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Sesame (*Sesamum indicum* L.) Response to Soil Additives Applied in-Furrow at Planting

W. James Grichar [a*]

[a] *Texas A & M AgriLife Research and Extension Center, 10345 State Highway 44, Corpus Christi, TX 78406, USA.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: Studies were conducted to study the response of sesame to soil additives applied in-furrow.
Study Design: Randomized complete block with 4 replications.
Place and Duration of Study: Field experiments were carried out during the 2016 through 2018 growing seasons in south-central Texas near Yoakum (29.27704º N, -97.12453º W).
Methodology: Sesame seed was planted < 2.54 cm deep. Treatments were applied using a CO_2-pressurized sprayer in 46.8 L ha^{-1} of water with one Teejet® orifice disc #45 nozzle per row immediately after seed drop but prior to furrow closure. Each plot consisted of two rows spaced 97 cm apart and 7.6 m long. Sprinkler irrigation was applied on a 2- to 3-wk schedule throughout the growing season as needed. *S*-metolachlor at 1.4 kg ha^{-1} was applied preemergence while clethodim at 0.11 kg ha^{-1} and diuron at 1.12 kg ha^{-1} were applied postemergence to control annual grasses and broadleaf weeds that were present.
Results: In 2016, treatments containing 7% N + 10% chelated Fe, gibberellic acid + 3-indolebutyric acid (0.045%) + cytokinin as Kinetin (0.09%), and pop-up fertilizer (9-30-0 + Zn) resulted in the greatest sesame emergence. In 2017, 2% N, bifenthrin + *Bacillus amyloliquefaciens* strain D747,

Corresponding author: E-mail: james.grichar@agnet.tamu.edu, w-grichar@tamu.edu, James.Grichar@ag.tamu.edu;

and humic acids + *Bacillus* spp. resulted in greater emergence (90-97%) while in 2018, *Azospirillum brasilense* and 2% N resulted in the greater emergence (90-91%). In 2016, 2% N produced the greatest yield while in 2018 2% N and the 3-way combination of cytokinin as kinetin (0.090%) + gibberellic acid + indole-3-butyric acid (0.045%) resulted in up to a 117% increase in yield over the untreated.

Conclusion: The 3-way combination of gibberellic acid + 3-indolebutyric acid (0.045%) + cytokinin as kinetin (0.090%) and 2 % N proved to be the most consistent soil additives and resulted in a yield increases in the two years that the studies were harvested.

Keywords: Soil additives; sesame growers; fungicides; microbial enhancers.

1. INTRODUCTION

"Sesame growers are always attempting to improve their production by making use of new technologies and ideas. Using soil additives which includes fungicides, insecticides, soil activators, soil conditioners wetting agents, inoculants, microbial enhancers, and soil stimulants have been investigated and researched since the beginning of the 20th century" [1,2]. Increases in production costs for growers, especially for fertilizers, has renewed interest in these products.

"The production and application of fertilizers are not only costly but can result in unwanted consequences since they are produced from natural gas and their excessive use causes movement into groundwater, ammonia volatilization, and denitrification" [3]. Soil additives vary from synthetic fertilizers in that they usually do not have any nutrient value and they do not have a quality analysis of their content (e. g., 10-34-0 or 32-0-0) [1,2]. "The literature on such products often suggests that by using soil additives, crop production will increase since root growth and nutrient uptake will be improved and therefore, result in an increase in yield. These improvements to the soil are thought to happen when applications are made at the recommended or near recommended rates; however, some additives also claim to reduce or replace the use for fertilizers" [1,2].

"Soil additives can also be used to improve the texture of the soil. Fertilizers can just add nutrients to the soil; however, some additives can alter the soil condition and also add nutrients. Tilth is the physical condition of the soil and factors which determine tilth include soil texture, structure, fertility, and interaction with the organic content and living soil organisms" [4]. By improved the tilth of the soil, roots can penetrate the soil easier and help with water infiltration [4]. Soil amendments can also change the soil in ways that affect the use of plant nutrients [1,2].

