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RESPONSE OF AGRONOMIC BIOFORTIFICATION WITH ZINC ON DUAL-PURPOSE OATS AND POST-HARVEST SOIL NUTRIENT STATUS IN ZINC DEFICIENT SOIL OF NORTHEASTERN REGION OF INDIA

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ABSTRACT

Zinc is pivotal for normal metabolism in plants, animals and humans and its deficiency is generally known as hidden hunger. The North-eastern region of India with predominantly humid subtropical climate is deficient in zinc owing to acidic soil, presence of iron and aluminium oxides/ hydroxides and low organic matter content due to excessive rainfall and high temperatures. Hence, in order to evaluate the effect of agronomic biofortification of dual-purpose oats with zinc, a field experiment at the Instructional-cum-Research Farm (ICR Farm) of Assam Agricultural University (AAU), Jorhat, Assam was conducted during the *rabi* season of 2021-2022. The research was laid out in Randomized Block Design (RBD) with 12 treatments and three replications with the variety 'Kent'. Along with the recommended dose of fertilizers (RDF), different doses of zinc were applied as basal (5kg ha^{-1}, 7.5kg ha^{-1} and 10kg ha^{-1}), foliar spray (0.5%, 0.75% at 30 and 75 days after sowing) and in combination of basal and foliar. The chemical analysis of green fodder, grain and straw showed significant improvement in nutrient content (nitrogen, potassium and zinc) and uptake (nitrogen, phosphorus, potassium and zinc) with the combined application of $ZnSO_4$ as basal at the rate of 7.5 kg ha^{-1} and foliar spray of 0.5% at 30 and 75 DAS along with RDF (T_{11}). Similarly, application of $ZnSO_4$ as basal at the rate of 7.5 kg ha^{-1} and foliar spray of 0.5% at 30 and 75 DAS along with RDF (T_{11}) improved the quality by significantly increasing the crude protein content and yield and reducing the crude fibre percentage. A fodder crop with higher crude protein to crude fibre ratio is considered superior due to its high digestibility and palatability. However, the post-harvest soil zinc content was significantly enhanced with the basal application of $ZnSO_4$ at the rate of 10kg ha^{-1} along with RDF (T_4) due to its direct availability. Hence, zinc fertilization is a promising tool in successful biofortification of grain and fodder as well as improving the zinc status in otherwise deficient soil for enriching micronutrient levels in soil-plant-animal-human continuum.
Keywords: Agronomic biofortification, Crude protein, Crude fibre, Nutrient content, Zinc

Introduction

Livestock is the foundation of Indian economy. It is the key source of milk and meat proteins, as well as raw materials for leather, draught power, and biomass enriching Indian agriculture since civilization. Over 62% of marginal households engage in livestock farming, making it a crucial part of the Indian farming system, particularly for small and marginal farmers (Das *et al*., 2020). Livestock sector generates employment to over 300 million rural people

(Muthukumar *et al*., 2021), contributing nearly 26% to the income of small farmers and 24% to total rural households (Arya and Singh, 2020), thus eliminating poverty. The 20^{th} livestock census (Department of Animal Husbandry and Dairying) indicates that the overall livestock population rose by 4.6% from 512.06 million in 2012 to 536.76 million in 2019. However, this increase is not in synchrony with the national fodder supply. With 11% of the world's livestock population in India, the area under fodder meagrely remains at 4% of the gross cropped area since the past four decades. According to the estimates of ICAR-National Institute of Animal Nutrition and Physiology (NIANP), there is a severe shortfall of green fodder, dry fodder and protein by 36%, 23% and 36%, respectively, that is expected to increase to 40%, 23% and 38%, respectively by 2025. The primary cause of the shortage of quality fodder is the paucity of area available for its production that critically influences animal productivity and national economic development. The animals require balanced feed to exhibit their full genetic production potential. Fodder production in India suffers negligence as it consists solely of agricultural crop residues, grasses and weeds grown on marginal or degraded areas without adequate resource application. Furthermore, in the lean times, when droughts and floods are common due to climate change, the fodder scarcity is crucial. As a result, there occurs discrepancy in fodder output negatively impacting livestock health and productivity. Hence, it is critical to fill the lacuna of fodder demand and supply by enhancing production both in terms of quality and quantity in order to achieve feed, nutritional, and livelihood security, as well as increased livestock productivity.

