RESEARCH ARTICLE

Effect of recycled liquid nano manganese fertiliser on wheat (*Triticum aestivum* L.) yield

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The productivity of agriculture is significantly hampered by micronutrient deficiencies, particularly manganese insufficiency. For agriculture to be sustainable, it is essential to address these shortcomings. In this context, a study was carried out to determine the effectiveness of "Mangnify," a nano manganese sulphate fertiliser made by recycling used single-use primary batteries, in enhancing wheat yield in Rajasthan. The field trials showed a considerable increase compared to control in wheat yield when treated with a foliar application of nano manganese fertiliser. The results of the ANOVA analysis showed that treated and controlled crops in every region had significantly different growth characteristics and yields. Kemla, in particular, revealed a noteworthy 30.8% rise in production, while Gudli showed increases of 19.3% and 5.8%. Furthermore, Bundi demonstrated a 6.7% yield improvement using a twofold application strategy. The study emphasises how recycled nano manganese sulphate fertilisers have the potential to address manganese deficiency and promote sustainable agriculture. According to the research, nano manganese fertiliser significantly enhances crop development and output while providing an environmentally friendly remedy for micronutrient deficiencies. This study highlights the potential of cutting-edge recycling methods to create successful agricultural interventions, ultimately pointing to a viable plan for boosting agricultural productivity while maintaining environmental sustainability.

Keywords: Nano manganese; Micronutrients; Primary battery recycling; Sustainable agriculture; Foliar application

Abbreviations: SS: Sum-of-Squares; df: degrees of freedom; MS: Mean Square; F: Mean of variation between samples/variation within samples; P-value: Probability value; Mn: Manganese; a: Bundi; b: Kemla; c: Gudli; V1: Variety 1; V2: Variety 2

INTRODUCTION

Agriculture plays a crucial part in supplying the world's food requirements and maintaining rural lives but conventional farming methods frequently result in soil deterioration, water pollution, and greenhouse gas emissions [1]. Therefore, it is crucial to use sustainable farming methods to provide food security while protecting the environment. A potential strategy to address the waste management challenges is recovering and recreating valuable non-renewable resources into sustainable products.

Micronutrient deficiencies pose significant challenges to agricultural productivity and human nutrition, impacting crop yields and food quality. In particular, deficiencies of essential micronutrients such as Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), and Zinc (Zn) can lead to decreased yields and compromise crop health. Addressing these deficiencies is crucial for sustainable and productive agriculture [2].

Micronutrient deficiencies have emerged as a significant challenge in Indian agriculture. The soil is degrading day by day due to the adoption of cropping practices, unbalanced fertiliser application, and overuse of urea. It is estimated that over 50% of Indian agricultural soils are deficient in micronutrients, leading to reduced crop yields and quality, and posing a threat to food security and economic growth.

In a study, soil samples from 508 districts around the nation were analysed and the results showed that 36.5%, 12.8%, 7.1%, 4.2%, and 23.2% of the soils, respectively, had deficiencies in important micronutrients like Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu), and Boron (B) [3]. Zn and B deficits were present in more than half of the districts, demonstrating the problem's pervasive prevalence. Along with the declining trend of Zn in the soils, Fe and Mn shortages have also increased.

Agricultural crops deplete 188,000 tonnes of micronutrients annually on average [4]. Proper micronutrient management is essential to resolve this problem, taking into account various aspects like crop kinds, soil types, the severity of the deficit, and suitable sources, techniques, rates, and treatment cycles. Studies have shown that including micronutrients in balanced fertilisation schedules improves the NPK fertilisers' internal usage efficiency, increasing crop productivity and output.

A novel approach to modern agriculture, nano-micronutrient fertilisers can increase crop output by utilising the potential of nanotechnology. Although nanotechnology has many uses in a variety of scientific disciplines, its use in agriculture has received very little attention globally. However, recent studies have looked at the effects of different sulphur fertilisers combined with nano-micronutrient fertilisers, notably nano-zinc, nano-iron, and nano-manganese, on the morpho-physiological characteristics of crops like chickpeas [5].

Applying recycled nano fertilisers effectively creates new opportunities for sustainable agriculture. These fertilisers increase plant growth and production by enabling efficient nutrient uptake and utilisation by the plants. Additionally, their targeted customised strategy guarantees that particular crop and nutrient deficits are addressed, resulting in optimised nutrient availability and diminished environmental effects [6].

Among the essential micronutrients, Manganese (Mn) plays a vital role in various physiological processes in plants, including photosynthesis, enzyme activation, and nutrient uptake. However, Mn deficiency is a widespread issue in many agricultural regions, affecting crops such as wheat, maize, and rice. It is very common in soils with low Manganese content, heavily weathered tropical and sandy soils, and organic-rich soils with high pH. Additionally, deficiency symptoms can occur in mineral soils with pH values above 6.5, including calcareous soils and those heavily limed.

