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Phosphorus management through sources of phosphorus, FYM and phosphate solubilizing bacteria in transplanted autumn rice (*Oryza Sativa* L.) for enhancing productivity under Assam conditions

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ABSTRACT

A field investigation was conducted during the autumn seasons of 2021 and 2022 at the Instructional-cum-Research Farm, Assam Agricultural University, Jorhat, to evaluate the effects of phosphorus management through sources of phosphorus, organic amendments and phosphate solubilizing bacteria (PSB) on the growth and productivity of transplanted autumn rice (*Oryza sativa* L.) under acidic soil conditions of Assam. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with 15 treatment combinations. The experiment comprising three phosphorus sources—100% SSP (P_1), 100% Rock Phosphate (P_2), and 50% SSP + 50% RP (P_3) as one of the factors, and five treatments of organic amendments and phosphate solubilizing bacteria viz., Control (No FYM), Farm Yard Manure @ 2 t/ha, Farm Yard Manure @ 2 t/ha + Phosphate Solubilising Bacteria I (*Parburkholderia tropica*), Farm Yard Manure @ 2 t/ha + Phosphate Solubilising Bacteria II (*Bacillus circulans*) and Farm Yard Manure @ 2 t/ha. Results revealed that among the sources of P in both the years, the combined application of 50% SSP + 50% RP i.e. P_3 , significantly enhanced growth attributes, yield attributes, and grain yield. And among the organic amendments and phosphate solubilizing bacteria, treatment F_5 (Farm Yard Manure @ 2 t/ha + Phosphate Solubilising Bacteria I (*Parburkholderia tropica*) + Phosphate Solubilising Bacteria II (*Bacillus circulans*)) showed the highest growth parameters, root growth parameters, yield attributes and yield in both the years. Hence, P_3F_5 combination results in enhancing yield and productivity of transplanted autumn rice in acidic soil-based rice ecosystems of Assam

Keywords: Autumn rice, Phosphorus, Rock phosphate, Farmyard manure, Phosphate solubilizing bacteria

Introduction

Rice (*Oryza sativa* L.) is the most important cereal crop globally and serves as the staple food for more than half of the world's population. Globally, 755.47 million tonnes of rice are produced from 162.05 million hectares (FAOSTAT, 2019) [1]. Asia contributes nearly 92% of global rice production while accommodating 59% of the world's population. China is the highest rice producer, followed by India. With the global population projected to reach 9.8 billion by 2050 (Reetz, 2016) [2], enhancing rice productivity is essential to meet future food demand. In India, rice occupies about 44 million hectares with an annual production of 172.58 million tonnes and an average productivity of 2.57 t/ha. In Assam, rice is the staple food and occupies nearly two-thirds of the gross cropped area. Due to agro-climatic diversity, Assam has three rice-growing seasons: autumn (ahu), winter (sali), and summer (boro). Autumn rice covers only 2.2 lakh ha with low productivity (Directorate of Economics and Statistics, 2016) [3]. Although autumn rice avoids flood damage common in winter rice, its productivity remains low due to water stress, weed infestation, and poor nutrient management. Phosphorus (P) is a crucial macronutrient involved in photosynthesis, ATP synthesis, root proliferation, tillering, flowering, and grain formation. However, only 0.1% of total soil phosphorus is available to plants due to fixation by iron and aluminium oxides in acidic soils (Pereira *et al.*, 2014; Panda *et al.*, 1984) [5, 4]. Acid soils of Assam exacerbate this problem, leading to low phosphorus use efficiency (PUE: 20–25%) and phosphorus recovery efficiency (PRE: ~10%) (Fageria *et al.*, 2015; Von & Mutert, 1995) [6, 7]. Excessive dependence on chemical P fertilizers not only increases production costs but also disrupts soil microbial diversity (Gyaneshwar *et al.*, 2002) [8]. India imports nearly 90% of its phosphate fertilizers, making rice cultivation economically vulnerable (Bagyaraj *et al.*, 2015) [9]. Rock phosphate (RP), a natural and low-cost P source, is more suitable for acidic soils due to its gradual dissolution and long-term nutrient release (Siddaramappa *et al.*, 1991) [10]. India has over 260 million tonnes of low-grade RP deposits (Kumari *et al.*, 2012) [11]; however, its low solubility limits direct application. Farmyard manure (FYM) improves soil