Oats (*Avena sativa* L.), a *rabi* cereal belonging to the family Poaceae, has been proven as a successful dual-purpose crop for its capacity to supply nutrient laden grains for human consumption and wholesome nutritious animal feed. It is the unique source of antioxidants such as avenanthramides (Ncinnamoylanthranilate alkaloids) and avenalumic acids (ethylenic homologues of cinnamic acids) absent in any other cereal grains (Kim *et al*., 2021). It ranks first among the *rabi* cereal fodder and hence, widely cultivated because of its luxuriant growth, high palatability and excellent nutrient value. It helps in combating fodder scarcity during the lean periods by offering a great scope for preservation in the form of silage, hay and haylage since it is abundantly rich in high water-soluble carbohydrates and low buffering capacity (Xiong *et al.,* 2022). Its ability to thrive in well-drained, acidic loamy soil and grow luxuriantly at temperatures ranging from 15 to 20°C makes the North-eastern Regions excellent for producing oats throughout the *rabi* season.

The objective of enhancing both quantity and quality, marks sagacious production of grain and fodder crops to achieve sustainable productivity, particularly addressing micronutrient deficiency. Micronutrients are essential for the proper functioning of plants, animals, and humans. Their deficiency is referred as "hidden hunger" since the symptoms frequently go undiscovered until the disease becomes severe. Zinc is an incredibly important microelement, and its significance is becoming increasingly apparent across the world. It is responsible for chlorophyll synthesis, drought stress resistance by maintaining water balance, tryptophane and auxin synthesis, cellular integrity, pollen grain formation, and activating over 300 enzymes such as carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase, carboxy peptidase, aldolase, and RNA polymerase, etc. (Das *et al*., 2019; Cabot *et al*., 2019). Zinc is required for protein synthesis, glucose metabolism, cell division, gene expression, reproductive health, DNA replication and RNA transcription and for other functions in both animals and humans. Its deficiency in animals is characterised by the formation of hard lessons on the skin of the head, scrotum, neck, and legs, a condition known as parakeratosis that was originally detected in swine in 1955 (Achonwa *et al*., 2020). Zinc deficiency in soils that accounts for nearly 49%, is a global nutritional issue aggravated by less than 3.5% zinc use efficiency due to the variations in soil zinc adsorptive capacity (Suganya *et al*., 2020). Limiting factors like high rainfall of more than 1350 mm, low soil pH, abundance of iron/aluminium oxides and hydroxides and low organic matter content, accentuates the problem of zinc deficiency in north-eastern region (Alloway *et al*., 2008; Behera *et al*., 2011). Furthermore, grains in particular are poor sources of zinc because much of it is found in the aleurone layer, which is removed during milling (Aiqing *et al*., 2022). According to the reports released by World Health Organization in 2002, zinc deficiency is the fifth most common cause of malnutrition in people of the developing nations (Balakrishnan, 2011). The relevance of dual-purpose crops stems from the fact that energy is transferred from one trophic level to the next via the soil-plant-animal-human continuum, and a lack or toxicity of nutrient in one can have a direct impact on the others. Hence, a study was attempted to enhance the nutrient content, nutrient uptake and quality of dual-purpose oats and post-harvest soil nutrient status by agronomic biofortification with zinc in North-eastern regions.

