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Using Biostimulants, Soil Additives, and Plant Protectants to Improve Corn Yield in South Texas

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Abstract: Field studies were conducted in 2016, 2017, and 2020 in the south-central and Coastal Bend regions of Texas to determine the effects of various biostimulants, soil additives, and plant protectants on corn growth and yield. In south-central Texas, the use of pop-up fertilizer (9-30-0 + Zn) either alone or in combination with either 2% N, bifenthrin, or bifenthrin + pyraclostrobin resulted in the greatest corn vigor but a yield response was only noted with pop-up fertilizer alone at 28,062 or 46,771 mL ha^{-1} in one year. In the Coastal Bend region, leaf tissue analysis showed that only Fe was affected with the use of any soil additive. *Bacillus licheniformis* + *Bacillus megaterium* + *Bacillus pumilus* increased Fe leaf tissue content by 20% over the untreated check. Radicoat seed coating at 438 mL ha^{-1} reduced corn plant stand by 10%, and *Pseudomonas brassicaceanum* reduced corn height when compared with the untreated check; however, no differences in test weight or yield from the untreated check were noted with any soil additives. Little if any impacts of the use of biostimulants, soil amendments, or plant protectants were seen in these studies.

Keywords: fungicide; inoculant; insecticide; microbial enhancer; soil activator; soil conditioner; soil stimulant

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1. Introduction

Growers are always trying to find ways to economically and efficiently improve their production systems. Since the early 1900s, the use of soil additives and plant protectants such as fungicides, insecticides, soil activators, soil conditioners, wetting agents, inoculants, microbial enhancers, soil stimulants, etc., have been promoted as a means to improve crop growth and yield [1,2]. Recent increases in production costs, especially for fertilizers, have renewed producers' interest in these products. Many of these products have not been investigated scientifically and the claims about what these products can do are unproven.

Generally, soil additives can be distinguished from fertilizers in that they usually have little or no nutrient content. They also differ from fertilizers in that they do not provide a guaranteed analysis (e.g., 10-34-0 or 32-0-0). The manufacturers of these products often suggest that adding these products to the soil will enhance crop production by improving root growth, nutrient uptake, and increased yield. These enhancements are generally said to occur when standard fertilizer applications are made to a crop at the recommended or near recommended levels, although some additives claim to replace or significantly reduce the need for fertilizers [1,2].

Soil amendments are added to the soil to change and improve the soil. Unlike fertilizers, which only add nutrients to the soil, soil amendments may add some nutrients but also modify the condition of the soil itself. Tilth is the condition of the soil, and specifically its suitability for supporting plant roots. With improved tilth, roots penetrate the surrounding soil more easily and water infiltration improves. Soil amendments alter the soil in ways that affect the availability of plant nutrients that occur naturally or that are added by fertilizers [1,2].

Fertilizers impact plant growth directly, while soil amendments affect growth indirectly. Soil amendments are not fertilizer substitutes; instead, they help fertilizers become more effective by improving soil texture and tilth. Soil additives can typically be divided into three categories: (1) soil conditioners, (2) soil activators, and (3) wetting agents and surfactants. Soil conditioners usually are defined as materials that improve a soil's physical condition or structure and, in turn, the soil's aeration and water relationships [1,2].

In-furrow starter fertilizers containing single nutrients or combinations of nutrients are applied to improve early-season nutrient uptake, nutrient use efficiency, and plant growth [3–6]. Quinn et al. [7] found that starter fertilizer applications increased corn yield by an average of 5.2%, regardless of placement. Bermudez and Mallarino [3] reported that in-furrow fertilizer could increase corn grain yield by 1.1%, early-season growth by 27%, and plant N or P uptake by 30%. Additionally, in-furrow placement is more common due to reduced equipment costs, faster planter speeds, and less of an influence from early-season soil moisture conditions compared to the 5 cm to side × 5 cm to the side of the seed (5 × 5) starter placement [5,6].

