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Nutrient content and uptake by *Kharif* groundnut as influenced by potash, iron, and zinc levels

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Abstract
A field investigation was conducted during the *Kharif* seasons of 2022 and 2023 at the Agronomy Instructional Farm, Department of Agronomy, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, to examine nutrient content and uptake in *Kharif* groundnut as influenced by potash, iron, and zinc levels. The experiment comprised a total of 27 treatment combinations, formulated by integrating three levels each of potassium (K_0: 0, K_1: 25, K_2: 50 kg K_2O ha^{-1}), iron (Fe_0: 0, Fe_1: 15, Fe_2: 30 kg Fe ha^{-1}), and zinc (Zn_0: 0, Zn_1: 8, Zn_2: 16 kg Zn ha^{-1}). The treatments were laid out in a factorial randomized block design (FRBD) with three replications to ensure experimental precision and statistical robustness. Pooled results over two years indicated that an application of potash, iron, and zinc significantly influenced both nutrient content and uptake in groundnut. Potash application notably enhanced nitrogen content in the kernel and potassium content in the kernel, shell, and haulm, while 50 kg K_2O ha^{-1} recorded the highest total uptake of N, P, K, Fe and Zn. Iron application improved nitrogen content in the kernel, sulphur content in the haulm, and iron content in all plant parts, with 30 kg Fe ha^{-1} resulting in significantly greater uptake of N, P, K, Fe, and Zn. Similarly, zinc application at 16 kg Zn ha^{-1} significantly increased nitrogen content in the kernel, sulphur content in the haulm, and zinc content in the kernel, shell, and haulm, along with enhanced uptake of N, P, K, Fe, and Zn.

Keywords: Groundnut, potash, iron, zinc, content, uptake

1. Introduction
The nutrient content in groundnut is significantly influenced by the balanced application of potassium and essential micronutrients such as iron and zinc. Potassium plays a critical role in maintaining ionic balance and enhancing the internal translocation of nutrients, which directly improves nutrient accumulation in plant tissues. Iron, being vital for chlorophyll formation and enzyme activity, contributes to improved nitrogen and sulphur assimilation in different plant parts. Zinc, an essential component of several enzyme systems, enhances protein synthesis and hormonal regulation, leading to better nutrient partitioning in the kernel, shell, and haulm. The improvements in nutrient content reflect the importance of balanced secondary and micronutrient management in maintaining the physiological and biochemical health of crops. Nutrient uptake in groundnut is strongly governed by both soil fertility status and the availability of macro- and micronutrients in the rhizosphere. Potassium improves root development and nutrient absorption efficiency, while iron and zinc facilitate the metabolic and transport mechanisms that influence total nutrient uptake.

Groundnut (*Arachis hypogaea* L.) holds a prominent place among oilseed crops due to its high content of edible oil and protein, earning it the title "king of oilseeds." India ranks first globally in groundnut cultivation, with Gujarat leading in both cultivated area and total production. In addition to its nutritional oil, which is rich in beneficial monounsaturated and polyunsaturated fatty acids, groundnut haulm serves as an important source of nutritious fodder for livestock. Despite its agronomic and economic value, the crop's potential is often hindered by deficiencies of essential nutrients particularly potassium, iron, and zinc which are prevalent in the sandy and low-fertility soils of North Gujarat.

2. Materials and Methods: The plant samples (kernel/ shell and haulm) were wet digested using a diacid mixture of HNO3 and HClO4 (3:1). The acid extract prepared after digestion was used for estimation of P, S, Fe and Zn. The N content in kernel/seed and haulm/stover was estimated by micro-kjeldahl's method. Further, the digested plant samples were analysed as per standard methods as describe in Table 3.1 Double distilled water was used to determine the micro nutrient contents of the samples. All the reagents used for analysis were AR grade

