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Impact of Nanofertilizers on Soil Microbial Populations

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during 2019 and 2020 to know the Impact of Nanofertilizers on Soil Microbial Populations. The experiment was laid out in Randomized Complete Block Design (Factorial concept) with two factors [Factor I - Seed treatment) [Factor II (F- foliar application of nutrients at ray floret stage) with two control C_1 : Recommended dose of fertilizers (RDF) only and C_2 : Recommended package of practices (RPP) treatments replicated thrice. In this experiment treatment seed priming with 1500 ppm nano boron nitride (Green synthesized particle) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (Green synthesized particle) significantly recorded higher dehydrogenase enzyme (2.61 µ g TPF g^{-1} h^{-1}), microbial population (13.1×10^5, 22.4×10^3, 12.5×10^3, 12.0×10^4 and 8.8×10^4 cfu/g of soil of bacteria, fungi, actinomycetes, azotobacter and PSB, respectively) but azospirillum population was found to be non significant. The same treatment also recorded higher nitrogen uptake (114.9 kg ha^{-1}), phosphorus uptake (34.30 kg ha^{-1}), potassium uptake (79.20 kg ha^{-1}) plant height (270.6 cm at harvest stage) and seed yield (3588 kg ha^{-1}) compared to other treatments.

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Keywords: Nanotechnology; fertiliser; microbial activity; soil health.

1. INTRODUCTION

The agriculture sector is experiencing enormous problems, such as feeding a growing global population, reducing environmental impact, and adapting to climate change [1]. Traditional farming approaches, while previously effective, are now becoming insufficient and unsustainable in addressing these needs. Fertiliser management is one of the crucial areas that need innovation, with a focus on nutrient application efficiency and environmental effect [2].

Nanotechnology appears as a transformational answer in this environment, providing unique techniques to improve fertiliser distribution, efficiency, and sustainability. Scientists and agricultural specialists are creating nano-fertilizers by manipulating materials at the nanoscale, with the potential to revolutionise crop output and soil health [3,4,5]. These sophisticated fertilisers may release nutrients in a regulated manner, distribute them to particular plant tissues, and greatly minimise nutrient loss due to leaching and volatilization [6].

Microbial activity in soil plays a pivotal role in the functioning of terrestrial ecosystems and the sustainability of agricultural practices [7]. Soil microbes, including bacteria, fungi, archaea, and protozoa, are essential for numerous biogeochemical processes that influence soil health, plant growth, and crop productivity [8]. These microorganisms drive nutrient cycling, organic matter decomposition, soil structure formation, and disease suppression, thereby directly impacting agricultural productivity and environmental quality [7,8].

The dynamic interactions between soil microorganisms and their environment underpin the fertility of soils. Microbial communities contribute to the breakdown of organic matter, releasing essential nutrients such as nitrogen, phosphorus, and sulfur in forms that are accessible to plants. Additionally, certain microbes form symbiotic relationships with plants, enhancing nutrient uptake and providing resilience against biotic and abiotic stresses [9].

In recent years, the significance of microbial activity in soil has gained renewed attention, driven by the need for sustainable agricultural practices and the pressing challenges of climate change [2,9]. The over-reliance on chemical fertilizers and pesticides has led to soil degradation, loss of biodiversity, and environmental pollution. Harnessing the potential of soil microbes offers a promising pathway to restore soil health, improve crop yields, and reduce the environmental footprint of agriculture [10].

When nanoparticles enter the soil, they do not remain inert. Instead, they engage with various microorganisms, including bacteria, fungi, archaea, and protozoa, which are integral to soil health and ecosystem functions [11]. These interactions can have profound implications for both soil biology and the overall efficacy of nano-fertilizers. The presence of nanoparticles in soil layers can elicit a range of responses from the microbial inhabitants, leading to a spectrum of ecological and biological outcomes [12].

The interaction between nanoparticles and soil microorganisms can manifest in several ways: Nanoparticles can stimulate microbial activity by providing additional surfaces for colonization and by facilitating the release of nutrients [13]. This can boost key soil processes such as nitrogen fixation, phosphorus solubilization, and organic matter decomposition, ultimately improving soil fertility and plant growth. Conversely, some nanoparticles may exhibit antimicrobial properties, inhibiting the growth and metabolic functions of certain microorganisms [3,14]. This inhibition can disrupt essential microbial-mediated processes, potentially leading to reduced soil fertility and adverse effects on plant health. The introduction of nanoparticles can shift the composition and diversity of soil microbial communities [15]. Some microorganisms may thrive, while others may be suppressed or outcompeted. These changes can affect the overall functionality and resilience of soil ecosystems.

Microorganisms can interact with nanoparticles, leading to their biotransformation. This process can alter the chemical properties and mobility of nanoparticles, influencing their persistence in the soil and their bioavailability to plants and other soil organisms. Microbial activity can also affect the aggregation and dispersion of nanoparticles, impacting their distribution within the soil matrix [16]. The overall impact of nanoparticles on soil health depends on the balance between their

beneficial and detrimental effects on microbial communities. Enhanced microbial activity and diversity can improve soil structure, nutrient cycling, and plant productivity [1,17]. However, negative impacts on key microbial functions could lead to soil degradation and reduced agricultural output.

The impact of nanoparticles in the soil is significantly influenced by the soil type and the intrinsic properties of the nanoparticles. Depending on their bioavailability, nanoparticles may exhibit strong interactions with charged particles present in the soil, dissolve in the soil's water content, or be absorbed by various soil-dwelling organisms [8,10]. Beyond soil, nanoparticles can also migrate to other environments, including sediments and aquatic systems. The physicochemical properties of nanoparticles, such as size, shape, chemical composition, and surface characteristics, play a pivotal role in determining their behavior in soil, as these attributes considerably affect their electrical, optical, and catalytic properties. Additionally, nanoparticle surfaces are often functionalized with inorganic or organic ligands and other polymeric surfactants to enhance colloidal stability, which influences their interactions with soil particles, including the formation of colloidal solutions in soil water and aggregation [11,17]. All nanoparticles undergo processes such as aging, chemical transformation, aggregation, and disaggregation within the soil environment. Hence present investigation was conducted to know the impact of nanoparticles on soil microbes.

2. MATERIALS AND METHODS

A field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during 2019 and 2020 to know the Impact of Nanofertilizers on Soil Microbial Populations. The experiment was laid out in Randomized Complete Block Design (Factorial concept) with two factors [Factor I (S - Seed treatment) S_1 : Seed priming with nano sulphur - 600 ppm (GsP*), S_2 : Seed priming with nano sulphur - 750 ppm (CP**), S_3 : Seed priming with nano boron - 1500 ppm (GsP) and S_4 : Seed priming with nano boron - 2000 ppm (CP)], [Factor II (F – foliar application of nutrients at ray floret stage) F_1 : Nano sulphur - 600 ppm (GsP), F_2 : Nano sulphur - 750 ppm (CP), F_3 : Nano boron - 1500 ppm (GsP), F_4 : Nano boron - 2000 ppm (CP), F_5 : Nano sulphur 600 ppm + Nano boron - 1500 ppm (GsP) and F_6 : Nano Sulphur - 750 ppm + Nano boron - 2000 ppm (CP)] with two control C_1 : Recommended dose of fertilizers (RDF) only and C_2 : Recommended package of practices (RPP) treatments replicated thrice. Note [GsP: Green synthesised nano particle; **CP : Commercially available nanoparticle; RDF : ($N:P_2O_5:K_2O$ 90:90 : 62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments; RPP : RDF + soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage].Sunflower was sown in a plot size of 5.4 m × 4.8 m with a distance between row to row (60 cm) and plant to plant (30 cm). The various parameters recorded by using following methods.

2.1 Plant Height (cm)

The plant height was recorded from the randomly selected five plants in each treatment at base of plant to the growing tip or point of attachment of the capitulum at 30, 60, 90 DAS and at the time of harvest by using a measuring scale and the average height of the plants in each plot is obtained.

2.2 Plant Analysis

Treatment wise plant samples were collected by uprooting the entire plant carefully. The samples were dried in shade and then oven-dried at 65 ^{0}C. Then the plant samples were weighed to record dry matter accumulation in different plant parts and then powdered separately into leaves, stem and reproductive parts with the help of a grinder and stored in butter paper bags. The samples were analyzed for nitrogen, phosphorus and potassium, uptake in seed and stalk at harvest stage, determined by following standard procedures and expressed as total uptake of nutrients.