Materials and Methods

Experimental site

An experiment was conducted on dual-purpose oats variety ‘Kent’ at the Instructional-cum-Research (ICR) farm of Assam Agricultural University, Jorhat, Assam during the *rabi* season of 2021-2022 to evaluate the effect of agronomic biofortification with zinc on dual-purpose oats in zinc deficient soil. The experimental site was geographically situated at 26°45'N latitude and 94°12'E longitude and at an altitude of 87 meters above the mean sea level (MSL). The site was uniformly fertile, well drained, sandy loam in texture with a pH of 5.5. The soil was low in organic carbon content (0.46%), medium in available nitrogen (308.93 kg ha^{-1}), low in available phosphorus (21.36 kg ha^{-1}), medium in available potassium (150.75 kg ha^{-1}) and low in available zinc (0.58 mg kg^{-1}). During the crop growing season, the mean weekly maximum and minimum temperature varied from 21.2°C to 33.3°C and 8.2°C to 18.9°C, respectively. The overall precipitation was 110 mm, with the highest of 33.7 mm during the last week of March.

Experimental details

The investigation was laid out in Randomized Block Design (RBD) with 12 treatments that were replicated thrice. The crop was harvested at 60 DAS for green fodder and 120 DAS for grain and straw. The RDF for dual purpose oats is 40-20-20 kg N, P_2O_5 and K_2O per hectare applied as urea, SSP and MOP. The first $2/3^{rd}$ of urea was applied during the final land preparation along with the full doses of SSP, MOP and $ZnSO_4$ (at the rate of 5, 7.5 and 10 kg ha^{-1} as per the treatments). The remaining $1/3^{rd}$ urea is applied 2 days after the first cut. $ZnSO_4$ was applied as foliar at the rate of 0.5% and 0.75% 15 days after the first cut i.e., at 75 DAS. The treatments details are provided in the Table 1.

Plant analysis

The plant samples were collected at each harvest (*viz.* at 60 and 120 DAS) and oven dried at 65°C for chemical analysis of green fodder, grain and straw. The laboratory analysis of total nitrogen, phosphorus, potassium and zinc was performed by modified Kjehdal method (Jackson, 1973), Tri acid digestion and vandomolybdo phosphoric acid method (Jackson, 1973), flame photometry method (Sparks, 1996) and atomic absorption spectrophotometer (Tandon, 2001), respectively. The nutrient uptake was calculated by multiplying nutrient content (%) and dry matter yield (DMY). Further, the crude protein was calculated by multiplying the nitrogen content (%) with a factor of 6.25 (Mariotti *et al.,* 2008). The product of crude protein content (%) and DMY was done to calculate the crude protein yield. The crude fibre and crude fat content were analysed according to the A.O.A.C. (2005).

Soil analysis

The initial and final soil samples were collected before and after completion of the experiment, respectively, followed by oven drying at 105°C for chemical analysis of organic carbon content by Walkley and Black’s method (1934), available nitrogen by alkaline potassium permanganate method (Subbiah and Asija, 1956), available (bray) phosphorus by stannous chloride blue colour method (Bray and Kurtz, 1945), 1N NH_4OAc extractable potassium by flame photometer (Jackson, 1973) and DTPA extractable zinc by atomic absorption spectrophotometer (Lindsay and Norvell, 1978). The data of initial soil chemical analysis is mentioned earlier in the section of experimental site.

Statistical analysis

The data recorded for various parameters during field and chemical studies were analysed statistically following the analysis of variance for randomized block design. The difference between the treatment means was tested for their statistical significance with an appropriate critical difference (C.D) value at 5% level of significance as suggested by Panse and Sukhatme (1985).

Results and Discussions

Effect on nutrient content of dual-purpose as influenced by agronomic biofortification with zinc

