4R Nutrient Stewardship for Sustainable Pulse Production in India

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4R-based nutrient management is needed to increase productivity of pulse crops in India to meet growing demands.

Dr. Ummed Singh inspecting the standing crop during a field visit.

India is the world's largest producer of pulses. Pulses provide the cheapest source of vegetable protein for human and animal nutrition. Even though India produces 19.3 million (M) t of pulses with an average productivity of 764 kg/ha (FAI, 2015), the country still imports 2 to 3 M t of pulses every year to meet the growing demand. The projected pulse requirement for the year 2030 is 32 M t, which will require an annual production growth rate of 4.2% (Nadarajan et al., 2013). The diversified agro-climatic condition in India supports the growing of a variety of pulses; however, a large gap exists between attainable and actual yield. Bridging this gap would substantially increase the country's pulse production. Pulses are predominantly grown by resource poor farmers in the marginal lands. Low adoption of improved varieties coupled with inadequate agronomic and nutrient management by farmers, have resulted in static production of pulses in the country.

The United Nations declared 2016 as the International Year of Pulses, aimed at positioning pulses as a primary source of protein and other essential nutrients, especially for countries with a large vegetarian population. The FAO intends to make people more aware of the nutritional value of pulses and their contribution to sustainable food production to ensure food security and improved human nutrition. The general consensus is to promote better production of pulses worldwide through improved crop rotation and better crop management. In support of the International Year of Pulses, the authors have made an attempt to assemble the 4R nutrient management guidelines for increasing productivity and profitability of pulses in India.

Abbreviation and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Se = selenium.

4R Nutrient Stewardship for Macronutrients

Appropriate nutrient management is one of the important factors for increasing the production of pulses. Studies reported that in N deficient soils, application of N to pulse crops considerably increases productivity. Higher doses of N application is generally avoided as it decreases nodulation; however, lower doses of N at early growth stages often benefits the symbiosis. Biological N_2 fixation enables pulse crops to meet 80 to 90% of their N requirements, hence a small dose of 15 to 25 kg N/ha is sufficient to meet the requirement of most pulse crops (Thiyagarajan et al., 2003). In emerging cropping systems like rice-chickpea, a higher dose of N (30 to 40 kg/ha) has shown beneficial effect. Kaushik et al. (1993) studied the impact of different N sources, including urea, ammonium sulphate, and

Table 1. Yield response of phosphate fertilizer application in different pulses. (Source: Majumdar and Govil, 2015).

Crop	P_2O_5 applied, kg/ha	Yield increase due to P_2O_5, kg/ha (±SE)	Response per kg of P_2O_5 applied, kg/kg
Black gram (7)[1]	90	106 (±20)	1.7
Gram (5)	147	445 (±91)	3.3
Greengram (6)	58	221 (±19)	4.4
Pigeon pea (9)	111	460 (±41)	4.6
Urdbean (5)	72	129 (±33)	1.9
Cowpea (1)	20	139	7.0
Chickpea (26)	68	640 (±60)	11.5
Mung bean (3)	59	127 (±3)	3.4

[1]Number of studies

potassium nitrate at variable rates of application, and reported that application of N to pigeon pea at 20 kg/ha was optimum and all three sources were at par in terms of grain yield and N concentration enhancement. In chickpea, positive responses to a starter doses of N at 15 to 20 kg/ha have been observed particularly in soils of poor texture, but a similar response may or may not be found in soils with better texture (Thiyagarajan et al., 2003). In pulses, low levels of available soil N causes "N hunger" and may reduce yield, nodulation, and N_2 fixation. Therefore, applying starter doses of N fertilizer at the time of seeding could alleviate N deficiency during the early plant growth stage.

Phosphorus nutrition in pulses assumes primary importance due to its role in root proliferation and atmospheric N_2 assimilation. Phosphorus is involved in metabolic and enzymatic reactions and is a constituent of ATP and ADP. Chesti and Ali (2012) evaluated the right source and rate of P application to green gram and suggested a combined application of farm yard manure (FYM) at 10 t/ha and P_2O_5 at 30 kg/ha through diammonium phosphate (DAP), which significantly improved the rhizosphere microflora, nutrient availability, and yield of green gram. Differences among sources of phosphatic fertilizers for legume production were reported, where application of single superphosphate (SSP) recorded higher nodulation, yield, N and P uptake, and available soil P than DAP. Moreover, SSP was found to be a superior source of P in terms of higher agronomic and recovery efficiency (Singh et al., 2012).

