Controlled and slow release fertilizers for enhanced growth and productivity in oilseed crops

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Abstract

The demand for oilseeds has increased at a very high rate due to the increasing global population and improved standard of living. Heavy doses of chemical fertilizers were applied to soil to fulfill the increased demand for edible oil. However, due to low-nutrient use efficiency and other environmental factors such as rainfed conditions, most chemical fertilizers are lost to the environment through leaching, runoff, emissions, and volatilization, etc. These conditions decrease the soil fertility, and as a result, reduce crop productivity and increase the nitrogen accumulation in plant parts. Crop productivity in terms of response to fertilizers can be sustained only if soil fertility levels are maintained to match crop needs and in proper proportions. Evolving strategies and policies are needed to increase quantities of nutrients, and evolving technologies are needed to increase fertilizer use efficiency and decrease the nutrient losses to environment. One such strategy is the use of controlled and slow-release fertilizer technology. This review highlights that the application of such customized slow-release fertilizers to oilseed crops can enhance the crop growth, nutrient use efficiency, photosynthetic activity, and yield and productivity of the oil seeds.

Keywords: Chemical fertilizer, Oilseed, Nutrient use efficiency, Photosynthetic activity, Slow-release fertilizer, Yield

Introduction

Growth and sustainability in agricultural sector are required to meet the global need for food and agricultural products. The decreasing trends in crop productivity may be related to the hidden hunger of other limiting nutritional factors in agricultural fields which may be corrected by adding them in adequate quantities, which can put back agricultural production on sound footing [1]. The requirement for edible oil will be much greater in view of the burgeoning population and improved standard of living. The global demand for vegetable oil is projected to increase by 33 million tons by 2030 (OECD/FAO 2021). In India, oilseed production is expected to increase to approximately 35 to 40 million tons (MT) by 2030-31, with the gap between demand and supply likely to increase to 3 MT by 2025-26 and 6 MT by 2030-31, even if per capita incomes increase by just 5.1%. Considering the increased demand for edible oil, there is an urgent need for enhanced yield and productivity of oilseed crops in addition to improved seed quality. Heavy doses of chemical fertilizers were applied to oilseed crops to fulfill the increased demand. However, due to low-nutrient use efficiency and other environmental factors such as rainfed conditions, most chemical fertilizers are lost to the environment through the leaching, runoff, emissions and volatilization [2-7]. Nitrogen (N) application rates have increased approximately 15-fold during the last five decades, whereas N accumulation in the grain has increased up to approximately fourfold, and the remaining fraction of the applied chemical N lost in the environment [8]. In addition, the volatilization of NH_3, nitrification, and denitrification of volatilized nitrogen also add to global warming, the depletion of the ozone layer, and acid rain in the atmosphere [9, 10]. Thus, the large increase in the consumption of nitrogen fertilizers represents a potentially alarming situation from the environmental, economic, and resource conservation points of view and indicates an urgent need for improving the efficiency of fertilizer use. These losses are due to the significant waste of precious energy used for the synthesis of chemical fertilizers, the foreign currency invested in the import of chemicals used as precursors as well as synthesized fertilizers, and the cost subsidies given to farmers. Heavy loading of chemical N fertilizers also causes excessive vegetative growth, plant lodging, susceptibility of crops to diseases and insect pests and depletion of other nutrients in the plant rhizosphere, especially those not routinely added to soil, e.g., micronutrients. Leaching losses cause serious environmental hazards, e.g., high nitrate and nitrite levels in ground water and water bodies; eutrophication of streams and lakes; and soil acidification caused by leaching and runoff of excessive N-salts applied as fertilizers as well as destruction of the ozone layer [10, 11]. Considering the severity of this problem, many alternative strategies have been suggested. A substantial improvement in fertility management can be expected from programming nutrient supply rates to fit the physiological requirements at the different growth stages of plants and from simultaneously reducing nutrient losses, for better performance under salinity stress as well as cost bases of minerals, transportation, equipment, and labor [12]. Nitrogen application should be performed according to the demand of crops [13, 14]. The application of slow-release fertilizers (SRFs)/controlled-release fertilizers (CRFs) can potentially contribute to these goals. Slow (control) release fertilizers, especially those containing nitrogen, reduce nutrient losses because at any given time, only a small fraction of the total application is present in a readily leachable form [15-17]. SRFs are produced by immobilizing chemical fertilizer, within solid materials, such as impermeable or semipermeable coatings, through which dissolved nutrients diffuse. Slow-release fertilizers are those fertilizers containing plant nutrients in a form that delay nutrient availability significantly longer than the reference "rapidly available nutrient fertilizes" such as ammonium nitrate or urea (Association of American Plant Food Control Officials, 1995). SRFs are supplied to various oilseed crops to increase their growth, nutrient use efficiency, and productivity.

