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Nagesh R Navghare
PG Student, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

AB Age
Assistant Professor, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

SD Jadhao
Associate Professor, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

OS Rakhonde
Assistant Professor, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

MR Pandao
Ph.D Student, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

Corresponding Author:
Nagesh R Navghare
PG Student, Department of Soil Science and Agricultural Chemistry, PGI, Akola, Maharashtra, India

The impact of different phosphorus levels on soil fertility, yield, phosphorus dynamics, and use efficiency after cotton harvest

Nagesh R Navghare, AB Age, SD Jadhao, OS Rakhonde and MR Pandao

Abstract
The objective of this study was to investigate the impact of different levels of phosphorus on soil fertility, phosphorus use efficiency, and seed cotton and stalk yield after harvest of cotton. The study was conducted at the Research Farm, Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during the kharif season of 2021-2022. The experiment followed a Randomized Block Design with eight treatments replicated three times. The recommended dose of fertilizer 120:60;60 NPK kg ha^{-1} was applied to each treatment. The cotton variety PDKV JKL116 was used for the investigation, and Nano DAP was applied at seed treatment and foliar application at 30 DAS according to the treatments. Soil and plant samples were collected and analyzed using standard procedures. The results showed that the highest seed cotton and stalk yield was recorded with 100% NPK application. Inorganic phosphorus fractions (Ca-P, Al-P, and Fe-P) were significantly higher with 100% NPK, which was comparable to N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS). The highest value of total organic phosphorus was also recorded with 100% NPK, which was comparable to N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS). The highest phosphorus use efficiency was recorded with the application of N50 P50 K100 + Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS). The available nitrogen, phosphorus, and potassium were significantly higher with 100% NPK, which was comparable to N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS). The application of 100% NPK slightly improved pH, EC, OC $CaCO_3$, available S, Zn, Cu, Fe, and Mn.

Keywords: Phosphorus, cotton, vertisol, nano DAP

Introduction
Cotton, derived from the Arabic word "quotn", is a natural fiber crop belonging to the Gossypium genus. This genus includes 52 chromosomes, with G. herbaceum and G. arboreum referred to as old world cotton, and G. hirsutum and G. barbadense as new world cotton. Cotton is a vital crop in the textile and other industries, with its fiber being called the "white gold." It is also a source of vegetable oil, medicine, cosmetic, and animal feed, with its seed cake being rich in oil and protein.

One of the major limiting factors for plant growth is the low availability of phosphorus (P) in the soil. Despite being the second most abundant macronutrient in plants after nitrogen, P has low availability due to slow diffusion and high fixation in soils. Most agricultural soils contain larger amounts of fixed P than available P, with a considerable part accumulating as a result of regular applications of P fertilizers. However, a large proportion of added soluble inorganic phosphate is quickly fixed as insoluble forms, making it unavailable to plants. This low availability of P in the soil to crops is mainly due to fixation by Al, Fe, and Ca in acid and alkaline soils. Additionally, P bioavailability in soil is influenced by various factors such as pH, texture, moisture, lime content, and applied nutrients. The complex chemistry of P in the soil further complicates its availability to plants. (Kothandaraman and Krishnamoorthy, 1979) [9].

Methods and Materials
In 2021-22, a field experiment was carried out at the research farm of the cotton research unit, Dr. PDKV, Akola. The experimental site has a sub-tropical climate with an average maximum high temperature of 37.8 °C and a minimum low temperature of 13.5 °C. The soil was classified as Vertisols belonging to the smectite, hyperthermic family of Typic Haplusterts. It was clay in texture, slightly alkaline in pH (8.12), with an EC of 0.22 dS m^{-1}, and had organic carbon content of 4.72 g kg^{-1}, available N of 174.86 kg ha^{-1}, available P of 12.84 kg ha^{-1}, and

available K of 378.14 kg ha^{-1}. The experiment included eight treatments (T_1-T_8) with three replications in a randomized block design. The treatments were: T_1 as the absolute control, T_2 as N0P0K100 (00:00:60 NPK kg ha^{-1}), T_3 as 100% NPK (120:60:60 NPK kg ha^{-1}), T_4 as 50% NP + 100% K, T_5 as N50 P50 K100 + Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS), T6 as N50 P50 K100 + Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS), T_7 as N75 P75 K100 + Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS), and T_8 as N75 P75 K100 + Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS). The recommended basal dose of fertilizer was applied to the soil using urea, MOP, DAP at sowing, and spraying of 0.2 Nano DAP at 30 DAS sowing. Cotton variety "PDKV JKAL 116 Bt" was sown on July 6, 2021, and picking of cotton was done on December 2, 2021, and January 23, 2022.

