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Yield and Micro Nutrient Uptake of Rapeseed (*Brassica campestris* var. *toria*) under Graded Doses of Rock Phosphate and Single super Phosphate in Acidic Soils

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ABSTRACT: In acidic soils, efficiency of applied phosphatic fertilizer is relatively poor due to P fixation. The availability of P also depends on the sources of applied P. The direct application of rock phosphate (RP) as a source of P may be helpful in acidic P fixing soils. It is a source of not only P, but also of many micro nutrients like iron, copper and zinc. Therefore, a pot culture experiment was carried out in winter season of 2016-17 to investigate the influence of graded doses of rock phosphate and single super phosphate in six graded doses i.e. 0, 30, 60, 90, 120 and 150 mg P kg^{-1} soil on yield and micro nutrient uptake of rapeseed cv. M-27 in Alfisol and Inceptisol of Meghalaya. The trial was laid out in completely randomized design with three replications. The maximum mean dry matter yield of rapeseed was recorded 16.1 g pot^{-1} with 120 mg P kg^{-1} of soil. The dry matter yield obtained with RP was of lower degree in comparison to SSP at all levels of P irrespective of different acidic soils. The uptake of micronutrients *viz.* Fe, Cu, Zn and Mn increased up to 90 mg P kg^{-1} soil and thereafter decreased. The uptake of micro nutrients by rapeseed was of lower order in Alfisol with RP compared with SSP. Hence, farmers of Meghalaya may be advised to apply 90 mg of P kg^{-1} of soil with SSP for getting higher yield of mustard in Alfisol and Inceptisol.

Keywords: Phosphorus, sources, rapeseed, acidic soils, yield and micro nutrient uptake.

INTRODUCTION

Out of total cultivated area of North Eastern Hill (NEH) region, about 81 percent (%) soils are acidic in reaction (Sharma *et al.*, 2006, Singh and Sanjay-Swami, 2020). Acidic soils limit phosphorus (P) availability to the crops because these soils exhibit tendency to fix P in the form of iron and aluminium phosphate (Sanjay-Swami, 2021). Sufficient supply of P, based on accurate assessment of soil P, is therefore critical for getting better crop productivity in the NEH region (Singh *et al.*, 2014, Tamang and Sanjay-Swami, 2021, Satya and Sanjay-Swami, 2021). P is essential for energy transformation, especially in oilseed crops and ultimately, improves the oil percentage (Fohse *et al.*, 1991, Sanjay-Swami, 2019). Application of P not only affects its own absorption and assimilation in plants but also influence a number of other essential elements present in the soil.

Meghalaya is one of the agriculturally important states of NEH region where 99% soils fall under acidic category (Sanjay-Swami and Maurya, 2018). Rapeseed in Meghalaya is cultivated on an area of 9720 ha with production of 9270 tones and productivity of 9.5 q ha^{-1}. The availability of oil in Meghalaya, per day per capita, is just 8.0 g that is moderate compared to the national requirement (Sanjay-Swami *et al.*, 2019). In acidic soils, efficiency of applied P fertilizer is relatively low, mainly because plant roots are incapable to grow and function to their full extent in utilizing the soil available nutrient. There are reports in literature that availability of P also depends on the sources of P. Rock phosphate (RP) has been revealed to be an effective P fertilizer on low pH soils with plenty rainfall, which is regular to the tropics (Chien, 1982). RP, the prime source of P in phosphatic fertilizers is one of the world's most important mineral resources. The direct application of RP as a source of P has been found helpful in acidic P fixing soils, particularly for long duration crops. It is a source of not only P, but also of other critical nutrients like calcium, magnesium, sulphur, iron, copper and zinc (Rajan and Marwaha, 1993). Several studies have been concerned with the primary reactions of single super phosphate (SSP) in soil and the issues that manage the amounts of plant available P from SSP over time. Contrary to this, only few studies investigated the reasons that influence the initial dissolution and quantity of plant-available P in soil from rock phosphate (RP). A better understanding of reaction of RP materials in acidic soils may be useful in assessing RP material for best advantage. Therefore, the present investigation was carried out to find out optimal dose and source of P application in Alfisol and Inceptisol of Meghalaya for higher productivity and micro nutrient uptake in rapeseed.