Fertilizers will have an effect on plant growth directly by delivering nutrients to plants while soil amendments or additives can affect growth indirectly. Soil additives can not be considered fertilizer substitutes; however, they can help fertilizers become more effective by improving soil texture and tilth and improving microbial activity. Soil additives are most often separated into three different categories: 1) soil conditioners, 2) soil activators, and 3) wetting agents and surfactants. Soil conditioners are defined as products that can help improve a soil's physical condition or structure which, improves the soil's aeration and water relationships [1,2].

Improving and/or maintaining soil structure is one of the main goals in crop production and adding organic matter is one way to improve soil structure [5]. "Soil additives are sold on the basis that they inoculate the soil with new beneficial organisms or stimulate existing soil microbes [5]. Some manufacturers also suggest that these products may improve the physical properties of soil which includes increasing structure and reducing compaction, increase the uptake of fertilizers and soil nutrients, improve crop yields, improve other soil issues such as salinity, and may also help in disease and insect control/resistance" [6]. "Wetting agents and surfactants have helped reduce the surface tension of spray droplets and increase the coverage of the leaf surface with the application of postemergence (POST)pesticides. Adding surfactants to POST herbicides can be used to reduce the risk of crop injury and also has shown to improve the efficiency of preemergence herbicides that have residual soil activity" [7]. Also, some of these 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 [8].

Some soil additives have been investigated through research trials to document their benefits and limitations. However, sufficient research funds are frequently not available to study the many new products being marketed. Sesame producers need to be made aware of the products available and have some knowledge of their potential for improved sesame production. Therefore, this study was conducted to evaluate soil additives that are currently on the market to determine sesame growth and yield response.

2. MATERIALS AND METHODS

2.1 Field Studies

These studies were conducted during the 2016 through 2018 growing seasons at the Texas A&M AgriLife Research Site near Yoakum (29.1642º N, -97.1243º W) in south-central Texas to evaluate sesame response to soil additives applied in-furrow at planting. The tests were located in the same general area but different parts of the field in the three test years. Soils were a Denhawken-Elmendorf complex (fine, smectitic, hyperthermic Vertic Ustochrepts) with < 1% organic matter, 25% sand content, 38% clay content, and 37% loam with a pH of 7.8 and a cation exchange capacity (CEC) of 34.

2.2 Soil Additives and Sesame Planting

The soil additives in this study are listed in Table 1. Sesame was planted July 13, 2016, July 5, 2017, and May 9, 2018 using a Monosem® planter calibrated to deliver 320 seed m^{-1}. The later planting dates in 2016 and 2017 were later due to heavy rains in April, May and early June which prevented timely entry into the field. The sesame variety S-35 was planted in 2016 and 2017 while S-34 was planted in 2018.

Table 1. Type, manufacturer, active ingredient, and formulation of in-furrow soil additives used in sesame studies

