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OPTIMIZATION OF COBALT AND NITROGEN FOR IMPROVING SEED YIELD, PROTEIN CONTENT AND NITROGEN USE EFFICIENCY IN MUNGBEAN

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ABSTRACT

Background Cobalt (Co) is a beneficial element involved in the synthesis of vitamin B_{12} in pulses while, nitrogen (N) is essential for pulses because it is the major component of amino acids and proteins. There was a need to evaluate the combined effect of Co and N application on grain yield and quality of mungbean (*Vigna radiata* L.).

Methodology Field experiment consisting of four levels of cobalt sulfate (0, 0.04, 0.09, 0.14 kg ha^{-1}) and three N levels (0, 12.5, 25.0 kg ha^{-1}) was conducted to evaluate their effects on mungbean growth and yield. The experiment was laid out in a randomized complete block design with the factorial arrangement. Mungbean variety NIAB-Mung 2011 was used as a test crop.

Results Significantly ($p \leq 0.05$) the maximum number of nodules $plant^{-1}$ (12.33), pods $plant^{-1}$ (32.83), seeds pod^{-1} (12.83), seed yield (1303 kg ha^{-1}), protein (25.96%) and Co contents (108.97 ppb) were recorded in the mungbean plants supplied with cobalt sulfate @ 0.14 kg ha^{-1} and N 25 kg ha^{-1}. Maximum agronomic N use efficiency (34.64%) was recorded with the application of cobalt sulfate @ 0.14 kg ha^{-1} and N 12.5 kg ha^{-1} while, physiological N use efficiency (18.6-20.6%) was same at both levels of N (12.5 and 25 kg ha^{-1}) application with cobalt sulfate levels of 0.04-0.09 kg ha^{-1}. Further increase in the level of cobalt sulfate decreased the physiological N use efficiency.

Conclusion Integrated application of cobalt sulfate @ 0.14 kg ha^{-1} and N 25 kg ha^{-1} proved to be the best for improving the grain yield, protein content and N use efficiency of mungbean

INTRODUCTION

Mungbean (*Vigna radiata* L.) is one of the best pulse crops as a protein supplement in the world. It is also a well-known pulse crop of Pakistan. However, the average yield of mungbean in Pakistan is only 661.5 kg ha^{-1}, which is far below than its potential yield (1971 kg ha^{-1}) (Government of Pakistan 2013). Yield loss in mungbean may be due to many physiological and management factors that are responsible for plant growth and development. The use of high yielding cultivars and balanced fertilization are important factors to enhance the yield of mungbean. Quddus et al. (2011) reported that nutrient deficiency is a major factor of lower yield of pulses including mungbean. Among plant nutrients, nitrogen (N) is the most important element for all crops including legumes because it is an integral component of amino acids and proteins (Khan et al. 2016). Moreover, the legumes are more susceptible to micronutrients deficiency which significantly affects their production and quality (Kaisher et al. 2010).

Cobalt (Co) is not classified as an essential element, but it is usually described as beneficial (Young 1983). Cobalt is important for legume crops due to its role in vitamin B_{12} synthesis and to fix the atmospheric N (Basu et al. 2005; Gad et al. 2011). Vitamin B_{12} is required for the initiation of nodulation. The specific cobalamine dependent enzyme systems in *Rhizobium*, which may account for the influence of Co on nodulation and N-fixation, are methionine synthase, ribonucleotide reductase and methylmalonyl co-enzyme A mutase (Das 2000). The combination of Co and N had a positive effect on chlorophyll content, shoot growth, number of nodules, seed quality and N use efficiency (NUE) (Akbar et al. 2013). Increasing NUE and limiting the N fertilizer use are important challenges to preserve the environment, and

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improve the sustainable and productive agriculture (Daubresse et al. 2010). It has been reported that combined use of ammonium nitrate and Co increased the growth and concentration of N, phosphorus (P), potassium (K), manganese (Mn), zinc (Zn) and copper (Cu) in soybean leaves and seeds as well as oil and protein contents in seeds, and crop yield. However, Co concentration beyond 12 mg kg^{-1} had an adverse effect on plant growth (Kandil and El-Maghraby 2016). The addition of Co saved about 75 and 33.3% of inorganic and organic N fertilizer, respectively which helps in mitigation of soil contamination and reduces the input expenditure bear by farmers (Gad 2006). Keeping in view the above-mentioned facts, a field study was conducted to determine the interactive effect of N with Co on growth, yield, nutrient uptake and NUE in mungbean.

