean sea level. The soil was sandy clay in texture having pH 5.1, organic matter 1.3%, and available nitrogen, phosphorus and potassium 38.08, 44.80 and 197.12 kg ha^{-1} respectively. Based on this report, fourteen treatment combinations were prepared and with these, two more treatments were added which were the state fertilizer recommendation and the fertilization practice commonly used in the area by the farmer. Mustard was cultivated after *Kharif* rice during the post monsoon period using different fertilization doses.

T1 ($N_{105}P_{175}K_{140}$B S)	T7 ($N_{140}P_{175}K_{0}$B S)	T13 ($N_{140}P_{140}K_{112}$B S) (Recommended fertilizer dose)
T2 ($N_{140}P_{175}K_{140}$B S)	T8 ($N_{140}P_{175}K_{84}$B S)	T14 ($N_{105}P_{105}K_{84}$B S)
T3 ($N_{175}P_{175}K_{140}$B S)	T9 ($N_{140}P_{175}K_{112}$B S)	T15 ($N_{60}P_{20}K_{20}$) (Farmers practice)
T4 ($N_{140}P_{0}K_{140}$ B S)	T10 ($N_{140}P_{175}K_{140}$B)	T16 ($N_{80}P_{40}K_{40}$) (State recommendation)
T5 ($N_{140}P_{105}K_{140}$B S)	T11 ($N_{140}P_{175}K_{140}$B S)	
T6 ($N_{140}P_{140}K_{140}$B S)	T12($N_{140}P_{175}K_{140}$ S)	

Sulphur and boron were applied @16.80 kg ha^{-1} and 1.12 kg ha^{-1}, respectively. The experiment was laid out in a Randamised Block Design replicated thrice. The mustard (var. RW-351) was sown at a spacing of 20 cm x 10 cm. Recommended package and practices were followed to raise the crop.

RESULTS AND DISCUSSION

Data on plant height, dry matter accumulation and CGR (Table 1) were influenced significantly by different levels of nutrient application in all the three years i.e.2002-03, 2003-04 and 2004-05. Maximum plant height, dry matter accumulation and CGR were recorded in the treatment receiving 140 kg N, 175 kg P_2O_5, 112 kg K_2O, 1.12 kg B and 16.80 kg S (T_9) and it was closely followed by T_{13} ($N_{140}P_{140}K_{112}$BS) treatment. Although the treatment T_{15} ($N_{60}P_{20}K_{20}$) and T_{16} ($N_{80}P_{40}K_{40}$) included smallest doses of N, P and K, yet the lowest plant height was found in the plot receiving comparatively much higher doses of N and K along with B and S but with out P (T_4). It is well known that availability of P controls the uptake of different nutrients through its effect on extension of root activities. Greater height of plant and dry matter accumulation receiving adequate and balanced nutrition might be due to better metabolic activities performed by the crop at optimum fertility levels.

The variation of treatments using various combinations of nutrients showed significant effect on production of number of branches per plant, number of siliqua per plant, number of seeds per siliqua. The maximum numbers of branches per plant, number of siliqua per plant, number of seeds per siliqua (Table 2) were found in $N_{140}P_{175}K_{112}$BS treatment (T_5) and it was found to be at par with $N_{140}P_{140}K_{112}$BS treatment (T_{13}) in all the years under study. The significant variation in number of branches per plant, number of siliquae per plant, number of seeds per siliqua might be due to presence of all the nutrients in more balanced and optimum manner in these treatments than the others. Considerably lower numbers of siliqua per plant were recorded from the plot receiving no phosphatic fertilizer (T_4) during all the three years of experimentation. Since oilseed cultivation in India is largely carried out in low fertile soils, balanced management of different productivity limiting soil nutrients is likely to be more important for increasing yield levels of such crops [9].

Seed yield, stick yield and oil yield of mustard (Table 3) varied significantly due to different nutrient combinations in all the three years. Crops receiving 140 kg N, 175 kg P_2O_5, 112 kg K_2O, 1.12 kg B and 16.80 kg S (T_9) produced the maximum seed yield (1.69 t ha^{-1}, 1.65 t ha^{-1} and 1.61 t ha^{-1} during 2002-03, 2003-04 and 2004-05 respectively).