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structure, enhances microbial activity, reduces P fixation by chelating Fe and Al ions, and increases available phosphorus through mineralization (Sharma *et al.*, 1985; Guppy *et al.*, 2005; Huang *et al.*, 2014) [13, 12, 14]. Moreover, phosphate-solubilizing bacteria (PSB) such as *Bacillus*, *Paraburkholderia*, and *Pseudomonas* solubilize insoluble phosphates by organic acid secretion, enzyme production, and phytohormone synthesis like IAA, enhancing root growth and nutrient uptake (Chen *et al.*, 2006; Ahemad *et al.*, 2014) [16, 15].

Materials and Methods

The field experiment was conducted during the autumn seasons (March–July) of 2021 and 2022 at the Instructional-cum-Research (ICR) Farm, Assam Agricultural University, Jorhat. The experimental soil was sandy loam, acidic (pH 5.2–5.5), low in available phosphorus (20.45–22.28 kg P₂O₅/ha), medium in available nitrogen (308.13–328.71 kg N/ha) and potassium (137.50–138.42 kg K₂O/ha). The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications comprising 15 treatment combinations involving three phosphorus sources—P₁: 100% SSP, P₂: 100% Rock Phosphate (RP), P₃: 50% SSP + 50% RP—and five organic amendments and phosphate solubilizing bacteria treatments—F₁: Control, F₂: FYM @ 2 t/ha, F₃: FYM + *Paraburkholderia tropica*, F₄: FYM + *Bacillus circulans*, F₅: FYM + *Paraburkholderia tropica* + *Bacillus circulans*. The rice variety ‘Lachit’ (125–130 days duration) was taken and 21 days old seedlings were transplanted maintaining a spacing of 20 cm × 15 cm with two seedlings per hill. The recommended fertilizer dose (RDF) of 40:20:20 kg N: P₂O₅: K₂O/ha was applied; N (urea) was applied in three splits—½ basal, ¼ at active tillering, and ¼ at panicle initiation; full P and K were applied as basal using SSP, RP, and MOP. Rock phosphate was mixed with soil/FYM and incubated for 21 days to enhance mineralization and P release and applied as basal. In PSB-treated plots, seedlings were root-dipped in a slurry containing 500 ml/ha of PSB inoculum. To study root growth parameters, a separate pot experiment was also conducted in both the years. For the pot experiment, fertilizer requirements were calculated considering a 1ha area containing 2.24 × 10⁶ kg soil up to 15 cm depth. Therefore, for 5 kg soil, Urea @ 0.190g, MOP @ 0.074g, SSP @ 0.279g (100 %) and 0.1395g (50 %), RP @ 0.223g (100 %) and 0.112g (50 %), and FYM @ 4.4g were applied in respective pots. The application of manures and fertilizer in the pot experiments in both the years were done in the same way as in field conditions. The field was maintained at 5 cm standing water until flowering and then kept under saturated conditions. For weed and insect pest control the recommended package of practices were followed. For the purpose of studying roots, plants from their respective pots were removed, and roots were gently washed under a fine water jet to remove the soil from them. The root mean length was measured using a measuring scale from their bases to their tips. Root volume was measured using the displacement-based root volume technique (Mishra *et al.*, 1987) [17]. For root fresh weight and dry weight, roots were collected, the soil was removed gently, and the fresh weight of roots was recorded. For dry weight, same samples were dried in sunlight followed by in an oven at 60 °C for 72 hrs before being weighed. The averages values were considered. For the field experiment, five plants were randomly chosen from each treatment to record growth and yield parameters. Plants from a net plot area of 6 m² and were harvested, sun-dried, threshed, and yields were recorded. All the data pertaining to the present investigation were statistically analysed for Factorial Randomized Block Design (FRBD). Critical differences (CD) at 5 per cent probability level was calculated when the *F* value was found out to be significant.