MATERIALS AND METHODS

Site description

For physico-chemical analysis of experimental soil, composite and representative soil samples to a depth of 0-30 cm were obtained with soil auger before and after the experiment. The soil was analyzed for its different chemical characteristics using the techniques as illustrated by Homer and Pratt (1961). The soil was analyzed for N, P, K and Co. The soil analysis report before sowing and after harvesting of mungbean is presented in Table 1 which indicated that Co was deficient in the soil. Nitrogen and Co doses for the production of mungbean were adjusted on the basis of this analysis. The weather data of crop season were obtained from the meteorological observatory, University of Agriculture Faisalabad situated approximately 150 m away from the experimental site. The weekly mean values of temperature, relative humidity, rainfall and pan evaporation are given in Figure 1.

Experimental detail

The experiment was conducted at the Agronomic Research Area, University of Agriculture Faisalabad, Pakistan. The treatments comprised of four cobalt sulfate levels i.e. 0 (control), 0.04, 0.09 and 0.14 kg ha^{-1} and three N levels i.e. 0 (control), 12.5 and 25.0 kg ha^{-1}. The experiment was laid out in randomized complete block design in a factorial arrangement with three replications using a net plot size of 5 m x 1.8 m. Mungbean variety NIAB-Mung 2011 was used as a test crop. The crop was sown in 30 cm apart rows using a seed rate 30 kg ha^{-1} with the help of hand drill and plant to plant distance of 10 cm was maintained by thinning. Nitrogen was applied as basal dose according to treatments. Phosphorus and potassium were applied at 57 and 62 kg ha^{-1} in the form of triple superphosphate and muriate of potash, respectively at sowing time. Cobalt sulfate was applied as a foliar spray at anthesis stage of mungbean. In addition to rainfall received during the whole growing period of the crop, a total of three irrigations were applied at different plant growth stages till the physiological maturity of the crop. First irrigation was applied 25 days after crop sowing while subsequent irrigations were applied at flowering and seed formation stages. Hand weeding was done twice during the experimental period (25 and 45 days after sowing) to keep the field free from weeds. At appropriate growth stage, when 90% of the pods were ripened and turned yellowish brown, the crop was harvested manually. The crop was sun dried for four days in the field and then threshing was done manually.

