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Nutrient and PGR Based Foliar Feeding for Yield Maximization in Pulses: A Review

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ABSTRACT

Pulses are the cheapest and pioneer source of protein for human diet. They have immense potential in improving human health, conserving soil, protecting the environment and contributing to global food security. However, productivity of pulses is lower compared to cereals. Application of nutrients *via* foliage, in addition to recommended dose of fertilizers (RDF) and plant growth regulators (PGRs) at critical growth stages is a unique and easy way to increase the pulse productivity by curbing the barriers encountered during flowering and pod setting. Nutrients applied *via* foliage will be absorbed and translocated into the vascular system and made available for plant metabolism. The commonly used fertilizers for foliar application are urea, DAP, K_2SO_4 and micronutrient mixtures. Foliar application of PGRs can modify the source-sink relationship by stimulating the photo-assimilate translocation leading higher productivity. PGRs like NAA, IBA, salicylic acid, brassinosteriods *etc.* are effective for foliar application. Providing nutrients as wells as PGRs are known to enhance the yield by 15-25% compared to soil nutrition alone.

Key words: Assimilate partitioning, Critical growth stage, Foliar application, Plant growth regulators, Productivity, Pulses, Source sink limitation, Translocation, Yield maximization.

Pulses are nature's amazing gift with incomparable abilities like deep root system, biological nitrogen fixation, mobilization of insoluble soil nutrients and are called as soil fertility restorers as they bring qualitative variations in soil properties (Kumar *et al.*, 2018). Pulses are the most affordable dietary protein in a cereal dominant vegetarian Indian diet contributing about 14% of the total protein need (Yadav *et al.,* 2017). They are good source of vitamins like riboflavin, thiamine, niacin and minerals like iron (Fe), calcium (Ca) and phosphorus (P) (Venkidasamy *et al.,* 2019). About 33% of world area and 22% of world production of pulses is contributed by India covering an area of about 28.1 mha with an annual production of 18.31 mt, with a productivity of 835 kg ha^{-1} (Deol *et al.,* 2018). Average per capita consumption of pulses in India has shown a declining trend from 64 g in 1950 to 35 g day^{-1} in 2011, however, it has increased to 56 g day^{-1} in 2018 (Tiwari and Shivhare, 2017). Continued population upsurge necessitates the need for the greater supply of plant protein which already has remained too short of its requirement. This has led to an increment in annual import of pulses overall from 0.50 mt to 1.80 mt during the last 5 years, causing a reduction in the contribution of pulses in the national food basket from 17% to 7% (DPD, 2018). There is a dire need to stress upon pulse cultivation to advance food and nutritional security and to offset the gap between demand and supply. However, breaking the trap of low productivity is critical for Indian pulses to be globally competitive.

Reasons for low productivity of pulses

The average yield of pulse crop in India is only 835 kg ha^{-1} (Table 1) which is very less in comparison to the potential yield and there exists an exploitable yield gap between the potential farm yield and actual average farm yield in almost all pulses. For *e.g*. in case of redgram, the actual yield is 74% lower than that of its potential yield as reported by Tiwari and Shivhare, 2017.

The important factors for yield reduction in pulses are; ecological factors, socio-economic constraints, constraints in post-harvest technology, susceptibility to pest and diseases, varietal constraints, low input use and physiological limitations. Among these, physiological limitations have significant importance as it reduces the yield drastically in pulses (Karamanos and Gimmenz, 1991; Narayanan and Kumar 2015; Deol *et al.,* 2018).

There are certain inherent physiological factors which contribute to yield gap in pulses. The important limitations are;

Diversion of metabolic energy to sinks for protein synthesis

In general, pulses are high energy requiring crops, as it can fix Nitrogen N from the atmosphere in the roots. Nitrogen assimilation *via* N_2 fixation involves higher metabolic energy expenditure than root uptake of nutrients. This is due to high nitrogen requirement of nitrogenase enzyme and for growth

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Table 1: Status of pulse production in India.