Results and Discussion

Plant Growth Parameters: A critical examination of the data (Table 1) revealed that growth parameters of transplanted autumn rice—plant height, number of tillers/hill, leaf area index (LAI), and dry matter accumulation were significantly influenced by sources of phosphorus during both years. The combined application of single super

phosphate (50% RDP) + rock phosphate (50% RDP) (P₃) resulted in markedly higher plant height (88.47 and 87.28 cm), number of tillers/hill (19.28 and 19.17), LAI (4.64 and 4.57), and dry matter accumulation (28.26 and 27.31 g/hill) in 2021 and 2022, respectively, compared to the sole use of either SSP or rock phosphate. The superiority of P₃ can be attributed to the complementary effects of soluble and slowly available phosphorus forms, ensuring a steady nutrient supply and efficient utilization throughout crop growth. The better performance of P₃ could be related to improved phosphorus availability, root proliferation, and higher photosynthetic efficiency, supporting vigorous plant growth—findings consistent with Sarkar *et al.* (2018) [18]. Treatment F₅ (FYM @ 2 t/ha + PSB I (*Paraburkholderia tropica*) + PSB II (*Bacillus circulans*)) produced significantly greater plant height (90.58 and 89.40 cm), number of tillers/hill (16.49 and 15.31), LAI (4.75 and 4.66), and dry matter accumulation (29.15 and 28.67 g/hill) in both years, compared with the control. The superior response of F₅ likely resulted from favourable soil conditions created by FYM and enhanced phosphorus solubilization by PSB, which stimulated nutrient uptake, hormonal activity (IAA, GA, cytokinins), and overall physiological function, as observed by Jalil *et al.* (2014) [19], Bakhshandeh *et al.* (2015) [20], and Biswakarma *et al.* (2018) [21]. The control (F₁) consistently recorded the lowest values for all parameters.

Root Growth Parameters: Root growth characteristics—root length, volume, fresh and dry weights showed significant variation under different phosphorus sources (Table 2). The treatment P₃ (SSP 50% RDP + RP 50% RDP) recorded the highest root length (27.04 and 26.19 cm), root volume (79.32 and 78.16 cc), root fresh weight (14.10 and 13.01 g/hill), and root dry weight (4.51 and 4.22 g/hill) in 2021 and 2022, respectively. This improvement is likely due to the continuous availability of both soluble and slow-release phosphorus fractions, ensuring sustained nutrient supply and encouraging root proliferation. Similar observations were made by Sarkar *et al.* (2018) [18], who reported that partial substitution of SSP with rock phosphate improved root development and phosphorus-use efficiency in cereals. Treatment F₅ (FYM @ 2 t/ha + PSB I + PSB II) produced the longest roots (27.57 and 26.63 cm), greatest root volume (82.69 and 82.14 cc), and highest fresh (15.92 and 14.84 g/hill) and dry weights (5.17 and 4.88 g/hill) during both years, followed by F₄ (FYM + PSB II). The control (F₁) registered the lowest values. The improvement under F₅ can be ascribed to the combined benefits of FYM and PSB, which improved soil structure, enhanced nutrient availability, and stimulated rhizosphere microbial activity. Phosphate-solubilizing bacteria increased phosphorus availability through secretion of organic acids and phosphatases, while FYM provided a conducive medium for microbial proliferation and root elongation. Enhanced root biomass under PSB inoculation might also result from the production of plant growth regulators such as indole acetic acid and gibberellins, promoting root elongation and branching. These results are in conformity with the findings of Hatia *et al.* (2000) [22], Rahi *et al.* (2010) [23], and Singh *et al.* (2014) [24].

Yield and Yield Attributes: Yield and yield-attributing characters *viz.* number of panicles/hill, panicle length, filled and unfilled grains/panicle, test weight, grain yield, straw yield and harvest index—varied significantly with phosphorus sources and organic amendments in both years, (Table 3). Application of P₃ (50% SSP + 50% RP) resulted in the highest number of panicles/hill (14.49 and 13.53), panicle length (22.98 and 22.29 cm), filled grains/panicle (92.95 and 91.00), and test weight (19.50 and 19.45 g) during 2021 and 2022, respectively. This treatment also produced highest grain yields (3287.17 and 3247.11 kg/ha) straw yields (4042.68 and 4037.71 kg/ha) and harvest index (44.83 and 44.55 %), followed by P₂, whereas P₁ recorded the minimum. The improvement under P₃ may be attributed to balanced and prolonged phosphorus availability through the combined effect of readily soluble and slow-release forms, resulting in better nutrient uptake, root development, and efficient partitioning of photosynthates towards reproductive sinks. These observations agree with those of Sarkar *et al.* (2018) [18]. Treatment F₅ (FYM @ 2 t/ha +

