Bioalgalization—A Novel Approach for Soil Amendment to Improve Fertility

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Abstract Current problems of world including food security, water scarcity, soil erosion, climate changes, population demand and environmental safety can be challenged by agriculture science by introduction of biotech crops, new farming practices and new crop protection methods. The efficiency of crops is improved by a novel technique like bioalgalization for soil amendments. In this aspect, *Spirulina* is applied to soils along with biofertilizers, organic manure and vermicompost anticipating enhanced soil mineral status to help the growth and yield of crops. The present experiment was carried out with field studies on Amaranthus, Green gram and Tomato using different combinations and concentrations of *Spirulina* with biofertilizer, vermicompost and organic manure and different treatments to estimate the NPK status in plants and in soils prior and after the studies. There was 10–20 fold increase of protein content in yield of tomato when compared with reference value of 0.9/100 g with different concentrations of *Spirulina*. The soil nitrogen levels were found to be increased in experimental set up of green gram seeds soaked in *Spirulina*, 5 g concentration resulted in N content as (0.84 ± 0.04%) compared to control (0.03 ± 0.02%). In experimental method of biofertilizer and *Spirulina* combination Phosphorus content of soil after harvest of *Amaranthus* plants was 44.5 ± 0.70 mg/100 g and the control value was 37 ± 0.70 mg/100 g. In post-harvest soil of tomato plants the potassium (K) levels were increased to 184.5 ± 2.1 mg/100 g from the control value of 44 ± 0.70 mg/100 g in 3 h of soaking experimental group. Bioalgalization is a promising technology to prevent soil erosion and pollution caused by use of heavy chemical fertilizers and also helps to improve soil fertility.

Keywords *Spirulina* · Biofertilizer · Vermicompost · Amaranthus · NPK status

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1 Introduction

Key issues such as water scarcity, soil erosion, climate changes, population demand and environmental safety are to be addressed by improving the agriculture technology, thereby improving crop yields for ensuring food security according to demand. The soil should be supplied with sufficient nutrients and is amended with effective fertilization techniques. Balanced fertilization ensures adequate availability of nutrients in soil, so as to meet the requirement of crops at critical stages of growth. The efficiency of crops is improved by reduction of usage of chemical fertilizers, practicing conservative agriculture farming which focus on reducing the adverse impacts on the environment by promotion and utilization of biofertilizers and organic manures globally [1].

The use of biofertilizers in current agricultural practices enhances the crop growth and yield. The biofertilizers are applied along with vermicompost, organic manure and microbial inoculants [2]. The microbial biofertilizers used include seaweed liquid extracts, microbial inoculants, biostimulators and biofortification agents. All these categories of microbial biofertilizers are involved in the enhancement of plant nutrient uptake. This in turn results in crops with high vitamin and nutrient content, and high yields [3]. Agriculture should play a major role in improving nutrition, in particular by paying more attention to the nutritional quality of food. Biofortfication is a scientific method for improving the nutritional value of foods. Biofortification holds great promise for improving nutrition and should continue to be explored [4].

Biofortification has four main advantages when applied in the context of the poor in developing countries. First, it targets the poor who eat large amounts of staple foods daily. Second, biofortification targets rural areas where it is estimated that 75% of the poor live mostly as subsistent or small hold farmers, or landless labourers. These populations rely largely on cheaper and more widely available staple foods such as rice or maize for sustenance [23]. Biofortification is cost effective and has distinct advantages that can complement other traditional approaches to improve nutrition. Microbial inoculants have been the primary focus of programs to enhance staple food crops with sufficient levels of Fe, Zn, and provitamin A, carotenoids [5].

The utilization of bacterial, algal and fungal biofertilizers were recommended. In this aspect use of *Spirulina* application to soils along with biofertilizers or vermicompost is studied for increasing the levels of protein, macro and micronutrients in soil as well as in the yield. *Spirulina platensis* can be used as a microbial inoculant or a biofortification agent to the plants to enhance the nutrients and helps to improve the nutrient status of human population and in turn reducing malnutrition. Thus, the present study aims to appraise the soil fertility using *Spirulina* by pot studies. Field studies are carried out with different concentrations and fertilizer combination methods of application of *Spirulina* and study its effect on NPK status of crops and as well as soil.

2 Materials and Methods

The experiment was carried out with different methods such as soaking of seeds in *Spirulina* extract for different time periods, different concentrations, and different proportions of *Spirulina* extract mixed with biofertilizers, vermicompost, organic manure and foliar application of *Spirulina* extract in different concentration. Further, nutrient profile of *Spirulina*, soil prior to experimentation and nutrient profile of the yield has been studied.

