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Research Article

Effects of Manganese on Yield and Yield Attributing Parameters of Rice (*Oryza sativa* L.)

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ABSTRACT

Background: *Manganese (Mn) being one of the micronutrients available in acid soils acts crucial role in crop plants. In Assam soil, its concentration is 3-52 ppm whereas in plants the critical limit is 2-3ppm. Although the effects Mn on plants have been well documented, information on its impacts on yield and yield components in upland rice crop grown in Assam was scanty, and deserved its investigation.*

Method: *A pot experiment was carried out to study the effects of Mn (0, 10,20,30 ppm Mn as* $MnSO_4H_2O$*) foliar spray (each* $1000cm^3$*) at vegetative stage i.e.70days after sowing, on yield and yield components of ten rice genotypes (Kanaklata, Mulagabharu, Kapilee, Disang, Kolong, Joymoti, Jyoti Prasad, Luit, Lachit and Chilarai) cultivated in Assam.*

Conclusion: *The lower dose of Mn (10ppm) significantly increased panicle length (16.29-37.46%), panicle weight (10.54-19.50%), panicle number per plant (4.54-13.63%), number of seeds per panicle (18.38-36.48%), test weight (7.21-29.15%), high density grains (5.59-30.45%), economic yield (14.40-28.03%), biological yield (32.58-47.70%), and harvest index (3.2-7.90%). 30ppm Mn affected adversely all the physiological attributes in the study. Among the ten genotypes, Kanaklata performed the best followed by Chilarai in the experiment.*

Keywords: *acid soil, Harvest index, High density grains, Manganese, Rice, Sterility, Yield.*

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop for more than fifty per cent of the world's population. The sustainable rice productivity in acid soil is expected if the 50% of the total yield losses due to abiotic stresses are mitigated. The use of micro nutrients like manganese (Mn) below a critical limit is crop specific. In India, the extent of arable and non arable acid soils (Harinkhere & Samadhiya, 2016) in North East Hill region is about 21 million comprising of Arunachal Pradesh (6.8 Mha), Assam (4.7 Mha), Meghalaya, (2.24 Mha), Manipur (2.19 Mha) and Mizoram (2.0 Mha).

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In Assam, Karbi Anglong district has relatively more area under acid soils (Kumar et al., 2016). In acid soils, Mn is abundant (3-52 ppm in Assam soil), and it's critical limit is 2-3ppm, whereas in plants it is 15-20 ppm g^{-1}dry weight based on species and genotypes, beyond which Mn becomes toxic to crop plants (Basumatary et al., 2014).

Manganese activates more than 35 enzymes in plants (Mousavi et al., 2011), and it catalyses splitting of water molecules during photolysis process of photosynthesis (Gardner et al., 1985; Humphrise, 2006; & Aref, 2012). Application of Mn especially on older leaves helps in photoassimilation (Sutedjo, 2008; & Agustina, 2011). Because, Mn influences in chlorophyll synthesis, and its presence is essential in Photo system II (Diedrick, 2010). Nevertheless, an excess of Mn is toxic for most plants (Millaleo et al., 2010). Both low and excess Mn depresses the growth of plants (Dube et al., 2002). Manganese stress increases the peroxidase activity linked to respiration in leaves, and stunts growth (Dube et al., 2001). There is paucity of information on the effects of Mn on rice crop grown in Assam. Hence, an investigation concerning how Mn brings about physiological changes in upland rice was undertaken in acid soil of Assam.

MATERIALS AND METHODS

A pot experiment (January-June, 2019) was carried out at the 'Stress Physiology' experimental site of the Department of Crop Physiology, Assam Agricultural University, Jorhat. The site is geographically located at 26°45′ N latitude, 94°12′ E longitude having an elevation of 87 m above mean sea level. As a subtropical region, the total rainfall received during the period was 292 mm with the highest in the month of June (149.5mm), and the lowest was in January (6.6 mm). The maximum bright sunshine hour was in the month of January (7.7hrs/day), and the minimum was in the month of May (1.9hrs/day). The relative humidity was in the range of 84-98%, during the experimental period. The soil was acidic in nature with low pH (4.92&5.62), moderate Mn contents (30.2&27.426ppm) initially and at harvesting time of the crop respectively. The rice genotypes *viz*., Kanaklata, Mulagabharu, Kapilee, Disang, Kolong, Joymoti, Luit, Jyoti prasad, Lachit, and Chilarai were shown in pots prefilled with sandy loamy sol mixed with FYM @50:50, moistened well prior to sowing the seeds thinly. The seedlings at 21 days after sowing (DAS) were transplanted in the experimental pots (following two factorial Completely Randomized Design), filled with the pot mixture (Acid mineral soil and FYM @50:50) for raising plants. NPK fertilizers @ 60:40:20 $Kgha^{-1}$ in the form of Urea, SSP & MoP were applied amounting 23.25g urea (half dose of N), 89.25g SSP, and 11.857g MoP (full doses) as basal; further 11.625g urea (2^{nd} half dose of N) at the maximum tillering stage of the crop. A constant water supply (2-3cm) was ensured from transplanting till seven days before harvesting along with other cultural operations like weeding and prophylactic measures from time to time. Mn (0, 10, 20 and 30ppm) as $MnSO_4.H_2O$ (MW:159.08g) solutions were misted on foliage of the rice crop varieties in three splits during tillering to heading stage (i.e. 70 DAS) weekly using hand sprayer. So, the total volume of the solution received by each genotype under respective treatment was $1000cm^3$. Care was taken to get rid of the drifting of the solutions either from one treatment to another or draining the excess of it from the leaves into the soil.

