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Allelopathic Effects of Wheat Straw on Cotton Germination, Emergence, and Yield

S. K. Hicks,* C. W. Wendt, J. R. Gannaway, and R. B. Baker

ABSTRACT

Because of recently enacted conservation compliance legislation, reduced and no-till farming systems in which crop residues are left on the soil surface are becoming more important in areas where soils are highly erodible. On the southern high plains of Texas, many producers are planting cotton (*Gossypium hirsutum* L.) into wheat straw (*Triticum aestivum* L.). This study was conducted to determine the allelopathic potential of wheat residues on cotton germination, emergence, seedling growth, and lint yield. Laboratory bioassays revealed that cotton seedling development was inhibited by aqueous extracts of wheat straw. Cotton cultivars were screened for the ability to tolerate the inhibitive effects of wheat straw in laboratory bioassays and greenhouse pot studies. Tolerant 'Paymaster 404' and intolerant 'Acala A246' were identified and used in field experiments that were conducted in 1986 and 1987 to determine the influence of wheat stubble residues on their emergence and yield. Major reductions in emergence only occurred when aboveground residues were present in the seedbed. Emergence was reduced by an average of 9% for Paymaster 404 and 21% for Acala A246 when wheat stubble residues were present in the seedbed. The allelopathic effect of wheat stubble indirectly influenced lint yield by affecting population densities. The negative effect of wheat stubble on cotton stand establishment can apparently be overcome by; limiting the amount of aboveground residues that are incorporated into the seedbed during planting, increasing the seeding rates, and planting tolerant cultivars.

ALLELOPATHY is the influence of one plant on another through the production of chemicals that escape into the environment (13). Crop and weed residues can result in decreased stand establishment and growth of succeeding crops (12,13). The phytotoxic effect can be attributed to either allelochemicals present in plant residue or microbial toxins produced during decomposition (9,10,11,12,13).

Placement of plant residues in the soil environment influences duration and degree of plant growth inhibition associated with allelochemicals. Patrick and Koch (11) determined that greatest toxicity was associated with crop residues decomposing under saturated soil conditions. Corn (*Zea mays* L.) performed poorly when planted into stubble mulch of white sweet clover (*Melilotus alba* Medixus) or wheat straw (12). In Austriali, allelopathic agents associated with knotweed (*Polygonum aviculare* L.) were only present in the top 1 cm of soil beneath weed residues, and removal of the aboveground residue and top 1 cm of soil eliminated the phytotoxins that inhibited the germination of burclover medic (*Medicago polymorpha* L.) (8). Barnes and Putnam (1) studied the influence of rye (*Secale cereale* L.) residue placement in soil on germination of various plant species. As distance between residue and seed increased, phytotoxicity decreased.

Cotton producers on the southern High Plains of Texas are beginning to use reduced and no-till farming systems for increased profitability and as a means of conserving soil and water (2, 7, 14). One system involves planting cotton into standing wheat stubble after a fallow period, or into wheat stubble that was chemically terminated prior to planting. Genetic variability exists among commercial soybean [*Glycine max* (L.) Merr.] cultivars for resistance to phytotoxins contained in wheat straw (5). Information on the possible allelopathic effect of wheat residues on cotton emergence and yield is limited. The objectives of this study were to determine if: (i) wheat stubble residues inhibit germination and seedling development of cotton, (ii) genetic variability exists among commercial cotton varieties for tolerance to phytotoxic compounds present in wheat stubble, and (iii) wheat stubble placement in the soil influences cotton germination and establishment.

MATERIALS AND METHODS

Cotton Variety Screen

Ten certifies seed lots of commercial cotton seed and an experimental cultivar, Acala A246, produced in 1986 (Table 1) were evaluated for resistance to germination and seedling growth inhibitors present in aqueous extracts of wheat straw. Mature 'TAM 104' wheat straw was collected at grain harvest, air-dried, and ground in a Willey Mill to pass through a 20 mesh screen. The ground straw was homogenized with distilled water at 1 g straw to 10 mL water (1:10). The extract was filtered through cheese cloth and diluted to a concentration of 1 g wheat straw to 100 mL of water (1:100). The seeds were placed between two sheets of filter paper in petri

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dishes. Petri dishes and filter paper were sterile prior to the experiment. Five milliliters of the 1:100 solution were used to germinate 10 cotton seeds at 25 °C. Controls were germinated with 5 mL of distilled water. Total germination and radical fresh wt. were obtained after 5 d. Germination was counted when radical protrusion through the seed coat was greater than 1 mm. Germination and radical fresh wt. were expressed as a percentage of the control germination for each cultivar. A completely randomized experimental design was utilized with ten replicates.

