Management of soya bean nutrition

By Dr Fernando Salvagiotti: Crops, soils and water management, INTA EEA Oliveros, Santa Fe

Crop production is closely related to resource capture. The maximum grain production in a particular environment is determined by three defining factors: Radiation and CO_2 that crops can capture; the potential for generating yield that each genotype has; and the temperature regime (*Figure 1*).

The expression of potential production will be constrained by the limiting factors – water and nutrients. In dryland soya bean production systems, the yield gap due to limiting factors is a combination of nutrients and water deficits.

The magnitude of the response to fertiliser addition of those nutrients identified as deficient in the soil and/or those that are necessary for sustaining high yielding crops defines the 'nutritional gap'. The use of chemical fertilisers, the inclusion of cover crops, the addition of organic manure and the use of associated or symbiont microorganisms are tools that may contribute to reducing the nutritional gap.

Therefore, the reduction in this gap requires a thorough understanding of soil-plant relationships, including crop ecophysiology and nutrition, soil fertility and soil microbiology.

Essential nutrients have specific roles in plants. The deficiency of each nutrient will depend on soil characteristics and yield potential of the crop in each particular system. Fertilisation is an important tool for correcting these deficiencies, however, excessive chemical fertiliser application may have negative consequences for the environment.

For an efficient fertilisation practice, not only knowledge of fertiliser efficiency use is important, but also the relative importance of each nutrient in yield formation and the relative proportions needed for maximising yield. There are certain physiological aspects related to crop nutrition and yield.

Figure 1: Representative scheme between maximum attainable, feasible and actual yield as related to reducing, limiting and defining factors.

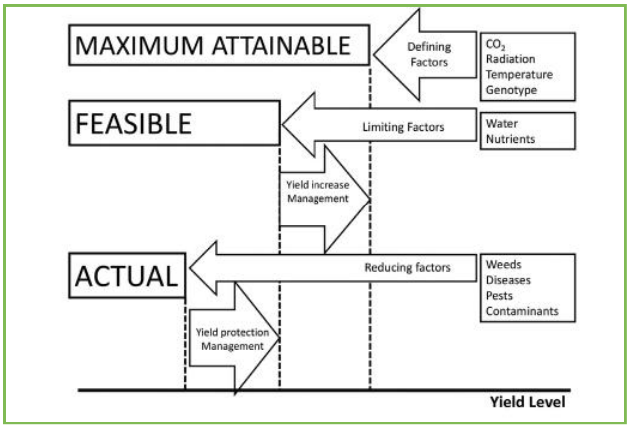


Figure 2: Relationship between N content and biomass of seed per unit of photosynthate produced in 24 cultivated species.

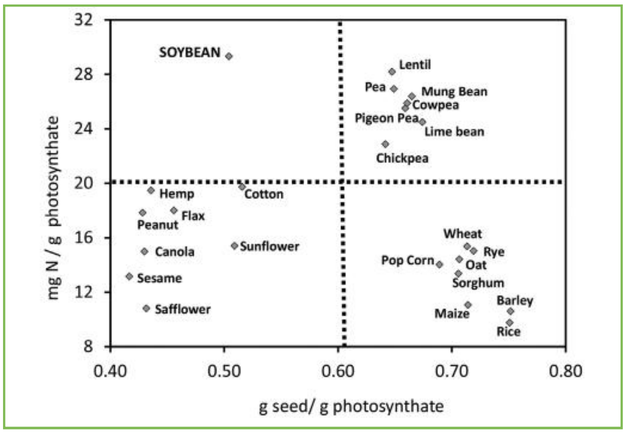


Figure 3: Relationship between N content in leaves and leaf photosynthesis in maize, rice and soya beans.