Table 1. Effects of different treatments on plant height, dry matter accumulation (g m^{-2}) and crop growth rate (CGR) of mustard

Treatment	Plant height at 60 DAS (cm)			Dry matter accumulation at 60 DAS (g m^{-2})			CGR during 45-60 DAS		
	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr
T1 (N_{105} P_2O_5 $_{175}$ K_2O $_{140}$B S)	122.00 bc	124.28 de	121.27 fg	1219.1 f	1295.24 e	1270.29 ef	71.61 cd*	67.09 bc	70.21 c
T2 (N_{140} P_2O_5 $_{175}$ K_2O $_{140}$B S)	125.22 b	134.54 ab	129.57 bc	1266.97 cd	1356.19 c	1344.24 c	75.58 b	70.05 b	74.91 ab
T3 (N_{175} P_2O_5 $_{175}$ K_2O $_{140}$B S)	118.57 cd	119.67 fgh	116.87 hij	1218.35 f	1254.27 h	1239.62 i	69.41 d	67.28 bc	68.89 cd
T4 (N_{140} P2O_5 $_0$ K_2O $_{140}$ B S)	67.07 h	71.25 j	67.10 m	714.73 k	786.93 l	771.37 m	41.42 f	36.88 e	40.81 f
T5 (N_{140} P_2O_5 $_{105}K_2O$ $_{140}$B S)	122.00 bc	125.13 cd	122.39 ef	1236.74 e	1299.54 de	1280.15 de	72.05 cd	68.14 bc	70.87 c
T6 (N_{140} P_2O_5 $_{140}$ K_2O $_{140}$ B S)	119.22 c	121.33 ef	118.66 gh	1227.03 ef	1284.25 f	1261.56 fg	71.27 cd	67.67 bc	69.84 c
T7 (N_{140} P_2O_5 $_{175}K_2O$ $_0$B S)	111.83 e	117.56 h	113.98 j	1194.39 g	1206.19 i	1188.54 j	66.34 d	65.87 c	65.63 d
T8 (N_{140} P_2O_5 $_{175}K_2O$ $_{84}$B S)	124.89 b	133.17 b	128.50 cd	1277.00 bc	1295.34 de	1274.34 e	71.62 cd	70.67 b	70.40 c
T9 (N_{140} P_2O_5 $_{175}$ K2O $_{112}$B S)	129.00 a	137.56 a	135.74 a	1365.21 a	1383.87 b	1390.62 a	76.22 ab	75.24 a	76.91 a
T10 (N_{140} P_2O_5 $_{175}K_2O$ $_{140}$B)	120.56 c	121.20 efg	117.95 ghi	1229.03 ef	1276.65 g	1254.34 gh	70.78 cd	67.99 bc	69.79 c
T11 (N_{140} P_2O_5 $_{175}K_2O$ $_{140}$B S)	124.67 b	128.51 c	125.37 de	1270.57 bcd	1275.29 g	1250.28 hi	70.32 cd	70.26 b	68.85 cd
T12(N_{140} P_2O_5 $_{175}K_2O$ $_{140}$ S)	115.27 de	118.00 fgh	115.23 hij	1261.18 d	1302.56 d	1289.37 d	72.66 c	70.18 b	72.27 bc
T13 ($N_{140}P_2O_5$ $_{140}K_2O$ $_{112}$B S)	125.22 b	135.29 ab	132.61 ab	1281.55 b	1405.17 a	1370.55 b	78.42 a	70.46 b	76.31 a
T14 (N_{105} P_2O_5 $_{105}K_2O$ $_{84}$B S)	113.24 e	117.78 gh	114.90 ij	1171.3 h	1259.42 h	1243.11 i	69.88 cd	64.22 c	69.31 cd
T15 (N_{60} P_2O_5 $_{20}K_2O$ $_{20}$)	99.42 g	109.00 i	105.34 l	768.67 j	844.51 k	829.50 l	43.97 f	39.23 e	43.09 f
T16 (N_{80} P_2O_5 $_{40}K_2O$ $_{40}$)	103.74 f	111.78 i	109.55 k	1012.54 i	1041.56 j	1033.23 k	55.59 e	53.92 d	55.41 e
CD(P =0.05)	3.45	3.44	3.52	12.12	7.31	10.95	2.78	4.00	3.86