PSB I + PSB II) consistently outperformed others, producing more panicles/hill (15.65 and 14.71), longer panicles (23.40 and 22.86 cm), higher number of filled grains/panicle (95.55 and 94.10), and greater test weight (19.63 and 19.57 g) in both years. It also achieved the maximum grain yield (3351.23 and 3325.06 kg/ha), straw yields (4110.06 and 4087.26 kg/ha) and harvest index (44.89 and 44.64 %) which were superior to other treatments. Enhanced yield under F₅ can be linked to the combined action of FYM and PSB, which improved phosphorus solubilization and mineralization, resulting in better nutrient uptake and utilization. FYM contributed to improved soil structure and microbial activity, promoting higher productive tillers and efficient grain filling. The beneficial effects of P₃ likely resulted from the synchronized release of phosphorus—SSP supplying readily available P in the early growth stages and RP releasing it slowly later—thus supporting continuous nutrient uptake and better yield formation. Comparable results have been reported by Babu *et al.* (2006) [25], Sarkar *et al.* (2018) [18], and Akbari *et al.* (2010) [26].

The data about grain and straw yield as influenced the interaction of sources of P, organic amendments and phosphate solubilizing microbe has been presented in Table 4. Regarding the interaction effect, the sources of P, organic amendments and phosphate solubilizing microbe interacted significantly in respect of grain yield and straw yield in both the years of experimentation. The highest values of grain yield (3559.44 and 3521.18 kg/ha in 2021 and 2022 respectively), straw yield (4251.73 kg/ha and 4260.63 kg/ha in 2021 and 2022, respec-

tively) were obtained in treatment combination of P₃F₅ which caused in 49.05 % and 51.70 % increase in grain yield in both the years than that in P₁F₁ combination. In P₃F₅, combined application of SSP and RP might have provided P throughout the growing season of rice crop; application of PSB might have further augmented the release P from RP in later growth stages, in addition to these, FYM application also boosted favorable soil condition for root proliferation and large biomass production resulted in better growth attributes leading to increase in grain yield and straw yield.

Conclusion

It can be concluded that P₃F₅ combination proved to be the most effective approach in enhancing yield of transplanted autumn rice. The superior performance of P₃F₅ was attributed to improved phosphorus availability from synergistic effects of water-soluble P from SSP, slow-release P from RP, enhanced microbial solubilization, and soil biological activity due to FYM and PSB application. So P₃F₅ is a sustainable alternative to sole chemical P fertilization in acidic soil-based rice ecosystems of Assam, which also enhances productivity of transplanted autumn rice.

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Table 1. Effect of different sources of phosphorus, organic amendments and phosphate solubilizing bacteria on growth parameters of transplanted autumn rice