2.1 Estimation of Nitrogen and Protein

The Nitrogen and protein content was analyzed by Kjeldahl method by kjeltech model, Pelican Kelplus—KES 12 INL [6].

2.2 Estimation of Phosphorus

The amount of phosphorous was estimated by Fiske and Subba Row Calorimetric method [7].

2.3 Estimation of Potassium and Sodium

The amount of Potassium and Sodium was estimated byElico CL 22D Flame Photometer [8].

2.4 Estimation of Nitrogen, Phosphorous and Potassium in Soil

The amount of N, P and K present in soil was estimated by Soil Testing Centre, Government Limited [9].

2.5 Protein and Nitrogen Estimation in Yield of Crops

Estimation of Protein Nitrogen in *Amaranthus*, Green gram and Tomato samples was carried out by Kjeldahl method Pelican Kelplus—KES 12 INL [6].

3 Results and Discussion

3.1 Estimation of Soil Nutrient Profile

The soil nutrient profile was studied and the soil was analyzed for minerals like: Nitrogen, Phosphorous and Potassium. Studies were carried out on soil properties like pH and Electric conductivity. All nutrients were high in the soil treated with *Spirulina* when compared with control except potassium (Table 1).

The yield of the crop mainly depends on the soil health which is a crucial factor. The soil pH, conductivity and nitrogen have been reported higher when compared with control. Physical and chemical properties of soil from Olasati village were studied in detail and carried out the pot experiment analysis for response of green gram to the application of Minjingu Mazao fertilizer (31% P_2O_5) in Tanzania, and the results indicated that N, P, K in soil were increased [10]. Zodape et al., [11] studied the foliar application of seaweed extract. *Kappaphycus alvarezii* extract was applied on green gram plants (*Phaseolus radiata* L) to enhance the yield and nutritional quality. The yield was analyzed for total carbohydrates, total Nitrogen, total protein and various micro nutrients like Fe, Zn and Cu etc. The foliar application resulted in high yield and improved nutrients of green gram.

The field experiment was carried out to study the effect of chemical fertilizers, Biofertilizers, Organic matter, vermicompost combination with *Spirulina* and soaking in *Spirulina* hydrolysate to enhance the level of minerals like P, K, Zinc and Iron, the components like Nitrogen and Protein in *Amaranthus*, Green gram and Tomato plants. Due to the leaching of Nitrogen, phosphorous and potassium from the soil the amounts of these elements have to be replenished in soil with fertilizers. Chemical fertilizers like Urea, super phosphates and potassium fertilizers are widely used.

The Table 2 shows the effect of various experimental methods resulting in increased status of NPK levels in *Amaranthus* plants. Time period soaking is a traditional approach that allows the transport of mineral ions between *Spirulina* extract and *Amaranthus* seeds. Different concentrations method also works on same principle but the equilibrium of ions is established at a certain concentration. *Spirulina* in

Table 1 Effect of *Spirulina* on selected soil nutrient profile of pot study prior and after experimentation

Parameters	Pre-experimentation	Post experimentation	Control
pH	7.0	7.3	7.1
E.C ds m^{-1}	0.23	0.37	0.12
Nitrogen (%)	0.50	0.55	0.36
Phosphorous mg/100 g	33	39	37
Potassium mg/100 g	124	81	62
Zinc mg/100 g	26	32	28

Table 2 Effect of *Spirulina* supplementation on *Amaranthus* plants

Experimental methods	Protein (%)	Nitrogen (%)	Phosphorus (mg/g)	Potassium (mg/g)
Time period soaking	9.8 ± 0.00 (4 h)	1.5 ± 0.00 (4 h)	332 ± 0.70 (4 h)	121 ± 0.70 (3 h)
Soaking in different concentration	9.5 ± 0.00 (15 g)	1.5 ± 0.00 (15 g)	332 ± 0.70 (30 g)	116.5 ± 0.70 (30 g)
Biofertilizer	13.0 ± 0.00 (25:75)	2.0 ± 0.00 (25:75)	356. ± 0.70 (75:25)	111.5 ± 0.70 (75:25)
Vermicompost	11.5 ± 0.00 (75:25)	2.6 ± 6.36 (75:25)	302 ± 2.10 (50:50)	126 ± 1.41 (50:50)
Organic manure	13.3 ± 0.00 (75:25)	2.1 ± 0.00 (75:25)	211 ± 1.41 (25:75)	106 ± 1.41 (50:50)
Chemical fertilizer	11.9 ± 0.00 (50:50)	1.9 ± 0.00 (50:50)	276 ± 0.70 (50:50)	103 ± 1.41 (25:75)
Spray method	12.9 ± 0.00 (25/5L)	2.07 ± 0.00 (25/5L)	228 ± 0.70 (25/5L)	173.5 ± 4.94 (25/5L)