Table 3.1: Methods of plant analysis

Sr. No.	Determination	Method	Reference
Plant analysis			
1.	Nitrogen	Micro-Kjeldahl's method	Jackson (1973)
2.	Phosphorus	Vanadomolybdo phosphoric acid yellow colour method	Jackson (1973)
3.	Potassium	Flame photometric method	Jackson (1973)
4.	Sulphur	Turbidimetric method	Chaudhary and Cornfield (1966)
5.	Fe and Zn	Atomic Absorption Spectrophotometer	Lindsay and Norvell (1978)

Table 4.1: Effect of potash, iron and zinc on nitrogen content in kernel, shell and haulm of groundnut

Treatments	N content (%)								
	Kernel			Shell			Haulm		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	4.098	4.143	4.120	1.098	1.091	1.095	1.686	1.426	1.556
K_1: 25 kg ha^{-1}	4.141	4.228	4.185	1.089	1.080	1.085	1.670	1.496	1.583
K_2: 50 kg ha^{-1}	4.331	4.332	4.331	1.112	1.071	1.092	1.702	1.463	1.582
S.Em ±	0.047	0.051	0.035	0.009	0.012	0.007	0.022	0.016	0.014
C.D. at 5%	0.134	0.145	0.097	NS	NS	NS	NS	NS	NS
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	4.094	4.140	4.117	1.085	1.067	1.076	1.664	1.454	1.559
Fe_1: 15 kg ha^{-1}	4.197	4.238	4.217	1.104	1.090	1.097	1.707	1.479	1.593
Fe_2: 30 kg ha^{-1}	4.278	4.325	4.302	1.111	1.087	1.099	1.688	1.452	1.570
S.Em ±	0.047	0.051	0.035	0.009	0.012	0.007	0.022	0.016	0.014
C.D. at 5%	0.134	0.145	0.097	NS	NS	NS	NS	NS	NS
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	4.100	4.163	4.131	1.111	1.070	1.091	1.662	1.435	1.548
Zn_1: 08 kg ha^{-1}	4.135	4.190	4.163	1.090	1.078	1.084	1.678	1.493	1.585
Zn_2: 16 kg ha^{-1}	4.334	4.350	4.342	1.099	1.095	1.097	1.719	1.457	1.588
S.Em ±	0.047	0.051	0.035	0.009	0.012	0.007	0.022	0.016	0.014
C.D. at 5%	0.134	0.145	0.097	NS	NS	NS	NS	NS	NS
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	-	-	-	-	-	-	-
Year and Year interactions									
Y S.Em ±	-	-	0.028	-	-	0.006	-	-	0.011
C.D. at 5%	NS	NS	NS	NS	NS	0.016	NS	NS	0.031
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	5.84	6.25	6.05	4.38	5.55	4.99	6.86	5.79	6.44

Table 4.2: Effect of potash, iron and zinc on phosphorus content in kernel, shell and haulm of groundnut

Treatments	P content (%)								
	Kernel			Shell			Haulm		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	0.354	0.480	0.417	0.071	0.112	0.091	0.139	0.190	0.165
K_1: 25 kg ha^{-1}	0.360	0.473	0.416	0.068	0.112	0.090	0.140	0.193	0.166
K_2: 50 kg ha^{-1}	0.366	0.472	0.419	0.070	0.110	0.090	0.138	0.189	0.164
S.Em ±	0.004	0.005	0.003	0.001	0.001	0.001	0.002	0.002	0.001
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	0.364	0.473	0.419	0.069	0.113	0.091	0.140	0.189	0.165
Fe_1: 15 kg ha^{-1}	0.360	0.482	0.421	0.070	0.111	0.090	0.140	0.192	0.166
Fe_2: 30 kg ha^{-1}	0.355	0.471	0.413	0.068	0.111	0.090	0.137	0.191	0.164