Maintaining and/or improving soil structure is highly desirable in crop production and one of the most common methods of improving soil structure is by adding organic matter. Soil activators are marketed on the basis that they stimulate existing soil microbes or inoculate the soil with new beneficial organisms. Some manufacturers suggest that such products may improve the soil's physical properties (increased structure, reduced compaction), increase fertilizer and soil nutrient uptake, improve crop yields and/or quality, correct soil 'toxicities' (such as salinity), and provide disease and insect control/resistance [8]. Wetting agents and surfactants have long been used to reduce the surface tension of water droplets and improve leaf surface coverage with foliar sprays. Surfactants are also used to reduce the risk of crop injury and improve the efficiency of preemergence herbicides having residual soil activity [9]. However, many related products are marketed on the basis that they will loosen tight or compacted soils, improve water infiltration and retention, enhance nutrient availability, and increase crop yields [10].

Plant protectants such as fungicides and insecticides are also used to improve emergence, early-season plant growth, and crop yield [11–15]. Interestingly, Jordan et al. [12] reported that the peanut (*Arachis hypogaea* L.) yield response to acephate, *Brady rhizobium* (inoculant), and tebuconazole was independent and no interactions were involved. However, interactions were noted for tobacco thrips (*Frankliniella fusca* Hinds) control and peanut emergence and diameter. Additionally, with little disease occurrence, tebuconazole reduced yield in one experiment and did not positively affect yield in others. Pierson et al. [13] reported similar results in soybean [*Glycine max* (L.) Merr.]. They reported that the use of a prophylactic application of a fungicide and starter fertilizer may not be profitable without the risk of soilborne diseases and nutrient deficiencies.

Several traditional soil amendments, plant protectants, and commercial fertilizers have been tested extensively through research trials to document both their benefits and limitations. Unfortunately, sufficient research funds often are not available to investigate the many new products being marketed, including non-traditional additives. Nevertheless, producers need to be aware of the types of products available and have some knowledge of their potential for improved crop production. Therefore, this research was conducted to evaluate biostimulants, soil additives, and plant protectants that are currently on the market in order to determine corn growth and yield response.

2. Materials and Methods

Field studies were conducted on grower's fields in south-central Texas near Ganado during the 2016 and 2017 growing seasons and in the Coastal Bend region at the Texas A&M AgriLife Research and Extension Center near Corpus Christi during the 2020 growing season to determine corn response to various biostimulants, soil additives, and plant protectants applied in-furrow at planting. Products used at each location are listed in Tables 1 and 2, while variables for each location are presented in Table 3. The experimental design was a randomized complete block with three to four replications depending on location. An untreated check was included each year at all locations.

Table 1. Type, manufacturer, and properties of in-furrow soil amendments used in south-central Texas.

Trade Name	Type	Manufacturer	Active	Formulation
Advance LCO	Nutrient	Coastal AgroBusiness, 112 Staton Rd., Greenville, NC 27834, USA	Natural carboxylic acid solution + 2×10^{-7}% lipo-chitooligosaccharide	Liquid
Capture LFR	Insecticide	FMC Corp., 2929 Walnut St., Philadelphia, PA 19104, USA	Bifenthrin	Liquid
VGR	Bacterium	FMC Corp.	*Bacillius licheniformis* (35%)	Granule
Ethos XB	Insecticide + bacterium	FMC Corp.	Bifenthrin + *Bacillus amyloliquefaciens* strain D747 (5%)	Liquid
Headline	Fungicide	BASF Corp., Carl-Bosch-StraBe 38, 67056, Ludwigshafen/Rhein, Germany	Pyraclostrobin	Liquid
Levesol	Chelator	CHS Agronomy, 5500 Cenex Dr., Inver Grove Heights, MN 55077, USA	2% N	Liquid
Micro AZ	Bacterium	TerraMax, Inc., 3650 Dodd Rd., Eagan, MN 55123, USA	*Azospirillum brasilense* 2×10^4 per mL	Liquid
Pop-Up fertilizer	Nutrient	Numerous	(N-P-K) 9-30-0	Liquid
Pro-Gibb	Hormone	Valent USA, P.O. Box 8025, Walnut Creek, CA 94596, USA	Gibberelic acid (GA3)	Granule
Pure algae	Biological	Algeternal Technol., 3637 W State Highway 77, La Grange, TX 78945, USA	Microalgae	Liquid
Quicksol	Nutrient	Quick-Sol Global, 808 Highway 473, Comfort, TX 78013, USA	Ionized sodium silicate family consisting of Ca, Fe, humic acid, fulvic acid, silicon, Na, Cu, Mg, Mn, Zn	Liquid
Radiate	Hormone	Loveland Products, Inc., 3005 Rocky Mountain, CO 80538, USA	3-indolebutyric acid (0.85%) Cytokinin, as Kinetin (0.15%)	Liquid
Sprint	Nutrient	BASF Corp.	7% Total N + 10% Chelated Fe	Granule
Torque	Fungicide	BASF Corp.	Tebuconazole	Liquid
Xanthion	Bacterium + fungicide	BASF Corp.	*Bacillus amyloliquefaciens* strain MBI 600 (2.2×10^{10} viable spores/mL) + pyraclostrobin	Liquid

