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Effect of Zinc and Magnesium on Orange-Fleshed Sweet Potato in Alfisols of Odisha, India

K. Laxminarayana[1] and K. Susan John[2]

[1]Regional Centre of Central Tuber Crops Research Institute, Dumduma, Bhubaneswar, 751 019, Odisha, India

[2]Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, 695 017, Kerala, India

Corresponding author: K. Laxminrayana, e-mail: klnarayana69@rediffmail.com

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Abstract

The effect of application of zinc (Zn) and magnesium (Mg) individually and in combination on yield, proximate composition and nutrient uptake of orange-fleshed sweet potato was studied in an acidic Alfisol of Odisha, India, by conducting field experiments for two *kharif* (rainy) seasons during 2009-2010 and 2010-2011. The results revealed that significantly highest mean tuber yield (11.9 t ha^{-1}) and vine yield (18.1 t ha^{-1}) was obtained due to application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively. The mean yield response was 12, 19 and 10% higher due to application of $ZnSO_4$ @ 10, 20 and 30 kg ha^{-1} over control, while it was 7, 11 and 8% more with respect to 15, 30 and 45 kg ha^{-1} of $MgSO_4$. Highest mean starch content (22.4%), total sugars (3.61%) and dry matter (29.4%) was observed due to application of $ZnSO_4$ @ 20 kg ha^{-1}. Combined application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$ respectively produced significantly highest total uptake of N and P (67.4 and 24.7 kg ha^{-1}, respectively), however, the total uptake of K was highest (93.1 kg ha^{-1}) due to application of 10 and 45 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$ respectively. Addition of Zn and Mg resulted in significant improvement of soil properties. The results emphasized that application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively along with the optimum doses of NPK and FYM produced sustainable sweet potato yields with good quality tubers and maintained the soil fertility.

Key words: Acid soil, sweet potato, zinc, magnesium, tuber yield, proximate composition, nutrient uptake, soil properties

Introduction

Among the tropical tuber crops, sweet potato has a long history as a crop to stave off famine especially from the point of view as a cheap source of energy. China is the largest producer of sweet potato with 72% of the world's production (104.26 m t) and 40% of the Chinese harvest is used as animal feed to support a growing domestic demand for animal protein. In South America and Africa, 90% of the production is used for human consumption. In India it is grown in an area of 1.132 lakh ha with a production of 10.47 lakh tones and the average productivity is 9.25 t ha^{-1} (FAOSTAT, 2012). In Odisha state of India, it is cultivated in an area of 0.44 lakh ha with a production of 4.10 lakh tones and the state has a low productivity of 9.30 t ha^{-1} as against the world average productivity of 13.15 t ha^{-1}. Sweet potato is nutritionally rich with respect to minerals, vitamins and antioxidants. Orange-fleshed sweet potatoes (OFSP) are presently grown and popularized in the tribal belts of the country for combating night blindness, which is prevalent among them due to their nutritionally poor food habits.

Soil acidity is a major constraint to crop production in most of the agricultural soils of the tropics and liming is a common practice to ameliorate the acid soils (Brady and Weil, 2006). In Odisha, out of the net sown area of 5.57 m ha, acid soils occupy an area of 47 lakh ha and deficiency of secondary nutrients such as Ca and Mg and micronutrient, Zn, is a major constraint to crop production in these soils (Pattanayak et al., 2011). Average consumption of fertilizers in Odisha is far below (57.6 kg ha^{-1}) the national average of 135.25 kg ha^{-1}. The escalating fertilizer prices coupled with unsustainable crop production practices necessitates the use of locally available low cost organic sources along with chemical fertilizers and micronutrients in a synergistic manner for sustainable crop production and to maintain soil health (Acharya, 2002). Application of chemical fertilizers alone has not been found helpful under intensive agriculture to maximize productivity and maintain soil health because it is often associated with reduced crop yield, increased soil acidity and nutrient imbalances (Ojeniyi, 2000). Keeping this in view, the present study was conducted to find out the effect of application of secondary nutrient, Mg and the micronutrient, Zn along with recommended doses of NPK and organic manure on yield, proximate composition and nutrient uptake of sweet potato and their residual effect on soil fertility.