The effect on nutrient content of dual-purpose oats is influenced by agronomic biofortification of zinc that is represented in Table 2. The laboratory analysis for nutrient content in fodder, grain and straw revealed that, the content of nitrogen (2.681%, 3.870% and 0.806%, respectively), potassium (1.151%, 1.190% and 1.464%, respectively) and zinc (28.430 mg kg^{-1}, 33.660 mg kg^{-1} and 34.670 mg kg^{-1}, respectively) was found to be significantly highest when $ZnSO_4$ was applied as basal at the rate of 7.5 kg ha^{-1} and foliar spray of 0.5% at 30 and 75 DAS along with RDF (T_{11}). This effect might be due to the application of zinc that promotes the bioavailability of nutrients via mineralization in the rhizosphere and improved cation exchange capacity of the roots. The synergistic effect between zinc and nitrogen, and zinc and potassium are responsible for their increased absorption (Kashyap *et al.,* 2023). However, with respect to the phosphorus content in fodder, grain and straw, it was highest (0.230%, 0.184% and 0.212%, respectively) without showing any significant effect under the similar treatment (T_{11}) due to the synergistic relationship between zinc and phosphorus that exist only at their low concentrations. If an increase in either of the one element occurs, antagonistic effect rule between zinc and phosphorus reducing their uptake (Paramesh *et al.*, 2014; Abdullahi and Bello, 2020).

Effect on nutrient uptake as influenced by agronomic biofortification with zinc

The uptake of nitrogen, phosphorus, potassium and zinc by green fodder, grain and straw, and the total nutrient uptake showed significant increase when $ZnSO_4$ as basal at the rate of 7.5 kg ha^{-1} and foliar spray of 0.5% at 30 and 75 DAS was applied along with RDF (T_{11}). The effect on nutrient uptake by dual-purpose oats is represented in Table 3. This was probably due to the steady and continuous availability of nutrients due to the application of zinc. The uptake of any nutrient is determined by its content and the ability of the crop to produce dry matter. Hence, higher nutrient content (Table – 2) and higher DMY of dual-purpose oats may be relevant reasons for higher nutrient uptake. The significant increase in dry matter due to the combined application of $ZnSO_4$ at the rate of 7.5 kg ha^{-1} and 0.5% of at 30 and 75 DAS and RDF (T_{11}) as showed in Fig. 1 might be attributed due to the effectiveness of zinc in promoting photosynthesis, carbohydrate metabolism and protein synthesis by enhancing enzymatic activity, regulating auxin synthesis, chlorophyll formation and functioning as structural or regulatory co-factor which resulted in rapid assimilation of photosynthates and dry matter accumulation. These results were in conformity with Chand *et al.* (2018) and Ramakrishna *et al.* (2022).

Effect on quality as influenced by agronomic biofortification with zinc

The effect on quality of dual-purpose oats as influenced by agronomic biofortification of zinc is represented in Table 4. The quality analysis revealed that, the crude protein content of fodder (16.76%), grains (24.19%) and straw (5.04%) was significantly increased when $ZnSO_4$ was applied as basal and foliar at the rate of 7.5 kg ha^{-1} and 0.5% at 30 and 75 DAS along with RDF (T_{11}). This might be due to the improved nitrogen content of the crop (as showed in Table 2) that is a crucial element for synthesis of crude protein. Thus, zinc is directly involved in the metabolism of crude protein. Likewise, the crude protein yield of fodder (483.19 kg ha^{-1}), grains (55.34 kg ha^{-1}), straw (306.59 kg ha^{-1}) and total crude protein yield (1354.12 kg ha^{-1}) were found to be significantly highest when RDF with basal application of 7.5 kg ha^{-1} and foliar sprays of 0.5% of $ZnSO_4$ at 30 and 75 DAS was applied (T_{11}). The increase might be due to the improved dry matter yield and crude protein content of the crop. Similar results were reported by Dhaliwal *et al.* (2020); Rajendra and Veeramani (2022) and Sewhag *et al.* (2022). The crude fibre content in fodder, grains and straw was highest when RDF was applied solely (T_1) (14.58%, 1.43% and 29.15%, respectively) that was statistically at par with RDF combined with water spray at 30 and 75 DAS (T_{12}). Whereas, it was significantly lowest (12.09% in fodder, 1.18% in grains and 24.18% in straw) with the combination of basal and foliar at the rate of 7.5 kg ha^{-1} and 0.5% at 30 and 75 DAS along with the RDF (T_{11}). Zinc is responsible for nitrogen metabolism and reduces the amount of pectin, cellulose and hemicellulose, thereby increasing the succulent nature of the crop (Waite, 1970; Noller and Rhykerd, 1974) that might be the reason for lowered crude fibre content. These findings could be ascribed to increased protein synthesis at greater rates of zinc application, lowering fibre content by lowering the soluble carbohydrates (Kumar *et al.*, 2015). A fodder crop with higher proportions of crude protein as compared to the crude fibre is highly digestible and palatable and hence considered superior. The analysis for crude fat content reported that no significant effects among the treatments were observed. However, it was found to be highest in fodder (2.51%), grains (7.52%) and straw (1.67%) with the combination of basal and foliar at the rate of 7.5 kg ha^{-1} and 0.5% at 30 and 75 DAS along with the RDF (T_{11}). The combination of basal and foliar application methods can be stated as a promising strategy for raising the quality of fodder and grain that can be an excellent way of enriching soil-plant-animal-human continuum with micronutrients (Kumar and Ram, 2021).