MATERIAL AND METHODS

A trial was conducted in pots at School of Natural Resource Management, College of Post-Graduate Studies in Agricultural Sciences, Central Agricultural University, Barapani, Meghalaya in winter season of 2016-17. The trial was comprised of twenty four treatments *viz.*, two types of acidic soil namely Alfisol and Inceptisol, two P sources i.e. single super phosphate and rock phosphate, and six levels of P i.e. 0, 30, 60, 90, 120 and 150 mg kg^{-1} of soil. Rapeseed (cv. M-27) was cultivated as test crop. The trial was laid out in completely randomized design with three replications.

Two bulk acidic soil samples were collected from Bhoirymbong (Alfisol) and Umiam (Inceptisol) villages in Ri-Bhoi district, Meghalaya from surface (0 to 15 cm soil depth). The collected soil samples were dried and ground to pass through 2 mm sieve to remove foreign materials for conducting pot culture trial. The collected soils were analyzed in laboratory for estimation of physio-chemical properties using standard methods as indicated against each parameter (Table 1).

Table 1: Physio-chemical properties of experimental soils.

Parameters	Alfisol	Inceptisol	Methods
Soil texture	Sandy loam	Sandy clay loam	International pipette method (Olmstead *et al.*, 1930)
pH	4.86	5.02	pH meter with glass electrode (Piper, 1966)
Organic carbon (%)	1.1	1.3	Rapid titration method (Walkley and Black, 1934)
CEC (meq100 g $soil^{-1}$)	2.8	3.7	Ammonium acetate saturation method (Jackson, 1973)
Available Nitrogen (kg ha^{-1})	275.0	350.0	Alkaline potassium permanganate method (Subbiah and Asijah, 1956)
Available Phosphorus (kg ha^{-1})	8.0	13.0	Bray and Kurtz No. 1 method (Bray and Kurtz, 1945)
Available Potassium (kg ha^{-1})	259.8	280.0	Neutral Normal Ammonium Acetate Method (Knudsen *et al.*, 1982)
Available Sulphur (kg ha^{-1})	14.3	18.5	$CaCl_2$-extractable S (Chesnin and Yien, 1951)

Available micronutrients (mg kg^{-1} soil)	Fe	Cu	Zn	Mn	Fe	Cu	Zn	Mn	DTPA Method (Lindsay and Norvell, 1978)
	12.32	2.10	0.53	3.00	9.81	2.50	0.61	3.45	

The P doses were given through single super phosphate (SSP) and rock phosphate (RP) according to the treatments and posts were placed in poly house. The seeds of rapeseed cv. M-27 were purchased from ICAR Research Complex for NEH Region, Barapani, Meghalaya. The sowing of the crop was done on 5^{th} November, 2016 and it was harvested at physiological maturity stage on 24^{th} January, 2017 and dry matter yield was measured. The plant samples were also collected from each pot for testing of micro nutrients *viz.*, Fe, Cu, Zn and Mn following the standard methods as outlined by Jackson (1973). The plant samples were oven dried, grinded with grinder and kept individually in sealed and labelled containers. Only 0.5 g oven dried and powered plant samples were digested in di-acid mixture (HNO_3 + $HClO_4$) in 5:2 ratio until the clear solution appears. The concentration of micro nutrients in the digested plant samples were determined using atomic absorption spectrophotometer (AAS) and expressed in mg kg^{-1}. The uptake of Fe, Cu, Zn and Mn by rapeseed was obtained by multiplying dry matter yield and concentration of respective micro nutrient and expressed as µg pot^{-1}.

The data acquired from the trial were administered to statistical analysis (ANOVA) and the significant difference was obtained at 5 per cent level of significance (Fisher, 1958).

