MM05: Biostimulants

Category
Cropland management: agronomy

Overview
According to the definition by the European Biostimulants Industry Council, plant biostimulants contain microorganism(s) and/or substance(s) whose function, when applied to plants or the rhizosphere, is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality (Colantoni et al. 2017). There is a wide range of different types of biostimulants, including the following categories specified in the AHDB (2016) biostimulant report 1) Seaweed extracts, 2) Humic substances, 3) Phosphite and other inorganic salts, 4) Chitin and chitosan derivatives, 5) Anti-transpirants, 6) Protein hydrolysates and free amino acids, 7) Non-essential chemical elements, 8) Complex organic materials, 9) Plant growth promoting bacteria and rhizobacteria, 9) Non-pathogenic fungi, 10), Arbuscular mycorrhizal fungi and 11) Protozoa and nematodes. There is also a wide variety of different products within each of these category, strongly differing in their mechanism of action.

Biostimulants have been used in horticultural production, but more large-scale use in cereal and oilseed production also exists, and that could potentially provide opportunities for significant reduction of GHG emissions.

Mitigation summary

Effect on GHG categories*	Rating	Notes
Enteric CH4		
Manure CH4		
Manure N2O		
Soil N2O: applied N	-	May be possible to reduce fertilisation due to improved nutrient uptake
Soil N2O: grazing		
Energy CO2: fieldwork		
Energy CO2: other		
CO2 liming and urea		
CO2 sequestration below ground		
CO2 sequestration above ground		
Pre-farm emissions	+	Production of biostimulants
Post-farm emissions		
Substitution of higher C products		
Production increases by more than the emissions	-	
Confidence in mitigation effect	Low	
Cost-effectiveness**	Low	
Confidence in cost-effectiveness	Low	

*   ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential synergies

Measure	Impact on other measures

Inclusion in other marginal abatement cost curves

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
No	No	No	No	No	?

What does the measure entail?

Due to the huge variety of different types of biostimulants and potential mechanisms of their actions in crops and soils (many of which are not precisely understood), it would not be possible to provide an overall conclusion of the effect of biostimulant use on the GHG emissions arising from crop production. Therefore, a typical effect of biostimulant in the yield of crops in cool and temperate climate was estimated based on available literature. The reduction of the GHG emission intensity was then calculated based on the increased yield. This was then compared to the potential GHG emissions arising from the production of biostimulants.

Abatement rate

A recent review published by AHDB (2016) presents several scientific experiments where the effects of biostimulants on various crop properties are studied. Table 1 shows a list of studies selected according to a criteria that 1) they are field experiments (not e.g. laboratory or greenhouse studies) 2) the location is in cool or temperate region, and 3) changes in yield are reported. It can be seen that although there is a wide variety in responses, a typical increase in yield as a use of biostimulants is around 10%. However, these results should be interpreted with caution. The results come from highly controlled experiments where the management may be different than in commercial crop production. It is also likely that in some experiments much higher dosage of biostimulant is used compared to the recommendations by manufacturers. It should also be noted that these experiments are largely carried out in sub-optimal conditions. Therefore, if the baseline yield is already high (e.g. in the UK cereal production), much smaller improvement as a result of biostimulant use may be expected. AHDB (2016) suggests that the impacts on yields are mainly seen when the products were tested under soil and weather conditions which were not comparable with UK agriculture. More evidence from UK based studies are needed to prove the effectiveness of the different biostimulant products.

Table 1. Effects of biostimulants on the yield of cereals in cool and temperate regions.

Type of biostimulant	**Crop**	**Country**	**Yield (% of untreated)**	**Reference**
Seaweed extract	Barley	Canada	73% - 131%	Taylor et al. 1990
Seaweed extract	Barley	Canada	85% - 109%	Taylor et al. 1990
Fulvic acid (humic substance)	Wheat	Australia	101%	Dunstone et al.1988
Fulvic acid (humic substance)	Wheat	China	107% - 118%	Xudan 1986
Fulvic acid (humic substance)	Wheat	China	110% - 111%	Zhang et al. 2016
Phosphite	Spring barley	UK	100% - 108%	AHDB 2016
Phosphite	Spring wheat	UK	105% - 106%	AHDB 2016
Phosphite	Spring wheat + winter barley	UK	97% - 106%	Roques et al. 2013
Phosphite	Spring wheat + winter barley	Ireland	95% - 112%	Roques et al. 2013
Chitosan	Dryland wheat	USA	134 %	Freepons 1996
Chitosan	Irrigated wheat	USA	110 %	Freepons 1996
Chitosan	Winter wheat	China	94% -111%	Wang et al. 2015
Anti-transpirant	Winter wheat	UK	88% -110%	Kettlewell et al. 2010
Anti-transpirant	Winter wheat	UK	107% - 112%	Weerasinghe et al. 2016
Anti-transpirant	Wheat	Argentina	79% - 132%	Travaglia et al. 2010
Anti-transpirant	Winter wheat	China	106% - 138%	Zhang et al. 2016
Rhizobacteria	Spring wheat	Turkey	103% - 150%	Çakmakçi et al. 2014
Rhizobacteria	Spring barley	Turkey	93% - 167%	Çakmakçi et al. 2014
Non-pathogenic fungi	Wheat	Turkey	107%	Öğüt et al. 2005
Mycorrhizal fungi	Wheat	USA	117% - 141%	Al-Karaki et al. 2004
Mycorrhizal fungi	Maize	Italy	97% - 118%	Cozzolino et al. 2013
Mycorrhizal fungi	Winter wheat	USA	95% - 130%	Mohammad et al. 1998
Mycorrhizal fungi	Barley	UK	96% - 97%	Khaliq & Sanders 2000
Mycorrhizal fungi	Barley	UK	93% - 233%	Clarke & Mosse 1981