Five panicles were collected randomly from each variety under treatments. Length of panicle was measured from the base of the panicle to the tip of the spikelet, and average was recorded as panicle length in cm. The individual weight of five panicles was measured; the average was calculated and expressed in gram (g). Five plants in a hill were collected randomly at the time of harvesting from each pot. The number of panicles per plant was counted, and the average was recorded. Five panicles were collected randomly at the time of harvest from each pot. The number of filled grains per panicle was counted and the average was documented. Thousand filled grains were randomly selected from each seed lot of individually harvested pot, and weighed using an electronic balance after proper drying (with ≈14% moisture) at sunlight. Sterile seeds and high density (HD) grains in a seed lot from five panicles were separated using table salt solution of specific gravity: 1.20 as suggested by Barmudoi and Bharali (2016). For economical yield, seed weight from each sample plant was recorded, while in case of biological yield, the total weight of the sample plants excluding root portion was considered. Both the yield parameters were expressed as g/plant. The harvest index (HI) was calculated for each genotype as suggested by Nichi Provinch (1967).

RESULTS AND DISCUSSION

There were significant variations of panicle length due to Mn treatment and the varieties **(Table 1)**. Over all, the highest panicle length was observed at 10ppm Mn (23.889cm) followed by (>) 20ppm (21.776cm)>control (17.623cm), and the lowest was in case of 30ppm (15.512cm) irrespective of varieties. The panicle length increased significantly at10ppm Mn in Joymoti (37.46%) > Lachit (35.39%). In case of treatment 20 ppm Mn, the variety Lachit (32.62%) showed significant increase in the panicle length > Joymoti (27.64%). However, 30 ppm Mn, showed significant reductions in the panicle length (0.49 to 27.32%). On an average, among the genotypes, the highest panicle length was recorded in Disang (21.040cm)>Kanaklata (20.709cm)>Mulagabharu (20.271cm) while the lowest was recorded in Joymoti (18.284cm). These facts are in agreement with Zayed et al. (2011) who reported that plant height and panicle length were significantly higher when rice plant received Mn nutrition in comparison to the control.

Table 1. Variation of panicle length of rice crop under different manganese treatments

Panicle length (cm)					
Treatments (T)→ / Varieties (V)↓	**0 ppmMn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	19.520	26.175	21.070	16.070	20.709
Mulagabharu	19.385	23.160	22.080	16.460	20.271
Kapilee	19.430	24.045	21.070	15.260	19.951
Disang	19.570	25.050	22.495	17.045	21.040
Kolong	18.895	23.550	22.020	15.350	19.954
Joymoti	14.830	23.715	20.495	14.095	18.284
Luit	16.325	23.605	22.375	15.645	19.488
Jyoti prasad	16.335	23.180	22.355	16.250	19.530
Lachit	15.245	23.590	22.620	14.340	18.949
Chilarai	16.690	22.815	21.180	14.605	18.823
Mean	17.623	23.889	21.776	15.512	
	T	**V**	**T X V**		
S.Ed (±)	0.045	0.028	0.090		
CD	0.091	0.057	0.182		

There were significant differences of panicle weight among the Mn treatments and among the varieties **(Table 2)**. The highest panicle weight was observed at 10ppm Mn (6.481g) followed by (>) 20ppm (5.824g)> control (5.527g), and the lowest was at 30ppm Mn (4.736g) treatment. The panicle weight increased significantly at 10ppm Mn in Chilarai (19.50%) > Kanaklata (18.95%). In case of 20 ppm Mn, Kolong (11.44%) showed significant increase in the panicle weight > Lachit (9.51%) except variety Jyotiprasad (3.92%). However, at 30 ppm Mn, all the rice varieties showed significant reductions in the panicle weight (7.85 to 34.40%). On an average, among the genotypes, the highest panicle weight was recorded in Kanaklata (5.999g) > Mulagabharu (5.721g), Lachit (5.819g) while the lowest was recorded in Kolong (5.418g). Dube et al. (2002) in a field trial complied that yield parameters of rice crop especially plant biomass, panicle weight, grain weight, 1000 grain weight increased with increasing concentration of Mn up to 0.55 mg L^{-1} followed by a decrease with further increase in Mn.

Table 2. Variation of panicle weight of rice crop under different manganese treatments

Panicle weight (g panicle^{-1})

Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	5.730	7.070	6.050	5.145	5.999
Mulagabharu	5.655	6.550	5.775	4.905	5.721
Kapilee	5.470	6.115	5.740	4.410	5.434
Disang	5.410	6.220	6.000	4.745	5.594
Kolong	5.225	6.115	5.900	4.430	5.418
Joymoti	5.645	6.650	6.105	4.200	5.650
Luit	5.520	6.495	5.575	4.820	5.603
Jyoti prasad	5.560	6.335	5.350	5.115	5.590
Lachit	5.565	6.435	6.150	5.125	5.819
Chilarai	5.490	6.820	5.595	4.465	5.593
Mean	5.527	6.481	5.824	4.736	
	T	**V**	**T X V**		
S.Ed (±)	0.092	0.058	0.185		
CD	0.187	0.118	0.375		

There were significant variations of panicle number per plant due to Mn treatments and the varieties (**Table 3**). The highest panicle number per plant was observed in treatment 10ppm (6.275) followed by (>) 20ppm (5.750)> control (5.625), and the lowest was at 30ppm Mn (5.025). The panicle number per plant increased significantly at 10ppm Mn in variety Mulagabharu (13.63%) > Lachit (13.04%). In case of 20 ppm Mn, Mulagabharu (5.00%) showed significant increase in panicle number per plant> Luit (4.10%) except Disang (5.88%). However, at 30 ppm Mn, all the rice varieties showed significant reductions in the panicle number per plant (8.00 to 26.66%). Overall, there was higher panicle number per plant in varieties under treatment of 10ppm Mn as compared to other doses of Mn treatments. On an average, among the genotypes, the highest panicle number per plant was recorded in Kanaklata (6.875) > Joymoti (6.625)>Chilarai (6.500), while the lowest was recorded in Disang (4.375). Li et al. (2016) reported that 250 mg $MnSO_4$ pot^{-1} might increase panicle number (20-43%) and 1000 grain weight (5-13%) for Meixiangzhan and Nongxiang18 rice varieties.