RESULTS AND DISCUSSION

A. Dry matter yield

The mean dry matter yield of rapeseed improved significantly with the escalating levels of P up to 90 mg of P kg^{-1} soil though, the maximum mean dry matter yield (16.1 g pot^{-1}) was obtained with 120 mg of P kg^{-1} of soil. Subsequent increase in P dose by 150 mg P kg^{-1} soil significantly reduced the dry matter yield by 4.6 per cent above 120 mg of P kg^{-1}. The dry matter yield obtained with RP was of lower degree in comparison to SSP at all levels of P irrespective of different acidic soils. Among different two ways and three way interactions, all interactions were observed to be significant. This massive response in the dry matter yield of rapeseed with applied P was due to low available P category of the soil under trial. It indicated that the optimal mean dry matter yield observed with 90 mg P kg^{-1} soil was 2.44 times more than the control pots. It also indicated the high degree of responsiveness of rapeseed crop to phosphorus fertilization. The results of dry matter yield observed in the present investigation are in agreement with the results observed by Singh and Bishnoi (1994) and Yousaf *et al.*, (2017) who stated that phosphorus application to the soil, varying from low to high in available P, augmented dry matter yield of sunflower and rapeseed, respectively.

The interaction between diverse levels of applied phosphorus and different rapeseed growing acidic soils of Meghalaya was significant in dry matter yield. It described the phosphorus deficiency of acidic soils and high response of P application in rapeseed. The results obtained in the present trial are in conformity with the results depicted by Tyagi and Rana (1992) that with applied P fertilizer, the yield of mustard crop significantly improved up to 80 kg P_2O_5 ha^{-1} which was at par with 100 kg P_2O_5 ha^{-1}. Results in the same line were also observed in sunflower crop by Prabhuraj *et al.*, (1993).

B. Iron concentration

The data presented in Table 3 depicted that overall mean value of Fe concentration decreased significantly with the rising levels of applied P in soil ranging from 375.2 mg kg^{-1} in control to 241.0 mg kg^{-1} with 150 mg P kg^{-1} soil level. The concentration of Fe in plants grown in acidic soils of Meghalaya significantly differed among themselves. The overall mean Fe concentration was recorded to be the highest (385 mg Fe kg^{-1}) through SSP over the RP (384 mg kg^{-1}).

A critical analysis of Fe concentration data revealed that the soils x P levels interaction were non-significant. Fe concentration was found to be highest in control through SSP i.e. 385 mg kg^{-1} and 370 mg kg^{-1}, whereas through RP i.e. 384 mg kg^{-1} and 362 mg kg^{-1} soil in Inceptisol and Alfisol, respectively. However, the Fe concentration decreased from 362 to 230 and 384 to 245 under RP in Alfisol and Inceptisol, respectively, whereas under SSP, it ranges from 370 to 235 and 385 to 354 mg kg^{-1} in Alfisol and Inceptisol, respectively, with the application of 0 to 150 mg P kg^{-1} soil. The mean Fe concentration through SSP was recorded (316.58 mg kg^{-1}) over the RP (310.42 mg kg^{-1}). The decrease in Fe concentration with increasing levels of P in soil might be due to the formation of insoluble Fe-phosphate in soil and thereby reducing the availability of Fe in soil for its absorption by crop.

Table 2: Dry matter yield of rapeseed (g pot^{-1}) as influenced by P sources and levels in acidic soils of Meghalaya.

P levels mg kg^{-1} soil	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	5.57	6.00	7.02	7.20	6.45
30	9.34	10.30	10.77	11.89	10.58
60	12.12	13.20	14.14	15.61	13.77
90	14.21	15.00	16.13	17.68	15.76
120	14.44	15.20	17.02	17.81	16.11
150	14.12	14.90	15.80	16.65	15.37
RP	12.56	Alfisol	12.03		
SSP	13.45	Inceptisol	13.98		
S.E(m)±	0.14				
CD (p=0.05)	0.39				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	0.08	0.11	0.19	0.19	0.28
CD (p=0.05)	0.23	0.32	0.55	0.55	0.78

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

Table 3: Fe concentration (mg kg^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	362	370	384	385	375.2
30	345	351	356	360	353.0
60	316	325	340	345	331.5
90	302	308	300	309	304.8
120	265	270	280	287	275.5
150	230	235	245	254	241.0
RP	310.42	Alfisol	306.58		
SSP	316.58	Inceptisol	320.42		
S.E(m)±	2.88				
CD (p=0.05)	8.18				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	1.66	2.35	4.07	4.07	5.76
CD (p=0.05)	4.72	6.68	11.57	11.57	16.36

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

Similar results were obtained by Adriano *et al.*, (1971) who observed that Fe concentration in seedling shoots of corn crop were depressed by the high P levels.