Table 2. Type, manufacturer, and properties of soil amendments used in the Coastal Bend area of Texas.

Trade Name	Type	Manufacturer	Active [a]	Formulation
Bio-Yield	Bacterium	3 Bar Biologicals, 1275 Kinnear Rd., Columbus, OH 43212, USA	*Pseudomonas brassicaceanum* (1 × 10^4 cfu/mL)	Liquid
Nutrio Unlock	Bacterium	Wilbur-Ellis, 345 California St., San Francisco, CA 94104, USA	*Rhodopseudomonas palustris*; *Bacillus brevis*; *Bacillus licheniformis*; *Bacillus megaterium*; *Streptomyces griseus*; *Rhodococcus rhodochrous*; *Lactobacillus plantarum* All bacteria contain 2.26 × 10^3 cfu/mL	Liquid
Zypro	Enzyme	Helena Chemical Co., 225 Schilling Blvd., Collierville, TN 38017, USA	Unspecified enzymes	Liquid
RadiCoat	Seed coating	Bio S. I., PO Box 784, Argyle, TX 76226, USA	Seed primer coating	Liquid
Accomplish LM	Bacterium	BASF Corp., Carl-Bosch-StraBe 38, 67056, Ludwigshafen/Rhein, Germany	*Bacillus licheniformis*; *Bacillus megaterium*; *Bacillus pumilus* All *Bacilli* contain 1 × 10^3 cfu/mL	Liquid
Pop-Up fertilizer	Nutrient	Numerous	8-24-0 (N-P-K)	Liquid

[a] Abbreviation: cfu, colony forming units.

Table 3. Variables associated with soil amendment studies in south-central and the Coastal Bend regions of Texas.

Variable	2016	2017	2020
Location	**Ganado**	**Ganado**	**Corpus Christi**
Coordinates	29.0522° N −96.4731° W	29.0518° N −96.4369° W	27.7803° N −97.5733° W
Soil type	DaCosta sandy clay loam	DaCosta sandy clay loam	Victoria Clay
Taxonomic class	Fine, smectitic, hyperthermic Vertic Argiudolls	Fine, smectitic, hyperthermic Vertic Argiudolls	Fine, smectitic, hyperthermic Sodic Haplusterts
Soil profile			
pH	6.5	6.6	8.4
Sand (%)	52	54	46
Silt (%)	21	17	15
Clay (%)	27	29	39
Organic matter (%)	1.8	1.8	1.29
CEC	19.2	19.5	32
Plot size	2 rows by 7.6 m	2 rows by 7.6 m	4 rows by 12.6 m
Row spacing	96.5 cm	96.5 cm	96.5 cm
Planting date	21 March	22 March	17 March
Harvest date	28 July	1 August	8 August
Variety	BH 8660 VTTP	BH 8660 VTTP	DKC 63-99 RIB
Previous crop	Cotton	Corn	Cotton

At all three locations, treatments were applied in 46.8 L ha^{-1} of water using a CO_2-pressurized sprayer with one Teejet® orifice disc # 45 nozzle per row immediately after seed drop but prior to furrow closure. For the studies near Ganado, each plot consisted of two rows spaced 97 cm apart and 7.6 m long, while at the Corpus Christi location plot size was 4 rows spaced 102 cm apart and 9.1 m long. Traditional production practices were used to maximize corn growth, development, and yield at each location.

