

Effect of Different Slow Release and Controlled Release Fertilizers on Growth, Quality, Yield and Nutrient Uptake in Soybean

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Abstract

The field experiments were conducted at research farm, Department of Soil Science, VNMKV, Parbhani during kharif- 2019 and 2020 to study the response of soybean to different slow release and controlled release fertilizers on Vertisols. The design of the experiment was randomized block design with four replications and ten treatment combinations. The treatment consisted of absolute control, recommended dose of fertilizers through conventional fertilizers (urea, DAP, MOP and elemental S), combinations of slow release and controlled release fertilizers (CDU, SCU, Polymer coated DAP, Karanj oil coated DAP, Bentonite S and WDG-S) along with FYM. The significantly highest plant height, oil content, test weight, number of nodules per plant, fresh and dry weight of nodules was recorded in treatment with RDF through CDU + Polymer coated DAP + WDG of sulphur. The treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur recorded significantly highest number of pods, seed protein content. The leaf chlorophyll content was also significantly influenced as result of different slow release fertilizers at 20 DAS, 40 DAS and 60 DAS. The seed and straw yield of soybean was recorded significantly highest in treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur. The total nitrogen, phosphorus, potassium, sulphur uptake and micronutrient uptake (Fe, Mn, Zn and Cu) was recorded higher in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur. The use of slow release and controlled release fertilizer sources viz; CDU, Polymer coated DAP and Bentonite Sulphur/ WDG of Sulphur to soybean was found beneficial for obtaining higher yield, quality, nutrient uptake and growth attributes on Vertisol.

Key words : Slow release and controlled release fertilizers, Soybean, Growth, Quality, Yield, Nutrient uptake.

Soybean (*Glycine max* L. Merrill) is world's very important leguminous seed crop contributing 25 percent need of oil globally and two - third supply of protein concentrates for feeding livestock (Agarwal *et al.*, 2013). It is at top among seed legumes as it is major source protein and oil with Omega 6 and Omega 3 poly-unsaturated fatty acids (Verma *et al.*, 2015). Production of soybean in India is dominated by Maharashtra and Madhya Pradesh contributing 89 per cent of total production. Andhra Pradesh, Rajasthan, Chhattisgarh, Karnataka and Gujarat contribute rest of 11 per cent production. The area of soybean in India is 12.27 million ha, production is 12.99 million ton with average productivity 1,059 kg ha⁻¹ (Anonymous, 2022), whereas world's area,

production and productivity of soybean is 139.4 million ha, 398.2 million ton and 2,860 kg ha⁻¹, respectively (Elena Volkova and Natalia Smolyaninova, 2024). The area, production and productivity of Maharashtra is 4.69 million ha, 5.47 million tons and 1,168 kg ha⁻¹, respectively (Anonymous, 2022). Soybean still suffers many constraints despite made rapid stride for total production and area coverage.

For leguminous oil seeds like soybean, the nutrients, which deserve attention from fertilizer management point of view, are phosphorus, sulphur, calcium and zinc, as these crops can meet a large part of their nitrogen needs through biological nitrogen fixation. Efficient fertilizer application is critical to crop

production, ecological advantages and economical benefit (Ohyama *et al.*, 2017). A major drawback of conventional fertilizer is their fast dissolution in soil compare to their absorptivity by crops. Consequently, water runoff results in loss of fertilizers nutrients and contamination of environment around us. In order to improve the efficiency of inorganic fertilizers and minimize the loss of nutrients supplied by them, many researchers focusing on development of slow release fertilizers (SRF) or controlled release fertilizers (CRF), AlShamaileh *et al.*, (2017). Use of slow release fertilizers (SRFs) or controlled release fertilizers (CRFs) can increase nutrient use efficiency, minimize nutrient losses and protect the environment. Thus, use of SRFs or CRFs considered being a Best Management Practice (BMP) tool for achieving higher yield goals (Liu *et al.*, 2017). A relatively small research quantum is reported with regard to production of controlled release coated fertilizers and their use in oilseeds (Azeem *et al.*, 2014).