Effect of slow release fertilizers on growth and productivity

The growth of oil palm plants treated with a single annual application of slow-release fertilizer or four applications of compound fertilizers was generally superior to that of plants receiving 9-12 applications of standard fertilizers. Although slow-release fertilizer has the potential to replace traditional fertilizer, its high cost and lower net returns may limit its use [18].

Table 1: Effect of slow-release fertilizers on growth, nutrient use efficiency, and productivity of oilseed crops

Plant species	SRF used	Growth and yield attributes	Reference
Oil palm	Slow release fertilizer	Increased growth	Sidhu *et al.* 2000
Brassica compestris cv. Kuromaru Komatruna	Poly-olefin coated urea (POCU)	Increased the N-use efficiency, N content, N uptake, fresh weight, and yield	Ombodi and Saigusa 2000
Soybean	Slow controlled release fertilizer	Higher dry matter accumulation and seed yield	Zhang *et al*. 2002
Long leaf pine	Controlled release fertilizer	Improved seedling growth and quality	Dumroese *et al*. 2005
Indian mustard (*Brassica juncea*)	Organic matrix-based slow release fertilizer (SRF)	Increased growth and yield	Sharma and Singh 2011
Soybean	Slow release nitrogen fertilizer	Increase in seed yield, straw yield, seed oil %, crude protein %, and total carbohydrates	Abou-Zied *et al*. 2014
Brassica napus L. Xiangzayou 1613	Controlled-release fertilizer	Higher growth and seed yield	Tian *et al*. 2016
Oilseed rape (*Brassica napus* L.)	Biochar-based controlled-release nitrogen fertilizer – BCRNF	Promoted growth and enhanced yield	Liao *et al*. 2020
Sunflower	Slow release nitrogenous fertilizers	Significantly enhanced crop growth and yield	Waqar *et al*. 2022

The application of polyolefin-coated urea (POCU) increased the fresh weight and yield of *Brassica campestris* cv. Kuromaru Komatruna during the autumn rainy season as compared to those under nitrogen fertilizer, such as urea [19].

The effects of slow/controlled-release fertilizer on dry matter accumulation/partitioning, nutrient absorption, and yield of soybean plants were investigated by Zhang *et al*. 2002. Higher amounts of dry matter accumulated in the slow/controlled-release fertilizer-treated plants than in the control plants.

Increasing the amount of nitrogen applied to container long leaf pine plants by incorporating controlled release fertilizer (CRF) into the media improved the seedling growth and quality [20]. Compared with control plants that received 40 mg N, plants that received 66 mg N through CRF supplemented with liquid fertilizer had needles that were 4 inch (10 cm) longer and had 42%, 84%, and 47% greater root collar diameter, shoot biomass, and root biomass, respectively (Table 1).

Organic matrix-based slow-release fertilizers (SRF-I and SRF-II) applied to Indian mustard (*Brassica juncea* L cv. Pusa Bold) enhanced biomass production in terms of both fresh and dry root weights and fresh and dry leaf weights [21]. The organic matrix-based SRF-II significantly increased the seed yield by 28% in Indian mustard. Cost analysis revealed that this formulation is cost effective because it is based on agro-waste materials.

The application of sulphur-coated urea (SCU), phosphogypsum-coated urea (PGCU), and bentonite-coated urea (BCU) to soybean plants significantly increased the plant height, 100-seed weight and, ultimately the seed yield per plant. All forms of coated urea increase grain or seed yields by 3-16% [22].