S.Em ±	0.004	0.005	0.003	0.001	0.001	0.001	0.002	0.002	0.001
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	0.356	0.482	0.419	0.070	0.111	0.091	0.139	0.194	0.167
Zn_1: 08 kg ha^{-1}	0.359	0.471	0.415	0.068	0.112	0.090	0.140	0.188	0.164
Zn_2: 16 kg ha^{-1}	0.365	0.471	0.418	0.070	0.111	0.090	0.139	0.189	0.164
S.Em ±	0.004	0.005	0.003	0.001	0.001	0.001	0.002	0.002	0.001
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	0.01	NS
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	-	-	-	-	-	-	-
Year and Year interactions									
Y S.Em ±	-	-	0.003	-	-	0.001	-	-	0.001
C.D. at 5%	NS	NS	0.007	NS	NS	0.001	NS	NS	0.002
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	5.28	5.52	5.48	6.55	6.69	6.83	5.77	5.40	5.60

4. Results and Discussion

4.1 Nutrient Content

4.1.1 N content (%): Application of 50 kg K_2O ha^{-1} significantly increased nitrogen content in the kernel compared to control, while no significant effect was observed in the shell and haulm (Table 4.1). Similarly, 30 kg Fe ha^{-1} and 16 kg Zn ha^{-1} also significantly enhanced kernel nitrogen content over their respective controls. However, nitrogen content in the shell and haulm remained statistically unaffected by the application of potassium, iron, or zinc. Interaction effects among nutrients were non-significant (Table 4.1). These results corroborate the findings of Borah *et al.* (2018) [4] and Sakarvadia *et al.* (2020) [7]. These findings suggest that individual application of K, Fe, and Zn improves nitrogen accumulation in groundnut kernels, likely due to enhanced nutrient availability and metabolic activity.

4.1.2 P content (%): The results revealed that phosphorus content in the kernel, shell, and haulm of groundnut was not significantly influenced by the application of potassium (K), iron (Fe), or zinc (Zn) during both years and on pooled basis These results corroborate the findings of Borah *et al.* (2018) and Sakarvadia *et al.* (2020) (Table 4.2) [4, 7].

4.1.3 K content (%): Application of potash significantly influenced the potassium content in the kernel, shell, and haulm of groundnut (Table 4.3). The highest K content in kernel (0.822%), shell (0.675%), and haulm (0.941%) was observed with the application of 25 kg K_2O ha^{-1}, which was statistically at par with 50 kg K_2O ha^{-1}. This indicates that 25 kg K_2O ha^{-1} was sufficient to optimize potassium accumulation in different plant parts. These results corroborate the findings of Borah *et al.* (2018) and Sakarvadia *et al.* (2020) [4, 7].

4.1.4 Fe content

Application of iron significantly enhanced the iron content in kernel, shell, and haulm of groundnut, with the highest values observed under 30 kg Fe ha^{-1} (Fe_2), owing to increased Fe availability in plant. Iron plays a crucial role in enzymatic functions and chlorophyll synthesis, which likely improved its translocation to different plant parts. In contrast, potassium and zinc applications showed no significant effect on Fe content, possibly due to limited interaction in nutrient uptake.

4.1.5 Zn content

Application of zinc significantly improved the zinc content in the kernel, shell, and haulm of groundnut, with the highest values recorded at 16 kg Zn ha^{-1} (Zn_2). This increase can be attributed to enhanced Zn availability in soil and its efficient uptake and translocation within the plant

Table 4.3: Effect of potash, iron and zinc on potassium content in kernel, shell and haulm of groundnut

Treatments	K content (%)								
	Kernel			Shell			Haulm		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	0.762	0.830	0.796	0.601	0.720	0.661	0.862	0.971	0.917
K_1: 25 kg ha^{-1}	0.797	0.847	0.822	0.623	0.727	0.675	0.885	0.998	0.941
K_2: 50 kg ha^{-1}	0.785	0.812	0.798	0.609	0.706	0.657	0.899	0.975	0.937
S.Em ±	0.009	0.009	0.006	0.005	0.005	0.004	0.007	0.011	0.006
C.D. at 5%	0.03	0.02	0.02	0.01	0.01	0.01	0.020	0.031	0.018
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	0.785	0.847	0.816	0.617	0.723	0.670	0.880	0.990	0.935
Fe_1: 15 kg ha^{-1}	0.779	0.818	0.799	0.604	0.715	0.660	0.894	0.986	0.940
Fe_2: 30 kg ha^{-1}	0.779	0.825	0.802	0.612	0.716	0.664	0.873	0.969	0.921
S.Em ±	0.009	0.009	0.006	0.005	0.005	0.004	0.007	0.011	0.006
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Zinc (Zn)									