Materials and Methods

Field experiments were conducted for two consecutive *kharif* (rainy) seasons during 2009-2010 and 2010-2011 in a Typic Haplustalf at the farm of the Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India to study the effect of application of zinc (Zn) and magnesium (Mg) on tuber yield, proximate composition of tubers and nutrient uptake in sweet potato. The soil of the experimental site is sandy loam. The soil was acidic (pH 4.73), non saline (EC 0.34 dS m^{-1}) with 0.36% organic C, 144, 16.4 and 288 kg ha^{-1} of N, P and K, respectively. The experiment was laid out in a two factorial randomized block design with four levels of Zn ($ZnSO_4$ @ 0, 10, 20 and 30 kg ha^{-1}) and 4 levels of Mg ($MgSO_4$ @ 0, 15, 30 and 45 kg ha^{-1}) replicated thrice. Well rotten farmyard manure (FYM) @ 4.0 t ha^{-1} on dry weight basis containing 0.46, 0.28 and 0.54% N, P and K, respectively was applied one month in advance of planting of the cuttings. One third of N, entire P and half K in the form of urea, single super phosphate and muriate of potash, respectively were applied at the time of planting followed by one third N and half of K at 45 days after planting (DAP) and the balance one third of N at 60 DAP.

Orange-fleshed sweet potato (cv ST-14) cuttings were planted at a spacing of 60 x 20 cm. The crop was managed by following the cultural practices as per package of practices. The crop was harvested at physiological maturity (120 DAP) and the tuber yield, vine yield, number of tubers per plant and the average weight of tubers were recorded. Post harvest soil samples were collected from individual plots, processed and analyzed for physico-chemical properties by adopting standard analytical procedures (Jackson, 1973). The plant samples (tubers and vines) were collected during harvest, washed thoroughly with distilled water, oven dried and dry weights were recorded. Total sugar in the tuber samples was estimated in the alcohol filtrate and starch was determined in the residue following the procedure outlined by Moorthy and Padmaja (2002). The oven dried tuber and vine samples were powdered and digested in concentrated H_2SO_4 and analysed for N content by steam distillation (Humphries, 1956) and the N uptake was computed. The plant samples were digested in diacid mixture (HNO_3 and $HClO_4$, 7:3) and total P and K were estimated by using spectrophotometer and flame photometer, respectively (Jackson, 1973) and the uptake of P and K was computed. Per cent yield/uptake response was derived as

Per cent yield/uptake response: ((Treatment yield/uptake – control yield/uptake) ÷ (Control yield/ uptake)) x 100.

Results and Discussion

Yield attributes

Tuber yield showed significant increase with the increasing doses of $ZnSO_4$ up to 20 kg ha^{-1} and decreased at higher dose of 30 kg ha^{-1} (Table 1). But in the case of $MgSO_4$, there was an increasing trend up to 30 kg ha^{-1} and the tuber yield decreased with further increase in application of Mg. The mean tuber yield was significantly highest (11.2 t ha^{-1}) due to application of 20 kg ha^{-1} $ZnSO_4$ followed by 10 kg ha^{-1} $ZnSO_4$ (10.5 t ha^{-1}). Significantly highest mean tuber yield (10.8 t ha^{-1}) was obtained due to application of 30 kg ha^{-1} $MgSO_4$ followed by 45 kg ha^{-1} $MgSO_4$ (10.5 t ha^{-1}). The mean yield response was 11.7, 19.2 and 9.6% more due to application of 10, 20, and 30 kg ha^{-1} $ZnSO_4$ over control, while it was 7.0, 11.1 and 8.4% more with respect to 15, 30, and 45 kg ha^{-1} $MgSO_4$. The vine yield also showed similar trend of response due to application of Zn and Mg. The combined effect of Zn and Mg showed significantly highest mean tuber yield (11.9 t ha^{-1}) and vine yield (18.1 t ha^{-1}) due to combined application of