2.3 Methodology used for Plant Analysis

List 1. Use of Nitrogen, phosphorus and potassium for plant analysis

Preparation of sample	A destructive plant sample for dry weight estimation was used for plant analysis. nitrogen, phosphorus, potassium content in the whole plant was analyzed at the end.

Nitrogen uptake (kg ha^{-1})	Nitrogen uptake on a dry weight basis was determined by modified Kjeldahl's method [18]
Phosphorus uptake (kg ha^{-1})	Plant samples were digested with a triacid mixture. The phosphorus uptake on a dry weight basis was determined by vanadomolybdic phosphoric acid yellow colour method in HNO_3 system [19]
Potassium uptake (kg ha^{-1})	Potassium uptake on a dry weight basis was determined by feeding digested plant samples to flame photometer [19]

2.4 Nutrient Uptake by Plant

Based on the nutrient content of plants and dry matter production, uptake of nutrients were worked out by using the following formula.

$$\text{Macronutrient uptake (kg ha}^{-1}) = \frac{\%\ \text{Nutrient content x Dry matter yield (kg ha}^{-1})}{100}$$

2.5 Seed Yield Per Hectare (kg ha^{-1})

Capitulums in the net plot were harvested, seeds were separated by hand threshing, dried and weighed at 8 per cent moisture. Seed yield was computed per hectare (kg ha^{-1}) based on the area of each net plot.

2.6 Microbial Population

The microorganisms from the soil samples before and after harvest of the crop were enumerated by using different media by standard serial dilution plating technique [17]. The population of microorganisms were counted and expressed as the number of colony forming unit (CFU) per gram of soil. Media used to enumerate different microorganisms were listed below:

List 2. Media used to enumerate different microorganisms

01	Bacteria	Nutrient agar
02	Fungus	MRBA
03	Actinomycetes	Kusters agar
04	*Azotobacter*	Waksman No. 77 media
05	Phosphorus solubilising bacteria (PSB)	Pikovskaya's media
06	*Azospirillum*	N free semi solid malate agar

2.7 Dehydrogenase Activity

Dehydrogenase activity in the samples was determined by following the procedure described by [10]. Five grams of sample was thoroughly mixed with 0.2 g of $CaCO_3$, and transferred to test tubes. One ml of 1.5 *per cent* aqueous solution of 2,3,5 triphenyl tetrazolium chloride (TTC) was added to each tube. One ml of 1 *per cent* glucose solution and 8 ml of distilled water was added in such a way that it should form a thin film of water just above the sample layer. The tubes were stoppered and incubated at 30°C for 24 hours. At the end of incubation, the contents in the tube were rinsed down into a small beaker through Whatman No.15 filter paper. Repeated rinsing of sample with methanol was continued till the filtrate ran free of red colour. The volume of the filtrate was made up to 50 ml with methanol in a volumetric flask. The intensity of red colour was measured at 485 nm against a methanol blank using UV-VIS Spectrophotometer. The concentration of formazan formed in samples was determined by using graded concentrations of formazan. The results were expressed as microgram of triphenyl formazan (TPF) formed per gram of sample per hour.

2.8 Statistical Analysis and Interpretation of Data

The data collected from the experiment at different phenological growth stages were subjected to statistical analysis as described by [20]. The level of significance used in 'F' and 't' test was 5 per cent (P=0.05) or (F- test *) and 1 per cent (P=0.01) or (F- test **) for a laboratory experiment. Wherever the F-test was found significant for comparison among treatment means, an appropriate value of critical difference (CD) was worked out. Otherwise, the abbreviation NS was indicated against the CD values.

3. RESULTS AND DISCUSSION

3.1 Plant Height

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP)

recorded significantly higher plant height (41.2, 249.2, 253.0 and 255.0 cm at 30, 60, 90 DAS and at harvest stage, respectively). Results are inlined with [21] and [22]. Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) recorded significantly higher plant height (44.0, 252.7, 257.9 and 259.9 cm at 30, 60, 90 DAS and at harvest stage, respectively). The interaction data on plant height revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) recorded significantly higher plant height at all the stages (47.2, 261.5, 268.2 and 270.6 cm at 30, 60, 90 DAS and at harvest stage, respectively). When compared with recommended practices, the best treatment (S_3F_5) recorded higher plant height than control treatments (Tables 1 and 2). The plant height increased to the extent of (92.6, 45.6, 47.8 and 48.3 per cent at 30, 60, 90 DAS and at harvest stage, respectively) over RPP. The increased plant height is ascribed to the increase in nano boron nitride and sulphur (GsP) uptake by sunflower due to higher available nutrients and enhanced cell size as results of addition at sufficient levels [23]. Green synthesised nano boron nitride and sulphur were more effective in increasing in cell size compared to commercially available nano boron nitride and sulphur. Similarly, it is quite understandable that green synthesised nutrients regulated the nutrients slowly and steadily to crop that may have facilitated for enhanced crop growth [24,25] revealed that the profound influence of sulphur fertilization on growth and height of plant might be due to increase in metabolic processes in plant, which have promoted meristematic activities causing higher apical growth and photosynthetic area. Similar results were reported by [22,26] and [18] reported that foliar application of 220 ppm nano sulphur (GsP) in onion crop enhanced the plant height.

Table 1. Plant height (cm) of sunflower at 30 and 60 DAS

			30 DAS			60 DAS		
Treatments:			**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			37.5	36.5	37.0	242.6	240.5	241.6
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			30.5	29.1	29.8	229.5	228.7	229.1
S_3 : Seed priming with nano boron-1500 ppm (GsP)			41.8	40.5	41.2	249.8	248.6	249.2
S_4 : Seed priming with nano boron-2000 ppm (CP)			33.5	32.5	33.0	234.5	232.4	233.5
SEm±			1.2	1.1	1.2	1.5	1.4	1.4
CD (P=0.05)			3.6	3.4	3.7	4.6	4.2	4.3
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			30.5	29.4	30.0	225.5	222.1	223.8
F_2 : Nano sulphur-750 ppm (CP)			25.1	24.5	24.8	221.5	218.5	220.0
F_3 : Nano boron-1500 ppm (GsP)			37.8	37.1	37.5	240.8	239.8	240.3
F_4 : Nano boron-2000 ppm (CP)			32.5	31.5	32.0	235.8	232.6	234.2
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			44.5	43.5	44.0	253.5	251.8	252.7
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			39.7	39.5	39.6	248.8	242.9	245.9
SEm±			1.4	1.2	1.3	2.3	2.1	1.9
CD (P=0.05)			4.2	3.6	4.1	6.9	6.3	5.7
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	27.8	26.9	27.4	198.5	195.5	197.0
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	27.4	26.2	26.8	191.4	189.7	190.6
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	32.8	32.3	32.6	228.7	226.7	227.7
$S_1 \times$		F_4 : Nano boron-2000	30.8	29.5	30.2	220.5	215.5	218.0

Treatments:			30 DAS			60 DAS		
			2019	2020	Pooled data	2019	2020	Pooled data
F_4		ppm (CP)						
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	41.5	39.8	40.7	251.5	250.8	251.2
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	35.2	34.8	35.0	235.5	232.5	234.0
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	29.1	28.3	28.7	203.8	201.5	202.7
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	26.5	25.8	26.2	185.4	182.5	184.0
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	31.5	30.8	31.2	222.5	220.5	221.5
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	29.5	28.7	29.1	204.7	202.4	203.6
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	37.6	37.1	37.4	242.5	241.8	242.2
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	34.5	34.5	34.5	232.8	231.5	232.2
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	28.4	27.7	28.1	200.8	198.8	199.8
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	27.5	26.5	27.0	195.4	193.5	194.5
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	33.1	32.5	32.8	229.8	228.7	229.3
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	31.2	30.2	30.7	221.8	217.6	219.7
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	47.5	46.8	47.2	262.5	260.5	261.5
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	36.5	35.8	36.2	239.5	237.5	238.5
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	28.1	27.4	27.8	199.5	197.8	198.7
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	27.1	26.1	26.6	188.4	185.5	187.0
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	32.1	31.5	31.8	225.4	224.5	225.0
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	30.1	29.2	29.7	205.8	203.5	204.7
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	39.4	38.8	39.1	245.8	244.5	245.2
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	33.5	32.8	33.2	230.4	229.5	230.0
SEm±			1.8	1.7	1.8	3.1	2.9	2.7
CD (P=0.05)			5.5	5.2	5.6	9.3	8.8	8.1
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			18.2	17.9	18.1	166.8	164.5	165.7
C_2 : Recommended package of practices (RPP)			24.9	24.1	24.5	180.4	178.8	179.6
SEm±			2.1	1.9	2.0	4.1	3.9	3.8
CD (P=0.05)			6.3	5.8	6.1	12.4	11.8	11.5
F- test			*	*	*	*	*	*