Material and Methods

The field experiments were conducted to study the effect of different slow release and controlled release fertilizers on growth, quality, yield and nutrient uptake in soybean during *kharif* -2019 and 2020 at research farm of Department of Soil Science, College of Agriculture, VNMKV, Parbhani (M.S.), India. The soils of experimental site of present investigation was classified as Vertisol belonging to Parbhani soil series which comprised of fine Montmorillonite isohyperthermic family of Typic Haplusterts. The experimental soil was alkaline in reaction (pH 8.08), low in salt content (0.20 dS m^{-1}) with high calcium carbonate content (132.3 g kg^{-1}). The organic carbon status of the soil was medium (0.44 per cent). The soil available nitrogen was low (163 kg ha^{-1}), available phosphorus was medium (10.20 kg ha^{-1}), available potassium was very high (560 kg

ha^{-1}) and available sulphur was medium (23.32 kg ha^{-1}). The DTPA micronutrients viz., iron, manganese, zinc, and copper were 4.48, 3.96, 0.60 and 1.78 mg kg^{-1} , respectively. The soybean (Cv. MAUS-162) was used as test crop. The design of the experiment was randomized block design (RBD), with four replications and ten treatment combinations. The treatment comprised were absolute control, recommended dose of fertilizers through conventional fertilizers (urea, DAP, MOP and elemental S) and combinations of slow release and controlled release fertilizers (CDU, SCU, Polymer coated DAP, Karanj oil coated DAP, Bentonite S and WDG-S) along with FYM. The fertilizer sources for RDF (T_2) were neem coated urea, DAP, MOP and elemental sulphur. The fertilizers sources viz; Crotonylidenediurea (CDU), Sulphur coated urea (SCU), Karanj oil coated DAP, Polymer coated DAP, Water dispersible granules- Sulphur (WDG-S), Bentonite Sulphur were used in respective treatments from T_3 to T_{10} . The FYM @ 5 Mg ha^{-1} , biofertilizers viz; Rihizobium and PSB @ 5 mL kg^{-1} of seed were used for treatments from T_2 to T_{10} . The sulphur coated urea (SCU), Karanj oil coated DAP (K-DAP), Polymer coated DAP (P-DAP) were prepared in laboratory by physical mixing and Urea, Diammonium phosphate (DAP), Muriate of potash (MOP), elemental sulphur, Bentonite sulphur (Bentonite S), Water dispersible granules of sulphur (WDG-S) were purchased from local market. The CDU was supplied by M/S Godavari Biorefineries, Sakarwadi, Kopargaon, Dist. Ahilyanagar (M.S.), India. The SCU was prepared by taking 88.5 g urea mixed with 10.7 g of elemental sulphur powder + 0.8 ml formaldehyde solution (Green, 1967). The mixture was thoroughly mixed on dry and clean plastic paper. The karanj oil coated DAP was prepared by mixing karanj oil (50 mL) with DAP (1 kg). The DAP fertilizer was taken in circular plastic bowl and karanj oil was sprayed with the help of spray gun. The mixture was continuously

swirled by rotating the bowl in circular manner. The process was repeated 2-3 times until satisfactory visual coating was obtained (Singh, 2003, Shelke, 2017). The polymer coated DAP was prepared in similar manner. The 50 ml polymer was used per 50 kg DAP. The proportion of polymer and DAP fertilizer was used as per dose suggested by manufacturer of polymer. The coated granules were air dried under shade and after drying, filled in clean airtight polythene bags. The treatmentwise manure and fertilizers were applied and crop was sown in *kharif* season after standard package of tillage operations. The initial and after harvest soil samples were collected and analysed for major and micronutrient content by using standard procedures. The observations regarding growth attributes were recorded during crop growth period. The plant samples were taken for chlorophyll content at 20, 40 and 60 DAS and analysed by using method suggested by Arnon, (1949). The observations of number of nodules, fresh and dry weight of nodules per plant were recorded at 45 DAS. Plant samples (seed and straw) were collected, cleaned with deionised water and dried in sample process room and subsequently in oven at 65°C until constant weight and grinded well to maximum fineness. The processed plant samples were analysed for N, P, K, S and micronutrient content by using standard procedures (Parkinson and Allen, 1975, Piper, 1966, Jackson, 1973, Tabatabai and Bremner, 1970a and Zososki and Burau, 1977). The seed samples were also analysed for quality parameters viz; protein content (A.O.A.C., 2012) and oil content (Ranganna, 1994). The test weight was calculated by weighing hundred seeds. The data was analyzed statically by using method given by Panse and Sukhatme, (1985).

Results and Discussion

Plant height : The better nutritional environment for soybean through slow release

and controlled release fertilizers throughout crop growth period resulted improvement in root growth, which ultimately increased plant height and crop growth rate. The treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) recorded significantly highest plant height (90 cm) of soybean and it was at par with the rest of the treatments except plant height (80.21, 80.13 and 60.46 cm) recorded in treatments RDF through SCU + Karanj oil coated DAP + WDG of sulphur (T₇), RDF through SCU + Karanj oil coated DAP + Bentonite sulphur (T₈) and absolute control (T₁), respectively at 60 DAS (Table 1). Similarly, the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) noted significantly highest plant height (101.29 cm) and it was found statistically at par over rest of the treatment except plant height (91.71 cm) observed in the treatment with RDF (T₂) and plant height (68.92 cm) found in absolute control (T₁) at harvest of soybean. Increase in plant height might be owing to the positive role of slow release and controlled release fertilizers in timely supply of plant nutrients and plant metabolic activity, which increased photosynthesis and thereby soybean plant height. These results clearly indicated that, slow release and controlled release fertilizers has a definite positive impact on the plant height. The results are in conformity with the findings of Ali *et al.*, (2017).