20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively (Table 2) with a yield response of 38.3 per cent over control. Other yield parameters like vine length, number of tubers per plant and average tuber weight also followed the same trend in line with the tuber and vine yields. Integrated use of organic manures like FYM along with optimum levels of chemical fertilizers including secondary and micronutrients provided a conducive physical environment which might have helped in better root growth and absorption of nutrients from the native as well as applied sources which in turn favoured highest tuber and vine yields. These results are in conformity

Table 1. Effect of Zn and Mg on yield parameters of sweet potato (mean of 2 years)

Treatment	Vine length (cm)	No. of tubers plant^{-1}	Average tuber weight (g)	Tuber yield (t ha^{-1})			Yield response (%)	Vine yield (t ha^{-1})		
				2009	2010	Mean		2009	2010	Mean
Zn levels (kg ha^{-1} $ZnSO_4$)										
0	125.6	1.74	125.0	10.63	8.19	9.41	-	14.25	16.11	15.18
10	133.1	1.91	138.7	11.97	9.06	10.51	11.7	14.86	17.52	16.19
20	133.1	1.79	130.6	12.84	9.61	11.22	19.2	15.26	18.59	16.92
30	132.6	1.71	121.1	11.66	8.95	10.31	9.6	15.01	16.90	15.96
CD (P= 0.05) Zn	5.46	0.10	5.64	0.31	0.40	0.227	-	1.38	0.60	0.56
Mg levels (kg ha^{-1} $MgSO_4$)										
0	123.4	1.65	121.8	11.10	8.35	9.72	-	13.72	16.09	14.91
15	129.9	1.79	127.4	11.93	8.86	10.40	7.0	14.71	17.37	16.04
30	134.7	1.86	132.3	12.21	9.38	10.80	11.1	15.73	18.18	16.96
45	136.4	1.85	134.0	11.87	9.21	10.54	8.4	15.22	17.48	16.35
CD (P= 0.05) Mg	4.10	0.06	9.28	0.36	0.25	0.209	-	0.50	0.42	0.19

Table 2. Interaction effect of Zn and Mg on yield parameters of sweet potato (mean of 2 years)

Treatment	Vine length (cm)	No. of tubers plant^{-1}	Average tuber weight (g)	Tuber yield (t ha^{-1})			Yield response (%)	Vine yield (t ha^{-1})		
				2009	2010	Mean		2009	2010	Mean
Zn_0Mg_0	114.4	1.56	107.5	9.47	7.73	8.60	-	13.12	14.15	13.64
Zn_0Mg_1	122.5	1.70	121.2	10.12	8.10	9.11	5.9	14.07	16.25	15.16
Zn_0Mg_2	126.0	1.77	130.0	11.39	8.47	9.93	15.5	14.68	17.62	16.15
Zn_0Mg_3	139.5	1.91	141.4	11.54	8.44	9.99	16.2	15.11	16.43	15.77
Zn_1Mg_0	123.9	1.67	143.5	10.61	8.29	9.45	9.9	13.53	15.88	14.70
Zn_1Mg_1	130.6	1.86	137.5	12.03	8.83	10.43	21.3	14.49	16.95	15.72
Zn_1Mg_2	139.9	2.07	137.2	12.80	9.55	11.18	30.0	15.97	18.60	17.29
Zn_1Mg_3	138.0	2.05	136.7	12.43	9.55	10.99	27.8	15.46	18.64	17.05
Zn_2Mg_0	126.0	1.65	119.1	12.28	8.72	10.50	22.1	14.14	17.21	15.67
Zn_2Mg_1	131.3	1.81	126.6	12.92	9.50	11.21	30.3	15.12	18.86	16.99
Zn_2Mg_2	139.7	1.92	139.9	13.38	10.40	11.89	38.3	16.45	19.76	18.10
Zn_2Mg_3	135.5	1.77	136.8	12.76	9.82	11.29	31.3	15.33	18.51	16.92
Zn_3Mg_0	129.3	1.72	117.2	12.02	8.66	10.34	20.2	14.09	17.12	15.61
Zn_3Mg_1	135.3	1.78	124.3	12.65	9.01	10.83	25.9	15.15	17.43	16.29
Zn_3Mg_2	133.2	1.67	121.9	11.25	9.10	10.18	18.4	15.82	16.73	16.28
Zn_3Mg_3	132.4	1.67	121.1	10.73	9.02	9.87	14.8	14.98	16.33	15.66
CD (P=0.05) Zn x Mg	8.19	0.13	18.56	0.29	0.35	0.418	-	1.19	0.52	0.38