Crop	Area (lakh ha)	Production (lakh tones)	Yield (kg ha^{-1})
Bengal Gram	105.73	111.58	1056
Red gram	44.59	41.80	937
Blackgram	50.31	32.84	653
Green gram	40.70	19.01	467
Other Kharif pulses	18.74	7.99	426
Other Rabi pulses	33.53	31.83	903
Total	**293.60**	**245.06**	**835**

(MoA and FW, GOI, 2018)

and maintenance of root nodules (Lynch and Wood, 1988). This additional energy requirement results in diversion of energy to fix N_2 rather than used for growth processes. For fixing one molecule of N, it requires about 20 molecules of ATP. In case of dry matter production in non-nodulating crop, it requires about 530 mg of CO_2, on the other hand, for pulses, which are nodulating, it requires about 810 mg of CO_2. Munier-Jolain and Salon (2005) attributed lower productivity in legumes to the higher energy costs due to protein-rich seed production. Also, there is competition for photosynthates between early formed and late formed inflorescence, which results in low rate of photosynthetic influx to late formed ones. Thus, they fail to form powerful sinks (Deol *et al*., 2018).

Source limitation and lower leaf area development

Another inherent cause leading to low yield in pulses is the inadequate supply of nutrients to developing embryos. Pulses are source limited crops. Yoshida (1972) stated that source size is important for productivity. Furthermore, in pulses overlapping of vegetative and reproductive phase, high energy requirement for protein formation and unit allocation for dinitrogen reduction causes constant changes in source size and activity (Fahad *et al.,* 2017). Inadequate source size of pulses may lead to lower growth attributes (Deol *et al.,* 2018).

Slow dry matter accumulation

Pulses are characterized with slow initial dry matter accumulation due to their lower leaf area index (LAI), extinction coefficient and photosynthetic rates. Sheldrake and Saxena (1979) studied dry matter accumulation pattern in chickpea (*Cicer arietinum* L.) and concluded that around 60-80% of total dry matter is accumulated in one- third to one-fourth period in the life cycle which is mostly in post-flowering phase.

Decline in nodule activity

In pulses, the number and weight of nodules per plant increases up to flowering, but in post-flowering stage there is a sudden decline in number of nodules due to disintegration. Sinha *et al.* (1988) reported that there is decrease in nitrogen (amino nitrogen) per plant in legumes during post-flowering stage. The level of nitrogen content especially in legume leaves shows their ability to utilize inorganic nitrogen which ultimately affect yield.

Indeterminate growth habit

Inherently pulse crops possess indeterminate growth habit and summer sown pulses pose the threat especially when summer rainfall turns erratic. Due to indeterminate nature of pulses there is a competition between the vegetative and reproductive sink (inter organ competition) resulting in ineffective partitioning of assimilates. This competition causes failure of pods to set seeds, low partitioning coefficient, poor harvest index, lower seed yields and seed quality (Nithila and Shivakumar,2017, Deol *et al.,* 2018).

C_3 photosynthetic apparatus

Pulses being C_3 plants are potentially low yielders and sometimes considered physiologically inefficient compared to C_4 cereals such as sorghum, maize *etc.* (Reddy, 2009). In C_3 plants rubisco enzyme has more affinity towards O_2 than CO_2, photorespiration will occur which make rubisco inefficient (Sharma-Natu and Ghildiyal, 2005). Lower light saturation point and higher CO_2 compensation point of C_3 pulses generally reduce photosynthetic rate leading reduced yield (Ainsworth and Long, 2005). Furthermore, in the post-flowering period, a serious decline in photosynthetic rate has been observed which is attributed to factors such as loss of activity of RuBP and reduced total nitrogen content in leaves following the flowering period (Sage and Kubien 2007).

Pod and flower abscission

In pulses each flower is capable of producing greater number of seeds, which makes its yield potential higher than cereals. However, high flower shedding due to less photosynthesis, hormones, inhibitors, gas exchange in canopies, humidity, soil and water factors and other genetic factors reduces yield drastically. In pulses, at the maturity stage, photoassimilates are stored more in mature pods which lead to immature pod shedding (Majumdar, 2011).

Stress caused due to high temperature, low temperature, water or other may lead to production of abscisic acid in pulses. Limited nitrogen availability due to disintegration of nodules at the peak flowering stage further accelerate the shedding process. In pigeon pea, almost 80% flower produced are shed leading to very poor yield (Ramesh and Thirumurgan, 2001).

To overcome these problems and to provide balanced nutrition, additional feeding through foliar nutrition can be done which will help to stimulate better growth, nodulation of roots and assimilate partitioning for enhancing the productivity.