Greenhouse Experiments

Ground, mature, air-dried TAM 104 straw was added to small pots (400 cm^3) containing surface soil of an Olton loam (fine, mixed, thermic, Aridic Paleustoll) at rates of 0 (control), 0.5, 1.0, and 2.5% by weight of soil. This provided a range of residue amounts that may occur within the surface 5 cm of soil across a range of production levels (6). Stubble was either applied to the surface or incorporated throughout the pot. Six seed of Paymaster 404 (tolerant) and Acala A246 (intolerant) were planted 2.5 cm deep in 10 pots of each straw treatment. The experimental arrangement was a complete factorial in a randomized-complete block design. The pots were frequently watered to prevent drying of the seedbed. Germination, emergence, and total root and shoot biomass were measured after 19 d from planting and were expressed as a percentage of the control for each cultivar.

Table 1. Germination and seedling growth of cotton cultivars treated with water extracts of wheat straw, 1986.

Cultivar	Seedling growth: Germination†	Radical fresh wt.
	%	%
Rilcot RK-6	102a‡	63a
Paymaster 145	107ab	44ab
Quapaw	104a	51ab
Paymaster 404	96bc	70a
Dunn 1047	96bc	51ab
Delta Pine 90	93bcd	36ab
Tamcot CAB-CS	92bcd	34ab
Rogers 7590	89bcd	53ab
All Tex WM-571	89bcd	35ab
Lankart LX-571	80cd	34ab
Acala A246	75d	20b

† Seed germination and radical fresh wt. are expressed as a percentage of the control (water) germination for each cultivar.
‡ Means within columns not followed by the same letter are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range Test.

Table 2. Analysis of variance results for the greenhouse pot study in 1986.

Effect	df	Germination	Emergence	Dry wt.
Replications	9	NS†	NS	NS
Cultivars	1	*	**	NS
Rate	2	**	**	**
Incorporation (Inc)	1	**	NS	*
Cult × Rate	2	NS	NS	NS
Cult × Inc	1	NS	NS	NS
Rate × Inc	2	*	NS	NS
Cult × Rate × Inc	2	NS	NS	NS

*, ** Significance at the 0.05 and 0.01 levels of probability.
† NS indicates nonsignificance of the main effect or interaction.

Field Experiments

Studies were conducted under a rainout shelter in 1986 and 1987 at the Texas Agricultural Experiment Station, Lubbock, TX to determine the influence of wheat stubble on emergence, stand establishment, and lint yield of Acala A246 and Paymaster 404 in a field environment. The rainout shelter was used to protect the experiment from damaging storms and to control the amount of water applied. The soil was an Olton loam. The area under the shelter was 444 m^2. The line TAM 104 was planted in early January and cut at a height of 20 cm at maturity in early June of both years. Excess straw was removed by raking in order to leave only standing wheat stubble. Tillage treatments consisted of: (i) clean tillage in which wheat stubble, crown, and adhering roots were removed by hand and surface 15 cm tilled prior to planting, (ii) planting into standing wheat stubble, and (iii) planting into standing wheat stubble with a small amount (0.05 g) of ground mature wheat stubble, collected at time of wheat harvest, and placed in direct contact with each seed by hand. Cotton planting was conducted by hand-punching holes 3 cm deep and 10 cm apart and placing seed in each hole. Tillage was replicated four times in four-row plots with 67 cm between rows and an area of 36 m^3. Plots were lightly watered during germination and emergence to reduce crusting of the soil surface. Subsequent irrigations were applied with a metered drip irrigation system. The total amount of water applied was approximately 29 cm which is equivalent to the long term average rainfall at Lubbock for the period of May through September (3). Herbicides were not used and weeds were removed by hand.