- Values followed by common letters do not differ significantly

This may be due to adoption of soil test based balanced fertilization in this treatment [10]. This importance of P was more pronounced from the observations that the lowest seed yield was noticed in the plot with good amount of application of all the required plant nutrients excepting phosphatic fertilizer in T_4 ($N_{140}P_0K_{140}$BS) in all the three years. In addition, inclusion of S and B in the treatments produced significantly higher seed yields than the ones without S or B (N_{140} $P_{175}K_{140}$ B i.e. T_{10} or N_{140} $P_{175}K_{140}$ S i.e. T_{12}). The role of S and B in activation of enzymes responsible for yield increase in oilseed is well known. The treatments which received higher doses of NPK along with B and S resulted, in general, in higher harvest index values indicating larger economic yield per unit of biological yield [4,11]. The results of Sustainable yield index (SYI) values under different treatments confirmed that supply of adequate amount of required plant nutrients in balanced manner forms the major key for sustaining the productivity levels of rice-mustard-sesame cropping sequence in red and lateritic soils. While preparing the fertilization schedule, however, due considerations should be given to the nature and properties of the soils with relation to use efficiency of the added fertilizers. In case of any possibility of reduced use efficiency of any fertilizer due to some specific soil property, due compensation for the expected reduction in efficiency should be made to enable the plants to get adequate nutrition from that fertilizer. Low availability of P in red and lateritic soils due to high P fixing capacity appeared to be the major productivity limiting constrain in the present study. Addition of 25% extra P as compensation to this high P fixing capacity helped to increase the production levels and also to sustain the yields. Available nitrogen values depicting the easily mineralisable form, varied significantly for various treatments during the three years of study (Table 4). Such variations were primarily attributed to different doses of nitrogenous fertilizer added to the soils under different treatments. In general, the treatments with higher dose of nitrogen resulted in higher amount of residual nitrogen in available form and *vice versa*. This deficiency controls the productivity of such soils to a considerable extent. In the present investigation also, lower availability of P in several treatments affected the production of mustard under the rice-mustard-sesame cropping system significantly. While this behaviour may be primarily attributed to acute deficiency of P in red and lateritic soils [12] and high P fixing capacity of the soils [13] appeared to play another important role in reducing the availability of added P in these soils. The treatments where P was either not applied (T_4) or added in smaller doses (T_{15}, T_{16}) showed extremely low availability and this situation affected the yield levels. On the other hand, it was interesting to observe that there was wide variation in availability of P in soil among the treatments where same dose of P was added. Again, treatments where P was added in high doses but yielded low production due to imbalanced use of other nutrients also showed low residual availability of P.

The results, as a whole, show that while there is need of applying adequate amount of P fertilizer in red and lateritic soils to provide P nutrition to the crops, the fertilization should be done in balanced manner along with other nutrients so that good production of the crop may be obtained to utilize the added P. However, in view of the critical role played by P is influencing productivity of red and lateritic soils and also the rapid rate of transformation of this nutrient element to insoluble forms through P fixation [14], some measures need to be taken for reducing the quantum of P fixation in these soils. Use of organic matter, split use of P fertilizer etc are known to improve the P use efficiency of soils by reducing P fixing capacity of soils [13]. Use of K fertilizer in different doses tended to increase the residual available K status (Table 5) in the soils depending largely on the doses of K applied in different treatments. There was a distinct declining trend in the availability of residual K in soil after mustard cultivation for succeeding three years under the treatment-7 where no K was included in the fertilization schedule.

Table 2. Effects of different treatments on number of branches per plant, number of siliquae per plant and number of seeds per siliqua of Mustard

