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INFLUENCE OF DIFFERENT SLOW RELEASE AND CONTROLLED RELEASE FERTILIZERS ON YIELD AND NUTRIENT DYNAMICS IN SOYBEAN PRODUCTION

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ABSTRACT

The field experiments were conducted at research farm, Department of Soil Science and Agril. Chemistry, College of Agriculture, VNMKV, Parbhani for two consecutive years i.e. *kharif*- 2019 and 2020 to study the response of soybean to different slow release and controlled release fertilizers on Vertisols. The field experiments were conducted in RBD 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) 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 seed and straw yield of soybean were recorded significantly highest in the treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur. The soil pH, EC and $CaCO_3$ was not influenced significantly due to different slow release and controlled release fertilizers. The treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur recorded significantly highest soil OC content. The significantly highest soil available N was found in the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur. The RDF through CDU + Polymer coated DAP + Bentonite sulphur recorded the significantly highest soil available phosphorus and soil available sulphur. The effect of different slow release and controlled release fertilizers on soil available potassium was found non significant. There was improvement in soil available micronutrients *viz*; Fe, Mn, Zn and Cu in all the slow release and controlled release fertilizers treatments at harvest of soybean. Net soil available nitrogen balance was found positive in all the slow release and controlled release fertilizer treatments except RDF and absolute control treatments. Soil available phosphorus balance was positive was recorded in all the treatments except in absolute control treatment. The maximum net positive balance of soil available potassium was found in the RDF treatment. Soil available sulphur balance was positive in all the slow release and controlled release fertilizer treatments over initial soil available sulphur. The nutrient management of soybean through slow release and controlled release fertilizers resulted in higher seed and straw yield, improvement in soil fertility and positive nutrient balance.

(Key words: Slow release and controlled release fertilizers, yield, nutrient dynamics, soybean production)

INTRODUCTION

The legumes play vital role in human nutrition, as they are rich source of minerals, vitamins, calories and proteins. Soybean (*Glycine max* L. Merril) is world's very important leguminous seed crop contributing 25 per cent need of oil globally and two - third supply of protein concentrates for feeding livestock (Karhale *et al.*, 2021). The area of soybean in India is 11.38 million ha; production is 11.94 million ton with average productivity of 1,050 kg ha^{-1} (Anonymous, 2020). Production of soybean in India is dominated by Maharashtra and Madhya Pradesh contributing 89 per cent of the total production. Andhra Pradesh, Rajasthan, Chhattisgarh, Karnataka and Gujarat contribute the rest of 11 per cent production. The area, production and productivity of Maharashtra is 4.04 million ha, 4.55 million tons and 1,125 kg ha^{-1}, respectively, (Anonymous, 2019). Out of different vegetable oils imported, the palm oil constituted the share of 60 %, followed by soybean oil (22 %) and sunflower oil (17 %) (Anonymous, 2020).Soybean still suffers many constraints despite made rapid stride for total production and area coverage. The

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constraints limiting soybean production in India includes production and technology aspects, climatic and edaphic factors. Efficient fertilizer application is critical to crop production, ecological advantages and economical benefit (Ohyama *et al.,* 2017).Intensive cultivation coupled with growing of exhaustive crops in the past has rendered soil deficient in major and secondary nutrients. This has resulted in deterioration in soil health and productivity.Chemical fertilizers are playing a crucial role to meet the nutrient requirement of the crop; however persistent nutrient depletion is posing a greater threat to sustainable agriculture (Asefa and Wagari, 2021). The improvement in fertilizer use efficiency of chemical fertilizers by using nitrification inhibitors may play a key role in minimizing environmental damage and increasing productivity (Chen *et al*., 2008). The slow release or coated P fertilizer could increase the P availability by limiting the contact of applied P with soil thereby reducing the possibility of its precipitation and/or adsorption on soil colloids. Diez *et al.* (1992) demonstrated that the use of coated phosphate fertilizers had clear advantages for controlling phosphorus fixation in calcareous soils.The slow release sulphur fertilizer sources *viz;*bentonite sulphur, phospho-gypsum, WDG sulphur are available in the country. These sources can be an effective tool for fertilizer management in order to get higher yields and reduce the loss of nutrients from soil. The nutrient demand in modern agriculture is fulfilled by chemical fertilizers. As result of increased productivity and production of crops, the demand for nutrients is also increased markedly and shifted the nutrient balance towards the negative side in most of Indian soils (Tandon, 2007).A relatively small research quantum is reported with regard to the production of controlled release coated fertilizers and their use in oilseeds (Azeem *et al.*, 2014).