Assuming that biostimulants increase the yield by 10%, their application would reduce the GHG emission intensity for example in UK wheat production by about 29 kg CO2e/t, if other agricultural practices remain unchanged. With a 5% yield improvement, this reduction would be about 14 kg CO2e/t.

Very limited information exists concerning the GHG emission arising from the production of biostimulants. Based on the LCA studies by Ghosh et al. (2015) and Munoz et al. (2018) on seaweed sap and chitosan biostimulants, and following the dosage per ha obtained from literature (Ghosh et al. 2015, Singh et al. 2016), additional GHG emissions arising from biostimulant production would range from 0.1 to 3 kg CO2e per t wheat produced in the UK. That would be much less than the emission reduction as a result of improvement of yield.

Cost-effectiveness
The quantities of the biostimulants used per hectare are relatively low, and therefore the costs of their use are also expected to be low. The price of a typical biostimulant chitosan for agricultural use is about $1500/t. Since the product will be heavily diluted for applications (less than 0.1 kg/ha), even a moderate increase in yield could cover the cost of the use of this product.

Applicability, current uptake and potential additional maximum uptake
The area treated with biostimulants in Europe has been estimated to be over 6 million ha (AHDB 2016, Calvo et al. 2014). However, there has been little interest towards biostimulant use in the UK until recent years. This has mainly been because of the lack of evidence of their effects. However, a general trend in Europe is an increasing market for biostimulants, with an expected growth 10% per year (AHDB 2016). The increase is driven by consumer demand for healthy and environmentally products, and partly by high fertiliser prices. However, the lack of knowledge and instructions on the optimal way of using these products for different crops in different growing conditions, and lack of proven benefits is likely to strongly limit their uptake. It should also be noted that the biggest effects of biostimulants are likely to occur in sub-optimal conditions. For example, highest benefits may be achieved when using those products instead of, not in addition to fertilisers. Due to uncertainties concerning the effects of biostimulants, such practice may not be easily adopted by commercial farmers. Otherwise, there are no technical limits for the use in biostimulants in most of the crop production area in the UK.

Assumptions used in the MACC
1. Biostimulants increase the yield of crops by 5%
2. Emissions associated to production of biostimulants are 0.5 kgCO2e/ t of cereals (based on chitosan produced in Europe)
3. No other changes in crop production emissions per ha
4. Cost-effectiveness: $0/tCO2e
5. Applicable to cereal and oilseed production.

Ancillary effects

Table 2. Ancillary effects of the operation

Positive effects		**Source**
Off-farm GHG	Possible reduction in fertiliser production	Literature
Production	Possible reductions in emissions from fertiliser use	Literature
Adaptation		
Environment	Reduced fertiliser use could lead to reduction of non GHG emissions	Literature
Negative effects		
Off-farm GHG	Emissions related to production of biostimulants	
Production	Uncertainties in possible effects: incorrect use to replace fertilisers/pesticides may actually reduce yields	Literature, Defra peer review
Adaptation		
Environment		

Identified implementation challenges and barriers

Table 3 Potential barriers to uptake and key risks/uncertainties

Barrier to uptake	**Source**
Uncertainties in potential benefits	Defra peer review, literature
Difficulties to identify correct use	
Other key risks/uncertainties	

References

AHDB 2016. Research Review No. 89. A review of the function, efficacy and value of biostimulant products available for UK cereals and oilseeds.

Al-Karaki G, Mcmichael B, Zak J. 2004. Field response of wheat to arbuscular mycorrhizal fungi and drought stress. Mycorrhiza 14:263-269.