Trade name	Type	Manufacturer	Active	Formulation
Ascend SL	Hormone	Winfield Solutions	Cytokinin, as Kinetin (.09%) + Gibberellic acid (0.030%) + 3-indolebutyric acid (0.045%)	Liquid
Bacillus subtilis	Bacterium	Numerous	*Bacillus subtilis*	Liquid
Capture LFR	Insecticide	FMC Corp.	Bifenthrin	Liquid
VGR	Bacterium	FMC Corp.	*Bacillius licheniformis*	Granule
Ethos XB	insecticide + bacterium	FMC Corp.	Bifenthrin + *Bacillus amyloliquefaciens* strain D747	Liquid
Headline	Fungicide	BASF Corp.	Pyraclostrobin	Liquid
Levesol	Chelator	CHS Agronomy	2% N	Liquid
Micro AZ	Bacterium	TerraMax, Inc	*Azospirillum brasilense*	Liquid
MycoApply DR	Mycorrhizal fungi	Valent USA	Arbuscular mycorrhizal fungi	Granular
Pop-Up fertilizer	Nutrient	Numerous	9 Lbs N, 30 lbs P_2O_5 + Zn	Liquid
Pro-Gibb	Hormone	Valent USA	Gibberellic acid (GA3)	Granule
Pure algae	Biological	Algeternal Technol.	Microalgae	Liquid
Quicksol	Nutrient	Quick-Sol Global	Ionized sodium silicate family consisting of Ca, Fe, humic acid, fulvic acid, silicon, Na, Cu, Mg, Mn, Zn	Liquid
Radiate	Hormone	Loveland Products, Inc.	3-indolebutyric acid (0.85%) Cytokinin, as Kinetin (0.15%)	Liquid
Sprint	Nutrient	BASF Corp.	7% Total N + 10% Chelated Fe	Granule
Terragrow	Biological	BioSafe Systems	Humic acids (derived from leonardite) + organic matter (derived from soy protein hydrolysate) + various strains of *Bacillus* spp.	Granule
Torque	Fungicide	BASF Corp.	Tebuconazole	Liquid

Sesame seed was planted < 2.54 cm deep and treatments were applied in-furrow with 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. Each individual plot consisted of two rows spaced 97 cm apart and 7.6 m long. The experimental design was a randomized complete block with four replications. An untreated check was also included in each test. Sprinkler irrigation was applied on a 2- to 3-wk schedule throughout the growing season as needed. *S*-metolachlor at 1.4 kg ha^{-1} was applied preemergence while clethodim at 0.11 kg ha^{-1} and diuron at 1.12 kg ha^{-1} were applied postemergence to control annual grasses and broadleaf weeds that were present in the test area. Clethodim was applied prior to sesame bloom to prevent any type of injury to the sesame [9].

2.3 Sesame Stand Counts and Harvest

Sesame emergence or stand was estimated visually on a scale of 0 to 100 (0 = no emergence and 100 = complete emergence) [10]. Emergence was evaluated 7 and 161 days after planting (DAP) in 2016, 5 and 64 DAP in 2017, and 15 DAP in 2018. In 2017, the 64 DAP evaluation was taken after sesame death due to excessive moisture while no late-season evaluation was taken in 2018 due to a limited time schedule. Sesame was harvested at 6% moisture in 2016 (161 DAP) and in 2018 (208 DAP) using an Almaco® small-plot combine. Yields were not taken in 2017 due to Hurricane Harvey which came through the area on August 25-29 and dumped over 430 mm of rainfall. This high amount of rainfall killed the sesame.

2.4 Data Analysis

Data for percentage of sesame stand and yield were transformed to the arcsine square root prior to analysis; however, non-transformed means are presented because arcsine transformation did not affect interpretation of the data. Data were subjected to ANOVA and analyzed using the SAS PROC MIXED procedure 23 [11]. Treatment means were separated using Fisher's Protected LSD at P = 0.05 and the untreated check was used for all data analysis.

3. RESULTS AND DISCUSSION

3.1 Sesame stand

3.1.1 2016. When evaluated 7 DAP, tebuconazole, *Azospirillum brasilense*, 3-indolebutyric acid (0.85%) + cytokinin, as kinetin (0.15%), and 2% N resulted in lower sesame emergence than the untreated check (Table 2). Pop up fertilizer at 46771 ml ha^{-1} resulted in the greatest emergence. At the 161 DAP evaluation, taken just prior to harvest, only 7% N + 10% chelated Fe produced sesame stands greater than the untreated check. Gibberellic acid (0.03%) + 3-indolebutyric acid (0.045%) + cytokinin as kinetin (0.09%) and pop up fertilizer at 46771 ml ha^{-1} also produced > 90% sesame stands (Table 2). *Azospirillum brasilense* showed a 25% reduction in stand from the untreated check. The lack of a sesame response seen with tebuconazole was surprising because these soils do have a history of seedling diseases [12] and fungicides in furrow at planting has shown to improve seed emergence and early-season vigor in soils with a history of seeding diseases [13]. Phipps [13] also reported in peanut (*Arachis hypogaea* L.) tebuconazole suppressed *Cylindrocladium* black rot (caused by *Cylindrocladium parasiticun*).