After the harvest of cotton, surface (0-15 cm) soil samples were collected from the plots and analyzed for pH, EC, organic carbon (Jackson, 1973) [6], available nitrogen (Subbiah and Asija, 1956) [20], available phosphorus (Olsen, 1954) [17], available potassium (Hanway and Heidel, 1952) [4], available micronutrients (Lindsay and Norvell, 1978) [11], and inorganic P fractions (Peterson and Corey, 1966) [18]. The mean data on various parameters were analyzed statistically using the procedure given by Gomez and Gomez (1984) [3], and the significance of difference between treatment means was determined using least significant difference (LSD) values at P = 0.05 were used to determine the significance of difference between treatment means.

Result and Discussion

Yield

Table 1 shows that the yield of seed cotton and cotton stalks ranged from 8.28 to 16.93 q ha^{-1} and 12.43 to 29.62 q ha^{-1}, respectively. Treatment T3 resulted in the highest yield of both seed and stalks, while treatment T1 had the lowest yield. Compared to the control, treatment best increased the seed cotton and cotton stalk yield by 104.46% and 138.29%, respectively. The increase in yield may be attributed to the application of different levels of phosphorus, which increased the crop's yield-contributing characteristics, along with the application of N and P nutrients at different rates. These findings are consistent with those of Saleem *et al.*, (2010) [19], Khaswa *et al.*, (2014) [8], and Begum *et al.*, (2015) [1].

Phosphorus dynamics

The application of 100% NPK resulted in the highest Ca-P fraction (62.31mg kg^{-1}), which was comparable to the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (59.28 mg kg^{-1}) and N75 P75 K100+ Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS) (58.04 mg kg^{-1}). The Fe-P fraction was significantly highest with the application of 100% NPK (24.48 mg kg^{-1}), which was comparable to the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (21.06 mg kg^{-1}) and N75 P75 K100+ Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS) (20.17 mg kg^{-1}). The Al-P fraction was significantly highest with the application of 100% NPK (22.41 mg kg^{-1}), which was comparable to the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (19.29 mg kg^{-1}) and N75 P75 K100+ Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS) (18.71 mg kg^{-1}). The control plot had the lowest inorganic fractions.

The study showed that the Ca-P fraction was the highest, followed by the Fe-P and Al-P fractions, which could be due to the alkaline pH of the soil. The fixation of phosphate in alkaline soils by calcium is higher than iron and aluminum, and increasing levels of phosphorus application in Vertisols lead to moderately high fixation of phosphorus in alkaline conditions. These findings are consistent with the findings of Murthy *et al.* (2002) [16] and Monika *et al.* (2018) [14]. The study also found a significant effect of various levels of phosphorus on the total organic P after harvest of cotton, which ranged from 23.00 to 35.86 mg kg^{-1}. The application of 100% NPK resulted in the highest total organic phosphorus (35.86 mg kg^{-1}), followed by N75 P75 K100+ Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS) (32.62 mg kg^{-1}) and N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (15.44 mg kg^{-1}). The lowest total organic P was recorded in the control plot. The presence of relatively high levels of organic carbon and inorganic forms of P in the application of 100% NPK may have positively affected the presence of total organic phosphorus. These results are consistent with the findings of Monika *et al.*, (2018) [14].

Table 1: Effect various levels of phosphorus on yield and soil inorganic fractions of P.

Treatments		Yield q ha^{-1}		Inorganic forms of P (mg kg^{-1})		
		Seed	Stalk	Ca-P	Fe-P	Al-P
T1	N0P0K0	8.28	12.43	47.61	12.16	9.81
T2	N0P0K100	9.86	15.18	48.12	13.29	10.44
T3	N100 P100 K100	16.93	29.62	62.31	24.48	22.41
T4	N50 P50 K100	13.95	23.16	51.04	15.34	13.54
T5	T4 + Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2% at 30 DAS)	14.70	24.42	53.64	17.61	15.81
T6	T4 + Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS)	14.63	25.86	54.28	18.69	16.04
T7	N75 P75 K100+ Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2% at 30 DAS)	14.80	26.02	58.04	20.17	18.71
T8	N75 P75 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS)	15.05	26.60	59.28	21.06	19.29
	SE (M) ±	0.60	0.96	2.48	0.78	0.68
	CD at 5%	1.80	2.89	7.47	2.35	2.06

