Factsheet # 3

Title: IMPROVING SOIL HEALTH BY USING BIOFERTILIZERS ON BIOMASS CROPS (SWITCHGRASS & MISCANTHUS)

By

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WHAT ARE BIOFERTILIZERS?

"Biofertilizer" refers to inoculants of plant-growth-promoting rhizobacteria (PGPR) or mycorrhizal fungi (hereinafter, "microbial inoculants", "inoculants"), or organic fertilizers[1]. These fertilizers can be made from a variety of sources. In particular, organic biofertilizers can be derived from livestock manure, plant matter, or municipal sewage[2]. Municipal sewage (or biosolids) fertilizers are of interest for biomass crop production. Any toxic trace elements in the biosolids the plants may take up will not pose a health concern since the crops are not used for human consumption[3]. Microbial inoculants may be particularly valuable for switchgrass and miscanthus production because these crops heavily rely on soil microbial relations to acquire soil nutrients[4]. Research regarding the use of biosolids for biomass crop production has demonstrated success with miscanthus and switchgrass[3]. Several microbial inoculants have been successfully tested in switchgrass and miscanthus cropping systems[5]. However, further study is required to determine which options can consistently enhance the yields of these crops. In this context, three promising microbial inoculants were tested in switchgrass and miscanthus production systems. They are, JumpStart® by Novozymes (inoculant of the phosphorus-solubilizing fungus *Penicillium bilaiae*), MYKE® Pro or AGTIV® by Premier Tech (inoculant of the arbuscular mycorrhizal fungus, or AMF, *Glomus intraradices*), and Optimyc and MooR by VisscherHolland (inoculants of endo mycorrhizae and *rhizobacteria consortia*). Results from the above study are presented in this factsheet.

BIOFERTILIZERS AND PERENNIAL BIOMASS CROPS (PBSs)

While it may seem that switchgrass and miscanthus represent robust solutions to environmental challenges within and beyond the agricultural sector, affordable methods of increasing yields for both species must be established to be economically viable while offering competitive advantages and prices for their products[6]. Research has shown that synthetic nitrogen fertilizer significantly increased yields for both species[7]. However, these fertilizers have adverse environmental impacts when excess nutrients enter adjacent ecosystems or are released as GHGs[8]. Synthetic fertilizers can also negatively impact soil microbial communities that are vital for several ecosystem functions, including nutrient cycling[9]. In addition to the large amount of energy and non-renewable resources required to produce synthetic fertilizers, these direct negative impacts make it essential to minimize their use in the expanding biomass production industry[8].

BENEFITS OF BIOFERTILIZERS AND YIELDS

Studies from the University of Guelph showcased that synthetic N produced significantly higher autumn-harvested biomass yield in 2020 than the combined average for all three biofertilizers (JumpStart®, AGTIV®, Optimyc + MooR (Figure 1). However, observed lack of significant response of switchgrass biomass yield to biofertilizers does contradict existing literature; it is worth noting that there are very few studies that have tested commercial biofertilizer products, particularly microbial inoculants, with perennial grasses[3,10]. Therefore, the results from this study may simply add to the growing body of literature beginning to investigate the viability of these products for commercial biomass production.

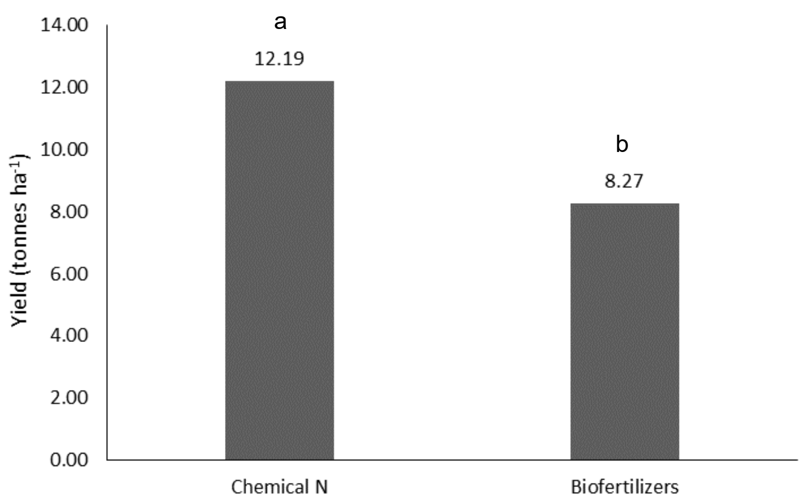

Figure 1. Influence of synthetic nitrogen (N) fertilizer versus the combined average of three biofertilizers (JumpStart®, AGTIV®, Optimyc + MooR) on switchgrass biomass yield (tonnes ha^{-1}) at the Guelph Switchgrass site in 2020. Different letters indicate significantly different means according to orthogonal contrast ($p \leq 0.05$).