Number of pods per plant : The optimum vegetative growth is necessary to obtain an appropriate number of pods per plant. The number of nodes of the main stem of soybean is determined during early vegetative growth. Therefore, increase in seed yield could be achieved by increasing numbers of branches and pods per node by fertilizer management practices. The number of pods per plant (36.00) was found significantly highest in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) and it was statistically at

par with the number of pods per plant (34.12) recorded in RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) (Table 1) at harvest of soybean. Increased number of pods per plant might be due to significant increase in growth, number of leaves, plant height, nodulation and efficient nutrient utilization. Slow release N fertilizer applied to bean reflected in higher number pods as compared to conventional fertilizers (El-Tohamy *et al.*, 2009). Tian *et al.*, (2016) also reported increase in number of pods per plant of rape seed with controlled release fertilizers as compared to soluble fertilizers.

Number of nodules per plant : Legumes vary in their quantity and weight due to the effects of mineral nitrogen in soil either because

of mineralization of organic matter or of inorganic fertilizer application. Soybean is a relatively sensitive crop, both mineral and fixed nitrogen seems to be essential for maximum yield and nitrogen content. This is because nitrogen fixation begins only after root nodule formation. The treatment with RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) found significantly highest number of nodules per plant (73.63) and it was statistically at par with number of nodules per plant (69.88) found in RDF through SCU + Polymer coated DAP + WDG of sulphur (T₉) and number of nodules per plant (69.80) observed in RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) at 45 DAS (Table 1). The average number of nodules per plant (61.01) was recorded at 45 DAS. The higher number of

Table 1. Effect of different slow release and controlled release fertilizers on plant height, number of pods, number of nodules, fresh weight and dry weight of nodules plant⁻¹ in soybean (Pooled data of two years)

Treatment details	Plant height (cm)		No. of pods plant ⁻¹		No. of nodules plant ⁻¹	Fresh wt. of nodules plant ⁻¹ (mg)	Dry wt. of nodules plant ⁻¹ (mg)
	60 DAS	At harvest	60 DAS	At harvest			
T ₁ - Absolute control	60.46	68.92	17.83	18.88	38.75	368.75	171.00
T ₂ - Recommended dose of fertilizer (N:P ₂ O ₅ :K ₂ O:S 30:60:30:20 kg ha ⁻¹) + FYM- 5 Mg ha ⁻¹ , <i>Rhizobium</i> and PSB, micronutrients as per soil test	83.50	91.71	25.79	30.71	51.25	645.13	269.00
T ₃ - RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	85.71	95.46	24.54	31.21	59.50	732.00	289.38
T ₄ - RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	87.96	95.92	25.12	31.83	58.75	690.00	283.25
T ₅ - RDF through CDU + Polymer coated DAP + WDG of Sulphur	90.00	101.29	24.50	34.12	73.63	871.00	359.63
T ₆ - RDF through CDU + Polymer coated DAP + Bentonite Sulphur	85.54	97.58	24.29	36.00	69.80	850.38	342.63
T ₇ - RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	80.21	94.50	24.21	30.79	60.13	726.13	304.63
T ₈ - RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	80.13	93.29	24.79	32.29	61.50	736.50	307.88
T ₉ - RDF through SCU + Polymer coated DAP + WDG of Sulphur	82.21	97.42	24.71	31.96	69.88	841.50	344.50
T ₁₀ - RDF through SCU + Polymer coated DAP + Bentonite Sulphur	85.04	97.75	24.46	33.21	66.75	785.88	324.88
SE±	2.71	2.72	0.95	0.92	1.97	31.24	13.65
CD 5%	7.85	7.90	2.75	2.66	5.73	90.66	39.60

nodules per plant in slow release and controlled release fertilizers treatment, (CDU, Polymer coated DAP and Bentonite S) + FYM, is might be due to availability of sufficient organic matter for effective microbial activities, healthy soil environment and better aeration for higher nodulation. The higher number of nodules with use of slow release sulphur fertilizers were recorded earlier by Jamal *et al.*, (2010) and Sharma *et al.*, (2004).