Table 3. Variation of panicle number per plant of rice crop at harvest under different manganese treatments

Panicle number					
Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	6.750	7.500	7.000	6.250	6.875
Mulagabharu	4.750	5.500	5.000	3.750	4.750
Kapilee	5.250	5.500	5.250	4.500	5.125
Disang	4.500	5.000	4.250	3.750	4.375
Kolong	6.000	6.750	6.250	5.500	6.125
Joymoti	6.500	7.250	6.750	6.000	6.625
Luit	5.750	6.500	6.000	5.250	5.875
Jyoti prasad	5.500	6.000	5.500	4.750	5.438
Lachit	5.000	5.750	5.000	4.250	5.000
Chilarai	6.250	7.000	6.500	6.250	6.500
Mean	5.625	6.275	5.750	5.025	
	T	**V**	**T X V**		
S.Ed (±)	0.354	0.224	0.707		
CD	0.454	0.454	N/A		

Manganese treatment caused significant effects on number of seeds per panicle of the rice varieties (**Table 4.**). The highest number of seeds per panicle was observed at treatment 10ppm (81.689) followed by (>) 20ppm (68.553)> control (58.771), and the lowest was at 30ppm Mn (51.740). The number of seeds per panicle increased significantly at 10ppm Mn in Disang (36.48%) > Joymoti (35.44%). In case 20 ppm Mn Lachit (23.10%) showed significant increase in the number of seeds per panicle > Kanaklata (18.38%). However, at 30 ppm Mn, all the rice varieties showed significant reductions in the number of seeds per panicle (2.76 to 28.40%). Overall, there was higher number of seeds per panicle in varieties at 10ppm Mn as compared to other doses of Mn. On an average, the highest number of seeds per panicle was recorded in Kanaklata (70.670)> Kolong (67.200)>Luit (65.478), while the lowest was recorded in Chilarai (62.783). Sharma et al. (1991) studied the effects of Mn on Maize (*Zea mays* L. cv. G2) with 0.55 mg L^{-1} (sufficient), or 0.0055 mg L^{-1} (deficient) Mn concentration in the medium of sand. Manganese-deficient plants developed visible deficiency symptoms, showed poor tassel and delayed anther development. Compared to Mn-sufficient plants, Mn-deficient plants produced fewer and smaller pollen grains with reduced cytoplasmic contents. Manganese deficiency reduced invitro germination of pollen grains significantly. Ovule fertility was not significantly affected by Mn. But in Mn-deficient plants, seed-setting and development was reduced significantly. Sawidis and Reiss (1995) studied the influence of different concentrations of the heavy metals including manganese (Mn^{2+}) on pollen germination and tube growth of *Lilium longiflorum* using light microscopy. Although Mn showed lighter adverse effects with 3 µM and 100 µM, swelling of the tip region and abnormal cell wall organization for the pollen tube growth were detected. In our study, too, decrease in number of seeds might be due to the pollen deformities brought about by higher Mn concentration.

Table 4.Variation of number of seeds panicle per of rice crop under different manganese treatments

Number of seeds panicle^{-1}					
Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	63.035	88.195	77.230	54.220	70.670
Mulagabharu	55.230	78.565	65.410	52.785	62.998
Kapilee	64.270	78.750	66.745	48.975	64.685
Disang	55.460	87.315	66.640	47.295	64.178
Kolong	62.450	80.890	70.265	55.195	67.200
Joymoti	56.405	87.380	65.920	50.275	64.995
Luit	58.405	78.820	70.795	53.890	65.478
Jyoti prasad	63.000	78.745	64.610	49.065	63.855
Lachit	55.275	79.220	71.885	53.790	65.043
Chilarai	54.180	79.010	66.035	51.905	62.783
Mean	58.771	81.689	68.553	51.740	
	T	**V**	**T X V**		
S.Ed (±)	0.406	0.257	0.812		
CD	0.823	0.521	1.647		

The test weight of the rice varieties varied significantly due to Mn treatments **(Table 5.**). The highest test weight was recorded at 10ppm Mn (23.986g) followed by (>) 20ppm Mn (21.395g)>control (20.288g), and the lowest was at 30ppm Mn (18.307g). The test weight increased significantly at 10ppm Mn in variety Luit (29.15%) > Lachit (19.32%) as compared with control. In case of 20 ppm Mn, the variety Luit (16.38%) showed significant increase in the test weight of rice seed>Disang (10.10%). However, at 30 ppm Mn, all the rice varieties showed significant reductions in the test weight of rice (3.90 to 38.89 %) except Kolong (2.93%). On an average, among the genotypes, the highest test weight was recorded in Jyoti prasad (27.113g) followed by Lachit (25.016g), Joymoti (23.489g) while the lowest was recorded in the genotype Mulagabharu (17.176g). Singh and Patra (2017) reported that the test weight, tillers/m^2, plant height, grain and straw yield of wheat increased linearly up to10 kg Mn ha^{-1}.