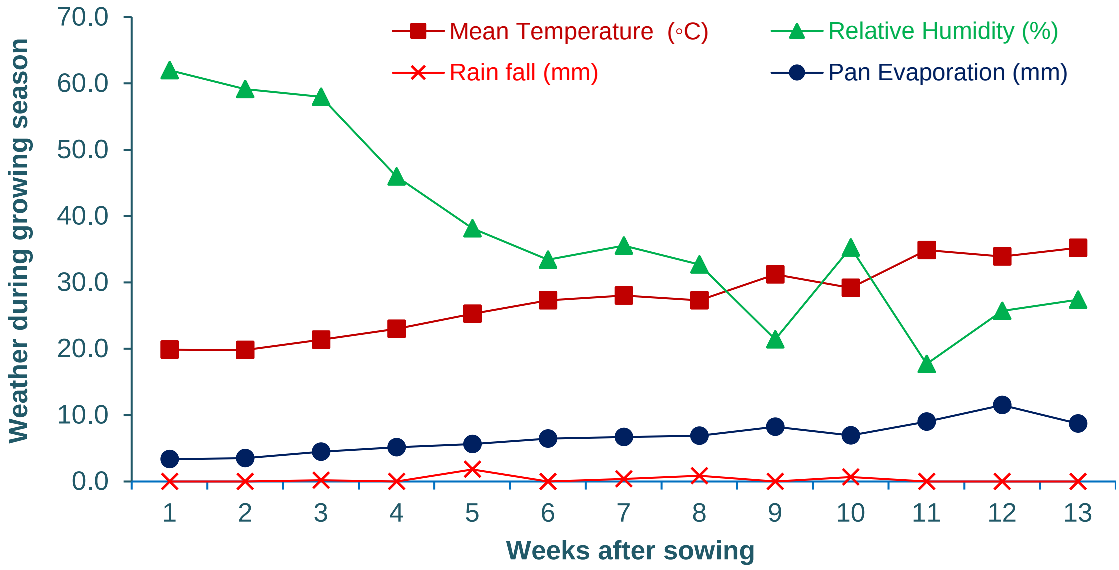

Figure 1 Weather data of mungbean growing season

Growth and yield related traits

To record the data of number of nodules plants^{-1}, three plants per plot were taken out by digging their roots and then washed with water to clean them. Nodules were counted manually and their average was calculated. Ten randomly selected plants at maturity were used to determine the number of pods per plant. The pods of all ten plants were removed by hands and then counted. Average was taken to get the number of pods per plant. The removed pods of ten randomly selected plants were used for calculating number of seeds per pod. The seeds from pods were removed by hand and seeds were counted using a seed counter. Total number of seeds was divided by total number of pods to get number of seeds per pod. Two samples of 1000-seed from each treatment were taken and their weight was recorded using an electric balance and then the average was computed to get 1000-seed weight. Randomly two samples (1 m^2) for grain yield were taken from each plot. Samples were sun-dried, threshed manually, and grain yield was recorded. The grain yield m^{-2} was converted to kg per hectare.

Table 1 Physico-chemical analysis of soil before sowing and after harvesting

Characteristics	**Soil analysis**	
	Pre-sowing	**Post-harvest**
Sand (%)	33.80	33.80
Silt (%)	34.00	34.00
Clay (%)	32.20	32.20
Textural class	Loam	
Saturation (%)	37	37
SAR (mmol L^{-1})$^{1/2}$	6.0	6.0
ESP	7.0	7.0
pH	8.0	8.0
EC (dS m^{-1})	1.2	1.2
Organic matter (%)	0.78	0.89
Total nitrogen (%)	0.048	0.60
Available P (mg kg^{-1})	8.8	9.2
Available K (mg kg^{-1})	130	135
$CaCO_3$ (%)	5.0	4.8
Available Co (%)	0.03	0.04

Seed nitrogen and protein content

One gram of oven dried plant material was taken in a digestion flask, 30 mL of concentrated H_2SO_4 and 5 g of digestion mixture [K_2SO_4: $FeSO_4$: $CuSO_4$ (20: 2: 1)] was added, and then the material was digested in a digestion chamber at 400 ˚C for 2-3 hours. The digestion mixture was cooled down and dilution was made with distilled water in 250 mL volumetric flask. Distillation was done taking 10 mL of diluted samples in Kjeldahl's apparatus and N evolved as NH_3 gas was collected in receiver containing 2% H_3BO_3 solution with mixed indicator and this was titrated against standard 0.1 N H_2SO_4 till golden yellow color (Barbano et al. 1990) Nitrogen percentage was calculated by following formula:

$$Nitrogen\ (\%) = \frac{(V1 - V2)N}{100\ w} \times 100 \times 14$$

Where
V1= Sample titration (mL)
V2= Blank titration (mL)
N= Normality of standardized H_2SO_4
W= 100 (sample weight) (g)

Then N% was multiplied by 6.25 to get crude protein percentage.

$$Crude\ protein\ (\%) = Nitrogen\ (\%) \times 6.25$$

Where 6.25 = Protein conversion factor

Leaf cobalt content

A 0.5 g sample of ground plant material was taken in 30-50 mL porcelain crucibles. Porcelain crucibles were placed in a cool muffle furnace and the temperature was increased gradually up to 550°C. Ashing was continued for 5 hours after attaining 550°C then muffle was shut off, the sample was taken out when cooled. The cooled ash was dissolved in 5 mL of 2 N hydrochloric acid and mixed thoroughly by a plastic rod. The digest was diluted, filtered through Whatman No. 42 filter paper and made up to 50 mL volume. The solution was directly aspirated to an Atomic Absorption Spectro-photometer, with air/ acetylene flame for estimating Co concentration in leaves of plants (Champan and Pratt 1961).