Fresh and dry weight of nodules : The fresh weight of nodules per plant (871.00 mg) was recorded significantly highest in the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) and it was followed by fresh weight of nodules per plant (850.38 mg) found in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) at 45 DAS of soybean (Table 1). It was observed that, dry weight of nodules per plant (359.63 mg) was found significantly highest in RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) and it was followed by dry weight of nodules per plant (344.50 mg) recorded in treatment RDF through SCU + Polymer coated DAP + WDG of sulphur (T₉). The slow release of nitrogen through these fertilizers enhanced nodulation as excess available nitrogen has inhibiting action on nodulation. The combined use of slow release and controlled release fertilizers along with FYM and biofertilizers enhanced nodule number, fresh and dry weight of nodules per plant. Similar line of results were also reported earlier by Aziz *et al.* (2016) and Singh and Kumar, (2012).

Chlorophyll : Chlorophyll is an important photosynthetic pigment in soybean. The chlorophyll content in soybeans is highly correlated with photosynthetic rate, which in turn is recognized as primary process that decides yield. The chlorophyll as influenced by different slow release and controlled release fertilizers at various stages of soybean is presented in Table 2.

Chlorophyll a : The chlorophyll a was found significantly highest (0.33 mg g⁻¹) in treatment with RDF (T₂) and it was followed by chlorophyll a (0.31 mg g⁻¹) observed in RDF through CDU + Karanj oil coated DAP + Bentonite sulphur (T₄) and RDF through SCU + Polymer coated DAP + WDG of Sulphur (T₉) at 20 DAS of soybean (Table 2). The significantly highest chlorophyll a (1.84 mg g⁻¹) was found in the treatment RDF (T₂), RDF through CDU + Karanj oil coated DAP + WDG of Sulphur (T₃) and RDF through CDU + Polymer coated DAP + WDG of Sulphur (T₅) at 40 DAS of soybean. It was statistically at par with rest of the treatment except chlorophyll a (1.64 and 1.53 mg g⁻¹) recorded in the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur (T₇) and absolute control (T₁), respectively at 40 DAS of soybean. The treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) showed significantly highest chlorophyll a content (2.41 mg g⁻¹) and it was followed by chlorophyll a content (2.38 mg g⁻¹) observed in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) at 60 DAS of soybean.

Chlorophyll b : The results revealed that, significantly highest chlorophyll b (1.21 mg g⁻¹) was observed in the treatment RDF (T₂) and it was statistically at par with rest of all the treatments except chlorophyll b (1.06 and 1.02 mg g⁻¹) found in the treatment RDF through SCU + Polymer coated DAP + Bentonite Sulphur (T₁₀) and absolute control (T₁), respectively at 20 DAS. The significantly highest chlorophyll b (0.72 mg g⁻¹) was recorded in RDF through CDU + Polymer coated DAP + WDG of Sulphur (T₅) over rest of the treatments at 40 DAS. The treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) recorded significantly highest chlorophyll b (0.90 mg g⁻¹) and it was statistically at par with chlorophyll b content (0.82 mg g⁻¹) observed in the treatment RDF through CDU + Polymer

coated DAP + Bentonite sulphur (T₆) at 60 DAS of soybean.

Total chlorophyll : It was observed that, significantly highest total chlorophyll (1.47 mg g⁻¹) in treatment RDF (T₂) and it was followed by total chlorophyll (1.39 mg g⁻¹) with the treatment RDF through CDU + Karanj oil coated DAP + WDG of Sulphur (T₃) at 20 DAS of soybean. The results revealed that, total chlorophyll (2.46 mg g⁻¹) was recorded significantly highest in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) and it was followed by total chlorophyll (2.37 mg g⁻¹) observed in RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) at 40 DAS of soybean. The total chlorophyll (3.20 mg g⁻¹) was recorded significantly highest

in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) and it was followed by total chlorophyll (3.08 mg g⁻¹) found in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) at 60 DAS of soybean.