Effect on post-harvest soil nutrient status as influenced by agronomic biofortification with zinc

The data of laboratory analysis for soil nutrient content after harvesting the crop is represented in Table 5. It depicts that the concentration of available nitrogen, phosphorus and potassium were significant highest (299.56 kg ha^{-1}, 24.79 kg ha^{-1} and 147.88 kg ha^{-1}, respectively) under the treatment where RDF was solely applied (T_1). It was statistically at par with treatment where water was applied as foliar along with RDF (T_{12}). The lowest concentration was observed when $ZnSO_4$ was applied in the combination of basal and foliar at the rate of 7.5 kg ha^{-1} and 0.5% at 30 and 75 DAS along with the RDF (T_{11}) (285.20 kg ha^{-1} nitrogen, 16 kg ha^{-1} phosphorus and 136.13 kg ha^{-1} potassium). This might be due to the increased dry matter yield as shown in Fig. 1 and nutrient uptake (Table 3) with application of zinc under treatment T_{11} that have resulted in decreased post-harvest soil nutrient status. Similar results were reported by Chand *et al.* (2018).

The results for the analysis of DTPA extractable zinc after harvesting presented in Table 5, depicted that significantly highest amount of available zinc (0.71 mg kg^{-1}) was recorded with the basal application of $ZnSO_4$ at the rate of 10 kg ha^{-1} along with RDF. This significant increase in zinc over control by 31.48% may be due to the higher solubility and mobility of the applied zinc (Chitdeshwari and Krishnasamy, 1997). These results were in accordance with Muthukumararaja and Sriramachandrasekharan (2012). The increase in soil zinc content as a result of zinc application was earlier reported by Naik and Das (2007) and Chaudhary *et al.* (2007). Whereas, the lowest concentration was observed when $ZnSO_4$ was applied in the combination of basal and foliar at the rate of 7.5 kg ha^{-1} and 0.5% at 30 and 75 DAS along with the RDF (T_{11}) (0.60 mg kg^{-1}) due to its maximum uptake by the crop as the result of increased dry matter yield and zinc content.

Conclusion

The findings of this study underscore the efficacy of zinc biofortification in enhancing the nutrient content, nutrient uptake, and overall quality of dual-purpose oats grown in zinc-deficient soils. Specifically, the combination of $ZnSO_4$ applied as a basal treatment at 7.5 kg ha^{-1} along with foliar sprays of 0.5% at 30 and 75 days after sowing (DAS), integrated with the recommended dose of fertilizers (RDF), proved to be the most effective treatment. The exogenous application of zinc has the potential to achieve effective biofortification of dual-purpose oats. Furthermore, for immediate improvements in soil zinc levels, the basal application of $ZnSO_4$ at 10 kg ha^{-1}, in combination with RDF, can be recommended as a short-term solution for zinc-deficient soils. These results offer practical implications for sustainable livestock and crop management systems, contributing to both fodder security and the nutritional needs of smallholder farmers. Continued research into micronutrient management specific to regional soil and crop requirements is essential for promoting long-term soil fertility and crop productivity in zinc-deficient areas.