Plant nitrogen use efficiency

Agronomic and physiological NUEs were calculated by the following formulae:

$$Agronomic\ NUE = \frac{Grain\ yield\ F - Grain\ yield\ C}{Fertilizer\ nutrients\ applied}\ kgkg{-}1$$

Where
Grain yield F = Grain yield with N fertilizer application
Grain yield C = Grain yield of control plot (without N fertilizer application)

$$Physiological\ NUE = \frac{Grain\ yield\ F - Grain\ yield\ C}{N\ uptake\ F - N\ uptake\ C} kg\ kg{-}1$$

Where
Grain yield F = Grain yield with N fertilizer application
Grain yield C = Grain yield of control plot (without N fertilizer application)
N uptake F = Total N uptake with N fertilizer application
N uptake C = Total N uptake without N fertilizer application

Statistical analysis

All the data collected were analyzed statistically using Fisher's analysis of variance technique and least significant difference (LSD) test was used to compare differences among treatments means at 0.05 probability level (Steel et al. 1997).

RESULTS AND DISCUSSION

Number of nodules plant^{-1}

A higher number of nodules (11.83-12.33 plant^{-1}) was recorded in mungbean plants treated with higher dose of N (25 kg ha^{-1}) and nodules formation was increased with the increasing level of cobalt sulfate (Table 2). While, the lowest number of nodules was found in control (no application of fertilizer). Increase in number of nodules by Co application might be due to increased nitrogenase and leghaemoglobin contents that promoted nodulation in mungbean. Cobalt application reduced the ethylene production and inhibitory effect of nitrate on nodulation that increased the nitrogen fixation in mungbean (Jain and Nainawatee 2000). These results are supported by the findings of Gad (2012) who stated that cobalt sulfate significantly increased the number of nodules, nodule weight and its efficiency due to enhanced nitrogenase activity, especially with both 100 and 75% rich N fertilizers in groundnut crop. Moreover, significantly ($p \leq 0.05$) higher number and dry weight of nodules were observed when Co was applied at the rate of 0.21 kg ha^{-1}. Similar research findings were obtained by Gad (2006), Mohamed et al. (2011) and Gad et al. (2011).

Number of pods plant^{-1}

Number of pods $plant^{-1}$ is one of major yield contributing parameters which contribute towards final grain yield in legumes. The effect of different levels of cobalt sulfate and N on the number of pods $plant^{-1}$ of mungbean are shown by the data presented in Table 2. The results of the current study showed that interaction between Co and N was found significant for number of pods $plant^{-1}$. The application of cobalt sulfate and N at the rate of 0.14 kg ha^{-1} and 25 kg ha^{-1}, respectively gave the maximum number of pods $plant^{-1}$ (32.83) and it was statistically at par with that observed with the application of 0.09 kg ha^{-1} cobalt sulfate and 25 kg ha^{-1} N (31.47). The minimum number of pods $plant^{-1}$ (18.53) was recorded in control plot (no application of cobalt sulfate and N). Gad (2006) reported that Co application at 8 ppm increased the number of pods $plant^{-1}$ and also increased the uptake efficiency of inorganic N fertilizers (NH_4NO_3 and urea). The combination of Co, molybdenum (Mo) and N had an opposite effect on chlorophyll and number of pods $plant^{-1}$ of groundnut crop (Mohamed et al. 2011).

Number of seeds pod^{-1}

It is a key factor towards the yield of leguminous crops. The results concerning to the effect of different levels of cobalt sulfate and N on the number of seeds pod^{-1} of mungbean are presented in Table 2 which showed that this parameter was significantly influenced by cobalt sulfate and N interaction. The number of seeds pod^{-1} was increased with increasing level of cobalt sulfate and N. The highest number of seeds pod^{-1} (12.83) was observed in plots where cobalt sulfate and N were applied at the rate of 0.14 kg ha^{-1} and 25 kg ha^{-1}, respectively. The lowest number of seeds pod^{-1} (7.96) was recorded in the plot where cobalt sulfate was applied at the rate of 0.04 kg ha^{-1} and no N was applied. According to Hanan et al. (2012), the combined application of cobalt sulfate and N increased the number of seeds and thus yield of cowpea. Similar research findings were obtained by Pattanyak et al. (2000) on mungbean, Junior et al. (2008) on common bean and Gad et al. (2011) on tomato. The reason was that Co works as a cofactor of cobalamine (Vitamin B_{12}) which functions as a coenzyme in N_2 fixation and nodule growth (Licht et al. 1996; Jordan and Reichard 1998) and thus enhances the efficiency of N and other primary nutrients, leading ultimately to increase seeds per pod of mungbean.