The chlorophyll a, chlorophyll b and total chlorophyll was significantly influenced by use of different slow release and controlled release fertilizers might be due to supplementation of balanced dose of NPKS as well as organic matter through FYM. The nitrogen supplied in inorganic slow release and controlled release fertilizer was properly utilized due to more microbial activities in soil with organic matter. This led to better physiological development owing to facilitating in formation of chlorophyll

Table 2. Effect of different slow release and controlled release fertilizers on chlorophyll content at 20 DAS, 40 DAS and 60 DAS in soybean (Pooled data of two years)

Treatment details	Chlorophyll a (mg g ⁻¹)			Chlorophyll b (mg g ⁻¹)			Total Chlorophyll (mg g ⁻¹)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
T ₁ - Absolute control	0.13	1.53	2.19	1.02	0.33	0.63	1.21	1.85	2.67
T ₂ - Recommended dose of fertilizer (N:P ₂ O ₅ :K ₂ O:S 30:60:30:20 kg ha ⁻¹) + FYM- 5 Mg ha ⁻¹ , <i>Rhizobium</i> and PSB, micronutrients as per soil test	0.33	1.84	2.20	1.21	0.56	0.67	1.47	2.31	2.80
T ₃ - RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	0.28	1.84	2.36	1.13	0.55	0.77	1.39	2.29	2.96
T ₄ - RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	0.31	1.83	2.35	1.11	0.51	0.77	1.38	2.25	2.99
T ₅ - RDF through CDU + Polymer coated DAP + WDG of Sulphur	0.20	1.84	2.41	1.19	0.72	0.90	1.38	2.46	3.20
T ₆ - RDF through CDU + Polymer coated DAP + Bentonite Sulphur	0.16	1.83	2.38	1.15	0.63	0.82	1.33	2.37	3.08
T ₇ - RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	0.29	1.64	2.22	1.08	0.51	0.67	1.36	2.06	2.77
T ₈ - RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	0.20	1.70	2.21	1.11	0.50	0.67	1.30	2.11	2.76
T ₉ - RDF through SCU + Polymer coated DAP + WDG of Sulphur	0.31	1.80	2.31	1.11	0.51	0.71	1.38	2.21	2.91
T ₁₀ - RDF through SCU + Polymer coated DAP + Bentonite Sulphur	0.30	1.74	2.27	1.06	0.51	0.69	1.22	2.16	2.85
SE±	0.01	0.06	0.05	0.05	0.03	0.03	0.04	0.07	0.09
CD 5 %	0.04	0.19	0.15	0.13	0.07	0.09	0.11	0.21	0.27

and photosynthates in leaves. At 20 DAS, the soybean recorded the higher content of leaf chlorophyll a, b and total chlorophyll in treatment where conventional fertilizers were applied (T_2). It might be due to higher dissolution rates of these fertilizers in initial crop growth period. The slow release and controlled release fertilizer treatments recorded higher content leaf chlorophyll content at 40 DAS and 60 DAS due to their slow dissolution and slow availability to soybean as compared to conventional fertilizer treatments. The results are in conformity with Mo, *et al.*, (1991). They found that slow release urea fertilizer retained its effectiveness for 100 to 120 days and increased chlorophyll content by 0.8 percent as compared with uncoated urea. The coated fertilizers along with nitrification inhibitors increased chlorophyll content in later stage of crop growth. The combination of coating and nitrification inhibitors can make nutrient release more reasonably to crop (Dong *et al.*, 2016). Increased in chlorophyll content up to 28 and 8 percent over control and uncoated DAP treatments were also reported earlier in wheat by Noor *et al.*, (2017). Similar line of results reported earlier by Wang *et al.*, (2021).

Seed protein : The application of different slow release and controlled release fertilizers significantly influenced to seed protein content of soybean (Table 3). It was also observed that, treatment RDF through CDU+Polymer coated DAP+Bentonite sulphur (T_6) observed significantly highest protein (38.88 per cent). It was statistically at par with protein (37.39 per cent) observed in treatment RDF through CDU+Polymer coated DAP + WDG of sulphur (T_5). The highest protein percentage in slow and controlled release fertilizer treatments is might be due to beneficial effect coating material on soybean which regulate the nutrient release and enhancement the nitrogen use efficiency by soybean than uncoated fertilizers provide a steady supply of nutrients to the root. This results in increased absorption of nutrients especially N and synthesis of proteins in seed. The results are in agreement with Abou-Zied *et al.*, (2014). They found that highest percentage of seeds crude protein was recorded with coated urea in both seasons (6.11 and 11.13%) and it was higher than treatment of uncoated urea (control) in first and second season, respectively. All coated forms of urea increased crude protein percentage of maize grains in both seasons.

