

Rhizobia:

What do nodule numbers tell us?

By Dr Ronel Hendriks, chief scientific officer, Microbika

Soya bean nodulation is a very complex interaction between a legume host plant and its symbiotic bacterial co-worker. Nodule number is a topic with many diverse opinions. What is our current scientific understanding of the process of nodulation, the communication between the host plant and *Rhizobium* bacteria, as well as the factors involved in determining nodule number?

Nodules: Nitrogen factories

Nodules are plant structures but for the sake of the simplicity of this article, we will call them nitrogen factories; factories that do not initiate or become active in the absence of factory workers (rhizobia). When a legume plant senses nitrogen limitation, it will produce signalling molecules (called flavonoids) to inform rhizobia of its intention to put up nitrogen factories.

In response to this recruiting signal, rhizobia will respond by signalling molecules (called nod factors). This complex exchange of signals is essentially an agreement between the employer (the legume plant) and the employees (the rhizobia) to put up nitrogen factories (Figure 1).

Different employers (legume cultivars) and employees (*Rhizobium* strains) have diverse and multifaceted skill sets. For example, some *Rhizobium* strains are more competitive, better communicators and more productive (Narožna *et al.*, 2015; Mendoza-Suárez *et al.*, 2021).

The same goes for different cultivars (employers) and how they manage their resources (i.e., water and nutrition) and perform (photosynthesise) under a specific set of conditions. Some employers perform better under stress, while others are more vulnerable to disease or nutritional deficiencies (Nicolás *et al.*, 2002; Kunert *et al.*, 2016).



It has been suggested that different employers (cultivars) communicate and interact in a diverse manner with different employees (*Rhizobium* strains). Some data has even confirmed that certain cultivars are unable to effectively communicate with specific *Rhizobium* strains (Nicolás *et al.*, 2002; Hayashi *et al.*, 2012).

The nitrogen factories require energy, such as sugars from photosynthesis, to run nitrogen fixation. The production team (rhizobia) consumes a lot of photosynthates to perform the conversion of atmospheric nitrogen to ammonia (Wagner, 2011). Although the exact metabolism inside the nodule is still under investigation, we know that photosynthesis (sugar production) plays a major part in the productivity of the nitrogen factories (Lopes *et al.*, 2019).

Legume plant plays a key role

The employer (legume plant) is the main decision maker. The decision-making

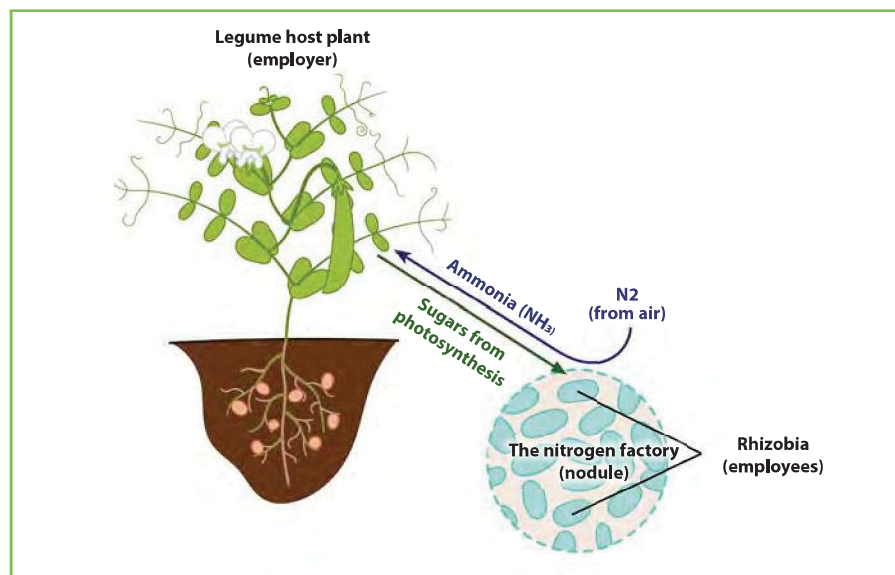
process by which a specific legume cultivar regulates the number of nodules, and the activity of these nitrogen factories, is called autoregulation of nodulation (Kinkema *et al.*, 2006; Ferguson *et al.*, 2010; Reid *et al.*, 2011; Mortier *et al.*, 2012).

When a hypernodulating mutant is constructed, the legume plant is essentially stripped from this decision-making function. The result? Plants with an average of 282 nodules per plant (Lopes *et al.*, 2019). Is this the next step towards record yields? Unfortunately not.

What happens in these hypernodulating mutants is that the nitrogen factories deplete the plant of all its carbohydrate sugars, resulting in the plants becoming stunted and producing no yield.

At this point, it seems that the number of nodules is not only a good indicator of a successful employer-employee match, but it can also be indicative of how effective a specific employer (cultivar)

Figure 1: Relationship between the legume host (employer) and rhizobia that are employed to work on the production line in the nitrogen factories (nodules).
(Source: Wikimedia Commons, 2022)



manages its resources under the specific set of conditions (soil, climate and nutrition) (Nicolás *et al.*, 2002; Kunert *et al.*, 2016).

Photosynthetic efficiency plays a central role in providing the fuel for the production team and increasing production in the nitrogen factories

(Libault, 2014). Larger nodules equal higher nitrogen fixation (King and Purcell, 2001).

Size matters too

Nodule number is not as simple as more is better. However, nodule size seems to correlate with more efficient factories

(King and Purcell, 2001; Lopes *et al.* 2019). Nodule number is a complex interplay between cultivar, *Rhizobium* strain, plant nutrition, stress and photosynthetic efficacy. All these factors play a crucial role in the plant's decision-making process with regard to the number, size and activity of nitrogen factories (nodules).

For now, nodule number is but a single indicator of how a specific cultivar-rhizobia strain combination responds to a specific set of conditions. Although we cannot control nodule numbers, we can support optimal nitrogen fixation by choosing the best cultivars, quality *Rhizobium* inoculants, and optimal plant nutrition to facilitate optimal photosynthesis, the driving force behind nitrogen fixation and yield. 🌱

For enquiries, send an email to Dr Ronel Hendriks at ronel@microbika.com or contact Mikrobika at 018 632 0362. Alternatively, visit www.microbika.com.

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