Available online at
www.agrospheresmagazine.com

ISSN: 2582 – 7022

Agrospheres:e-Newsletter, (2021) *2*(6), 38-41

Agrospheres: e-Newsletter

Article ID: 250

Role of Nitrogen-Fixing Legume Crops to the Productivity of Agricultural Systems

S.R. Jakhar[1*] C.R. Kantwa[1] and R. Sutaliya[2]

[1]Krishi Vigyan Kendra, Ratlam - 457340 (M.P), India
[2]Agricultural Research Sub Station, (Agriculture University, Jodhpur),
Samdari, Barmer-344021 (Raj.), India

Open Access

*Corresponding Author
S.R. Jakhar*
E-mail: soilshish1993@gmail.com

Article History
Received: 21.04.2021
Revised: 4.05.2021
Accepted: 10.06.2021

INTRODUCTION

Approximately 80% of Earth's atmosphere is nitrogen gas (N_2). Unfortunately, N_2 is unusable by most living organisms. Plants, animals, and microorganisms can die of nitrogen deficiency, surrounded by N_2 they cannot use. All organisms use the ammonia (NH_3) form of nitrogen to manufacture amino acids, proteins, nucleic acids, and other nitrogen-containing components necessary for life. Biological nitrogen fixation (BNF) is the process that changes inert N_2 into biologically useful NH_3. This process is mediated in nature only by N-fixing rhizobia bacteria (*Rhizobiaceae*, *α-Proteobacteria*) (Sorensen & Sessitsch, 2007). Other plants benefit from N-fixing bacteria when the bacteria die and release nitrogen to the environment, or when the bacteria live in close association with the plant. In legumes and a few other plants, the bacteria live in small growths on the roots called nodules. Within these nodules, nitrogen fixation is done by the bacteria, and the NH_3 they produce is absorbed by the plant. Nitrogen fixation by legumes is a partnership between a bacterium and a plant. Legumes are plants that bear their seeds in pods. They differ markedly from grasses, cereals and other non-legume crops because much of the nitrogen they require is produced through fixation of atmospheric nitrogen by bacteria in nodules on their roots. As a result, legumes are rich in protein. World-wide more than 16,000 species of legumes are known, including herbs, shrubs and trees, but only about 200 are cultivated.

BNF can take many forms in nature, including blue-green algae (a bacterium), lichens, and free-living soil bacteria. These types of nitrogen fixation contribute significant quantities of NH_3 to natural ecosystems but not to most cropping systems, with the exception of paddy rice. Their contributions are less than 5 lb of nitrogen per acre per year. However, nitrogen fixation by legumes can be in the range of 25–75 lb of nitrogen per acre per year in a natural ecosystem, and several hundred pounds in a cropping system (Frankow-Lindberg & Dahlin, 2013; Guldan et al., 1996; & Burton, 1972).

Amounts of BNF

In view to understand legume N_2 fixation and N-cycling in a farming system the following terms are essential to know:

Terms used to describe legume N_2 fixation and N-cycling in farming systems

Term	Meaning
N_2 fixation	The reduction of atmospheric nitrogen (N_2) gas to ammonia (NH_3). N fixation in legumes is a biological process in which root nodule bacteria (rhizobia) fix N_2 via the enzyme nitrogenase.
Total crop N fixed	The total contribution of N_2 fixation to legume biomass, including above-ground vegetation and below-ground roots and nodules. In legumes, 30-50% of total crop N is in the below ground portion of the plant.
Crop N balance	The difference between N inputs and N outputs. N inputs are N_2 fixation + fertilizer N (if applied). Outputs are the N in harvested grain or hay/fodder + N lost through volatilization and leaching.
NO_3-N benefit	The extra NO_3-N available after a legume; best described as the difference between soil NO_3-N when the legume was sown and NO_3-N at sowing of the following crop.

Nitrogen fixation by crop legumes has now been estimated in many studies. Average amounts of N fixed range from 60 kg N /ha for lentils to 183 kg N/ha for Faba bean (Table 1).

Table 1: Estimates of N_2 fixation by different legume crops

Crop	Average crop N fixed (kg.N/ha)
Faba bean	183
Ground nut	150
Pigionpea	146
Green gram	112
Cowpea	110
Soybean	92
Mung bean	80
Pea	80
Chickpea	70
Lentils	60

Benefits of Legumes in Crop Rotations

1. Uptake of legume N by following crops

- In the legume-cereal sequence, the legume crop uses most of the N_2 it fixes during the growing season (about 60% BNF out of total N requirement), eliminating the cost of fertilizer N to produce a crop. After harvest, about 20-30% of BNF-N is mineralized from the legume residues in the form of NO_3-N to the succeeding crop, while adding a lot of N (70-80% of BNF-N) to native soil organic matter. Further this cropping sequence reduces gaseous N losses as NO (a potent greenhouse gas) giving environmental benefit.