Zn_0: 00 kg ha^{-1}	0.794	0.823	0.809	0.605	0.713	0.659	0.873	0.974	0.923
Zn_1: 08 kg ha^{-1}	0.775	0.821	0.798	0.616	0.715	0.666	0.881	0.976	0.928
Zn_2: 16 kg ha^{-1}	0.774	0.846	0.810	0.611	0.726	0.669	0.893	0.994	0.944
S.Em ±	0.009	0.009	0.006	0.005	0.005	0.004	0.007	0.011	0.006
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	-	-	-	-	-	-	-
Year and Year interactions									
Y S.Em ±	-	-	0.005	-	-	0.003	-	-	0.005
C.D. at 5%	NS	NS	0.014	NS	NS	0.008	NS	NS	0.014
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	6.32	5.49	5.90	4.31	3.69	3.97	4.06	5.81	5.11

Table 4.4: Effect of potash, iron and zinc on iron content in kernel, shell and haulm of groundnut

Treatments	Fe content (mg kg⁻¹)								
	Kernel			Shell			Haulm		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	78.59	81.42	80.00	517.9	608.9	563.4	479.3	576.8	528.0
K_1: 25 kg ha^{-1}	77.39	82.59	79.99	529.3	606.2	567.8	485.9	586.1	536.0
K_2: 50 kg ha^{-1}	76.54	83.30	79.92	528.0	619.5	573.7	483.9	586.1	535.0
S.Em ±	0.876	0.954	0.648	4.753	5.058	3.470	6.164	6.073	4.326
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	73.22	79.84	76.53	512.3	601.1	556.7	470.9	572.4	521.7
Fe_1: 15 kg ha^{-1}	77.30	82.81	80.06	533.1	610.3	571.7	485.2	579.3	532.3
Fe_2: 30 kg ha^{-1}	82.00	84.65	83.33	529.7	623.3	576.5	492.9	597.4	545.1
S.Em ±	0.876	0.954	0.648	4.753	5.058	3.470	6.164	6.073	4.326
C.D. at 5%	2.49	2.71	1.82	13.49	14.35	9.73	17.49	17.23	12.13
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	78.09	80.76	79.43	519.0	607.2	563.1	479.7	573.8	526.8
Zn_1: 08 kg ha^{-1}	77.37	82.97	80.17	528.1	619.8	574.0	485.3	592.9	539.1
Zn_2: 16 kg ha^{-1}	77.06	83.58	80.32	528.1	607.5	567.8	484.1	582.3	533.2
S.Em ±	0.876	0.954	0.648	4.753	5.058	3.470	6.164	6.073	4.326
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	-	-	-	-	-	-	-
Year and Year interactions									
Y S.Em ±	-	-	0.529	-	-	2.834	-	-	3.533
C.D. at 5%	NS	NS	1.483	NS	NS	7.946	NS	NS	9.906
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	5.88	6.01	5.95	4.70	4.30	4.49	6.63	5.41	5.96

Table 4.5: Effect of potash, iron and zinc on zinc content in kernel shell, and haulm of groundnut

Treatments	Zn content (mg kg⁻¹)								
	Kernel			Shell			Haulm		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	28.80	29.96	29.38	25.69	25.68	25.69	12.60	14.59	13.59
K_1: 25 kg ha^{-1}	28.82	30.14	29.48	25.74	26.04	25.89	12.84	14.75	13.79
K_2: 50 kg ha^{-1}	29.11	30.31	29.71	25.89	26.28	26.09	12.97	14.91	13.94
S.Em ±	0.224	0.334	0.201	0.252	0.268	0.184	0.159	0.170	0.116
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	28.57	29.97	29.27	25.68	25.66	25.67	12.69	14.60	13.64
Fe_1: 15 kg ha^{-1}	28.99	30.10	29.54	25.72	26.14	25.93	12.81	14.64	13.72
Fe_2: 30 kg ha^{-1}	29.17	30.34	29.76	25.92	26.20	26.06	12.90	15.01	13.96
S.Em ±	0.224	0.334	0.201	0.252	0.268	0.184	0.159	0.170	0.116