GsP: Green synthesised nano particle and
***CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 2. Plant height (cm) of sunflower at 90 DAS and at harvest stage

Treatments:			90 DAS			At harvest		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			243.8	241.5	242.7	245.7	243.5	244.6
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			230.2	229.5	229.9	233.4	230.5	232.0
S_3 : Seed priming with nano boron-1500 ppm (GsP)			254.3	251.6	253.0	255.8	254.1	255.0
S_4 : Seed priming with nano boron-2000 ppm (CP)			237.8	234.6	236.2	239.8	236.5	238.2
SEm±			1.8	1.8	1.7	1.9	1.7	1.9
CD (P=0.05)			5.5	5.6	5.4	5.7	5.2	5.9
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			228.6	223.6	226.1	230.9	225.7	228.3
F_2 : Nano sulphur-750 ppm (CP)			225.6	219.8	222.7	227.8	221.8	224.8
F_3 : Nano boron-1500 ppm (GsP)			243.9	241.2	242.6	245.4	242.8	244.1
F_4 : Nano boron-2000 ppm (CP)			239.7	237.6	238.7	241.8	238.7	240.3
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			258.8	256.9	257.9	260.8	258.9	259.9
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			250.8	248.6	249.7	252.8	251.1	252.0
SEm±			2.3	2.2	2.3	2.4	2.3	2.3
CD (P=0.05)			6.9	6.6	6.9	7.2	6.9	6.9
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	203.6	201.5	202.6	206.2	203.1	204.7
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	197.8	192.2	195.0	199.1	195.4	197.3
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	231.8	231.1	231.5	235.8	234.2	235.0
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	224.6	223.3	224.0	228.7	225.9	227.3
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	257.8	256.3	257.1	260.2	259.1	259.7
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	239.8	238.7	239.3	243.7	242.8	243.3
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	208.8	207.8	208.3	212.1	208.4	210.3
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	190.6	187.8	189.2	192.4	190.5	191.5
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	227.8	226.8	227.3	230.5	228.7	229.6
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	209.8	208.7	209.3	212.8	209.7	211.3
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	246.9	244.2	245.6	250.7	248.7	249.7
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	236.8	235.9	236.4	241.0	240.1	240.6
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	206.7	205.6	206.2	208.7	207.4	208.1
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	201.8	199.8	200.8	203.4	200.2	201.8
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	232.5	231.5	232.0	237.1	236.1	236.6
$S_3 \times$		F_4 : Nano boron-2000 ppm	225.8	225.2	225.5	229.5	226.8	228.2

Treatments:			90 DAS			At harvest		
			2019	2020	Pooled data	2019	2020	Pooled data
F_4		(CP)						
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	268.8	267.5	268.2	271.4	269.8	270.6
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	243.6	242.8	243.2	247.7	246.7	247.2
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	204.5	203.7	204.1	207.1	205.7	206.4
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	193.2	189.5	191.4	195.5	192.8	194.2
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	229.8	228.6	229.2	233.6	232.4	233.0
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	211.8	209.9	210.9	214.1	210.8	212.5
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	248.8	246.8	247.8	253.5	252.1	252.8
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	234.5	233.6	234.1	238.1	236.7	237.4
SEm±			3.2	3.1	3.1	3.3	3.1	3.3
CD (P=0.05)			9.6	9.3	9.4	9.9	9.3	9.9
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			168.2	165.3	166.8	169.8	166.8	168.3
C_2 : Recommended package of practices (RPP)			183.5	179.2	181.4	184.6	180.2	182.4
SEm±			4.4	4.2	4.3	4.5	4.1	4.2
CD (P=0.05)			13.2	12.6	12.9	13.8	12.5	12.6
F- test			*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

3.2 Total Nitrogen Uptake (Accumulation in Seed and Stalk)

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher nitrogen uptake (74.31, 31.85 and 106.2 kg ha^{-1} in seed, stalk and total uptake, respectively). Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher nitrogen uptake (77.0, 33.0 and 110 kg ha^{-1} in seed, stalk and total uptake, respectively). The interaction data on nitrogen uptake revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher nitrogen uptake (80.43, 34.47 and 114.9 kg ha^{-1} in seed, stalk and total uptake, respectively) (Tables 3 and 4). When compared with recommended practices, the best treatment (S_3F_5) significantly recorded higher nitrogen uptake than control treatments. Results were inlined with [27] and [28] and [29] revealed that application of nano boron nitride will enhance the uptake of nitrogen in cotton crop.

3.3 Total Phosphorus Uptake (Accumulation in Seed and Stalk)

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher phosphorus uptake (21.29, 11.46 and 32.75 kg ha^{-1} in seed, stalk and total uptake, respectively). Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher phosphorus uptake (21.61, 11.64 and 33.25 kg ha^{-1} in seed, stalk and total uptake, respectively). The interaction data on phosphorus uptake revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher phosphorus uptake (22.30, 12.01 and 34.30 kg ha^{-1} in seed, stalk and total uptake, respectively) (Tables 5 and 6). When compared with recommended practices, the best treatment

(S_3F_5) significantly recorded higher phosphorus uptake than control treatments. Results were inlined with [30,31] and [32,33] revealed that application of nano boron nitride will enhance the uptake of phosphorous in cotton crop.

3.4 Total Potassium Uptake (Accumulation in Seed and Stalk)

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher potassium uptake (22.71, 51.74 and 74.45 kg ha^{-1} in seed, stalk and total uptake, respectively). Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher potassium uptake (23.29, 53.06 and 76.35 kg ha^{-1} in seed, stalk and total uptake, respectively). The interaction data on potassium uptake revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher potassium uptake (24.16, 55.04 and 79.20 kg ha^{-1} in seed, stalk and total uptake, respectively) (Tables 7 and 8). When compared with recommended practices, the best treatment (S_3F_5) significantly recorded higher potassium uptake than control treatments. Similar results were obtained by [34,35] and [36]

Table 3. Nitrogen uptake in seed and stalk of sunflower

			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
Treatments:			**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			71.75	71.05	71.40	30.75	30.45	30.60
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			66.85	65.87	66.36	28.65	28.23	28.44
S_3 : Seed priming with nano boron-1500 ppm (GsP)			74.76	73.85	74.31	32.04	31.65	31.85
S_4 : Seed priming with nano boron-2000 ppm (CP)			68.95	68.25	68.60	29.55	29.25	29.40
SEm±			0.60	0.50	0.50	0.21	0.19	0.20
CD (P=0.05)			1.80	1.50	1.50	0.63	0.57	0.60
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			66.85	66.08	66.47	28.65	28.32	28.49
F_2 : Nano sulphur-750 ppm (CP)			63.07	62.65	62.86	27.03	26.85	26.94
F_3 : Nano boron-1500 ppm (GsP)			71.96	71.47	71.72	30.84	30.63	30.74
F_4 : Nano boron-2000 ppm (CP)			68.25	67.55	67.90	29.25	28.95	29.10
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			77.35	76.65	77.00	33.15	32.85	33.00
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			73.29	73.15	73.22	31.41	31.35	31.38
SEm±			0.90	0.80	0.90	0.43	0.38	0.41
CD (P=0.05)			2.70	2.40	2.80	1.29	1.14	1.24
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	64.96	64.33	64.65	27.84	27.57	27.71
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	64.68	63.84	64.26	27.72	27.36	27.54
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	68.46	68.11	68.29	29.34	29.19	29.27
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	67.06	66.15	66.61	28.74	28.35	28.55
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	73.78	73.36	73.57	31.62	31.44	31.53
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	70.14	69.86	70.00	30.06	29.94	30.00
$S_2 \times$	S_2: Seed	F_1 : Nano sulphur-600	65.87	65.31	65.59	28.23	27.99	28.11