At Ganado, corn vigor was estimated visually on a scale of 1 to 9 (1 = large plant, vigorously growing; 9 = small, weak plants). Vigor was evaluated 21 and 51 days after planting (DAP) in 2016 and 6 and 16 DAP in 2017.

At Corpus Christi, plant height was measured at tassel by measuring the distance from the soil surface to the ear node and the tip of the tassel. Corn plants were evaluated for leaf damage (0 = no leaf damage; 9 = severe damage) 30 days after planting and during silk formation and for ear injury from insects (number of kernels affected/ear). No diseases were observed at the soft dough stage and lodging was not detected pre-harvest at any location. Ear leaf samples (15/plot) were collected at the R1 stage at mid-morning after the leaves had dried off. Samples were refrigerated and sent to the Texas A&M Soil, Water, and Forage Testing Laboratory (2610 F&B Road; College Station, TX 77845, USA) for analysis.

Corn yield was determined near Ganado using a Gleaner K2® small plot combine with a Harvest Master 800® scale system, while at the Corpus Christi location harvesting was completed using a 4-row New Holland TR 87® combine. Harvest was at 13 to 17% moisture and yield at all locations was adjusted to 15% moisture.

Data for the percentage of corn vigor, plant height, plants ha^{-1}, test weight, and yield were transformed to the arcsine square root prior to analysis; however, non-transformed means are presented because arscine transformation did not affect the interpretation of the data. Data were subjected to ANOVA and analyzed using the SAS PROC MIXED procedure 23 [16].

Treatment means were separated using Fisher's Protected LSD at $p \leq 0.10$ at the Ganado locations and $p \leq 0.05$ at the Corpus Christi location. The untreated check was used for all data analysis.

3. Results

3.1. Ganado Locations

3.1.1. Vigor

In 2016, when evaluated 21 days after planting (DAP), any treatment which included the pop-up fertilizer resulted in greater vigor than any other treatment. Tebuconazole (Torque) and gibberellic acid (Pro-Gibb) + cytokinin (Radiate) also had greater vigor than the untreated check (Table 4). The use of an insecticide (bifentrin) or the fungicide (pyraclostrobin) alone did not improve vigor. At the 51 DAP evaluation, any pop-up fertilizer treatment, ionized sodium silicate (Quicksol), and *Bacillus amyloliquefaciens* + pyraclostrobin (Xanthion) at the low rate, and the microalgae (Pure Algae) treatment, resulted in greater vigor than the untreated check. Interestingly, although corn responded early-season to tebuconazole, the later-season evaluation showed no difference from the untreated check. Jordan et al. [12] reported in peanut that the use of tebuconazole in-furrow resulted in slow emergence and reduced early-season growth. They reported that tebuconazole reduced yield in only one of five experiments, even though peanut emergence was delayed in most experiments and peanut diameter was less when tebuconazole was applied. In peanut, Phipps [11] reported that the use of tebuconazole applied in-furrow suppressed *Cylindrocladium* black rot (caused by *Cylindrocladium parasiticun*); however, in our research no disease issues were noted.

Table 4. Use of soil amendments to improve corn yield near Ganado in 2016.