Table 5. Variation of test weight of rice crop under different manganese treatments

Test weight (g)					
Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	18.010	19.410	18.405	17.050	18.219
Mulagabharu	16.885	18.220	17.350	16.250	17.176
Kapilee	20.240	23.250	20.550	16.685	20.181
Disang	17.900	20.845	19.920	13.950	18.154
Kolong	20.540	24.055	21.450	21.160	21.801
Joymoti	22.190	27.250	23.230	21.285	23.489
Luit	17.960	25.350	21.480	12.935	19.431
Jyoti prasad	26.350	31.150	27.650	23.300	27.113
Lachit	23.900	29.650	24.615	21.900	25.016
Chilarai	18.900	20.680	19.300	18.555	19.359
Mean	20.288	23.986	21.395	18.307	
	T	**V**	**T X V**		
S.Ed (±)	0.686	0.434	1.372		
CD	1.392	0.880	2.783		

There were significant differences of high density (HD) grains due to Mn treatments upon the rice crop (**Table 6**.).The highest HD grains were found at 10ppm Mn (80.53) > 20ppm Mn (70.916)>control (62.416), and the lowest of it (51.418) was at 30ppm Mn. The HD grain was higher significantly at 10ppm Mn in Joymoti (32.49%) followed by (>) Disang (30.45%). At 20 ppm Mn, Disang (22.54%) showed significant increase in the HD grains > Jyotiprasad (14.22%). However, at 30 ppm Mn all the ten rice varieties reduced HD grains (3.21 to 17.86%) significantly. Overall, there were higher HD grains in varieties treated with 10ppm Mn as compared to other doses of Mn treatment. On an average, among the genotypes, the highest HD grains were recorded in Chilarai (74.675)> Mulagabharu (70.855)> Kolong (69.849) while the lowest was recorded in Disang (55.223). Timotiwu et al. (2017) reported that application of 5 ppm Mn along with 50 ppm of Si increased the filled grain weight and grain yield of rice crop. Venkateswarlu et al. (1977) opined that the grain yield can be enhanced by increasing the HD grains in rice. The percentage contribution of HD grains to total grain emerges as a major determinant of grain yield. Thus, cultivars possessing a higher production of HD grains would be advantageous even under excess Mn stress condition.

Table 6. Variation of high density (HD) grains of rice crop under different manganese treatments

HD grains (%)					
Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	62.900	81.990	74.130	57.335	69.089
Mulagabharu	65.460	81.895	73.815	62.250	70.855
Kapilee	57.480	79.885	65.495	39.765	60.656
Disang	43.900	74.350	66.440	36.200	55.223
Kolong	68.790	79.995	73.140	57.470	69.849
Joymoti	52.840	85.335	54.350	34.985	56.878
Luit	68.360	79.785	78.170	51.930	69.561
Jyoti prasad	59.480	80.580	73.705	53.280	66.761
Lachit	68.500	79.530	72.180	58.480	69.673
Chilarai	76.450	82.040	77.730	62.480	74.675
Mean	62.416	80.539	70.916	51.418	
	T	**V**	**T X V**		
S.Ed (±)	1.139	0.721	2.279		
CD	2.311	1.462	4.623		

There were significant variations of grain sterility in the varieties due to Mn treatments (**Table 7**). The highest grain sterility was observed at 30ppm Mn (48.583%) followed by (>) control (37.584%)>20ppm Mn (29.085%), and the lowest was at 10ppm Mn (19.462%). The sterility per cent increased significantly at 30 ppm Mn in Joymoti (17.85%) > Kapilee (17.71%). In case of 10 ppm Mn, Disang (22.54%) showed significant reductions in the sterility per cent of rice seed > Jyotiprasad (14.23%). At 20 ppm Mn, all the rice varieties showed significant reductions in the sterility (5.59 to 32.50%). Overall, there was higher grain sterility in varieties at 30ppm Mn as compared to other doses of Mn. On an average, among the genotypes, the highest grain sterility was recorded in Disang (44.778%) > Joymoti (43.123%)>Kapilee (39.344%), while the lowest was recorded in the genotype Chilarai (25.325%). Jhanji et al. (2015) studied Mn in relation to differential production and allocation of carbohydrates between source and sink organs of diverse wheat genotypes**.** It unravelled the relationship between Mn efficiency of a genotype, production and partitioning of carbohydrates during grain filling period. The plants were grown with two treatments of Mn viz. low Mn (no Mn fertilizer, 0 ppm) and high Mn (50 mg Mn kg^{-1} soil applied as $MnSO_4.H_20$). The deficiency of Mn hampered the production of dry matter and carbohydrates in Mn-efficient and Mn-inefficient genotypes differentially. Spikelet sterility, one of the constraints in rice productivity, influenced the grain yield directly by limiting the number of filled grains per unit area (Vergara et al., 1966). The lower grain yield due to any unfavourable factor viz., low light, is caused mostly by high sterility of spikelets. It possess a consequent reduction in the number of HD grains per panicle per unit ground area, and imbalance in source and sink relationship in rice (Yoshida & Parao, 1976). Rao et al. (1986) pointed that the partially filled grains appear in declining order with the initiation of grain-filling, and the number of grain increasers linearly with time.

