Madras Agric. J., 99 (7-9): 548-552, September 2012
https://doi.org/10.29321/MAJ.10.100136

Nutrient Management on Soil Health, Nutrient Uptake and Yield of Maize under Temporary Submerged Condition in Mollisol

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A field experiment was conducted during *Kharif* 2010 with a view to find out the effect of different integrated nutrient management practices on soil quality parameters, growth, yields and yield attributes and nutrient uptake by maize (PEHM-5) under managed temporary excess soil moisture stress at knee high stage in mollisol. Results showed an improvement in soil quality parameters in plots supplied with organic sources either individually or combination of all with 100% NPK fertilizers to that grown with inorganics alone or no fertilizers. Bulk density was lowest under combined application of vermicompost, zinc, PSB and *Azospirillum* with 100% NPK but applied $ZnSO_4$ increased bulk density to a maximum of 1.38 Mg m^{-3}. Inoculation of biofertilizers along with vermicompost enhanced organic carbon by 0.02 - 0.14 per cent over other treatments. Availability of N, P, K and Zn was significantly influenced by applied organic sources with chemical fertilizers. Treatments received 100% NPK along with zinc, *Azospirillum*, PSB and vermicompost significantly recorded higher values of 187.32, 31.96, 178.35 and 2.71 kg ha^{-1} available N, P, K and Zn, respectively, but individual application of *Azospirillum*, PSB and zinc responded to least availability of zinc, N and P, respectively. Higher total uptake of N, P, K and Zn was recorded with combined application of organic and inorganic inputs with 100% NPK followed by 100% NPK+ vermicompost. Nutrient management practices had significant effect on growth, yields and yield attributing parameters; however nodes with brace roots and ASI were not significantly affected. Different organic and inorganic combinations produced 144-917 kg ha^{-1} more grain yield over 100% NPK whereas reduced by 1237-2154 kg ha^{-1} to the treatment subjected to no submergence. Inclusion of *Azospirillum* and PSB with 100% NPK gave statistically on par grain yields. Maize plants grown with vermicompost, 125% NPK and combination of all inputs showed in general, lower net photosynthetic rate, transpiration rate and leaf temperature, respectively, while higher leaf diffusive resistance to that of normal condition. Integrated use of biofertilizers and vermicompost with 100% NPK was found to be the best for maize production under excess soil moisture stress.

Key words: Temporary water logging, maize, nutrient management, biofertilizers, physiological parameters, mollisol

Maize (*Zea mays* L) is one of the most important cereal crops and ranks third after rice and wheat. In India, *Kharif* season (June- October) is the main growing season in most parts of the country. Among the various abiotic stresses, excess soil moisture (ESM) stress at early stage is the most important constraint for maize production and productivity. Maize cannot withstand excessive soil moisture in rhizosphere, caused by temporary water logging or flooding due to excessive rainfall or poor drainage or high ground water table or heavy soil texture. In South and Southeast Asia alone, over 18% of total maize growing areas are greatly affected by flood and water logging problem (Zaidi *et al.,* 2009). In India, excess soil moisture during *kharif* season is one of the most serious constraints and out of total 8.17 million hectare area under maize, about 2.5 million hectare is affected by excess soil moisture, causing great losses in maize production by 25-30% almost every year (DMR, 2001).

The climate of the *tarai* is humid sub tropical with an annual rainfall of >1400 mm, of which more than 85% is received during monsoon season from June to September with a very erratic and heavy rainfall in almost every year. The soil is heavy textured with poor drainage and the dominant cropping system is rice-wheat for the last few decades resulting in gradual decline especially in nitrogen and zinc in most of the area. *Tarai* region occupies the main growing area for maize in Uttarakhand state where prolonged excess soil moisture owing to heavy precipitation as well as shallow water table

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during *kharif* season is the main constraint, often hinder the desired yield potential.

Maize responds well to proper irrigation and nitrogen management practices and has relatively more nitrogen use efficiency of about 50 per cent; but under poor management viz, poor water supply or excessive soil water will result in less availability of nitrogen. Since maize requires higher amount of macro and micronutrients in comparison to other crops, a proper nutrient management system is needed to fulfill the optimum nutrient requirement. The use of nutrients either through chemical fertilizers or along with organic sources, nutrient uptake behavior and yield sustainability in maize under ESM condition has not received much attention so far.

In view of this severe problem in maize, the present experiment was conducted to find out the best nutrient management practice to sustain soil health and productivity under waterlogged condition.