However, Jordan et al. [14] found that using tebuconazole in-furrow in peanut showed a slower than normal emergence and a reduction in early-season growth. They found that tebuconazole reduced yield in only one of five experiments even though peanut emergence was delayed in most of the studies and plant diameter was reduced when tebuconazole was applied.

3.1.2 2017. At the 5 DAP evaluation, no sesame had emerged in the untreated check, *Azospirillum brasilense*, 7% N + 10% chelated Fe, ionized sodium silicate family, bifenthrin, pop-up fertilizer + Zn, pyraclostobin alone, pop-up fertilizer + Zn + pyraclostobin, microalgae, arbuscular mycorrhizal fungi, or humic acids + various strains of *Bacillus* spp. at 3363 gr ha^{-1} plots (Table 2). Treatments of gibberellic acid (0.03%) + 3-indolebutyric acid (0.45%) + cytokinin as kinetin (0.09%), 2% N, bifenthrin + *Bacillus amyloliquefaciens* strain D747, and humic acids + various strains of *Bacillus* spp. at 1121 gr ha^{-1} resulted in sesame emergence which ranged from 15 to 35%. At the 64 DAP evaluation, all treatments with the exception of those containing pop-up fertilizer + Zn, resulted in greater stands than the untreated check. Mascagni et al [15] reported in corn (*Zea mays* L.) that excessively high rates of starter fertilizer applied in-furrow could injure plants and this may have accounted for the reduced stands with the in-furrow application of a pop-up fetilizer. They

Table 2. Using soil additives in sesame in the 2016 and 2017 growing seasons

Treatment	Rate ha^{-1}	2016 Stand DAP[a,b] 7	161	Yield	2017 Stand DAP 5	64
		%		Kg ha^{-1}	%	
Untreated	-	83	77	775	0	20
Tebuconazole	585 ml	64	72	819	-	-
Azospirillum brasilense	935 ml	50	58	668	0	55
7% N + 10% chelated Fe	1169 ml	83	97	711	0	77
Ionized sodium silicate family consisting of Ca, Fe, humic acid, fulvic acid, silicon, Na, Cu, Mg, Mn, Zn	1462 ml	68	74	514	0	75
3-indolebutyric acid (0.85%) + cytokinin, as kinetin (0.15%)	146 ml	64	72	748	5	58
Gibberellic acid (GA3)	73 ml	84	85	966	5	70
Gibberellic acid (0.03%) + 3-indolebutyric acid (0.045%) + cytokinin, as kinetin (0.09%)	73 ml + 146 ml	86	92	1024	15	84
Bifenthrin	300 ml	-	-	-	0	79
Pop-Up 9-30-0 + Zn	28062 ml	75	64	611	0	24
Pop-Up 9-30-0 + Zn	46771 ml	88	92	919	-	-
Bacillus subtilis + pyraclostrobin	42 gr + 219 ml	70	72	662	-	-
Bacillus subtilis + pyraclostrobin	84 gr + 438 ml	68	65	720	-	-
Pyraclostrobin	438 ml	75	68	641	0	71
2% N	4677 ml	64	68	1035	35	97
Pop-Up 9-30-0 + Zn + pyraclostrobin	28062 ml + 438 ml	78	68	875	0	5
Microalgae	73 ml	78	82	996	0	60
Microalgae	146 ml	70	70	744	-	-
Arbuscular mycorrhizal fungi	1.6 gr	-	-	-	0	53
Bifenthrin + *Bacillus amyloliquefaciens* strain D747	1242 ml	-	-	-	20	90
Humic acids (derived from leonardite), organic matter (derived from	1121 gr[c]	-	-	-	25	93
soy protein hydrolysate) +	3363 gr	-	-	-	0	95
various strains of *Bacillus* spp.	11210 gr	-	-	-	10	81
LSD (0.05)		16	18	253	13	30