MATERIALS AND METHODS

The field experiments were conducted to study the influence of different slow release and controlled release fertilizers on yield, nutrient dynamics, microbial population and enzyme activity in soybean production during *kharif* - 2019 and 2020 at research farm of Department of Soil Science and Agril. Chemistry, College of Agriculture, VNMKV, Parbhani (M.S.), India. The soils of experimental was Vertisol belonging to Parbhani soil series which comprise of fine Montmorilloniteisohyperthermic family of *Typic Haplusterts*. The texture of the soil was clayey. 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 (4.40 g kg^{-1}). 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 comparised 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 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 market. The CDU was supplied by M/S Godavari Biorefineries, Sakarwadi, Kopargaon, Dist. Ahmednagar (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 basin and karanj oil was sprayed with the help of spray gun. The mixture was continuously swirled by rotating the basin in circular manner. The process was repeated 2-3 times until satisfactory visual coating was obtained (Shelke, 2017, Singh, 2003). The polymer coated DAP was prepared in similar way. The 50 ml polymer was used 50 kg^{-1}DAP. The proportion of polymer and DAP fertilizer was used as per dose recommended by manufacturer of polymer. The coated granules were air dried under shade and after drying, filled in the clean airtight polythene bags. The treatmentwise manure and fertilizers were applied and crop was sown in *kharif* season after standard package of tillage operations. Initial and after harvest soil samples were collected.The pH, EC, organic carbon and soil available potassium was analysed by the procedures suggested by Jackson, (1973). The calcium carbonate content was analysed by rapid titration method (Puri,1949). The soil available nitrogen was analysed by the method given by Subbiah and Asija, (1956). The soil phosphorus was estimated by using the procedure suggested by Olsen *et al.,* (1954). The soil available sulphur was analysed by the method given by Williams and Steinbergs, (1959). The DTPA extractable micronutrients (Fe, Mn, Zn and Cu) were estimated by using Atomic absorption spectrophotometer (Lindsay and Norvell, (1978). The data was analyzed statically by using method given by Panse and Sukhatme, (1985).

RESULTS AND DISCUSSION

Soil chemical properties

pH

The effect of different slow release and controlled release fertilizers on soil pH was found non significant in soybean (Table 1). It was observed that, there was slightly decreased in soil pH at harvest of soybean as compared to initial soil pH. The highest soil pH (8.06) was observed in absolute control (T_1) with mean value of 7.98. The lowest soil pH (7.94) was recorded in the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur (T_7).The FYM incorporated treatments showed comparatively lower pH than the absolute control treatment and over the initial values which may be attributed to production of organic acids during the process of decomposition of organic matter supplied through FYM and respective CDU treated plots. The decrease in soil pH over initial values in the treatment with the application of 100 per cent NPK + FYM to the soybean was reported earlier by Arbad *et al.* (2014).

Electrical conductivity

The electrical conductivity is a measure of total soluble salts present in soil solution. The electrical conductivity was not influenced significantly due to different slow release and controlled release fertilizer treatments in soybean (Table 1). It was observed that, there was increase in electrical conductivity of soil over the initial value in all the treatments except absolute treatment (T_1). The numerically highest electrical conductivity (0.23 dS m^{-1}) was observed in the treatment with RDF through SCU + Karanj oil coated DAP + Bentonite sulphur (T_8) and RDF through SCU + Polymer coated DAP + Bentonite sulphur (T_{10}) with mean value of 0.21 dSm^{-1}. The presence of soluble salts in mineral fertilizers might have increased electrical conductivity of soil at harvest of soybean over the initial values. The increase in soil electrical conductivity with the application of 125 per cent neem coated urea to rice crop was also reported by Khandey *et al.*(2017).

Calcium carbonate content

The data pertaining to soil calcium carbonate content at harvest of soybean is presented in Table 1. There was decrease in calcium carbonate content in all the treatments over the initial values. However, the results of calcium carbonate of soil were non-significant due to different slow release and controlled release fertilizer treatments. The maximum decrease in soil calcium carbonate content (109.85 g kg^{-1}) was found in the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur (T_7). The mean value of calcium carbonate content of 121.69 g $kg^{-1}$was observed. The decrease calcium carbonate content in the treatments with the application of FYM and chemical fertilizer might be because of secretion of organic acids during decomposition of FYM. That causes slightly decrease in soil pH and dissolution of calcium carbonate present in soil. The decrease in calcium carbonate content with the application of compost was found earlier by Barka *et al.* (2018).