Treatment	Number of branches per plant			Number of siliquae per plant			Number of seeds per si		
	1^{st} yr	2^{nd} yr	3^{rd} yr	1^{st} yr	2^{nd} yr	3^{rd} yr	1^{st} yr	2^{nd} yr	3
T1 ($N_{105}\ P_2O_{5\ 175}\ K_2O\ _{140}B\ S$)	19.45 e	13.78 f*	13.66 cde	128.00 g	119.23 de	118.53 d	10.67 gh	10.91 d*	1
T2 ($N_{140}\ P_2O_{5\ 175}\ K_2O\ _{140}B\ S$)	20.15 c	16.24 c	16. 05 bc	147.00 cd	139.29 b	138.03 b	11.00 fg	13.01 a	12
T3 ($N_{175}\ P_2O_{5\ 175}\ K_2O\ _{140}B\ S$)	19.23 e	11.29 i	13.21 cde	107.33 h	109.82 f	108.36 f	12.33 bc	10.23 g	10
T4 ($N_{140}\ P2O_{5\ 0}\ K_2O\ _{140}\ B\ S$)	11.17 l	8.97 k	8.8 5 f	62.33 k	54.69 j	51.37 j	9.67 i	5.12 l	5
T5 ($N_{140}\ P_2O_{5\ 105}K_2O\ _{140}B\ S$)	20.67 b	14.03 f	13.8 9 cde	157.33 ab	121.34 cd	120.85 d	12.67 b	10.95 d	10
T6 ($N_{140}\ P_2O_{5\ 140}\ K_2O\ _{140}\ B\ S$)	20.50 b	13.27 g	13. 60 cde	151.67 bc	113.21 ef	112.50 e	12.33 bc	10.67 e	10
T7 ($N_{140}\ P_2O_{5\ 175}K_2O\ _{0}B\ S$)	15.10 j	11.43 i	11. 35 ef	93.00 i	99.43 g	98.24 g	10.33 h	9.89 i	9
T8 ($N_{140}\ P_2O_{5\ 175}K_2O\ _{84}B\ S$)	17.99 g	15.63 d	15.42 cd	94.00 i	127.54 c	126.87 c	10.33 h	12.43 b	1
T9 ($N_{140}\ P_2O_{5\ 175}\ K2O\ _{112}B\ S$)	21.50 a	19.94 a	19.64 a	162.00 a	147.56 a	145.45 a	13.33 a	13.06 a	1
T10 ($N_{140}\ P_2O_{5\ 175}K_2O\ _{140}B$)	18.60 f	12.54 h	13.25 cde	134.33 f	111.73 f	109.42 e	12.00 cd	10.54 f	1
T11 ($N_{140}\ P_2O_{5\ 175}K_2O\ _{140}B\ S$)	19.81 d	15.06 e	14. 93 cd	139.67 ef	125.17 cd	125.01 c	11.33 ef	12.24 c	1
T12($N_{140}\ P_2O_{5\ 175}K_2O\ _{140}\ S$)	17.45 h	13.23 g	11.23 ef	105.00 h	101.54 g	99.37 g	10.67 gh	10.05 h	1
T13 ($N_{140}P_2O_{5\ 140}K_2O\ _{112}B\ S$)	20.05cd	19.57 b	19.43 ab	160.33 a	140.59 b	140.28 b	11.67 de	13.04 a	1
T14 ($N_{105}\ P_2O_{5\ 105}K_2O\ _{84}B\ S$)	17.45 h	13.87 f	12.42 def	141.33 de	102.31 g	100.88 g	10.33 h	9.98 h	9
T15 ($N_{60}\ P_2O_{5\ 20}K_2O\ _{20}$)	12.73 k	9.27 j	9.1 7 f	74.00 j	66.09 i	64.24 i	10.33 h	7.32 k	7
T16 ($N_{80}\ P_2O_{5\ 40}K_2O\ _{40}$)	15.05 j	11.29 i	11.18 ef	106.67 h	92.43 h	90.68 h	11.33 ef	8.51 j	8
CD(P =0.05)	0.33	0.28	3.57	5.89	6.87	4.08	0.53	0.08	

- Values followed by common letters do not differ significantly

The T_9 ($N_{140}\ P_2O_{5\ 175}\ K2O\ _{112}B\ S$), which resulted in highest seed yield of mustard during the three years of study, also showed highest uptake of N,P and K(Table 6) due to varying yield rates of mustard which were, in turn, controlled by different fertilizer doses. Treatment 9 ($N_{140}P_{175}K\ _{112}BS$), which resulted in highest production of mustard during all the three years of study, showed highest removal of N,P and K by the crop which amounted to, on an average, 138.58 kg N ha^{-1} , 73.78 kg P ha^{-1} and 164.37 kg K ha^{-1}, respectively. On the other hand, treatment 4 ($N_{140}\ P2O_{5\ 0}\ K_2O\ _{140}\ B\ S$), which resulted in lowest yield due to imbalanced use of fertilizers, showed, on an average, lowest uptake of N and P from soil. Treatments 15 and 16 which also resulted in very poor yield rates also showed very low levels of nutrient removal. Treatment 9, which included the required essential nutrients viz. N, P, K, B and S in adequate amount, resulted in removal of 84.0 kg N ha^{-1} for each ton of mustard seed production. On the other hand, treatment 4, which consisted of all N, K, B and S in almost the same dose like treatment 9 but did not include P in the fertilization schedule, resulted in an average uptake of 364.9 kg N for every ton of mustard seed production. Even after this excessive high rate of N uptake, the yield level of mustard in this treatment remained restricted to only 0.24 t ha^{-1}. This behaviour may be explained to be due to the important role played by P in seed formation of plants [15]. Exclusion of P from the fertilization schedule in T4 treatment ($N_{140}P_2O_{5\ O}\ K_2O_{140}BS$), encouraged vegetative growth of the plants but inhibited the seed production resulting in very high amount of N removal per ton of mustard seed production.. On the other hand, the treatments which included adequate concentration of different nutrients in more balanced manner, showed almost similar range of P removal per ton of mustard seed production.