Foliar nutrition

Foliar nutrition *i.e.* fertilizer and plant growth regulator (PGR) application through foliage serves as an effective and convenient method of nutrition and growth stimulation as it facilitates quick and easy absorption through stomatal

openings or cuticles which may result in quick and efficient response (Patil and Chetan, 2018). Foliar nutrition is a way of nourishing plants using liquid fertilizer directly to foliage. Plants are capable of absorbing all essential nutrients through leaves. Plants take nutrients rapidly through stomatal opening, but total absorption may be higher through the epidermis. Apart from this, plant take nutrients *via* bark also. Foliar nutrition is important when soil nutrient availability or root activity is reduced and can be opted as a choice when quick adjustment of nutrient deficiencies is required. Nutrient sprays can be given at any point of time during the growing season to improve the appearance, colour, size and quality of fruits. Foliar fertilization can be given in combination with herbicides, insecticides, fungicides *etc.* and is more efficient during adverse climatic conditions such as drought, disease or insect attack (Ahmad *et al.,* 2019).

Foliar fertilization is found most efficient in situations where soil moisture is inadequate and the roots are not able to uptake the nutrients from soil, leaching of nutrients, low soil temperature and high degree of fixation (Singh *et al*., 1970). Foliar application of fertilizers helps to get nutrients efficiently and will reduce the environmental pollution by reducing the amount of fertilizers added to the soil (Abou El-Nour, 2002).

Asserting the need for foliar nutrition

Nutrients are essential to plants for increasing the productivity and can be applied either through soil or foliage. For increasing crop production, application of nutrients through foliage is found to be a good practice as supplement to soil application (Alam *et al.,* 2010). When the nutrients are applied through soil, it may result in lesser efficiency of the particular nutrients. It is because nutrients given *via* soil can be lost through leaching and volatilization. Also adverse soil conditions like inadequate soil moisture, water logging, salinity, pH imbalance *etc* would make unable the plants to absorb nutrients (Deol *et al*., 2018). This lack of nutrients especially at critical stage may result in flower abscission, flower drop leading to poor pod setting and reduced yield (Mahala *et al*., 2001). To make nutrients available at critical period of requirement, foliar application of nutrients is vital. In rainfed farming, moisture availability may not be uniform and under such situation, foliar spray will provide effective absorption of nutrients with respect to economics also. The other striking factors limiting yield like flower drop and senescence as well as poor pod fillings can also be corrected by nutrient and PGR spray directly foliage. Foliar application of nutrients helps to translocate the nutrients from leaves to all parts therby helps in synchronizing flowering as well as pod setting.

PGRs when applied to the foliar will be directly taken by the plants which will alter the source sink dynamics and promotes faster translocation of photo-assimilate to the growing reproductive regions and ultimately enhance productivity of the crops (Amanullah *et al.,* 2010). PGR application will reduce the flower drop and improve pod formation and seed setting (Mir *et al*., 2010). Studies have shown that, TNAU Pulse wonder, polyfeed and growth regulators like NAA spraying will reduce flower drop (Raj *et al*., 2016; Sathishkumar *et al.,* 2020).

Physiology of foliar nutrition

Ability of leaf to absorb nutrients was first recorded by Gris (1844). Die-back disease in citrus due to Cu deficiency corrected by Bordeaux-mixture application on leaves (Floyd,1917) had proved the concept. In 1950s, radioisotope were introduced and it marked the understanding foliar uptake of organic and inorganic ions (Biddulph *et al*., 1958).

Nutrient must enter into the leaf prior to entering the cytoplasm for effective utilization by the plant. For achieving this, the nutrient applied must cross the outer cuticle and enter into the epidermal cell. After penetration, absorption of nutrients is similar as in case of roots. Once penetration has occurred, nutrient absorption by the cell is similar to absorption by the roots. Along the pathway, the outermost cuticle offers high resistance for the absorption of applied nutrients in the foliage.

Stages in foliar uptake of nutrients

There are two steps in uptake of nutrients through leaves. First step is penetration of molecules via stomata or cuticle of leaf from where it is translocated through vascular channels (xylem, phloem) *via* cell to cell transport of ions to the site finally where they are consumed.