1000-seed weight

The data pertaining to the effect of different levels of cobalt sulfate and N application on 1000-seed weight of mungbean are presented in Table 2 which showed the significant effect of treatments on the parameter under discussion. The maximum 1000-seed weight (70.87 g) was recorded with the application of cobalt sulfate and N at the rate of 0.14

Table 2 Interactive effect of cobalt sulfate and N levels on yield parameters of mungbean (*Vigna radiata* L.)

Treatments	Number of nodules $plant^{-1}$	Number of pods $plant^{-1}$	Number of seeds pod^{-1}	1000-seed weight (g)	Seed yield (kg ha^{-1})
N_0CS_0	5.10f	18.53i	6.77h	47.73f	678.30k
N_0CS_1	5.97f	20.27h	7.96g	52.57ef	712.30j
N_0CS_2	8.37e	21.50gh	8.43fg	57.70de	719.30j
N_0CS_3	10.10c	22.57fg	9.00ef	64.26bc	790.30h
N_1CS_0	8.63de	23.33f	9.97cde	62.50cd	742.30i
N_1CS_1	9.67cde	24.93e	9.83cde	65.33abc	888.00g
N_1CS_2	9.87cd	26.70cd	10.10cd	66.80abc	1044.0e
N_1CS_3	10.57bc	25.57de	10.83bc	70.87a	1111.30d
N_2CS_0	9.53cde	27.93bc	9.57de	67.37abc	980.3f
N_2CS_1	11.83ab	28.97bc	10.73bc	69.80ab	1177.00c
N_2CS_2	11.83ab	31.47a	11.63b	69.96ab	1234.00b
N_2CS_3	12.33a	32.83a	12.83a	66.30abc	1303.30a
LSD value	1.375	1.383	1.002	5.738	8.547

Means not sharing the same letters differ significantly at 5% probability level. N = Nitrogen levels (kg ha^{-1}), CS = Cobalt sulfate levels (kg ha^{-1}). N_0= N at 0.00 kg ha^{-1}, N_1= N at 12.5 kg ha^{-1}, N_2 = N at 25.0 kg ha^{-1}, CS_0= Cobalt sulfate at 0.00 kg ha^{-1}, CS_1= Cobalt sulfate at 0.04 kg ha^{-1}, CS_2= Cobalt sulfate at 0.09 kg ha^{-1}, CS_3= Cobalt sulfate at 0.14 kg ha^{-1}.

kg ha^{-1} and 12.5 kg ha^{-1}, respectively followed by application of cobalt sulfate and N at the rate of 0.09 kg ha^{-1} + 25 kg ha^{-1}. Barbo et al. (2009) reported that application of Co and Mo resulted in significant increase in seed weight in different cultivars of soybean. The enhanced seed weight by Co application might be the result of improved efficiency of macro and micronutrients uptake by the plants and thus vegetative and reproductive growth. Cobalt also reduced the titrate-able acidity which increased the seed weight (Gad 2005).

Seed yield

Nitrogen and cobalt sulfate application had significant interactive effects on seed yield of mungbean. Maximum mungbean seed yield (1303.3 kg ha^{-1}) was recorded in the plots treated with cobalt sulfate at the rate of 0.14 kg ha^{-1} and N at the rate of 25 kg ha^{-1} (Table 2). The minimum yield was observed in control plots. The results of the current study are supported by the findings of Gad (2006) that cobalt sulfate applied at the rate 8 ppm along with N fertilizer increased the number of pod-bearing branches, number of nodules and seed yield of pea plants. Kandil (2007) studied the influence of different levels of Co viz. 0, 5, 15 and 20 ppm on faba bean plants and revealed that greatest increase in growth, yield and nutrients uptake occurred by using 20 ppm Co. Junior et al. (2008) evaluated the efficiency of N-fixing inoculum associated with Co and Mo spray on the common bean grain yield and grain nutrients, and showed that Co and Mo spray at higher doses increased grain yield. Awomi et al. (2012) reported that P, Co and Mo fertilization is needed for proper growth, yield and quality of legumes.