Table 7. Variation of grain sterility of rice crop under different manganese treatments

Grain sterility (%)					
Treatments (T)→ / Varieties (V)↓	**0 ppm Mn (Control)**	**10 ppm Mn**	**20 ppm Mn**	**30 ppm Mn**	**Mean**
Kanaklata	37.100	18.010	25.870	42.665	30.911
Mulagabharu	34.540	18.105	26.185	37.750	29.145
Kapilee	42.520	20.115	34.505	60.235	39.344
Disang	56.100	25.650	33.560	63.800	44.778
Kolong	31.210	20.005	26.860	42.530	30.151
Joymoti	47.160	14.665	45.650	65.015	43.123
Luit	31.640	20.215	21.830	48.070	30.439
Jyoti prasad	40.520	19.420	26.295	46.720	33.239
Lachit	31.500	20.470	27.820	41.520	30.328
Chilarai	23.550	17.960	22.270	37.520	25.325
Mean	37.584	19.462	29.085	48.583	
	T	**V**	**T X V**		
S.Ed (±)	1.139	0.721	2.279		
CD	2.311	1.462	4.623		

There were significant effects of Mn treatment (**Fig.1.**) on economic yield of the rice varieties. The highest economic yield was recorded at 10ppm Mn (13.608g) followed by (>) 20ppm Mn (11.160g)> control (10.384g), and the lowest was at 30ppm Mn (7.898g). On an average, among the genotypes, the highest economic yield was recorded in Kanaklata (13.856g) > Joymoti (12.616g)>Chilarai (12.170g) while the lowest was recorded in Disang (8.234g). The economic yield of rice varieties increased significantly at 10 ppm Mn in Chilarai (28.03%)> Kanaklata (27.09%). In case of treatment 20 ppm Mn, Kolong (15.04%) showed significant increase in the economic yield> Joymoti (10.98%), whereas the variety Jyotiprasad (3.98%) had reductions in economic yield as compared with the control. At 30 ppm Mn, all the rice varieties showed significant reductions in the economic yield (20.18 to 45.52%). These findings are supported by Barros et al. (2019) who reported that among the treatments (0.5, .0, 1.5, 2.0 and 2.5 kg ha^{-1}), the production of the highest grain yield (7,375 kg ha^{-1}) was at 1.5 kg ha^{-1} Mn applied as foliar at 15 days after emergence of rice sedlings. Zulfiqar et al. (2020) studied effects of Mn (0.02 M solution) in improving the productivity of rice in transplanted flooded rice and direct-seeded aerobic rice production systems. Mn nutrition augmented considerably the economic yield. Similar findings were also reported by Kumar et al. (2017) who conducted an experiment comprising 3 levels of manganese concentration 0, 5 and 10 kg ha^{-1} upon rice variety HUBR2- 1. In the study, Mn 5 kg ha^{-1} showed the maximum growth attributes and yield of rice.

