Root Morphological Characteristics ofFive Rice Genotypes with Different Nitrogen Use Efficiency

ABSTRACT

While nitrogen(N) uptake in rice has been extensively studied, the influence of root morphology on this process is not fully elucidated. This study explores the root morphological characteristics and N uptake of five diverse rice genotypes under different N sources, including novel slow-release nanoclaypolymer/biopolymer composite (NCPC/NCBPC) fertilizers. A greenhouse experiment was conducted using five diverse rice genotypes (Swarna, Pusa Basmati-1, Pusa-44, MTU1010 and Nagina-22) with five N treatments (T1- control (without N fertilizer), T2- 100% RDF of N through urea, T3- 75% RDF of N through urea loaded NCPC, T4- 75% RDF of N through urea loaded NCBPC-I (NCBPC prepared with wheat flour), T5- 75% RDF of N through urea loaded NCBPC-II (NCBPC prepared with maida)). The results of the study revealed that maximum overall root growth was recorded under Pusa Basmati-1 followed by Swarna, MTU 1010, Nagina-22 and Pusa-44. Among the N treatment, maximum root growth and N uptake was recorded under NCPC treatment followed by NCBPC-II, NCBPC-I, urea and control. Thus,the study reveals significant variations in root traits among genotypes and N treatments, with notable improvements observed under NCPC and NCBPC based N treatments.

***Keywords**: Root morphology, Slow-release fertilizers, Nano clay polymer composites, Nitrogen uptake, Genotypes*

1. INTRODUCTION

Rice is the second most widely consumed cereal in the world after wheat [1] with a global harvested area of approximately 158 million hectares and an annual production of more than 700 million tonnes as paddy rice [2]. Rice is a heavy user of nitrogen (N) fertilizers[3]. The nitrogen recovery efficiency from fertilizer in rice cultivation is only 30-39% [4], primarily due to N losses occurring through ammonia volatilization, denitrification, leaching, and runoff from rice fields. These losses not only reduce the yield and economic efficiency of applied N [5], but also cause grave environmental consequences.Currently, the way to increase N use efficiency (NUE) is the development and selection of new N-efficient genotypes and to improve cultivation technologies to minimize the N loss.The root morphology is a crucial characteristic for resource acquisition due to the distribution of nutrients across various soil layers and the availability of these nutrients in different environment [6]. Because rice is generally grown under submerged

UNDER PEER REVIEW

condition, root morphology and physiology plays an important role in nutrient acquisition. As N is the major plant nutrient essential for growth and productivity of plants, the variation in N uptake by rice has been widely studied but variations in rice root morphology that may contribute to this variationare not completely understood [7].Due to their underground location, beneficial root traits are currently difficult to characterize and select for plant breeding [8].In order to increase biomass and production in soils with low nutrient availability, intense fertilization is frequently needed. To lessen the detrimental effects of fertilization, more effective fertilizer uptake is required. This can be accomplished by adopting genotypes with roots that are better at absorbing nutrients from the soil and selection of fertilizer sources that provide nutrients to the roots for a longer time as per their need. As part of this effort, several slow and controlled release N fertilizers has been developed and tested under field conditions [9].Nano clay polymer composites are a possible new alternative of conventional fertilizers which releases nutrients as a slower rate and provide the plants more opportunity to absorb the nutrients [10]. The application of clay polymer composites serves a dual purpose - they not only regulate the release of nitrogen but also function as water reservoirs. These fertilizer materials have potential to address the drawbacks of conventional fertilizers by decreasing nutrient loss, continuously supplying nutrients for longer duration, enhancing microbial activity, improving soil aeration so that the overall plant growth [11].

Therefore, keeping all the above discussion in view, In the present study, we have attempted to study the root morphology and nitrogen uptake in five different rice genotypes under different sources of nitrogen.