[a] *Abbreviations: DAP, days after planting.*
[b] *Sesame emergence or stand was estimated visually on a scale of 0 to 100 (0 = no emergence and 100 = complete emergence)*
[c] *These are 3 different rates of the humic acid, organic matter + Bacillus mixture*

Table 3. Use of soil additives in sesame for the 2018 growing season

Treatment	Rate ha^{-1}	Stand DAP[a,b] %	Yield Kg ha^{-1}
Untreated	-	52	333
Azospirillum brasilense	935 ml	89	425
7% N + 10% chelated Fe	1169 ml	53	352
Ionized sodium silicate	1462 ml	77	548
Bacillus licheniformis	13 ml	56	467
Gibberellic acid (0.03%) + 3- indolebutyric acid (0.045%) + cytokinin, as kinetin (0.09%)	365 ml	72	722
Gibberellic acid (GA3)	73 ml	84	507
Bifenthrin + *Bacillus licheniformis*	300 ml +, 13 ml	52	587
Pop-Up 9-30-0 + Zn	28062 ml	66	498
Bifenthrin + *Bacillus amyloliquefaciens* strain D747	1242 ml	81	396
Humic acids (derived from leonardite) + organic matter (derived from soy protein hydrolysate)+ various strains of *Bacillus* spp.	454 gr	57	379
Pyraclostrobin	438 ml	75	377
2% N	4677 ml	86	665
Arbuscular mycorrhizal fungi	1.6 gr	57	503
Bifenthrin	300 ml	79	535
Pop-Up 9-30-0 + Zn + pyraclostrobin	28062 ml + 438 ml	57	299
Microalgae	438 ml	65	532
LSD (0.05)	-	22	275

[a] *Abbreviation: DAP, days after planting*

[b] *Stand counts taken 15 DAP. Sesame emergence or stand was estimated visually on a scale of 0 to 100 (0 = no emergence and 100 = complete emergence)*

also found that on the lighter sandy loam and silt soils, growth responses with pop-up fertilizer over N alone was primarily due to the P in the pop-up fertilizer. This was probably because of reduced P availability on the sandy, low organic matter, and light colored soils which are typically cold-natured, especially early in the growing season.

3.1.3 2018. *Azospirillum brasilense*, ionized sodium silicate, gibberellic acid, bifenthrin + *Bacillus amyloliquefaciens* strain D747, pyraclostrobin, 2% N, and bifenthrin alone resulted in greater emergence than the untreated check (Table 3). Using *A. brasilense* as an inoculant can affect important changes in the morphology of the plant root. This can be caused by the bacterial production of plant growth regulating substances such as auxin and gibberellins [16,17]. Bolton et al. [18] reported that *A. brasilense* did not consistently increase vegetative growth, turfgrass color, or quality of hybrid bermudagrass [*Cyndon dactylon* (L.) Pers. x *Cynodon transvaalensis* Burtt Davy] compared with the nontreated check.

3.2 Sesame Yield

3.2.1 2016. Gibberellic acid + 3-indolebutyric acid + cytokinin (as kinetin) and 2% N produced yields 32 to 34% higher than the untreated check while the ionized sodium silicate family treatment resulted in a 34% reduction in yield (Table 2). The treatment of 3-indolebutyric acid (0.85%) + cytokinin, as kinetin (0.15%) without gibberellic acid resulted in a 3% yield reduction over the untreated check. Lemus et al [19] reported that using 22.4 and 44.8 kg ha^{-1} of N produced significantly greater ryegrass (*Lolium multiforum* Lam.) biomass production than the untreated check or gibberellic acid treatment at 29.2 ml ha^{-1}. They speculated that normal growing condition temperatures in the southern US during ryegrass production may be too mild to observe a gibberellic acid response at the applied rates.