Significant effects of Mn shortage include decreased crop output and weakened plant health. For instance, Mn deficiency is the most prevalent

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micronutrient deficiency in field crops, including cereals, sugar, beetroot, potatoes, oilseed and peas. and it is widespread throughout northern Europe. Interveinal or blotched chlorosis in old and young leaf blades, interveinal necrosis in young leaf blades, and stunted growth are all signs of a manganese deficiency.

Temperature, soil moisture, and light intensity are a few examples of variables that might affect how severe a deficiency [7].

Innovative strategies have surfaced to solve the issue of Mn deficiencies and promote sustainable agriculture. Aloe Ecell has created a novel solution by recycling spent primary single-use batteries to create Mangnify, a carbon-negative nano manganese sulphate fertiliser. This eco-friendly procedure not only offers a long-term supply of manganese sulphate but also addresses the problem of waste management and pollution produced by disposing of batteries.

Field Trials were conducted on wheat (*T. aestivum*) in the Kemla, Gudli, and Bundi regions of Rajasthan to assess the effectiveness of nano manganese sulphate in enhancing crop output. These places were chosen due to their potential for increased agricultural productivity and recognized vulnerability to manganese deficiency. This research paper aims to present the findings of the field trials specifically focusing on the effectiveness of nano manganese sulphate fertiliser in mitigating Mn deficiency and its impact on wheat crop productivity [8].

The study aims to present a comprehensive analysis of the field trial results, including detailed observations on crop growth, nutrient status, and overall agricultural performance. By shedding light on the efficacy of recycled nano manganese sulphate fertiliser derived from primary single-use batteries, this study not only addresses the pressing issue of micronutrient deficiencies but also showcases the potential for innovative and environmentally friendly solutions in agriculture [9].

MATERILAS AND METHODS

Study site selection

The field trials were conducted in the Indian state of Rajasthan's Bundi (a), Kemla (b), and Gudli (c) regions. These areas are susceptible to soil Manganese (Mn) deficiency.

Experimental design

The field trials were conducted using Randomised Complete Block Design (RCBD), with two treatments and four repetitions. A control group received no fertiliser application and a treatment group received the nano manganese sulphate fertiliser (Mangnify).

To reduce bias and guarantee the results were representative, the experimental plots were spread randomly within each region.

Treatment

The nano manganese sulphate fertiliser (Mangnify) used in the study was derived by recycling spent primary single-use batteries developed at Aloe Ecell Pvt. Ltd. The recommended application rate of Mangnify was 2 L/ hectare. Foliar application of fertiliser was done once in Kemla and Gudli regions at the tillering stage. While in the Bundi region, two applications were done, the first application of conventional $MnSO_4$ Fertilizer as basal application and then nano manganese sulphate was sprayed at the tillering stage [10].

Wheat crop management

The wheat (*T. aestivum*) crops were sown in the experimental plots following standard agricultural practices for each region. Proper crop management techniques were employed throughout the growing season, including irrigation, pest and disease control, and weed management, to ensure uniform crop growth and development [11].

Data collection

Data collection was carried out at various stages of the wheat crop's growth cycle. Crop growth parameters and yield parameters were recorded. Additionally, the health and visual appearance of the wheat crops were monitored, including the presence of any symptoms related to manganese deficiency and disease resistance [12].

Statistical analysis

To determine the statistically significant differences between the control and treatment groups and to compare the treated groups of each location, the gathered data were subjected to statistical analysis using Analysis of Variance (ANOVA). The goal of the statistical analysis was to determine how nano manganese sulphate affected wheat yield and nutrient levels in the soil and plants [13].

RESULTS

Anova Analysis was conducted on various growth parameters and yield parameters. The comparison done on the yield parameters like no of spikelets, awns, grain weight, no of grains per spike, etc. between control and treated groups of all regions is shown in the given Tables 1-5 and Figure 1 and 2 [14].