Çakmakçi R, Dönmez M F, Erdoğan Ü. 2007. The effect of plant growth promoting rhizobacteria on barley seedling growth, nutrient uptake, some soil properties, and bacterial counts. Turkish Journal of Agriculture and Forestry. 31:189-199.

Calvo P, Nleson L, Kloepper J W. 2014. Agricultural uses of plant biostimulants. Plant and Soil 383:3-41.

Clarke C, Mosse B. 1981. Plant growth responses to vesicular Arbuscular mycorrhiza xii. Field inoculation responses of barley at two soil P levels. New Phytologist 87:695-703.

Colantoni A., Recchia L, Bernabei G, Cardarelli M, Rouphael Y, Colla G. 2017. Analyzing the environmental impact of chemically-produced protein hydrolysate from leather waste vs. enzymatically-produced protein hydrolysate from legume grains. Agriculture 7, 62; doi:10.3390/agriculture7080062.

Cozzolino V, Di Meo V, Piccolo A. 2013. Impact of arbuscular mycorrhizal fungi applications on maize production and soil phosphorus availability. Journal of Geochemical Exploration 129:40-44.

Dunstone R L, Richards R A, Rawson H M. 1988. Variable responses of stomatal conductance, growth, and yield to fulvic acid applications in wheat. Australian Journal of Agricultural Research 39:547-553.

Freepons D. 1996. Enhancing food production with chitosan seed-coating technology. CRC Press.

Ghosh A, Vijay Anand K G, Seth A. 2015. Life cycle impact assessment of seaweed based biostimulant production from onshore cultivated Kappaphycus alvarezii (Doty) Doty ex Silva—Is it environmentally sustainable? Algal Research 12: 513–521

Kettlewell P S, Heath W L, Haigh I M. 2010. Yield enhancement of droughted wheat by film antitranspirant application: rationale and evidence. Agricultural Sciences 1:143–147.

Khaliq A, Sanders F E. 2000. Effects of vesicular–arbuscular mycorrhizal inoculation on the yield and phosphorus uptake of field-grown barley. Soil Biology and Biochemistry 32:1691-1696.

Mohamed W H. 2012. Effects of humic acid and calciumforms on dry weight and nutrient uptake of maize plant under saline condition. Australian Journal of Basic and Applied Science 6:597–604.

Muñoz I, Rodríguez C, Gillet D, Moerschbacher B M. 2018. Life cycle assessment of chitosan production in India and Europe. Int J Life Cycle Assess 23:1151–1160

Öğüt M, Akdağ C, Düzdemir O, Sakin M A. 2005. Single and double inoculation with Azospirillum/Trichoderma: the effects on dry bean and wheat. Biology and Fertility of Soils 41:262-272.

Roques S, Kendall S, Smith K, Price P N, Berry P. 2013. Research Review No. 78. A review of the non-NPKS nutrient requirements of UK cereals and oilseed rape. HGCA Report.

Singh S, Singh M K, Pal S K, Trivedi K. Yesuraj D, Singh C S, Vijay Anand K G, Chandramohan M, Patidar R, Kubavat D, Zodape S T, Ghosh A. 2016. Sustainable enhancement in yield and quality of rain-fed maize through *Gracilaria edulis* and *Kappaphycus alvarezii* seaweed sap. J. Appl. Phycol. 28:2099–2112

Taylor J S, Harker K N, Robertson I, Foster K R. 1990. The effect of a seaweed extract containing cytokinin on the growth and yield of barley. Canadian Journal of Plant Science. 70:1163-1167.

Travaglia C, Reinoso H, Cohen A, Luna C, Tommasino E, Castillo C, Bottini R. 2010. Exogenous ABA increases yield in field-grown wheat with moderate water restriction. Journal of Plant Growth Regulation 29:366-374.

Wang M, Chen Y, Zhang R, Wang W, Zhao X, Du Y, Yin H. 2015. Effects of chitosan oligosaccharides on the yield components and production quality of different wheat cultivars (Triticum aestivum L.) in Northwest China. Field Crops Research 172:11-20.

Weerasinghe M M, Kettlewell P S, Grove I G, Hare M C. 2016. Evidence for improved pollen viability as the mechanism for film antitranspirant mitigation of drought damage to wheat yield. Crop and Pasture Science 67:137-146.

Xudan X. 1986. The effect of foliar application of fulvic acid on water use, nutrient uptake and yield in wheat. Australian Journal of Agricultural Research 37:343–350.

Zhang X, Zhang X, Liu X, Shao L, Sun H, Chen S. 2016. Improving winter wheat performance by foliar spray of ABA and FA under water deficit conditions. Journal of Plant Growth Regulation 35:83-96.