Materials and Methods

A field study was conducted during *kharif* 2010 with early maturing single cross hybrid maize variety PEHM-5 at Pantnagar. The soil of the experimental field was calcareous alluvium with normal pH (7.2), medium in organic carbon (7.3 g kg^{-1}), low in available nitrogen (187 kg ha^{-1}) and medium in phosphorus (18.5 kg ha^{-1})and potassium (155.6 kg ha^{-1}) and classified as fine silty, mixed hyperthermic *Aquic Hapludoll* (Deshpande *et al.*, 1971). The nine treatment combinations were; No fertilizer (T1), 100% NPK (T2), 125% NPK (T3), 100% NPK+Zn (T4), 100% NPK + *azospirillum* (T5), 100% NPK + *PSB* (T6), 100%NPK+Vermicompost @5t ha^{-1} (T7), 100% NPK+Zn+*Azospirillum* +*PSB*+ Vermicompost @ 5t ha^{-1} (T8) and 100% NPK (T9) laid out in randomized block design replicated thrice. In treatment T9, maize was grown in normal condition while in rest of the treatments, temporary flooding was started at 30 days after sowing (DAS) at knee high stage for a period of 7 days by keeping continuous submergence with an average depth of ponding of about 5 cm. After 7 days of ponding, water was completely drained out from each plot. In 100% NPK (120N, 60P and 40K kg ha^{-1}) and 125% NPK treatment, one third quantity of nitrogen and full phosphorus and potassium were applied as basal and remaining two third nitrogen was applied as topdressing in two equal splits at knee high and tassel emergence stages. Full doses of zinc through $ZnSO_4$@ 25 kg ha^{-1} and vermicompost @ 5 t ha^{-1} in the respective treatments were also applied as basal. The properly inoculated seeds with *Azospirillum* and phosphorus solubilizing bacteria (*PSB*) cultures were sown immediately after inoculation. The maize seed was sown on July 03, 2010 manually in well prepared beds at the spacing of 60 cm x 20 cm. The recommended cultural practices, except execution of temporary water logging were adopted to raise the crop during the season.

Results and Discussion

Effect on plant growth and yield attributes

The growth and yield parameters of crop among different nutrient management practices were significantly influenced by the temporary waterlogging condition (Tables 2 and 3). Treatment T8 in general, had recorded the maximum values of all attributes whereas T1 (no fertilizer) was the least as compared to other waterlogged treatments. Plant population under waterlogged condition ranged from 62.4 -70.4 thousand ha^{-1} which was decreased by 10.5 - 20.7% over normal conditions. This decrease in plant population has significant effect on reduction in grain yield. Huseyin *et al*. (2003) reported that the grain yield had increased with increasing plant density up to 90 thousand ha^{-1}, but slightly decreased at 100 thousand ha^{-1}. Among the waterlogged treatments, T8 had recorded higher plant population by 3.74 -16.44 thousand ha^{-1} over others but significantly higher over T1, T2 and T5. Addition of Zn, 25% NPK, *PSB* or *Azospirillum* separately did not increase the plant population over 100% NPK alone (T2) . Plant height in different waterlogged treatments decreased from 19.6 - 39.8 % as to that of normal condition. The decrease in plant height might be due to insufficient aeration and less availability of nutrients. The combined application of Zn + *Azospirillum* + *PSB* + vermicompost with 100% NPK increased maximum plant height (26.2 cm) followed by *Azospirillum* inclusion (16.1 cm) over 100% NPK indicated that these sources enhanced the plant height under waterlogged condition. Temporary waterlogging of one week drastically reduced the 100 grain weight by 23.8 – 31.4 % over normal condition and was the main cause for low grain yield. However, the addition of different organic and inorganic sources either alone or in combination with chemical fertilizer in general, did not significantly influence this yield controlling factor. Waterlogged led to significant reduction in grain yield over normal condition (Zaidi *et al.*, 2004,

Table 1. Effect of organic and inorganic sources on grain yield under temporary waterlogged conditions

Particular	% grain yield increase over 100% NPK	% grain yield decrease over normal condition
25% extra NPK	7.29	36.14
Zinc @ 25 kg ha^{-1}	7.70	35.90
PSB	4.55	37.77
Azospirillum	6.09	36.93
Vermicompost @ 5 t ha^{-1}	12.79	32.87
Combination of Zn, *PSB, Azospirillum and v*ermicompost	28.95	23.25

