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Effect of Frequency and Rate of Zinc Application on Nodulation, Chlorophyll Content, Yield, and Quality of Soybean Grown in a Vertisol of Jabalpur, Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Zinc (Zn) fertilizer is commonly used in nutrient intensively cultivated deficient soils of central, India. Zn is a structural components of plants. However, little is known, on optimum dose of Zn especially in a vertisol of Jabalpur district. This study was required to find out Zn dose for sustainable productivity and maintenance of soil fertility. The study comprised of three frequency levels, Zn application in 1st year only, Zn application in alternate year, and Zn application in every years and five rates of Zn, (0, 2.5, 5.0, 7.5, and 10.0 kg Zn ha^{-1}) was applied in *Kharif* season. The result of analysis revealed that the highest symbiotic traits *viz.,* nodule number of 36.78, fresh and dry weight (1.09 and 0.31 g $plant^{-1}$) were found with application of 5 kg Zn ha^{-1} at 45 DAS at alternate year. The highest SPAD score of 44.98 and relative water content of 62.41 % was recorded with 5 kg Zn

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ha^{-1} at 60 DAS and found significant at alternate year. The Zn addition @ 5.0 kg ha^{-1} through $ZnSO_4.7H_2O$ to soybean in alternate year which increased by 1.28 to 1.53 (19.53 %) over only single year Zn addition. This was the best practice in a typic haplusterts as it resulted in an average production of 1.54 t ha^{-1} of seed yield ha^{-1} over no zinc application (1.24 t ha^{-1}) which increased by 24.19 %. The zinc application improved quality of seed in terms of oil and protein over control. So it was concluded that Zn application at alternate year and 5 kg Zn ha^{-1} for increasing yield and quality of soybean in a vertisol of Jabalpur district.

Keywords: Zinc fertilization; soybean; Vertisol; SPAD; nodulation; RWC.

1. INTRODUCTION

Soybean (*Glycine max* L.) is one of the most valuable food crops in oilseed cultivation scenario. It has high productivity and vital in maintaining soil fertility [1]. The crop fixes N up to 200 kg ha^{-1} $year^{-1}$ under optimal field conditions [2]. It is composed of 40 and 20 per cent protein and oil contributes globally [3]. In India, soybean accounts an area of 12.07 M ha with a production 13.98 m tonnes and productivity of 1158 kg ha^{-1}. Madhya Pradesh is the leading state with an area of 6.50 m ha with a production 4.61 m tonnes and productivity of 710 kg ha^{-1} (IISR, 2022). The yield of soybean is low due to nutrient deficiencies [4].

Zinc (Zn) is an important micronutrient for plants since it is involved in many key cellular functions such as metabolic and physiological processes, enzyme activation, and ion homeostasis [5,6]. Zn has an important role as a constituent of over 300 enzymes from all six enzyme classes. Despite its importance, Zn deficiency disrupts the basic operations of plant metabolism, causing growth retardation and leaf chlorosis, which can impair nutrient intake and eventually contribute to Zn deficiency in the human diet [7].

Zn deficiency is a serious problem in agricultural soils across the world. In India, soil zinc deficiency is estimated to be 49% [8]. The deficiencies were found to be even more severe (57%) in the soils of Madhya Pradesh India [9]. Its deficiency is becoming a severe agricultural concern, resulting in decreased crop output and nutritional quality [10]. Numerous factors negatively affect the available Zn in soils for plants, including low/total Zn contents, high pH >7, low redox potential, prolonged flooding, microbial communities in the rhizosphere, high organic matter, high calcium carbonate and bicarbonate contents, high iron/manganese oxide contents, high exchangeable magnesium/calcium ratio, high sodium and phosphorus availability [11,12]. Nowadays, zinc fertilizer used for quality food production globally. However, knowledge about proper application time and rates of Zn fertilizers is necessary to obtain higher crop production.

