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Greenhouse Screening of Corn Gluten Meal as a Natural Control Product for Broadleaf and Grass Weeds

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Abstract. **Corn** *(Zea mays* L.) **gluten meal (CGM) was evaluated under greenhouse conditions for efficacy on 22 selected monocotyledonous and dicotyledonous weed species. Corn gluten meal was applied at 0, 324, 649, and 973 g•m^{-2} and as a soil-surface preemergence (PRE) and preplant-incorporated (PPI) weed control product. CGM reduced plant survival, shoot length, and root development of all tested species. Black nightshade *(Solanum nigrum* L.), common lambsquarters *(Chenopodium album* L.), creeping bentgrass *(Agrostis palustris* Huds.), curly dock *(Rumex crispus* L.), purslane *(Portulaca oleracea* L.), and redroot pigweed *(Amaranthus retroflexus* L.) were the most susceptible species. Plant survival and root development for these species were reduced by 275%, and shoot length was decreased by >50% when treated PRE and PPI with 324 g CGM/m^2. Catchweed bedstraw *(Galium aparine* L.), dandelion *(Taraxacum officinale* Weber), giant foxtail *(Setaria faberi* Herrm.), and smooth crabgrass *[Digitaria ischaemum* (Schreb.) Schreb. ex Muhl] exhibited survival and shoot length reductions >50% and an 80% reduction in root development when treated with PPI CGM at 324 g•m^{-2} Barnyardgrass *[Echinochloa crus-galli* (L.) Beauv.] and velvetleaf *(Abutilon theophrasti* Medic.) were the least susceptible species showing survival reductions ≤31% when treated with 324 g CGM/m^2.**

Synthetic herbicides often are used for weed control in vegetable crop and turfgrass management systems. Public awareness of the widespread use of herbicides and the possible negative effects of their residues on the environment are incentives for researchers to identify natural plant substances with herbicidal properties.

Several researchers have reported inhibition of shoot and root elongation of selected plant species by corn stalks and residue (Bonner, 1950; Nielsen et al., 1960). Water soluble extracts from cornstalks significantly inhibited the root and shoot growth of wheat *(Triticum aestivum* L.) and sorghum *[Sorghum bicolor(L.)* Moench.] seedlings (Guenzi and McCalla, 1962). In addition, aqueous extracts from decomposing corn residues suppressed root elongation in lettuce *(Lactuca sativa L.* 'Great Lakes'), suggesting that inhibition resulted from damage to the meristematic tissue of the emerging radicles (Chou and Patrick, 1976). Recent research has shown that corn gluten meal (CGM), the protein fraction of corn grain extracted in the wetmilling process, effectively controlled several weed species and has potential for use as a natural herbicide in turfgrass (Christians, 1993) and strawberry *(Fragaria xananassa* Duch.) weed management programs (Nonnecke and Christians, 1993).

Root formation during germination is inhibited by CGM in susceptible species. When CGM-treated plants were subjected to moisture stress, they died (Christians, 1993). In addition, CGM contains ≈10% N by weight and provides an additional N source to plant species with well-developed root systems. United States patent 5,030,268 has been granted for using CGM as a surface-applied preemergence herbicide (Christians, 1991).

Our objective was to evaluate the effects of CGM on plant survival and shoot and root growth of selected monocotyledonous and dicotyledonous

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Materials and

Twenty-two plant species were screened for susceptibility to CGM. The 10 dicotyledonous species used were black medic *(Medicago lupulina* L.), black nightshade, buckhorn plantain *(Plantago lanceolata* L.), catchweed bedstraw, common lambsquarters, curly dock, dandelion, purslane, redroot pigweed, and velvetleaf. Twelve monocotyledonous species were screened: annual bluegrass *(Poa annua* L.), barnyardgrass, creeping bentgrass, giant foxtail, green foxtail *[Setaria viridis* (L.) Beauv.], large crabgrass *[Digitaria sanguinalis* (L.) Scop.], orchardgrass *(Dactylic glomerta* L.), quackgrass *[Agropyron repens* (L.) Beauv.], shattercane *(Sorghum bicolor* L.), smooth crabgrass, woolly cupgrass *[Eriochloa villosa* (Thunb.) Kunth], and yellow foxtail *[Setaria lutescens* (Weigel) Hubb.].