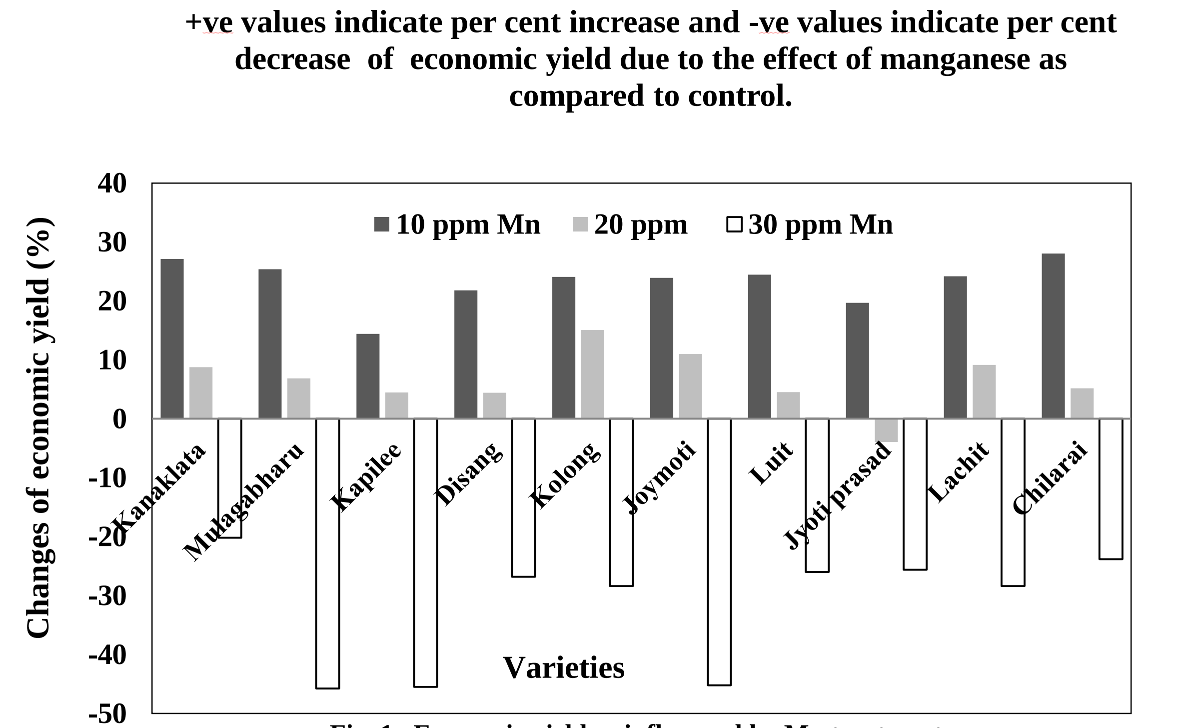

Fig. 1. Economic yield as influenced by Mn treatments

There were significant changes of biological yield because of Mn treatment, and the varieties (**Fig.2.**). The highest biological yield was observed at 10ppm Mn treatment (50.053g) followed by (>) 20ppm (32.806g)> control (27.848g), and the lowest was at 30ppm (19.916g) Mn. On an average, among the genotypes, the highest biological yield was recorded in Kanaklata (46.094g) >Joymoti (43.531g)> Chilarai (35.625g) while the lowest was recorded in Disang (25.816g). The biological yield of rice varieties increased significantly at 10 ppm Mn in Joymoti (61.18%) > Jyoti prasad (47.70%). At 20 ppm Mn, Chilarai (24.75%) showed significant increase in the biological yield>Lachit (24.51%) but Jyoti prasad (1.05%) showed reductions in the biological yield of the rice. However, at 30 ppm Mn, all the rice varieties showed significant reductions in the biological yield (16.80 to 67.80%). Ibrahim et al. (2018) studied the effects of Mn in the form of $MnSO_4$ (0, 5, 10, 15 and 20 kg ha^{-1}) on the growth and yield of rice grown in soil containing low manganese content (0.70 mg kg^{-1}). Manganese @10 kg ha^{-1} produced the tallest plant, higher number of tillers, the highest grain yield and highest dry matter weight. Wang et al. (2015) also reported that rice vegetative growth was inhibited by supra optimal concentration of Mn, induced wilting in older leaves. So, shoot height decreased significantly with increase in Mn concentration. Narender and Malik (2016) also reported that the highest yields of grain and straw were recorded with 25 mg Mn kg^{-1} and 90 mg NO_3^- kg^{-1} soil application. A study conducted by Abbas et al. (2011) reported that wheat economic yield, a component of biological yield was increased significantly at Mn (0, 4, 8, 12, 16 $Kgha^{-1}$) with NPK fertilizers (@150-100-60$Kgha^{-1}$). The highest economic yield was recorded at 16kg $Mnha^{-1}$ in the experiment.

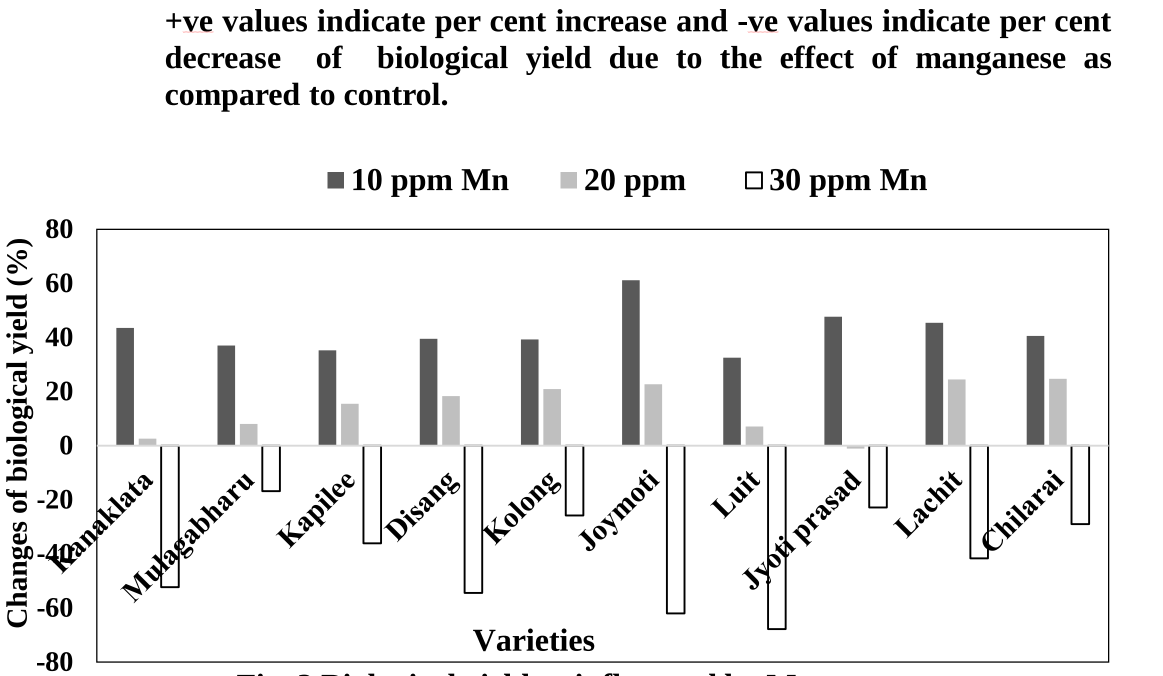

Fig. 2.Biological yield as influenced by Mn treatments

There were significant changes of HI due to Mn treatment and the varieties **(Fig.3.).** The highest HI was observed at 10ppm Mn (43.9%) followed by (>) 20ppm Mn (41.2%)> control (39.4%), and the lowest was in 30ppm (36.8%). On an average, among the genotypes, the highest HI was recorded in Kanaklata (47.4%) > Joymoti (46.1%)>Chilarai (47.4%) while the lowest HI was recorded in Disang (34.4%). The HI increased significantly at 10 ppm Mn in Luit (7.50%) > Mulagabharu (5.10%) as compared with control. In case of 20 ppm Mn, Kolong (3.60%) showed significant increase in HI > Kanaklata (7.60%). However, at 30 ppm Mn, all the rice varieties showed significant reductions in HI (0.70 to 5.00%). Shahrajabian et al. (2020) also found increases in HI along with high values of thousand grain weight, grain yield, grain protein and manganese content of grain with the application of manganese sulfate.

It's concluded that as a micronutrient, Mn played vital roles in plant growth and development thereby the yield and yield attributes in rice crop grown under the acidic soil condition. Manganese is dose responsive. So, when Mn was applied in lower quantity (10ppm Mn as $MnSO_4.H_2O$), it acted positively, but at higher quantity beyond 10ppm Mn, it was detrimental to physiology including economic yield of rice crop. Among the ten genotypes tested, the genotype Kanaklata performed the best followed by Chilarai in the investigation.