In 1986 two seeds were planted in each hole on 17 June. At this planting rate the maximum plant population is 287 038 plants/ha. Nitrogen was applied as a side-dress at a rate of 45 kg/ha prior to first bloom. Irrigations were applied on 12 June (10 cm), 11 July (10 cm), and 15 August (10 cm). Data were analyzed as a split plot arrangement of

Table 3. Population densities, lint yields, and yield components for cotton cultivars and tillage treatments, 1986.

Treatment	Population	CV	Lint yield and components: Lint	CV	Open bolls	CV	Lint	CV
	plants/ha^{-1}	%	kg/ha	%	no./plant	%	g/plant	%
			Paymaster 404					
1†	224770a‡	7	308a	18	2.4b	9	1.4a	14
2	212420a	18	390a	18	2.6ab	19	1.8a	26
3	197600a	6	389a	18	3.2a	15	2.0a	22
			Acala A246					
1	177840a	12	381b	20	2.5b	24	2.1b	22
2	158080ab	23	427a	6	3.1ab	14	2.8b	23
3	140790b	41	455a	21	3.4a	23	3.2a	25

† Treatments: 1 = clean tillage, 2 = wheat stubble, 3 = wheat stubble with straw in the seed bed.
‡ Means within columns and cultivars not followed by the same letter are significantly different at the 0.05 level according to Duncan's New Multiple Range Test.

treatments with tillage as main plots and cultivars as subplots.

The 1987 study was designed to investigate effects of seed quality on emergence, stand establishment, and lint yield. Seed quality was evaluated to determine if the different response to inhibitive effects in wheat straw exhibited by Paymaster 404 and Acala A246 was truly genetic. The same seed lots used in 1986 were divided into four density classes by floating the seed in solutions of varying concentrations of NaCl. Density classes were : (i) $D < 1.00$ Mg m^3, (ii) $1 < D < 1.05$ Mg m^3 (iii) $1.05 < D < 1.10$ Mg m^3, and (iv) $D > 1.10$ Mg m^3. Paymaster 404 separated into 10, 40, 30, and 20% by weight, respectively, for density classes one through four. Acala A246 separated into 35, 35, 20, and 10% by weight for the above classes. Standard germination tests were conducted for each group and showed that germination was positively correlated with seed density. Total germination was greater for Paymaster 404 (92%) than Acala A246 (87%). Seed from each density class for both cultivars were planted into single rows in 8-row tillage plots on 10 June. One seed was hand-planted at a depth of 3 cm every 10 cm within a row. At this seeding rate the maximum possible population was 143 519 plants/ha. Both N and P were applied prior to planting at rates of 90 and 67 kg/ha, respectively. Emergence counts were obtained for the first 19 d after planting. Irrigations were applied on 2 June (5 cm), 18 June (10 cm), and 6 August (13.8 cm). Hand harvest was conducted on 2 November. Data were analyzed as a split-split plot with tillage treatments as main plots, cultivars as subplots, and seed density class as sub-subplots.

RESULTS AND DISCUSSION

Cotton Variety Screening

Germination and radical fresh wt. percentages are presented in Table 1. Paymaster 404 was identified as tolerant of wheat straw due to relatively high germination and radical development when germinated with extracts of wheat straw. Acala A246 was considered to be intolerant of wheat straw due to low germination and radical development in wheat straw extracts. The results of this preliminary experiment were used to identify cultivars that were used in subsequent experiments.

Greenhouse Pot Study

Results of the analysis of variance for germination, emergence, and dry matter in the greenhouse pot study are given in Table 2. Germination and seedling emergence of Acala 246 were reduced by 23 and 22%, respectively, compared to Paymaster 404. Incorporation of wheat straw residues throughout pots resulted in reductions in germination and dry matter of 26 and 14% respectively in comparison with surface-applied residues. The influence of contact between seed and wheat straw residues was further evaluated in the field studies. Rate of straw application significantly influenced all measured parameters and these relationships are shown in Fig. 1. All levels of wheat straw used in this study caused large reductions in germination, emergence, and dry matter. These reductions were greater for Acala A246 than for Paymaster 404.