Role of plant morphology and structure

The cuticle serves as an efficient barrier against the loss of water and also it facilitates effective uptake of foliar nutrients (Fageria and Baligar, 2005). The nutrient applied through foliage will cross the leaf surface *via* the cuticle along cuticular cracks or imperfections, or through modified epidermal structures such as stomata, trichomes or lenticels (Fageria *et al*., 2009). The structure and chemistry of the plant surface will affect the rate of uptake of foliar fertilizers and also the bi-directional diffusion of substances between the plant, the leaf surface and the surrounding environment (Berry *et al.,* 2018).

Cuticular permeability

The cuticle consists of three layers, epicuticular wax layer (EW), cuticle proper (CP) and cuticular layer (CL). According to Fick´s first law, the diffusive flux is related to the concentration gradient with solutes moving from regions of high to low concentration with a magnitude that is proportional to the concentration gradient. According to the cuticular diffusion model, diffusive flux (J) is proportional to the permeability of the membrane multiplied by the concentration difference between the inner and the outer sides of the cuticle (Oosterhuis, 2009).

$$J = P * (C_i - C_o)$$

Stomatal permeability

Stomata plays a significant role in permitting the entry of nutrients applied to leaves. Foliar applied nutrients can penetrate into the leaf through stomata via mass flow

process. Foliar penetration rate is higher at abaxial side as compared to the adaxial side (Marschner, 2012).

Ectoteichodes and foliar absorption

Inorganic ions present in the foliar applied substance are taken up by the plant through special structures present in the inner surface of the cuticle which adjoins the epidermal cell. These are called 'ectodesmata', 'ectocythodes', or 'ectoteichodes' in the cell wall. Franke (1971) considers that these facilitate the entry of solutes across the cuticle and also the cell wall.

Leaf venation has also role in nutrient absorption. In case of a monocot leaf, the nutrients applied at the tip or middle of leaf move towards the base (Kannan and Keppel, 1977) and there is no lateral transport from one half to the other half of a monocot leaf. But in case of a dicot leaf including pulses, the nutrient applied at the tip will move towards the base as well as laterally due to reticulate venation. This points to the effectiveness of foliar feeding in pulses (Kannan, 1978).

Uptake by the leaf cells and transport from the leaf

Plasma tubules provide connection from leaf cells to vascular system. The transport within the leaf follows two routes to reach the symplast and apoplast. Apoplastic movement is a passive process and hence it is slow process compared to symplast (Van Steveninck and Chenoweth, 1972). In the symplastic pathway, plasmodesmata and sieve plate pores act as communication channels. Foliar absorbed nutrients would largely move through the plasmodesmata to other cells, reach the sieve elements of the conducting tissues of the midrib and petiole and are transported to the shoot and root. Nutrients applied on to leaves will penetrate through leaf cuticle or stomata for easy and fast absorption into the cell (Latha and Nadanassababady, 2003). Foliar application increases the yield from 12 to 25% and it was found to be 20 times more effective than soil applied fertilizers. Foliar application is quick and has efficient utilization of nutrients, elimination of losses through leaching and fixation and regulating the uptake of nutrients by plants (Manonmani and Srimathi, 2009).

The main objective of foliar application is to allow greater absorption of plant available nutrients into the plant tissue for effective utilization. To avoid foliar damage, the foliar fertilizer formulations should meet certain standards (Fageria *et al*., 2009). Main attributes for foliar fertilizer materials are it should have high solubility as well as high purity with low salt index. We should apply nutrients like N, P and K through foliar application at low rate as it causes foliar burn if its concentration is high (Singh *et al.,* 2013).

Among nitrogenous fertilizers, urea is the most suitable nitrogen source for foliar applications, because of its low salt index and high solubility. If we use urea for foliar application, it should be with low biuret content to reduce the urea foliage burn. Foliar application of N at flowering stage may solve the problems like slow growth, nodule senescence and low seed yield of pulse crops without involving root absorption at critical stage (Latha and Nadanassababady, 2003).

The response of crop to foliar application of phosphorus depends on soil and climatic conditions, type of crop as well as concentration and source of fertilizers. The main water-soluble P fertilizers are single superphosphate [$Ca(H_2PO_4)_2 + CaSO_4$], triple superphosphate [$Ca(H_2PO_4)_2$], monoammonium phosphate [$NH_4H_2PO_4$], diammonium phosphate [$(NH_4)_2H_2PO_4$], monopotassium phosphate (KH_2PO_4) and phosphoric acid [H_3PO_4] which are being used as foliar spray (Rafiullah *et al.,* 2017).