Organic carbon content

The organic carbon content in soil at harvest of soybean was significantly influenced by different slow released and controlled release fertilizer treatments (Table 1). It was observed that, there was improvement in soil organic carbon content over the initial values in all the treatments. The results revealed that, significantly highest soil organic carbon content (5.80 g kg^{-1}) recorded in treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the treatment RDF through CDU + Polymer coated DAP + WDG of Sulphur-T_6(5.59g kg^{-1}). The lowest soil organic carbon content (4.74 g kg^{-1}) was found in absolute control (T_1). The farmyard manure along with the chemical fertilizers might have contributed the improvement in organic carbon status of soil. Yaseen *et al.* (2017) also observed the improvement in soil organic carbon with the use of polymer coated DAP in wheat.

Soil available nutrients

Nitrogen

The data pertaining to soil available nitrogen at harvest of soybean showed significant results due to different slow release and controlled release fertilizer treatments (Table 1). It was observed that, significantly highest soil available nitrogen (183.63 kg ha^{-1}) was found in the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur (T_9) followed by treatment RDF through SCU + Polymer coated DAP + Bentonite sulphur- T_{10} (179.66 kg ha^{-1}). The slow release nitrogenous fertilizer sources might have released nitrogen slowly coupled with reduced losses due to NH_3 volatilization and leaching. It results in efficient utilization of soil available nitrogen as well as maintained the soil residual nitrogen after harvest of soybean. These results are in agreement with Jagadeeswaran *et al.* (2007). They reported increase in soil available nitrogen in the treatment 125 per cent NPK fertilizers through slow release fertilizers tablet (urea formaldehyde, ammonium sulphate, amophos, rock phosphate, muriate of potash and clay) as compared to 125 per cent NPK through straight fertilizers at harvest of the crop.

Phosphorus

The effect of different slow release and controlled release fertilizers on soil available phosphorus at harvest of soybean was found significant (Table 1). There was improvement in soil available phosphorus over the initial value. The results revealed that, the significantly highest soil available phosphorus (13.36 kg ha^{-1}) observed in RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) followed by treatment RDF through CDU + Polymer coated DAP + WDG of sulphur-T_5(12.96 kg ha^{-1}). The lowest soil available phosphorus (10.18 kg ha^{-1}) was observed in absolute control (T_1). The coated phosphorus fertilizers might have reduced the dissolution rate and fixation of fertilizer phosphorus in soil. The higher efficiency of these coated fertilizers, due to slower and gradual release, helpful to reduce frequency of application and to minimize the negative effects associated with over dosage. Moreover, polymer coated phosphatic fertilizer have potential to reduce phosphorus fixation and precipitation and release the phosphorus slowly as per requirement of the crop. It results in higher residual soil available phosphorus in coated fertilizer treatments. The increase in soil available phosphorus and phosphorus use efficiency with the application of 1 per cent double layer polymer coated DAP in wheat was found by Noor *et al.* (2017).

Potassium

The effect of different slow release and controlled release fertilizers on soil available potassium was found non significant (Table 1). The results revealed that, numerically highest soil available potassium (599.07 kg ha^{-1}) was observed in RDF (T_2) and it was followed by RDF through SCU + Karanj oil coated DAP + WDG of sulphur- T_7 (587.84 kg ha^{-1}). The lowest soil available potassium (556.25 kg ha^{-1}) was found in absolute control (T_1). The application of potasic fertilizers along with FYM might have maintained higher level of potassium in soil solution for longer period than the absolute control treatment. The higher potassium availability was due to beneficial effect of organic manures, reduction of potassium fixation, direct effect of addition of potassium through mineralization from the FYM. The improvement in soil available potassium in the treatment 125 per cent neem coated urea in three splits (439 kg ha^{-1}) was reported by Khandey *et al*. (2017).