The concentration of Fe in plants grown in different rapeseed growing acidic soils of Meghalaya significantly differed among themselves. Srinivasarao *et al.*, (2007) also observed decrease in the concentration of Fe with the increase in the application of P levels.

C. Iron uptake

The mean Fe uptake increased from control i.e. 2426.94 µg pot^{-1} to 4804.10 µg Fe pot^{-1} with the application of 90 mg P kg^{-1} soil and then decreased with increased P (Table 4). The Fe uptake significantly differed in different sources of applied P. The highest Fe uptake (5463.84 µg pot^{-1}) was found at 90 mg P kg^{-1} soil through SSP over RP while the lowest uptake (2016.74 µg pot^{-1}) was obtained through RP. It is also evident that the Fe uptake (µg pot^{-1}) increased with increasing P level through SSP over RP in both the soils. A comparative study on both the soil reveals that the Fe uptake was always higher in Inceptisol by both P sources over Alfisol. The lowest mean value of Fe uptake was in Alfisol i.e. 2016.74 µg pot^{-1}) in control and highest (4293.33 µg pot^{-1}) by RP whereas, through SSP (2222.77 µg pot^{-1}) uptake was found in control and the highest value (4618.94 µg pot^{-1}) was obtained in 90 mg kg^{-1} application of P. The uptake of Fe increased significantly with increasing levels of applied P up to 30, 60 and 90 mg P kg^{-1} soil in Alfisol and Inceptisol, respectively. However, the interaction between soil and phosphorus was significant. The mean of Fe uptake higher with the sources of P by SSP (4133.67 µg Fe pot^{-1}) compared to RP (3770.97 µg Fe pot^{-1}), whereas in Inceptisol (4339.45 µg Fe pot^{-1}) compared to Alfisol (3565.19 µg Fe pot^{-1}).

Table 4: Fe uptake (µg pot^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	2016.74	2222.77	2695.87	2772.39	2426.94
30	3219.54	3611.88	3834.23	4284.53	3737.54
60	3829.36	4289.39	4809.04	5388.67	4579.12
90	4293.33	4618.94	4840.30	5463.84	4804.10
120	3825.42	4103.66	4767.55	5111.66	4452.07
150	3246.87	3504.43	3873.43	4231.85	3714.15
RP	3770.97	Alfisol	3565.19		
SSP	4133.67	Inceptisol	4339.45		
S.E(m)±	66.50				
CD (p=0.05)	189.06				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	38.39	54.30	94.04	94.04	133.00
CD (p=0.05)	109.15	154.37	267.37	267.37	378.12

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

The increase in uptake of Fe might be due to increased dry matter yield of rapeseed crop with increasing P levels in soil. However, Fe uptake decreased significantly at higher levels of applied P as dry matter production of rapeseed was also retarded at higher levels of applied P fertilizer. The Fe uptake significantly differed in different acidic soils of Meghalaya. The least mean value of Fe uptake was in Alfisol and it increased in Inceptisol, respectively. These variations in Fe uptake in different soils followed the trend of dry matter yield produced in these soils. The uptake of Fe improved significantly with rising levels of applied P up to 90 and 150 mg P kg^{-1} soil in Inceptisol and Alfisol, respectively. In Alfisol, the uptake of Fe increased by 1.6 and 1.5 times in RP and SSP, respectively whereas in case of Inceptisol the uptake increased by 1.45 times in RP and 1.5 times in SSP, over control. The uptake of Fe was significantly retarded at higher levels of applied P. Increase in Fe uptake with applied P was also reported by Ismail *et al.*, (1986) in tomato plants.