SOIL HEALTH AND BIOFERTILIZERS

There is promising potential for biofertilizers to improve soil biological health under switchgrass biomass crops, particularly by enhancing 16S bacterial and 18S gene abundance (which are indicative of bacterial and fungal population sizes) (Figures 2 and 3). Further study will be required, however, to determine the long-term effects of these treatments that may emerge with consistent application. Additional studies should also investigate treatment effects on soil microbial community composition and activity to create a clearer picture of how biofertilizers affect soil ecosystem services. In the above context, it should be noted that the synthetic N treatment led to a significant reduction in 16S bacterial and 18S fungal gene abundance in the soil in comparison with biofertilizer Optimyc + MooR (Figures 2 and 3), which could be indicative of reduced soil health and ecosystem function. It is therefore important to study synthetic N fertilizer's effect on soil microbial community structure and activity to confirm potential negative effects on soil health. Furthermore, the biofertilizers did not reduce 16S bacterial or 18S fungal gene abundance like the synthetic N treatment. Although it did not significantly increase the abundance of these genes in the soils across all tested biofertilizers, the need to continue studies of this nature, therefore, is further emphasized.

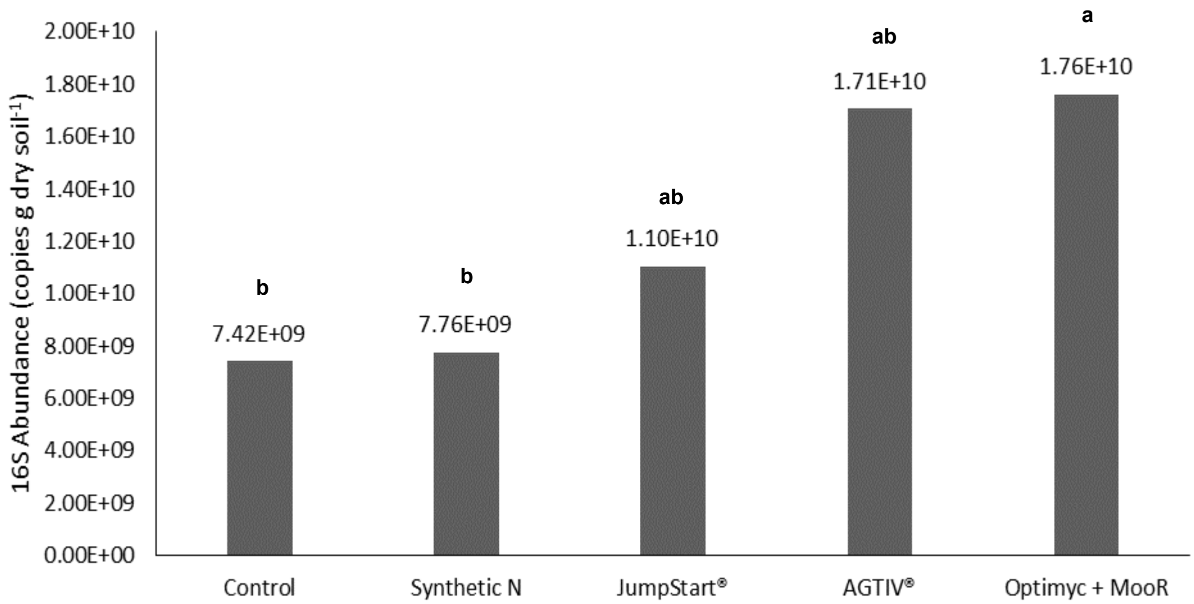

Figure 2. Peak season 16S bacterial gene abundance (copies g dry soil^{-1}) in the top 10 cm of soil as influenced by fertilizer treatment at the Guelph Switchgrass site in 2020. Different letters indicate significantly different means according to least-square means comparison adjusted per the Tukey test ($p \leq 0.05$).