Treatments:			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
F_1	priming with	ppm (GsP)						
$S_2 \times F_2$	nano sulphur 750 ppm (CP)	F_2 : Nano sulphur-750 ppm (CP)	64.05	63.56	63.81	27.45	27.24	27.35
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	67.55	67.06	67.31	28.95	28.74	28.85
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	66.15	65.59	65.87	28.35	28.11	28.23
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	71.82	71.47	71.65	30.78	30.63	30.71
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	69.65	69.65	69.65	29.85	29.85	29.85
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	65.38	64.89	65.14	28.02	27.81	27.92
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	64.75	64.05	64.40	27.75	27.45	27.60
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	68.67	68.25	68.46	29.43	29.25	29.34
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	67.34	66.64	66.99	28.86	28.56	28.71
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	80.92	79.94	80.43	34.68	34.26	34.47
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	71.05	70.56	70.81	30.45	30.24	30.35
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	65.17	64.68	64.93	27.93	27.72	27.83
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	64.47	63.77	64.12	27.63	27.33	27.48
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	67.97	67.55	67.76	29.13	28.95	29.04
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	66.57	65.94	66.26	28.53	28.26	28.40
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	73.08	72.66	72.87	31.32	31.14	31.23
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	68.95	68.46	68.71	29.55	29.34	29.45
SEm±			1.20	1.10	1.10	0.76	0.74	0.75
CD (P=0.05)			3.60	3.30	3.30	2.28	2.22	2.25
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			55.02	54.18	54.60	23.58	23.22	23.40
C_2 : Recommended package of practices (RPP)			62.93	62.37	62.65	26.97	26.73	26.85
SEm±			1.50	1.40	1.50	1.10	1.00	1.10
CD (P=0.05)			4.50	4.20	4.50	3.30	3.00	3.30
F-test			*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 4. Total nitrogen uptake (kg ha^{-1}) in sunflower

Treatments:	2019	2020	Pooled data
Factor I: Seed priming (S)			
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)	102.5	101.5	102.0
S_2 : Seed priming with nano sulphur-750 ppm (CP**)	95.5	94.1	94.8
S_3 : Seed priming with nano boron-1500 ppm (GsP)	106.8	105.5	106.2
S_4 : Seed priming with nano boron-2000 ppm (CP)	98.5	97.5	98.0

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
SEm±			1.00	0.90	0.90
CD (P=0.05)			3.00	2.70	2.80
Factor II: Foliar application (F) at ray floret stage					
F_1 : Nano sulphur-600 ppm (GsP)			95.5	94.4	95.0
F_2 : Nano sulphur-750 ppm (CP)			90.1	89.5	89.8
F_3 : Nano boron-1500 ppm (GsP)			102.8	102.1	102.5
F_4 : Nano boron-2000 ppm (CP)			97.5	96.5	97.0
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			110.5	109.5	110.0
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			104.7	104.5	104.6
SEm±			1.30	1.20	1.20
CD (P=0.05)			3.90	3.60	3.90
Interaction: (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	92.8	91.9	92.4
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	92.4	91.2	91.8
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	97.8	97.3	97.6
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	95.8	94.5	95.2
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	105.4	104.8	105.1
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	100.2	99.8	100.0
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	94.1	93.3	93.7
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	91.5	90.8	91.2
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	96.5	95.8	96.2
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	94.5	93.7	94.1
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	102.6	102.1	102.4
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	99.5	99.5	99.5
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	93.4	92.7	93.1
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	92.5	91.5	92.0
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	98.1	97.5	97.8
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	96.2	95.2	95.7
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	115.6	114.2	114.9
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	101.5	100.8	101.2
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	93.1	92.4	92.8
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	92.1	91.1	91.6
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	97.1	96.5	96.8
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	95.1	94.2	94.7
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	104.4	103.8	104.1
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	98.5	97.8	98.2
SEm±			1.80	1.60	1.70
CD (P=0.05)			5.40	4.80	5.10
Control plots: (C)					
C_1 : Recommended dose of fertilizers (RDF) only			78.6	77.4	78.0

Treatments:	2019	2020	Pooled data
Factor I: Seed priming (S)			
C_2 : Recommended package of practices (RPP)	89.9	89.1	89.5
SEm±	2.10	1.90	2.00
CD (P=0.05)	6.30	5.70	6.10
F-test	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 5. Phosphorous uptake in seed and stalk of sunflower

			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
Treatments:			**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			19.19	18.97	19.08	10.33	10.22	10.27
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			17.62	17.55	17.58	9.49	9.45	9.47
S_3 : Seed priming with nano boron-1500 ppm (GsP)			21.39	21.19	21.29	11.52	11.41	11.46
S_4 : Seed priming with nano boron-2000 ppm (CP)			18.69	18.66	18.68	10.07	10.05	10.06
SEm±			0.28	0.27	0.27	0.19	0.18	0.19
CD (P=0.05)			0.84	0.81	0.82	0.57	0.54	0.57
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			18.32	18.24	18.28	9.87	9.82	9.84
F_2 : Nano sulphur-750 ppm (CP)			18.01	17.98	17.99	9.70	9.68	9.69
F_3 : Nano boron-1500 ppm (GsP)			19.34	19.06	19.20	10.41	10.26	10.34
F_4 : Nano boron-2000 ppm (CP)			18.77	18.74	18.75	10.10	10.09	10.10
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			21.71	21.52	21.61	11.69	11.59	11.64
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			19.49	19.19	19.34	10.50	10.34	10.42
SEm±			0.43	0.42	0.43	0.28	0.26	0.27
CD (P=0.05)			1.29	1.26	1.30	0.84	0.78	0.81
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	17.51	16.90	17.20	9.43	9.10	9.26
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	17.46	16.68	17.07	9.40	8.98	9.19
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	18.62	18.54	18.58	10.03	9.99	10.01
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	17.93	17.77	17.85	9.66	9.57	9.61
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	20.03	19.93	19.98	10.78	10.73	10.76
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	19.23	19.15	19.19	10.35	10.31	10.33
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	17.71	17.41	17.56	9.53	9.38	9.46
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	17.42	16.50	16.96	9.38	8.88	9.13
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	18.28	18.24	18.26	9.84	9.82	9.83
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	17.72	17.52	17.62	9.54	9.44	9.49

Treatments:			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	19.58	19.56	19.57	10.54	10.53	10.54
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	19.21	19.10	19.16	10.34	10.29	10.31
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	17.65	17.31	17.48	9.50	9.32	9.41
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	17.50	16.87	17.19	9.42	9.09	9.25
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	18.72	18.69	18.71	10.08	10.07	10.07
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	18.04	17.98	18.01	9.71	9.68	9.70
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	22.43	22.17	22.30	12.08	11.94	12.01
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	19.29	19.24	19.27	10.39	10.36	10.37
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	17.61	17.23	17.42	9.48	9.28	9.38
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	17.44	16.51	16.97	9.39	8.89	9.14
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	18.50	18.45	18.48	9.96	9.94	9.95
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	17.91	17.63	17.77	9.64	9.49	9.57
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	19.75	19.70	19.73	10.64	10.61	10.62
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	19.07	18.97	19.02	10.27	10.22	10.24
SEm±			0.61	0.60	0.60	0.36	0.35	0.35
CD (P=0.05)			1.83	1.80	1.80	1.08	1.05	1.05
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			14.30	13.98	14.14	7.70	7.53	7.61
C_2 : Recommended package of practices (RPP)			17.02	16.48	16.75	9.17	8.88	9.02
SEm±			0.75	0.74	0.74	0.43	0.42	0.42
CD (P=0.05)			2.25	2.22	2.23	1.29	1.26	1.27
F-test			*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 6. Total phosphorous uptake (kg ha^{-1}) in sunflower

Treatments:	2019	2020	Pooled data
Factor I: Seed priming (S)			
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)	29.52	29.19	29.36
S_2 : Seed priming with nano sulphur-750 ppm (CP**)	27.10	27.00	27.05
S_3 : Seed priming with nano boron-1500 ppm (GsP)	32.90	32.60	32.75
S_4 : Seed priming with nano boron-2000 ppm (CP)	28.76	28.71	28.74
SEm±	0.69	0.67	0.68
CD (P=0.05)	2.07	2.01	2.05
Factor II: Foliar application (F) at ray floret stage			
F_1 : Nano sulphur-600 ppm (GsP)	28.19	28.06	28.13
F_2 : Nano sulphur-750 ppm (CP)	27.70	27.66	27.68
F_3 : Nano boron-1500 ppm (GsP)	29.75	29.32	29.54
F_4 : Nano boron-2000 ppm (CP)	28.87	28.83	28.85