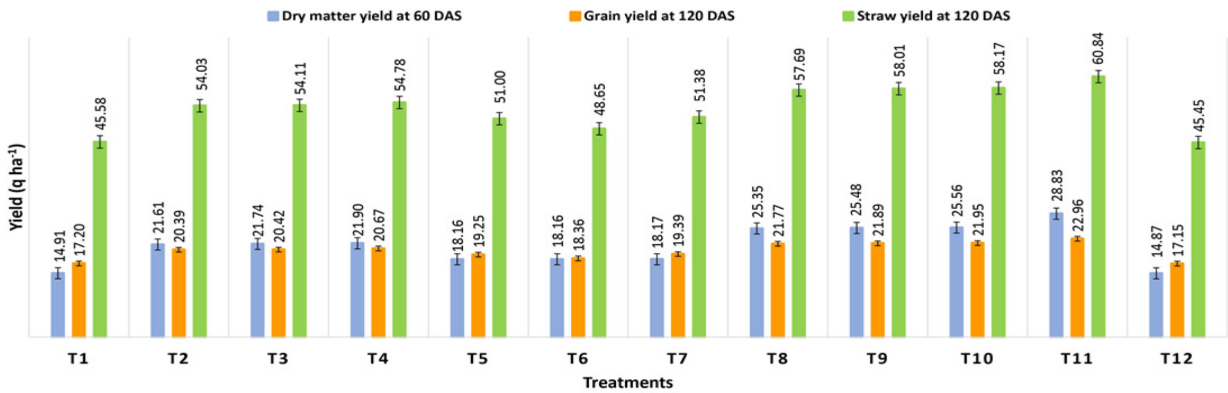

Fig. 1: Effect on dry matter yield of green fodder, grain yield and straw yield dual-purpose oats as influenced by agronomic biofortification with zinc

Table 1: Treatment details of the experiment

Symbols	Treatment details
T_1	Control (RDF: N: P_2O_5: K_2O at the rate 40-20-20 kg ha^{-1})
T_2	RDF + soil application of $ZnSO_4$ at the rate 5 kg ha^{-1}
T_3	RDF + soil application of $ZnSO_4$ at the rate 7.5 kg ha^{-1}
T_4	RDF + soil application of $ZnSO_4$ at the rate 10 kg ha^{-1}
T_5	RDF + one foliar application of 0.5% $ZnSO_4$ at 30 DAS
T_6	RDF + one foliar application of 0.75% $ZnSO_4$ at 30 DAS
T_7	RDF + two foliar applications of 0.5% $ZnSO_4$ at 30 and 75 DAS
T_8	RDF + soil application of $ZnSO_4$ at the rate 5 kg ha^{-1}+ foliar application of 0.5% $ZnSO_4$ at 30 DAS
T_9	RDF + soil application of $ZnSO_4$ at the rate 5 kg ha^{-1}+ foliar application of 0.75% $ZnSO_4$ at 30 DAS
T_{10}	RDF + soil application of $ZnSO_4$ at the rate 5 kg ha^{-1}+ foliar application of 0.5% $ZnSO_4$ at 30 and 75 DAS
T_{11}	RDF + soil application of $ZnSO_4$ at the rate 7.5 kg ha^{-1}+ foliar application of 0.5% $ZnSO_4$ at 30 and 75 DAS
T_{12}	RDF + Water spray at 30 and 75 DAS

Table 2: Influence of agronomic biofortification with zinc on nutrient content of dual-purpose oats