Field Studies

Cotton population density, lint yield, and components for the 1986 study are contained in Table 3.

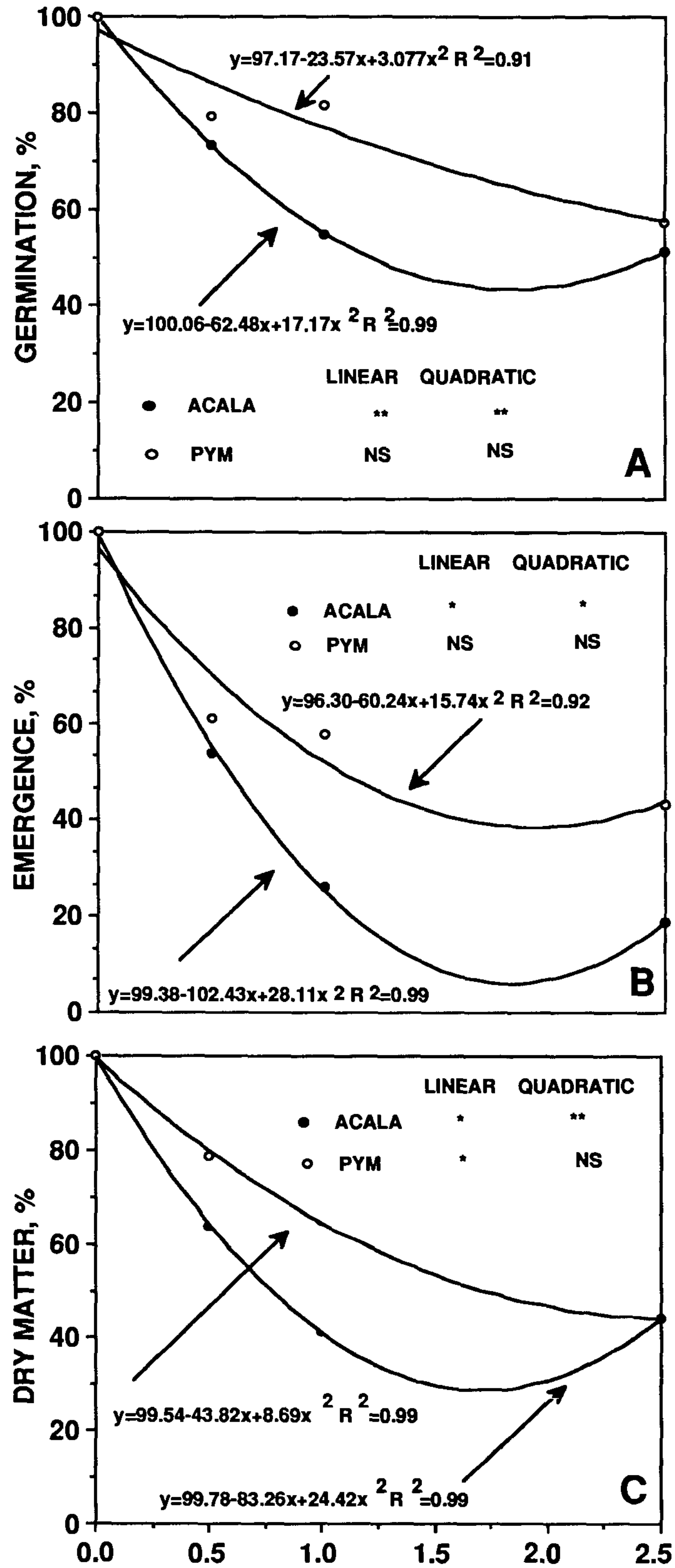

Fig. 1. Relationship between percent wheat straw in soil and cotton germination (A), emergence (B), and dry matter (C) 14 d after planting in the 1986 greenhouse study for cotton cultivars Acala A246 (Acala) and Paymaster 404 (PYM). * and ** indicate significance of linear and quadratic components at the 0.05 and 0.01 levels of probability respectively, while NS indicates nonsignificance at the 0.05 level.

