Biostimulants: Boom or Bull

Bryan G. Hopkins, Ph.D., CPSS
Do we have good science behind mode-of-action and crop response for biostimulants?
An industry scientist shared this with me

“. . . there are a myriad companies and products looking for recognition . . . in this (biostimulant) arena, not all of which have a sound scientific basis . . . (with many in government, etc.) . . . openly promoting biostimulants as the panacea for all things soil health, some restraint, reason, and science is sorely needed.”
References


Published Responses to Biostimulants

**Fruit**
- Setting processes
- Fruit size and weight
- Quality

Croucher and Staden, 1992; Chouliais et al., 1997; Colapietra and Alexander, 2006; Basak, 2008; Chouliais et al., 2009; Ross and Holdan, 2010; Loyola and Muñoz, 2011; Pandikov et al., 2011; Kumar et al., 2012; Pandikov et al., 2013; El-Hamidi et al., 2015.

**Seeds / Seedlings**
- Germination
- "Starter effect"
- Overcoming transplant stress
- Priming effect
- Seed quality

Aldworth and Staden, 1987; Featonby-Smith and van Staden, 1987; Croucher and Staden, 1992; Russo et al., 1993; Möller and Smith, 1998; Demir et al., 2006; Sivasankeri et al., 2006; Farooq et al., 2008; Neily et al., 2010; Kumar and Sahoo, 2011; Matysiak et al., 2011; Kalaivanan and Venkatesalu, 2012.

**Plant**
- Plant growth/yield and physiological modulation
- Water/nutrient uptake
- Stress response

Beckett and van Staden, 1990; Beckett et al., 1994; Bhudden et al., 1996; Adami, 1998; Mancuso et al., 2006; Zhang and Erwin, 2008; Ross and Holdan, 2010; Sangeetha and Thevanathan, 2010; Zhang et al., 2010; Fan et al., 2011; Kumar and Sahoo, 2011; Matysiak et al., 2011; Pandikov et al., 2011; De Luca and Vecchietti, 2012; Petrazza et al., 2012; Pandikov et al., 2013; Alaman et al., 2014; Petrazza et al., 2014; Sut et al., 2015.

**Flowers**
- Flowering and sprouting induction

Basak, 2008; Petri et al., 2008; Hawerroth et al., 2010; Parreira et al., 2011.

**Soil**
- Physico-chemical properties
- Development of beneficial soil microorganisms
- Water/nutrient retention
- Overcoming salinity stress

Booth, 1969; Guiry and Bhudden, 1991; Temple and Bonke, 1988; Chen et al., 2002; Gulser et al., 2010; Ross and Holdan, 2010; Garcia-Martinez et al., 2010; Tejeda et al., 2011; Alaman et al., 2014.

Combination of environmental stresses

- Abiotic stress
- Biotic stress

Perception of stress
- e.g. by osmoreceptors, pathogen recognition receptors

Signal transduction
- MAP kinase cascades
- ROS accumulation
- Hormone signalling

Cytokinin, ABA, Eth, Brassinosteroids
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Induction of multiple and individual stress-induced transcription factors
  e.g. HSF, AP2/ERF, WRKY, NAC, MYB, AREB/ABF, DREB/CEB, Zinc Finger

Post-translational regulation of TFs

Expression of functional downstream response genes
  e.g. LEA proteins, heat shock proteins, ion channels, genes involved in lignin and secondary metabolite biosynthesis, ROS detoxification, stomatal closure, growth regulation, cell death

Post-transcriptional regulation
  e.g. by small RNAs

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Currently identified modes of action of biostimulants.

Likelihood of response is complicated—interactions between multiple stresses.
Is it possible for a biostimulant to positively influence plant response to multiple stresses?