Table 2. Growth parameters as influenced by different nutrient management practices under normal and temporary waterlogged conditions

Treatment	Plant height (cm)	Ear height (cm)	Plant population (000' ha^{-1})	Number of cobs ha^{-1}	100- grain weight (g)	Cob yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
T1	134.50	81.3	56.43	54.7	18.19	3451	4256	2038
T2	153.47	87.1	64.10	62.4	19.19	4378	5389	3167
T3	161.93	91.4	68.67	64.2	19.43	4838	5600	3398
T4	153.80	93.5	68.47	64.4	19.19	5263	5611	3411
T5	169.53	87.5	64.93	63.1	19.11	4562	5445	3356
T6	161.23	90.4	67.87	63.1	19.19	4780	5400	3311
T7	163.57	97.3	69.13	66.0	19.26	5312	5755	3572
T8	179.67	98.1	72.87	71.6	20.19	6884	6032	4084
T9	223.53	105.3	78.70	83.5	26.50	8742	8278	5321
SEm±	2.95	1.6	2.10	2.1	0.65	162	102	53
CD *(P=0.05)*	8.85	5.0	6.30	6.5	1.94	488	307	160

Zhou, 2010). The grain yield without fertilizer (T1) was severely reduced by 38.4-50.1% and 61.7% over other waterlogged treatments and normal condition, respectively. Addition of *PSB* with 100% NPK did not enhance grain yield significantly under temporary water logging over 100% NPK but significantly reduced over normal condition (Table 3). Collective application of Zn + *Azospirillum* + *PSB* + vermicompost increased maximum (28.95%) and decreased minimum (23.25%) in grain yield over 100% NPK and normal condition, respectively. Among all individual sources, vermicompost showed the highest response because it serves as storehouse of all nutrients in addition to improving physical properties.

Anthesis silking interval, 50% tassel and silk emergence were the highest in no fertilized treatments whereas the lowest was in T8. Waterlogging delayed the 50% tassel emergence by 4.3 – 7.7 days as well as 50% silk emergence by 4.0 – 8.9 days under different treatments over normal condition. Application of Zn alone and all inputs (T8) with 100% NPK recorded least days for the 50% tassel and silk emergence in waterlogged condition. Waterlogging stress resulted in a non-significant increase in ASI in all the treatments over normal condition. In general, effects of various abiotic stresses, as water-logging (Zaidi *et al*., 2004, 2007), drought (Bolaños and Edmeades, 1996), and

Table 3. Yield contributing parameters as influenced by different nutrient management practices under normal and temporary waterlogged conditions

Treatment	Days to 50% Tasseling	Days to 50% silking	ASI (days)	Plant barrenness (%)	Plant mortality (%)	Nodes with brace root	Grains/ cob	Root dry biomass (kg ha^{-1})
T1	50.7	54.9	4.3	21	16.00	2.00	225.3	563
T2	49.3	53.0	3.7	13	12.33	2.33	260.3	774
T3	48.7	52.2	3.7	12	11.33	3.00	277.7	892
T4	47.3	50.6	3.3	11	10.33	2.67	284.7	867
T5	49.3	53.0	3.7	13	12.33	2.67	281.3	638
T6	49.0	52.3	3.3	13	10.00	3.00	295.3	556
T7	49.0	53.0	3.7	13	8.67	2.67	284.7	840
T8	47.3	50.0	3.3	7	5.67	2.67	318.7	1170
T9	43.0	46.0	3.0	0.67	0	1.33	359.0	1953
SEm±	0.71	0.57	0.49	1.12	0.77	0.40	7.19	54.9
CD *(P=0.05)*	2.12	1.72	NS	3.36	2.32	NS	21.55	164.5

nitrogen deficiency (Banziger and Laffitte, 1997), on ASI were found to be largely based on delayed silking, not on anthesis. Plant barrenness and plant mortality followed the similar trend as to ASI, 50% tassel and silk emergence. A water-logging induced in brace root development however, the maximum was in T3 and T6 and identified as one of the stress-adaptive traits under water-logging stress (Zaidi *et al*., 2007). The brace roots which developed near the surface of water might have contributed to larger gaseous spaces, thereby enabling the plants to tolerate oxygen stress and to take up more atmospheric oxygen under high soil water condition.