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			33.40	33.10	33.25
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			29.99	29.53	29.76
SEm±			0.75	0.74	0.75
CD (P=0.05)			2.25	2.22	2.26
Interaction: (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	26.94	26.00	26.47
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	26.85	25.66	26.26
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	28.65	28.53	28.59
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	27.59	27.34	27.47
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	30.81	30.66	30.74
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	29.58	29.46	29.52
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	27.24	26.79	27.01
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	26.80	25.38	26.09
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	28.12	28.06	28.09
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	27.26	26.96	27.11
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	30.12	30.09	30.11
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	29.55	29.39	29.47
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	27.15	26.63	26.89
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	26.92	25.96	26.44
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	28.80	28.76	28.78
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	27.75	27.66	27.71
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	34.50	34.10	34.30
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	29.68	29.60	29.64
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	27.09	26.50	26.80
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	26.83	25.40	26.12
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	28.46	28.39	28.43
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	27.55	27.12	27.34
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	30.39	30.31	30.35
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	29.34	29.19	29.27
SEm±			0.96	0.94	0.95
CD (P=0.05)			2.88	2.82	2.85
Control plots: (C)					
C_1 : Recommended dose of fertilizers (RDF) only			22.00	21.50	21.75
C_2 : Recommended package of practices (RPP)			26.19	25.36	25.78
SEm±			1.30	1.20	1.20
CD (P=0.05)			3.90	3.60	3.70
F-test			*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 7. Potassium uptake in seed and stalk of sunflower

Treatments:			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			21.83	21.62	21.72	49.74	49.25	49.50
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			21.34	21.15	21.25	48.62	48.21	48.41
S_3 : Seed priming with nano boron-1500 ppm (GsP)			22.81	22.60	22.71	51.99	51.50	51.74
S_4 : Seed priming with nano boron-2000 ppm (CP)			21.69	21.52	21.61	49.43	49.05	49.24
SEm±			0.16	0.15	0.15	0.33	0.32	0.33
CD (P=0.05)			0.48	0.45	0.46	0.99	0.96	0.99
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			21.58	21.39	21.48	49.18	48.73	48.96
F_2 : Nano sulphur-750 ppm (CP)			21.32	21.13	21.23	48.59	48.15	48.37
F_3 : Nano boron-1500 ppm (GsP)			22.05	21.85	21.95	50.26	49.78	50.02
F_4 : Nano boron-2000 ppm (CP)			21.83	21.65	21.74	49.74	49.33	49.54
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			23.42	23.15	23.29	53.38	52.75	53.06
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			22.11	21.87	21.99	50.39	49.83	50.11
SEm±			0.22	0.20	0.21	0.69	0.67	0.68
CD (P=0.05)			0.66	0.60	0.63	2.07	2.01	2.05
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	20.78	20.51	20.65	47.35	46.74	47.04
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	20.67	20.47	20.57	47.10	46.65	46.87
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	21.80	21.62	21.71	49.66	49.26	49.46
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	21.47	21.26	21.37	48.92	48.45	48.68
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	22.53	22.35	22.44	51.33	50.93	51.13
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	22.08	21.89	21.99	50.32	49.89	50.10
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	21.11	20.90	21.00	48.09	47.62	47.86
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	20.61	20.39	20.50	46.96	46.46	46.71
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	21.65	21.44	21.54	49.33	48.84	49.09
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	21.27	21.05	21.16	48.46	47.97	48.22
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	22.21	22.01	22.11	50.60	50.17	50.38
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	22.03	21.84	21.94	50.20	49.77	49.98
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	20.97	20.79	20.88	47.79	47.38	47.58
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	20.73	20.49	20.61	47.23	46.69	46.96
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	21.90	21.71	21.81	49.90	49.48	49.69
$S_3 \times$		F_4 : Nano boron-2000	21.53	21.34	21.44	49.07	48.64	48.85

Treatments:			Seed (kg ha^{-1})			Stalk (kg ha^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
F_4		ppm (CP)						
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	24.28	24.03	24.16	55.32	54.77	55.04
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	22.15	21.96	22.05	50.46	50.05	50.26
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	20.91	20.67	20.79	47.65	47.11	47.38
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	20.66	20.44	20.55	47.07	46.58	46.83
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	21.72	21.51	21.61	49.49	49.01	49.25
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	21.41	21.19	21.30	48.80	48.28	48.54
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	22.32	22.13	22.23	50.87	50.44	50.65
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	21.98	21.79	21.88	50.08	49.65	49.87
SEm±			0.36	0.34	0.35	0.86	0.85	0.85
CD (P=0.05)			1.08	1.02	1.05	2.58	2.55	2.56
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			18.85	18.36	18.61	42.95	41.84	42.40
C_2 : Recommended package of practices (RPP)			20.60	20.35	20.47	46.94	46.37	46.66
SEm±			0.44	0.43	0.44	1.10	1.00	1.00
CD (P=0.05)			1.32	1.29	1.33	3.30	3.00	3.10
F-test			*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 8. Total potassium uptake (kg ha^{-1}) in sunflower

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			71.57	70.87	71.22
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			69.96	69.36	69.66
S_3 : Seed priming with nano boron-1500 ppm (GsP)			74.80	74.10	74.45
S_4 : Seed priming with nano boron-2000 ppm (CP)			71.12	70.57	70.85
SEm±			0.91	0.89	0.90
CD (P=0.05)			2.73	2.67	2.71
Factor II: Foliar application (F) at ray floret stage					
F_1 : Nano sulphur-600 ppm (GsP)			70.76	70.12	70.44
F_2 : Nano sulphur-750 ppm (CP)			69.91	69.28	69.60
F_3 : Nano boron-1500 ppm (GsP)			72.31	71.63	71.97
F_4 : Nano boron-2000 ppm (CP)			71.57	70.98	71.28
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			76.80	75.90	76.35
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			72.50	71.70	72.10
SEm±			1.18	1.16	1.17
CD (P=0.05)			3.54	3.48	3.51
Interaction: (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	68.13	67.25	67.69
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	67.77	67.12	67.45
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	71.46	70.88	71.17

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	70.39	69.71	70.05
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	73.86	73.28	73.57
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	72.40	71.78	72.09
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	69.20	68.52	68.86
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	67.57	66.85	67.21
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	70.98	70.28	70.63
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	69.73	69.02	69.38
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	72.81	72.18	72.50
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	72.23	71.61	71.92
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	68.76	68.17	68.47
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	67.96	67.18	67.57
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	71.80	71.19	71.50
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	70.60	69.98	70.29
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	79.60	78.80	79.20
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	72.61	72.01	72.31
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	68.56	67.78	68.17
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	67.73	67.02	67.38
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	71.21	70.52	70.87
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	70.21	69.47	69.84
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	73.19	72.57	72.88
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	72.06	71.44	71.75
SEm±			1.45	1.44	1.44
CD (P=0.05)			4.35	4.32	4.33
Control plots: (C)					
C_1 : Recommended dose of fertilizers (RDF) only			61.80	60.20	61.00
C_2 : Recommended package of practices (RPP)			67.54	66.72	67.13
SEm±			1.80	1.76	1.79
CD (P=0.05)			5.40	5.28	5.37
F-test			*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

3.5 Seed Yield

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher seed yield (2778 kg ha^{-1}) (Table 9). The nano sulphur seed treatment in safflower resulted in better plant metabolism and photosynthetic activity improved yield components [25] and [26,33] reported that seed treatment with nano boron nitride (500 ppm GsP) in groundnut enhanced the pod yield compared to control. Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher seed yield (3404 kg ha^{-1}). The increased pod yield in ground nut is due to foliar application of nano sulphur uptake as the result of enhanced availability of essential nutrients in plant [37]. Foliar application of nano boron nitride (400 ppm GsP) in sunflower enhanced the seed yield due to more accumulation of amino acids and amide substances and their translocation to reproductive organs [38,39].

The interaction data on seed yield revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher seed yield (3588 kg ha^{-1}). When compared with recommended practices, the best treatment

(S_3F_5) significantly recorded higher seed yield than control treatments. The increased in seed yield of sunflower due to application of nano boron nitride as it is involved in chlorophyll synthesis through its influence on protein, carbohydrate and energy metabolism further, if it is of nano size then speed of action is more [40,41].