	Rate	Vigor [a]		Test wt	Yield
	Ml ha^{-1}	DAP [b]		Kg	Kg ha^{-1}
Treatment		21	51		
Untreated	-	5.0	4.8	26.2	7865
Tebuconazole	585	4.0	4.2	26.0	7520
Azospirillum brasilense	935	4.8	4.2	25.9	7476
7% Total N + 10% Chelated Fe	1169	5.0	4.4	25.5	7175
Ionized sodium silicate	1462	4.8	4.0	26.4	7369
3-indolebutyric acid (0.85%); Cytokinin, as Kinetin (0.15%)	146	5.0	5.5	26.4	7489
Gibberelic acid (GA3)	73	4.7	4.3	26.4	7319
Gibberelic acid (GA3) 3-indolebutyric acid (0.85%); Cytokinin, as Kinetin (0.15%)	73 146	4.5	4.2	26.4	6898
Bifenthrin	730	4.8	4.2	26.4	7394
Pop-Up (9-30-0)	28,062	2.3	2.7	26.4	7482
Pop-Up (9-30-0)	46,771	2.3	2.0	26.1	8160
Bacillus amyloliquefaciens strain MBI 600 + pyraclostrobin	44 + 219	5.0	3.3	26.4	7281
Bacillus amyloliquefaciens strain MBI 600 + pyraclostrobin	88 + 438	5.0	4.3	25.7	7702
Pyraclostrobin	438	5.0	4.5	26.4	7413
2% N	4677	5.0	4.5	25.9	7300
Pop-Up (9-30-0) + 2% N	28,062 + 4677	2.5	2.2	26.0	7589
Pop-Up (9-30-0) + Bifenthrin + Pyraclostrobin	28,062 + 730 + 438	2.5	2.2	26.1	8210
Pop-Up (9-30-0) + Pyraclostrobin	28,062 + 438	2.8	2.2	26.5	7551
Microalgae	1462	4.8	4.0	26.5	7382
LSD (0.10)		0.4	0.7	0.6	4339

[a] Vigor scale: 1, most vigorous; 9, least vigorous. [b] DAP, days after planting.

In 2017, at the 6 DAP evaluation, all treatments with the exception of those that contained pop-up fertilizer, *Bacillus amyloliquefaciens* strain MBI 600 + pyraclostrobin, pyraclostrobin alone (Headline), and 2% N (Levesol), resulted in greater vigor than the untreated check (Table 5). The only exception for those treatments that contained pop-up fertilizer was pop-up fertilizer at the low rate, which resulted in a 19% increase in vigor over the untreated check. *Bacillus licheniformis* (VGR) + bifenthrin (Capture LFR) resulted in the greatest vigor. Mascagni et al. [17] reported that pop-up fertilizer at high rates may injure plants, and this may have accounted for the reduced vigor with pop-up fertilizer at this early evaluation. If fertilizer rates are too high or planting time conditions are too dry, salt injury can affect seed germination and the early growth of seedling corn plants.

Table 5. Use of soil amendments to improve corn yield near Ganado in 2017.

	Rate	Vigor [a]		Test wt	Yield
	Ml ha^{-1}	DAP [b]		Kg	Kg ha^{-1}
Treatment		6	15		
Untreated	-	6.4	5.0	26.7	7143
Natural carboxylic acid solution + 2 × 10^{-7}% lipo-chitooligosaccharide	585	4.6	4.0	26.9	7250
Azospirillum brasilense	935	4.2	4.2	26.9	7131
3-indolebutyric acid (0.85%) Cytokinin, as Kinetin (0.15%)	146	3.8	4.0	26.6	7139
Bifenthrin + *Bacillus amyloliquefaciens* strain D747	730	4.4	5.2	26.9	6961
Bacillius licheniformis Bifenthrin	13 730	3.0	3.4	26.9	7325
Bifenthrin	730	3.8	4.2	27.0	7018
Pop-Up (9-30-0)	28,062	5.2	2.0	26.9	7627
Pop-Up (9-30-0)	46,771	7.2	1.6	27.3	7758
Bacillus amyloliquefaciens strain MBI 600 + pyraclostrobin	88 + 438	6.8	4.4	27.0	7281
Pyraclostrobin	438	6.2	5.0	26.9	6993
2% N	4677	6.0	5.0	27.0	7099
Pop-Up (9-30-0) + 2% N	28,062 + 4677	6.0	1.4	26.9	7457
Pop-Up (9-30-0) + Bifenthrin + Pyraclostrobin	28,062 + 730 + 438	6.6	1.8	27.0	7118
Pop-Up (9-30-0) + Pyraclostrobin	28,062 + 438	7.0	1.6	26.9	7394
Microalgae	1462	4.8	4.6	26.9	6660
Microalgae	4386	4.6	4.4	27.0	7325
LSD (0.10)		0.9	0.7	0.7	395

[a] Vigor scale: 1, most vigorous; 9, least vigorous. [b] Days after planting.