2. MATERIALS AND METHODS

2.1 Location and Treatment of Experiment

A field experiment was conducted at Research Farm of Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur (M.P.) during *Kharif* season of 2016. The research site was situated at 23° 13´ North latitude and at 79°57´ East longitudes in the South-East part of Madhya Pradesh at an elevation of 393 meters above mean sea level. The experiment consisted of frequencies of Zn application as main treatment (single year application: Zn applied during *Kharif* 2012; alternate year application: Zn applied during *Kharif* 2012, 2014 and 2016 and each year application: Zn applied during *Kharif* 2012, 2013, 2014, 2015 and 2016) and five levels of Zn (0, 2.5, 5, 7.5 and 10 kg ha^{-1} as sub treatments. Zinc sulphate was used as Zn source were applied to soybean. These fifteen treatments randomly allocated in split plot design with three replications. The basal dose of 20 kg N, 80 kg P_2O_5 and 20 kg K_2O ha^{-1} was applied to soybean crop at the time of sowing. Soybean variety (JS-9752) was sown at 40 cm row to row distance at the rate of 100 kg seed ha^{-1}.

2.2 SPAD Reading

The SPAD-502 a hand-held chlorophyll meter was used for rapid and non-destructive estimation of chlorophylls in leaves. The mean of three readings from the portable chlorophyll meter was recorded for different treatment of soybean leaf. This instrument uses a silicon photo-iodide to detect transmittance of light emitted by two light emitting diodes through a leaf sample, one with peak emittance 650 nm where absorbance by chlorophylls is high and relatively unaffected by carotene and one with peak emittance at 940 nm where absorbance by chlorophyll content index was recorded in upper 4th and 5th leaf at 30, 45 and 60 DAS.

2.3 Relative Water Content % (RWC)

At the mid of flowering, heading and grain filling stages, the flag leaves of plants were selected for measuring the relative water content. Weight of fresh tissue of flag leaves was measured just after detached from the plants then taken turgid weight after leaf was incubated in distilled water for 24 h to obtain a full turgidity. Dry weight of leaf was measured after it was dried at 60°C for 24 h in an oven.

RWC (%) = [(FW − DW)/ (TW − DW)] ×100, where, RWC, FW, DW and TW are relative water content, fresh weight, dry weight and turgid weight, respectively.

2.4 Symbiotic Traits

Nodulation study was done by uprooting three plants per plot by placing notch at 30, 45 and 60 DAS. The rhizosphere soil was washed in the running water and no. of nodules per plant was counted. Fresh weight of nodules was recorded and kept in small paper bags then kept in hot air oven at temperature of 70 ± 2˚C for 24 hours (till constant weight) to record their dry weight.

2.5 Yield Attributes and Yield

Observation of five plants were taken for no of pods per plant. The grain yield was subtracted from bundle weight for obtaining the stover yield.

2.6 Quality of Seed Determination

All samples of seeds were ground to a fineness that provided maximum homogeneity and minimum sampling variation. Protein and oil concentrations were determined in whole grain samples method (Kjeldahl and Soxhlet extraction unit).

2.7 Statistical Analysis

Analysis of variance and mean comparisons were performed with excel in MS Office. The main effects and interactions were tested using the least significant difference (LSD) test at 0.05 probability level.

3. RESULTS AND DISCUSSION

3.1 Growth, SPAD and RWC

3.1.1 Plant height

The results of analysis of variance for plant height is presented in Table 1. The table showed that frequency of Zn application and doses of Zn showed non-significant different on plant height measured at 30 DAS. Only, Zn applied each year increased plant height significantly but it was at par with Zn application alternative years at 45 and 60 DAS. At 60 DAS, plant height was observed to be 44.21 cm with single year application of Zn which significantly increased to 46.26 cm and 46.18 cm with alternate and each year Zn application, respectively.