C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	28.43	29.82	29.12	25.34	25.50	25.42	12.54	14.38	13.46
Zn_1: 08 kg ha^{-1}	29.05	29.93	29.49	25.76	26.14	25.95	12.72	14.85	13.79
Zn_2: 16 kg ha^{-1}	29.25	30.66	29.96	26.24	26.36	26.30	13.14	15.02	14.08
S.Em ±	0.224	0.334	0.201	0.252	0.268	0.184	0.159	0.170	0.116
C.D. at 5%	0.634	0.947	0.563	0.715	0.761	0.516	0.452	0.482	0.326
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	-	-	-	-	-	-	-
Year and Year interactions									
Y S.Em ±	-	-	0.164	-	-	0.150	-	-	0.095
C.D. at 5%	NS	NS	0.459	NS	NS	NS	NS	NS	0.266
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	4.02	5.75	5.00	5.08	5.36	5.22	6.47	5.98	6.21

Table 4.6: Effect of potash, iron and zinc on total nitrogen, phosphorus and potash uptake by groundnut crop

Treatments	Total uptake (kg ha^{-1})								
	Nitrogen			Phosphorus			Potash		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	115.3	118.1	116.7	9.56	14.43	11.99	41.73	51.75	46.74
K_1: 25 kg ha^{-1}	130.6	132.3	131.4	10.93	15.72	13.32	49.78	58.50	54.14
K_2: 50 kg ha^{-1}	140.9	136.1	138.5	11.50	15.98	13.74	51.72	58.17	54.95
S.Em ±	2.385	2.885	1.872	0.178	0.289	0.170	0.797	1.119	0.687
C.D. at 5%	6.77	8.19	5.25	0.505	0.821	0.476	2.262	3.176	1.927
Levels of Iron (Fe)9									
Fe_0: 00 kg ha^{-1}	122.7	122.5	122.6	10.44	14.76	12.60	46.38	54.75	50.57
Fe_1: 15 kg ha^{-1}	129.0	129.5	129.2	10.63	15.50	13.06	47.81	56.21	52.01
Fe_2: 30 kg ha^{-1}	135.1	134.5	134.8	10.92	15.87	13.39	49.04	57.47	53.25
S.Em ±	2.385	2.885	1.872	0.178	0.289	0.170	0.797	1.119	0.687
C.D. at 5%	6.77	8.19	5.25	NS	0.821	0.476	NS	NS	1.927
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	122.6	122.5	122.5	10.26	15.12	12.69	45.91	53.92	49.91
Zn_1: 08 kg ha^{-1}	128.8	130.6	129.7	10.73	15.39	13.06	47.98	56.33	52.16
Zn_2: 16 kg ha^{-1}	135.4	133.3	134.4	11.00	15.61	13.30	49.34	58.17	53.76
S.Em ±	2.385	2.885	1.872	0.178	0.289	0.170	0.797	1.119	0.687
C.D. at 5%	6.77	8.19	5.25	0.50	NS	0.48	2.262	3.176	1.927
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	K x Fe	-	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe
Year and Year interactions									
Y S.Em ±	-	-	1.528	-	-	0.139	-	-	1.190
C.D. at 5%	NS	NS	NS	NS	NS	0.388	NS	NS	3.34
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	9.61	11.64	10.67	8.67	9.77	9.58	8.68	10.36	9.72

4.2 Nutrient uptake

4.2.1 Total N, P and K uptake (kg/ha)

The data in Table 4.6 clearly indicate that the total uptake of nitrogen (N), phosphorus (P), and potassium (K) by groundnut was significantly affected by the individual application of potassium (K), iron (Fe), and zinc (Zn).