UNDER PEER REVIEW

2. MATERIALS AND METHODS

2.1 Synthesis of nano clay biopolymer composites fertilizers

Nano clay polymer composites (NCPCs) were synthesized by copolymerization ofpartially neutralized acrylic acid and acrylamide in presence of N, N'-methylene bisacrylamide, ammonium persulphate and bentonite clay (10 wt%) [12]. For synthesizing nanoclay biopolymer composites (NCBPCs), the acrylic acid was substituted with naturally occurring starch materials *viz*. wheat flour and maida at 20% by weight, restof the procedure remains same[11]. The synthesized NCPC and NCBPCs were loaded with nitrogen by immersing dry gels into the aqueous solution of urea. Thereafter, the swollen gels were dried at 60^0C for 6 days, milled and screened. Thus, following three superabsorbent polymers were synthesized; 1) NCPC (Acrylic acid (AA) + acrylamide (Am) NCPC), 2) NCBPC-I (20% replacement of acrylic acid with wheat flour) and 3) NCBPC-II (20% replacement of acrylic acid with maida).

2.2 Details of Greenhouse experiments

A greenhouse experiment was conducted at Nanaji Deshmukh Plant Phenomics Centre, IARI, New Delhiduring*kharif*2020. For the experiment surface soil (0–15 cm, Typic Haplustepts) was collected from Research Farm of IARI, New Delhi. The experiment uses five rice genotypes *ie.*, Swarna, Pusa Basmati-1, Pusa-44, MTU1010 and Nagina-22.Total five N treatments were applied under pot culture experiment using completely randomized design. Treatments combination were - T1- control (without N fertilizer), T2- 100% RDF of N through urea, T3- 75% RDF of N through urea loaded NCPC, T4- 75% RDF of N through urea loaded NCBPC-I (NCBPC prepared with wheat flour), T5- 75% RDF of N through urea loaded NCBPC-II (NCBPC prepared with maida).Transplanting of riceseedlingswasdonealongwith application of full recommendeddose ofphosphorus and potassium and one third dose of N.The remaining N wasapplied in twosplits at tillering and booting stage.

2.3 Plant sampling and analysis

Plants were harvested at tillering, booting, and heading stages. Plant shoots and roots were separated and fresh roots were washed free of soil. After washing the roots properly, fine roots and root hairs were removed from the main root to avoid overlapping of roots during scanning. Roots were analysedfor different root parameters using a root analysis instrument WinRhizo-LA1600 (Regent Instruments Inc., Quebec, Canada),specifically designed for root measurement in different forms. It can do root morphology (length, area, volume etc.), topology, root architecture and color analyses.Then shoots and roots were dried at 70 °C to constant weight for shoot and root dry weight measurements. Total N in plant samples was analysed by Kjeldahl digestion–distillation method [13].

UNDER PEER REVIEW

Figure 1. Root scanning (Winrhizo root scanner)

2.4 Statistical analysis

All the data generated during the experiment were subjected to ANOVA with completely randomized design [14]. The R studio(Version 2022.07.1-554) program was used for statistical analyses of the data.

3. RESULTS

3.1 Root length

The various N fertilizer treatments significantly affected the root architecture of the rice genotypes. At tillering stage, the variation among the treatments and genotypes was very less which increased with the growing stage (table 1). At heading stage maximum root length was recorded under NCPC (1946 cm) treatment which was statistically at par with NCBPC-II treatment (1846 cm) but significantly higher than NCBPC-I and urea treatment. Treatment NCBPC-I and urea were at par in terms of root length. Among genotypes significantly highest root length was recorded in PB-1 (1913 cm) and lowest was in pusa-44 (1600 cm) which was statistically at par with Swarna, MTU1010 and N-22 at heading stage.