At 30 DAS, the height of plant was increased significantly up to 7.5 kg Zn ha^{-1} application which varied from 25.22 cm at control to 28.28 cm at 7.5 kg Zn ha^{-1}. The levels of Zn @ 2.5, 5.0, 7.5 and 10 kg Zn ha^{-1} significantly superior over control but among themselves they were statistically at par. At 45 DAS, height of plant increased significantly with the application of Zn up to 7.5 kg Zn ha^{-1}. It varied from 39.19 cm at control to 44.28 cm at 7.5 kg Zn ha^{-1}. However, levels of Zn were statistically at par among themselves at 45 and 60 DAS. The plant height was also increased significantly with the increasing levels of Zn over control at 60 DAS. The lowest height 42.11 cm was observed at control and maximum height 47.19 cm was observed at 7.5 kg Zn ha^{-1}. The application of 7.5 kg Zn ha^{-1} also showed its superiority over control and 2.5 kg Zn ha^{-1} rest of treatment. During advanced growth stages, the control plot was unable to fulfill the need of nutrients by the crop; which resulted in production of the shortest plants. The deficiency of Zn was limited growth [13]. But other treated plots might be able to fulfill the minimum need of nutrients by the crop, hence they produced plants of identical or more height. Zinc is required as structural and catalytic components of protein and enzymes for normal growth and development [14]. Application of Zn has been reported significant positive effects, on growth by 50% in soybean [15].

3.1.2 SPAD reading

The maximum SPAD value was recorded with alternate year Zn application which was

Table 1. Effect of zinc application on plant height, SPAD and relative water content in leaves of soybean

Treatment		Plant height (cm)			SPAD value			RWC (%)
		30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	
Frequencies								
F1 (Single)		27.19	41.37	44.21	35.29	36.19	42.17	59.39
F2 (Alternate)		27.59	42.48	46.26	37.46	39.44	44.92	61.01
F3 (Each)		27.01	44.28	46.18	37.38	38.24	44.74	60.16
SEm±		**1.048**	**0.473**	**0.408**	**0.513**	**0.6**	**0.577**	**0.279**
CD(P=0.05)		**NS**	**1.858**	**1.603**	**2.015**	**2.358**	**2.269**	**1.097**
Zn Levels (kg ha^{-1})								
0		25.22	39.19	42.11	35.68	36.51	41.17	54.25
2.5		27.26	42.87	45.61	36.17	37.92	43.94	61.98
5		28.15	43.66	46.48	37	38.29	44.98	62.41
7.5		28.28	44.28	47.19	36.98	38.11	44.87	60.43
10		27.39	43.56	46.35	37.73	38.96	44.75	61.86
SEm±		**0.48**	**0.586**	**0.523**	**0.452**	**0.394**	**0.591**	**0.558**
CD(P=0.05)		**1.371**	**1.675**	**1.493**	**1.29**	**1.125**	**1.689**	**1.595**
FXZn*	SEm±	**0.831**	**1.016**	**0.905**	**0.782**	**0.682**	**1.024**	**0.967**
	CD(P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
FXZn**	SEm±	**2.224**	**1.311**	**1.149**	**1.241**	**1.346**	**1.474**	**1.029**
	CD(P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

**Comparison of Two Zn levels at the same frequency.* RWC – Relative Water Content *NS – Non-Significant*
***Comparison of Two frequencies at the same or different levels of Zn.*