D. Copper concentration

The effect of P sources and levels on Cu concentration in rapeseed growing acidic soils is presented in Table 5. The mean Cu concentration decreased significantly with the rising levels of P up to 90 mg of P kg^{-1} soil though, the highest Cu concentration of rapeseed (11.21 mg kg^{-1}) was observed in control. The further increase in the doses of P application from 120 mg of P kg^{-1} to 150 mg P kg^{-1} soil significantly decreased the Cu concentration by 1.12 times. All the interactions among different two way and three way interactions were observed to be significant. The Cu concentration of rapeseed differed significantly among different types of soils. A critical examination of Cu concentration data in Table 5 in different soils at various levels of applied P exposed that the Cu concentration formed at every respective levels of P was superior in Inceptisol followed by Alfisol. The Inceptisol has produced significant advanced amount of Cu concentration as compared to Alfisol irrespective of P sources.

Table 5: Cu concentration (mg kg^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	10.21	10.40	12.01	12.23	11.21
30	8.34	8.45	10.00	10.22	9.25
60	7.58	7.61	8.62	9.34	8.29
90	6.89	7.01	7.01	7.50	7.10
120	6.66	6.83	6.34	6.57	6.60
150	5.56	5.72	5.99	6.18	5.86
RP	7.93	Alfisol	7.60		
SSP	8.17	Inceptisol	8.50		
S.E(m)±	0.26				
CD (p=0.05)	0.74				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	0.15	0.21	0.37	0.37	0.52
CD (p=0.05)	0.43	0.60	1.04	1.04	1.48

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

The uppermost Cu assimilation (12.23 mg pot^{-1}) was recorded in Inceptisol within the control under SSP, whereas the lowest Cu concentration (5.56 mg pot^{-1}) was recorded in Alfisol with highest dose of P application under RP. Similarly, significant difference in Cu concentration of rapeseed was found between the two sources of P irrespective of the soil nature. In Alfisol, the SSP has produced 0.40 per cent higher Fe concentration over RP in (60 mg kg^{-1} soil) whereas, in Inceptisol SSP has produced 8.35 per cent higher Cu concentration in (60 mg kg^{-1} soil).

Significant decrease in mean Cu concentration in rapeseed with increased P application might be due to lower absorption of Cu by the plants due to formation of sparingly soluble complexes of copper phosphate in soil. Gupta *et al.*, (1987) had earlier also observed that the application of P decreased the Cu content in shoot and leaves of pigeon pea crop in a pot culture experiment. The relative lower Cu concentration in different rapeseed growing acidic soils of Meghalaya might be due to the competition between Cu and the respective nutrients present in these two soils for getting absorbed by the plant and also a root-shoot junction for metabolically being utilized by plants.

E. Copper uptake

The consequence of P sources and levels on Cu uptake of rapeseed growing acidic soils presented in Table 6. The mean plant Cu uptake lowered significantly with the raising levels of P up to 150 mg P kg^{-1} soil. On the other hand, the highest mean Cu uptake of rapeseed (114.99 µg pot^{-1}) was observed with the applied P at the rate of 60 mg kg^{-1} soil. All the interactions among various two way and three way interactions were observed to be significant. The Cu uptake of rapeseed differed significantly among different types of soil data are presented in Table 4.7 in different soils at various levels of applied P showing that the Cu uptake at each respective levels of P was the higher in Inceptisol followed by Alfisol.

Table 6: Cu uptake (µg pot^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	56.86	62.49	84.32	86.40	72.52
30	77.98	86.97	107.60	121.82	98.59
60	91.85	100.41	121.84	145.85	114.99
90	97.96	105.09	113.02	132.64	112.18
120	96.22	103.71	107.84	116.96	106.18
150	78.45	85.25	94.67	102.90	90.32
RP	94.05	Alfisol	86.94		
SSP	104.21	Inceptisol	111.32		
S.E(m)±	2.26				
CD (p=0.05)	6.41				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	1.30	1.84	3.19	3.19	4.51
CD (p=0.05)	3.70	5.24	9.07	9.07	12.83

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

The Inceptisol has produced significant higher extent of Cu uptake as compared to Alfisol irrespective of P sources. The maximum Cu uptake (145.85 µg pot^{-1}) was recorded in Inceptisol with (60 mg kg^{-1}) soil under SSP, whereas the lowest Cu uptake (56.86 µg pot^{-1}) was recorded in Alfisol with control under RP. Similarly, major difference in Cu accumulation of rapeseed was found between the two sources of P irrespective of the soil type. In Alfisol, the SSP has produced 9.90 per cent least Cu uptake over RP in control, whereas in Inceptisol SSP has produced 2.47 per cent least Cu uptake in lowest application of P in control, while the higher Cu uptake 19.71 times in (60 mg kg^{-1} soil) by SSP in Inceptisol over the 9.32 per cent in (60 mg kg^{-1} soil) through SSP in Alfisol.