The application of controlled-release fertilizer (CRF) to early ripening rapeseed (*Brassica napus* L. Xiangzayou 1613) grown in the red-yellow soil of southern China resulted in higher seed yields than soluble fertilizer (SF) in both seasons by 14.51%. In each group, CRF4 and SF3 in each group achieved the maximum seed yield (2066.97 and 1844.50 kg/hm^2, respectively), followed by CRF3 (1929.97 kg/hm^2) and SF4 (1839.40 kg/hm^2) [23].

Compared with urea treatment, the application of the biochar-based controlled release nitrogen fertilizer (BCRNF) to oilseed rape plants (*Brassica napus* L.) successfully enhanced the yield (~16.6%). BCRNF significantly improved soil NO^{3-}, leading to an increase in N uptake by rape and NUE, thereby promoting rape growth and increasing grain yield [24].

Slow-release nitrogenous fertilizers were applied to sunflower crops under arid climatic conditions to improve sunflower productivity and minimize N losses [25]. Treatment with neem-coated urea (148 kg N ha^{-1}) significantly enhanced the crop growth rate (CGR) (19.16 g m^{-2} d^{-1}); leaf area index (2.12, 3.62, 5.97, and 3.00) at 45, 60, 75, and 90 days after sowing

(DAS); total dry matter (14.27, 26.29, 122.67, 410, and 604.33 g m^{-2}) at 30, 45, 60, 75, and 90 DAS, respectively. Similarly, neem-coated urea produced the maximum achene yield (2322 kg ha^{-1}), and greatest biological yield (9000 kg ha^{-1}), and greatest harvest index (25.8%) for the sunflower crop.

SRFs provide nutrients to crop plants for longer periods at different growth stages. Nutrients are immobilized in the coatings and matrices used in the preparation of slow-release fertilizers and are released into the soil slowly in accordance with the crop requirements. In this way, crop plants utilize the nutrients completely without any losses to the environment. This process has improved the product quality of the oilseeds, produced more biomass and yield, and has reduced the risk of various environmental and health hazards.

Effect of slow release fertilizers on nitrogen use efficiency

Compared with urea, polyolefin-coated (POCU) applied to *Brassica campestris* cv. Kuromaru Komatruna during the autumn rainy season increased the N use efficiency, N content, and N uptake [19].

The long-term release of controlled release-fertilizer reduced the N absorption at earlier stage in soybean plants. However, controlled release fertilizers can increase the absorption of K+ to a certain extent, but have no effect on the absorption of PO_4 [26].

The application of organic matrix-based slow release fertilizer (SRF-II) to Indian Mustard (*Brassicajuncea* L. cv. Pusa Bold) increased the acquisition and assimilation of nitrate from the plant rhizosphere, as indicated by a 45.6% increase in nitrate content, 27.5% in increase nitrite content, and 11.7% increase in nitrate reductase activity (NRA) in the leaves of 45-d-old plants compared with those of control plants [21].

Compared with soluble fertilizer, controlled-release fertilizer (CRF) significantly increased the N, P, and K uptake and usage efficiency in early-ripening rapeseed plants (*Brassica napus* L. Xiangzayou 1613) in the red-yellow soil of southern China [23].

Compared with those of soluble fertilizer (SF), the N accumulation and N use efficiency of CRF increased by an average of 13.66% and 9.74%, respectively.

Compared with urea treatment, biochar-based controlled release nitrogen fertilizer (BCRNF) enhanced the nitrogen use efficiency (~58.79%) of oilseed rape plants (*Brassica napus* L.) by slowly releasing N and modulating the abundance of functional microbes through increased soil nitrification and reduced denitrification [24]. BCRNF significantly improved soil NO^{3-}, leading to an increase in N uptake by rape and NUE.

Sunflower plants require consistent amount of nitrogen for optimum growth and development. However, NUE of sunflower crops is low due to the loss of various nitrogen (N) sources. Four types slow-release nitrogenous fertilizers [SRNF (bacterial, neem, and sulfur-coated urea and N-loaded biochar)] and three N levels (100% = 148 kg N ha^{-1}, 80% = 118 kg N ha^{-1}, and 60% = 89 kg N ha^{-1}) of the recommended application (100%) were supplied to sunflower plants under arid climatic conditions [25]. Among the various N fertilizers, neem-coated urea had a greater NUE (for N applied) than did the other in comparison to other slow-release N fertilizers. Similarly, N_{60} had a greater NUE (22.40 kg grain yield kg^{-1} N applied) than did N_{80} and N_{100}.