By 15 DAP, corn vigor evaluations had changed considerably as all treatments which contained pop-up fertilizer produced the greatest plant vigor. Treatments containing the *Bacillus amyloliquefaciens* strain D747 + bifenthrin (Ethos XB), 2% N and both rates of the microalgae resulted in plant vigor similar to that of the untreated check. As in 2016, the use of fungicide only (pyraclostrobin) did not improve seedling vigor; however, contrary to 2016, the insecticide (bifenthrin)-only treatment did improve corn seedling vigor over the untreated check. Mascagni et al. [17] reported that on sandy loam and silt soils, growth responses with pop-up fertilizer over N alone were primarily due to the P in pop-up. This effect was probably due to reduced P availability early-season in the sandy, low organic matter, and light-colored soils, which are typically cold-natured.

3.1.2. Test Weight

In 2016, only the 7% total N + 10% chelated Fe (Sprint) treatment resulted in a lower test weight than the untreated check (Table 4), while in 2017 no differences were noted between the untreated check and any treatment (Table 5).

3.1.3. Yield

In 2016, although not significantly different from the untreated check, pop-up fertilizer + Zn at the high rate and pop-up fertilizer + Zn + bifenthrin + pyraclostrobin produced the highest numerical yields (Table 4). Several treatments, including 7% total N + 10% chelated Fe, ionized sodium silicate, both gibberellic acid treatments (Pro-Gibb), bifenthrin alone, *Bacillus amyloliquefaciens* strain MBI 600 + pyraclostrobin at 44 + 219 ml ha^{-1}, pyraclostrobin alone, and 2% N, produced yields that were lower than the untreated check, but none of those treatments included any pop-up fertilizer treatment. Lemus et al. [18] reported that the seasonal annual ryegrass (*Lolium multiflorum* Lam.) dry matter yield was not different between the untreated check and gibberellic acid treatments. They concluded that temperatures in the southern US during annual ryegrass production may be too mild to observe a gibberellic acid response.

In 2017, pop-up fertilizer alone at 28,062 and 46,771 ml ha^{-1} resulted in corn yields that were greater than the untreated check, while the microalgae treatment at 1462 m ha^{-1} produced a yield lower than the untreated check (Table 5). No other treatments resulted in any differences compared to the untreated check. Placing small amounts of starter fertilizer in close proximity to the seed at planting can alleviate the effects of cold soil temperature on the P uptake and early corn growth [17]. Mascagni et al. [17] reported in 15 trials in Louisiana that starter fertilizer increased yield in only one third of the studies; however, early season plant growth was increased in all trials. The largest yield increases occurred on sandy loam soils with low organic matter.

Pop-up or starter fertilizers have shown mixed results in other studies [19–23]. Niehaus et al. [19] researched starter fertilizer placements of direct seed contact, dribble over-the-row, and a subsurface band (5 cm below and 5 cm to the side of the seed row) and reported that starter fertilizer, regardless of placement, often increased early-season dry matter production and significantly increased grain yields. Pierson et al. [13] concluded that the use of a fungicide and/or starter (pop-up) fertilizer in soybean was not profitable if soil-borne diseases or nutrient deficiencies were not present.

Wise [15] reported that the use of *Bacillus amyloliquefaciens* strain D747, MBI 600 *Bacillus amyloliquefaciens* strain MBI 600 + pyraclostrobin, or pyraclostrobin alone did not improve corn plant populations or yield at three planting dates. He concluded that where growers do not have a history of seedling disease, they may not need in-furrow fungicides even when planting in cool, wet conditions.

A. brasilense has been used on corn as a seed treatment in Brazil to improve N use and yield, resulting in increased corn growth and yield when combined with only half of the optimum rate of fertilizer N [21,22]. A meta-analysis of *Azospirillum* spp. indicated that yield increases in corn were achieved when the bacteria were applied without additional N, and only minimal increases when applied with N [23].