Among potash levels, the application of 50 kg K_2O ha^{-1} (K_2) resulted in significantly higher pooled nitrogen uptake (138.5 kg ha^{-1}), phosphorus uptake (13.74 kg ha^{-1}), and potassium uptake (54.95 kg ha^{-1}) compared to K_0 and K_1. The enhancement in nutrient uptake with higher potassium application may be attributed to potassium's role in improving root growth, enzymatic activity, and energy transfer mechanisms, which facilitate greater absorption of other nutrients. Potassium also regulates stomatal function and enhances the translocation of assimilates, thus increasing the nutrient demand and uptake efficiency of the plant. These findings are in agreement with the observations of Hadwani *et al.* (2005) [6], Salve and Gunjal (2011) [8] who reported increased NPK uptake in groundnut with graded levels of potassium fertilization.

With regard to iron, the application of 30 kg Fe ha^{-1} (Fe_2) recorded the highest total uptake of nitrogen (134.8 kg ha^{-1}), phosphorus (13.39 kg ha^{-1}), and potash (53.25 kg ha^{-1}), and showed significant differences over the control, especially in nitrogen and potash uptake. The improvement in nutrient uptake due to Fe application can be scientifically explained by iron's critical role in chlorophyll synthesis, electron transport in photosynthesis, and activation of enzymatic systems, all of which promote better root function and metabolic activity, leading to greater absorption of nutrients. Moreover, iron helps in nitrate reduction and nitrogen assimilation, thereby directly influencing nitrogen uptake and utilization.

In the case of zinc, the application of 16 kg Zn ha⁻¹ (Zn_2) significantly enhanced the total uptake of nitrogen (134.4 kg ha⁻¹), phosphorus (13.30 kg ha⁻¹), and potassium (53.76 kg ha⁻¹), compared to control and lower zinc levels. Zinc is known to be a cofactor for many enzymes involved in protein synthesis, auxin metabolism, and membrane integrity, which improves root development and nutrient transport mechanisms. In particular, zinc enhances phosphorus availability in the rhizosphere by improving phosphatase activity and root exudation, which may explain the increased P uptake. These results corroborate the findings of Tathe (2008) [10] Akbari *et al.* (2011) [1] who demonstrated improved NPK uptake with increasing Zn levels in leguminous crops.

Table 4.7: Effect of potash, iron and zinc on total sulphur, iron and zinc uptake by groundnut crop

Treatments	Total uptake								
	Sulphur (kg ha^{-1})			Iron (g ha^{-1})			Zinc (g ha^{-1})		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Levels of Potash (K)									
K_0: 00 kg ha^{-1}	4.482	5.328	4.905	2005	2630	2317	96.29	114.2	105.2
K_1: 25 kg ha^{-1}	5.158	6.065	5.611	2369	2963	2666	109.9	125.8	117.8
K_2: 50 kg ha^{-1}	5.636	6.329	5.983	2422	3026	2724	115.9	130.1	123.0
S.Em ±	0.097	0.124	0.079	42.71	53.74	34.32	1.734	2.783	1.639
C.D. at 5%	0.274	0.352	0.220	121	153	96	4.920	7.898	4.598
Levels of Iron (Fe)									
Fe_0: 00 kg ha^{-1}	4.736	5.551	5.144	2138	2719	2428	102.9	117.9	110.4
Fe_1: 15 kg ha^{-1}	5.066	5.908	5.487	2267	2864	2566	107.1	122.9	115.0
Fe_2: 30 kg ha^{-1}	5.474	6.262	5.868	2391	3036	2713	112.1	129.3	120.7
S.Em ±	0.097	0.124	0.079	42.71	53.74	34.32	1.734	2.783	1.639
C.D. at 5%	0.274	0.352	0.220	121	153	96	4.920	7.898	4.598
Levels of Zinc (Zn)									
Zn_0: 00 kg ha^{-1}	4.792	5.630	5.211	2174	2739	2457	102.0	117.2	109.6
Zn_1: 08 kg ha^{-1}	5.171	5.953	5.562	2290	2951	2621	107.9	124.6	116.2
Zn_2: 16 kg ha^{-1}	5.313	6.139	5.726	2332	2928	2630	112.2	128.3	120.2
S.Em ±	0.097	0.124	0.079	42.71	53.74	34.32	1.734	2.783	1.639
C.D. at 5%	0.274	0.352	0.220	121	153	96	4.920	7.898	4.598
Interaction									
K × Fe, K × Zn, Fe ×Zn, K × Fe × Zn	-	-	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe	K x Fe
Year and Year interactions									
Y S.Em ±	-	-	0.064	-	-	28.02	-	-	1.339
C.D. at 5%	NS	NS	0.180	NS	NS	78.59	NS	NS	3.754
Y × K, Y × Fe, Y × Zn, Y × K × Fe, Y × K × Zn, Y × Fe × Zn, Y × K × Fe × Zn	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	9.85	10.92	10.50	9.80	9.72	9.82	8.39	11.72	10.44