P use efficiency

Table 2 shows that the range of phosphorous use efficiency is between 14.32% and 22.96%. The highest P use efficiency was achieved with the application of N50 P50 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) at 22.96%, followed by N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) at 21.37%. On the other hand, the lowest P use efficiency was observed in the application of 100% NPK. The increase in NPK fertilizer levels resulted in decreased P use efficiency, which may be due to the fact that lower fertilizer applications have the capacity to maximize nutrient utilization, resulting in lower nutrient losses. These findings are consistent with those of Jadhao *et al.*, (2020) [7].

Table 2: Effect various levels of phosphorus on total organic phosphorus, P use efficiency and physio-chemical properties of cotton.

Treatments		Org-P (mg kg^{-1})	P use efficiency %	pH	EC	OC	CaCO3
				(1:2.5)	(dSm^{-1})	(g kg^{-1})	(%)
T1	N0P0K0	8.28	12.43	8.12	0.20	4.78	4.11
T2	N0P0K100	9.86	15.18	8.14	0.21	4.82	4.19
T3	N100 P100 K100	16.93	29.62	8.19	0.28	5.00	4.49
T4	N50 P50 K100	13.95	23.16	8.16	0.25	4.90	4.23
T5	T4 + Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2%at 30 DAS)	14.70	24.42	8.16	0.25	4.90	4.07
T6	T4 + Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2%at 30 DAS)	14.63	25.86	8.16	0.25	4.93	4.18
T7	N75 P75 K100+ Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2%at 30 DAS)	14.80	26.02	8.15	0.27	4.97	4.21
T8	N75 P75 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2%at 30 DAS)	15.05	26.60	8.18	0.28	4.98	4.26
	SE (M) ±	0.60	0.96	0.028	0.027	0.076	0.43
	CD at 5%	1.80	2.89	NS	NS	NS	NS

Physico-chemical Properties

According to table 2, the soil p^{H} ranged from 8.12 to 8.19, with the highest pH recorded when 100% NPK was applied (8.19), followed by the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (8.18), and the lowest pH value observed in the absolute control. The electrical conductivity ranged from 0.20 to 0.28 dSm^{-1}, with the highest electrical conductivity recorded when 100% NPK and N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) were applied (0.28 dSm^{-1}), followed by the application of N75 P75 K100+ Nano DAP (ST @ 2.5 ml/kg seed & FS @ 0.2% at 30 DAS) (0.27 dSm^{-1}). The lowest electrical conductivity was observed in the absolute control. The organic carbon ranged from 4.78 to 5.00 g kg^{-1}, with the highest organic carbon recorded when 100% NPK was applied (5.00 g kg^{-1}), followed by the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2% at 30 DAS) (4.98 g kg^{-1}). The lowest organic carbon value was observed in the absolute control. These results are consistent with the findings of Mathew *et al*. (2018) [12] and Tembhurne *et al.*, (2020) [21].

Table 3: Effect of various levels of phosphorus on available N, P, K, S and available micronutrients in soil after harvest of cotton.

Treatments		Available nutrients				Available micronutrients mg kg^{-1}			
		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (mg kg^{-1})	Zn	Cu	Fe	Mn
T1	N0P0K0	172.20	12.18	376.34	9.22	0.52	2.25	8.17	12.66
T2	N0P0K100	178.24	13.22	390.20	9.24	0.52	2.26	8.19	12.68
T3	N100 P100 K100	191.59	16.65	398.64	9.41	0.56	2.33	8.22	12.72
T4	N50 P50 K100	184.73	14.78	392.26	9.34	0.54	2.28	8.18	12.66
T5	T4 + Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2%at 30 DAS)	185.26	14.82	392.67	9.33	0.54	2.31	8.17	12.69
T6	T4 + Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2%at 30 DAS)	185.91	14.88	392.96	9.36	0.55	2.30	8.19	12.70
T7	N75 P75 K100+ Nano DAP (ST @ 2 .5 ml / kg seed & FS @ 0.2% at 30 DAS)	188.96	15.38	395.16	9.37	0.56	2.31	8.20	12.68
T8	N75 P75 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS)	190.09	15.44	396.32	9.39	0.56	2.32	8.21	12.70
	SE (M) ±	3.85	0.84	3.62	0.064	0.033	0.29	0.052	0.043
	CD at 5%	11.62	2.54	10.86	NS	NS	NS	NS	NS