A combination of poly and ortho-phosphates show less leaf burn and aid in leaf phosphate absorption (Zekhri, 2014). Depending on availability, potassium polyphosphates are an excellent source of K which has low salt index and high solubility. On the other hand, potassium sulfate has low salt index, but a rather low solubility (Patil and Chetan, 2018).

Based on the mobility in plant, nutrients can be freely mobile like N, P, K and Mo; partially mobile like Fe, Mn, Zn, Cu and B; and relatively immobile like Ca, Mg. Even among the nutrients, the time for absorption also varies. For *eg.* in case of nitrogen when applied as urea, it is absorbed within 30 minutes to 2 hours. But in case of nutrients like Fe, Mo, it may take about 10-20 days for 50% absorption (Alshaal and El-Ramady, 2017).

Plant growth regulators for foliar feeding

Plant growth regulators (PGR) are biochemicals which are produced in plants (endogenous) or synthetic chemicals which are applied to plants exogenously (Sathishkumar *et al*., 2020). The increased source-sink relationship using growth regulators includes enhanced transport of assimilates from source and thereby increased productivity (Shinde, 2010).

Application of growth regulators can help in overcoming these stresses and thus ensure higher germination percentage. Akbari *et al*. (2008) reported that application of gibberelic acid (GA_3) significantly improved green gram germination and yield attributes in saline conditions. GA_3 plays an important role in supplying stored assimilates in the germinating seeds to the growing embryo, thus significantly improves germination percentage and ensures proper plumule and radicle development. Srivastava *et al*. (2011) reported that brassinolide application (0.4 ppm) significantly improved green gram germination with highest germination percentage. In general, brassinolides are known to enhance seed germination and cause elongation of hypocotyls, epicotyls and peduncles in dicots. Yadav and Singh (2014) reported enhanced germination percentage, radicle length and plumule length in SML-668 and K-851 varieties of green gram with 2,4-D application.

Application of indole-3-acetic acid (IAA) was found to increase leaf numbers as well as yield-attributes such as number of pods per plant, seeds per pod and seed weight per plant due to better source development in green gram reported by Quaderi *et al*. (2006). GABA [GA_3 + abscisic acid (ABA)] @1ppm application resulted in significantly

greater number of leaves per plant and leaf area index (LAI) at all crop growth stages in blackgram (Islam *et al*., 2010). Parmar *et al.* (2012) reported that GA_3 (20 ppm) applied at 20 and 40 days after sowing (DAS) significantly increased number of leaves per plant in summer green gram. Try iodo benzoic acid (TIBA) is known to stimulate photosynthesis due to higher assimilative area production which leads to better growth, development and higher yield (Jahan and Khan, 2014).

PGR application improves the sink development through higher number of pods per plant, seeds per pod, seed weight, harvest index and other important yield attributes (Nithila and Shivakumar 2017). Ullah *et al*. (2007) reported significantly increased yield in cowpea with application of 1250 ppm potassium naphthenate (K-nap) which attributed to better sink development *i.e.,* higher number of pods per plant, seeds per pod, 1000 seed weight and harvest index. Application of 2,4-dichlorophenoxyacetic acid (2,4-D) @ 5 ppm resulted in significantly higher seed yield in pea (Thomson *et al.,* 2015).

Importance of wetting agent in foliar feeding

As there are a number of barriers for the foliar uptake of nutrients like presence of trichomes, cuticular resistance, stomatal resistance *etc*., which will increase the surface tension. The nutrients must break these all to enter into the cell. Therefore, any additive included in the aqueous sprays should reduce the surface tension and increase the surface area of absorption. The most commonly used surfactants are stanowet, volta 19, natural wet (McPhail and Duncan 2018).

With the use of efficient adjuvant, the foliar nutrient formulation can be considered as a best supplement to crops for correcting immediate deficiencies and to provide nutrients at critical growth stages, thus act a supplement rather than as a substitute to soil applied nutrients (Stevans 1993).

Factors favouring effective foliar feeding

a) Growth stage of crop

Nutrients should be applied through foliage as a supplement to soil application. It has to be done at proper growth stage so that it can be effectively utilized at post reproductive developmental stages. The immature leaves will absorb more of nutrients than the mature leaves.

b) Soil and crop health

Crops that are nutritionally sound will be most likely to respond to foliar feeding. Plants may show less response to foliar applications under poor soil condition or heat or moisture stress. Hence foliar feeding has to be done prior to stress for getting good response from the crop.

c) Proper meteorological conditions

Climatic factors such as rainfall, humidity, temperature, time of the day and wind speed affect the foliar applications due to effect on plant tissue permeability.