Physiological Rationale for Biostimulants and Microbiome Manipulation

**Stress Hypothesis**
- Abiotic ‘stress’ occurs in all environments and as a consequence yield rarely reaches full potential.
  - Biostimulants enable plants to respond more effectively to stress
  - Biostimulants ‘short-circuit’ normal molecular constraints to productivity

**Microbiome Hypothesis**
- Microbes in the environment have beneficial effects on crop growth
  - Biostimulants can favorably alter the plant microbiome
    - Live cultures
    - Substrate enrichment
  - Biostimulants can ‘mimic’ the beneficial effects of microbial metabolites.
  - The microbiome produced biostimulants or ‘detect’ stress

The Microbiome of the Plant is the Most Diverse Biological Environment on Earth
Microbial Populations Vary by Species, Environment and Agronomic Management
Robert Arnason writes on The Western Producer website about an article from Wired magazine that argues that farmers are overly dependent on synthetic fertilizers, which is why companies and scientists are designing microbes (bacteria and fungi) that can deliver nitrogen to crops such as wheat, corn and canola.

Getting microbes to provide nutrients instead of adding fertilizer to the soil is definitely an appealing concept. It could also be lucrative because the global fertilizer market is expected to hit $245 billion by 2020.

Read it all here
Survey Says . . .

*Biostimulants – Large companies are “investing heavily”*

top trend in agriculture
What is biostimulant?

• Misperception
• Confusion
• Generally lacking credentialed recommendations
Biostimulant definition?

*not in major dictionaries

*not defined in encyclopedic references

*not listed in USDA National Agricultural Library glossary of defined agricultural terms.
Closest thing we have to an official definition comes from the new Farm Bill

“a substance or micro-organism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield.”
• Composed of either or:
  • Chemicals
  • Microbial Products

• Action
  • Abiotic Stress
  • Microbial Biome

• Impact
  • Plant Growth
  • Yield
  • Crop Quality Traits

• Does not include fertilizer, pesticide, soil amendments (eg. gypsum & lime), despite many overlapping benefits possible.
Do they work?
“Foliar applications of *unnamed biostimulant* did not improve potato yield and quality.”

“Adding *unnamed biostimulant* in different combinations did not provide a measurable benefit.”

*Unnamed biostimulant* did not improve yield or quality over the local standard.”
6 of 9 treatments > control for total yield; but only 1 > control for marketable yield

Mixing *unnamed biostimulant* with the standard fertilizer did not improve potato:

- ✓ growth
- ✓ yield
- ✓ grade
- ✓ emergence
- ✓ row closure
- ✓ vigor
- ✓ NDVI
- ✓ visual
- ✓ specific gravity
- ✓ economic return
all 6 treatments > control for total yield; and 5 > control for marketable yield

✓ Differences for tuber size and process dollar return
✓ However, no differences for:
  ✓ stand
  ✓ growth
  ✓ specific gravity
  ✓ yield
  ✓ grade
  ✓ net dollar return
Example of one of our studies

Biostimulant “carbon” fertilizer applied to Kentucky bluegrass

Percent relative to the control

NDVI

Control
Carbon
Percent relative to the control

- NDVI
- Visual (verdure)
Percent relative to the control

- NDVI
- Visual (verdure)
- Percent Cover

Control
Carbon
Percent relative to the control

- NDVI
- Visual (verdure)
- Percent Cover
- Height
* = statistically significant difference compared to the control
But, was this a valid evaluation of carbon fertilization?
No, let’s look at the “rest of the data”
The negative “control” received nothing.
But, the positive control had the identical mineral nutrients applied as found in the carbon biostimulant product.
So, using “traditional fertilizers”, we crafted a matching blend so that the only notable difference was the carbon.

• Negative control had nothing applied
• Biostimulant product
  • 5-2-4-1(S) + trace micros + “carbon”
• Positive control
  • 5-2-4-1(S) + trace micros
There were no statistical differences between the positive control and the carbon fertilizer.
Conclusion

“fertilizer provided a benefit”
We’ve done 31 of these trials, evaluating various carbon fertilizers with “biostimulant” claims, using both a negative and a positive control.
Fig. 2. Average increase/decrease over an unfertilized control for yield/growth and carbon and nitrogen plant concentration for 31 trials of carbon-based fertilizers compared with conventional fertilizers (all mineral nutrients were applied at equivalent rates for both). Values shown are significantly different from the untreated control, but there are no differences between the carbon vs. non-carbon fertilizer sources.
This graph does not include the negative control data, which typically had lower yield/growth than the treated plots.