Zn_0, Zn_1, Zn_2, Zn_3: 0, 10, 20, 30 kg ha^{-1} $ZnSO_4$ Mg_0, Mg_1, Mg_2, Mg_3: 0, 15, 30, 45 kg ha^{-1} $MgSO_4$

with the findings of Singh et al. (2002). The results obtained in these acid soils which are marginal with respect to all essential nutrients are in accordance to the findings of Halavatau et al. (1998) that by satisfying both the major as well as micronutrient requirement of marginal soils, the tuber as well as vine yield can be increased considerably.

Proximate composition

Significantly highest mean starch content (22.4%), total sugars (3.61%) and dry matter (29.4%) was observed due to application of 20 kg ha^{-1} of $ZnSO_4$ (Table 3), however, the starch, total sugars and dry matter contents were highest (22.2, 3.60 and 29.3%, respectively) due to addition of 30 kg ha^{-1} $MgSO_4$ which was on par with that of addition of 45 kg ha^{-1} $MgSO_4$ (22.1, 3.58 and 29.0%, respectively). Combined application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively (Table 4) showed significantly highest mean starch content (23.3%), total sugars (3.75%) and dry matter (30.2%) over that of the other treatment combinations. Total sugars and dry matter ranged from 2.99-3.75 and 27.4-30.2%, respectively. Application of Zn had significant effect on biochemical constituents rather than Mg application.

Nutrient uptake

Significantly highest total uptake of N, P and K (64.2, 23.5 and 87.7 kg ha^{-1}, respectively) was noticed due to application of 20 kg ha^{-1} $ZnSO_4$ (Table 5) followed by 10 kg ha^{-1} $ZnSO_4$ (62.8, 22.9 and 86.4 kg ha^{-1}, respectively). Highest total uptake of N, P and K was observed due to application of 30 kg ha^{-1} $MgSO_4$ (63.9, 22.7 and 86.3 kg ha^{-1}). Combined application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively (Table 6) showed significantly highest total uptake of N and P (67.4 and 24.7 kg ha^{-1}, respectively), however, the total uptake of K was highest due to application of 10 and 45 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively (93.1 kg ha^{-1}). The uptake response of N and P was highest (35.4 and 43.2 %, respectively) due to combined application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$ respectively over control, while the K uptake was highest (28.4%) due to application of 10 and 45 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively.