Sulphur

The soil available sulphur was significantly influenced by different slow release and controlled release fertilizer treatment (Table 1). The results revealed that, treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) recorded the significantly highest soil available sulphur (30.04 kg ha^{-1}) and it was statistically at par with the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur-T_5(28.16 kg ha^{-1}) and treatment RDF through SCU + Polymer coated DAP + Bentonite sulphur-T_{10}(27.48 kg ha^{-1}). The significantly lowest soil available sulphur (21.09 kg ha^{-1}) was observed in absolute control (T_1). The coated sulphur fertilizer treatments recorded higher soil available sulphur at harvest of soybean. It might be due to slow release and minimum leaching losses of sulphur. The results are in agreement with Jena and Kabi (2012). They found increment in soil available sulphur with the application of gromorbentonite S pastilles @ 60 kg ha^{-1}rice-potato-green gram cropping sequence.

DTPA micronutrients

Iron

The data regarding DTPA extractable soil iron content as influenced by different slow release and controlled release fertilizer treatments are reported in Table 1. The results revealed that, significantly highest iron content (4.83 mg kg^{-1}) was observed in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the treatment RDF through CDU + Karanj oil coated DAP + WDG of sulphur- T_3 (4.78 mg kg^{-1}). The mean iron content was recorded 4.60 mg kg^{-1}.The DTPA extractable soil iron content was improved due to application of FYM alongwith coated fertilizers. There was build up of iron content in soil resulting from integral use of coated fertilizers and FYM. Such build up of iron in soil might be partly owing to release of native iron resulting from the dissolution action of organic manures and partly due to release from applied farmyard manure. The DTPA extractable iron content was improved in the treatment with the application of NPK + organic manure 4 t ha^{-1}(Sur *et al.*,2010).

Manganese

The influence of different slow release and controlled release fertilizer treatments on soil available manganese was found significant (Table1). The significantly highest manganese content (5.60 mg kg^{-1}) was found in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur- T_7 (4.90 mg kg^{-1}). The improvement in DTPA extractable soil available manganese was recorded higher in the treatments receiving FYM along with the coated fertilizers. The significantly highest soil available manganese content (12.46 mg kg^{-1}) was reported earlier in the treatment with 25 % N through CDU + (40:200 g P_2O_5: K_2O + 10 kg FYM plant^{-1}) by Pawar *et al.* (2017).

Zinc

The data regarding DTPA extractable soil available zinc status at harvest of soybean as influenced by different slow release and controlled release fertilizer treatments are given in Table 1. The results showed that, the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur (T_9) recorded significantly highest soil available zinc content (0.81 mg kg^{-1}) and it was followed by the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur-T_7(0.80 mg kg^{-1}). There was improvement in zinc status of soil in all fertilizer treatments. Addition of coated fertilizers along with organic manures to soil, besides increasing the availability of zinc in soil, the complexing properties of FYM with zinc might have prevented precipitation, fixation, leaching and kept it in soluble form.Improvement in DTPA extractable soil available Zn due to application of slow release fertilizers along with organic manures also reported earlier by Kumar *et al.* (2017). They found significantly highest soil available zinc (0.54 mg kg^{-1}) at harvest of maize in the treatment with 85 per cent RDN through Agro-N protect coated Urea.

Copper

The effect of different slow release and controlled release fertilizer treatments on DTPA soil available copper content was found non significant at harvest of soybean (Table 1). The numerically highest soil available copper content (1.88 mg kg^{-1}) was recorded in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur- T_9 (1.84 mg kg^{-1}). The mean soil available copper was found 1.79 mg kg^{-1}. The numerically highest in DTPA extractable soil available copper was found in the treatments with the application of coated fertilizer along with FYM. The increased availability of copper content in soil might be due to the application of manures, which could be ascribed to mineralization of the manure and complexing properties of these manures with micronutrients. These results are in agreement with Prashanth *et al.* (2019). They found the significantly highest soil copper (1.88 mg kg^{-1}) in the treatment with the application of FYM @ 10 t ha^{-1} + 100 % RDF at harvest of crop.