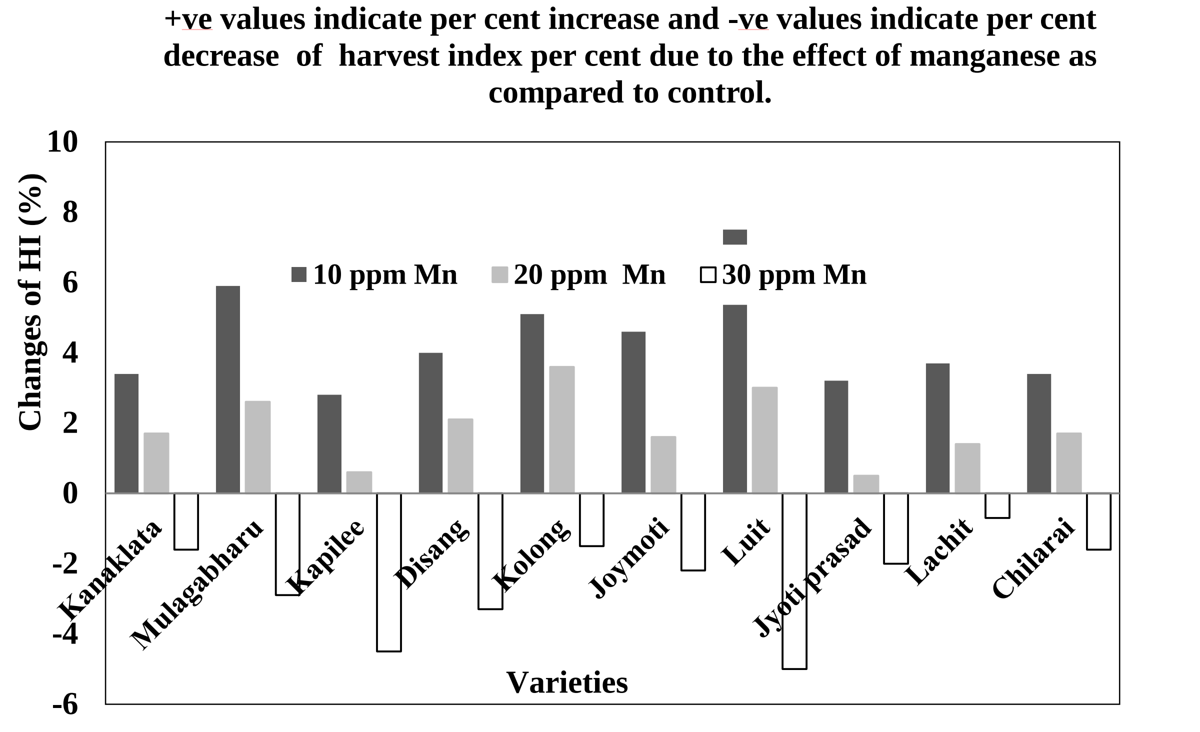

Fig. 3. Harvest index (HI) as influenced by Mn treatments

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REFERENCES

Abbas, G., Khan, M. Q., Khan, M. J., Tahir, M., Ishaque, M., & Hussain (2011). Nutrientuptake, growth and yield of wheat (*Triticum aestivum* L.) as affected by manganese application. *Pak. J. Bot.*, *43*(1), 607-616.

Agustina, L. (2011). Micro nutrient I (Fe, Mn, Zn, Cu, B, Mo dan Cl) importance of nutrient deficiency and toxicity (in Indonesian). Post-Graduate Program University of Brawijaya. *Malang*: 25-32.

Aref, F. (2012). Manganese, iron, and copper contents in leaves of maize plant (*Zea mays* L.) grown with different boron and zinc micronutrients. African *Journal of Biotechnology 11*(4), 896-903.

Bandeira Barros, H., Emiliano Souza, M., Sandro Dario, A., de Almeida Santos, M. P., & Nascimento, V. L. (2019). Manganese foliar supplementation impacts rice yield in tropical lowlands. *J. Plant Nutr*. *42*(14), 1567-1574.

Barmudoi, B., & Bharali, B. (2016). Effects of light intensity and quality on physiological changes in winter rice (*Oryza sativa* L.). *International Journal of Environmental and Agriculture Research*, *2*(3), 2454-1850.

Basumatary, A., Rashmi, B., & Medhi, B. K. (2014). Spatial variability of fertility status of soils of upper Brahmaputra valley zone of Assam. *Asian Journal of Soil Science*, *9*(1), 142-148.

Diedrick, K. (2010). Manganese fertility in soybean production. *Pioneer Hi-Bred Agronomy Sciences 12*(2), 124-127.

Dube, B. K., Khurana, N. E. E. N. A., & Chatterjee, C. (2002). Yield, physiology and productivity of rice under manganese stress. *Indian*

Journal of Plant Physiology, *7*(4), 392-395.

Dube, B. K., Sinha, P., & Chatterjee, C. (2001). Relative susceptibility of black gram genotypes to manganese deficiency *Indian J. Plant Physiol. 6*, 61-66.

Gardner, F. P., Pearce, R. B., & Mitchell, R. L. (1985). Physiology of crop plants. *The Iowa State University Press. Iowa.* 98-129.

Goodroad, L. L., & Jellum, M. D. (1988). Effect of N fertilizer rate and soil pH on N efficiency in corn. *Plant and soil*, *106*(1), 85-89.

Harinkhere, S., &Samadhiya, V. K. (2016). Responses of rice genotypes grown under acidic and neutral soils of northern hills of Chhattisgarh, India. *Plant Archives*, *16*(1), 384-386.