It may be inferred from the data in Table 6 that mean Cu uptake significantly increased with the successive increasing levels of applied up to 60 mg P kg^{-1} soil treatment. This increase in Cu uptake might be due to increase in dry matter yield of rapeseed with increase in applied P levels in soil. However, Cu uptake decreased significantly and subsequently with the addition of 90, 120 and 150 mg P kg^{-1} soil which might be due to decrease in dry matter yield of rapeseed at higher levels of applied P. Safaya (1976) also reported that although uptake of Cu increased with the increasing P levels in soil but high levels of P reduced the Cu uptake in corn plants. The maximum Cu uptake was observed in Inceptisol soil which was significantly higher than that recorded in Alfisol. This decrease in Cu uptake in these two types of soils might be due to lesser concentration of Cu.

F. Zinc concentration

The mean concentration of Zn decreased with the increase in the applied P levels (Table 7). This decreased Zn concentration might be due to formation of Zn-phosphate in soil, which is insoluble in nature. Similar results were also reported by Chahal and Ahluwalia (1977) who observed that the application of P reduced Zn concentration of stem, leaves, kernel and shell of groundnut. The mean concentration of Zn in rapeseed plants differed significantly among two rapeseed growing acidic soils of Meghalaya. The mean Zn concentration was recorded as the highest in Inceptisol soil followed by Alfisol. The data revealed that the soil x P levels interaction in Zn concentration was significant. A gradual decrease in Zn concentration was observed with the application of P in both types of soils, although the pattern of decrease in Zn content varied among them. The values of Zn content in rapeseed plants in control where no P was applied were i.e. in Alfisol under RP 1.33 times SSP 2.5 times higher while, in Inceptisol under RP 2.0 times and SSP 1.94 times in comparison to the values recorded with the application of 150 mg P kg^{-1} soil, respectively.

Table 7: Zn concentration (mg kg^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	86.34	87.01	97.24	98.11	92.18
30	68.41	70.11	87.44	89.31	78.82
60	54.44	56.02	79.34	80.26	67.51
90	45.37	46.34	65.30	66.40	55.85
120	38.48	42.43	56.38	58.41	48.92
150	30.66	33.56	48.60	50.34	40.79
RP	63.17	Alfisol	54.93		
SSP	64.86	Inceptisol	73.09		
S.E(m)±	0.53				
CD (p=0.05)	1.50				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	0.30	0.43	0.74	0.74	1.05
CD (p=0.05)	0.86	1.22	2.12	2.12	2.99

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

G. Zinc uptake

The mean plant Zn uptake decreased significantly with the escalating levels of P up to 90 mg P kg^{-1} soil though, the highest mean Zn uptake of rapeseed i.e. 943.82 µg pot^{-1} was recorded with the application of 90 mg P kg^{-1} soil (Table 8). The additional increase in the dose of P up to 150 mg P kg^{-1} soil significantly increased the Zn uptake by 49.03 per cent over 90 mg P kg^{-1}. All the interactions among various two way and three way interactions were observed to be significant. The Zn uptake of rapeseed differed significantly among different types of soils data are given in Table 8 in dissimilar soils at various levels of applied P exposed that the Zn uptake at each respective levels of P was higher in Inceptisol compared to Alfisol. The Inceptisol has produced significant higher quantity of Zn uptake as compared to Alfisol irrespective of P sources. The maximum Zn uptake (1253.25 µg pot^{-1}) was recorded in Inceptisol with 60 mg kg^{-1} soil under SSP, whereas the lowest Zn uptake (432.75 µg pot^{-1}) was observed in Alfisol with highest dose of P application under RP. Similarly, major difference in Zn uptake of rapeseed was found between the two sources of P irrespective of the soil type. In Alfisol, the SSP has produced 16.15 per cent higher Zn uptake over RP in 120 mg kg^{-1} soil P application whereas, in Inceptisol SSP has produced 8.33 per cent Zn uptake in P application (120 mg kg^{-1} soil) while the least Zn uptake 7.69 per cent in P application of 90 mg kg^{-1} soil by SSP in Alfisol over the 11.38 per cent (90 mg kg^{-1} soil) through SSP in Inceptisol. Zn uptake by rapeseed crop in each soil differed significantly. The mean Zn uptake was the highest in Inceptisol through SSP (706.77 µg pot^{-1}) in control over the RP (682.69 µg pot^{-1}) which was followed by Alfisol by SSP (522.39 µg pot^{-1}) compared to RP (480.68 µg pot^{-1}), respectively. The Zn uptake increased significantly up to 30, 60 and 90 mg P kg^{-1} in both soils, respectively.