Table 9. Seed yield (kg ha^{-1}) of sunflower

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			2710	2687	2699
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			2588	2526	2557
S_3 : Seed priming with nano boron-1500 ppm (GsP)			2798	2758	2778
S_4 : Seed priming with nano boron-2000 ppm (CP)			2618	2608	2613
SEm±			**15.7**	**13.8**	**15.1**
CD (P=0.05)			**50.4**	**46.2**	**48.6**
Factor II: Foliar application (F) at ray floret stage					
F_1 : Nano sulphur-600 ppm (GsP)			2252	2210	2231
F_2 : Nano sulphur-750 ppm (CP)			2043	2039	2041
F_3 : Nano boron-1500 ppm (GsP)			2882	2861	2872
F_4 : Nano boron-2000 ppm (CP)			2408	2394	2401
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			3419	3389	3404
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			3071	3038	3055
SEm±			**20.0**	**17.6**	**18.4**
CD (P=0.05)			**65.8**	**57.9**	**60.2**
Interaction: (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2242	2217	2230
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2109	2086	2098
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2886	2861	2874
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2436	2416	2426
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	3490	3459	3475
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	3099	3076	3088
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	2265	2251	2258
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	1896	1879	1888
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2811	2784	2798
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2310	2291	2301
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	3241	3259	3250
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	3010	2984	2997
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2253	2235	2244
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2167	2151	2159
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2956	2937	2947
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2514	2499	2507
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	3601	3574	3588
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	3194	3170	3182
$S_4 \times F_1$	S_4 : Seed priming with nano boron	F_1 : Nano sulphur-600 ppm (GsP)	2248	2231	2240

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
$S_4 \times F_2$	2000 ppm (CP)	F_2 : Nano sulphur-750 ppm (CP)	1999	1984	1992
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2875	2857	2866
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2374	2354	2364
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	3350	3328	3339
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	2981	2957	2969
SEm±			**24.8**	**21.3**	**23.8**
CD (P=0.05)			**78.8**	**67.2**	**75.8**
Control plots: (C)					
C_1 : Recommended dose of fertilizers (RDF) only			1689	1649	1669
C_2 : Recommended package of practices (RPP)			1798	1742	1770
SEm±			**29.6**	**28.5**	**29.1**
CD (P=0.05)			**94.5**	**87.6**	**90.7**
F-test			*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

3.6 Dehydrogenase enzyme (µ g TPF g^{-1} h^{-1})

The data pertaining to dehydrogenase enzyme as influenced by different forms, levels and methods of nano boron nitride and sulphur application are presented in Table 10. The data on different seed priming treatments, different foliar sprays and their interaction as well as between all treatment combinations and control treatments were found to be statistically significant (Fig. 1). Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher dehydrogenase enzyme (2.09 µ g TPF g^{-1} h^{-1}). Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher dehydrogenase enzyme(2.34 µ g TPF g^{-1} h^{-1}). The interaction data on dehydrogenase enzyme revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher dehydrogenase enzyme (2.61 µ g TPF g^{-1} h^{-1}). When compared with recommended practices, the best treatment (S_3F_5) significantly recorded higher dehydrogenase enzyme than control treatments. Similar findings were recorded with [42,43].

Fig. 1. Dehydrogenase enzyme activity in sunflower grown soil as influenced by different forms, levels and methods of nano boron and Sulphur application

Table 10. Dehydogenase activity (µ g TPF g^{-1} h^{-1}) of sunflower grown soil after harvest

Treatments:			2019	2020	Pooled data
Factor I: Seed priming (S)					
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			1.77	1.75	1.76
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			1.33	1.33	1.33
S_3 : Seed priming with nano boron-1500 ppm (GsP)			2.11	2.07	2.09
S_4 : Seed priming with nano boron-2000 ppm (CP)			1.62	1.62	1.62
SEm±			0.03	0.02	0.02
CD (P=0.05)			0.09	0.06	0.06
Factor II: Foliar application (F) at ray floret stage					
F_1 : Nano sulphur-600 ppm (GsP)			1.52	1.51	1.52
F_2 : Nano sulphur-750 ppm (CP)			1.27	1.26	1.27
F_3 : Nano boron-1500 ppm (GsP)			1.83	1.81	1.82
F_4 : Nano boron-2000 ppm (CP)			1.68	1.67	1.67
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			2.34	2.33	2.34
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			1.97	1.96	1.97
SEm±			0.06	0.05	0.05
CD (P=0.05)			0.18	0.15	0.16
Interaction: (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	0.98	0.95	0.96
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.92	0.90	0.91
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	1.61	1.61	1.61
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	1.36	1.35	1.36
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	2.12	2.11	2.11
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	1.81	1.80	1.80
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	1.17	1.15	1.16
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.88	0.86	0.87
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	1.49	1.47	1.48
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	1.24	1.22	1.23
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	1.91	1.89	1.90
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	1.77	1.76	1.77
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	1.12	1.11	1.12
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.95	0.93	0.94
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	1.69	1.68	1.69
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	1.42	1.41	1.41
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	2.62	2.60	2.61
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	1.85	1.84	1.85
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	1.05	1.03	1.04
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.90	0.88	0.89
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	1.54	1.52	1.53
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	1.32	1.29	1.31

Treatments:		2019	2020	Pooled data
Factor I: Seed priming (S)				
$S_4 \times F_5$	F_5 : F_1 + F_3 (GsP)	1.99	1.98	1.99
$S_4 \times F_6$	F_6 : F_2 + F_4 (CP)	1.73	1.72	1.73
SEm±		0.08	0.07	0.07
CD (P=0.05)		0.24	0.21	0.22
Control plots: (C)				
C_1 : Recommended dose of fertilizers (RDF) only		0.51	0.46	0.48
C_2 : Recommended package of practices (RPP)		0.84	0.81	0.83
SEm±		0.10	0.09	0.09
CD (P=0.05)		0.30	0.27	0.27
F-test		*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

3.7 Microbial Population

The data pertaining to microbial population are presented in Tables 11, 12 and 13. The data on different seed priming treatments, different foliar sprays and their interaction as well as between all treatment combinations and control treatments were found to be statistically significant (Fig. 2).

Among different seed priming treatments, seed priming with 1500 ppm nano boron nitride (GsP) significantly recorded higher microbial population (10.4×10^5, 18.5×10^3, 10.7×10^3, 9.5×10^4 and 4.6×10^4 cfu/g of soil of bacteria, fungi, *actinomycetes*, *azotobacter* and PSB, respectively) but *azospirillum* population was found to be non significant. Among different foliar sprays, foliar application of 600 ppm of nano sulphur (GsP) + 1500 ppm of nano boron nitride (GsP) significantly recorded higher microbial population (11.1×10^5, 19.6×10^3, 11.8×10^3, 11.5×10^4 and 5.5×10^4 cfu/g of soil of bacteria, fungi, *actinomycetes, azotobacter* and PSB, respectively) but *azospirillum* population was found to be non significant). The interaction data on microbial population revealed that seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) (S_3F_5) significantly recorded higher microbial population (13.1×10^5, 22.4×10^3, 12.5×10^3, 12.0×10^4 and 8.8×10^4 cfu/g of soil of bacteria, fungi, *actinomycetes, azotobacter* and PSB, respectively) but *azospirillum* population was found to be non significant. When compared with recommended practices, the best treatment (S_3F_5) significantly recorded higher microbial population than control treatments. Similar findings were recorded with [23,44]. Seed treatment with nano fertilizers did not recorded any difference in the microbial population after harvest of the ground nut [45,46]. Seed treatment and foliar application of nano boron nitride recorded higher microbial population due to higher vegetative matter production in treated plot compared to control plot, because of higher organic matter in nano boron treated plot higher organic carbon was available for the microorganisms so their population was increased [47,48] and [49].