Nutrient balance

Nitrogen

The data in respect of nitrogen balance at harvest of soybean are presented in Table 2. It was observed that, actual difference of initial and final of nitrogen was found positive in all the treatments except nitrogen balance in absolute control (T_1) and RDF (T_2). The highest nitrogen balance (18.58 kg ha^{-1}) was observed in the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur (T_9) and it was followed by the treatment RDF through SCU + Polymer coated DAP + Bentonite sulphur-T_{10}(14.61 kg ha^{-1}). The per cent nitrogen gain or loss over initial values showed similar trend. The highest nitrogen gain (11.26 per cent) was recorded in the treatment RDF through SCU + Polymer coated DAP + WDG of sulphur (T_9). The nitrogen balance was maximum in the treatments with slow release and controlled release fertilizers treatments. The amount of nitrogen uptake by soybean was more as compared to nitrogen applied through fertilizer sources. The excess nitrogen requirement might have fulfilled by atmospheric nitrogen fixation. There was buildup of soil available nitrogen in all the slow release and controlled release fertilizer treatments. The buildup of soil available nitrogen at harvest of soybean is mainly because of fertilizer nitrogen sources and biological nitrogen fixation. The applied FYM along with fertilizers might have enhanced the biological immobilization and continuous mineralization of FYM on surface layer, supplied the nitrogen to soybean in adequate amount and remained in soil in considerable quantity after meeting the nitrogen requirement of soybean that also eventually improved the residual nitrogen in soil. Meena *et al.* (2016) reported the highest soil nitrogen balance (6.95 kg ha^{-1}) in the treatment with 125 per cent RDF + FYM 5 t ha^{-1} to the soybean.

Phosphorus balance

The results revealed that, the phosphorus balance was positive in all the treatments except in absolute control-T_1(Table 2). The maximum phosphorus balance (2.97 kg ha^{-1}) was recorded in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed by the treatment RDF through CDU + Polymer coated DAP + WDG of sulphur-T_5(2.57 kg ha^{-1}). Similar trend was observed in per cent phosphorus gain or loss over initial status soil available phosphorus.There was positive balance of soil available phosphorus at harvest of soybean in all the fertilizer treatments. However, the maximum build up of soil available phosphorus was observed in slow release and controlled release fertilizer treatments than conventional fertilizer treatments. It might be due to timely availability of phosphorus from sources and reduced losses. The results are corroborated with Pohare *et al.* (2018), who found the highest soil available phosphorus (28.96 kg ha^{-1}) in the treatment with 25% recommended dose of nitrogen through chemical fertilizers +25% recommended dose of nitrogen through farmyard manure +25% recommended dose of nitrogen through vermicompost +25% recommended dose of nitrogen through Neem cake (T_5) in soybean-onion cropping sequence.

Potassium balance

The data regarding potassium balance as influenced by different slow release and controlled release fertilizer treatments are presented in Table 3. The results revealed that, the highest potassium balance (36.07 kg ha^{-1}) was recorded in the treatment with RDF (T_2) and it was followed by the treatment RDF through SCU + Karanj oil coated DAP + WDG of sulphur-T_7(24.84 kg ha^{-1}). The lowest potassium balance (-6.75 kg ha^{-1}) was observed in the absolute control (T_1). The per cent gain or loss of soil available potassium showed the similar trend. The positive soil available potassium balance in all the fertilizer treatments might be due to incorporation of potasic fertilizer, which might have increased the potassium content in soil. The results are in agreement with the Ugale (2014). He found the highest potassium balance (24.34 kg ha^{-1}) in the treatment with 50 % RDN through FYM + 50 % RDN through neem seed powder + *Jeevamrut* two times in soybean – wheat cropping sequence.

Sulphur balance

The application of different slow release and controlled release fertilizers influenced the sulphur balance at harvest of soybean (Table 3). The sulphur balance was positive in all the treatment except absolute control (T_1) and in RDF (T_2). The highest sulphur balance (6.34 kg ha^{-1}) was recorded in the treatment RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) and it was followed the treatment RDF through CDU + Polymer coated DAP + WDG of Sulphur-T_5(4.46 kg ha^{-1}). The per cent gain or loss of soil available sulphur had showed similar trend. There was improvement in soil available sulphur in slow release and controlled release fertilizer treatments. The positive balance of sulphur in coated fertilizers treatments might be due to addition of sulphur through fertilizer, FYM and reduced losses by leaching. The results are corroborated with Szulc *et al.* (2014). They reported the highest sulphur balance (58.8 kg ha^{-1}) at harvest of barley in CaNPK2 fertilizer treatment.