Table-1 Effect of nitrogen fertilizer treatments on root length (cm) of five rice genotypes at three different growth stages

Treatment	**Swarna**	**Pusa-44**	**PB-1**	**MTU 1010**	**Nagina-22**	**Mean**
				Tillering		
Control	749	704	896	917	862	**826**
Urea	844	953	884	1006	952	**928**
NCPC	987	1039	1024	1153	1019	**1044**

UNDER PEER REVIEW

NCBPC-1	949	1037	910	1089	966	**990**
NCBPC-II	980	1036	938	1091	991	**1007**
Mean	**902**	**954**	**930**	**1051**	**958**	
SEm (±)	G= 26.1, T= 26.1, G×T = 57.1					
LSD(p≤0.05)	G= 79.5, T= 79.5, G×T = 177					
			Booting			
Control	1109	974	1055	1081	1128	**1069**
Urea	1439	1491	1628	1477	1539	**1515**
NCPC	1713	1630	1876	1707	1608	**1707**
NCBPC-1	1479	1424	1855	1494	1502	**1551**
NCBPC-II	1589	1514	1818	1560	1603	**1617**
Mean	**1466**	**1407**	**1646**	**1464**	**1476**	
SEm (±)	G= 30.1, T=30.1, G×T = 67.3					
LSD(p≤0.05)	G= 85.5, T= 85.5, G×T = 191					
			Heading			
Control	1237	1033	1175	1243	1259	**1189**
Urea	1655	1715	1873	1698	1703	**1729**
NCPC	1970	1875	2157	1963	1767	**1946**
NCBPC-1	1701	1638	2268	1718	1727	**1810**
NCBPC-II	1827	1741	2091	1794	1777	**1846**
Mean	**1678**	**1600**	**1913**	**1683**	**1647**	
SEm (±)	G= 32.8, T= 32.8, G×T = 73.3					
LSD(p≤0.05)	G= 93.1, T= 93.1, G×T = 208					

*G =genotype and T= treatment

3.2 Root surface area

Even though all fertilizer treatments recorded greater root surface areas than the control at the tillering stage but they all remained statistically at par with each other. At this stage, variation among the genotypes was less increased with the growing stage (table 2). At heading stage, maximum root surface area was recorded in NCPC treatment (356 cm^2) which was significantly higher than other treatments. Lowest root surface area was recorded in urea treatment (310 cm^2) which was statistically at par with NCBPC-I treatment. Among genotypes maximum root surface area was recorded in PB-1 (356 cm^2) followed by Swarna, MTU 1010, N-22 and pusa-44.

UNDER PEER REVIEW

Table-2 Effect of nitrogen fertilizer treatments on root surface area (cm^2) of five rice genotypes at three different growth stages

Treatment	**Swarna**	**Pusa-44**	**PB-1**	**MTU 1010**	**Nagina-22**	Mean
			Tillering			
Control	132	138	138	148	143	**140**
Urea	140	157	143	155	150	**149**
NCPC	153	163	148	164	158	**157**
NCBPC-1	142	162	140	164	155	**153**
NCBPC-II	156	163	144	165	156	**157**
Mean	**144**	**157**	**142**	**159**	**152**	
SEm (±)	G= 4.13, T= 4.13, G×T = 9.25					
LSD(p≤0.05)	G= 11.7, T= 11.7, G×T = 26.3					
			Booting			
Control	196	163	191	189	211	**190**
Urea	265	235	302	256	261	**264**
NCPC	296	271	334	284	287	**294**
NCBPC-1	266	232	329	262	266	**271**
NCBPC-II	287	242	323	277	278	**281**
Mean	**262**	**229**	**296**	**253**	**260**	
SEm (±)	G= 3.55, T=3.55, G×T = 7.95					
LSD(p≤0.05)	G= 10.1, T= 10.1, G×T = 22.6					
			Heading			
Control	219	181	219	220	222	**212**
Urea	307	273	366	296	308	**310**
NCPC	375	307	407	356	333	**356**
NCBPC-1	308	269	402	304	308	**318**
NCBPC-II	319	273	388	344	329	**331**
Mean	**306**	**261**	**356**	**304**	**300**	
SEm (±)	G= 6.87, T=6.87, G×T = 10.9					
LSD(p≤0.05)	G= 13.8, T= 13.8, G×T = 30.9					

*G =genotype and T= treatment

UNDER PEER REVIEW

3.3 Root volume

Application of N fertilizer treatments significantly increased root volume of different rice genotypes (table 3). At heading stage, maximum root volume was recorded in NCPC treatment (5.39cm^3) followed by NCBPC II, NCBPC I, urea and control. The lowest root volume was recorded in urea (4.26 cm^3) treatment which was statistically at par with NCBPC-I treatment. Among genotypes significantly highest root volume was recorded in PB-1(5.10cm^3),followed by Swarna, N-22, MTU 1010 and pusa-44.