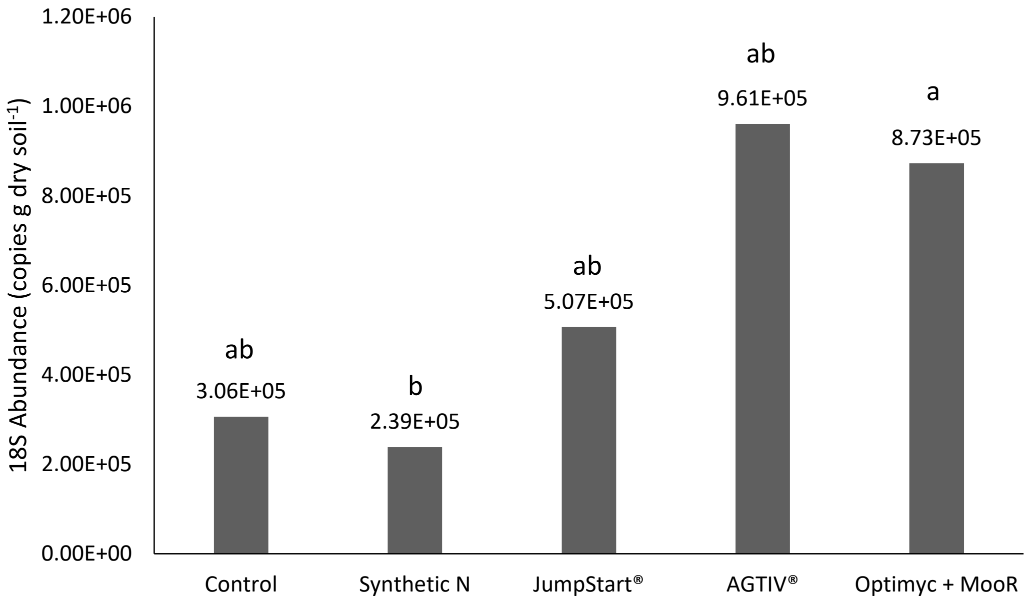

Figure 3. Peak 18S fungal gene abundance (copies g dry soil^{-1}) in the top 10 cm of soil as influenced by fertilizer treatment at the Guelph Switchgrass site in 2020. Different letters indicate significantly different means according to least-square means comparison adjusted per the Tukey test ($p \leq 0.05$).

BIOFERTILIZERS AND SOIL NUTRIENT RELEASE

The significant increase in soil NO_3^--N, NH_4^+-N, total mineral N and P by LysteGro (Figure 4) can likely be attributed to the supply of readily mineralizable organic N and P in the biosolids material. This agrees with existing literature, as increased availability of NO_3^--N , NH_4^+-N and available P with the application of municipal biosolids has been observed in numerous studies[3].

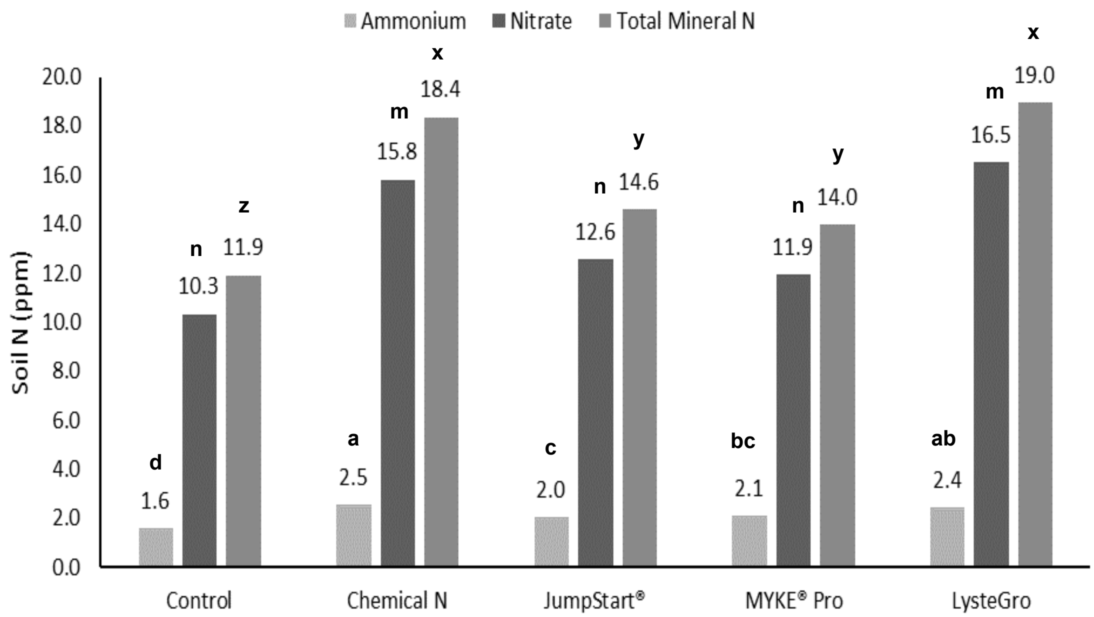

Figure 4. The average availability of NH_4^+, NO_3^-, and total mineral N in the soil over a seven-week incubation period as affected by fertilizer treatment. Different letters indicate significantly different means according to least-square means comparison adjusted according to the Tukey test ($p \leq 0.05$).