Uptakes of K were in lower side for the treatments-4, 15 and 16 which showed lower yield rates due to imbalanced and inadequate fertilizer application. Treatment-7, which did not include K in the fertilization schedule, showed the lowest removal of K per ha^{-1}. Although total K removal for mustard production per ha land area was comparatively lower in treatment 4, this effected highest amount of K removal per ton of mustard seed production. Very low yield of mustard in this treatment due to imbalanced use of fertilizers has been discussed earlier. This poor yield levels resulted in the high rate of K removal per ton of mustard seed production in this treatment. On the other hand, treatment 7, which did not include K in the fertilization schedule, showed lowest removal of this nutrient element for each ton of mustard seed production. Overall results of uptake of the three primary plant nutrients under different fertilizer treatments of mustard under rice-mustard-sesame cropping system shows that balanced and adequate use of fertilizers helped to record rational uptakes of the three nutrient elements through the increased yield rates of the crops. On the other hand, imbalanced use of fertilizers not only affected the crop yields but also resulted in larger removal of the nutrients per ton production of the crops.

Table 3. Effects of different treatments on seed yield (t ha^{-1}), stick yield (t ha^{-1}), oil yield (Kg ha^{-1}) and Sustainable Yield Index (SYI) of mustard

Treatment	Seed yield (t ha^{-1})			Stick yield (t ha^{-1})			Oil yield (Kg ha^{-1})			SYI
	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr	
T1 ($N_{105}P_2O_{5\ 175}K_2O_{140}B$ S)	1.14 ef*	1.21 e	1.17 cd	6.13 h	6.57 f	6.27 f	456 h	484 f	468 f	0.94
T2 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$ S)	1.50 c	1.31 d	1.26 c	7.97 b	7.12 e	6.74 e	600 c	524 e	504 e	0.82
T3 ($N_{175}P_2O_{5\ 175}K_2O_{140}B$ S)	1.09 f	1.07 fg	1.06 ef	5.79 i	5.84 i	5.69 i	436 i	428 i	424 h	0.97
T4 ($N_{140}P2O_{5\ 0}K_2O_{140}B$ S)	0.28 h	0.23 k	0.20 i	2.51 n	2.26 o	1.08 o	112 l	92 o	80 m	0.70
T5 ($N_{140}P_2O_{5\ 105}K_2O_{140}B$ S)	1.39 d	1.20 e	1.18 cd	7.46 c	6.55 f	6.32 f	556 d	480 f	472 f	0.82
T6 ($N_{140}P_2O_{5\ 140}K_2O$ 140B S)	1.21 e	1.09 f	1.11 de	7.06 e	6.06 h	5.97 g	484 f	436 h	444 g	0.89
T7 ($N_{140}P_2O_{5\ 175}K_2O_{0}B$ S)	0.96 g	0.84 i	0.79 g	5.21 k	4.57 l	4.23 l	384 j	336 l	316 j	0.81
T8 ($N_{140}P_2O_{5\ 175}K_2O_{84}B$ S)	1.37 d	1.42 c	1.44 b	7.24 d	7.85 d	7.75 c	548 d	568 d	576 c	0.95
T9 ($N_{140}P_2O_{5\ 175}K2O_{112}B$ S)	1.69 a	1.65 a	1.61 a	9.04 a	9.24 a	8.61 a	676 a	660 a	644 a	0.95
T10 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$)	1.16 ef	1.00 gh	1.02 ef	6.33 g	5.41 j	5.49 j	464 g	400 j	408 i	0.84
T11 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$ S)	1.34 d	1.44 c	1.41 b	7.25 d	7.99 c	7.59 d	536 e	576 c	564 d	0.93
T12($N_{140}P_2O_{5\ 175}K_2O_{140}$ S)	1.15 ef	1.12 f	1.09 def	5.57 j	6.29 g	5.85 h	460 gh	448 g	436 g	0.95
T13 ($N_{140}P_2O_{5\ 140}K_2O_{112}B$ S)	1.59 b	1.55 b	1.49 b	7.98 b	8.33 b	7.97 b	636 b	620 b	596 b	0.94
T14 ($N_{105}P_2O_{5\ 105}K_2O_{84}B$ S)	1.15 ef	0.98 h	1.00 f	6.45 f	4.95 k	5.36 k	460 gh	392 k	400 i	0.83
T15 ($N_{60}P_2O_{5\ 20}K_2O_{20}$)	0.30 h	0.27 k	0.23 i	2.63 m	2.46 n	1.24 n	120 l	108 n	92 l	0.77
T16 ($N_{80}P_2O_{5\ 40}K_2O_{40}$)	0.91 g	0.61 j	0.60 h	4.09 l	3.42 m	3.21 m	364 k	244 m	240 k	0.58
CD(P =0.05)	0.08	0.07	0.09	0.08	0.06	0.11	7.14	7.69	8.05	