Spraying should be done before 9.00 am or after 6.00 pm as the temperature optimum being 21°C. The humidity at the time of spraying should be more than 70% with a wind velocity of less than 7.5 kmph (Patil and Chetan, 2018).

Influence of foliar application of nutrients and PGR on growth, physiology and yield of pulses

a) Growth attributes

Application of nutrients as well as growth regulators have important role which influence morphological character such as plant height, number of leaves, number of branches *etc*. Foliar spray of 0.05% $ZnSO_4$ at flowering and pod formation stage recorded higher plant height and number of branches in pigeonpea (Verma *et al*., 2004). According to Dwivedi *et al.* (2014) plant height (70.88 cm), dry matter accumulation (17.09 g per plant), number of branches (3.8 per plant) and pods per per plant (34.3) were considerably higher in black gram under foliar spray of 15% *Kappaphycus* Sap + RDF (20:40:20) than others treatments.

Rajesh *et al*. (2014) reported that the morphological characters, days to 50% flowering, total dry matter and maturity were profoundly increased when NAA @ 20 ppm was sprayed at 50% flowering in green gram. Jayakumar *et al.* (2008) found that, NAA at 40 ppm given through foliage at pre flowering stage in black gram produced higher plant height (30.1 cm), a greater number of branches (2.3) and higher leaf area index (2.94). Foliar application of urea apart from the basal application of recommended dose of fertilizers increased branching in chickpea by 8-23% over no spray or water spray (Venkatesh and Basu, 2011). Li Yunsheng *et al*. (2015) found that glutamine @ 25 ppm had a significant effect in the vegetative growth parameters of garden pea (plant height, number of leaves, number of branches, fresh and dry weight of leaves) in both the seasons of study compared to that of 100 ppm concentration. Increased plant height with NAA @ 10 ppm in black gram was reported by Reddy *et al*. (2004).

Foliar application of N@ 25 kg ha^{-1} + urea 2% + Brassinosteriod 0.1 ppm recorded higher leaf area (102.8, 246.1, 567.0 and 494.4 cm^2) at vegetative, flowering, pod filling and harvest stage respectively. The LAI increased upto pod filling stage and declined at harvest stage of black gram (Surendar *et al*., 2013). Ramesh and Ram Prasad (2013) reported that foliar application of NAA (20 ppm) and brassinosteroid (25 ppm) in soybean recorded higher growth attributes as well as higher CGR and RGR.

b) Physiological attributes

Seed treatment with Mo along with 2% urea spray twice at flower initiation and 15 days later resulted in greater level of chlorophyll-a, b and total chlorophyll in leaves. The substantial results for chl-a, chl-b and total chl were obtained when 7.5 ppm of Mo was sprayed (Datta *et al*., 2011). The stimulatory effect of 75 ppm boron applied through foliage on leaf chlorophyll content in broad bean and lupin plants was reported by Sharaf *et al*. (2009).

Srivastava, *et al*. (2011) conducted an experiment to study the effect of brassinolide @. 0.1, 0.2, 0.3, 0.4, 0.5,

0.6, 0.7, 0.8 ppm and control on germination of green gram (*Vigna radiata* L.). They reported that brassinolide application (0.4 ppm) significantly improved green gram germination with highest germination percentage (100%), germination index (1.89), speed of germination (1.53), coefficient of velocity of germination (59.3) and relative seed germination (126.4%).

Pegu *et al*. (2013) reported that foliar feeding with 100 ppm boron caused increase in the amount of total chlorophyll in leaf. Foliar feeding was found to be more effective when it was done at 20 and 35 days after sowing. In black soils, higher chlorophyll could be obtained by the application of 20 kg N ha^{-1} as basal + Rhizobium + PSB + PGPR seed inoculation + 2% urea spray at flowering and 10 days thereafter under rainfed conditions (Gupta *et al*., 2011). Foliar spray of brassinosteroid @ 0.1 ppm at 30 and 65 DAS resulted in higher chlorophyll content as well as fertility coefficient in pigeonpea (Sumathi *et al.,* 2016).

c) Yield components and yield

Molybdenum spray to leaves produced higher number of pods per plant, seeds per plant and seed yield in lentil (Togay *et al*. 2008). Khanal *et al*. 2009 found that molybdenum application to foliage increased growth as well as yield attributes in chickpea. Sashikumar *et al*. (2013) reported significantly higher grain yield (1298 kg ha^{-1}), number of pods/plant (38.73), number of seeds/pod (6.47) and test weight (61.90 g) in black gram.