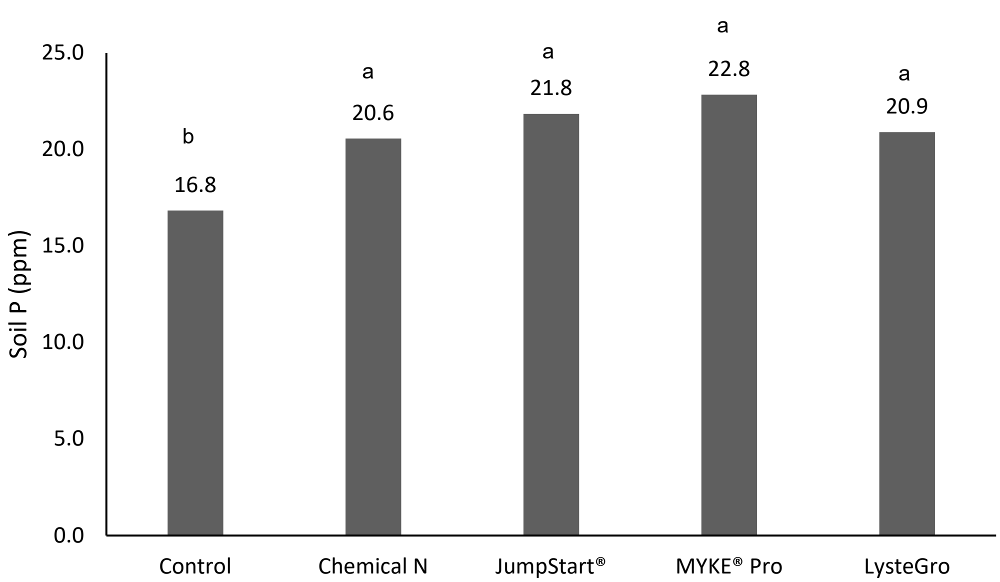

Figure 5. Average availability of P in the soil over a seven-week incubation period as affected by fertilizer treatment. Different letters indicate significantly different means according to least-square means comparison adjusted according to the Tukey test ($p \leq 0.05$).

BIOFERTILIZERS AND ECONOMIC FEASIBITY

Table 1: Product pricing ($ CAD) and biomass yield (tonnes ha^{-1}) for fertilizer treatment options applied to mature switchgrass at the Guelph Switchgrass site and mature miscanthus at the Burlington Miscanthus site.

		Yield (tonnes ha^{-1}) [1]	
Treatment	*Price ($ ha^{-1} $year^{-1}$)*	Switchgrass (GS)	Miscanthus (BM)
Synthetic N (60 kg N ha^{-1})	28.97	11.33	13.05
JumpStart®	88.65 - 100.79[2]	8.70	12.09
MYKE® Pro (2019) / AGTIV® (2020)	34.45-35.70[3]	8.61	16.22
Optimyc + MooR (2020 only)	98.84[4]	8.56	N/A
LysteGro (2019 only)	100.58	10.66	11.68

[1] Averaged over all available years of study.
[2] Price changes depending on the amount purchased and is based on the application rate used in 2020, which was triple the rate applied in 2019.
[3] Price changes depending on the amount purchased and is based on cost of AGTIV® (agricultural-grade version of the product), not MYKE® Pro (retail-grade version of the product).
[4] Average annual cost, based on the following 7-year cycle: Optimyc and MooR both applied in year 1, just MooR applied in years 2-4, and no applications in years 5-7.

This data demonstrates that synthetic N applied at 60 kg N ha^{-1} is the least expensive of all fertilizer treatments. Unlike seen in switchgrass, synthetic N fertilizer did not result in the highest miscanthus biomass yield over the two study years. The highest miscanthus biomass yields were achieved in MYKE® Pro / AGTIV® treatment (2019/2020), which is also relatively less expensive biofertilizer treatment in this study. Furthermore, the cost-effectiveness of MYKE® Pro / AGTIV® biofertilizer was close to the synthetic N fertilizer cost-effectiveness based on the data from the present study. MYKE® Pro / AGTIV® produced an average biomass yield of 0.35 tonnes ha^{-1} yr^{-1} for each dollar spent on the biofertilizer (dependent on the amount purchased). Conversely synthetic N fertilizer produced an average biomass yield of 0.42 oven dried tonnes ha^{-1} yr^{-1} per dollar spent on the fertilizer. These estimations were made by dividing the mean annual biomass yield of each treatment by its annual cost per hectare. This demonstrates how MYKE® Pro / AGTIV® may represent a beneficial option for miscanthus producers, as long as the yield benefits associated with this biofertilizer are consistent over several years. It remains important to emphasize, however, that all biofertilizer treatments from this study are more expensive than the traditional synthetic fertilizer. If biofertilizers are established as a viable method of increasing miscanthus yields while reducing the environmental impact of its production compared to synthetic N fertilizers, government policies should be established to provide financial support to growers choosing to apply effective biofertilizers in place of synthetic fertilizers.