3.2. Corpus Christi Location

3.2.1. Tissue Samples

No differences were noted in leaf content with P, K, Ca, Mg, Na, Zn, Cu, Mn, S, or B (Table 6). N levels (%) in the tissue samples were highest with the starter fertilizer only. N levels in the corn leaf tissue typically run from a low of 2.45% to a high of 3.51%, with normal being 2.76% [24]. All treatments produced N levels that were above normal. Fe levels (ppm) were highest, with *Bacillus licheniformis* + *Bacillus megaterium* + *Bacillus pumilus* (Accomplish LM) at 2339 mL ha^{-1}. Typically, the concentration of Fe in corn leaf tissue samples taken at silking can range from a low of 10 ppm to a high of 251 ppm, with normal being 21 ppm [24]. No other differences were noted. In research on guar (*Cyamopsis tetragonoloba* L.), El-Sawah et al. [25] reported that biofertilizers produced from *Bacillus* spp. and arbuscular mycorrhizal fungi improved N, P, and K content in guar leaves. They suggested that biofertilizers increased the availability of essential nutrients in the soil, which translocated to the guar through the root system and therefore improved guar growth and yield.

Table 6. Corn tissue content when using soil amendments in the Coastal Bend area (Corpus Christi) of Texas in 2020.

	Rate	**N**		**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**	**S**	**B**
Treatment	**Ml ha^{-1}**	**%**						**ppm**					
Untreated	-	3.1	3172	21,026	4879	2458	530	29	86	14	111	2250	14
Pseudomonas brassicaceanum	219	3.2	3173	20,363	4818	2565	465	25	81	14	96	2191	13
Rhodopseudomonas palustris; Bacillus brevis; Bacillus licheniformis; Bacillus megaterium; Streptomyces griseus; Rhodococcus rhodochrous; Lactobacillus plantarum	2339	3.1	3158	20,839	4881	2499	487	29	83	15	104	2283	13
Rhodopseudomonas palustris; Bacillus brevis; Bacillus licheniformis; Bacillus megaterium; Streptomyces griseus; Rhodococcus rhodochrous; Lactobacillus plantarum	4577	3.1	3238	20,775	4722	2435	540	31	83	14	127	2296	15
Phospholpase	585	3.1	3147	22,001	5250	2498	531	28	89	15	120	2357	14
Phospholpase	1169	3.2	3430	21,948	4919	2469	463	29	88	14	114	2319	12
Radicoat-seed coating	219	3.0	3353	21,870	5167	2506	464	25	80	15	131	2392	13
Radicoat-seed coating	438	3.2	3358	21,137	5067	2543	548	28	81	14	126	2294	16
Bacillus licheniformis; Bacillus megaterium; Bacillus pumilus	2339	3.1	3.269	20,480	5106	2627	467	29	103	14	122	2360	17
Bacillus licheniformis; Bacillus megaterium; Bacillus pumilus	4577	3.2	3284	20,722	4793	2439	585	31	83	14	127	2334	16
Pop-up (8-24-0)	46,771	3.4	3343	21,233	4785	2364	483	31	76	15	118	2250	17
LSD (0.05)		0.2	NS	NS	NS	NS	NS	NS	16	NS	NS	NS	NS

3.2.2. Plant Populations

Seed coating (Radicoat) at 438 mL ha^{-1} resulted in a 10% stand reduction when compared with the untreated check. No other differences were noted (Table 7).

3.2.3. Plant Height

Pseudomonas brassicaceanum (Bio-Yield) resulted in a 5% reduction in plant height compared with the untreated check. No other differences were noted (Table 7).

3.2.4. Leaf Damage

Bacillus licheniformis + *Bacillus megaterium* + *Bacillus pumilus* at 2339 Ml ha^{-1} and pop-up fertilizer resulted in the greatest leaf damage (Table 7). Leaf damage was very low because of the use of a hybrid with the Bt gene [26].

3.2.5. Test Weight

No differences were noted between any treatments (Table 7).

3.2.6. Yield

No differences were noted between any treatments (Table 7).

Table 7. Corn plant response to soil amendments in the Coastal Bend area of Texas in 2020.