Seed nitrogen content

The analyzed data showed that interaction of cobalt sulfate and N was non-significant while the individual effect of cobalt sulfate on N content (%) of mungbean was significant. The results showed that the highest level of cobalt sulfate and N gained the highest seed N content of mungbean (3.59 and 3.61%, respectively) (Table 3). These results are in harmony with those obtained by Kandil et al. (2013) who reported that Co is an essential element for the growth of rhizobium, the specific bacteria involved in legume nodulation and fixation of atmospheric N into amino acids in legumes. Cobalt enhanced the N_2 fixation process in legumes and consequently increased plant N content (Gad 2006). Cobalt is an essential element for legumes due to bacteria that live in root nodules and synthesize vitamin B_{12} which is required for the microorganisms fixing N in nodules and nitrogenase activity in mungbean (Basu et al. 2005).

Seed protein content

The results of the current study revealed that interaction of cobalt sulfate and N levels remained significant ($p \leq 0.05$) regarding protein contents of mungbean. The result revealed that increased level of cobalt sulfate and N increased the protein content of seed (Table 4). The maximum protein content (25.96%) was recorded with the highest level of cobalt sulfate (0.14 kg ha^{-1}) and N (25 kg ha^{-1}). Minimum protein content (14.88%) was recorded with control (no application of cobalt sulfate and N). Basu et al. (2005) reported that Co and N application improved protein content in groundnut. Another study on groundnut revealed that Co addition in plant media increased protein, total soluble solids, total carbohydrates and total soluble sugars in groundnut seeds (Gad 2012). According to Sarada and Polasa (1992), and Gad (2012), Co is an essential element for the growth of rhizobium that fixes atmospheric N into amino acids and N markedly increased seed proteins in legumes. Finally, Co is an essential element for legumes due to its requirement for the microorganisms fixing N in nodules and nitrogenase activity in mungbean. Therefore, Co application increased the grain protein content of mungbean in current study.

Leaf cobalt content

In our study, application of cobalt sulfate and N at the rate of 0.14 kg ha^{-1} and 25 kg ha^{-1}, respectively showed maximum Co content (108.97 ppb) in mungbean leaves and it was statistically at par with that observed with 0.14 kg ha^{-1} and 0.0 kg ha^{-1} of cobalt sulfate and N, respectively. While, the minimum Co contents (11.63 ppb) were recorded in control (no application of cobalt sulfate and N) treatment. The results obtained in the current study are in good agreement with those obtained by Gad et al. (2011). From these results, it could be concluded that increased Co levels in plant media increased Co content in mungbean plants compared with control.

Table 3 Effect of cobalt sulfate and N levels on seed N content of mungbean (*Vigna radiata* L.)

Treatments	N content (%)
Factor A: Cobalt sulfate levels	
CS_0	2.82d
CS_1	3.07c
CS_2	3.29b
CS_3	3.59a
LSD value ($p \leq 0.05$)	0.110
Factor B: Nitrogen levels (N)	
N_0	2.73c
N_1	3.25b
N_2	3.61a
LSD value ($p \leq 0.05$)	0.096

Means not sharing the same letters differ significantly at 5% probability level. N = Nitrogen levels (kg ha^{-1}), CS = Cobalt sulfate levels (kg ha^{-1}). N_0 = N at 0.00 kg ha^{-1}, N_1 = N at 12.5 kg ha^{-1}, N_2 = N at 25.0 kg ha^{-1}, CS_0 = Cobalt sulfate at 0.00 kg ha^{-1}, CS_1 = Cobalt sulfate 0.04 kg ha^{-1}, CS_2 = Cobalt sulfate at 0.09 kg ha^{-1}, CS_3 = Cobalt sulfate at 0.14 kg ha^{-1}.

Nitrogen use efficiency

Agronomic NUE (ANUE) is used to describe the capability of yield increase per kilogram N applied. The maximum ANUE (34.64 %) was recorded with the medium level of N (12.5 kg ha^{-1}) in combination with the highest level of cobalt sulfate (0.14 kg ha^{-1}). However, a further increase in N application rate in combination with all the three cobalt sulfate levels reduced ANUE (Table 4). A significant increase in physiological NUE (PNUE), the plant N uptake per unit of applied N occurred by Co application in response to increasing N level from 0 to 12.5 kg ha^{-1}. However, further increase in N application rate could not improve PNUE (Table 4). Even, the highest N dose (25 kg ha^{-1}) along with maximum cobalt sulfate level resulted in reduced PNUE. Maximum PNUE (20.63%) was observed with the application of cobalt sulfate at 0.04 kg ha^{-1} and N 25 kg ha^{-1}. Both N and Co increased the mass of nodulation and N fixation that increased the NUE. These findings have also been supported by Gad et al. (2011), Akbar et al. (2013), Gad (2013), and Kandil (2013). A previous study showed that Co treatments increased all the tested growth parameters, nutrient uptake and biochemical attributes in canola seeds as compared to control plants (Gad et al. 2011).