Humphrise, J. M. (2006). Handbook of plant nutrition. Edited by Allen Barker, V., & *David, J. Pilbeam.* CRC Press. New York. 351–366.

Ibrahim, F., Anebi, S. I., & Michael, A. P. (2018). Response of Rice (Oryza sativa) to the Application of Manganese in Makurdi, Benue State, Nigeria. *Journal of Horticulture and Plant Research*, *17*.

Jhanji, S., Sadana, U. S., & Shukla, A. K. (2015). Manganese efficiency in relation to differential production and allocation of carbohydrates between source and sink organs of diverse wheat genotypes. *Acta physiologiae plantarum*, *37*(2), 38.

Kumar, A., Sen, A., Upadhyay, P. K., & Singh, R. K. (2017). Effect of Zinc, Iron and Manganese Levels on Quality, Micro and Macro Nutrients Content of Rice and Their Relationship with Yield. *Communications in Soil Science and Plant Analysis*, *48*(13), 1539-1551.

Kumar, R., & Meena, V. S. (2016). Towards the Sustainable Management of Problematic Soils in Northeast India. In *Conservation Agriculture*. Springer, Singapore. pp. 339-365.

Li, M., Ashraf, U., Tian, H., Mo, Z., Pan, S., Anjum, S. A., & Tang, X. (2016). Manganese-induced regulations in growth, yield formation, quality characters, rice aroma and enzyme involved in 2-acetyl-1-pyrroline biosynthesis in fragrant rice. *Plant Physiology and Biochemistry*, *103*, 167-175.

Millaleo, R., Reyes-Díaz, M., Ivanov, A. G., Mora, M. L., & Alberdi, M. (2010). Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. *Journal of soil science and plant nutrition*, *10*(4), 470-481.

Mousavi, S. R., Shahsavari, M., & Rezaei, M. (2011). A General Overview on Manganese (Mn) Importance for Crops Production. *Australian Journal of Basic and Applied Sciences 5*(9), 1799-1803.

Narender & Malik, R. S. (2016). Effect of nitrate and manganese application on Manganese pools in soil and its uptake in wheat (*Triticum aestivum* L.) *An international quarterly journal of environmental sciences. 10*(1&2), 97-103.

Nichi Provinch, A. A. (1967). In: Nichi-Provinch, A. A. (eds.): Photosynthetic Production System, pp. 3-36.

Rao, S. P. B., Venkateswrulu, V., & Rao, S. (1986). Studies on grain filling and grain growth rate of different rice varieties in relation to chlorophyll content. *Indian Journal of Plant Physiology*, *29*(2), 160-165.

Sawidis, T., & Reiss, H. D. (1995). Effects of heavy metals on pollen tube growth and ultrastructure. *Protoplasma*, *185*(3-4), 113-122.

Shahrajabian, M. H., Khoshkharam, M., Sun, W., & Cheng, Q. (2020). The Impact of Manganese Sulfate on Increasing Grain Yield, Protein and Manganese

Content of Wheat Cultivars in Semi Arid Region. *Journal of Stress Physiology & Biochemistry*, *16*(1).

Sharma, C. P., Sharma, P. N., Chatterjee, C., & Agarwala, S. C. (1991). Manganese deficiency in maize affects pollen viability. *Plant and soil*, *138*(1), 139-142.

Singh, V. I. N. A. Y., & Patra, A. B. H. I. K. (2017). Effect of FYM and manganese on yield and uptake of nutrients in wheat (*Triticum aestivum* L.). *Annals of Plant and Soil Research*, *19*(4), 381-384.

Sutedjo, M. M. (2008). Fertilizer and how to fertilize (in Indonesian). RinekaCipta. Jakarta: 177.

Timotiwu, P. B., Nurmauli, N., & Yulianti, P. (2017). Application of manganese and silica through leaves and their effect on growth and yield of rice in rice field in village of Sinar Agung, Sub-District of PulauPanggung, district of Tanggamus, Lampung Province, Indonesia. *MAYFEB Journal of Agricultural Science*, *4*, 48-60.

Venkateswarlu, B., Prasad, V. V. S. S., & Rao, A. V. (1977). Effects of low light intensity on different growth phases in rice (*Oryza sativa* L.). *Plant and Soil*, *47*(1), 37-47.

Vergara, B. S., Tanaka, A., Lilis, R., & Puranabhavung, S. (1966). Relationship between growth duration and grain yield of rice plants. *Soil Science and Plant Nutrition*, *12*(1), 31-39.

Wang, Wei, Xue Qiang Zhao, Zhen Min Hu, Ji Feng Shao, Jing Che, Rong Fu Chen, Xiao Ying Dong, and Ren Fang Shen. (2015). "Aluminium alleviates manganese toxicity to rice by decreasing root symplastic Mn uptake and reducing availability to shoots of Mn stored in roots." *Annals of botany 116*(2), 237-246.

Yoshida, S., & Parao, F. T. (1976). Climatic influence on yield and yield components of lowland rice in the tropics. *Climate and rice*, *20*, 471-494.

Zayed, B. A., Salem, A. K. M., & El Sharkawy, H. M. (2011). Effect of different micronutrient treatments on rice (Oriza sativa L.) growth and yield under saline soil conditions. *World J. Agric. Sci*, *7*(2), 179-184.

Zulfiqar, U., Hussain, S., Ishfaq, M., Ali, N., Yasin, M. U., & Ali, M. A. (2020). Foliar manganese supply enhances crop productivity, net benefits, and grain manganese accumulation in direct-seeded and puddled transplanted rice. *J. Plant Growth Regul.*, pp. 1-18.