Available N, P, K and S

The available N in soil varied from 172.20 to 191.59 kg ha^{-1} (Table 3). The higher available N (211.1 kg ha^{-1}) was observed with application of 100% NPK and lowest (181.8 kg ha^{-1}) in control. There was 11.27% increase in available N content in the treatment best T3 i.e. 100% NPK over control. The increment in available nitrogen might be due to additional supply of nitrogen with the increasing phosphorus levels. The results are in agreement with the findings of Gadhiya *et al*, (2009) [2], and Mathew *et al.* (2018) [12]. The available P in soil varied from 12.18 to 16.65 kg ha^{-1} (Table 2). The higher available P (16.65 kg ha^{-1}) was observed with application of 100% NPK and lowest P (12.18 kg ha^{-1}) in control. There was 36.70% increase in available P content in the treatment best T3 i.e. 100% NPK over control. The increment in available phosphorus might be due to additional supply of phosphorus with increasing levels. The results are in agreement with the findings of Gadhiya *et al*, (2009) [2], Mathew *et al.* (2018) [12] and Tembhurne *et al*. (2020) [21]. The soil was very high in available K and ranged from 376.76 to 398.64 kg ha^{-1}. The highest available K (398.64 kg ha^{-1}) was observed in the treatment 100% NPK and lowest (376.67 kg ha^{-1}) in control. It was increased 5.92% in treatment best T3 over control. The available sulphur content in soil after harvest was ranged from 9.22 to 9.41 mg kg^{-1} as no significantly influenced by various levels of phosphorus application. Maximum available sulphur was recorded with the application 100% NPK (9.41 mg kg^{-1}) followed by the application of N75 P75 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS) (9.39 mg kg^{-1}) and lowest available sulphur was observed in the absolute control. The similar findings were also quoted by Mena *et al.*, (2013) [13].

Available micronutrients (Zn, Fe, Cu and Mn.)

The data revealed that, the available zinc in soil ranged from 0.52 mg kg^{-1} to 0.56 mg kg^{-1}. (Table. 3) Maximum available zinc was recorded with the application of. 100% NPK (0.56 mg kg^{-1}) and followed by with the application of

N50 P50 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS) (0.55 mg kg^{-1}) lowest available zinc was observed in absolute control plot kg^{-1}). However, the data revealed that the available ferrous in soil ranged from 8.17 to 8.22 mg kg^{-1}. Maximum available ferrous was recorded with the application of 100% NPK (8.22 mg kg^{-1}) and followed by with the application of N75 P75 K100+ Nano DAP (ST @ 5 ml / kg seed & FS @ 0.2% at 30 DAS) (8.21 mg kg^{-1}) and lowest available ferrous observed in absolute control plot.

In respect of available copper after harvest of cotton in soil ranged from 2.25 mg kg^{-1} to 2.33 mg kg^{-1}. Maximum available copper was recorded with the application of 100% NPK (2.33 mg kg^{-1}) and followed by with the application of N75 P75 K100+ Nano DAP (ST @ 5 ml/kg seed & FS @ 0.2%at 30 DAS) (2.32 mg kg^{-1}) and lowest available copper observed in absolute control, whereas the data revealed that the available manganese in soil ranged from 12.66 mg kg^{-1} to 12.72 mg kg^{-1}. The maximum available manganese was recorded with the application of 100% NPK (12.72 mg kg^{-1}) and followed by with the application of N75 P75 K100+ Nano DAP (ST @ 5 ml /kg seed & FS @ 0.2% at 30 DAS) (8.21 mg kg^{-1}) and lowest available manganese recorded in absolute control. The results are closely related to Kumar *et al*., (2010) [10].

Conclusion

From the present investigation it can be concluded thatseed cotton and stalk yield of cotton were recorded significantly highest with the application of 100% NPK, the application of 100% recommended NPK dose and 75% N, P,100% K recommended dose with 0.2% foliar application of Nano DAP were found equally beneficial to phosphorus dynamics of the soil, phosphorous use efficiency and slight improvement in residual fertility of soil.

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