In the cereal-cereal sequence, fertilizer N is applied to the first cereal crop and no N is released after harvest. In fact, there is a deficit because of the high C:N ratio of the cereal stubbles and eventually a net immobilization occurs and gaseous N losses.

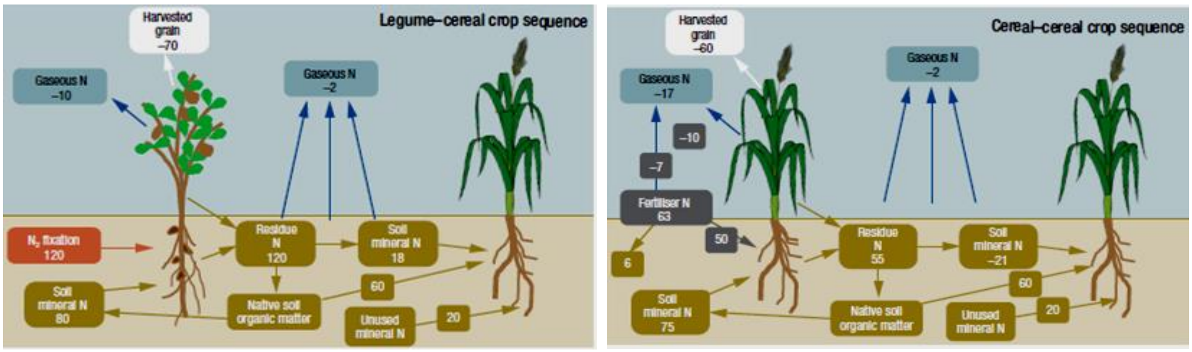

Fig. 1: Contrasting N-cycling in legume-cereal and cereal-cereal crop sequence. The values for N (kg/ha) in the boxes are a combination of experimental data and simulated estimates

- A notable feature of the decomposition and release of N from legume organic material is that, after a period of time, the subsequent rate of mineralization becomes quite slow, regardless of the initial quality of the residues, so that the legume N not mineralized during the first season becomes available only very slowly thereafter (usually <5-10% per year) for successive crops (Fillery, 2001). This suggests that legumes are an efficient short-term source of N (Hesterman et al., 1987, & Harris et al., 1994). Certainly <15% of the N in a following crop appear to be derived from the prior legume. However, there are also situations where legume sources have provided a significant proportion (20~33%) of the next crop's N requirements, as residual N from legumes.
- This ignores the potentially large amounts of below-ground legume N associated with, or derived from, roots and nodules (Rochester et al., 1998; & Khan et al., 2002). Wheat *(Triticum aestivum)* has been reported to utilize between 3-10% of the residual below-ground N from a previous lupin crop (McNeill & Fillery, 2008), or 8% and 15% of the below-ground N of prior faba bean and chickpea crops, respectively (Khan, 2000).
- The below-ground legume N plays a key role in contributing to the soil pool of particulate organic matter (Schwenke et al., 2002) and may be the source between 30-75% of the total mineral N accumulating after legumes (Evans et al., 2003). Thus the below-ground pool of legume N appears to be an important source of N for following crops.

2. Rotational benefits not related to N

2.1. Impacts on soil structure or nutrient and water availability

- There is evidence that legume species such as chickpea, pigeon pea and white lupin *(Lupinus albus)* can mobilize fixed forms of soil phosphorus by the secretion of organic acids such as citrate and malate (and other compounds) from their roots (Hocking, 2001) and influence supply of plant-available phosphorus for subsequent crops (Nuruzzaman et al., 2005).
- Tap-rooted legume species can also assist the roots of following crops to explore a larger soil volume through improvements in soil aggregate structure and organic carbon (Rochester et al., 2001; & Shah et al., 2003), the penetration of soil hardpans, and by providing a continuous network of residual root channels and macro-pores in the subsoil (e.g. Lesturgez et al., 2004).
- Species such as pea use less water than other crops (Merrill et al., 2007). Such carryover of available soil water after legumes has been identified as an important factor contributing to higher yields by following wheat crops (Miller et al., 2002).

2.2. Impacts on soil biology

- Legumes can also influence the populations of specific rhizosphere organisms which may compete, antagonize or suppress pathogens (Kirkegaard et al., 2008). Some legumes appear to reduce the survival of certain species of nematodes.
- Legumes also encourage mycorrhizal associations that assist nutrient uptake, and stimulate the activity of a plethora of soil organisms such as earthworms (Jensen & Hauggaard-Nielsen, 2003; & Lupwayi & Kennedy, 2007).
- Legumes in rotations also result in greater microbial activity and diversity in soils (Lupwayi & Kennedy, 2007).
- Some symbioses also influence the composition of the microbial population in the legume's rhizosphere *via* the release of molecular hydrogen (H_2) as a by-product of symbiotic N_2fixation in legume nodules. About 35% of the energy consumed in the overall nitrogenase activity goes towards H_2production (Hunt & Layzell, 1993). In some legume systems, the rhizobial bacteria (*Bradyrhizobium* sp.) possess a hydrogenase uptake system (uptake hydrogenase, designated Hup+) that is able to recycle almost all of the H_2 evolved and recover most of the energy that might otherwise be lost (Evans et al., 1988) and significantly increase grain yield of a succeeding barley crop by 48% or a succeeding maize *(Zea mays)* crop by 32%.