4.2.2 Total S (Kg/ha), Fe and Zn uptake (g/ha)

The data in Table 4.7 show that the uptake of sulphur (S), iron (Fe), and zinc (Zn) by the groundnut crop was significantly influenced by the individual application of potassium (K), iron (Fe), and zinc (Zn).

Among potassium treatments, the application of 50 kg K_2O ha⁻¹ (K_2) resulted in significantly higher uptake of sulphur (5.983 kg ha⁻¹), iron (2724 g ha⁻¹), and zinc (123.0 g ha⁻¹), compared to lower doses. The increased uptake can be scientifically attributed to potassium's role in enhancing enzyme activity, improving membrane permeability, and stimulating root growth, which collectively increase the plant's ability to absorb both macronutrients and micronutrients from the soil. Moreover, potassium facilitates the translocation of nutrients within the plant, which contributes to higher accumulation of S, Fe, and Zn in plant tissues. These findings are supported by Borah *et al.* (2018) [4] who reported enhanced micronutrient uptake in legumes and oilseeds with increasing potassium doses.

Application of 30 kg Fe ha⁻¹ (Fe_2) significantly increased sulphur (5.868 kg ha⁻¹), iron (2713 g ha⁻¹), and zinc uptake (120.7 g ha⁻¹) over the control. The positive effect of Fe application on its own uptake is expected, but its influence on S and Zn uptake can be scientifically explained by iron's role in regulating root respiration, chlorophyll biosynthesis, and activation of transport proteins, which improves root efficiency and nutrient absorption. Iron also plays a role in improving the redox balance in the rhizosphere, which may enhance the availability of sulphur and zinc in soils, particularly under oxidized conditions. These results corroborate the findings of Chauhan *et al.* (2024) [5].

The application of 16 kg Zn ha⁻¹ (Zn_2) significantly improved the uptake of sulphur (5.726 kg ha⁻¹), iron (2630 g ha⁻¹), and zinc (120.2 g ha⁻¹), compared to the untreated control. This may be due to the fact that zinc is a key component of several metalloenzymes and regulatory proteins that support active uptake and assimilation of nutrients. Zinc enhances auxin production and root proliferation, thereby increasing the root surface area and improving the plant's ability to absorb S and Fe. Zinc also aids in sulphur assimilation through its effect on sulphur-containing amino acids like cysteine and methionine.

Bairwa *et al.* (2013), Singhal *et al.* (2014), Ankesh *et al.* (2023) [2, 3, 9].

5. Summary & conclusion

Application of 50 kg K_2O ha^{-1} significantly increased nitrogen content in kernel and potassium content in kernel, shell, and haulm, along with higher total uptake of N, P, K, S, Fe, and Zn by groundnut. Iron application at 30 kg ha^{-1} significantly improved nitrogen content in kernel, sulphur content in haulm, and iron content in kernel, shell, and haulm, and also resulted in higher uptake of N, P, K, S, Fe, and Zn. Zinc application at 16 kg ha^{-1} significantly enhanced nitrogen content in kernel, sulphur content in haulm, and zinc content in kernel, shell, and haulm, with a corresponding increase in the uptake of N, P, K, S, Fe, and Zn.

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