Physico-chemical properties

Significantly highest soil pH was observed due to the application of 20 kg ha^{-1} $ZnSO_4$ (5.18), while it was highest (5.15) with 30 kg ha^{-1} $MgSO_4$ (Table 7) from the initial level of 4.73. Combined application of organic and inorganic sources of nutrients along with liming materials showed relatively higher soil pH, since organic matter has higher cation exchange capacity (CEC) and it facilitated retention of exchangeable bases (Svotwa et al., 2007; Ossom and Rhykerd, 2008). The soluble salt content also progressively increased with the addition of both $ZnSO_4$ and $MgSO_4$. The organic C content

Table 3. Effect of Zn and Mg on biochemical constituents of sweet potato (mean of 2 years)

Treatment	Starch (%)*			Total sugars (%)*			Dry matter (%)		
	2009	2010	Mean	2009	2010	Mean	2009	2010	Mean
Zn levels (kg ha^{-1} $ZnSO_4$)									
0	22.64	19.94	21.29	3.21	3.35	3.29	27.24	29.28	28.27
10	22.87	20.70	21.79	3.48	3.63	3.56	28.14	30.05	29.10
20	23.33	21.48	22.41	3.50	3.72	3.61	28.27	30.52	29.39
30	22.82	20.78	21.80	3.64	3.30	3.47	27.39	29.88	28.64
CD (P= 0.05) Zn	0.66	0.58	0.57	0.41	0.24	0.19	0.59	0.73	0.44
Mg levels (kg ha^{-1} $MgSO_4$)									
0	21.97	20.22	21.10	3.15	3.43	3.29	26.71	29.71	28.21
15	22.8	20.90	21.85	3.37	3.53	3.45	27.60	30.18	28.89
30	23.41	21.07	22.24	3.62	3.57	3.60	28.36	30.14	29.25
45	23.48	20.72	22.10	3.69	3.47	3.58	28.38	29.70	29.04
CD (P= 0.05) Mg	0.33	1.12	0.62	0.22	0.19	0.12	0.37	0.32	0.25

* Starch and total sugars expressed on fresh weight basis

Table 4. Interaction effect of Zn and Mg on biochemical constituents of sweet potato (mean of 2 years)

Treatment	Starch (%)*			Total sugars (%)*			Dry matter (%)		
	2009	2010	Mean	2009	2010	Mean	2009	2010	Mean
Zn_0Mg_0	21.63	19.48	20.56	2.92	3.05	2.99	26.21	28.63	27.43
Zn_0Mg_1	22.67	19.99	21.33	3.04	3.19	3.12	27.07	29.37	28.22
Zn_0Mg_2	23.00	20.13	21.57	3.33	3.60	3.47	27.57	29.73	28.65
Zn_0Mg_3	23.24	20.16	21.70	3.55	3.56	3.56	28.11	29.40	28.76
Zn_1Mg_0	21.75	20.52	21.13	3.04	3.49	3.27	26.61	29.87	28.24
Zn_1Mg_1	22.57	19.95	21.26	3.30	3.79	3.54	27.68	30.33	29.01
Zn_1Mg_2	23.36	21.51	22.44	3.66	3.80	3.73	28.86	30.53	29.70
Zn_1Mg_3	23.81	20.82	22.32	3.93	3.45	3.69	29.42	29.47	29.45
Zn_2Mg_0	22.08	19.97	21.03	3.04	3.64	3.34	27.04	30.33	28.69
Zn_2Mg_1	22.97	22.64	22.81	3.33	3.85	3.60	27.97	30.63	29.30
Zn_2Mg_2	24.22	22.38	23.30	3.84	3.65	3.75	29.54	30.93	30.24
Zn_2Mg_3	24.05	20.94	22.50	3.78	3.72	3.75	28.52	30.17	29.34
Zn_3Mg_0	22.42	20.90	21.66	3.59	3.54	3.56	26.98	30.00	28.49
Zn_3Mg_1	22.99	21.00	22.00	3.81	3.28	3.55	27.66	30.37	29.02
Zn_3Mg_2	23.05	20.25	21.65	3.66	3.22	3.44	27.47	29.37	28.42
Zn_3Mg_3	22.82	20.96	21.89	3.48	3.15	3.32	27.45	29.77	28.61
CD (P= 0.05) Zn x Mg	0.66	0.50	1.24	0.45	0.21	0.23	0.73	0.63	0.50