Table 4. Population densities, lint yields, and yield components for cotton cultivars and seed density treatments, 1987.

Seed Density	Population	CV	Lint yield and components					
			Lint	CV	Open bolls	CV	Lint	CV
Mg/m³	plants/ha	%	kg/ha	%	no./plant	%	g/plant	%
			Paymaster 404					
D < 1	42440c†	26	420c	24	8.5a	20	10.1a	21
1 < D < 1.05	52601b	20	524b	25	8.5a	12	9.9a	14
1.05 < D < 1.10	57184b	22	547b	17	8.5a	23	9.8a	19
D > 1.10	68740a	14	651a	21	8.1a	16	9.5a	18
			Acala A246					
D < 1	28492c	27	300c	28	8.2a	21	10.9a	28
1 < D < 1.05	43237b	26	367c	29	6.6c	17	8.6b	20
1.05 < D < 1.10	49214ab	49	468b	32	7.5ab	20	10.3a	23
D > 1.10	55789a	22	544a	24	6.9c	14	9.8ab	16

† Means within columns and cultivars not followed by the same letter are significantly different at the 0.05 level according to Duncan's New Multiple Range Test.

Table 5. Population densities, lint yields, and yield components for cotton cultivars and tillage treatments in 1987.

Treatment	Population	CV	Lint yield and components					
			Lint	CV	Open bolls	CV	Lint	CV
	plants/ha	%	kg/ha	%	no./plant	%	g/plant	%
			Paymaster 404					
1†	52774a‡	31	517a	29	8.9a	23	10.1a	23
2	59800a	22	576a	21	8.1a	8	9.7a	9
3	50232a	24	532a	29	8.2a	16	9.8a	19
			Acala A246					
1	45596a	43	453a	32	7.5a	25	10.5a	26
2	50978a	34	445a	36	6.8a	15	8.8a	20
3	36030b	38	364b	37	7.7a	17	9.8a	21

† Treatments: 1 = clean tillage, 2 = wheat stubble, 3 = wheat stubble with straw in the seed bed
‡ Means within columns and cultivars not followed by the same letter are significantly different at the 0.05 level according to Duncan's New Multiple Range Test.

Placement of ground wheat straw in the seedbed resulted in a significant reduction in plant population and a significant increase in lint yield per plant of Acala A246 (21%) but not of Paymaster 404 (12%). Number of open bolls per plant was increased in the wheat stubble with seedbed straw treatment of both cultivars. In 1986 plant population was negatively correlated with lint yield (−0.45, significant at the 0.05*), number of open bolls per plant (−0.79*,* significant at the 0.01 probability level), and lint weight per plant (−0.85**). Fowler and Ray (4) determined that the optimum plant populations for lint yield ranged from 79 000 and 155 000 plants/ha, and this suggests that planting rates and resulting populations in 1986 were too great for maximum lint production in all but the wheat stubble with seedbed straw treatment of Acala A246.

The 1987 planting rate was reduced to 50% of that in 1986 in order to obtain plant populations within the optimum range for lint production. The influence of seed density on plant population, lint yield, and yield components is given in Table 4. Increased seed density resulted in increased plant populations and lint yield of both cultivars. The interactions of seed density × cultivar, seed density × tillage treatment, and seed density × cultivar × tillage treatment were not significant. Plant populations obtained in the 1987 study were below the optimal level for lint production, although the planting rate was sufficient (143 519 seed/ha). The decreased emergence in the 1987 study probably was the result of an increase in the number of lower quality seed planted (lower seed density), as well as other factors such as increased seed age and planting one rather than two seed per hole.

Total emergence during the first 19 d after planting in the stubble treatments is shown in Fig. 2. Plots of Acala A246 where wheat stubble was placed in the seedbed had significantly lower emergence (23%) compared with the clean-tilled plots. Plant populations, lint yields, and yield components as influenced by cultivars and tillage treatments are given in Table 5. Population densities and lint yields were significantly lower only for Acala A246 when wheat stubble was placed in the seedbed. Thus a difference in tolerance to emergence inhibition by wheat straw was exhibited by cultivars. There was no significant difference in open bolls and lint produced per plant among treatments, although populations varied. There was a positive correlation between population density and lint yield (0.81**) across all treatments. Analysis of covariance indicated that this relationship was the same for both cultivars and that differences in lint yield between cultivars could be explained primarily by differences in population density.