Table 3. Effect of different slow release and controlled release fertilizers on quality and yield of soybean (Pooled data of two years)

Treatment details	Prot- ein (%)	Oil (%)	Test wt. (g)	Yield (q ha ⁻¹)	
				Seed	Straw
T_1 - Absolute control	31.78	17.33	12.45	17.92	24.63
T_2 - Recommended dose of fertilizer (N:P ₂ O ₅ :K ₂ O:S 30:60:30:20 kg ha ⁻¹) + FYM- 5 Mg ha ⁻¹ , <i>Rhizobium</i> and PSB, micronutrients as per soil test	35.41	18.36	13.53	25.47	33.40
T_3 - RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	35.76	18.60	13.85	27.39	35.08
T_4 - RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	35.72	19.32	13.96	27.60	35.62
T_5 - RDF through CDU + Polymer coated DAP + WDG of Sulphur	37.39	19.68	14.68	28.86	38.92
T_6 - RDF through CDU + Polymer coated DAP + Bentonite Sulphur	38.88	19.27	14.42	30.29	41.43
T_7 - RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	35.58	18.51	13.65	25.91	34.15
T_8 - RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	35.68	18.84	13.83	26.18	33.86
T_9 - RDF through SCU + Polymer coated DAP + WDG of Sulphur	35.98	18.75	14.00	27.32	36.21
T_{10} - RDF through SCU + Polymer coated DAP + Bentonite Sulphur	36.16	19.06	14.09	27.83	37.36
SE±	0.91	0.26	0.21	0.59	1.39
CD 5 %	2.64	0.76	0.61	1.71	4.04

Oil : The oil synthesis in oil seeds depends upon balanced nutrition of crop. The macro and micronutrients supply through chemical fertilizer and organic manures helps in synthesis of fatty acids and their esterification by accelerating biochemical reactions in glyoxalate cycle. The application of different slow release and control release fertilizers significantly influenced the oil content in soybean (Table 3). The significantly highest oil content (19.68 per cent) was recorded in treatment with RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) and it was followed by oil content (19.32 per cent) recorded in RDF through CDU + Karanj oil coated DAP + Bentonite sulphur (T₄). The application of slow release and controlled release N, P and S fertilizers treatments recorded higher oil content as compared to application of conventional fertilizer treatments. The slow release sulphur sources might have contributed higher synthesis of oil because fundamental function of sulphur in the production of oil containing amino acids i.e., cystine, methionine and cysteine and prolonged availability of sulphur from these fertilizer sources. The sulphur also increases the availability of N, P and K. (Perveen *et al.*, 2021). Application of slow release nitrogen fertilizers to soybean recorded an increase in oil percent in soybean seed (Abou-Zied *et al.*, 2014).

Test weight : Test weight is used as an indicator of general seed quality and is a measure of seed bulk density. Test weight, but not overall seed weight, normally increases during drying. The test weight (100 seed weight) as influenced by different slow release and control released fertilizer treatment is presented in Table 3. The treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅) noted significantly highest test weight of (14.68 g) and it was statistically at par with test weight (14.42 g) observed in treatment with RDF through CDU + Polymer coated DAP +

Bentonite sulphur (T₆) and test weight (14.09 g) found in the treatment RDF through SCU + Polymer coated DAP + Bentonite sulphur (T₁₀). The prolonged and steady supply of nutrients by different slow release and controlled release fertilizers to soybean during the active growth phase might have contributed to increase in test weight of seed. The results are corroborated with Eyvazi *et al.*, (2010). Similar line of results were also reported earlier by Shivay *et al.*, (2014). They found higher test weight of Basmati rice with application of Bentonite sulphur as compare to other sources of sulphur viz., gypsum and elemental sulphur. The increase in test weight because of coated fertilizers was also reported by Shivay *et al.*, (2016).

Seed yield : The use of slow release and controlled release fertilizers is better option to uncoated fertilizers with advantage of slow and continuous nutrient release for plant uptake at different stages of crop growth. The seed yield of soybean was significantly influenced by different slow release and controlled release fertilizers (Table 3). The treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur (T₆) recorded significantly highest seed yield (30.29 q ha⁻¹) and it was at par with mean seed yield (28.86 q ha⁻¹) observed in treatment with RDF through CDU + Polymer coated DAP + WDG of sulphur (T₅). The mean seed yield was observed 26.48 q ha⁻¹. The lowest seed yield (17.92 q ha⁻¹) was recorded in absolute control treatment (T₁). The seed yield of soybean depends on dry matter production of shoots. To produce higher seed requires a continuous supply of a large amount of nitrogen along with other nutrients. The production of higher seed in slow release and controlled release fertilizer treatments is might be due to promotion of vegetative shoot growth by the continuous supply of nitrogen and other nutrients after flowering stage (Kaushal *et al.*,

2006). The results are in agreement with Eyvazi *et al.*, (2010), Sanders *et al.*, (2012), Dong *et al.*, (2016).