Zn_0, Zn_1, Zn_2, Zn_3: 0, 10, 20, 30 kg ha^{-1} $ZnSO_4$ Mg_0, Mg_1, Mg_2, Mg_3: 0, 15, 30, 45 kg ha^{-1} $MgSO_4$

* Starch and total sugar expressed on fresh weight basis

Table 5. Effect of Zn and Mg on nutrient uptake (kg ha^{-1}) by sweet potato (mean of 2 years)

Treatment	Tubers			Vines			Total nutrient uptake		
	N	P	K	N	P	K	N	P	K
Zn levels (kg ha^{-1} $ZnSO_4$)									
0	15.20	9.06	32.20	41.70	10.86	48.73	56.90	19.88	80.93
10	17.73	10.53	37.10	45.10	12.34	50.09	62.83	22.86	86.36
20	18.63	11.28	38.54	45.55	12.25	49.20	64.17	23.53	87.73
30	15.91	9.50	32.84	41.91	10.81	46.11	57.82	20.30	78.95
CD (P= 0.05) Zn	0.72	1.01	2.67	0.98	0.64	2.20	1.33	1.46	3.53
Mg levels (kg ha^{-1} $MgSO_4$)									
0	15.52	9.41	32.79	40.48	10.75	45.77	56.00	20.10	78.55
15	16.98	10.27	35.81	43.62	11.66	48.90	60.60	21.93	84.71
30	17.81	10.51	36.27	46.07	12.19	50.83	63.88	22.70	86.27
45	17.17	10.18	35.81	44.07	11.66	48.63	61.24	21.85	84.43
CD (P= 0.05) Mg	0.44	0.36	1.09	1.04	0.35	0.73	1.14	0.56	1.72

increased significantly to 0.45% from the initial status of 0.36% due to addition of 10 kg ha^{-1} $ZnSO_4$, which was on par with that of 30 kg ha^{-1} $MgSO_4$ (0.44%). Total N and available N were found highest due to application of 20 kg ha^{-1} $ZnSO_4$ which was on par with that of 30 kg ha^{-1} $MgSO_4$, whereas the available P and K contents were highest due to application of 10 kg ha^{-1} $ZnSO_4$ followed by 15 kg ha^{-1} $MgSO_4$. The exchangeable Ca and Mg significantly improved due to increased doses of $MgSO_4$; however, the available Zn status showed a significant improvement due to increased doses of $ZnSO_4$.

Interaction effect between Zn and Mg showed a significant improvement of all soil physico-chemical

Table 6. Interaction effect of Zn and Mg on nutrient uptake (kg ha^{-1}) by sweet potato (mean of 2 years)