The relationship between population density and lint yield across both years is given in Fig. 3. From the cubic regression equation it was determined that the optimal plant populations for lint yield is indicated to be between 70000 and 140,000 plants/ha, which is similar to the findings of Fowler and Ray (4). In 1986,

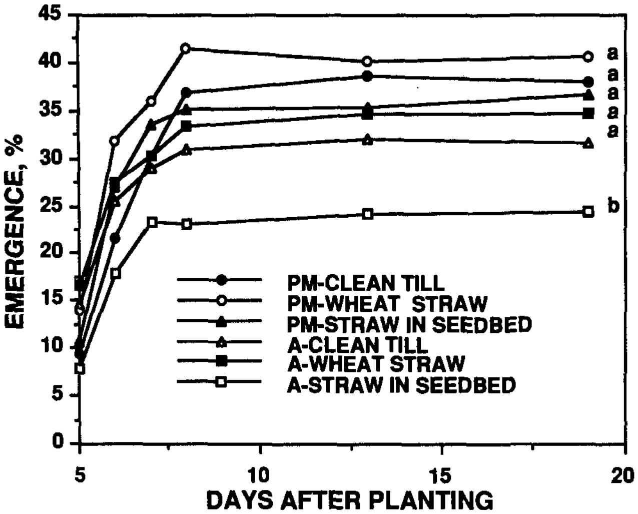

Fig. 2. Cotton emergence during the first 19 d after planting in 1987 across seed density treatments. Means for 19-d emergence not followed by the same letter within cultivars are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range Test.

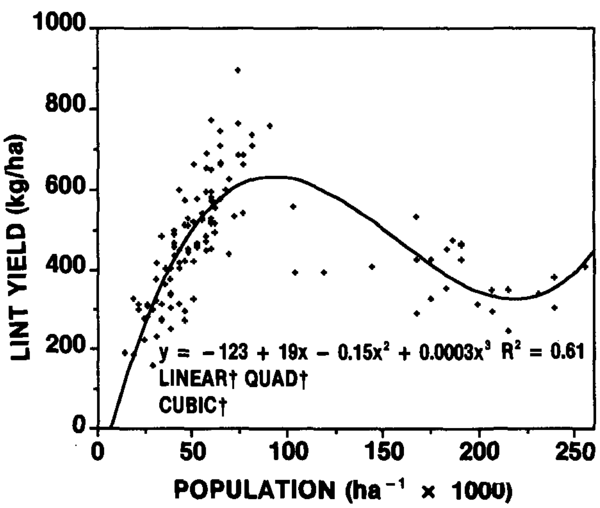

Fig. 3. Relationship between plant population density and lint yield across treatments and years. † indicates significance of linear, quadratic, and cubic components at the 0.001 level of probability.

when the planting rates and resulting populations were above the optimal level for lint production, direct contact between seed and wheat stubble residue resulted in decreased population densities and increased lint yield for Acala A246. In 1987, when the resulting populations were below the optimal level for lint production, decreased population densities due to direct contact between wheat stubble residues and seed resulted in reduced lint yield for Acala A246.

In conclusion, wheat straw was found to have an inhibitory effect on cotton germination, seedling growth, and emergence in laboratory, greenhouse, and field studies. Tolerant (Paymaster 404) and intolerant (Acala A246) cultivars were identified. This is similar to findings among soybean cultivars (5). In the greenhouse study, the greatest reduction in cotton germination and emergence occurred when residues were incorporated throughout the soil. In the field studies, significant reductions in cotton emergence only occurred when seed were in direct contact with wheat straw residues. This is similar to results from other studies in which the phytotoxicity of plant residues only occurred when residues were in close proximity of germinating seeds (1,8). The negative effect of wheat stubble on cotton stand establishment can apparently be overcome by limiting the amount of aboveground residue incorporated into the seedbed during planting, increasing the seeding rate, and planting tolerant cultivars.

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