Treatment details	Plant height (cm)		No. of tillers/hill		Leaf Area Index		Dry matter accumulation (g/hill)	
	At harvest		60 days after transplanting		At harvest		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
Sources of phosphorus								
P ₁ : Single superphosphate(100%RDP)	84.36	83.66	16.05	15.36	4.43	4.33	26.58	25.69
P ₂ : Rock phosphate (100%)	85.70	84.53	17.86	17.20	4.58	4.44	26.92	26.16
P ₃ : SSP (50% RDP) +RP (50%RDP)	88.47	87.28	19.28	19.17	4.64	4.57	28.26	27.31
S Em (±)	0.76	0.77	0.45	0.65	0.02	0.03	0.18	0.33
CD(P = 0.05)	2.21	2.23	1.32	1.88	0.08	0.07	0.54	0.98
Organic amendments and phosphate solubilizing microbes								
F ₁ : Control (No FYM)	82.21	81.00	12.27	11.10	4.33	4.23	25.36	24.48
F ₂ : FYM@ 2t/ha	85.21	83.66	12.86	11.86	4.46	4.34	26.40	26.14
F ₃ : FYM@ 2 t/ha +PSB I (<i>Parburkholderia tropica</i>)	86.70	85.37	13.66	12.57	4.55	4.42	27.56	26.24
F ₄ : FYM@ 2 t/ha +PSB II (<i>Bacillus circulans</i>)	87.40	86.37	15.31	14.19	4.64	4.56	27.79	26.40
F ₅ : FYM@ 2 t/ha +PSB I+PSB II	90.58	89.40	16.49	15.31	4.75	4.66	29.15	28.67
S Em (±)	0.94	0.99	0.37	0.32	0.04	0.03	0.24	0.43
CD(P = 0.0)	2.73	2.89	1.08	0.94	0.10	0.09	0.69	1.26
Interaction (P x F)	NS	NS	NS	NS	NS	NS	NS	NS
NS=Nonsignificant								

Table 2. Root growth response of transplanted autumn rice using different phosphorus sources, organic amendments and phosphate-solubilizing bacteria

Treatment details	Root length (cm)		Root volume (cc)		Root fresh weight (g/hill)		Root dry weight (g/hill)	
	At harvest		At harvest		At harvest		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
Sources of phosphorus								
P ₁ : Single Super Phosphate (100%RDP)	22.52	21.34	71.49	69.20	11.70	11.04	4.10	3.81
P ₂ : Rock Phosphate (100% RDP)	24.24	23.52	74.14	72.67	13.33	11.74	4.29	4.05
P ₃ : SSP (50%RDP) + RP (50%RDP)	27.04	26.19	79.32	78.16	14.10	13.01	4.51	4.22

(continued on next page)

	Root length (cm)		Root volume (cc)		Root fresh weight (g/hill)		Root dry weight (g/hill)	
S Em ($\pm$)	0.28	0.28	0.72	1.28	0.26	0.26	0.07	0.06
CD($P = 0.05$)	0.82	0.81	2.11	3.72	0.77	0.76	0.20	0.19
Organic amendments and phosphate solubilizing microbes								
F ₁ : Control (No FYM)	20.25	19.44	67.57	62.75	9.30	8.27	3.54	3.27
F ₂ : FYM @2 t/ha	22.82	21.89	71.46	69.72	11.98	11.04	4.02	3.58
F ₃ : FYM@ 2 t/ha + PSB I (<i>Parburkholderia tropica</i>)	25.88	24.72	74.73	74.73	13.47	12.39	4.30	4.15
F ₄ : FYM@ 2 t/ha + PSBII (<i>Bacillus circulans</i>)	26.48	25.72	78.46	77.39	14.55	13.57	4.48	4.27
F ₅ : FYM@ 2 t/ha +PSB I+PSBII	27.57	26.63	82.69	82.14	15.92	14.84	5.17	4.88
S Em ($\pm$)	0.36	0.36	0.94	1.65	0.34	0.36	0.09	0.08
CD($P = 0.05$)	1.06	1.04	2.72	4.80	1.00	1.05	0.27	0.25
Interaction ($P \times F$)	NS	NS	NS	NS	NS	NS	NS	NS
NS=Nonsignificant								

Table 3. Effect of phosphorus sources, organic amendments, and phosphate solubilizing microbes on yield and yield attributes of transplanted autumn rice (*Oryza sativa* L.)