combination with biofertilizer, vermicompost, organic manure and chemical fertilizer work at different proportions and is evident from the table. Foliar application is a novel method that directly interacts with the plant leaf cells allowing the entry of mineral ions improving their concentrations [12]. The combination of cyanobacteria and flyash has known to improve the total soil nitrogen status and as well as other mineral status in rice crops and soil in which they were grown [13].

Seed priming is one of the promising technologies that influence the plant—soil interactions, mineral status and microbial community colonization in root zones of plants. Seed biopriming with *Spirulina* (soaking) has turned out to be novel method that improves soil as well as crop mineral characteristics. Therefore, seed priming enables to improve the soil mineral levels and thereby also help to increase crop growth and yield [19].

The Table 3 describes the effect of various experimental methods in improving the yield of green gram plants by utilization of *Spirulina*. High amounts of nitrogen (%N) were observed in experimental set up *Spirulina* + biofertilizer combination in 25:75 proportions. Increased amounts of phosphorus were observed in soaking method using 15 g of *Spirulina*. Potassium levels were found to be increased in the experimental method of *Spirulina* + chemical fertilizer in 25:75 proportions. The treatment of soil and chick pea crops with a combination of cyanobacteria and bacterial biofilms have enhanced various physical, biochemical and morphological parameters of the crops and also the mineral status of soil due to increased nitrogen availability in soil [14].

Soil microbial interactions play a major role in soil amendments that in turn increase the overall availability of soil minerals to crops due to which the crop

Table 3 Effect of *Spirulina* supplementation on green gram plants

Experimental methods	Protein (%)	Nitrogen (%)	Phosphorus (mg/g)	Potassium (mg/g)
Time period soaking	22.7 ± 0.00 (4 h)	3.6 ± 7.07 (4 h)	331 ± 1.41 (3 h)	122.5 ± 0.70 (1 h)
Soaking in different concentration	21.7 ± 0.00 (10 g)	3.4 ± 7.07 (10 g)	347 ± 0.70 (15 g)	84.5 ± 0.70 (20 g)
S + Biofertilizer	25.5 ± 0.00 (25:75)	4.0 ± 7.07 (25:75)	253 ± 0.20 (75:25)	57 ± 1.41 (25:75)
S + Vermicompost	24.1 ± 0.00 (25:75)	3.8 ± 7.07 (25:75)	243 ± 2.12 (75:25)	74.5 ± 6.70 (75:25)
S + Organic manure	23.8 ± 0.00 (75:25)	3.8 ± 0.00 (75:25)	231 ± 0.70 (75:25)	63 ± 4.24 (50:50)
S + Chemical fertilizer	24.1 ± 0.00 (50:50)	3.8 ± 0.00 (50:50)	308 ± 1.41 (25:75)	88.5 ± 0.70 (25:75)
Spray method	21.3 ± 0.00 (25/5L)	3.4 ± 7.07 (25/5L)	217 ± 1.41 (50/5L)	85.5 ± 2.12 (50/5L)

growth and yield are increased. In this experimental method, the synergistic interactions between *Spirulina* and biofertilizers were thought to have an important role in increasing soil nitrogen, phosphorus and potassium status [18].

Table 4 depicts the effect of *Spirulina* on tomato plants using different experimental methods. In tomato plants the % of Nitrogen was found to be higher in *Spirulina* + organic manure method in 50:50 proportions. Phosphorus levels were higher in *Spirulina* + biofertilizer and *Spirulina* + vermicompost methods in 75:25 proportions. High potassium levels were found in 5 h soaking method. Increased qualitative and quantitative traits have been observed in cherry tomato plants. The plant seeds were

