Original Research Article

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

ABSTRACT

Aims: Field studies were conducted to determine the effects of soil additives on sesame emergence and yield.
Study design: Randomized complete blockwith4 replications.An untreated check was included in each study.
Place and Duration of Study: Studies were conducted during the 2016 through 2018 growing seasons in south-central Texas near Yoakum (29.27704^{o} N, -97.12453^{o} W).
Methodology: Sesame seed was planted < 2.54 cm deep reatments were applied using a CO_2-pressurized sprayer in 46.8 L ha^{-1} of waterwith 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 7% N + 10% chelated Fe, gibberellic acid + 3-indolebutyric acid (0.85%) + cytokinin as Kinetin (0.15%), and pop-up fertilizer (9-30-0 + Zn) and gibberellic acid alone resulted in the greatest sesame emergence. In 2017, 2% N, bifenthrin + *Bacillus amyloliquefaciens* strain D747, and humic acids + *Bacillus* spp. resulted in greater emergence (90-97%) while in 2018, *Azospirillumbrasilense* 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 check.
Conclusion: The 3-way combinationofgibberellic 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.

1. INTRODUCTION

Sesame growers are constantly trying to find ways to improve their production systems. The use of soil additives such as fungicides, insecticides, soil activators, soil conditioners wetting agents, inoculants, microbial enhancers, andsoil stimulants have been discussed since the early 1900's [1,2].Increases in production costs, mainly for fertilizers, has renewed sesame growers interest in these products.

The production and application of fertilizers are not only costly but can result in unwanted consequences since their production relies on natural gas and their over-use causes leaching into groundwater, ammonia volatilization, and denitrification [3]. Generally, soil additives can be distinguished from fertilizers in that they usually have little or no nutrient content and they do not provide a guaranteed analysis (e. g., 10-34-0 or 32-0-0). The advertisement of these products often suggests that adding soil additives to the soil will increase crop production by improving root growth and nutrient uptake; therefore, increasing yield. These enhancements to the soil are generally thought to occur when fertilizer applications are made to a crop at the recommended or near recommended rates, although some soil additives claim to reduce or replace the need for fertilizers [1,2].

Soil additives are also added to the soil to improve the texture of the soil. Unlike fertilizers, which add just nutrients, some soil additives modify the condition of the soil itself in addition to adding nutrients. Tilth is the condition of the soil and is a function of soil texture, structure, fertility, and interplay with the organic content and living soil organisms [4]. With improved tilth, roots penetrate surrounding soil more easily and water infiltration improves [4]. 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 will impact plant growth directly while soil amendments or additives affect growth indirectly and sometimes may also deliver nutrients to plants. Soil additives 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].

Maintaining and/or improving soil structure is highly desirable in crop production and adding organic matter is one of the most common methods of improving soil structure [5]. 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 soil physical properties (increase structure, reduce 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 [6]. 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 or preemergence herbicides having residual soil activity [7]. 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 [8].

Several traditional soil additives 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, sesame producers need to be aware of the types of products available and have some knowledge of their potential for improved sesame production. Therefore, this research was conducted to evaluate some soil additives that are currently on the market to determine sesame growth and yield response.

2. MATERIAL AND METHODS

2.1 Field studies. These studies were conducted at the Texas A&M AgriLife Research Site near Yoakum (29.1642^{o} N, -97.1243^{o} W) in south-central Texas during the 2016 through 2018 growing seasons to determine sesame response to various soil additives applied in-furrow at planting. The test locations were in the same general area but different parts of the field in the three test years. Soils at this location were a Denhawken-Elmendorf complex (fine, smectitic, hyperthermicVerticUstochrepts) 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. Soil additives used 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, and properties 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	*Azospirillumbrasilense*	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 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 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 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 anAlmaco® 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, *Azospirillumbrasilense*, 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). *Azospirillumbrasilense*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 *Cylindrocladiumparasiticun*).

On the contrary, Jordan et al. [14] 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.

3.1.2 2017. At the 5 DAP evaluation, no sesame had emerged in the untreated check, *Azospirillumbrasilense*, 7% N + 10% chelated Fe, ionized sodium silicate family, bifenthrin,

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

	2016	2017

Treatment	Rate ha^{-1}	Stand DAP^{a,b}		Yield	Stand DAP	
		7	161		5	64
		%		Kg ha^{-1}	%	
Untreated	-	83	77	775	0	20
Tebuconazole	585 ml	64	72	819	-	-
Azospirillumbrasilense	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	1121 gr	-	-	-	25	93

leonardite), organic matter (derived from soy protein hydrolysate) + various strains of *Bacillus* spp.	3363 gr	-	-	-	0	95
	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).

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

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
Azospirillumbrasilense	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) [10].

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 also reported on 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 effect 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. *Azospirillumbrasilense*, ionized sodiumsilicate, gibberellic acid, bifenthrin + *Bacillus amyloliquefaciens* strain D747, pyraclostrobin, 2% N, and bifenthrin alone resulted in greater emergence than the untreated check (Table 3). Inoculation with *A. brasilense*stimulates important changes in plant root morphology, most likely due to the bacterial production of plant growth regulating substances such as auxin and gibberellins [16, 17] However, Bolton et al. [18] reported in field and experimental studies that *A. brasilense* didnot consistently increase the normalized vegetation, turfgrass color or quality of hybrid bermudagrass [*Cyndondactylon* (L.) Pers. x *Cynodontransvaalensis* Burtt Davy] compared with the nontreated check.

3.2 Sesame yield.

3.2.12016. 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 suggested that 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 combinationofgibberellic 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 combinationofgibberellic 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 increases in the two years that the studies were harvested. The3-way combinationofgibberellic 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].

The use of 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] concluded that the use of a fungicide and/or starter (pop-up) fertilizer in soybean [*Glycine max* (L.) Merr.] maynot be profitable if soil-borne diseases or nutrient deficiencies are not present. In a 2-year study, Grichar [10] reported that in one year, although not significantly different from the untreated check, pop-up fertilizer + Zn and pop-up fertilizer + Zn + pyraclostrobin produced the highest numerical yields while in the other year, pop-up fertilizer alone at 28062 and 46771 ml ha^{-1} resulted in corn yields that were greater than the untreated check.

Although *Azospirillumbrasilense* resulted in excellent sesame emergence in 2018, no improved emergence was seen in 2016 and 2017. Also, yields were not improved with the use of *A. brasilense*. *A. brasilense* has been used in corn as a seed treatment in Brazil to improve N use and yield and resulted in increased 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 yield increases in corn were achieved when the bacteria was applied without additional N and only minimal increases when applied with N [30].

McFarland [2] reported in various studies across the US that using soil additives did not show a significant benefit 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. [31] reported that various components of guar [*Cyamopsistetragonoloba* (L.)] 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%.

Additional research is needed to determine the effectiveness of these soil additives on crop growth and yield since many similar products are being introduced into the market place. Maximum economic yield depends on using only those inputs which will provide a return on investment.

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