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SOILS

Andrew Margenot[1]

Andrew Margenot

About the Author

[1]Andrew Margenot is an Assistant Professor with the Department of Crop Sciences at the University of Illinois Urbana-Champaign
Email: margenot@illinois.edu

1. Soybean in 'African Soils'

There is no such thing as a "tropical soil" or an "African soil". Regardless of the pitfalls of referring to soils by their climate or geographic region (Hartemink, 2015), such labels egregiously dismiss the tremendous soil diversity in sub-Saharan Africa (Pedro A Sanchez, 2002; Pedro A. Sanchez & Logan, 1992). The diversity of soils in the subcontinent challenge one-size-fits-all blanket recommendations for any crop. Understanding and adapting to soil context is thus critical for effective development and delivery of agricultural intensification technologies such as soybean.

Recent and accelerating cultivation of soybean across sub-Saharan Africa has raised prospects of a "soybean bonanza" (Foyer et al., 2019; Sinclair, Marrou, Soltani, Vadez, & Chandolu, 2014). From production largely as niche crop in the 1960s to nearly 1.5 million acres in 2016, soybean production is increasing in Africa despite decreasing consumption of other legumes (Foyer et al., 2019). Diversification of cropping systems with legumes such as soybean can increase food security due to beneficial impacts on pest and disease cycles, soil fertility, and as a source of human and/or livestock dietary protein (Snapp, Blackie, Gilbert, Bezner-Kerr, & Kanyama- Phiri, 2010). Harnessing the potential of Nitrogen fixation of legumes is a promising strategy for sustainable intensification of smallholder agricultural systems predicted on multiple soil-plant interactions, which for soybean in the African context may require unique consideration (Franke, van den Brand, Vanlauwe, & Giller, 2018; Snapp et al., 2010).

Soybean, like other legumes, can also offer a means to improve soil fertility and cropping system productivity beyond the soybean crop phase. Nitrogen (N) fixed by a soybean crop can contribute significantly to the N needs of ensuing grain crops such as maize. For example, up to 22 kg N ha-1 derived from soybean were taken up by following maize crops in Guinea (Sanginga, Okogun, Vanlauwe, & Dashiell, 2002), which is higher than estimated mean N inputs across SSA of 10 kg ha-1 (van der Velde et al., 2014). Soil fertility interventions that target soybean productivity – such as the SIL input bundles – can be therefore leveraged by soybean to the benefit of other crops important for food security and profitability.

However, soil fertility constraints to N fixation by legumes such as soybean can hamstring potential entry point of this crop to act as a fulcrum for improved production. In the smallholder agricultural systems that dominate production in much of sub-Saharan Africa (Pedro A Sanchez et al., 1997; Smaling, Nandwa, & Janssen, 1997), such soil constraints can be especially obstructive. To address these, SIL has focused on input bundles to maximize returns on soybean technology.

2. The (Soil) Science Behind Bundling: Making the most of soybean's potential

Three key components of bundled inputs are: phosphorus, inoculum, and lime. Each component targets a specific soil-related constraint in order to maximize the yield potential of soybean. Additionally, all components can synergize to amplify investments in two or more components.

2.1. Phosphorus

Phosphorus (P) is a building block of the genetic code (RNA, DNA), a structural component of all cells (lipid membrane), and drives energy transactions in cells (ATP, NADPH). As for most crops, sufficient soil P availability is critical to support soybean growth and yield (Dodd & Mallarino, 2005; Jones, Lutz, & Smith, 1977). Since soybean is thought to be able to meet a majority of its N needs via biological N fixation (Gelfand & Philip Robertson, 2015; Salvagiotti et al., 2008) and given generally high crop demand for P compared to other nutrients (Havlin, Tisdale, Nelson, & Beaton, 2013), P can be a key yield-limiting soil nutrient for soybean.

However, the occurrence of weathered soils (Margenot, Singh, Rao, & Sommer, 2016) and socioeconomic constraints to smallholder access to P inputs (Nziguheba et al., 2015) in sub-Saharan Africa means soybean productivity may be especially constrained by this macronutrient. Additionally, soybean has a relatively high P harvest index, with up to 80% of P uptake allocated to grain (Bender, Haegele, & Below, 2015). Thus, replenishing P exported by soybean grain harvest using P inputs is essential for long-term agroecosystem sustainability.

When soils are managed to offer soybean sufficient P, N fixation can be maximized (van Vugt, Franke, & Giller, 2018), and coupled use of P and inoculants can increase grain yield (van Vugt et al., 2018). Legumes such as soybean may also be able to preferentially scavenge non-available P contained in organic forms via secretion of phosphatases (Lelei & Onwonga, 2014; Oberson, Friesen, Tiessen, Morel, & Stahel, 1999; Rao, Borrero, Ricaurte, Garcia, & Ayarza, 1997). Meta-analysis suggests improved soil P availability to grain crops with the addition of a legume rotation explains non-N effects of legumes on non-legume grain yield increases across sub- Saharan Africa (Franke et al., 2018).