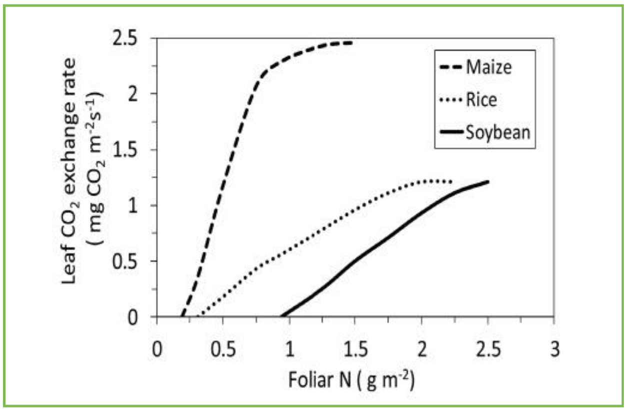
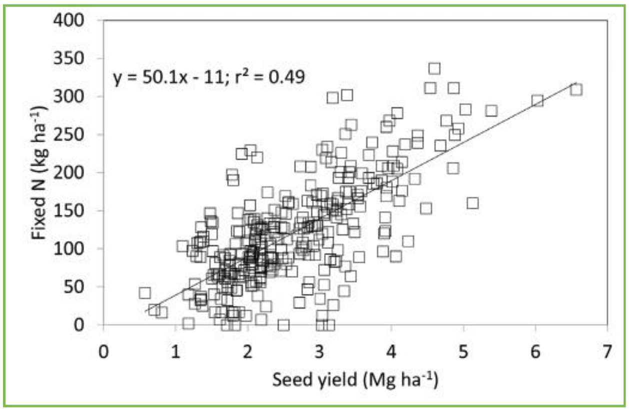


Figure 4: Relationship between seed yield and N derived from biological N fixation in soya beans.



Nitrogen the engine

Nitrogen (N) has two essential roles in plants: It is part of enzymatic systems in the cells, which are necessary for crop growth and development, and it is an essential constituent of reserve proteins. In the first case, N represents more than 60% in leaves as a component of ribulose bisphosphate carboxylase/oxygenase (Rubisco) and other enzymes involved in CO_2 assimilation.

Figure 2 depicts the distribution of several grain crops when considering the relationship between grain yield per unit of photosynthate (i.e. larger values are reached when the energetic value of the molecules that form the grain is low) and grain N content per unit of photosynthate (i.e. larger values in crops with greater protein content in grains).

Grains are grouped in the right-lower quadrant since starch (with low energy value) is the main constituent in the grain and they have relatively low protein content (less than 14%). In the left-lower quadrant are oil crops that accumulate molecules with high energetic value (mainly as oil), but with low protein content.

In the right-upper quadrant, leguminous crops with larger protein content than grains but also great accumulation of carbohydrates are grouped. Finally, soya bean is located in the left-upper section of the graph since it accumulates substances with high energetic value (more than 19% as oil) and high protein content (mostly above 38%).

This composition implies a large N demand, especially during the seed-filling period, when N mobilisation, mainly from leaves, begins at a high rate. N mobilisation would be a constraint for obtaining higher yield because the N pool in leaves accumulated as Rubisco will decrease. The positive relationship between N uptake and seed yield in soya beans may be explained by the fact that a greater part of N in leaves is in the photosynthetic system.

Figure 3 shows the relationship between foliar N in grams of N per unit leaf area (analogous of Rubisco content) and crop photosynthesis. Crops with C4 metabolism (e.g. maize) contrast with C3 crops (e.g. soya beans) because they have a larger N use efficiency and less N is required in leaves to get similar photosynthetic rates.

In line with these observations, increases in N uptake have been reported as a consequence of soya bean breeding. A rise was also observed in N content in seeds, but with a decline in protein content (N dilution effect). Soya bean breeding has achieved a crop with a larger capacity for assimilating more N during the seed-filling period (*Table 1*).

The basis for managing N in soya beans is the optimisation of the process of biological N fixation (BNF) from air. Crop management should optimise the contribution of this source, mainly through inoculation with highly effective rhizobium strains and using inoculants that ensure the number of bacteria in well conserved conditions.

The success of this practice will be achieved with crop and soil management practices that optimise the environment for the rhizobium-soya bean symbiosis. The amount of N fixed (kg/N) will depend not only on the proportion of N derived from BNF but also on the biomass production of the crop. In general, there is a strong association between growth, seed yield, N assimilation and BNF (*Figure 4*).

Results from experiments that evaluated N fertilisation in soya beans show erratic results, with a large proportion of cases with no response to N fertilisation. In general, a response to N fertilisation in soya beans has been

Table 1: Seed yield, grain quality and variables associated with N nutrition in old and modern soya bean cultivars.

Cultivar	Seed yield	Protein	Oil	N uptake in R4	N uptake R5-R7	Mobilized N	N in seeds	N total	ICN
	kg N ha^{-1}		%			kg N ha^{-1}			%
Old cultivars ('30s)	3000	37.6	19.1	110	14	95	104	120	91
Modern cultivars ('90s)	3775	35.7	21.4	113	39	100	131	143	91
	*	*	*	NS	*	NS	*	*	NS

* Significant differences at 5%; NS: not significant differences

observed when environmental conditions were not adequate for normal functioning of nodules. In Argentina, a response to N fertilisation was only observed in fields where soya beans were not planted before, and thus without a naturalised rhizobium population. After two years of inoculated soya beans, N fertilisation did not cause any increase in seed yield.