While determining the right rate, Thiyagarajan et al. (2003) found that P deficiency is widespread in Indian soils. Most of the grain legumes have shown good response to application of 20 to 80 kg P_2O_5/ha depending upon nutrient status of soil, cropping system, and moisture availability. The addition of the optimum amount of P had a positive influence on apparent P fertilizer utilization (APU) and native P use. Across India, pulses responded to P application—between 1.7 to 11.5 kg grain/kg P_2O_5 application (Majumdar and Govil, 2015; **Table 1**). Responses to applied P of 17 to 26 kg P_2O_5/ha have been observed in most of the pulse crops on soils of low to medium P availability. The response to applied P also varies considerably in pigeon pea (17 to 43 kg) depending upon the P status of soil. Chickpea was found to be more efficient than other pulses in taking up P from soil, as it secretes more acid, which helps in solubilizing Ca-P secondary minerals in the soil (Thiyagarajan et al., 2003). Majumdar and Govil (2015), while reviewing P response of pulses over a 10-year period across India, suggested that response quartiles of large data sets could be effectively used to determine the right rate of P application to pulses.

Since P is less mobile in soil, its uptake and the utilization can be increased by its placement at the proper soil depth. Singh and Singh (1992) studied the rate of application and placement of P and indicated that P application significantly improved the yield attributes and grain yield up to 80 kg P_2O_5/ha in pigeon pea, and up to 40 kg P_2O_5/ha in green gram and cowpea. The study above also reported that the placement of P at 15 cm depth significantly increased the yield in pigeon pea; whereas, placement at 7.5 cm was better in green gram and cowpea. Shallow placement of P in green gram was beneficial due to its shorter root length, whereas, pigeon pea benefited by deep placement of P because of deeper root geometry and long crop duration. In another study, Singh et al. (2015) reported that the application of full basal rate of P enhanced nodulation due to increased availability of P at the initial stage of root development and also helped in nodule initiation, multiplication, and proliferation. Split application of P (50% P as basal + 50% P as top dressing at branch initiation) reduced P fixation and improved P use efficiency. However, delayed application of P had little effect on plant growth and development.

Potassium is the key nutrient element in the biosynthesis of protein in pulse crops. In general, pulses require 16 kg K_2O (e.g., for pigeon pea grain) to as high as 73 kg K_2O (e.g., for green gram grain) from the soil to produce 1 t of grain (Majumdar and Govil, 2013). However, K fertilizer use is limited in pulse crops and a recent estimate suggests that only 41% of the cropped area under pulses receive about 6.3 kg K_2O/ha, indicating that lack of adequate K use in pulses is one of the major reasons for their low yields and poor crop quality in India (Majumdar and Govil, 2013). Majumdar and Govil (2013) also conducted a review on K response in pulses and found that responses varied between 1 to 22 kg grain per kg of applied K (**Table 2**).

Table 2. Yield response of potassium fertilizer application in different pulses. (Source: Majumdar and Govil, 2013).

Pulses	K_2O applied, kg/ha	Mean yield increase due to fertilizer K application, kg/ha (±SE)	Response per kg of K applied, kg/kg
Chickpea	50	385 (±128)	7.8
Urdbean	36	46 (±17)	1.5
Lentil	32	89 (±8)	3.2
Pigeon pea	38	115 (±32)	3.6
Pea	36	105 (±21)	3.4
Mung bean	30	30 (±0.5)	1.0
Green gram	25	265 (±44)	11.5
Black gram	85	302 (±10)	4.0
Cluster bean	40	160	4.0
Cowpea	50	1,100	22.0
Guar bean	30	170	5.7

Table 3. Response of grain legumes to different rates of sulphur applications (Ali and Singh, 1995).