Table 8: Zn uptake (µg pot^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	**SSP**	**RP**	**SSP**	
0	480.68	522.39	682.69	706.77	598.13
30	639.01	722.07	941.28	1063.17	841.38
60	659.63	740.05	1122.36	1253.25	943.82
90	644.91	694.52	1053.23	1173.08	891.44
120	555.44	645.16	959.91	1039.86	800.09
150	432.75	500.32	768.16	838.67	634.98
RP	745.00	Alfisol	603.08		
SSP	829.94	Inceptisol	966.87		
S.E(m)±	13.25				
CD (p=0.05)	37.67				
For Source of P and Soils		**Interaction**			
		S x So	**S x L**	**So x P**	**S x So x L**
S.E(m)±	7.65	10.82	18.74	18.74	26.50
CD (p=0.05)	21.75	30.76	53.27	53.27	75.34

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

The increase in Zn uptake might be due to the increase in dry matter yield of rapeseed with increasing P levels in soils. However Zn uptake decreased significantly at higher levels of applied P might be due to decrease in dry matter yield of rapeseed at those higher P levels, nevertheless, the Zn content had reduced with the application of P. Takkar *et al.*, (1976) indicated that the increasing levels of P increased the Zn uptake of maize plant but higher levels of P reduced Zn uptake of plants. Zn uptake by rapeseed crop in each soil differed significantly. The mean Zn uptake was the highest in Inceptisol soil, which was over the Alfisol. This significant decrease in Zn uptake in both soils through both the P sources of P might be due to lesser concentration of Zn and also lesser amount of dry matter yield of rapeseed obtained in the two rapeseed growing soils of Meghalaya.

H. Manganese concentration

The mean concentration of Mn in rapeseed plants differed significantly among two rapeseed growing acidic soils of Meghalaya (Table 9). The Inceptisol has twisted higher quantity of Mn concentration as compared to Alfisol irrespective of P sources. The highest Mn concentration (32.03 mg kg^{-1}) was observed in Inceptisol with control under SSP, whereas the lowest Mn concentration (18.21 g pot^{-1}) was recorded in Alfisol with highest dose of P application through RP (150 mg kg^{-1} soil). Similarly, major difference in Mn concentration of rapeseed was found between the two sources of P irrespective of the soil type. In Alfisol, the SSP has produced 15.65 per cent higher Mn concentration over RP in (150 mg kg^{-1} soil) whereas, in Inceptisol SSP has produced 8.6 per cent Mn in 150 mg kg^{-1} soil) while the lest Mn concentration 3.12 per cent in (30 mg kg^{-1} soil) by RP in Alfisol over the 6.26 per cent in (30 mg kg^{-1} soil) through SSP in Inceptisol.

The data presented in Table 9 revealed that the soil x P levels interaction in Mn concentration was non-significant. A gradual decrease in Mn concentration was observed with the application of P in two rapeseed growing acidic soils of Meghalaya, although the pattern of decrease in Mn content varied. Similar results were found by Halder and Mandal (1981) who also observed that application of phosphorus caused a decrease in the concentration of manganese.