2.2. Inoculum

As with any other legume, biological N fixation by soybean requires a compatible symbiotic rhizobacteria generally from the genus *Bradyrhizobium*. Given its Asian origins and historically recent introduction to Africa (Mpepereki, Javaheri, Davis, & Giller, 2000), the soybean symbiotic *Bradyrhizobium japonicum* is generally thought to not be present in soils in the continent (van Heerwaarden et al., 2018). Pioneering field trials in sub- Saharan Africa attributed limited N fixation by soybean to the absence of compatible *B. japonicum* (Kueneman, Root, Dashiell, & Hohenberg, 1984). Native or indigenous *Rhizobium* strains appear to have generally limited symbiotic effectiveness for soybean (Abaidoo, Keyser, Singleton, Dashiell, & Sanginga, 2007). Thus, inoculation with appropriate *Rhizobium* offers a means to enhance soil biological fertility for maximizing soybean production in this sub-Sahara Africa. For example, across more than 2,000 trials in ten sub-Saharan African countries, inoculation was found to increase soybean yield from a mean of nearly 9% from 1.22 to 1.34 Mg ha- 1, albeit with highly variable site-specific response (van Heerwaarden et al., 2018). However, emerging evidence suggests that indigenous *Rhizobium* are able to colonize and effectively symbiose with soybean in certain soils in the subcontinent (Jaiswal & Dakora, 2019). Though indigenous soil *Rhizobium* in sub-Saharan Africa appear to differ from those found in other subcontinents, it has been proposed that potentially high *Rhizobium* diversity may be harbored in Africa (Grönemeyer & Reinhold-Hurek, 2018) that could serve as a rich genetic resource for comparable or even improved inoculants for soybean and other leguminous crops in Africa and globally (Jaiswal & Dakora, 2019).

2.3. Lime

Lime works through multiple mechanisms to alleviate co-constraints to crop production, most notably decreasing aluminum toxicity to roots and enhancing the availability of soil nutrients already present. While not a nutrient, soil pH is critical for soybean growth indirectly via its effects on the availability of nutrients, in particular P and micronutrients, and directly via aluminum toxicity. Both of these constraints occur at low pH values (acidic soils) making liming an important strategy to enable soybean use of nutrients already present or applied to the soil. Soybean is responsive to liming applications that increase pH above the threshold of aluminum toxicity (Slaton, Roberts, & Ross, 2011), generally thought to be $pH > 5.5$ (Havlin et al., 2013).

References

Abaidoo, R. C., Keyser, H. H., Singleton, P. W., Dashiell, K. E., & Sanginga, N. (2007). Population size, distribution, and symbiotic characteristics of indigenous Bradyrhizobium spp. that nodulate TGx soybean genotypes in Africa. *Applied Soil Ecology, 35*(1), 57-67. doi:https://doi.org/10.1016/j.apsoil.2006.05.006

Bender, R. R., Haegele, J. W., & Below, F. E. (2015). Nutrient Uptake, Partitioning, and Remobilization in Modern Soybean Varieties. *Agronomy Journal, 107*(2), 563-573. doi:10.2134/agronj14.0435

Dodd, J. R., & Mallarino, A. P. (2005). Soil-Test Phosphorus and Crop Grain Yield Responses to Long-Term Phosphorus Fertilization for Corn-Soybean Rotations. *Soil Science Society of America Journal, 69*(4), 1118-1128. doi:10.2136/sssaj2004.027

Foyer, C. H., Siddique, K. H. M., Tai, A. P. K., Anders, S., Fodor, N., Wong, F.-L., Lam, H.-M. (2019). Modelling predicts that soybean is poised to dominate crop production across Africa. *Plant, Cell & Environment, 42*(1), 373-385. doi:10.1111/pce.13466

Franke, A. C., van den Brand, G. J., Vanlauwe, B., & Giller, K. E. (2018). Sustainable intensification through rotations with grain legumes in Sub-Saharan Africa: A review. *Agriculture, Ecosystems & Environment, 261*, 172- 185. doi:https://doi.org/10.1016/j.agee.2017.09.029

Gelfand, I., & Philip Robertson, G. (2015). A reassessment of the contribution of soybean biological nitrogen fixation to reactive N in the environment. Biogeochemistry, 123(1), 175-184. doi:10.1007/s10533-014-0061-4 Grönemeyer, J. L., & Reinhold-Hurek, B. (2018). Diversity of Bradyrhizobia in Subsahara Africa: A Rich Resource. *Frontiers in Microbiology, 9* (2194). doi:10.3389/fmicb.2018.02194

Hartemink, A. E. (2015). The use of soil classification in journal papers between 1975 and 2014. *Geoderma Regional, 5*, 127-139. doi:https://doi.org/10.1016/j.geodrs.2015.05.002

Havlin, J., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2013). Soil Fertility and Fertilizers: Pearson. Jaiswal, S. K., & Dakora, F. D. (2019). Widespread Distribution of Highly Adapted Bradyrhizobium Species

Nodulating Diverse Legumes in Africa. *Frontiers in Microbiology, 10*, 310-310. doi:10.3389/fmicb.2019.00310 Jones, G. D., Lutz, J. A., & Smith, T. J. (1977). Effects of Phosphorus and Potassium on Soybean Nodules and Seed Yield1. *Agronomy Journal, 69*(6), 1003-1006. doi:10.2134/agronj1977.00021962006900060024x