3.2.2 2018. Similar results as in 2016 were seen. The 3-way combination of gibberellic acid + 3-indolebutyric acid (0.045%) + cytokinin as kinetin (0.090%) and 2% N resulted in up to a 117% increase in yield over the untreated check

(Table 3). No other differences in yield were noted from the untreated check.

4. CONCLUSION

In these studies, the 3-way combination of gibberellic acid + 3-indolebutyric acid (0.045%) + cytokinin as kinetin (0.090%) (sold in the US as Ascend® SL) and 2 % N (sold in the US as Levesol®) proved to be the most consistent soil additives and resulted in a yield increase in the two years that these studies were harvested. The 3-way combination of gibberellic acid + 3-indolebutyric acid + cytokinin as kinetin works three different ways. Gibberellic acid stimulates cell division and elongation in leaves and stem, indolebutyric acid stimulates cell division and elongation in leaves and stem while cytokinin promotes cell division and leaf expansion [20]. Also, cytokinin has been found to help in enhancing plant resistance against plant pathogens [21]. The 2% N product has three modes of action: 1) unlocks nutrients in the soil, 2) enhanced nutrient availability results in increased early season growth, overall plant health, and 3) is mobile in the plant for season-long activity [22]. It makes phosphorus, zinc, and other key micronutrients more available to the plant and as a result increases early-season growth, overall plant health, and ultimately yield [22].

Using a starter (pop-up) fertilizer either alone or in combination with a fungicide did not greatly influence yield. Variable yield responses have been seen in corn and other crops as well [10, 23-27]. Pierson et al., [24] found that using a starter (pop-up) fertilizer and/or a fungicide in soybean [*Glycine max* (L.) Merr.] was not profitable if soil-borne diseases or nutrient deficiencies were not present. Grichar [10] reported, in a 2-year corn study, that using a pop-up fertilizer + Zn and pop-up fertilizer + Zn + pyraclostrobin in one year resulted inthe highest numerical yields, although this was not significantly different from the untreated check. In the other year, using pop-up fertilizer alone at 28062 and 46771 ml ha^{-1} resulted in corn yields that were greater than the untreated check.

Azospirillum brasilense resulted in excellent sesame emergence in 2018; however, no improved emergence with *A. brasilense* was shown in 2016 or 2017. Sesame yields were not improved using *A. brasilense*. *A. brasilense* has been used in Brazil with corn as a seed treatment to improve N use and increase yield [28,29]. *A. brasilense* has resulted in an increase in corn growth and yield when combined with only half of the optimum rate of fertilizer N [28,29]. A meta-analysis of *Azospirillum* spp. indicated that corn yield increases could be achieved when the bacteria was applied without additional N and only minimal increases when applied with N [30].

McFarland [2] had previously found in several studies across the US, that the use of soil additives did not show a significant benefit to crop yield and quality. Laboratory studies have shown that these products did not improve the activity or number of soil microbes and therefore would not be expected to increase the rate or extent of crop residue decomposition [2]. However, El Sawah et al. [31] reported that various components of guar [*Cyamopsis tetragonoloba* (L.)] plant growth including shoot length, root length, leaf area, plant dry weight, nutrient uptake, and yield were significantly affected by the application of biofertilizers and their combination. Soil enzymes activites such as dehydrogenase, phosphatase, protease, and invertase also improved in the soil rhizosphere of plants treated with biofertilizers. They also found 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%.

More work is needed to study the response of crop growth and yield when using soil additives since many new products are constantly being introduced into the market place. Maximum the economic yield of any crop is dependent on using only those inputs which will provide a return on investment.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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