All plants were grown under greenhouse conditions in square plastic pots with a surface area of 46.2 cm^2 and a depth of 5.7 cm. The planting medium was a Nicollet (fine-loamy mixed me sic Aquic Hap ludoll s) soil with a pH of 7.6 and 32 g organic matter/kg, 22 ppm extractable P, and 160 ppm exchangeable K. All seeds were planted to a depth of 0.6 cm. The number of seeds planted in each pot was species specific and was determined from previously obtained germination data (Table 1). Species with very small seeds were planted on a weight basis. Plants were watered to keep the soil uniformly moist, and no pesticides were applied. Because of the short duration of each test, no additional fertilizer was added.

CGM was applied at 0, 324, 649, and 973 g•m^{-2} These treatment levels were selected based on previous greenhouse research (Christians, 1993). CGM was applied to the soil surface for the preemergence (PRE) treatments. For the preplan/-incorporated (PPI) treatments, CGM was uniformly mixed in the upper 2.5 cm of soil in the pots.

Two studies were conducted in 1992, each with three replications: the first in late summer with natural lighting and the second in the fall using supplemental lighting from highpressure sodium lamps to enhance the natural irradiance and to extend the daylength to 16 h. These lights delivered ≈70 umol•m^{-2}•s^{-1} of irradiance.

The duration of each test was 16 days. On the last day, plant survival was assessed by counting the number of living plants in each pot, and shoot length was measured as the average length of the surviving plants. The soil residue was washed from the roots to examine the effects of CGM on rooting. The roots of CGM-treated plants were compared visually with the roots of nontreated plants. Differ

Table 1. Number and weight of seeds planted in each pot for the 22 species of plants screened.

Plant species	No. seeds/pot	Wt seeds/pot (g)
Annual bluegrass	500	0.219[z]
Barnyardgrass slack medic	25	0.101
Black nightshade	50	0.074[z]
Buckhorn plantain	15	0.020
Catchweed bedstraw		0.500[z]
Common lambsquarters	200	0.077
Creeping bentgrass Curly	25	0.120[z]
dock Dandelion Giant	150	0.200[z]
foxtail Green foxtail Large	1000	0.078[z]
crabgrass Orchardgrass	100	0.008
Purslane Quackgrass	15	0.040
Redroot pigweed	25	0.055
Shattercane Smooth	50	0.2007
crabgrass Velvetleaf	500	0.060
Woolly cupgrass Yellow foxtail	50	0.080[z]
	100	0.097
	30	0.007
	25	0.490
	30	0.200[z]
	100	0.142
	15	0.126
	15	0.046
	15	

[z]Because of the small seed size of these species, they were planted on the basis of weight per pot. The number of seeds per pot is a mean count.

ences between the amount of rooting for CGM treated plants and nontreated plants were estimated and recorded as percent reductions in root development. Reductions were estimated in 5% increments.

The statistical design was a split-split plot. The four CGM treatment levels were the whole plot treatments; the two application methods, the subplot treatments, and the weed species the sub-subplots. The results were similar for the two studies; therefore, data from both were combined for analysis.

The three replications in the first study were run consecutively because of space limitations, and those for the second study were run concurrently. Data were analyzed with the SAS version 6.6 (SAS Institute, 1990) analysis of variance procedure to test the significance of CGM effects on plant survival, shoot length, and root development. Least significant difference tests were used to compare significantly different means (Cochran and Cox, 1957).

Results

Plant survival. CGM reduced the survival of all broadleaf and grass species (Tables 2 and 3). There were no differences in the survival of plants receiving PRE applications and PPI treatments (Table 2).