Treatment	N content (%)			P content (%)			K content (%)			Zn content (mg kg^{-1})		
	Fodder	Grain	Straw	Fodder	Grain	Straw	Fodder	Grain	Straw	Fodder	Grain	Straw
T_1	1.870	2.180	0.454	0.221	0.177	0.203	0.803	0.670	0.825	24.406	29.636	30.507
T_2	1.991	2.341	0.488	0.222	0.178	0.204	0.854	0.720	0.886	25.060	30.290	31.199
T_3	2.000	2.350	0.490	0.223	0.179	0.206	0.858	0.723	0.889	25.427	30.657	31.576
T_4	2.121	2.520	0.525	0.224	0.179	0.206	0.910	0.775	0.953	26.060	31.290	32.229
T_5	2.247	2.700	0.563	0.226	0.181	0.208	0.964	0.830	1.021	26.710	31.940	32.898
T_6	2.385	2.800	0.583	0.228	0.182	0.210	1.023	0.861	1.059	27.380	32.610	33.588
T_7	2.259	3.000	0.625	0.227	0.182	0.209	0.969	0.923	1.135	26.760	31.990	32.950
T_8	2.515	3.200	0.667	0.228	0.182	0.210	1.079	0.984	1.210	27.430	32.660	33.640
T_9	2.522	3.220	0.671	0.229	0.183	0.211	1.082	0.990	1.218	27.470	32.700	33.681
T_{10}	2.531	3.570	0.744	0.229	0.183	0.211	1.086	1.098	1.350	27.780	33.010	34.000
T_{11}	2.681	3.870	0.806	0.230	0.184	0.212	1.151	1.190	1.464	28.430	33.660	34.670
T_{12}	1.850	2.170	0.452	0.221	0.177	0.203	0.794	0.667	0.821	24.406	29.636	30.525
S.Em(±)	0.015	0.008	0.002	0.0045	0.0036	0.0041	0.006	0.002	0.003	0.13	0.13	0.16
CD(p=0.05)	0.044	0.022	0.005	NS	NS	NS	0.019	0.007	0.008	0.392	0.390	0.472

Table 3: Influence of agronomic biofortification with zinc on nutrient uptake of dual-purpose oats

Treatment	N uptake (kg ha^{-1})				P uptake (kg ha^{-1})				K uptake (kg ha^{-1})				Zn uptake (g ha^{-1})			
	Fodder	Grain	Straw	Total	Fodder	Grain	Straw	Total	Fodder	Grain	Straw	Total	Fodder	Grain	Straw	Total
T_1	27.88	37.50	20.70	86.08	3.30	3.04	9.27	15.61	11.96	11.53	37.58	61.08	36.38	50.97	139.06	226.42
T_2	43.03	47.74	26.36	117.12	4.80	3.62	11.03	19.45	18.46	14.68	47.85	80.99	54.16	61.76	168.58	284.50
T_3	43.49	47.98	26.49	117.96	4.87	3.65	11.13	19.64	18.66	14.76	48.10	81.51	55.28	62.60	170.87	288.75
T_4	46.45	52.09	28.76	127.29	4.91	3.70	11.29	19.90	19.93	16.02	52.21	88.16	57.07	64.68	176.53	298.28
T_5	40.81	51.97	28.69	121.46	4.10	3.48	10.60	18.19	17.51	15.98	52.09	85.58	48.52	61.48	167.82	277.82
T_6	43.31	51.41	28.38	123.10	4.14	3.35	10.21	17.70	18.59	15.81	51.53	85.92	49.73	59.87	163.42	273.02
T_7	41.05	58.17	32.11	131.33	4.13	3.52	10.73	18.38	17.61	17.89	58.30	93.80	48.62	62.03	169.31	279.96
T_8	63.76	69.66	38.46	171.88	5.78	3.97	12.10	21.85	27.36	21.42	69.82	118.60	69.53	71.07	193.99	334.59
T_9	64.28	70.48	38.91	173.67	5.84	4.01	12.22	22.07	27.58	21.67	70.64	119.90	70.00	71.58	195.38	336.97
T_{10}	64.71	78.36	43.26	186.33	5.86	4.02	12.25	22.13	27.77	24.10	78.54	130.41	71.01	72.46	197.77	341.23
T_{11}	77.31	88.85	49.05	215.22	6.63	4.22	12.88	23.73	33.17	27.32	89.06	149.55	81.96	77.28	210.94	370.19
T_{12}	27.52	37.22	20.55	85.29	3.29	3.03	9.24	15.56	11.81	11.45	37.31	60.56	36.29	50.83	138.74	225.86
S.Em(±)	2.40	0.92	0.51	2.70	0.25	0.08	0.26	0.50	1.03	0.28	0.92	1.53	2.58	0.98	2.71	4.61
CD(p=0.05)	7.046	2.704	1.493	7.924	0.722	0.247	0.754	1.469	3.023	0.831	2.710	4.479	7.552	2.888	7.941	13.511