Table 11. Microbial population of sunflower grown soil after harvest of the crop

	Bacteria (No. × 10^5 cfu/g of soil)			Fungi (No. × 10^3 cfu/g of soil)		
Treatments:	**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
Factor I: Seed priming (S)						
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)	8.8	8.3	8.5	14.5	13.9	14.2
S_2 : Seed priming with nano sulphur-750 ppm (CP**)	5.3	5.2	5.2	11.7	11.3	11.5
S_3 : Seed priming with nano boron-1500 ppm (GsP)	10.6	10.2	10.4	18.9	18.2	18.5
S_4 : Seed priming with nano boron-2000 ppm (CP)	7.6	7.5	7.5	13.2	12.7	13.0
SEm±	0.10	0.09	0.10	0.20	0.10	0.20

Treatments:			Bacteria (No. × 10^5 cfu/g of soil)			Fungi (No. × 10^3 cfu/g of soil)		
			2019	2020	Pooled data	2019	2020	Pooled data
CD (P=0.05)			0.30	0.28	0.34	0.60	0.40	0.60
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			6.8	6.7	6.7	12.2	12.1	12.2
F_2 : Nano sulphur-750 ppm (CP)			5.7	5.6	5.7	11.1	10.8	10.9
F_3 : Nano boron-1500 ppm (GsP)			8.9	8.4	8.7	14.5	13.8	14.2
F_4 : Nano boron-2000 ppm (CP)			7.9	7.8	7.8	13.3	13.2	13.3
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			11.3	10.9	11.1	19.9	19.2	19.6
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			9.5	8.9	9.2	16.1	16.1	16.1
SEm±			0.22	0.20	0.20	0.30	0.20	0.20
CD (P=0.05)			0.68	0.70	0.65	0.90	0.60	0.70
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	4.6	3.5	4.0	10.1	9.8	10.0
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	4.3	3.4	3.9	9.2	8.7	9.0
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	7.4	7.2	7.3	13.6	12.8	13.2
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	5.8	5.5	5.7	12.0	11.4	11.7
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	10.6	10.3	10.4	18.6	18.3	18.4
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	8.7	8.5	8.6	14.7	14.3	14.5
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	5.1	4.6	4.9	10.8	10.6	10.7
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	4.2	3.1	3.6	8.6	7.8	8.2
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	6.6	6.5	6.5	13.0	12.3	12.7
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	5.2	4.9	5.0	11.1	10.9	11.0
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	9.4	9.3	9.4	15.7	15.4	15.5
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	8.6	8.3	8.5	14.3	13.6	14.0
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	5.0	4.4	4.7	10.7	10.2	10.4
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	4.5	3.4	3.9	9.6	9.2	9.4
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	7.7	7.6	7.6	13.9	13.2	13.6
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	6.1	6.0	6.0	12.6	12.1	12.4
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	13.2	13.0	13.1	22.7	22.1	22.4
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	8.8	8.7	8.8	15.0	14.5	14.8
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	4.8	4.1	4.5	10.3	10.0	10.2
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	4.2	3.2	3.7	9.0	8.3	8.7
$S_4 \times$		F_3 : Nano boron-1500	7.0	6.9	7.0	13.3	12.5	12.9

Treatments:		Bacteria (No. × 10^5 cfu/g of soil)			Fungi (No. × 10^3 cfu/g of soil)		
		2019	2020	Pooled data	2019	2020	Pooled data
F_3	ppm (GsP)						
S_4 × F_4	F_4 : Nano boron-2000 ppm (CP)	5.6	5.1	5.4	11.5	11.2	11.3
S_4 × F_5	F_5 : F_1 + F_3 (GsP)	9.8	9.7	9.8	16.6	16.2	16.4
S_4 × F_6	F_6 : F_2 + F_4 (CP)	8.3	8.1	8.2	14.2	13.4	13.8
SEm±		0.30	0.29	0.30	0.40	0.40	0.40
CD (P=0.05)		0.90	0.87	0.95	1.20	1.30	1.30
Control plots: (C)							
C_1 : Recommended dose of fertilizers (RDF) only		3.1	2.8	3.0	8.5	8.0	8.3
C_2 : Recommended package of practices (RPP)		4.8	4.6	4.7	10.6	9.7	10.2
SEm±		0.40	0.36	0.40	0.60	0.50	0.50
CD (P=0.05)		1.20	1.11	1.30	1.80	1.50	1.60
F-test		*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

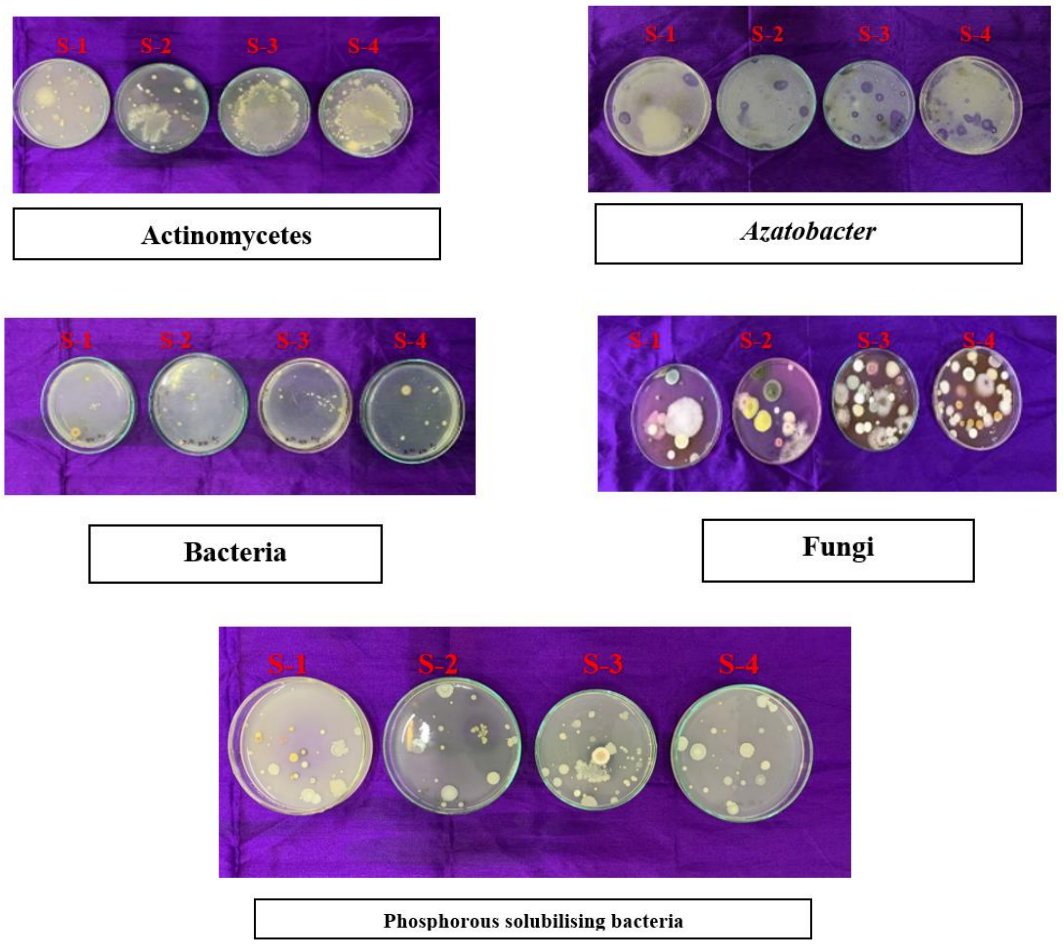

Fig. 2. Microbial population of sunflower-grown soil after harvest of the crop

Table 12. Microbial population of sunflower grown soil after harvest of the crop

Treatments:			*Actinomycetes* (No. × 10^3 cfu/g of soil)			*Azotobacter* (No. × 10^4 cfu/g of soil)		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			7.6	6.6	7.1	6.9	5.6	6.2
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			4.6	4.0	4.3	3.9	3.3	3.6
S_3 : Seed priming with nano boron-1500 ppm (GsP)			11.1	10.3	10.7	9.8	9.1	9.5
S_4 : Seed priming with nano boron-2000 ppm (CP)			6.0	5.3	5.7	5.3	4.6	5.0
SEm±			0.10	0.09	0.10	0.20	0.11	0.20
CD (P=0.05)			0.30	0.28	0.38	0.60	0.35	0.60
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			5.0	4.8	4.9	4.3	4.1	4.2
F_2 : Nano sulphur-750 ppm (CP)			3.7	3.5	3.6	3.0	2.8	2.9
F_3 : Nano boron-1500 ppm (GsP)			7.4	6.6	7.0	6.7	5.9	6.3
F_4 : Nano boron-2000 ppm (CP)			5.8	5.2	5.5	5.1	4.5	4.8
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			12.3	11.3	11.8	11.9	11.2	11.5
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			9.0	8.5	8.8	8.3	7.8	8.1
SEm±			0.20	0.21	0.21	0.30	0.23	0.30
CD (P=0.05)			0.60	0.65	0.65	0.90	0.70	0.90
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2.9	2.8	2.9	3.1	3.0	3.1
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.8	2.8	2.8	3.1	3.0	3.0
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	6.5	5.6	6.0	5.8	4.9	5.3
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	4.8	4.1	4.4	4.1	3.4	3.7
$S_1 \times F_5$		F_5 : $F_1 + F_3$ (GsP)	10.8	10.5	10.7	10.3	9.9	10.1
$S_1 \times F_6$		F_6 : $F_2 + F_4$ (CP)	7.1	7.1	7.1	6.4	6.4	6.4
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	3.6	3.4	3.5	3.2	3.0	3.1
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.8	2.7	2.8	3.1	2.9	3.0
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	5.9	5.1	5.5	5.2	4.4	4.8
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	4.0	3.6	3.8	3.3	3.1	3.2
$S_2 \times F_5$		F_5 : $F_1 + F_3$ (GsP)	8.5	8.3	8.4	7.8	7.6	7.7
$S_2 \times F_6$		F_6 : $F_2 + F_4$ (CP)	6.9	6.4	6.6	6.2	5.7	5.9
$S_3 \times F_1$	S_3: Seed priming with	F_1 : Nano sulphur-600 ppm (GsP)	3.3	2.9	3.1	3.2	3.0	3.1