Table-3 Effect of nitrogen fertilizer treatments on root volume (cm^3) of five rice genotypes at three different growth stages

Treatment	**Swarna**	**Pusa-44**	**PB-1**	**MTU 1010**	**Nagina-22**	**Mean**
			Tillering			
Control	1.43	1.65	1.56	1.67	1.73	**1.61**
Urea	1.53	1.89	1.61	1.83	1.79	**1.73**
NCPC	2.12	2.01	1.76	2.03	1.76	**1.94**
NCBPC-1	2.03	2.07	1.65	1.98	1.80	**1.91**
NCBPC-II	1.88	2.00	1.71	2.00	1.76	**1.87**
Mean	**1.80**	**1.92**	**1.66**	**1.90**	**1.77**	
SEm (±)	G= 0.08, T=0.07, G×T = 0.12					
LSD(p≤0.05)	G= 0.15, T= 0.15, G×T = 0.35					
			Booting			
Control	2.77	2.18	3.13	2.70	2.82	**2.72**
Urea	3.60	3.59	4.07	3.69	3.77	**3.74**
NCPC	4.28	4.08	5.02	4.13	3.77	**4.26**
NCBPC-1	3.70	3.56	4.93	3.73	3.75	**3.94**
NCBPC-II	3.97	3.78	4.55	3.90	3.78	**4.00**
Mean	**3.66**	**3.44**	**4.34**	**3.63**	**3.58**	
SEm (±)	G= 0.07, T=0.07, G×T = 0.16					
LSD(p≤0.05)	G= 0.20, T= 0.20, G×T = 0.44					
			Heading			
Control	3.17	2.28	3.23	3.25	3.22	**3.03**
Urea	4.19	3.43	5.01	4.03	4.62	**4.26**

UNDER PEER REVIEW

NCPC	5.69	4.67	6.17	5.27	5.13	**5.39**
NCBPC-1	4.29	3.83	6.01	4.06	4.68	**4.57**
NCBPC-II	4.94	3.90	5.10	5.04	5.10	**4.82**
Mean	**4.45**	**3.62**	**5.10**	**4.33**	**4.55**	
SEm (±)			G= 0.09, T=0.09, G×T = 0.192			
LSD(p≤0.05)			G= 0.24, T= 0.24, G×T = 0.55			

3.4 Root dry weight

At the heading stage, root dry weight under polymer based N fertilizers was higher than the conventional urea treatment for each selected genotype (table 4).Maximum root dry weight was recorded under NCPC treatment (13.3 g) followed by NCBPC II, NABPC I and urea. Among genotypes maximum root dry weight was observed in PB-1 (13.2 g) followed by swarna, pusa-44, MTU 1010 and N-22. Among the interactions PB-1 genotypes with NCPC treatment was recorded with maximum root dry weight (14.8 g).

Table-4 Effect of nitrogen fertilizer treatments on root dry weight (g) of five rice genotypes at heading stage

Treatment	Swarna	Pusa-44	PB-1	MTU 1010	Nagina-22	Mean
Control	8.4	8.0	8.7	6.9	5.4	**7.5**
Urea	12.4	12.0	14.0	10.5	9.0	**11.6**
NCPC	14.8	13.8	14.8	11.4	11.5	**13.3**
NCBPC-1	13.3	13.3	14.1	10.6	10.2	**12.3**
NCBPC-II	14.5	13.5	14.5	10.8	10.8	**12.8**
Mean	**12.7**	**12.1**	**13.2**	**10.0**	**9.4**	
SEm (±)			G= 0.20, T=0.20, G×T = 0.451			
LSD(p≤0.05)			G= 0.57, T= 0.57, G×T = 1.28			

3.5 Nitrogen uptake

The effect of different sources of fertilizers on nitrogen uptake by rice is presented in table-5. All the fertilizer treatments gave significant higher N- uptake values as compared to control. Highest