Effect on physico – chemical properties

Nutrient management practices in general, significantly influenced the different physico-chemical properties (Table 4). Soil pH, EC, organic C and bulk density within different treatments under temporary ponding of water varied from 6.79 -7.09, 0.323 -0.377 dS m^{-1}, 0.62 – 0.76 g kg^{-1} and 1.20 – 1.37 g cm^{-3}, respectively, Integrated use of organic and inorganic inputs with 100% NPK (T8) resulted in higher soil pH and organic C whereas least bulk density. Excess wetness lowered the soil pH by 0.16 – 0.25 unit (Sharma and Mishra, 2003) however, on the other hand an increase in EC in T2,T3,T4 and T8,

Table 4. Physico-chemical properties of soil as influenced by different nutrient management practices under normal and temporary waterlogged conditions

Treatment	pH	Organic C (%)	Electrical conductivity (dS m^{-1})	Bulk density (Mg m^{-3})	Available N(kg ha^{-1})	Available P(kg ha^{-1})	Available K(kg ha^{-1})	Available Zn(mg kg^{-1})
T1	6.87	0.62	0.323	1.32	145.51	13.66	146.29	0.81
T2	6.85	0.66	0.377	1.32	162.23	20.21	158.49	0.77
T3	6.79	0.69	0.383	1.36	174.78	27.57	167.04	0.73
T4	6.88	0.71	0.373	1.37	166.42	18.30	165.69	1.02
T5	6.94	0.66	0.347	1.23	174.76	23.97	166.59	0.82
T6	6.90	0.70	0.363	1.34	166.41	28.68	163.89	0.84
T7	6.84	0.74	0.353	1.22	178.96	29.23	173.35	1.02
T8	6.93	0.76	0.377	1.20	187.32	31.96	178.35	1.21
T9	7.09	0.69	0.347	1.27	168.50	26.22	172.17	0.90
SEm±	0.07	0.01	0.01	0.03	6.01	2.60	4.23	0.05
CD *(P=0.05)*	0.21	0.04	0.02	0.10	18.00	7.79	12.69	0.16

organic C in T7 and T8 and bulk density T3 and T4 was recorded over its initial levels of 7.15, 0.365 dS m^{-1}, 0.73 g kg^{-1} and 1.34 g cm^{-3}, respectively. Vermicompost alone (T7) or in combination (T8) enhanced the level of organic C, however, succeed to minimize bulk density. This could be due to increase in total pore space per unit soil mass. Mbonu and Elenwo (2006) also observed similar results.

Effect on nutrient availability and uptake

Nutrient availability was significantly affected among various nutrient management practices under excess soil moisture owing to alteration in its physico-chemical properties (Table 4). Treatments receiving organic sources attained low EC while increased with addition of inorganic fertilizers. However, it was found to increase under waterlogging over control in most of the treatments. Available N, P, K and Zn in T2 were reduced with waterlogging over normal. Combined application of Zn, PSB, *Azospirillum* and vermicompost (T8) gave the highest availability of all the nutrients while least with T1. Vermicompost enhanced 10.3% more available N while 25% extra NPK and *Azospirillum* both gave equal response (7.7%) over 100% NPK (T2) whereas available P and Zn were increased by 41. 9 and 32.5% with applied PSB and Zn, respectively.

Uptake of N, P, K and Zn significantly affected in different treatments under submerged condition (Table 5) and was related to dry matter production. Waterlogging significantly decreased N, P and K contents in grain and stover whereas, Zn decreased non-significantly over normal. Decrease in nutrient contents in maize under waterlogged condition was also observed by Fausey *et al.* (1985). Submergence reduced N uptake by 35.6-72.1 and 46.9-70.2% as compared to normal in grain and stover, respectively. Application of PSB alone or in combination with other inputs (T8) recorded higher P content in grain and stover over rest of the treatments in which PSB alone increased 43.7 and 15.1% P recovery, respectively. This might be due to the ability of PSB to convert the fixed form of phosphorus into ionic available form. On the other side, Zn application reduced the P uptake over those treatments where Zn was not applied. Nitrogen and P contents were found to be slightly higher in grain whereas K and Zn content was remarkably higher in stover. This shows that besides reducing nutrient absorption, one week submergence at knee high stage also affect the translocation of nutrients from vegetative parts to grain and further enhancing submergence for another few days may increase the intensity of reduction of absorption and translocation of N, P and K.