Treatment	Tubers			Vines			Total nutrient uptake			Nutrient uptake response (%)		
	N	P	K	N	P	K	N	P	K	N	P	K
Zn_0Mg_0	13.24	7.97	27.86	36.55	9.51	44.67	49.80	17.28	72.53	-	-	-
Zn_0Mg_1	14.67	8.74	32.18	41.53	11.15	49.33	56.20	19.90	81.51	12.9	15.2	12.4
Zn_0Mg_2	16.43	9.51	34.07	45.29	11.66	51.29	61.72	21.17	85.36	23.9	22.5	17.7
Zn_0Mg_3	16.47	10.02	34.68	43.42	11.13	49.62	59.89	21.15	84.30	20.3	22.4	16.2
Zn_1Mg_0	15.18	9.36	32.18	41.47	11.06	46.27	56.66	20.41	78.45	13.8	18.1	8.2
Zn_1Mg_1	17.60	10.82	36.26	44.26	12.04	48.87	61.86	22.87	85.13	24.2	32.3	17.4
Zn_1Mg_2	19.41	11.10	38.70	47.64	13.28	53.35	67.05	24.38	88.72	34.6	41.1	22.3
Zn_1Mg_3	18.71	10.83	41.27	47.02	12.96	51.85	65.73	23.79	93.13	32.0	37.7	28.4
Zn_2Mg_0	17.44	10.57	36.97	43.54	11.92	46.15	60.97	22.49	83.12	22.4	30.2	14.6
Zn_2Mg_1	18.63	11.37	39.24	45.56	12.47	50.02	64.18	23.84	89.25	28.9	38.0	23.1
Zn_2Mg_2	19.58	12.17	40.72	47.83	12.57	52.14	67.42	24.74	92.85	35.4	43.2	28.0
Zn_2Mg_3	18.86	11.00	37.21	45.25	12.05	48.49	64.11	23.06	85.70	28.7	33.4	18.2
Zn_3Mg_0	16.21	9.73	34.13	40.36	10.50	45.97	56.57	20.22	80.10	13.6	17.0	10.4
Zn_3Mg_1	17.00	10.13	35.57	43.14	10.98	47.39	60.15	21.11	82.96	20.8	22.2	14.4
Zn_3Mg_2	15.82	9.25	31.59	43.52	11.25	46.54	59.33	20.50	78.14	19.1	18.6	7.7
Zn_3Mg_3	14.62	8.87	30.06	40.60	10.51	44.54	55.22	19.38	74.60	10.9	12.2	2.9
CD (P= 0.05) Zn x Mg	0.89	0.72	2.19	2.09	0.69	1.45	2.29	1.11	3.45	-	-	-

Zn_0, Zn_1, Zn_2, Zn_3: 0, 10, 20, 30 kg ha^{-1} $ZnSO_4$ Mg_0, Mg_1, Mg_2, Mg_3: 0, 15, 30, 45 kg ha^{-1} $MgSO_4$

Table 7. Effect of Zn and Mg on physico-chemical properties of the soil

Treatment	pH (1:2)	EC (dS m^{-1})	Org. C (%)	Total N (%)	Available nutrient (kg ha^{-1}) N	P	K	Exch. Ca (mg kg^{-1})	Exch. Mg	DTPA-Zn
Initial	4.73	0.34	0.36	0.052	144.3	16.40	288.2	187.6	138.8	0.65
Zn levels (kg ha^{-1} $ZnSO_4$)										
0	4.96	0.50	0.39	0.060	185.3	51.53	208.0	180.3	140.0	0.62
10	5.06	0.51	0.45	0.066	188.6	47.50	227.4	187.7	140.3	0.91
20	5.18	0.51	0.43	0.067	200.4	43.05	219.3	175.6	145.8	0.95
30	5.15	0.53	0.43	0.063	198.6	40.70	216.0	184.3	136.8	1.02
CD (P= 0.05) Zn	0.070	0.034	0.02	0.001	1.82	2.88	2.07	3.20	2.16	0.035
Mg levels (kg ha^{-1} $MgSO_4$)										
0	4.98	0.48	0.40	0.061	188.8	48.18	213.2	170.5	138.0	0.853
15	5.11	0.52	0.42	0.065	191.6	47.93	220.9	175.5	139.1	0.888
30	5.15	0.52	0.44	0.065	197.1	43.93	219.7	184.6	141.7	0.925
45	5.12	0.54	0.44	0.064	195.4	42.78	216.9	197.3	144.2	0.988
CD (P= 0.05) Mg	0.099	0.030	0.02	0.002	2.80	3.64	3.53	2.70	2.57	0.022

properties (Table 8). Soil pH was progressively improved due to continuous addition of $MgSO_4$ and $ZnSO_4$. Significantly highest organic C (0.47%), total N (0.069%) and available N (214.5 kg ha^{-1}) contents were observed due to combined application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively. The available P was highest at lower doses of $ZnSO_4$ application and decreased at higher doses, which might be due to antagonistic effect between P and Zn. The available K content showed decreasing trend from the initial level of 288 kg ha^{-1}, however, significantly highest available K (232.5 kg ha^{-1}) was noticed due to application of 10 and