Yield

Seed yield

The seed yield of soybean was significantly influenced by different slow release and controlled release fertilizers (Table 4). The treatment with RDF through CDU + Polymer coated DAP + Bentonite sulphur (T_6) recorded significantly highest seed yield (30.29 q ha^{-1}) and it was statistically at par with mean seed yield (28.86 q ha^{-1}) observed in the treatment with RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The lowest seed yield (17.92 q ha^{-1}) was recorded in absolute control treatment

(T_1). The mean seed yield was observed 26.48 q ha^{-1}. The seed yield of soybean depends on dry matter production of shoots. The production of higher seed in slow release and controlled release fertilizer treatments was might be due to the promotion of the vegetative shoot growth by the continuous supply of nitrogen and other nutrients after flowering stage. Jagadeeswaran *et al.* (2005) reported similar line of results. They found wet rhizome yield varied from 28.10 t ha^{-1} with mixture 1 (contains phosphogypsum-urea, ammonium sulphate, amophos, rock phosphate, muriate of potash, clay and gypsum) at 75 % NPK level to 41.21 t ha^{-1} with tablet 2 (contains phosphogypsum-urea, ammonium sulphate, amophos, rock phosphate, muriate of potash, clay and gypsum + neem cake) at 125 % NPK level in turmeric. Application of 60 kg S ha^{-1} through gromorbentonite S pastille recorded higher seed yield (5.8 t ha^{-1}) in rice (Jena and Kabi, 2012).

Straw yield

The straw yield of soybean as influenced by different slow release and control released fertilizers are reported in Table 4. 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 the straw yield (38.92 q ha^{-1}) found in RDF through CDU + Polymer coated DAP + WDG of sulphur (T_5). The significantly lowest straw yield (24.63 q ha^{-1}) was recorded in the absolute control treatment (T_1). The mean straw yield was observed 35.07 q ha^{-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. Hatano *et al.* (2019) found the treatment consisting 50 % polymer coated DAP application recorded 12 per cent higher straw yield over commercial DAP treatment.

From the data it is to be stated that, 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 yields, maintaining soil fertility and positive nutrient balance in soil.

Table 1. Effect of different slow release and controlled release fertilizers on soil chemical properties and available nutrients at harvest of the soybean (Pooled data of two years)

Treatment details	Soil chemical properties				Soil available nutrients(kg ha^{-1})				DTPA micronutrients(mg kg^{-1})			
	pH	EC (dS m^{-1})	$CaCO_3$ (g kg^{-1})	O.C. (g kg^{-1})	N	P	K	S	Fe	Mn	Zn	Cu
T_1-Absolute control	8.06	0.19	128.98	4.74	154.68	10.18	556.25	21.09	4.40	3.73	0.61	1.76
T_2-Recommended dose of fertilizer ($N:P_2O_5:K_2O:S$ 30:60:30:20 kg ha^{-1}) + FYM- 5 Mg ha^{-1}, *Rhizobium* and PSB, micronutrients as per soil test	7.99	0.21	125.60	5.14	164.88	10.66	599.07	23.03	4.66	4.32	0.67	1.75
T_3-RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	7.93	0.20	123.90	5.42	168.63	11.10	564.76	23.98	4.78	4.84	0.74	1.76
T_4-RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	8.00	0.21	124.86	5.43	169.13	12.30	568.25	24.26	4.77	4.97	0.71	1.83
T_5-RDF through CDU + Polymer coated DAP + WDG of Sulphur	7.98	0.21	120.73	5.59	173.26	12.96	568.11	28.16	4.75	4.59	0.76	1.66
T_6-RDF through CDU + Polymer coated DAP + Bentonite Sulphur	7.99	0.21	115.48	5.80	172.93	13.36	565.63	30.04	4.83	5.60	0.78	1.88
T_7-RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	7.94	0.22	109.85	5.37	178.07	11.43	587.84	23.98	4.63	4.90	0.80	1.83
T_8-RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	7.95	0.23	127.69	5.29	177.15	11.62	586.36	24.72	4.59	5.52	0.73	1.77
T_9-RDF through SCU + Polymer coated DAP + WDG of Sulphur	7.96	0.22	121.36	5.52	183.63	12.21	564.13	25.84	4.64	5.36	0.81	1.84
T_{10}-RDF through SCU + Polymer coated DAP + Bentonite Sulphur	7.98	0.23	118.45	5.53	179.66	11.84	567.90	27.48	4.51	5.01	0.79	1.79
Mean	**7.98**	**0.21**	**121.69**	**5.38**	**172.20**	**11.77**	**572.83**	**25.26**	**4.66**	**4.88**	**0.74**	**1.79**
SE±	0.04	0.01	4.09	0.13	2.92	0.53	22.27	1.04	0.09	0.14	0.02	0.07
CD 5 %	-	0.03	-	0.39	8.75	1.58	-	3.12	0.26	0.42	0.06	-
Initial	8.08	0.20	132.3	4.40	163.00	10.20	560.11	23.32	4.48	3.96	0.60	1.78