Table 2. Effect of zinc application on symbiotic traits of soybean

Treatment		**No. of nodule plant^{-1}**			**NFW plant^{-1} (g)**			**NDW plant^{-1} (g)**		
		30 DAS	**45 DAS**	**60 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**30 DAS**	**45 DAS**	**60 DAS**
Frequencies										
F1 (Single)		10.67	32.02	29.98	0.324	0.972	0.835	0.122	0.3	0.276
F2 (Alternate)		11.37	34.84	31.16	0.352	1.048	0.897	0.125	0.308	0.281
F3 (Each)		11.31	34.53	30.84	0.324	1.001	0.879	0.125	0.308	0.278
SEm±		**0.248**	**0.304**	**0.203**	**0.0086**	**0.0079**	**0.0114**	**0.0008**	**0.0016**	**0.0014**
CD(P=0.05)		**NS**	**1.195**	**0.797**	**NS**	**0.0312**	**0.0446**	**NS**	**0.0064**	**0.0057**
Zn Levels (kg ha^{-1})										
0		9.28	28.56	28.63	0.315	0.886	0.803	0.121	0.296	0.271
2.5		10.85	31.56	29.63	0.319	0.973	0.853	0.123	0.304	0.277
5		12.07	36.78	32.26	0.34	1.099	0.92	0.126	0.31	0.283
7.5		11.48	36.41	31.26	0.349	1.029	0.9	0.125	0.309	0.281
10		11.89	35.7	31.52	0.344	1.048	0.877	0.123	0.307	0.28
SEm±		**0.256**	**0.545**	**0.332**	**0.0073**	**0.0135**	**0.0167**	**0.0009**	**0.0017**	**0.0016**
CD(P=0.05)		**0.73**	**1.557**	**0.949**	**0.0209**	**0.0385**	**0.0476**	**0.0025**	**0.0049**	**0.0046**
FXZn*	SEm±	0.443	0.944	0.575	0.0126	0.0234	0.0289	0.0015	0.003	0.0028
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FXZn**	SEm±	0.635	1.041	0.655	0.0207	0.0262	0.0344	0.0021	0.0042	0.0038
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

**Comparison of Two Zn levels at the same frequency. **Comparison of Two frequencies at the same or different levels of Zn.*
NFW – Nodule Fresh Weight, NDW – Nodule Dry Weight, NS – Non Significant T

Table 3. Effect of zinc application on yield attributes, yield and quality

Treatment		No. of pods plant^{-1}	Test weight (g)	Yield (t ha^{-1})		Seed quality (%)	
				Seed	Stover	Oil	Protein
Frequencies							
F1 (Single)		65.73	7.62	1.28	2.84	18.25	37.95
F2 (Alternate)		68.55	7.87	1.53	3.43	19.3	39.34
F3 (Each)		68.81	7.79	1.48	2.96	19.71	39.26
SEm±		**0.41**	**0.036**	**0.042**	**0.099**	**0.257**	**0.32**
CD(P=0.05)		**1.613**	**0.143**	**0.167**	**0.388**	**1.012**	**1.25**
Zn Levels (kg ha^{-1})							
0		61.57	7.5	1.24	2.61	18.03	37.43
2.5		67.08	7.74	1.41	3.19	19.02	38.89
5		71.57	8.01	1.54	3.28	19.94	39.39
7.5		69.29	7.82	1.47	3	19.88	39.53
10		68.98	7.78	1.46	3.19	19.73	39.76
SEm±		**0.502**	**0.097**	**0.042**	**0.13**	**0.169**	**0.257**
CD(P=0.05)		**1.435**	**0.278**	**0.12**	**0.372**	**0.482**	**0.735**
FXZn*	SEm±	**1.468**	**0.168**	**0.073**	**0.87**	**0.292**	**0.446**
	CD(P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
FXZn**	SEm±	**1.702**	**0.167**	**0.107**	**1.131**	**0.577**	**0.755**
	CD(P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

**Comparison of Two Zn levels at the same frequency. NS – Non-Significant*
***Comparison of Two frequencies at the same or different levels of Zn.*

significantly higher than single and each year of Zn application at 30, 45 and 60 DAS. Significantly maximum content of chlorophyll (37.00, 36.98 and 37.73) was exhibited by the application of 5.0, 7.5 and 10.0 kg Zn ha^{-1}, respectively at 30 DAS. However, the highest SPAD value (44.98) was noted under the application of 5.0 kg Zn ha^{-1} which was statistically at par with the levels consisting 2.5, 7.5 and 10 kg Zn ha^{-1} at 60 DAS. Result showed increased with the advancement of crop age and reached its peak at general flowering stage (60 DAS). Significant elevation due to treatment was observed over control at 45 and 60 DAS.