Another alternative in high-yielding soya beans is by locating fertiliser N below the area where nodules are present in order to avoid the negative effect of nitrates on BNF. Studies performed on soya bean crops that yielded above 5 000kg/ha showed increases of approximately 5% in seed yield when the crop received 180kgN/ha as fertiliser both on surface or locating the fertiliser (as a slow-release fertiliser) below the nodule area.

Phosphorus, potassium and sulphur

When planning nutrient management of phosphorus (P), potassium (K) or even sulphur (S) – nutrients that have medium to low mobility in the soil – it is important to not only take direct effects on the crop into account, but also residual effects for the crops in the sequence.

From a physiological viewpoint, P availability is relatively more important in early stages of crop growth when crop growth rates are high and the crop has a large P demand (which is accumulated as ribosomal RNA) in order to produce proteins that are necessary for this active growth.

In field experiments, the reduction in seed yield due to P deficiency was associated with a decline in seed numbers per unit area. This drop is a consequence of a reduction in growth, leaf area expansion and radiation capture in early reproductive stages (i.e. between R2 and R5) when seed numbers are determined. In general, the effect during seed-filling is relatively lower, and it is generally observed as a larger P mobilisation to the seeds accumulated as phytate.

High-yielding soya beans will have a high P uptake. However, a larger demand does not imply a rise in soil P calibrated thresholds. *Figure 5* shows that response to P fertilisation is high when soils have P contents below thresholds, but without relationships with the maximum seed yield per site.

Sulphur is closely related to N nutrition in soya beans, as was observed in several crops. Sulphur is the main component of enzymes involved in N uptake, N fixation and N assimilation in the plants. In addition, reserve protein in soya bean seeds are rich in sulphur-amino acids (methionine and cysteine), and thus a large demand is expected. Field experiments have shown increases both in seed numbers and individual weight. Even when S is more mobile than P, residual effects of S fertilisation have been reported, depending on soil type.

Cations (K, Ca and Mg)

Potassium has a central role in crop physiology since it is directly involved in regulating stomata movement, important for maintaining the hydric status of the crop and in solute transport across the phloem. As described for P, larger requirements are observed in early stages of the crop. Potassium mobilisation to seeds is low, and K is related to tissue strength.

Based on Table 2 values, it can be seen that the internal N requirement of soya beans is approximately 12, 19 and 2 times higher than the internal requirement of P, S and K, respectively.

Magnesium (Mg) is part of the chlorophyll molecule and intervenes in several physiological processes. Calcium (Ca) is mainly involved as a cell wall stabiliser. In general, a high Ca uptake may cause physiological disorders at the membrane level, and thus Ca uptake is regulated to prevent an increase above certain levels. A high Ca uptake has been observed in less differentiated tissues in the roots (close to the calyptra).

Figure 5: Response to P fertilisation as related to the maximum seed yield per site. Lines represent the average response in each soil P group.

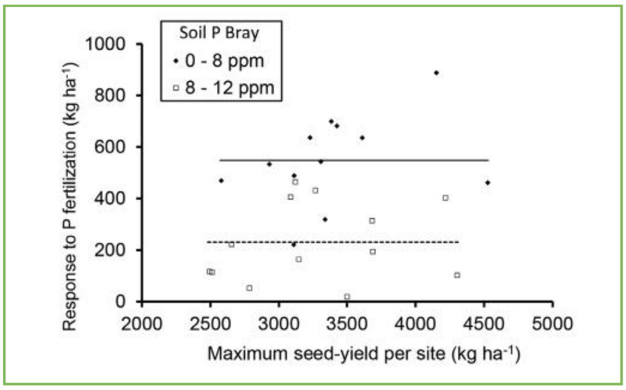


Figure 6: Relationship between seed yield (corrected to 13% moisture) and N uptake in aerial biomass.