Table 2. Effect of different slow release and controlled release fertilizers on soil available nitrogen and phosphorus balance at harvest of the soybean (Pooled data of two years)

Treatment details	Initial soil avail. N (kg ha^{-1})	N added through fertilizer (kg ha^{-1})	N added through FYM (kg ha^{-1})	Total N uptake (kg ha^{-1})	After harvest soil avail. N (kg ha^{-1})	N Apparent gain/ loss (kg ha^{-1})	Actual diff. of initial and final (N kg ha^{-1})	N gain/ loss over initial (%)	Initial soil avail. P (kg ha^{-1})	P added through fertilizer (kg ha^{-1})	P added through FYM (kg ha^{-1})	Total P uptake (kg ha^{-1})	After harvest soil avail. P (kg ha^{-1})	P Apparent gain/ loss (kg ha^{-1})	Actual diff. of initial and final (P kg ha^{-1})	P gain/ loss over initial (%)
T_1-Absolute control	165.05	0	0.00	96.41	154.68	86.05	-10.37	-6.28	10.39	0.00	0.00	6.87	10.18	6.66	-0.21	-2.02
T_2-Recommended dose of fertilizer (N:P_2O_5:K_2O:S 30:60:30:20 kg ha^{-1}) + FYM- 5 Mg ha^{-1}, *Rhizobium* and PSB, micronutrients as per soil test	165.05	30	28.75	151.44	164.88	92.52	-0.17	-0.10	10.39	26.20	11.50	11.40	10.66	26.03	0.27	2.65
T_3-RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	165.05	30	28.75	166.22	168.63	111.05	3.58	2.17	10.39	26.20	11.50	12.03	11.10	24.96	0.71	6.79
T_4-RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	165.05	30	28.75	167.77	169.13	113.11	4.08	2.47	10.39	26.20	11.50	13.62	12.30	22.17	1.91	18.43
T_5-RDF through CDU + Polymer coated DAP + WDG of Sulphur	165.05	30	28.75	185.63	173.26	135.09	8.21	4.97	10.39	26.20	11.50	13.96	12.96	21.17	2.57	24.69
T_6-RDF through CDU + Polymer coated DAP + Bentonite Sulphur	165.05	30	28.75	203.44	172.93	152.57	7.88	4.77	10.39	26.20	11.50	15.25	13.36	19.48	2.97	28.59
T_7-RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	165.05	30	28.75	156.47	178.07	110.74	13.02	7.89	10.39	26.20	11.50	12.43	11.43	24.23	1.04	10.06
T_8-RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	165.05	30	28.75	158.92	177.15	112.28	12.10	7.33	10.39	26.20	11.50	12.03	11.62	24.44	1.23	11.84
T_9-RDF through SCU + Polymer coated DAP + WDG of Sulphur	165.05	30	28.75	167.62	183.63	127.46	18.58	11.26	10.39	26.20	11.50	12.73	12.21	23.15	1.82	17.56
T_{10}-RDF through SCU + Polymer coated DAP + Bentonite Sulphur	165.05	30	28.75	171.73	179.66	127.59	14.61	8.86	10.39	26.20	11.50	13.41	11.84	22.84	1.45	13.91
Mean	**165.05**	**27**	**25.88**	**162.57**	**172.20**	**116.93**	**7.15**	**4.33**	**10.39**	**23.58**	**10.35**	**12.37**	**11.77**	**20.18**	**1.38**	**13.25**

Table 3. Effect of different slow release and controlled release fertilizers on soil available nitrogen and phosphorus balance at harvest of the soybean (Pooled data of two years)