TABLE 1
Average values of no spikelets of region a, b, c (V1 and V2)

Number of spikelet							
Bundi (a)		Kemla (b)		Gudli (c) (V1)		Gudli (c) (V2)	
Control	Manganese treated	Control	Manganese treated	Control	Manganese treated	Control	Manganese treated
28	32	44	54	31	59	48	53
30	32	41	48	31	35	59	52
30	34	43	49	32	55	40	45
31	26	44	45	37	40	38	43
28	28	36	51	40	41	51	43
28	24	47	49	38	42	52	54
30	30	42	49	37	49	53	53

32	29	46	56	38	44	44	41
32	28	33	45	43	34	30	43
21	32	42	46	33	45	35	42
28	34	46	47	51	32	50	48
35	31	44	53	44	49	44	45
29	30	38	42	46	50	37	40
24	28	40	46	42	37	36	43
24	29	37	53	35	36	42	48
22	26	36	56	36	45	45	52
26	24	38	51	38	44	51.2	54
16	22	31	53	40	46	47	51
27.4	28.8	40.4	49.6	38.4	43.5	44.6	47.2

TABLE 2

ANOVA analysis of control and treated crops (a) (Yield parameters)

ANOVA						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between groups	9225.32	5	1845.064	92.09087	3.24E-36	2.303493
Within groups	2043.596	102	20.03526			
Total	11268.92	107				

TABLE 3

ANOVA analysis of control and treated crops (b) (Yield parameters)

ANOVA						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between groups	80116.35	9	8901.817	472.6648	2.30E-115	1.935315
Within groups	3201.653	170	18.83325			
Total	83318.01	179				

TABLE 4

ANOVA analysis of control and treated crops (c) (V1) (Yield parameters)

ANOVA						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between groups	106718.6	5	21343.73	907.8977	3.78E-79	2.309202
Within groups	2256.86	96	23.50896			
Total	108975.5	101				

TABLE 5

ANOVA analysis of control and treated crops (c) (V2) (Yield parameters)

ANOVA						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between groups	561918.4	5	112383.7	90.83797	7.89E-35	2.309202
Within groups	118770.1	96	1237.189			
Total	680688.5	101				

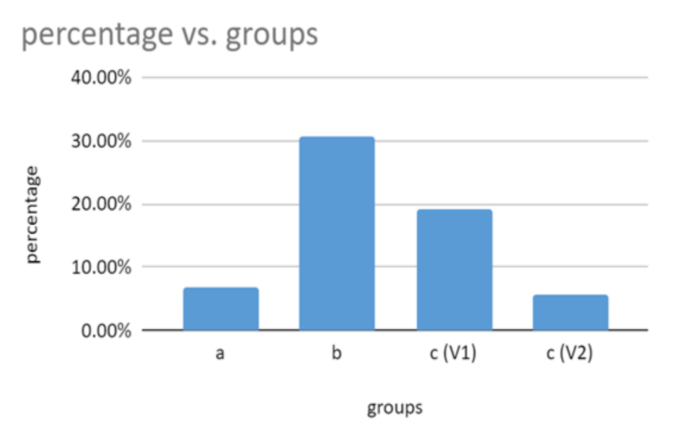

Figure 1) *Comparison of (Yield estimation) control to treated groups*

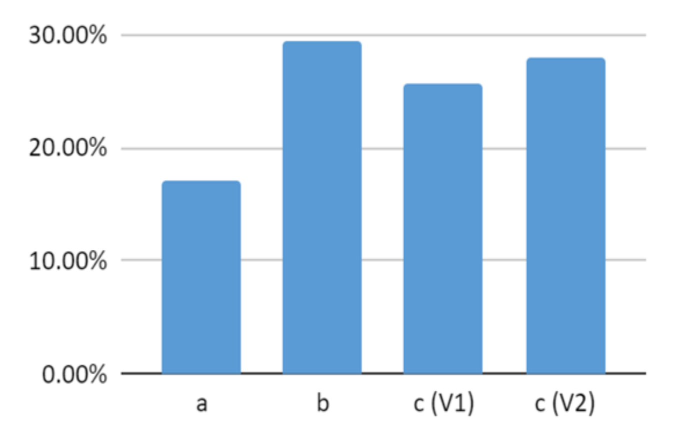

Figure 2) *Comparison of (Yield estimation) of treated groups of all regions*

The comparison of yield estimation between the control and treated group in all regions a, b and c (V1) and c (V2) showed a significant increase in yield shown in Figure 1. In Bundi (a) 6.7% and in Kemla (b) a 30.8% increase in yield was observed. In Gudli (c) V1 showed a 19.3% increase in yield while V2 showed a 5.8% increase in yield. Manganese-treated crops of all the regions were compared (Figure 2) in which the Kemla region showed the best result. The analysis and percentage increase in the yield clearly show the efficiency of nano manganese sulphate fertiliser on wheat crops.