CONCLUSION

Application of cobalt sulfate at the rate of 0.14 kg ha^{-1} and N at 25 kg ha^{-1} is the best combination for obtaining higher grain yield of mungbean along with good protein content and increased NUE under the agro-climatic conditions of Faisalabad, Pakistan. This treatment also showed maximum benefit cost ratio of 2.03.

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Table 4 Effect of cobalt sulfate and N levels on protein contents, cobalt concentration and NUE of mungbean (*Vigna radiata* L.)

Treatments	Seed protein content (%)	Leaf Co content (ppb)	Agronomic NUE (kg kg^{-1})	Physiological NUE (kg kg^{-1})
N_0CS_0	14.88h	11.63i	0.00i	0.00d
N_0CS_1	16.92g	64.70g	0.00i	0.00d
N_0CS_2	17.79fg	89.21d	0.00i	0.00d
N_0CS_3	18.67ef	106.89ab	0.00i	0.00d
N_1CS_0	18.09fg	13.06i	5.12h	13.58c
N_1CS_1	19.55de	68.51f	16.77g	20.32a
N_1CS_2	20.71cd	92.23c	29.25b	20.06a
N_1CS_3	22.75b	105.13b	34.64a	18.58ab
N_2CS_0	19.84cde	12.60i	24.16d	19.39a
N_2CS_1	21.00c	58.51h	19.95f	20.63a
N_2CS_2	23.33b	82.98e	22.23e	18.59ab
N_2CS_3	25.96a	108.97a	25.00c	16.72b
LSD value	1.194	2.876	0.439	2.952

Means not sharing the same letters differ significantly at 5% probability level. ppb = parts per billion, N = Nitrogen levels (kg ha^{-1}), CS = Cobalt sulfate levels (kg ha^{-1}); N_0 = N at 0.00 kg ha^{-1}, N_1 = N at 12.5 kg ha^{-1}, N_2 = N at 25.0 kg ha^{-1}, CS_0 = Cobalt sulfate at 0.00 kg ha^{-1}, CS_1 = Cobalt sulfate at 0.04 kg ha^{-1}, CS_2 = Cobalt sulfate at 0.09 kg ha^{-1}, CS_3 = Cobalt sulfate at 0.14 kg ha^{-1}.

Table 5 Effect of cobalt sulfate and nitrogen levels on benefit cost ratio (BCR) of mungbean (*Vigna radiata* L.)

Treatments	Total expenditure (Rs. ha^{-1})	Total Income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	BCR
N0CS0	53599.0	61050.0	7451.0	1.13
N0CS1	54515.4	64110.0	9594.6	1.18
N0CS2	54945.5	64740.0	9794.5	1.18
N0CS3	55019.8	71130.0	16110.2	1.29
N1CS0	54625.0	66810.0	12185.0	1.22
N1CS1	55541.4	79920.0	24378.6	1.44
N1CS2	55971.0	93960.0	37989.0	1.68
N1CS3	56539.8	100020.0	43480.2	1.77
N2CS0	55670.0	88230.0	32560.0	1.58
N2CS1	56586.4	105930.0	49343.6	1.87
N2CS2	57016.5	111060.0	54043.5	1.95
N2CS3	57584.8	117300.0	59715.2	2.03

N = Nitrogen levels (kg ha^{-1}), CS = Cobalt sulfate levels (kg ha^{-1}); N_0 = N at 0.00 kg ha^{-1}, N_1 = N at 12.5 kg ha^{-1}, N_2 = N at 25.0 kg ha^{-1}, CS_0 = Cobalt sulfate at 0.00 kg ha^{-1}, CS_1 = Cobalt sulfate at 0.04 kg ha^{-1}, CS_2 = Cobalt sulfate at 0.09 kg ha^{-1}, CS_3 = Cobalt sulfate at 0.14 kg ha^{-1}.

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