There was a wide degree of interspecific variation in plant survival of CGM-treated plants (Table 3). Survival of all species, except barnyardgrass, green foxtail, quackgrass, velvetleaf, and woolly cupgrass, was reduced ≥40% when treated with 324 g CGM/m^2, and eight broadleaf species incurred 75% reductions at this CGM level. Reductions in survival were 275% for 11 of the species treated with 649 g CGM/m^2, and the survival of six additional species was reduced >40%. At 973 g CGM/m^2, survival was reduced 263% for all species except barnyardgrass, shattercane, and velvetleaf (Table 3).

There also were differences among species in their response to CGM quantity (Table 2). Survival decreased for 15 broadleaf and grass species as the amount of applied CGM increased (Table 3). Survival reductions were ≥95% for purslane and ≥87% for redroot pigweed at all CGM quantities. The survival of 20 species was decreased > 50% by 973 gCGM/m^2, and eight broadleaf and four grass species experienced reductions ≥90%. Survival was reduced <51 % at all CGM levels for barnyardgrass, shattercane, and velvetleaf.

Seven broadleaf and one grass species had the fewest survivors. At 324 gCGM/m^2, survival of black nightshade, buckhorn plantain, common lambsquarters, creeping bentgrass, curly dock, dandelion, purslane, and redroot pigweed was reduced ≥75%. Annual bluegrass, catchweed bedstraw, giant foxtail, large crabgrass, orchardgrass, and smooth crabgrass showed survival reductions ≥51% at 324 g CGM/m^2. At this same CGM level, all quackgrass and velvetleaf plants survived, as did nearly all woolly cupgrass seedlings.

Shoot length. There was a wide range of interspecific variation in shoot length reduction at the various CGM treatment levels (Table 2). Shoot lengths decreased for 13 broadleaf and grass species as the amount of applied CGM increased (Table 4). Black medic, black nightshade, common lambsquarters, curly dock, dandelion, purslane, and redroot pigweed had shoot lengths >50% shorter than the control at all CGM levels. Green foxtail receiving PRE applications exhibited 0% reduction in shoot length at 324 g CGM/m^2, 10% at 649 g CGM/m^2, and did not grow at 973 g CGM/m^2. At 649 g CGM/m^2 black nightshade died, and buckhorn plantain, curly dock, dandelion, and redroot pigweed had ≥80% less shoot growth than the control for PRE and PPI CGM. Curly dock and redroot pigweed exhibited >90% shoot reduction, and black nightshade, common lambsquarters, dandelion, and green foxtail died with PRE and PPI at 973 g CGM/m^2.

The species x application method interaction was significant for shoot length (Table 2).

Most species treated with PPI CGM had shorter shoots than those treated with PRE applications (Table 4). Shoot lengths of buckhorn plantain, catchweed bedstraw, giant foxtail, green foxtail, and quackgrass were reduced ≤22% by 324 g PRE CGM/m^2 but were reduced ≥50% by PPI applications at this level. With PRE at 649 g CGM/m^2, large crabgrass, and yellow foxtail exhibited shoot reductions of 6% and 0%, respectively, but with PPI CGM at this level, they showed reductions of 49% and 87%, respectively. Treatment with a PRE application at 973 g CGM/m^2 reduced shoot length ≤ 32% for quackgrass, shattercane, woolly cupgrass, **and yellow foxtail; shoot lengths of barnyardgrass and large crabgrass** were not reduced. PPI applications of **973 g** CGM/m^2, however, resulted in ≥51% shoot length reductions for all species, and shoot lengths were decreased 55% for barnyardgrass and 87% for large crabgrass.

Root development. Rooting of all broad-

Table 2. Analysis of variance for a split-split-plot design showing the significance of corn gluten meal effects on plant survival, shoot length, and root development.[z]

		P>F		
Source	df	Plant survival	Shoot length	Root development
Replication (Rep)	5	0.0008	0.0007	0.0001
Corn gluten meal (CGM)	3	0.0001	0.0001	0.0001
Rep x CGM[Y]	15	0.1463	0.3182	0.0018
Application method (AM)	1	0.4864	0.0001	0.0001
Species	21	0.0001	0.0001	0.0001
AM x species	21	0.1188	0.0056	0.0001
Rep x AM x species[x]	215	0.0001	0.0001	0.0001
CGM x AM	3	0.5160	0.0015	0.0001
CGM x species	63	0.0054	0.0001	0.0001
CGM x AM x species	63	0.2691	0.0532	0.0003
Error (c)	645			

[z]Data from both studies were combined. [Y]This source is error (a). [x]This source is replication x application method x species and is error (b).