Crop	Fertilizer, kg/ha	Mode of application	% Yield increase over control
Lentil	20 kg S	Basal	50
Pigeonpea	20 kg S	Basal	16
Urdbean	20 kg S	Basal	25
Mungbean	40 kg S	Basal	20

Stewardship of Secondary and Micronutrients

Sulphur is now recognized as the fourth most important plant nutrient in India after N, P, and K. Oilseeds require high amounts of S, followed by pulses, forages, tuber crops, and cereals. Optimized S application is required to enhance uptake and use efficiency of other plant nutrients through synergism, and suppress the uptake of undesirable and toxic elements (e.g., Se through antagonism; Singh et al., 2015). In different studies, the right rate and right source of S fertilization increased mean grain yield by 18% in chickpea, 28% in lentil, 20% in mung bean, 20% in urd bean, 22% in pigeon pea, 32% in field pea, and 33% in cowpea over S omitted treatments (Singh et al., 2015). The rate of applied S to the grain legumes depended on type of crop, genotype, soil S status, soil status of N and P, crop yield potential, cropping intensity, management and environmental factors, etc. (Singh et al., 2015). An analysis of experiments revealed that the optimum rate for sulphate-S sources varies from 10 to 100 kg/ha across the crops under variable environmental conditions.

A wide range of S containing or straight S fertilizers are available in the market. Gypsum, pyrite, and elemental S are used as different sources of S fertilizers. Some of the fertilizers containing primary nutrients, such as SSP, potassium sulphate, ammonium sulphate, and sodium sulphate, etc. are also good sources of S. In neutral to slightly alkaline soils, easily soluble ammonium sulphate, potassium sulphate, and sodium sulphate are considered more suitable sources of S for easier uptake by plants. Granular form of modified pyrite and elemental S (e.g., S-Bentonite) are quickly dispersible upon wetting and readily available to the plants (Tiwari et al., 2002). In S deficient soils (e.g., calcareous soils), easily soluble sources such as ammonium sulphate, are more suitable to correct the deficiency rather than gypsum which is less soluble.

The source and rate of S fertilizer produces significant yield improvement in chickpea. Supplying S through ammonium sulphate proved better over gypsum and enhanced the grain yield of chickpea by 5% averaged over locations and years under sandy loam and loamy sand soils. Application of S at 20 kg/ha to lentil, enhanced grain yield by 50% over no S application (**Table 3**; Ali and Singh, 1995). Based on crop response analysis, application of 20 to 40 kg S/ha, in the form of sulphate-S, is necessary to supply an adequate amount of S to the pulses. A study on the different rates of application for S on yield, quality, and nutrient uptake of mung bean revealed a significant increase of grain yield from 1.7 to 16% with increasing levels of S application from 0 to 20 kg/ha (Singh et al., 2014). The study also indicated a significant increase in N uptake and protein content in grain. Sulphur application indirectly influenced N_2 fixation by increasing the number and size of nodules and helped in increasing the N uptake in mung bean through increased fixation of atmospheric N.

Sulphur is commonly applied to the main crop within a cropping system and the residual effect of the applied S shows a detrimental effect to the succeeding crop, unless the right source and rate of S was applied to the main crop. Kumar et al. (2014) studied the effect of different sources and rates of S application on yield, S uptake, and protein content in rice-pea cropping system. The study revealed that application of 30 kg S/ha as phosphogypsum or SSP proved to be sufficient for substantial increases in yield, S uptake, and protein content for rice grown on the S deficient acid soil. However, to ensure a better residual effect of S to the succeeding pea crop, the study suggested applying 40 kg S/ha through a pyrite source at 3 weeks before sowing of rice (Kumar et al., 2014).

Physiological functions such as photosynthesis and enzyme activities, etc. are severely affected by S deficiency, especially in the initial growth stage of the plants. Therefore, application of S at early growth stages of pulses produces better yield and use efficiency (Aulakh, 2003). Studies have reported both the synergistic and antagonistic relationship between S and P depending upon the crops grown and the rate of application of both the nutrients. For example, a synergistic effect was observed between P and S for yield enhancement of rice while the effect was antagonistic in case of mung bean (Singh et al., 2014).

Summary

The present article highlights the large potential for productivity improvement of pulses through 4R Nutrient Stewardship to achieve future production goals. However, limited number of farmers follow the 4R-based nutrient management for pulses and the focused extension efforts are needed for large-scale adoption. BC-SA

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