Zn maintains chlorophyll synthesis through sulphydryl group protection, a function primarily associated with Zn. The lowest SPAD reading of 35.68, 36.51 and 41.17 was recorded in control at 30, 45 and 60 DAS, respectively. The increased chlorophyll contents may be associated with zinc which acts as a structural and catalytic component of proteins, enzymes and as co-factor for normal development of pigment biosynthesis [16]. The reduction of SPAD value was probably related to the enhanced activity of the enzyme chlorophyllase and inducing the destruction of chloroplast structure and the instability of pigment protein complex. Zinc deficiency can cause a drastic decrease in chlorophyll content as well as a severe damage to the fine structure of chloroplasts [17] and promotes chlorosis of leaves [18].

3.1.3 Relative water content (RWC %)

The highest RWC % was recorded with an alternate-year Zn application but could not significantly increase. Treatment 5.0 kg Zn ha^{-1} possessed the highest RWC% (62.41) but it was at par with 2.5 and 10 kg Zn ha^{-1}. The interaction between frequencies and levels of Zn was non-significant. Sharma et al., 1995 observed a decrease in the K^+ content of guard cells in non-zinc application plants. Zinc may participate in stomatal regulation due to its role in maintaining membrane integrity. Silva et al. [19] stated that these parameters decrease in most plants under water deficit. A decrease in RWC in plants under drought stress may depend on plant vigor reduction and have been observed in many plants [20]. The decrease in leaf relative water content could be related to low water availability under stress conditions or to root systems, which are not able to compensate for water lost by transpiration through a reduction of the absorbing surface. The amelioration role of Zn in maintenance of relative water content might be attributed to improvement of vascular tissue [21].

3.2 Symbiotic Traits

3.2.1 Nodule number $plant^{-1}$

The number of nodules was significantly affected due to treatment but the interaction was found to be statistically non-significant. At 30 DAS, alternate year Zn application was found statistically non-significant while, at par with each year and it produced significantly higher nodule at 45 and 60 DAS over single year application. The lowest number of nodules was observed to be 10.67, 32.02 and 29.98 with single year Zn application at 30, 45 and 60 DAS, respectively. The no of nodules significantly increased to 34.84 and 34.53 with alternate and each year application of Zn at 45 DAS. Similarly, no of nodules increased to 31.16 and 30.84 with alternate and each year application at 60 DAS but both the frequencies were found to be on par at 45 and 60 DAS.

The maximum number of nodules $plant^{-1}$ was found at 45 DAS thereafter showed decline at 60 DAS. At 30 DAS, the application of 2.5 kg Zn ha^{-1} bring significant enhancement in nodule number over control but it was also at par with 7.5 kg Zn ha^{-1}. The number of nodules, increased significantly due to application of 5.0, 7.5 and 10 kg Zn ha^{-1} over control and 2.5 kg Zn ha^{-1} at 45 and 60 DAS. Furthermore, the application of 5 kg Zn ha^{-1} produced the highest mean nodule number (36.78) which was closely followed by 7.5 kg Zn ha-1 (36.41) and 10 kg Zn ha^{-1} (35.70) at 45 DAS and these were at par among themselves.

3.2.2 Nodule fresh weight (g $plant^{-1}$)

The fresh weight of nodules was observed to be 0.32 g with single year application of Zn which was non-significant at 30 DAS but at 45 and 60DAS it was significantly increased to 1.048 g and 0.897 g with alternate year application of Zn. Alternate and each year were found to be statistically at par at 60 DAS but at 45 DAS each year Zn application was non-significant.