Straw yield : The straw yield of soybean as influenced by different slow release and control released fertilizers are reported in Table 3. The straw yield (41.43 q ha^{-1}) recorded in the treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) was found significantly highest and it was statistically at par with straw yield (38.92 q ha^{-1}) found in RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The mean straw yield was observed 35.07 q ha^{-1} . The significantly lowest straw yield (24.63 q ha^{-1}) was recorded in the absolute control (T_1). The application of slow release and controlled release fertilizers showed maximum accumulation of dry matter in shoot resulted in higher straw yields as compared to conventional fertilizers. The coated fertilizers recorded higher straw yield in soybean as compared to conventional fertilizers (Shelke, 2017).

Nutrient uptake

Nitrogen : The influence of different slow and controlled release fertilizer treatment on total nitrogen uptake in soybean was found significant (Table 4). The treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) recorded significantly highest total nitrogen uptake ($203.44 \text{ kg ha}^{-1}$) and it was statistically at par with total nitrogen uptake (185.3 kg ha^{-1}) observed in the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The mean total nitrogen uptake was observed $162.57 \text{ kg ha}^{-1}$. Low total nitrogen uptake in conventional fertilizer treatment might be associated with large volatilization and leaching in alkaline soils. The superiority of slow release and controlled release fertilizers can be affirmed by giving significantly higher total nitrogen uptake. The higher nitrogen uptake in slow release and controlled

release fertilizers treatments over uncoated fertilizers was also reported earlier by Khan *et al.*, (2015).

Phosphorus : The total phosphorus uptake in soybean as influenced by different slow release and controlled release fertilizers is presented in Table 4. The significantly highest total phosphorus uptake (15.25 kg ha^{-1}) was found in RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the total phosphorus uptake (13.96 kg ha^{-1}) recorded in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). Phosphate fertilizers including Diammonium phosphate are water soluble and phosphate anions gets fixed quickly by reacting with soil constituents and recovery by the crop is poor. This limits productivity of crop. The uptake of phosphorus by soybean might be enhanced due to reduction its reaction with soil constituents through slow release of phosphate anions with polymer coating. The application of polymer coated DAP enhanced soluble forms of phosphorus in soil and prolonged its availability in soil, which results in more uptake of phosphorus by soybean. These results are in conformity with Ali *et al.*, (2017).

Potassium : The results revealed that, significantly highest total potassium uptake (51.88 kg ha^{-1}) was recorded in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by total potassium uptake (48.53 kg ha^{-1}) found in RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5), total potassium uptake (48.21 kg ha^{-1}) observed in treatment RDF through SCU + Polymer coated DAP + Bentonite sulphur- T_{10} (Table 4). It was observed that, total potassium uptake was increased with increased uptake of nitrogen due to positive relationship between nitrogen and potassium. This might be due to the better uptake of potassium and other nutrients because of

favorable conditions in rhizosphere with the use of slow release nitrogenous fertilizers. These results are corroborated with Shilpha *et al.*, (2017).

Sulphur : The total sulphur uptake was significantly influenced by different slow release and controlled release fertilizer treatments (Table 4). The total sulphur uptake (14.73 kg ha^{-1}) found in treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur (T6) was significantly highest and it was statistically at par with total sulphur uptake (13.84 kg ha^{-1}) recorded in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T5). Different forms of sulphur decide sulphur supplying power of a soil by influencing its release and dynamics in soils. Several soil factors

also influence availability of sulphur and hence the status of different forms of sulphur in soils varies widely with soil type. Total sulphur uptake was recorded significantly highest with bentonite sulphur as compared to rest two sources (WDG-S and elemental sulphur) of sulphur which might be attributed to higher sulphur content and sulphur uptake found in bentonite sulphur. The results are corroborated with Kumar *et al.*, (2018).

Micronutrient uptake : Increased biomass production may be a driving force for uptake and assimilation of micronutrients such as Fe, Mn, Zn and Cu. Similarly, the results showed, with increases of yield and biomass production, there was a concomitant increase in uptake and accumulation of Fe, Mn, Zn and Cu in seed and

Table 4. Effect of different slow release and controlled release fertilizers on nutrient uptake in soybean (Pooled data of two years)