Treatment details	Initial soil avail. K (kg ha^{-1})	K added through fertilizer (kg ha^{-1})	K added through FYM (kg ha^{-1})	Total K uptake (kg ha^{-1})	After harvest soil avail. K (kg ha^{-1})	K Apparent gain/ loss (kg ha^{-1})	Actual diff. of initial and final (K kg ha^{-1})	K gain/ loss over initial (%)	Initial soil avail. S (kg ha^{-1})	S added through fertilizer (kg ha^{-1})	S added through FYM (kg ha^{-1})	Total S uptake (kg ha^{-1})	After harvest soil avail. S (kg ha^{-1})	S Apparent gain/ loss (kg ha^{-1})	Actual diff. of initial and final (S kg ha^{-1})	S gain/ loss over initial (%)
T_1-Absolute control	563.00	0.00	0.00	27.60	556.25	20.84	-6.75	-1.20	23.70	0.0	0.00	6.11	21.09	-3.50	-2.62	-11.03
T_2-Recommended dose of fertilizer ($N:P_2O_5:K_2O:S$ 30:60:30:20 kg ha^{-1}) + FYM- 5 Mg ha^{-1}, *Rhizobium* and PSB, micronutrients as per soil test	563.00	24.00	33.25	39.51	599.07	18.33	36.07	6.41	23.70	20.0	3.75	10.25	23.03	14.17	-0.67	-2.83
T_3-RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	563.00	24.00	33.25	44.27	564.76	11.22	1.76	0.31	23.70	20.0	3.75	11.41	23.98	12.06	0.28	1.18
T_4-RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	563.00	24.00	33.25	45.23	568.25	6.78	5.25	0.93	23.70	20.0	3.75	12.05	24.26	11.14	0.56	2.36
T_5-RDF through CDU + Polymer coated DAP + WDG of Sulphur	563.00	24.00	33.25	48.93	568.11	3.22	5.11	0.91	23.70	20.0	3.75	13.84	28.16	5.46	4.46	18.81
T_6-RDF through CDU + Polymer coated DAP + Bentonite Sulphur	563.00	24.00	33.25	51.88	565.63	2.74	2.63	0.47	23.70	20.0	3.75	14.73	30.04	2.69	6.34	26.75
T_7-RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	563.00	24.00	33.25	41.85	587.84	9.43	24.84	4.41	23.70	20.0	3.75	10.65	23.98	12.82	0.28	1.16
T_8-RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	563.00	24.00	33.25	42.36	586.36	8.46	23.36	4.15	23.70	20.0	3.75	11.01	24.72	11.72	1.02	4.30
T_9-RDF through SCU + Polymer coated DAP + WDG of Sulphur	563.00	24.00	33.25	47.64	564.13	8.48	1.13	0.20	23.70	20.0	3.75	13.05	25.84	8.56	2.14	9.05
T_{10}-RDF through SCU + Polymer coated DAP + Bentonite Sulphur	563.00	24.00	33.25	48.21	567.90	4.15	4.90	0.87	23.70	20.0	3.75	12.90	27.48	7.07	3.78	15.94
Mean	**563.00**	**21.60**	**29.93**	**43.75**	**572.83**	**-2.05**	**9.83**	**1.75**	**23.70**	**18.0**	**3.38**	**11.60**	**25.26**	**8.22**	**1.56**	**6.59**

Table 4. Effect of different slow release and controlled release fertilizers on seed and straw yield of soybean (Pooled data of two years)

Tr. No.	Treatment details	Seed yield (q ha^{-1})	Straw yield (q ha^{-1})
T_1	Absolute control	17.92	24.63
T_2	RDF ($N:P_2O_5:K_2O$:S 30:60:30:20 kg ha^{-1}) + FYM- 5 Mg ha^{-1}, *Rhizobium* and PSB, micronutrients as per soil test	25.47	33.40
T_3	RDF through CDU + Karanj oil coated DAP + WDG of Sulphur	27.39	35.08
T_4	RDF through CDU + Karanj oil coated DAP + Bentonite Sulphur	27.60	35.62
T_5	RDF through CDU + Polymer coated DAP + WDG of Sulphur	28.86	38.92
T_6	RDF through CDU + Polymer coated DAP + Bentonite Sulphur	30.29	41.43
T_7	RDF through SCU + Karanj oil coated DAP + WDG of Sulphur	25.91	34.15
T_8	RDF through SCU + Karanj oil coated DAP + Bentonite Sulphur	26.18	33.86
T_9	RDF through SCU + Polymer coated DAP + WDG of Sulphur	27.32	36.21
T_{10}	RDF through SCU + Polymer coated DAP + Bentonite Sulphur	27.83	37.36
	Mean	**26.48**	**35.07**
	SE±	0.59	1.39
	CD 5 %	1.76	4.16

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