Clearly, from the literature, the application of SRFs significantly increased the nutrient use efficiency of crop plants. The nutrients are entrapped/immobilized within coating materials (semipermeable and impermeable) and matrices that act as walls for the release of nutrients. The matrices and coatings used for the immobilization are chemical and organic (containing agro waste materials) in nature. Therefore, when these materials (organic) are added to the soil, the soil microbial activities increase, thus increasing the soil nitrate and phosphate levels. The availability of soil nitrate and phosphate increase the N and P uptake by the plants and thus resulted in greater nutrient use efficiency.

Effect of slow release fertilizers on photosynthetic activity

Application of controlled release fertilizer to *Brassica napus* plants significantly enhanced the stomatal conductance and transpiration rate as compared to the conventional fertilizer and no fertilizer [27].

The bacterial coated urea at the highest rate of N application (160 kg ha^{-1}) resulted in a higher net leaf photosynthetic rate (32.8 µmol m^{-2} s^{-1}), leaf transpiration rate (8.10 mmol s^{-1}), and stomatal conductance (0.502 mol m^{-2} s^{-1}) in cotton plants [28].

Higher values of net leaf photosynthetic rate (25.2 µmol m^{-2} s^{-1}), transpiration rate (3.66 mmol s^{-1}), and leaf stomatal conductance (0.39 mol m^{-2} s^{-1}) were recorded in sunflower plants with the application of slow release nitrogenous fertilizers (neem-coated urea) [25].

The higher values of net photosynthetic rate were recorded at the blooming stage and fruiting stage in peanut plants when applied with slow release fertilizers [29]. The best results were obtained for T2 (homemade large granular slow-release fertilizer, LSRF), with 15.00% and 51.1% increase in pod and fruit set, respectively, compared to T1 (common commercially available urea). T2 increased the stomatal conductance by 102.5% and 89.5% at the blooming stage as compared to T0 (control) and T1, respectively (Table 2).

Table 2: Effect of slow-release fertilizers on photosynthetic parameters of oilseed crops

Plant species	SRF used	Growth and yield attributes	References
Brassica napus	Controlled release fertilizer	Net photosynthesis increased significantly	Li *et al*., 2012
Cotton	Slow-release nitrogen fertilizers (Bacterial coated urea)	Highest rate of N application (160 kg ha^{-1}) resulted in a higher net leaf photosynthetic rate (32.8 μmol m^{-2} s^{-1}), leaf transpiration rate (8.10 mmol s^{-1}), and stomatal conductance (0.502 mol m^{-2} s^{-1})	Manzoor *et al*., 2022
Sunflower	Slow-release nitrogen fertilizers (neem-coated urea)	Higher values of net leaf photosynthetic rate (25.2 μmol m^{-2} s^{-1}), transpiration rate (3.66 mmol s^{-1}), and leaf stomatal conductance (0.39 mol m^{-2} s^{-1}) were recorded	Waqar *et al*., 2022
Peanut	Granular slow-controlled release fertilizer	A significant contribution to the net photosynthetic rate was made for growth development and yield in the middle and late stages	Meng *et al*., 2024

The increase in net photosynthetic rate may be due to the more chlorophyll contents of the leaves as the more production of proteins supports the increase in leaf area and chlorophyll contents. The large leaf surface will have more number of stomata which contributes to higher transpiration rate. The stomatal conductance increases due to the better growth of plants.

The controlled and slow release fertilizers release nutrients slowly in a sustained manner in accordance with crop needs. SRFs significantly enhance the growth and productivity of various oilseed crops. These fertilizers increase nutrient use efficiency and photosynthetic activity and as a result reduce the nutrient losses. The SRFs also improve soil fertility by increasing soil microbial activities. Slow-release fertilizers are eco-friendly and cost effective formulations and are the best alternatives to the chemical fertilizers.

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