Table 4 Effect of *Spirulina* supplementation on tomato plants

Experimental methods	Protein (%)	Nitrogen (%)	Phosphorus (mg/g)	Potassium (mg/g)
Time period soaking	19.9 ± 0.00 (5 h)	3.1 ± 7.07 (5 h)	210 ± 0.71 (O.N)	127 ± 1.41 (5 h)
Soaking in different concentration	21.0 ± 0.00 (20 g)	3.3 ± 7.07 (20 g)	206 ± 7.07 (30 g)	84.5 ± 0.70 (20 g)
S + Biofertilizer	22.2 ± 0.00 (25:75)	3.4 ± 7.07 (25:75)	332 ± 0.71 (75:25)	58.0 ± 1.41 (25:75)
S + Vermicompost	19.2 ± 7.07 (75:25)	3.0 ± 7.07 (75:25)	332 ± 0.71 (75:25)	66.5 ± 0.70 (50:50)
S + Organic manure	23.1 ± 7.07 (50:50)	3.6 ± 7.07 (50:50)	294 ± 6.36 (75:25)	63.0 ± 4.24 (50:50)
S + Chemical fertilizer	17.1 ± 7.07 (75:25)	2.7 ± 7.07 (75:25)	243 ± 2.12 (50:50)	78.5 ± 0.70 (25:75)
Spray method	20.6 ± 7.07 (100/5L)	3.3 ± 0.00 (100/5L)	227 ± 1.41 (50/5L)	85.5 ± 2.12 (50/5L)

Table 5 Effect of *Spirulina* supplementation on % nitrogen in post-harvest soil of experimental plants

Experimental methods	Nitrogen (mg/g)		
	A	G	T
Time period soaking	0.77 ± 0.00 (4 h)	0.83 ± 0.042 (4 h)	0.80 ± 0.00(5 h)
Soaking in different concentration	0.80 ± 0.02 (15 g)	0.84 ± 0.04 (5 g)	0.68 ± 0.12 (5 g)
S + Biofertilizer	0.74 ± 0.04(25:75)	0.57 ± 0.07(50:50)	0.03 ± 0.02(50:50)
S + Vermicompost	0.81 ± 0.02 (50:50)	0.60 ± 0.02 (25:75)	0.60 ± 0.02(50:50)
S + Organic manure	0.76 ± 0.01(in control)	0.04 ± 0.01(25:75)	0.03 ± 0.02(in control)
S + Chemical fertilizer	0.83 ± 0.02(75:25)	0.03 ± 0.02(25:75)	0.03 ± 0.02(50:50)
Spray method	0.82 ± 0.00(50 g/5L)	0.04 ± 0.01(25 g/5L)	0.03 ± 0.01(25 g/5L)

A Amaranthus; *G* Green gram, *T* Tomato

treated with combination of brown algae *Ascophyllum nodosum* and vermicompost extracts. The experiment resulted in overall increase of all parameters of crops and the experiment was carried out in hydroponic conditions [15].

Integrated nutrient management of soil and crops is essential to improve the crop yield of tomato. Conventional agricultural methods are followed by application of biofertilizer and organic manures increased the plant morphological characters, yield and physiological status was improved by increased nutritional status. Utilization of effective soil amendment methods had resulted in increase in the yield of tomato in the current experiment [20]. The Table 5 shows increase in % Nitrogen in post harvest soil of three experimental plants. High amounts of Nitrogen were found in green gram plants in 5 g soaking method followed by Amaranthus plants in *Spirulina* + chemical fertilizer method in 75:25 proportions. The high amount of nitrogen in tomato plants was 0.80 ± 0.00 and was reported in 5 h soaking method.

Soil mineral status is known to improve by crop—soil interactions along with soil amendments. The utilization of biofertilizers, organic manure and vermicopost increased soil fertility by increasing soil nitrogen status. Soil nitrogen is improved by reducing the soil acidity and also preserving the root zone microorganisms attracting more microbes with root exudates. Application of biofertilizers along with *Spirulina* helped increasing the protein content of crops and nitrogen levels of soil since, *Spirulina* is protein rich cyanobacterial member that obviously contributes more nitrogen to post harvest soil [21]. The N, P and K in soil were found to increase significantly due to inoculation of cyanobacteria. High NPK levels were observed when the seed soaking + soil drench +75% of N was applied to plants [24].

The Table 6 shows the post-harvest phosphorus levels in soils after growing the experimental plants *Amaranthus*, Green gram and Tomato. High amounts of phosphorus were reported in green gram plants in soaking in 25 g concentration method.