**Fig. 2.** Average increase/decrease over an unfertilized control for yield/growth and carbon and nitrogen plant concentration for 31 trials of carbon-based fertilizers compared with conventional fertilizers (all mineral nutrients were applied at equivalent rates for both). Values shown are significantly different from the untreated control, but there are no differences between the carbon vs. non-carbon fertilizer sources.
For simplicity, only showing the “carbon” fertilizer (blue bars) compared to the positive control (red bars).

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Other than carbon, both treatments had the same nutrient concentrations.

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No difference in yield/growth

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Plant N concentrations not impacted

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Our work – Meta-Analysis

• 178 trials over two decades
• Well managed, high yield environments
  • potato
  • wheat
  • barley
  • corn
  • sugar beet
  • alfalfa
  • soybean
  • dry bean
  • turfgrass (mostly Kentucky bluegrass)
178 "biostimulant" trial yields

0.9% average increase
Summary of field and greenhouse trial results as a function of biostimulant type.

<table>
<thead>
<tr>
<th>Number</th>
<th>Biostimulant Type</th>
<th>Number of Trials</th>
<th>Significant Positive Response</th>
<th>Significant Negative Response</th>
<th>Average, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soil &amp; Geological Extracts</td>
<td>87</td>
<td>28</td>
<td>4</td>
<td>1.9*</td>
</tr>
<tr>
<td>2</td>
<td>Animal Hydrolysates &amp; Extracts</td>
<td>26</td>
<td>5</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>Botanical &amp; Algal Extracts</td>
<td>19</td>
<td>2</td>
<td>1</td>
<td>-0.1</td>
</tr>
<tr>
<td>4</td>
<td>Inorganic &amp; Synthetic Chemicals</td>
<td>15</td>
<td>1</td>
<td>0</td>
<td>-0.3</td>
</tr>
<tr>
<td>5</td>
<td>Microbial Inoculants &amp; Extracts</td>
<td>31</td>
<td>3</td>
<td>1</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
Rest were basically zero or negative.

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</table>
Our work

• 22% of these trials resulted in significant positive increases in yields
• All categories had at least one positive response, showing “potential”
• Most of the positive responses were with use of organic acids in combination phosphorus (P) fertilizer
3 year trial on Russet Burbank potato (UI – Jeff Stark)

• calcareous soil
• medium soil test P
• Ammonium polyphosphate (10-34-0)
• Concentrated band 3 inches to the side of seed piece
• with and without Humic Acid (HA)
  • 1:10 ratio of humic acid to 10-34-0
    • control
    • 15 gal 10-34-0 + 1.5 gal HA
    • 30 gal 10-34-0 + 3.0 gal HA
<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>60</th>
<th>60+HA</th>
<th>120</th>
<th>120+HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>327</td>
<td>333</td>
<td>338</td>
<td>347</td>
<td>364</td>
</tr>
<tr>
<td>2001</td>
<td>337</td>
<td>354</td>
<td>401</td>
<td>374</td>
<td>393</td>
</tr>
<tr>
<td>2002</td>
<td>394</td>
<td>431</td>
<td>444</td>
<td>438</td>
<td>446</td>
</tr>
</tbody>
</table>
Petiole P, %

<table>
<thead>
<tr>
<th>kg P$_2$O$_5$/ha</th>
<th>0</th>
<th>60</th>
<th>60+HA</th>
<th>120</th>
<th>120+HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.22 c</td>
<td>0.25 c</td>
<td>0.28$^{ab}$</td>
<td>0.27$^{bc}$</td>
<td>0.29$^a$</td>
<td></td>
</tr>
</tbody>
</table>
Additional trials with organic acids chemically bonded with P (Carbond P)
<table>
<thead>
<tr>
<th>Crop</th>
<th>Relative Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>potato</td>
<td>12%</td>
</tr>
<tr>
<td>dry bean</td>
<td>10%</td>
</tr>
<tr>
<td>sugarbeet</td>
<td>15%</td>
</tr>
<tr>
<td>silage corn</td>
<td>20%</td>
</tr>
<tr>
<td>wheat</td>
<td>7%</td>
</tr>
<tr>
<td>P</td>
<td>10%</td>
</tr>
<tr>
<td>Yield</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>8%</td>
</tr>
</tbody>
</table>
Carbond P Increases Phosphorus Solubility Relative to APP and MAP Applied in a Concentrated Band in Six Inch Soil Columns