At 30, 45 and 60 DAS, the highest nodule fresh weight was observed to be 0.34, 1.09 and 0.92 g $plant^{t-1}$ respectively with of 5 kg Zn ha^{-1} application. Fresh weight of nodules increased significantly with the level of 5.0, 7.5 and 10 kg

Zn ha^{-1} at 30 DAS over control. However, At 45 and 60 DAS all the Zn levels were recorded significantly higher nodule fresh weight over control but 5.0, 7.5 and 10 kg Zn ha^{-1} were statistically at par at 45 DAS. The levels of 5.0 and 7.5 kg Zn ha^{-1} produced identical at 60 DAS.

3.2.3 Nodule dry weight (g $plant^{-1}$)

Each year, Zn applications could bring about only numerical rise in nodule dry weight over the control, but it was statistically non-significant at 30 DAS. The alternate-year Zn application produced significantly higher nodule dry weight at 45 and 60 DAS than single -year Zn application. However, alternate and each-year of Zn application showed similar fresh weight. The nodule dry weight $plant^{-1}$ at 30, 45 and 60 DAS was significantly affected by the increasing levels of Zn. At 30 DAS, not much difference was recorded in dry weight of nodules but with the advancement of crop ages it was increased and the highest with 7.5 kg of Zn ha^{-1} (0.310 g $plant^{-1}$) and 5.0 kg Zn ha^{-1} (0.283 g $plant^{-1}$) application at 45 and 60 DAS, respectively. Yet these levels were at par with just higher and lower levels of Zn.

The data on symbiotic traits of soybean indicated that nodule number, fresh and dry weight of nodules increased progressively at 30 and 45 DAS, but the decline was noted at 60 DAS. This variation observed in soybean seems to be due to decay of nodular tissues at pod formation stage. The decline in quantity of nodule leghaemoglobin is logical as the nodules formed on the plant root system start decaying with the initiation of podding in the leguminous crops.

Zn is needed for chlorophyll formation, nodulation, growth hormone stimulation, lipid and protein metabolism, carbohydrate synthesis, enzymatic activity and reproductive processes [22]. It plays a vital role in photosynthesis, synthesizing RNA and DNA, synthesis of auxins, nitrogen fixation and production of biomass. The findings are in agreement with those reported by Awlad et al. [23] Surywanshi et al. (2015); Kulhare et al. [24]; Lamptey et al. (2014) and Vollmann et al., [25] which showed that increasing level of zinc increased the number of nodules. symbiosis and nodulation.

3.3 Effect of Zn Application on Yield Attributes, Yield and Quality of Soybean

The data on various parameters, *viz.,* number of pods $plant^{-1}$, test weight (g), seed and stover yield (t ha^{-1}) and quality of soybean as influenced by the application of zinc, are presented in Table 3. The interaction effect between Zn levels and frequencies was found to be statistically non-significant.

3.3.1 Number of pods $plant^{-1}$

Data revealed that, the number of pods $plant^{-1}$ was observed to be 65.73 with single -year application of Zn which significantly increased to 68.55 and 68.81 with alternate and each-year application of Zn. However, alternate and each-year application of Zn were statistically on par. The number of pods $plant^{-1}$ was minimum (61.57) at control and maximum (71) at 5.0 kg Zn ha^{-1}. The treatments of 7.5 and 10 kg ha^{-1} levels were statistically at par but significant over control and 2.5 kg Zn ha^{-1}. Moreover, the application of 5 kg Zn ha^{-1} produced significantly higher pods $plant^{-1}$ than all treatments.

3.3.2 Seed test weight (g)

Data indicated that the seed test weight was observed of 7.62 g with single year application of Zn which significantly increased to 7.87 g and 7.79 g with alternate and each year application of Zn, respectively. However alternate and each year application of Zn were statistically on par. The interaction effect between Zn levels and frequencies was found to be statistically non-significant. Seed test weight increased significantly with 5.0, 7.5 and 10 kg Zn ha^{-1} application over control but these levels of Zn were statistically at par among themselves. Application of 2.5 kg Zn ha^{-1} application did not bring a significant increase in seed test weight but it was equal with higher levels. The minimum seed test weight was obtained with the control (7.50 g ha-¹) and the highest was found at 5 kg Zn ha^{-1} (8.01 g).