UNDER PEER REVIEW

N uptake was recorded in NCPC treatment (0.35 g/plant) which is significantly higher than all other treatments as NCBPC-II (0.32 g/plant), NCBPC-I(0.28 g/plant) and urea (0.24 g/plant). Among genotypes maximum N uptake was recorded in Swarna (0.32 g/plant) which was significantly higher than all other genotypes. Pusa-44 (0.28 g/ plant) and PB-1 (0.27 g/plant) genotypes were at par with respect to N uptake. In case of interactions Swarna genotypeunder NCPC treatment (0.44 g/plant) was recorded with significantly maximum N uptake than all other genotypes and treatment interactions.

Table-5 Effect of different nitrogen fertilizer treatments on total nitrogen accumulation (g/ plant) in shoot by five rice genotypes at heading stage

Treatments	Swarna	Pusa-44	PB-1	MTU 1010	N-22	**Mean**
Control	0.11	0.11	0.10	0.07	0.07	0.09
Urea	0.31	0.28	0.23	0.20	0.18	0.24
NCPC	0.44	0.38	0.36	0.31	0.24	0.35
NCBPC-1	0.34	0.31	0.29	0.27	0.20	0.28
NCBPC-II	0.39	0.33	0.34	0.30	0.22	0.32
Mean	0.32	0.28	0.27	0.23	0.18	
SEm (±)		G= 0.004 ,	T= 0.004,	G×T = 0.009		
CD (5%)		G= 0.01,	T= 0.01,	G×T = 0.03		

4. DISCUSSION

Plant roots may react to nitrogen application rates differently. According to Jian-Bo *et al*.[7] overall root growth of rice is increase as fertilizer application level increased. In our study, Overall analysis of root architecture revealed that all the fertilizer treatments significantly influence root growth. Significantly, higher root growth was recorded in polymer based N treatments as compared to conventional urea fertilizers. Hydrolysis and transformation of urea in moist soil is very rapid, resulting in high losses of nitrogen from soil. The use of clay polymer composites regulates the release of urea by retaining it for longer periods of time [12] which provides more opportunity to plant to take nitrogen from soil. All the treatments applied with NCPC, NCBPC-I and II (@75%) promotes better root growth in rice due to long last release of

UNDER PEER REVIEW

N from these treatments [15]. The NCPC treatments produced greater root length and surface area because of better slow release property as compared to NCBPC products.

Among genotypes maximum root growth was obtained in PB-1 and least root growth was recorded in pusa-44.Our results revealed that the important period for N uptake and root development in the rice plants was from initiation of tillering to the end of heading. During this period, acquisition of N is essential for plant growth. At the tillering stage, root morphology parameters were similar between cultivars. At the booting and heading stages, PB-1 had greater root length and root surface area than other genotypes in the study. Especially at heading stage, variations in root parameters between rice cultivars were more significant. Our findings were in agreement with Jian-Bo *et al*. [7].Liu et al. [16] showed that longer axial roots appeared to be important in maize for NUE. Under N deficient situation, a larger root system that resulted mainly from the longer primary roots contributed to the efficient N accumulation. At sufficient N supply, longer lateral roots are the main factor that contributed to N accumulation [17]. Besides that, rice rhizosphere nitrification for NUE has also been identified to be important in rice[7].

CONCLUSION

This study investigated the combined influence of rice genotypes and nitrogen sources on root morphology and N uptake. The results demonstrate significant variations in root traits among genotypes with different N treatments. Specifically, the genotypes Pusa Basmati-1 exhibited the highest overall root growth. Additionally, the application of NCPC/NCBPC based N treatments led to notable improvements in root growth compared to conventional urea and control treatments.The finding suggests that the use of NCPC/NCBPC based N-fertilizers holds promise for improving nitrogen-use efficiency in rice cultivation.Overall, this study underscores the importance of considering root morphology in conjunction with fertilizer application strategies to optimize nutrient acquisition in rice.

UNDER PEER REVIEW

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UNDER PEER REVIEW

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UNDER PEER REVIEW