Table 6 Effect of *Spirulina* supplementation on % phosphorous in post-harvest soil of experimental plants

Experimental methods	Phosphorous (mg/g)		
	A	G	T
Time period soaking	34.5 ± 0.70 (3 h)	45 ± 1.41 (3 h)	41.5 ± 2.12 (5 h)
Soaking in different concentration	44.5 ± 0.70 (30 g)	45.5 ± 2.12(25 g)	42 ± 2.82 (10 g)
S + Biofertilizer	44.5 ± 0.70(25:75)	42 ± 0.70 (in control)	38 ± 0.70 (in control)
S + Vermicompost	40.0 ± 0.70(in control)	43 ± 1.41 (50:50)	46 ± 1.41 (75:25)
S + Organic manure	44.5 ± 0.70 (50:50)	37 ± 1.41(50:50)	36 ± 0.70 (75:25)
S + Chemical fertilizer	36.5 ± 0.70 (25:75)	32 ± 0.70 (50:50)	36 ± 0.70 (in control)

A Amaranthus; *G* Green gram; *T* Tomato

The high amounts of phosphorus levels were followed in soils after harvesting Amaranthus plants. The high amounts were observed in experimental methods of soaking in 30 g concentration, *Spirulina* + biofertilizers in 25:75 proportions and *Spirulina* + organic manure in 50:50 proportions. Foliar application of *Spirulina* was proved to be equally effective as NPK fertilizers in enhancing soil NPK status. This can be evident by study of yield of eggplants using a foliar *Spirulina* fertilizer called Spirufert. Soil mineral status is also improved with supplementation of biofertilizers and organic manures that stabilize soil acidity and prevent phosphorus leaching increasing phosphorus status of the soils [22].

Table 7 shows post-harvest soil levels of potassium. Post harvestings of experimental plants with various methods using *Spirulina* have reported with increased levels of potassium. High amounts of potassium were found in soils of tomato plants with experimental method *Spirulina* + biofertilizer in 25: 75 proportions. The high values were followed by green gram plants in *Spirulina* + vermicompost (25:75) method and 3 h time period soaking. Soil health reflects the soil mineral status.

Increased phosphorous and Potassium levels were observed in both seasons when mung bean plants are supplemented with phosphorus and potassium fertilization [25].

Sustainable agricultural practices increase the soil health and fertility. The sustainable agricultural practices include bio inoculation of soils with marine microalgae, cyanobacteria and combination methods including bio fertilizers, green manures and vermin compost. These methods improve overall soil health and crop yields. These methods also ensure the environmental safety and food security [16].

Table 7 Effect of *Spirulina* supplementation on % potassium in post-harvest soil of experimental plants

Experimental methods	Potassium (mg/g)		
	A	G	T
Time period soaking	77.5 ± 0.70 (O.N)	150 ± 0.70 (3 h)	184 ± 2.10 (3 h)
Soaking in different concentration	86.5 ± 0.70 (20 g)	78 ± 1.41 (20 g)	77.5 ± 0.7 (5 g)
S + Biofertilizer	89.0 ± 0.70 (in control)	208 ± 1.41 (75:25)	180 ± 0.7 (25:75)
S + Vermicompost	103 ± 0.70 (25:75)	166 ± 4.24 (25:75)	128 ± 0.7 (75:25)
S + Organic manure	76.0 ± 2.12 (in control)	125 ± 2.12 (in control)	153 ± 4.2 (in control)
S + Chemical fertilizer	82.5 ± 0.70 (25:75)	94 ± 1.41 (25:75)	98 ± 0.7 (25:75)
Spray method	65.5 ± 0.70 (50 g/5L)	103 ± 0.70 (100 g/5L)	64 ± 0.70 (50 g/5L)

A Amaranthus; *G* Green gram, *T* Tomato

3.2 Figures

The Fig. 1 helps to detect the increase in % nitrogen in *Amaranthus*, Green gram and Tomato plants as a comparison. High % of nitrogen is observed for *Amaranthus* among 3 plants and was found in experimental method *Spirulina* + vermicompost.