Table 4: Influence of agronomic biofortification with zinc on quality of dual-purpose oats

Treatment	Crude protein content (%)			Crude protein yield (kg ha^{-1})				Crude fibre content (%)			Crude fat content (%)		
	Fodder	Grain	Straw	Fodder	Grain	Straw	Total	Fodder	Grain	Straw	Fodder	Grain	Straw
T_1	11.69	13.63	2.84	174.26	234.37	129.39	538.01	14.58	1.43	29.15	2.10	6.29	1.40
T_2	12.44	14.63	3.05	268.92	298.36	164.72	732.00	12.93	1.26	25.85	2.11	6.33	1.41
T_3	12.50	14.69	3.06	271.79	299.91	165.57	737.27	12.88	1.26	25.77	2.14	6.41	1.42
T_4	13.26	15.75	3.28	290.31	325.55	179.73	795.59	12.80	1.25	25.60	2.17	6.51	1.45
T_5	14.04	16.88	3.52	255.04	324.80	179.32	759.15	12.72	1.24	25.43	2.20	6.61	1.47
T_6	14.91	17.50	3.65	270.71	321.30	177.38	769.39	12.62	1.23	25.23	2.26	6.78	1.51
T_7	14.12	18.75	3.91	256.53	363.55	200.71	820.80	12.50	1.22	25.00	2.24	6.72	1.49
T_8	15.72	20.00	4.17	398.49	435.40	240.38	1074.27	12.39	1.21	24.78	2.29	6.86	1.52
T_9	15.76	20.13	4.19	401.73	440.51	243.20	1085.44	12.30	1.20	24.60	2.30	6.90	1.53
T_{10}	15.82	22.31	4.65	404.43	489.77	270.39	1164.59	12.27	1.20	24.54	2.40	7.19	1.60
T_{11}	16.76	24.19	5.04	483.19	555.34	306.59	1345.12	12.09	1.18	24.18	2.51	7.52	1.67
T_{12}	11.56	13.56	2.83	172.00	232.63	128.43	533.06	14.27	1.40	28.53	2.04	6.13	1.36
S.Em(±)	0.09	0.05	0.10	15.01	5.76	3.18	16.89	0.44	0.04	0.88	0.17	0.52	0.12
CD(p=0.05)	0.273	0.139	0.029	44.035	16.898	9.329	49.523	1.290	0.126	2.579	NS	NS	NS

Table 5: Influence of agronomic biofortification with zinc on post-harvest soil nutrient status

Treatment	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	DTPA extractable Zn (mg kg^{-1})
T_1	299.56	24.79	147.88	0.54
T_2	292.85	20.35	141.62	0.61
T_3	292.63	20.29	141.55	0.66
T_4	292.57	20.23	141.47	0.71
T_5	296.09	22.58	144.46	0.56
T_6	296.00	22.50	144.37	0.55
T_7	295.97	22.44	144.22	0.55
T_8	289.50	18.18	138.88	0.61
T_9	289.12	18.10	138.75	0.61
T_{10}	288.32	18.04	138.68	0.60
T_{11}	285.20	16.00	136.13	0.60
T_{12}	299.22	24.72	147.62	0.54
S.Em(±)	0.92	0.50	0.72	0.01
CD(p=0.05)	3.114	1.703	2.448	0.027
Initial values	**308.93**	**21.36**	**150.75**	**0.58**

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Conflict of interests

The author state that no competing interests exist.

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