	Rate	Stand	Plant ht	Leaf Damage [a]	Ear Damage	Test wt	Yield
Treatment	**Ml ha $^{-1}$**	**Plants/ha**	**Cm**	**0–9**	**# kernels/ear**	**Kg bu^{-1}**	**Kg ha^{-1}**
Untreated	-	7595	145.0	0.5	0.1	25.3	8034
Pseudomonas brassicaceanum	219	7436	137.7	0.5	0	25.4	7658
Rhodopseudomonas palustris; *Bacillus brevis*; *Bacillus licheniformis*; *Bacillus megaterium*; *Streptomyces griseus*; *Rhodococcus rhodochrous*; *Lactobacillus plantarum*	2339	7316	140.2	0	0.3	25.4	7156
Rhodopseudomonas palustris; *Bacillus brevis*; *Bacillus licheniformis*; *Bacillus megaterium*; *Streptomyces griseus*; *Rhodococcus rhodochrous*; *Lactobacillus plantarum*	4577	7396	140.5	0	0	25.2	7972
Phospholpase	585	7356	141.5	0	0	25.5	7909
Phospholpase	1169	7873	142.7	0	0	25.0	8348
Radicoat-seed coating	219	7078	144.8	0	0	25.4	8851
Radicoat-seed coating	438	6839	144.5	1.0	0	25.1	7721
Bacillus licheniformis; *Bacillus megaterium*; *Bacillus pumilus*	2339	7714	140.2	1.5	0	25.1	8537
Bacillus licheniformis; *Bacillus megaterium*; *Bacillus pumilus*	4577	7515	144.0	0	0.1	25.3	8160
Pop-up 8-24-0 only	46,771	7515	143.5	1.5	0	25.2	7721
LSD (0.05)		731	5.8	1.0	NS [b]	NS	NS

[a] Leaf damage: 0 = none, 9 = severe damage. [b] Not significant at the 0.05 level of significance.

4. Conclusions

Few, if any, impacts of the use of biostimulants, soil amendments, or plant protectants were seen in these studies; however, other studies have reported varying results. McFarland [2] reported in various studies across the US that the use of soil activators has shown no significant beneficial effects on crop quality and yield. He also reported that lab evaluations of these products indicated that they did not increase the number or activity of soil microbes, and thus would not be expected to increase the rate or extent of crop residue decomposition. In contrast, El Sawah et al. [25] reported that various components of guar production (shoot length, root length, leaf area, plant dry weight, nutrient uptake, and yield) were significantly affected by the application of biofertilizers and their combination. Activities of soil enzymes, such as dehydrogenase, phosphatase, protease, and invertase, also improved in the rhizosphere soil of plants treated with biofertilizers. They also stated that increasing soil enzymes in the rhizosphere and the essential nutrients available for the guar plants increased seed quality by improving the proteins, carbohydrates, starch, fatty acids, and guaran content and reduced the use of chemical fertilizers by 25%.

When planting in other areas of the US, where cold, wet conditions may persist, the use of biostimulants, soil amendments, or plant protectants will prove beneficial. However, under conditions in south Texas where soil temperatures may commonly be 15 to 20 °C at planting, the corn seed can germinate and emerge in 7 days or less. Therefore, the use of biostimulants, soil amendments, or plant protectants is not as beneficial as under conditions where the corn seed may have to sit in cool, wet soils for several days or even several weeks before germination and emergence. Low temperatures delay seed germination [27], reduce growth rates and negatively impact plant vigor [28]. Temperature is also a primary driver of plant phenological development [29]. Vegetative growth and development processes, including the initiation of new leaves, the expansion of these leaves, and the extension of plant height, directly affect the plant's ability to intercept solar radiation throughout the growing season, and temperature can alter these processes [30]. Additionally, research has shown that plant responses to abiotic stress are the primary limiting factor in growth and development [31,32].

Although no response was seen with algae in this study, recent research has indicated that a fast-growing green algae, *Chlamydomonas reinhardtii*, contains an organelle called the pyrenoid that speeds up the conversion of carbon, which the algae absorbs from the air into a form that organisms can use for growth [33]. Using molecular modeling to identify the features of this pyrenoid that are most critical for enhancing carbon fixation and then engineering them into crops could provide a major boost to plant growth rates [34].

The use of these products will require recommendations specific to each individual farm to determine the appropriate organisms to use and the right agronomic management practices to ensure a positive crop response. Since many similar products are being introduced into the marketplace, additional research is needed to determine the effectiveness of these biostimulants, soil additives, and/or plant protectants on crop growth and yield. Achieving the maximum economic yield depends on using only those inputs which will provide a return on investment.

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