DISCUSSION

In the Bundi (a) region (Table 2), basal application of the conventional manganese sulphate fertiliser was done and later at the tillering stage, nano manganese sulphate fertiliser was sprayed on the treated group. The results of the study demonstrated that in comparison, nano manganese sulphate fertiliser showed significantly better growth characteristics in terms of spikelets (Table 1), awn length, and flag leaf size. The observed variations in stem diameter and chlorophyll concentration between the control and treated crops further demonstrated the beneficial impacts of nano Mn application on overall plant health. These results show that Mn treatment has a favourable impact on crop productivity and performance, making it a desirable agricultural strategy for increasing yields.

The ANOVA table revealed a highly significant difference ($p<3.24E-36$) between the means of the groups ($F=92.09087$). The variation between the groups was found to be 9225.32 units, while the variation within each group was 2043.596 units. These results indicate that the treatment had a significant effect on the measured variable compared to the control group.

In the Kemla (b) (Table 3) region, the ANOVA analysis conducted revealed a highly significant ($p<2.30E-115$) between the means of the two groups, supported by a large F-statistic of 472.6648, which exceeded the critical F-value of 1.935315. The between-groups variation (SS=80116.35) significantly outweighed the within-groups variation (SS=3201.653). These findings provide strong evidence that the treatment or condition applied to the groups had a substantial impact on the measured variable, resulting in an observable difference between the control and treated groups.

Mn-treated crops exhibited a substantial increase in spikes and spikelets, leading to enhanced grain production and overall yield.

In Gudli (c) the wheat was highly affected by leaf blotch disease, especially in control leading to a reduced yield while the manganese-treated crops showed resistance comparatively. As the trials were conducted to normal agricultural practices two different varieties were seen in the Gudli region in the first variety (c) (V1) (Table 4) ANOVA conducted on the data revealed a highly significant difference ($p<3.78E-79$) in means among the groups. The substantial between-groups variation (SS=106718.6) and the F-statistic (907.8977) exceeding the critical F-value (F crit=2.309202) strongly indicate that there is a significant difference between the control and Mn-treated group.

In the second variety (c) (V2) (Table 5) a notable difference was found as the results revealed data comparing the control and treated groups demonstrated a highly significant difference ($p<7.89E-35$). The substantial between-groups variation (SS=561918.4) and the F-statistic (90.83797), exceeding the critical F-value (F crit=2.309202), provide strong evidence of the treatment's significant effect on the measured outcome. This indicates that the application of Mn treatment had a substantial impact on the measured variable compared to the control group. The low p-value further strengthens the evidence, allowing us to confidently reject the null hypothesis.

CONCLUSIONS

The field trials conducted in the regions of Kemla, Gudli, and Bundi of Rajasthan show the beneficial effects of nano manganese sulphate on several growth parameters and yield characteristics.

The findings clearly show that wheat crop performance was greatly enhanced by the use of nano manganese sulphate fertiliser in comparison to the control groups. The treated crops had improved growth characteristics and disease resistance.

In all three regions, the results of the ANOVA analysis show statistically significant changes between the control and treated groups, together with observable yield percentage increases. A notable 30.8% rise in yield was seen in the Kemla region, while two separate kinds in Gudli exhibited increases of 19.3% and 5.8%. A 6.7% increase in the yield was seen in Bundi, where a basal application of traditional manganese sulphate fertiliser followed by nano manganese application at tillering stage.

The effectiveness of nano manganese sulphate fertiliser in reducing manganese deficiency in wheat crops and encouraging sustainable agriculture is emphasised by these studies. In addition to addressing the urgent problem of micronutrient deficiencies, the use of recycled nano manganese sulphate fertilisers illustrates the potential for creative and eco-friendly agricultural solutions.

We can decrease waste, pollution, and our reliance on non-renewable resources by using cutting-edge recycling technology to create nano micronutrient fertilisers. This study highlights the significance of utilising nanotechnology to improve nutrient availability and uptake by plants and adds to the body of knowledge on sustainable agricultural methods.

Nano manganese effective use in this study raises hopes for its wider adoption in agriculture, especially in areas where manganese insufficiency and micronutrient shortages are common. Recycled micronutrient fertilisers represent a fresh and environmentally friendly method of sustainable farming by bridging the gap between issues with waste management and agricultural output. The findings of this study demonstrate the viability and usefulness of recycled nano manganese fertiliser as a treatment for manganese deficiency in wheat crops, boosting agricultural output and promoting environmental sustainability.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FUNDING

No funding was provided.

AUTHORS' CONTRIBUTIONS

AV led field trials, collected readings, conducted analysis and authored the research paper.

NS did the trial planning and contributed to trial monitoring, data collection, and paper review.

NV Contributed to trial monitoring, data collection, and paper review.

RG Supported readings collection, and data analysis, and reviewed the research paper.

All authors have read and approved the manuscript.

All the authors are affiliated with Aloe Ecell Pvt Ltd.

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