According to Maral *et al*. (2012) foliar spray of amino acids (2 g L^{-1}) showed the highest seed yield (1166.8 kg ha^{-1}), number of pods per plant (54.1) and plant height (69.5 cm) in cowpea. Kumar *et al*. (2013) reported that foliar application of 2% DAP twice at flowering and pod formation stages of soybean produced significantly higher number of pods per plant. Amin *et al*. (2013) reported that foliar application of putrescine (Put) and/or IBA at 100 mg L^{-1} produced the highest numbers of pods which resulted in substantially the highest seed yield. Put and IBA increased the seed yield by 21.3 and 19.2%, respectively, while the combination of Put at 100 mg L^{-1} and IBA at 50 mg L^{-1} increased it by 27.4%.

Application of 100% recommended dose of NPK (25:50:25 kg ha^{-1}) + 2% DAP + TNAU pulse wonder at 5.0 kg ha^{-1} on 45 days after sowing can be recommended as a nutrient management strategy to exploit the genetic potential and enhancing the productivity of black gram (Marimuthu and Surendran, 2015).

Manivannan *et al.* (2002) found that foliar application of primary nutrients with chelated micronutrients had produced higher grain yield of blackgram. Pegu *et al.* (2013), reported that yield, root and physiochemical parameters under rainfed situation were influenced by foliar feeding with boron during summer season in black gram. Ganapathy *et al.* (2008) found that foliar nutrition of DAP 2% + NAA 40 ppm + $ZnSO_4$ 0.5% + $FeSO_4$ 1% at pre flowering and at flowering along with soil inoculation of phosphorous bacteria recorded significantly highest reproductive efficiency and grain yield of rice fallow pulses *viz*., black gram and green gram. Similarly, foliar spray of glutamine on growth, yield and quality of two snap bean varieties was reported by Li Yunsheng *et al*. (2015).

Surendar *et al*. (2013) indicated that the treatment combination (N 25 kg ha^{-1} + brassinosteriod 0.1 ppm + Urea 2%) was found to be the most effective treatment in improving the grain yield by 27% over control. A study was conducted by Raj *et al.* (2016) to know the effect of pulse magic on yield and yield attributes of transplanted pigeonpea. The variety used was BSMR-736. Pulse magic spray was given at 50% flowering and 15 days after first spray. The results revealed that average yield which was 13.64% higher yield over the check plot. Supplying pulse magic nutrients at reproductive stage of crop helped reduce the flower drop leading to higher yield.

Highest grain yield and yield attributes were recorded with 2% urea spray at 75 days after sowing (DAS). The results suggested that 2% foliar application of urea at 75 DAS significantly increased the seed size, leaf and seed nitrogen contents and also protein content of seeds. The nodule degeneration started at 60 DAS of crop growth stage, thereby lowering the nitrogen availability in leaves. Spraying 2% urea was found beneficial for increasing seed yield and quality in chickpea (Venkatesh and Basu, 2011).

Foliar spray of brassinosteroid @ 0.1 ppm at 30 and 65 DAS resulted in higher fertility coefficient, grain yield as well as harvest index. Application of PGRs increase the source activity during pod filling stage and thus diverts the assimilates for pod (sink)development. Spraying of brassinosteroid increases the activity of nitrate reductase helped in early flower induction. Higher yield due to higher chlorophyll content especially at later stages of crop growth enhances the photosynthetic activity and yield (Sumathi *et al.,* 2016).

Limbikai (2012) reported that foliar spray of 2% DAP + 40 ppm NAA at 45 and 55 DAS produced significantly higher seed yield (1202 kg ha^{-1}). Foliar spray of NAA @ 40 mg L^{-1} and salicylic acid @ 100 mg L^{-1} once at pre-flowering and another at 15 days later is recommended to increase flower production and pod setting in black gram (TNAU, 2012).