Kueneman, E. A., Root, W. R., Dashiell, K. E., & Hohenberg, J. (1984). Breeding soybeans for the tropics capable of nodulating effectively with indigenous Rhizobium spp. *Plant and Soil, 82*(3), 387-396. doi:10.1007/BF02184276

Lelei, J. J., & Onwonga, R. N. (2014). White Lupin (Lupinus albus L. cv. Amiga) Increases Solubility of Minjingu Phosphate Rock, Phosphorus Balances and Maize Yields in Njoro Kenya. *Sustainable Agriculture Research, 3*(3), 37. doi:10.5539/sar.v3n3p37

Margenot, A. J., Singh, B. R., Rao, I. M., & Sommer, R. (2016). Phosphorus Fertilization and Management in Soils of Sub-Saharan Africa. In R. Lal (Ed.), Soil Phosphorus (pp. 151-208). New York: CRC Press.

Mpepereki, S., Javaheri, F., Davis, P., & Giller, K. E. (2000). Soyabeans and sustainable agriculture: Promiscuous soyabeans in southern Africa. *Field Crops Research, 65*(2), 137-149. doi:https://doi.org/10.1016/S0378- 4290(99)00083-0

Nziguheba, G., Zingore, S., Kihara, J., Merckx, R., Njoroge, S., Otinga, A., Vanlauwe, B. (2015). Phosphorus in smallholder farming systems of sub-Saharan Africa: implications for agricultural intensification. *Nutrient Cycling in Agroecosystems*, 1-20. doi:10.1007/s10705-015-9729-y

Oberson, A., Friesen, D. K., Tiessen, H., Morel, C., & Stahel, W. (1999). Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian Oxisol. *Nutrient Cycling in Agroecosystems, 55*(1), 77-88. doi:10.1023/a:1009813008445

Rao, I. M., Borrero, V., Ricaurte, J., Garcia, R., & Ayarza, M. A. (1997). Adaptive attributes of tropical forage species to acid soils. III. Differences in phosphorus acquisition and utilization as influenced by varying phosphorus supply and soil type. *Journal of Plant Nutrition, 20*(1), 155-180. doi:10.1080/01904169709365240

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T., Weiss, A., & Dobermann, A. (2008). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Research, 108*(1), 1-13. doi:https://doi.org/10.1016/j.fcr.2008.03.001

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science, 295*(5562), 2019-2020.

Sanchez, P. A., & Logan, T. J. (1992). Myths and Science about the Chemistry and Fertility of Soils in the Tropics. In R. Lal & P. A. Sanchez (Eds.), Myths and Science of Soils of the Tropics (pp. 35-46): Soil Science Society of America and American Society of Agronomy.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A.-M. N., Place, F.M., Shepard, K.D., Soule, M.J. (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. *World Agroforestry*, 1-46.

Sanginga, N., Okogun, J., Vanlauwe, B., & Dashiell, K. (2002). The contribution of nitrogen by promiscuous soybeans to maize based cropping the moist savanna of Nigeria. *Plant and Soil, 241*(2), 223-231. doi:10.1023/A:1016192514568

Sinclair, T. R., Marrou, H., Soltani, A., Vadez, V., & Chandolu, K. C. (2014). Soybean production potential in Africa. *Global Food Security, 3*(1), 31-40. doi:https://doi.org/10.1016/j.gfs.2013.12.001

Slaton, N., Roberts, T., & Ross, J. (2011). Fertilization and liming practices. https://www.uaex.edu/publications/pdf/mp197/chapter5.pdf

Smaling, E. M. A., Nandwa, S. M., & Janssen, B. H. (1997). Soil Fertility in Africa Is at Stake. In R. J. Buresh, P. A. Sanchez, & F. Calhoun (Eds.), Replenishing soil fertility in Africa (pp. 47-61): Soil Science Society of America and American Society of Agronomy.

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences, 107*(48), 20840-20845. doi:10.1073/pnas.1007199107

Van der Velde, M., Folberth, C., Balkovič, J., Ciais, P., Fritz, S., Janssens, I. A., Peñuelas, J. (2014). African crop yield reductions due to increasingly unbalanced Nitrogen and Phosphorus consumption. Global Change Biology, 20(4), 1278-1288. doi:10.1111/gcb.12481

Van Heerwaarden, J., Baijukya, F., Kyei-Boahen, S., Adjei-Nsiah, S., Ebanyat, P., Kamai, N., . Giller, K. (2018). Soyabean response to rhizobium inoculation across sub-Saharan Africa: Patterns of variation and the role of promiscuity. *Agriculture, Ecosystems & Environment, 261*, 211-218. doi:https://doi.org/10.1016/j.agee.2017.08.016

Van Vugt, D., Franke, A. C., & Giller, K. E. (2018). Understanding variability in the benefits of N2-fixation in soybean-maize rotations on smallholder farmers' fields in Malawi. *Agriculture, Ecosystems & Environment, 261*, 241-250. doi:https://doi.org/10.1016/j.agee.2017.05.008