- Values followed by common letters do not differ significantly

Table 4. Effects of different treatments on pH and organic carbon (%) of soil after harvesting of mustard

Treatment	pH			Organic carbon (%)		
	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr
T1 ($N_{105}P_2O_{5\ 175}K_2O_{140}B$ S)	5.80	6.03	5.65	0.46	0.52	0.52
T2 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$ S)	5.51	6.29	5.72	0.58	0.60	0.64
T3 ($N_{175}P_2O_{5\ 175}K_2O_{140}B$ S)	5.55	6.15	5.69	0.50	0.54	0.53
T4 ($N_{140}P2O_{5\ 0}K_2O_{140}B$ S)	5.47	5.64	5.76	0.53	0.60	0.52
T5 ($N_{140}P_2O_{5\ 105}K_2O_{140}B$ S)	6.02	6.09	5.70	0.50	0.52	0.61
T6 ($N_{140}P_2O_{5\ 140}K_2O_{140}B$ S)	5.88	6.15	5.66	0.54	0.56	0.63
T7 ($N_{140}P_2O_{5\ 175}K_2O_{0}B$ S)	5.52	5.69	5.79	0.57	0.59	0.59
T8 ($N_{140}P_2O_{5\ 175}K_2O_{84}B$ S)	5.47	6.22	5.87	0.52	0.53	0.54
T9 ($N_{140}P_2O_{5\ 175}K2O_{112}B$ S)	5.69	5.73	5.82	0.50	0.59	0.63
T10 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$)	5.72	6.20	5.81	0.48	0.55	0.56
T11 ($N_{140}P_2O_{5\ 175}K_2O_{140}B$ S)	5.57	5.84	5.77	0.59	0.61	0.55
T12($N_{140}P_2O_{5\ 175}K_2O_{140}$ S)	5.74	5.92	5.79	0.59	0.61	0.60
T13 ($N_{140}P_2O_{5\ 140}K_2O_{112}B$ S)	5.93	6.08	5.67	0.57	0.59	0.62
T14 ($N_{105}P_2O_{5\ 105}K_2O_{84}B$ S)	5.56	6.07	5.73	0.52	0.58	0.61
T15 ($N_{60}P_2O_{5\ 20}K_2O_{20}$)	5.73	6.46	5.71	0.36	0.41	0.51
T16 ($N_{80}P_2O_{5\ 40}K_2O_{40}$)	5.82	6.11	5.78	0.57	0.60	0.58
CD(P =0.05)	NS	NS	NS	NS	NS	NS

* Values followed by common letters do not differ significantly

Table 5. Effects of different treatments on available nitrogen (kg ha^{-1}), available phosphorus (kg ha^{-1}) and available potassium (kg ha^{-1}) of soil after harvesting of mustard