Conclusions and Future Prospects

While the calculated inputs of fixed N by food legumes and the carryover of fixed N for the benefit of following crops may seem relatively small when compared to the 85 million t N applied as fertilizer each year, there are a number of environmental and rotational advantages in relying upon N_2 fixation rather than fertilizer N to produce high-quality foods. Strategies are available to improve N_2 fixation beyond what is currently being achieved. Provided that a legume crop is abundantly nodulated and effectively fixing N_2, enormous benefits in terms of crop production and N_2 fixed can be derived from the application of good agronomic principles. But the ability to overcome constraints at the farm level to undertake the applied N_2 fixation research for farmers' benefits, continues to deteriorate rather than improve. Hence, there is a need for some strong policy intervention to redress this trend.

REFERENCES

Burton, J. C. (1972). Nodulation and symbiotic nitrogen fixation. In C.H. Hanson (Ed.), Alfalfa Science and Technology (Monograph 15; pp. 229–246). Madison, WI: American Society of Agronomy.

Crews, T. E., & Peoples, M. B. (2004). Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. *Agriculture, Ecosystems and Environment 102*, 279–297.

Evans, H. J., Russell, S. A., Hanus, F. J., & Ruiz-Argüeso, T. (1988). The importance of hydrogen recycling in nitrogen fixation by legumes, p. 777-791. In R. J. Summerfield (ed.), World crops: cool season food legumes. Kluwer Academic Publishers, Boston, Mass.

Evans, J., Scott, G., Lemerle, D., Kaiser, A., Orchard, B., Murray, G. M., & Armstrong, E. L. (2003). Impact of legume 'break' crops on the residual amount and distribution of soil mineral nitrogen. *Australian Journal of Agricultural Research 54*, 763–776.

Fillery, I. R. P. (2001). The fate of biologically fixed nitrogen in legume-based dryland farming systems: a review. *Australian Journal of Experimental Agriculture 41*, 361–381.

Frankow-Lindberg, B. E., & Dahlin, A. S. (2013). N_2 fixation, N transfer, and yield in grassland communities including a deep-rooted legume or non-legume species. *Plant and Soil, 370*, 567–581.

Guldan, S. J., Martin, C. A., Cueto-Wong, J., & Steiner, R. L. (1996). Interseeding legumes into chile: Legume productivity and effect on chile yield. *HortScience, 31*, 1126–1128.

Harris, G. H., Hesterman, O. B., Paul, E. A., Peters, S. E., & Janke, R. R. (1994). Fate of legume and fertilizer nitrogen-15 in a longterm cropping systems experiment. *Agronomy Journal 86*, 910–915.

Hesterman, O. B., Russelle, M. P., Sheaffer, C. C., & Heiche, G. H. (1987). Nitrogen utilization from fertilizer and legume residues in legume-com rotations. *Agronomy Journal 79*, 726–731.

Hocking, P. J. (2001). Organic acids exuded from roots in phosphorus uptake and aluminium tolerance of plants in acid soils. *Advances in Agronomy, 74* (2001), pp. 63-97.

Hunt, S., & Layzell, D. B. (1993). Gas exchange of legume nodules and the regulation of nitrogenase activity. *Annu Rev Plant Biol 44*, 483–511.

Jensen, E. S., & Hauggaard-Nielsen, H. (2003). How can increased use of biological N2 fixation in agriculture benefit the environment? *Plant and Soil 252*, 177–186.

Khan, D. F. (2000). Reconciling Effects of Legume N with Reference to the Role of the Nodulated Root. Ph.D. Thesis. Melbourne University, Victoria, Australia.

Khan, D. F., Peoples, M. B., Chalk, P. M., & Herridge, D. F. (2002). Quantifying below-ground nitrogen of legumes. 2. A comparison of15N and non isotopic methods. *Plant and Soil 239*, 277–289.

Kirkegaard, J., Christen, O., Krupinsky, J., & Layzell, D. (2008). Break crop benefits in temperate wheat production. *Field Crops Research 107*, 185–195.

Lesturgez, G., Poss, R., Hartmann, E., Bourdon, E., & Ratana-Anupap, S. (2004). Roots ofStylosanthes hamata create macropores in the compact layer of a sandy soil. *Plant and Soil 260*, 101–109.