CONCLUSIONS

In summary, this study indicates that the best fertilizer options for Ontario switchgrass and miscanthus producers are the traditional synthetic N fertilizer or MYKE® Pro / AGTIV® biofertilizers based on the cost of fertilizer. LysteGrow resulted in higher switchgrass and miscanthus yields but the cost of fertilizer is high. Synthetic N may be applied conservatively coupled with careful management of soil N levels to increase yields while minimizing detrimental environmental impacts. However, government financial support for environmentally friendly agricultural management practices can promote the use of MYKE® Pro / AGTIV® or LysteGrow to support biomass yields while rehabilitating depleted soils. However, additional studies should be conducted to confirm these results under a range of field and climatic conditions. Long-term studies should also be established to confirm the longevity and consistency of the effects observed in the present study. Furthermore, future studies may consider conducting more detailed analyses for soil biological health that incorporate microbial diversity, activity, and community composition, as well as assessments of GHG fluxes associated with biofertilizer treatments compared to control and synthetic N fertilizer.

Acknowledgement

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References

1. Jacoby, R., Peukert, M., Succurro, A., Koprivova, A. & Kopriva, S. The Role of Soil Microorganisms in Plant Mineral Nutrition-Current Knowledge and Future Directions. *Front. Plant Sci.* **8,** 1617; 10.3389/fpls.2017.01617 (2017).

2. Tailor, A. J. & Joshi, B. H. Harnessing Plant Growth Promoting Rhizobacteria Beyond Nature: A Review. *Journal of Plant Nutrition* **37,** 1534–1571; 10.1080/01904167.2014.911319 (2014).

3. Kołodziej, B., Antonkiewicz, J. & Sugier, D. Miscanthus×giganteus as a biomass feedstock grown on municipal sewage sludge. *Industrial Crops and Products* **81,** 72–82; 10.1016/j.indcrop.2015.11.052 (2016).

4. Li, D., Voigt, T. B. & Kent, A. D. Plant and soil effects on bacterial communities associated with Miscanthus × giganteus rhizosphere and rhizomes. *GCB Bioenergy* **8,** 183–193; 10.1111/gcbb.12252 (2016).

5. Simpson, S. Ontario biomass crops' influence on soil organic carbon sequestration and potential biofertilizer enhancement of crop growth. Ontario biomass crops'

influence on soil organic carbon sequestration and potential biofertilizer enhancement of crop growth. University of Guelph.

6. Cobuloglu, H. I. & Büyüktahtakın, İ. E. Food vs. biofuel: An optimization approach to the spatio-temporal analysis of land-use competition and environmental impacts. *Applied Energy* **140,** 418–434; 10.1016/j.apenergy.2014.11.080 (2015).

7. Marsal, F. *et al.* Biomass yield assessment of five potential energy crops grown in southern Ontario, Canada. *Agroforest Syst* **90,** 773–783; 10.1007/s10457-016-9893-3 (2016).

8. Ashworth, A. J. *et al.* Environmental impact assessment of regional switchgrass feedstock production comparing nitrogen input scenarios and legume-intercropping systems. *Journal of Cleaner Production* **87,** 227–234; 10.1016/j.jclepro.2014.10.002 (2015).

9. Oates, L. G., Duncan, D. S., Sanford, G. R., Liang, C. & Jackson, R. D. Bioenergy cropping systems that incorporate native grasses stimulate growth of plant-associated soil microbes in the absence of nitrogen fertilization. *Agriculture, Ecosystems & Environment* **233,** 396–403; 10.1016/j.agee.2016.09.008 (2016).

10. Liu, X.-J. A., Fike, J. H., Galbraith, J. M. & Fike, W. B. Switchgrass Response to Cutting Frequency and Biosolids Amendment: Biomass Yield, Feedstock Quality, and Theoretical Ethanol Yield. *Bioenerg. Res.* **7,** 1191–1200; 10.1007/s12155-014-9454-4 (2014).