Treatment	Available nitrogen (kg ha^{-1})			Available phosphorus (kg ha^{-1})			Available potassium (kg ha^{-1})		
	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr
T1 ($N_{105}P_2O_{5\ 175}K_2O_{\ 140}$B S)	84.32 c	87.07 d*	86.82 f	40.13 a	43.11 a	42.75 a	161.63 ab	151.53 a*	150.88 ab
T2 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B S)	119.55 b	122.25 bc	118.63 d	38.46 ab	39.08 abc	38.67 bc	160.07 abc	149.56 a	148.79 ab
T3 ($N_{175}P_2O_{5\ 175}K_2O_{\ 140}$B S)	150.67 a	158.34 a	159.68 a	29.28 bc	33.31 bcde	33.01 de	158.13 abc	148.65 a	148.12 ab
T4 (N_{140} P2$O_{5\ 0}K_2O_{\ 140}$ B S)	122.93 b	125.12 bc	124.01 bc	1.39 d	2.14 g	2.10 j	163.54 a	142.44 a	140.16 ab
T5 ($N_{140}P_2O_{5\ 105}K_2O_{\ 140}$B S)	118.32 b	120.44 bc	118.46 d	27.42 c	28.32 de	27.96 fg	161.79 ab	154.39 a	153.77 a
T6 ($N_{140}P_2O_{5\ 140}K_2O$ 140B S)	118.67 b	122.48 bc	119.25 cd	25.86 c	26.96 e	26.38 g	158.35 abc	153.95 a	153.21 ab
T7 ($N_{140}P_2O_{5\ 175}K_2O_{\ 0}$B S)	117.54 b	126.39 b	125.02 b	28.51 bc	32.46 cde	32.20 de	40.67 g	38.41 e	38.15 ef
T8 ($N_{140}P_2O_{5\ 175}K_2O_{\ 84}$B S)	122.55 b	126.13 b	124.28 b	32.66 abc	35.69 abcd	35.24 cd	101.55 e	98.29 c	97.46 cd
T9 ($N_{140}P_2O_{5\ 175}$ K2O $_{112}$B S)	111.67 b	113.73 c	113.34 e	33.09 abc	35.46 abcd	35.13 cd	128.83 d	12.63 f	12.13 f
T10 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B)	115.34 b	119.39 bc	118.23 d	25.67 c	30.26 de	30.10 ef	152.96 bc	147.89 a	147.53 ab
T11 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B S)	119.65 b	123.77 bc	123.54 bc	38.65 ab	39.71 abc	39.38 ab	150.35 c	144.63 a	142.34 ab
T12($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$ S)	116.30 b	119.35 bc	118.08 de	34.72 abc	41.50 ab	41.36 ab	154.67 abc	148.48 a	148.02 ab
T13 ($N_{140}P_2O_{5\ 140}K_2O_{\ 112}$B S)	112.18 b	115.96 bc	114.29 e	26.03 c	29.06 de	28.55 fg	125.95 d	121.39 b	121.14 bc
T14 ($N_{105}P_2O_{5\ 105}K_2O_{\ 84}$B S)	85.75 c	89.10 d	88.61 f	28.03 c	33.52 bcde	33.09 de	100.84 e	95.65 c	95.33 cd
T15 ($N_{60}P_2O_{5\ 20}K_2O_{\ 20}$)	44.56 e	49.57 f	48.37 h	2.43 d	7.17 g	6.95 i	56.67 f	59.64 d	58.02 f
T16 ($N_{80}P_2O_{5\ 40}K_2O_{\ 40}$)	59.07 d	65.32 e	64.14 g	10.04 d	18.64 f	18.11 h	364 k	244 m	240 k
CD(P =0.05)	13.52	11.58	4.89	10.18	8.21	3.56	7.14	7.69	8.05

- Values followed by common letters do not differ significantly

Table 6. Effects of different treatments on uptake of nitrogen, phosphorus and potassium by mustard

Treatment	Nitrogen (kg ha^{-1})			Phosphorus (kg ha^{-1})			Potassium (kg ha^{-1})		
	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr
T1 ($N_{105}P_2O_{5\ 175}K_2O_{\ 140}$B S)	129.42 e*	126.88 b	125.62 bc	49.34 d	46.52 d	45.43 d	138.93 e	135.14 d	133.97 d*
T2 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B S)	137.03 bc	135.43 a	134.02 a	58.92 c	54.94 c	53.97 c	154.12 bc	153.29 b	151.63 b
T3 ($N_{175}P_2O_{5\ 175}K_2O_{\ 140}$B S)	115.96 gh	110.47 de	108.59 e	42.53 fg	39.02 f	38.46 ef	99.64 h	93.47 g	92.14 g
T4 (N_{140} P2$O_{5\ 0}K_2O_{\ 140}$ B S)	89.02 l	87.98 g	85.14 j	13.67 k	12.88 j	13.02 j	69.52 k	67.15 j	65.94 j
T5 ($N_{140}P_2O_{5\ 105}K_2O_{\ 140}$B S)	130.53 de	126.42 b	125.34 c	51.05 d	47.95 d	45.84 d	143.29 d	136.56 d	134.18 d
T6 ($N_{140}P_2O_{5\ 140}K_2O$ 140B S)	123.29 f	115.61 c	114.22 d	44.28 ef	42.64 e	40.94 e	132.75 f	129.67 e	128.87 e
T7 ($N_{140}P_2O_{5\ 175}K_2O_{\ 0}$B S)	100.52 j	97.34 f	95.21 h	32.97 h	30.19 g	25.14 h	61.62 l	59.54 k	57.05 k
T8 ($N_{140}P_2O_{5\ 175}K_2O_{\ 84}$B S)	134.15 cd	128.93 b	127.55 b	59.62 c	56.35 c	55.47 c	150.63 c	144.93 c	143.15 c
T9 ($N_{140}P_2O_{5\ 175}$ K2O $_{112}$B S)	142.76 a	137.56 a	135.42 a	76.38 a	73.42 a	71.55 a	166.97 a	163.62 a	162.51 a
T10 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B)	118.54 g	111.44 d	110.36 e	45.89 e	42.97 e	41.05 e	117.64 g	113.94 f	112.66 f
T11 ($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$B S)	132.37 de	125.93 b	125.16 c	57.3 c	54.64 c	53.62 c	146.28 d	142.1 c	141.92 c
T12($N_{140}P_2O_{5\ 175}K_2O_{\ 140}$ S)	113.65 hi	109.75 de	108.12 f	40.62 g	38.99 f	37.55 f	91.42 i	88.89 h	86.55 h
T13 ($N_{140}P_2O_{5\ 140}K_2O_{\ 112}$B S)	140.17 ab	136.07 a	134.19 a	65.77 b	61.47 b	60.52 b	157.1 b	154.26 b	152.96 b
T14 ($N_{105}P_2O_{5\ 105}K_2O_{\ 84}$B S)	110.74 i	107.13 e	97.62 g	33.09 h	32.05 g	31.67 g	83.97 j	81.57 i	80.10 i
T15 ($N_{60}P_2O_{5\ 20}K_2O_{\ 20}$)	90.96 k	89.02 g	87.32 i	20.14 j	19.17 i	18.69 i	64.16 l	61.68 k	59.37 k
T16 ($N_{80}P_2O_{5\ 40}K_2O_{\ 40}$)	101.62 j	98.54 f	97.13 gh	28.32 i	26.29 h	25.02 h	69.62 k	67.05 j	65.13 j
CD(P =0.05)	3.92	3.75	1.98	3.28	3.36	3.10	4.02	3.87	3.60