Treatment details	Nutrient uptake							
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	Fe (kg ha^{-1})	Mn (kg ha^{-1})	Zn (kg ha^{-1})	Cu (kg ha^{-1})
T ₁ - Absolute control	96.41	6.87	27.60	6.11	436.04	71.11	129.25	20.83
T ₂ - Recommended dose of fertilizer (N:P ₂ O ₅ :K ₂ O:S 30:60:30:20 kg ha ⁻¹) + FYM- 5 Mg ha ⁻¹ , Rhizobium and PSB, micronutrients as per soil test	151.44	11.40	39.51	10.25	669.74	113.65	197.24	31.28
T ₃ - RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	166.22	12.03	44.27	11.41	791.98	132.73	205.42	33.30
T ₄ - RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	167.77	13.62	45.23	12.05	827.64	134.46	217.74	32.58
T ₅ - RDF through CDU + Polymer coated DAP + WDG of Sulphur	185.63	13.96	48.93	13.84	1019.60	149.40	263.58	35.41
T ₆ - RDF through CDU + Polymer coated DAP + Bentonite Sulphur	203.44	15.25	51.88	14.73	1281.67	161.41	292.44	37.39
T ₇ - RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	156.47	12.43	41.85	10.65	700.95	121.40	198.23	31.22
T ₈ - RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	158.92	12.03	42.36	11.01	768.06	125.87	202.32	31.65
T ₉ - RDF through SCU + Polymer coated DAP + WDG of Sulphur	167.62	12.73	47.64	13.05	843.82	137.33	236.02	33.28
T ₁₀ - RDF through SCU + Polymer coated DAP + Bentonite Sulphur	171.73	13.41	48.21	12.90	968.39	139.42	241.34	33.37
SE±	6.47	0.58	1.39	0.51	35.65	4.65	11.70	1.14
CD 5 %	18.77	1.68	4.04	1.47	103.45	13.49	33.95	3.32

stover at physiological maturity of soybean.

Iron : The application of different slow release and controlled release fertilizers results in significant uptake of iron (Table 4). The significantly highest total iron uptake ($1281.67 \text{ g ha}^{-1}$) observed in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6). The beneficial effect of slow release and controlled release fertilizers along with FYM in increasing uptake of iron may be ascribed to direct supply this micronutrient on mineralization of FYM, the solubilization action of the organic acids produced during the decomposition of FYM. These facts due to applications of FYM not only solubilize unavailable nutrients but also contains significant amount of iron. Thus, application of slow release and controlled release fertilizers along with FYM had resulted in an overall increase in uptake of iron. Combined use of organic manure and chemical fertilizer has been found not only in maintaining higher productivity but also in providing sustainable yield of soybean. The results are in agreement with Priyanka *et al.*, (2019).

Manganese : The effect of different slow release and controlled release fertilizers on total manganese uptake was found significant (Table 4). The significantly highest total manganese uptake (161.41 g ha^{-1}) was recorded in the treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was statistically at par with total manganese uptake (149.40 g ha^{-1}) was found in the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The controlled release and slow released fertilizers in combination with farmyard manure had significantly increased total Mn uptake in soybean. The higher manganese uptake in slow release and controlled release fertilizer and FYM treatment is because of supply of manganese by soil as well as FYM. Application of FYM with fertilizers might have

augmented Mn supply in the soil after their mineralization/decomposition (Dhaliwal *et al.*, 2014, Walia and Kler, 2010).

Zinc : The total zinc uptake in soybean as influenced by different slow released and controlled released fertilizers is presented in Table 4. The significantly highest total zinc uptake (292.44 g ha^{-1}) was recorded in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was statistically at par with total zinc uptake (263.58 g ha^{-1}) observed in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). Total uptake of zinc in soybean was positively influenced with application of slow release and controlled release fertilizers. The results indicated that optimized nutrient management by using slow release and controlled release fertilizers might have maintained plant nutrition of zinc for maximum yields, uptake. The positive effects of N on zinc uptake is reported earlier by Xue *et al.*, (2014). The results are in agreement with Patil, (2018) who found increase in Zn uptake with the use slow release nitrogenous fertilizers.

Copper : Total copper uptake in soybean as influenced by different slow release and controlled release fertilizer treatment is presented in Table 4. The results revealed that, significantly highest total copper uptake (37.39 g ha^{-1}) was found in RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by total copper uptake (35.41 g ha^{-1}) observed in treatment RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The application of slow release and controlled release fertilizers with FYM significantly affected uptake of copper in seed and straw of soybean. During decomposition of FYM various substances *viz.*, organic acids, polyphenols, amino acids and polysaccharides are produced which might have stimulated solubility, transport and availability of copper

which results in higher uptake in slow release and controlled release fertilizer treatments. Increase in availability of micronutrient with incorporation of organic residues along with chemical fertilizers there by increment in uptake is also reported earlier by Kumari *et al.*, (2017). Similar line of results were recorded earlier by Pandey, (2018).

The nutrient management for soybean through slow release and controlled release fertilizer sources *viz*; CDU, Polymer coated DAP and Bentonite Sulphur/WDG was found beneficial for obtaining higher yield and quality on Vertisol. These fertilizers also recorded significantly highest nutrient uptake and growth attributes in soybean.

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