3.3.3 Seed and stover yield (t ha^{-1})

The data pertaining to the seed and stover yields of soybean have been presented in Table 3. The seed yield was observed to be 1.28 t ha^{-1} with single-year application of Zn, which significantly increased to 1.48 and 1.53 t ha^{-1} with each and alternate-year application of Zn, respectively. Alternate and each-year application of Zn were statistically equal. The interaction effect of Zn levels and their frequencies produced non-significant result. Seed yield due to different Zn levels varied from 1.24 t ha^{-1} (control) to 1.54 t ha^{-1} (5 kg Zn ha^{-1}). Significantly higher seed and stover yields (1.54 t ha^{-1} and 3.28 t ha^{-1}) were obtained with 5.0 kg Zn ha^{-1} application than control but on par with 7.5 and 10 kg Zn ha^{-1}. Zn applied in alternate years significantly increased the stover yield. However, single and each year application of Zn were statistically non-significant. Minimum stover yield 2.61 t ha^{-1} was obtained in control and maximum 3.28 t ha^{-1} with the application of 5 kg Zn ha^{-1}. Application of increasing levels of Zn significantly increased the stover yield of soybean over control but the increasing levels of Zn levels were found statistically at par among themselves for stover yield of soybean. The increase in yield may be attributed to beneficial effect of zinc on growth parameter yield attributing parameters, which finally reflected in increased both grain and straw yield. The similar result reported by Nandanwar et al., [26] reported that grain and straw yield of soybean increased significantly with Zn 5.0 kg Zn application as compared to control. Pable et al. [27] reported that zinc application increased the grain and straw yield of soybean over control. Similar results have been also reported by Kanase et al. [28] Kulhare et al. [24]. Application of Zn has been reported significant positive effects, on growth dry matter production by 50% in soybean [15,29].

3.3.4 Quality of seed of soybean

The data given in Table 3 on the protein and oil content of the seed were statistically equal at 39.34% and 39.26% and 19.30% and 19.71%, respectively, with Zn applied alternately and annually. The oil content was observed to be 18.25% with single year application of Zn which significantly increased with alternate and each year application of Zn. However, it significantly increased with increasing Zn levels over control. The highest protein content in seed, 39.76% was analyzed with application of 10 kg Zn ha^{-1}. Yet it was on par with 7.5 and 5 kg Zn ha^{-1}. The increasing levels of Zn significantly increased the oil content in seed over control and 2.5 kg Zn ha^{-1}. The minimum oil content of 18.03 % was found at control and maximum of 19.94 % was found at 5 kg Zn ha^{-1}. The interaction effect was found to be statistically non-significant. According to Hafeez et al., [30] low Zn levels actually inhibit the synthesis of RNA and proteins since Zn plays a significant role in several enzymes that are essential for protein synthesis, including glutamate dehydrogenase, ATPase, and ribonuclease. Zn deficiency causes the ribosomes to break down, which affects protein metabolism [31]. These findings were in accordance with Krishna [32] and Zeng et al., [10] who also reported a significant positive effect of zinc treatment on crude protein content [33-35].

4. CONCLUSIONS

Zn application at alternate year and 5 kg Zn ha^{-1} was observed positively significant on SPAD value and RWC per cent. The alternate year and 5 kg Zn ha^{-1} application showed significantly higher response with respect to plant height, symbiotic traits and yield attributes over the control. Zn application at alternate year increased seed yield by 19.53% over single year and 5.0 kg Zn ha^{-1} Zn application significantly increased seed yield by 24.19 % over control (1.24 t ha^{-1}). So it was recommended that Zn application at alternate year and 5 kg Zn ha^{-1} for increasing yield and quality of soybean in a vertisol of Jabalpur district.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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