- Values followed by common letters do not differ significantly

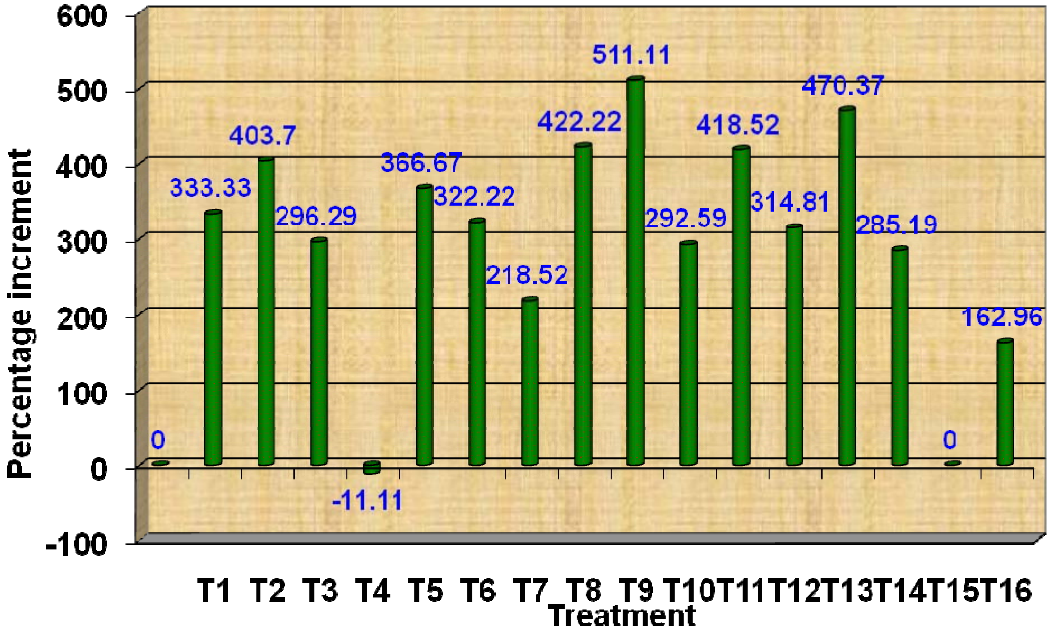

Fig. 1: Percentage increment in yield of mustard over farmers' practice (average of three years)

CONCLUSION AND RECOMMENDATION

The study revealed that yield target based balanced adequate use of different nutrients constitutes the key for increasing the productivity levels of mustard of the rice-mustard-sesame cropping system under red and lateritic soils. While applying the nutrients in balanced manner, due care should be exercised to use the fertilizers at adequate amount so that the doses of the nutrients can sustain the expected yield levels of the crops. In addition, the behaviours and efficiency levels of different fertilizers in a particular soil should also be given due importance.

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