			***Actinomycetes* (No. × 10^3 cfu/g of soil)**			***Azotobacter* (No. × 10^4 cfu/g of soil)**		
Treatments:			**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
$S_3 \times F_2$	nano boron 1500 ppm (GsP)	F_2 : Nano sulphur-750 ppm (CP)	2.8	2.8	2.8	3.1	3.0	3.0
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	6.6	5.9	6.2	5.9	5.2	5.5
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	5.5	4.8	5.1	4.8	4.1	4.4
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	12.9	12.1	12.5	12.1	12.0	12.0
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	7.8	7.7	7.7	7.1	7.0	7.0
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	2.9	2.8	2.9	3.2	3.0	3.1
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.8	2.7	2.8	3.1	3.0	3.0
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	6.1	5.3	5.7	5.4	4.6	5.0
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	4.2	3.8	4.0	3.5	3.1	3.3
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	9.1	8.6	8.9	8.4	7.9	8.2
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	6.8	6.1	6.5	6.1	5.4	5.8
SEm±			0.30	0.28	0.30	0.40	0.30	0.32
CD (P=0.05)			0.90	0.90	0.96	1.20	0.90	1.00
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			2.5	2.2	2.4	2.6	2.0	2.3
C_2 : Recommended package of practices (RPP)			3.8	3.7	3.8	4.5	4.0	4.3
SEm±			0.40	0.36	0.40	0.50	0.40	0.50
CD (P=0.05)			1.20	1.15	1.26	1.50	1.30	1.50
F-test			*	*	*	*	*	*

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Table 13. Microbial population of sunflower grown soil after harvest of the crop

	PSB (No. × 10^4 cfu/g of soil)			***Azospirillum* (No. × 10^4 cfu/g of soil)**		
Treatments:	**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
Factor I: Seed priming (S)						
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)	3.4	3.1	3.2	5.1	4.0	4.5
S_2 : Seed priming with nano sulphur-750 ppm (CP**)	1.6	1.1	1.3	3.9	3.8	3.9
S_3 : Seed priming with nano boron-1500 ppm (GsP)	4.9	4.3	4.6	5.3	4.2	4.8
S_4 : Seed priming with nano boron-2000 ppm (CP)	3.0	2.3	2.7	4.9	4.7	4.8

			PSB (No. × 10^4 cfu/g of soil)			*Azospirillum* (No. × 10^4 cfu/g of soil)		
Treatments:			**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
SEm±			0.13	0.11	0.12	0.21	0.20	0.20
CD (P=0.05)			0.39	0.33	0.36	NS	NS	NS
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			2.2	1.6	1.9	5.8	5.7	5.8
F_2 : Nano sulphur-750 ppm (CP)			1.3	1.1	1.2	5.3	5.4	5.4
F_3 : Nano boron-1500 ppm (GsP)			4.3	3.6	3.9	5.9	5.9	5.9
F_4 : Nano boron-2000 ppm (CP)			2.8	2.1	2.4	5.5	5.6	5.6
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			5.6	5.3	5.5	6.9	6.8	6.9
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			4.4	4.2	4.3	6.5	6.5	6.5
SEm±			0.21	0.20	0.20	0.29	0.28	0.29
CD (P=0.05)			0.63	0.60	0.61	NS	NS	NS
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2.2	2.1	2.2	3.1	2.1	2.6
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.2	2.1	2.1	3.1	2.0	2.6
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	4.0	3.6	3.8	4.0	3.1	3.5
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	3.2	3.2	3.2	3.5	2.4	3.0
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	7.2	7.1	7.2	8.5	8.5	8.5
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	4.4	4.3	4.3	4.6	4.6	4.6
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	2.7	2.5	2.6	3.3	2.3	2.8
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.2	2.0	2.1	3.0	2.0	2.5
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	3.7	3.4	3.5	3.7	2.7	3.2
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2.7	2.7	2.7	3.4	2.3	2.8
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	5.7	5.5	5.6	6.0	5.8	5.9
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	4.2	4.1	4.2	4.4	3.9	4.2
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2.4	2.2	2.3	3.2	2.2	2.7
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2.2	2.1	2.1	3.1	2.1	2.6
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	4.0	3.9	3.9	4.1	3.4	3.7
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	3.5	3.4	3.5	3.7	2.5	3.1
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	8.9	8.7	8.8	8.9	8.6	8.8
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	5.0	5.0	5.0	5.3	5.2	5.2
S_4	S_4 : Seed	F_1 : Nano sulphur-600	2.2	2.2	2.2	3.2	2.2	2.7

		PSB (No. × 10^4 cfu/g of soil)			*Azospirillum* (No. × 10^4 cfu/g of soil)		
Treatments:		**2019**	**2020**	**Pooled data**	**2019**	**2020**	**Pooled data**
× F_1	priming with nano boron 2000 ppm (CP) ppm (GsP)						
S_4 × F_2	F_2 : Nano sulphur-750 ppm (CP)	2.2	2.0	2.1	3.0	2.0	2.5
S_4 × F_3	F_3 : Nano boron-1500 ppm (GsP)	3.8	3.5	3.7	3.8	2.8	3.3
S_4 × F_4	F_4 : Nano boron-2000 ppm (CP)	3.0	3.0	3.0	3.4	2.3	2.9
S_4 × F_5	F_5 : F_1 + F_3 (GsP)	6.2	6.0	6.1	6.7	6.6	6.6
S_4 × F_6	F_6 : F_2 + F_4 (CP)	4.1	3.9	4.0	4.3	3.7	4.0
SEm±		0.28	0.25	0.29	0.36	0.35	0.35
CD (P=0.05)		0.84	0.75	0.87	NS	NS	NS
Control plots: (C)							
C_1 : Recommended dose of fertilizers (RDF) only		2.4	2.0	2.2	3.5	2.8	3.2
C_2 : Recommended package of practices (RPP)		3.6	3.4	3.5	4.6	3.7	4.2
SEm±		0.32	0.31	0.32	0.42	0.41	0.42
CD (P=0.05)		0.96	0.93	0.97	NS	NS	NS
F-test		*	*	*	-	-	-

*GsP: Green synthesised nano particle and **CP: Commercially available nano particle*
RDF: (N:P_2O_5:K_2O 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments
RPP: RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

4. CONCLUSION

Seed priming with 1500 ppm nano boron nitride (GsP) + foliar application of 600 ppm nano sulphur (GsP) + 1500 ppm nano boron nitride (GsP) significantly recorded higher microbial population of soil of bacteria, fungi, *actinomycetes, azotobacter* and PSB, respectively) but *azospirillum* population was found to be nonsignificant. When compared with recommended practices, the best treatment significantly recorded a higher microbial population than control treatments. The seed treatment and foliar application of nano fertilizers resulted in a higher microbial population due to increased vegetative matter production in the treated plot compared to the control plot. The elevated organic matter in the fertilizers treated plot provided more organic carbon, which supported the growth of microorganisms, thereby increasing their population. However, the application of very small quantities of nano fertilizers did not show any significant impact on the microbial population. This indicates that while nano boron nitride can enhance microbial activity and soil health when used in adequate amounts, its benefits are not evident at minimal application rates. Additionally, the study highlights the importance of optimizing nano fertilizer dosage to achieve the desired agricultural outcomes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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