Mondal *et al*. (2012) reported that foliar application of 1.5% urea thrice at reproductive stage increased the seed yield in soybean (3.19 t ha^{-1}). Yadav and Choudhary (2012) observed that 2% foliar spray each of DAP, urea and KCl resulted in higher seed yield, protein content, uptake of N, P, K and net return in cowpea. Mamathashree (2014) found that foliar application of 19:19:19 at 2% concentration produced significantly higher seed yield of pigeon pea (1272 kg ha^{-1}) as compared to other soluble fertilizers.

Combined spraying of 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ at 45 DAS proved most effective and increased the seed yield by 43.09% when compared with control followed by combined spraying of 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ at 25 DAS (40.14%) in cowpea (Anitha *et al.,* 2005). Kasthurikrishna and Ahlawat (2000) reported that zinc

application increased the grain yield of cowpea probably owing to its influence on auxin synthesis, nodulation and N fixation, which promoted plant growth and development, thereby favourably influencing grain yield. Zinc and iron take part in the metabolism of plant as an activator of several enzymes which in turn can directly or indirectly affect the synthesis of carbohydrate and protein.

In soils with high P content, the combination of foliar application of $ZnSO_4$ @ 0.025% (at branching and flowering) and K_2O @ 10 kg ha^{-1} along with recommended dose of N and farmyard manure (FYM) recorded higher yield, net income and BCR. The reason for higher yield may be attributed to antagonistic interaction between P and Zn. When Zn is given in soil, it gets fixed as Zinc phosphate and make it unavailable to the plants. But when given as foliar, it absorbed through leaves faster and utilized for metabolic activities as well as auxin synthesis (Anjaly, 2018).

Seed treatment with Mo along with 2% urea spray twice at flower initiation and 15 days later resulted in seeds per plant, maximum production efficiency (9.52 kg ha^{-1} day^{-1}) and economic efficiency in blackgram (Kumar *et al.,* 2018). Molybdenum is a constituent part of the enzyme nitrate reductase concerned with the reduction of nitrate to nitrite in both microorganism and higher plants. Presence of adequate amount of major nutrients and available Mo in the soil, might have enabled the plant to fix nitrogen from the atmosphere in nodules, increased growth attribute and finally enhanced the yield of blackgram. In blackgram, seed treatment with borax and sodium molybdate @ 1g kg^{-1} seed each and scheduling nutrient application at 20: 30: 30 kg NPK ha^{-1} as ½ N + full P + ½ K as basal followed by ½ N and ½ K as foliar spray of 13:0:45 at 15, 30, 45 and 60 DAS could be suggested for realizing higher yield and net returns.(Yamini, 2019).

Application of RDF, 12.5 t ha^{-1} of FYM and 25 kg $ZnSO_4$ as basal and foliar spraying of 1% KNO_3 at 50% flowering recorded higher grain yield, net return and B:C ratio in green gram (Keerthi *et al.,* 2015). Spraying brassinolide 0.25 ppm at 50% flowering and 15 days later showed significant increase on pod weight per plant, dry weight per plant, 1000 seed weight and harvest index in green gram (Matwa *et al*., 2017).

CONCLUSION

Foliar nutrition provides an excellent way for absorption of nutrients as it can be applied directly to site of metabolism. It increases yields from 12% to 25% and more than 90% of the fertilizer applied is utilized by the plant. Foliar nutrition in pulses increases significantly the growth attributes like number of branches, height, number of flowers and dry matter accumulation. It bypasses nutrient uptake through root and if any deficiencies found can be quickly corrected. It can be effectively used at varying topographical condition even in poor and marginal lands. It renders fertilizer application in combination with herbicides, insecticides and fungicides and reduce fertilizer requirement by increasing nutrient availability.

Foliar application has been proved to be an important strength in fertilizer application with a specific aim of increasing nutrient availability at the time of need especially in the later stage of plant growth (Kuepper,2003). Though, the emphasis has been laid on for foliar fertilization of trace elements yet it has repeatedly been observed that the foliar application of macronutrients, too, has a positive impact on plant metabolisms and ultimately on the yield (Fageria *et al.,* 2009).

In the present scenario of higher cost of cultivation and labour charges, there is need for finding the right combination of pesticides and herbicides with water soluble fertilizers for application at once in pulses for enhancing profitability. Nevertheless, foliar feeding approach is rather limited in India due to its technicalities, it has the potential of tackling production constraints and enhancing the productivity in pulses.

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