<table>
<thead>
<tr>
<th></th>
<th>24 days</th>
<th>48 days</th>
<th>110 days</th>
<th>365 days (tilled)</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB-P increase over MAP</td>
<td>400%</td>
<td>305%</td>
<td>217%</td>
<td>115%</td>
<td>323%</td>
</tr>
<tr>
<td>CB-P increase over APP</td>
<td>125%</td>
<td>138%</td>
<td>104%</td>
<td>105%</td>
<td>124%</td>
</tr>
</tbody>
</table>
Summary of these many trials

• Improved P solubility and plant uptake in calcareous, low OM
  • Other soil and cropping systems?
• Equal or increased yields with 30-40% less P when:
  • soil test P is low/medium and
  • fertilizer P rate is relatively low.
Mode-of-action was increased P nutrition and not any other “stimulation”

Summary of our organic acid trials. (Largely “enhanced efficiency” of the fertilizer, but some biostimulation?)
Meta analysis of over 500 field sites with a wide variety of crops, soils, and environments.
AVAIL response by P Rate

![Graph showing yield increase due to P fertilizer rate](image)

- **Yield increase due to P fertilizer (%)**
  - Low: b
  - High: a

![Graph showing additional yield increase due to AVAIL (%)](image)

- **Additional yield increase due to AVAIL (%)**
  - Low: a
  - High: b
Are these just responses to fertilizer or are they biostimulation?
Organic Acid Trials
P Responsive Sites with Low P Rates

4.4% average increase

Non P Responsive Sites and/or High P Rates

-1.4% average increase
Liquid Humic Products
Dan Olk, USDA-ARS, Ames, Iowa

• Not a phosphorus related response in their studies.
• Can improve corn and soybean growth and grain yield in Iowa. Dependent upon:
  • Annual weather patterns
  • Soil type
  • Crop
• Corn root growth responded more consistently than did grain yield.
• Evidence for toxicity at excessive rates.
• Evidence for improved soil physical properties with long-term product use, likely due to increased root biomass.
• Is their effectiveness primarily as mitigators of abiotic stress?
Soil type, cropping system, conditions, and stress are important factors when asking “will we get a response to biostimulants?”
Fungi & Bacteria Trials

- 31 trials - tested for live microbes, pH, EC (salts) in 19 of those studies.
  - Only 3 had live microbes/spores
  - 12 had extreme pH (< 3 or > 9)
  - 14 had salt levels in excess of 8 dS/m
Inorganic trials (mostly silica studies)

• Soils are 28% silica (a small, but significant percentage is in solution)
• We found no response or increase in plant Si in any study.
• Some published studies show it is beneficial, but not ours.
Is the use of biostimulants a best management practice in agriculture?”
“I view biostimulants in the same way I view insurance. Do you need every insurance policy out there? No. Is some insurance good? Yes. . . . Sometimes we do not get the perfect conditions we desire to grow those crops. During those periods of abiotic or biotic stress, I have seen products in the biostimulant category help to supplement the crop . . . in a significant way. Many times they work as an insurance policy against stress. This is not to say that they do not work during ideal growing conditions, but much of the success I have seen in this class of products has been during times of stress.”

- David Holden, Holden Research and Consulting
Conclusions

• Do biostimulants work?
  • It depends

• Buyer beware (data reliability?)

• Significant evidence for organic acids improving P nutrition and biostimulation

• Potential for the other categories as well.
Everyone else needs (reliable) data!