Table 5. Nutrient uptake as influenced by different nutrient management practices under normal and temporary waterlogged conditions

Treatment	Grain				Stover			
	N(kg ha^{-1})	P(kg ha^{-1})	K(kg ha^{-1})	Zn(g ha^{-1})	N(kg ha^{-1})	P(kg ha^{-1})	K(kg ha^{-1})	Zn(g ha^{-1})
T1	28.45	5.35	9.80	75.20	31.84	4.67	70.67	156.80
T2	45.90	7.25	18.03	129.55	46.89	8.73	89.55	196.25
T3	53.04	9.13	20.57	129.35	49.13	8.95	97.45	209.35
T4	46.39	7.52	18.70	154.25	46.71	7.68	102.19	376.35
T5	50.83	9.29	20.13	138.65	49.01	9.13	97.66	315.65
T6	47.23	10.42	20.82	147.40	44.33	10.05	97.67	268.00
T7	56.39	9.53	18.14	156.80	52.45	9.50	106.89	343.50
T8	65.61	10.46	27.55	194.10	56.71	13.49	114.03	447.65
T9	101.84	16.39	35.74	185.35	106.85	22.78	177.10	434.90
SEm±	1.58	1.26	1.61	8.78	2.35	0.70	2.61	53.01
CD *(P=0.05)*	5.15	4.10	5.26	28.64	7.67	2.27	8.51	172.76

Inter-character correlations

Under waterlogged condition, grain yield, 50%

tasselling and silking, ASI, plant mortality and barrenness in general, showed positive correlation with LDR (Leaf Diffusive Resistance) whereas negatively and significantly correlated with LT(Leaf Temperature), PAR (Photosynthetically Active Radiation) and TR(Transpiration Rate) (Table 6). Transpiration rate was more positively and significantly correlated with plant height (0.866**), root dry biomass (0.894**), total N (0.909**), P (0.855**) and K (0.886**) but more negative and significantly correlated with 50% tassel (-0.865**) and 50% silk (-0.813**) emergence. Uptake of N, P and K showed more close relation with different plant physiological parameters to that of Zn uptake.

Table 6. Correlation of plant physiological parameters and water temperature between various growth and yield attributes and nutrient uptake under temporary excess soil moisture condition

Physiological parameters	Plant height	Grain yield	50% tassel emergence	50% silk emergence	ASI	Plant barrenness	Plant mortality	Dry root biomass	Total N uptake	Total P uptake	Total K uptake	Total Zn uptake
PAR (μ mol $s^{-1}m^{-2}$)	0.774*	-0.867**	-0.746*	-0.751*	-0.704*	-0.865**	-0.765*	0.743*	0.785*	0.783*	0.780*	0.322
LDR (s cm^{-1})	-0.774*	0.659	0.725*	0.660	0.329	0.613	0.649	-0.809**	-0.821**	-0.767*	-0.768*	-0.354
TR (μ g cm^{-2} s^{-1})	0.866**	-0.770*	-0.865**	-0.813**	-0.518	-0.732*	-0.781*	0.894**	0.909**	0.855**	0.886**	-0.310
LT (^{o}C)	0.678*	-0.712*	-0.791*	-0.524	-0.815**	-0.699*	-0.732*	0.615	0.680*	0.753*	0.753*	0.160
WT (^{o}C)	-0.867**	-0.786*	0.884**	0.833**	0.555	0.752*	-0.791*	-0.900**	-0.916**	-0.896**	-0.896**	0.301

Grain yield was negatively and significantly related with LT (-0.712), PAR (0.867**), WT (Water Temperature) (-0.786*) and TR (-0.770*) but positively correlated with LDR (0.659) indicated that PAR had more impact on grain yield as compared to others. Similarly LDR had shown less impact on most of the growth and yield parameters and LT on nutrients uptake.

On the basis of findings from performance of maize it may be concluded that all growth, yield and physiological parameters of maize were adversely affected under temporary waterlogged condition to that of normal condition. However, no fertilizer application was found extremely detrimental for maize crop. Combined application of 100% NPK along with Zn, *Azospirillum, PSB* and vermicompost @ 5t ha^{-1} had produced the maximum grain yield of maize as well as maintained the soil quality hence can be adopted by the farmers of *tarai* region of Uttarakhand in the submerged condition specially during the rainy season.

Acknowledgement

The authors gratefully to the Director of Experimental Station of GBPUA&T, Pantnagar successful conduct of the experiment.

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Received: February 6, 2012; Accepted: June 25, 2012