I. Manganese uptake

The mean value of Mn uptake significantly and subsequently increased with the increasing levels of applied P up to 90 mg P kg^{-1} soil level (Table 10). This increase in Mn uptake might be due to the increase in dry matter yield of rapeseed with increasing P levels in soils. However, Mn uptake decreased significantly at higher levels of applied P due to decrease in dry matter yield of rapeseed at those higher P levels, nevertheless, the Mn content had reduced with the application of P. Mn uptake by rapeseed crop in each soil differed significantly. The mean Mn uptake was the highest in Inceptisol through the P source of SSP, which was greater P application by SSP in Alfisol. This significant decrease in Mn uptake in Inceptisol with fertilization through SSP (90, 120 and 150 mg P kg^{-1} soil) in Inceptisol and over Alfisol respectively might be due to lesser concentration of Mn and also lesser amount of dry matter yield of rapeseed obtained in the two rapeseed growing acidic soils of Meghalaya.

Table 9: Mn concentration (mg kg^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	28.34	30.20	31.11	32.03	30.42
30	26.32	27.14	29.07	30.89	28.35
60	24.42	25.56	27.33	29.65	26.74
90	21.41	22.89	26.55	28.03	24.72
120	19.24	21.00	25.43	27.81	23.37
150	18.21	21.06	24.30	26.39	22.49
RP	25.14	Alfisol	23.82		
SSP	26.89	Inceptisol	28.22		
S.E(m)±	0.39				
CD (p=0.05)	1.12				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	0.23	0.32	0.56	0.56	0.79
CD (p=0.05)	0.65	0.91	1.58	1.58	2.23

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

Table 10: Mn uptake (μg pot^{-1}) in rapeseed as influenced by P sources and levels in acidic soils of Meghalaya.

P levels	Alfisol		Inceptisol		Mean
	RP	SSP	RP	SSP	
0	157.83	181.45	186.84	230.88	189.25
30	245.81	279.11	298.93	367.66	297.88
60	295.84	337.11	361.49	463.53	364.49
90	304.33	343.66	397.95	495.63	385.39
120	277.77	318.99	386.79	494.93	369.62
150	257.10	313.75	361.83	439.72	343.10
RP	294.38	Alfisol	276.06		
SSP	355.53	Inceptisol	373.85		
S.E(m)±	6.38				
CD (p=0.05)	18.13				
For Source of P and Soils		Interaction			
		S x So	S x L	So x P	S x So x L
S.E(m)±	3.68	5.21	9.02	9.02	12.75
CD (p=0.05)	10.47	14.80	25.63	25.63	36.25

RP: Rock Phosphate, SSP: Single Super Phosphate, S: Sources of P, So: Soils, L: Levels of P

The Mn uptake increased significantly up to 0, 30, 60 and 90 mg P kg^{-1} in Inceptisol and Alfisol, respectively. Khan and Zende (1976) reported that the application of P significantly increased P, Mg and Mn contents and slightly increased N contents in maize and wheat crops.

CONCLUSION

The application of P at lower levels resulted in significant increase in dry matter yield of rapeseed under both the P sources in Alfisol and Inceptisol of Meghalaya. The dry matter yield produced with RP was of lower order as compared to SSP at each levels of applied P irrespective of soil. The concentration of micronutrients *viz.* Fe, Cu, Zn and Mn in rapeseed decreased with successive application of P from 0-150 mg kg^{-1} in both the acidic soils i.e. Alfisol and Inceptisol, irrespective of sources of applied P, whereas, uptake of these micro nutrients increased up to 90 mg P kg^{-1} soil and thereafter decreased up to the highest level of applied P. The uptake of micro nutrients by rapeseed was observed to be of lower order in Alfisol with RP source of applied P compared with SSP. Therefore, application of 90 mg of P kg^{-1} of soil with SSP may be advised to the farmers of Meghalaya for getting higher yield of mustard in Alfisol and Inceptisol.

FUTURE SCOPE

The future research may be taken up to find out the ways and means for increasing the phosphorus availability through rock phosphate in acidic soils. Use of organics and phosphorus solubilizing microbes would be a welcome approach.

Conflict of Interest. As the manuscript is authored by single author, there is no conflict of interest.

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