The Fig. 2 describes the % increase of phosphorus compared among three experimental plants. High amounts of phosphorus among 3 plants were observed in Amaranthus in *Spirulina* + organic manure method. Figure 3 is about effect of *Spirulina*

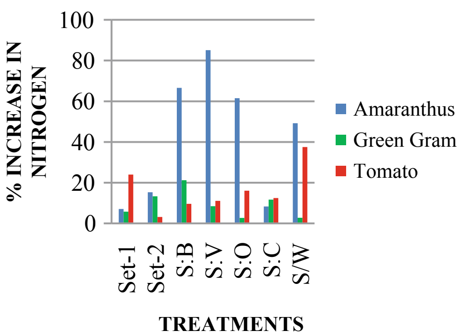

Fig. 1 Percent increase in nitrogen of *Amaranthus*, green gram and tomato by supplementation of *Spirulina* when compared with control *Set-1 Time period soaking, Set-2 Soaking in different concentrations of *Spirulina*, S:B—*Spirulina*: Biofertilizer, S:V—*Spirulina*: Vermicompost, S:O—*Spirulina*: Organic manure, S:C—*Spirulina*: Chemical Fertilizer, S/W—*Spirulina*/Water

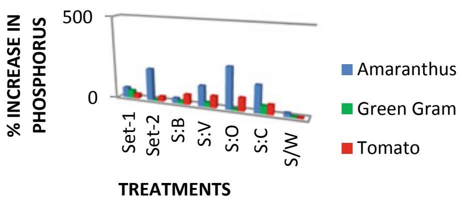

Fig. 2 Percent increase in phosphorus of *Amaranthus*, green gram and tomato by supplementation of *Spirulina*when compared with control *Set-1 Time period soaking, Set-2 Soaking in different concentrations of *Spirulina*, S:B—*Spirulina*: Biofertilizer, S:V—*Spirulina*: Vermicompost, S:O—*Spirulina*: Organic manure, S:C—*Spirulina*: Chemical Fertilizer, S/W—*Spirulina*/Water

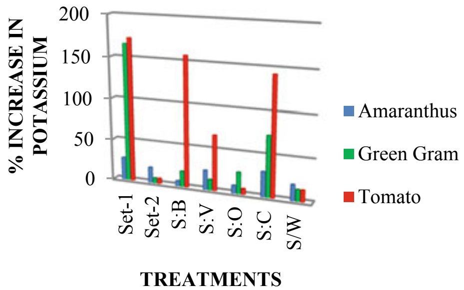

Fig. 3 Effect of *Spirulina* supplementation on potassium of *Amaranthus*, green gram and tomato yield when compared with control *Set-1 Time period soaking, Set-2 Soaking in different concentrations of *Spirulina*, S:B—*Spirulina*: Biofertilizer, S:V—*Spirulina*: Vermicompost, S:O—*Spirulina*: Organic manure, S:C—*Spirulina*: Chemical Fertilizer, S/W—*Spirulina*/Water

on 3 experimental plants in increasing the potassium levels by different experiment methods. High % of potassium was found in tomato plants in 5 h soaking method.

The growth periods of three types of plants used in the experiment were different. Here, only the influence on nutrient status in pre and post experimental treatments in crops and soil were discussed due to difference in growth, morphology, fruit and time of harvest and yields. This can be evident by evaluation of NPK in 3 plants as given in Figs. 1, 2 and 3. The experimental crops were compared with controls.

4 Conclusion

The overall outcome of the experiment evaluated was the nutrient profile of crops and postharvest soil with the use of *Spirulina* and other fertilizer combinations and their role in increasing the mineral status. The NPK had shown increase in overall growth of morphological parameters of plants and also maintained the soil fertility. The total increase in growth of plants also results in increase of nutrient content in the plants. In the field study the supplementation of *Spirulina* through different methods and also in combination with other biofertilizers, vermicompost, organics manure and chemical fertilizers had been used. The synergistic effect of these combinations had shown significant impact on the growth of plants. The soil supplementation of *Spirulina platensis* to plants had improved the soil mineral content. The increased soil phosphorus and potassium had greatly influenced the availability of iron and zinc to the plants. The soil nitrogen influenced the protein content in the plants and also the concentration of pigments like chlorophyll has been increased.

The NPK levels in the soils were increased due to the supplementation of *Spirulina* to the soil and in turn resulted in the overall growth and enhanced the minerals levels in the crops. The potassium is much required for water movement and stomatal movement in the leaves. Thus increased potassium levels helped the crops to uptake sufficient waters and also zinc by foliar application results in good overall growth of plants. This was evident by previous studies in which *Spirulina* application has increased the zinc levels in plants [17].

With the observed results, it can be concluded that *Spirulina platensis* is not only a simple protein supplement, but it can be a good biofortification agent to crops to enhance their mineral nutrient status. Further, this can be proved by complete bioavailability studies and molecular studies. Finally, the present study proves the efficiency of *Spirulina platensis* as a biofortification agent as it has enhanced the mineral nutrient level in the yield of all the three crops and also improves the soil fertility.

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