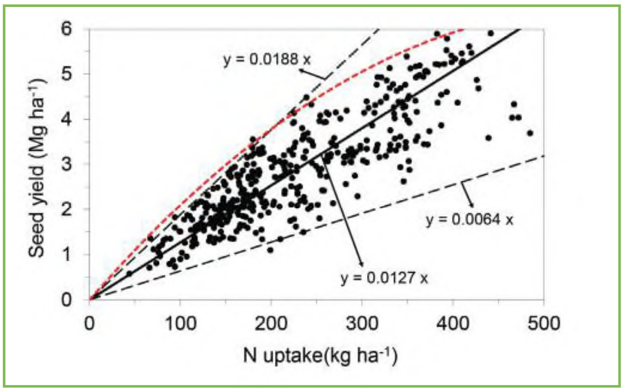


Table 2: Internal average requirement (AR), maximum dilution (MD), maximum accumulation (MA) and ranges of nutrient harvest index (HINu) of main macronutrients in soya beans.

Nutrient	AR	MD	MA	HINu
		kg nutrient / kg seed		%
N	79	53	156	53-76
P	6.5	3.8	10	35-75
S	4.1	2.1	7.8	40-59
K	36	23	48	27-44

The addition of Ca and Mg may have indirect effects via improving the proportion of these cations in the cation exchange capacity complex, affecting availability of other nutrients. In this situation, however, Ca and Mg rates are high and applied as amendment.

Micronutrients

Each micronutrient has particular roles in plant physiology, and contributes to increased yield and reduces the nutritional gap. The most studied micronutrients in agricultural systems have been molybdenum (Mo), boron (B), zinc (Zn) and manganese (Mn). Molybdenum is directly involved in N metabolism of the plant, and specifically in the BNF process since it is a constituent of the nitrogenase enzyme. Boron is related, among others, to processes such as the emission of pollen tubes in flowers. Then, addition of B is recommended during the flowering period.

Nutrient use efficiency

In grain crops such as soya beans, the agronomic use efficiency of a nutrient is generally expressed as kilogram of grain per unit of nutrient applied as fertiliser (i.e. agronomic efficiency, AE). This efficiency is the product of nutrient uptake efficiency (EUpt) and physiological use efficiency (EPhy).

Nutrient uptake efficiency can be estimated as the slope of the relationship between nutrient availability (soil or soil + fertiliser) and nutrient uptake. In general, these relationships are non-linear since nutrient uptake will be limited by the capacity of root cells to transport ions from soil to the internal part of the cells. This capacity is related to the presence of molecular transporters at the membrane level in the roots, which has a genetic control.

Analogously, the slope of the relationship between seed yield and nutrient uptake is the physiological nutrient efficiency. These relationships are also curvilinear, where a higher nutrient uptake is not accompanied by a proportional seed yield increase. These relationships are generally presented as an 'envelope' around the average fit. This envelope shows two processes: nutrient dilution and accumulation.

Identifying the nutrients that are deficient and defining a potential yield are important for reducing the nutritional gap.

Nutrient use efficiency will depend on the environmental conditions in which soya beans are growing. In *Figure 6*, even when an average fit can be defined, it can be seen as a non-linear trend when seed yield is increasing (i.e. there are no data points on the dilution curve for seed yield above 4mg/ha). The solid line is the average fit of the data with a slope of 0,0127mg seed per kg N. The dotted lines show the frontier line of maximum dilution (superior) and maximum accumulation (inferior) of N. The red dotted line shows the non-linear trend.

The internal nutrient requirement (the inverse of the slope of the relationship between nutrient uptake and seed yield) is important for planning crop and system nutrient management. *Table 2* shows internal nutrient requirements for the main macronutrients in soya beans, and also internal efficiencies of the dilution and accumulation lines. This knowledge may plan a more balanced nutrition of soya beans.

Based on *Table 2* values, it can be seen that the internal N requirement of soya beans is approximately 12, 19 and 2 times higher than the internal requirement of P, S and K, respectively. Likewise, the internal P requirement is 1,6 times larger than S.

Nutrient harvest index is another important variable for testing nutrient use efficiency, for knowing not only how much nutrient is exported from the system, but also how much nutrient is left with residues, and thus allowing for some insights of nutrient cycling in a sequence. The larger nutrient harvest indexes have been observed for N and P (*Table 2*).

Conclusions

Identifying the nutrients that are deficient and defining a potential yield are important for reducing the nutritional gap. In soya beans, the high N requirements should be primarily satisfied via the BNF process, and optimising crop management in order to maximise this contribution.

When planning fertilisation of low mobility nutrients, not only the effect on the crop but also residual effects of crops in the sequence should be considered. A deeper study is needed on the equilibrium between nutrients in order to optimise crop nutrition and minimise a negative impact on the environment.

References available from the author. For more information, email Dr Fernando Salvagiotti at salvagiotti.fernando@inta.gob.ar.