	No. of panicle/hill		Length of panicle(cm)		No. of filled grains/panicle		Test weight(g)		Grain yield (kg/ha)		Straw yield (kg/ha)		Harvest Index (%)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Sources of phosphorus														
P ₁ : Single Super Phosphate (100%RDP)	12.87	11.65	20.40	20.11	87.10	86.74	19.27	19.23	2941.16	2902.29	3736.67	3725.20	43.98	43.71
P ₂ : Rock Phosphate (100% RDP)	13.97	12.54	21.60	21.56	90.80	90.97	19.42	19.34	3091.27	3076.71	3892.73	3898.33	44.23	44.08
P ₃ : SSP (50% RDP) + RP (50% RDP)	14.49	13.53	22.98	22.29	92.95	91.00	19.50	19.45	3287.17	3247.11	4042.68	4037.71	44.83	44.55
S Em ($\pm$)	0.29	0.26	0.55	0.41	0.62	0.40	0.02	0.01	26.35	35.26	24.01	36.46	0.22	0.20
CD($P=0.05$)	0.84	0.76	1.59	1.20	1.89	1.17	0.07	0.05	76.33	102.16	69.56	51.57	0.66	0.59
Organic amendments and phosphate solubilizing microbes														
F ₁ : Control (No FYM)	10.40	9.38	19.56	19.54	84.25	83.93	19.16	19.12	2730.84	2727.70	3535.26	3607.88	43.52	42.98
F ₂ : FYM @2 t/ha	12.78	11.28	20.63	20.51	87.21	86.84	19.21	19.20	3049.17	3013.82	3863.50	3867.99	44.10	43.79
F ₃ : FYM @2 t/ha + PSB I (<i>Parburkholderia tropica</i>)	14.81	13.40	21.91	21.53	90.86	90.73	19.44	19.34	3168.88	3120.25	3954.57	3917.53	44.48	44.32
F ₄ : FYM @2 t/ha + PSB II (<i>Bacillus circulans</i>)	15.26	14.08	22.80	22.16	93.55	92.24	19.54	19.47	3232.56	3190.03	3990.07	3954.73	44.75	44.64
F ₅ : FYM @2 t/ha +PSB I+ PSB II	15.65	14.71	23.40	22.86	95.55	94.10	19.63	19.57	3351.23	3325.06	4110.06	4087.26	44.89	44.64
S Em ($\pm$)	0.37	0.34	0.71	0.53	0.84	0.52	0.03	0.02	34.01	45.53	31.00	47.08	0.29	44.84
CD($P = 0.05$)	1.08	0.99	2.06	1.56	2.44	1.51	0.10	0.06	98.54	131.89	89.80	136.38	0.85	0.26
Interaction ($P \times F$)	NS	NS	NS	NS	NS	NS	NS	NS	*	*	*	*	NS	NS

Table 4. Interaction effect of different sources of phosphorus, organic amendments, and phosphate solubilizing microbes on grain yield (kg/ha) and straw yield (kg/ha) of transplanted autumn rice

Organic amendments and phosphate solubilizing microbes	Sources of phosphorus											
	Grain yield (kg/ha) (2021)			Grain yield (kg/ha) (2022)			Straw yield (kg/ha) (2021)			Straw yield (kg/ha) (2022)		
	P ₁	P ₂	P ₃	P ₁	P ₂	P ₃	P ₁	P ₂	P ₃	P ₁	P ₂	P ₃
F ₁	2388.33	2734.44	3069.74	2321.08	2791.17	3070.86	3196.67	3582.11	3827.00	3197.67	3763.97	3862.00
F ₂	2945.26	3050.75	3151.50	2917.12	3017.15	3107.18	3774.00	3895.49	3921.00	3765.36	3876.16	3962.44
F ₃	3049.39	3163.26	3294.00	3017.14	3141.17	3202.45	3840.00	3942.72	4081.00	3842.80	3873.65	4036.15
F ₄	3127.12	3209.39	3361.17	3091.13	3145.07	3333.90	3890.00	3947.55	4132.67	3863.91	3932.95	4067.33
F ₅	3195.71	3298.53	3559.44	3165.00	3289.00	3521.18	3982.67	4095.79	4251.73	3956.25	4044.91	4260.63
S Em ($\pm$)	58.92			78.86			53.69			81.54		
CD ($P = 0.05$)	170.68			228.45			155.54			236.23		

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27. *Significant.
28. P1: Single Super Phosphate(100%RDP), P₂: Rock Phosphate (100% RDP), P₃: SSP (50% RDP) + RP (50% RDP), F1: Control (No FYM), F2: FYM @2 t/ha, F3: FYM @2 t/ha + PSBI (*Parburkholderia tropica*), F4: FYM @2 t/ha + PSB II (*Bacillus circulans*) and F5: FYM @2 t/ha +PSBI+ PSBII.

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