Tale 8. Residual effect of Zn and Mg on physico-chemical properties of the soil

Treatment	pH (1:2)	EC (dS m^{-1})	Org. C (%)	Total N (%)	Available nutrient (kg ha^{-1}) N	P	K	Exch. Ca	Exch. Mg (mg kg^{-1})	DTPA-Zn
Initial	4.73	0.34	0.36	0.052	144.32	16.4	288.20	187.6	138.8	0.65
Zn_0Mg_0	4.64	0.45	0.36	0.055	179.36	56.4	197.95	171.4	135.5	0.66
Zn_0Mg_1	5.13	0.53	0.39	0.062	180.63	54.0	201.70	175.2	137.3	0.77
Zn_0Mg_2	5.15	0.49	0.39	0.060	189.41	48.2	210.51	183.1	141.9	0.82
Zn_0Mg_3	4.93	0.52	0.42	0.061	191.92	47.5	221.76	191.5	145.4	0.85
Zn_1Mg_0	5.10	0.48	0.42	0.062	183.14	49.3	218.94	174.7	138.1	0.89
Zn_1Mg_1	5.01	0.51	0.45	0.066	185.65	51.6	229.28	179.4	139.5	0.87
Zn_1Mg_2	5.03	0.52	0.46	0.069	190.10	46.4	232.50	191.0	140.9	0.92
Zn_1Mg_3	5.09	0.54	0.47	0.067	195.65	42.8	228.91	205.5	142.6	0.95
Zn_2Mg_0	5.15	0.48	0.39	0.063	188.16	45.6	216.03	159.3	142.6	0.90
Zn_2Mg_1	5.19	0.51	0.40	0.067	203.21	45.2	230.83	167.9	143.3	0.92
Zn_2Mg_2	5.17	0.51	0.47	0.069	214.50	39.8	221.10	176.9	147.5	0.94
Zn_2Mg_3	5.22	0.55	0.45	0.068	195.65	41.6	209.20	198.4	149.9	1.05
Zn_3Mg_0	5.02	0.49	0.43	0.064	204.70	41.4	219.86	176.4	135.6	0.96
Zn_3Mg_1	5.12	0.53	0.44	0.065	196.90	40.9	221.98	179.5	136.1	0.99
Zn_3Mg_2	5.23	0.55	0.45	0.063	194.54	41.3	214.70	187.5	136.4	1.02
Zn_3Mg_3	5.23	0.54	0.43	0.062	198.19	39.2	207.54	193.7	139.0	1.10
CD (P= 0.05)										
Zn x Mg	0.199	0.059	0.04	0.003	5.59	7.28	7.05	5.39	5.15	0.044

Zn_0, Zn_1, Zn_2, Zn_3: 0, 10, 20, 30 kg ha^{-1} $ZnSO_4$ Mg_0, Mg_1, Mg_2, Mg_3: 0, 15, 30, 45 kg ha^{-1} $MgSO_4$

30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively, which might be ascribed to higher requirement of K by the crop for its physiological growth. Significantly highest exchangeable Mg (149.9 mg kg^{-1}) was observed due to application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively. The available Zn showed a significant improvement in all the treatment combinations over the initial value and it was found highest (1.10 mg kg^{-1}) due to application of 30 and 45 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively. Application of Mg and Zn along with the recommended doses of organic and inorganic fertilizers had significant effect on enhancing the productivity of sweet potato, efficiency of applied chemical fertilizers by countering the acidity and exchangeable aluminium content in the soils and thereby improving the soil fertility (Vele et al., 2000).

Thus, the results emphasized that application of 20 and 30 kg ha^{-1} of $ZnSO_4$ and $MgSO_4$, respectively, along with the recommended doses of NPK and FYM was essential to produce sustainable crop yields and biochemical constituents of orange-fleshed sweet potato.

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