Table 3. Reductions in survival, relative to tbe control, of weeds treated with three quantities of corn gluten meal (CGM).[z]

	% Reduction[Y]		
	Quantity of CGM		
Weed species	324 g•m^{-2}	649 g•m^{-2}	973 g•m^{-2}
Annual bluegrass	60	81	72
Barnyardgrass	31	35	41
Black medic	49	63	63
Black nightshade	78	99	100
Buckhorn plantain	80	95	96
Catchweed bedstraw	66	33	94
Common lambsquarters	82	88	99
Creeping bentgrass	85	85	96
Curly dock	75	94	97
Dandelion	75	90	100
Giant foxtail	63	54	83
Green foxtail	37	78	100
Large crabgrass	51	70	82
Orchardgrass	56	53	92
Purslane	97	95	100
Quackgrass	0	20	71
Redroot pigweed	87	96	99
Shattercane	42	43	51
Smooth crabgrass	51	85	97
Velvetleaf	0	18	35
Woolly cupgrass	6	29	79
Yellow foxtail	43	65	78

[z]Least significant difference (LSD0 05 = 40) for mean comparisons among CGM quantities for each species.
[Y]These data include the results of two studies and are mean percentages of the surface-applied (PRE) and preplan/-incorporated (PPI) survival reductions relative to tbe survival of the control plants (n = 12).

leaf and grass species was reduced by CGM (Tables 2 and 5). Reduction in root development significantly differed among CGM levels and species (Table 2). Interspecific variation in rooting ranged widely at all CGM levels (Table 5). With increasing amounts of applied CGM, root development decreased for black nightshade, buckhorn plantain, common lambsquarters, dandelion, quackgrass, and smooth crabgrass. Rooting reductions were ≥80% at all PRE and PPI levels for black medic, black nightshade, curly dock, creeping bentgrass, and purslane. Buckhorn plantain, catchweed bedstraw, common lambsquarters, dandelion, giant foxtail, green foxtail, orchardgrass, smooth crabgrass, and yellow foxtail had root development reduced >80% at all PPI levels. Rooting decreased ≤45% at all PRECGM levels for barnyardgrass, large crabgrass, shattercane, and woolly cupgrass.

The species x application method interaction was significant (Table 2). Dandelion, green foxtail, and yellow foxtail had ≤35% rooting reductions when treated with 324 g PRE CGM/m^2 but exhibited ≥90% reductions when subjected to PPI applications at the same level (Table 5). Large crabgrass root development was not decreased with 324 g PRE CGM/m^2 but was reduced 80% with 324 g PPI CGM/m^2. Root development reductions were ≤55% for annual bluegrass, catchweed bedstraw, large crabgrass, woolly cupgrass, and yellow foxtail with 649 g PRE CGM/m^2 but were ≥90% with 649 g PPI CGM/m^2. PPI applications at 973 g CGM/m^2 resulted in ≥75% root development reductions for all species. PRE applications at this CGM level, however, reduced rooting ≤45% for barnyardgrass, large crabgrass, shattercane, and woolly cupgrass.

Rooting decreased unequally among species in the same genus. When treated with 324, 649, and 973 g PRE CGM/m^2, large crabgrass exhibited 0%, 0%, and 45% root reductions, respectively, and smooth crabgrass had 65%, 95%, and 100% reductions, respectively. Rooting reductions for yellow foxtail treated with 324,649, and 973 g PRE CGM/m^2 were 20%, 20%, and 60%, respectively. At the same levels, reductions were 65%, 85%, and 95%, respectively, for giant foxtail and 35%, 85%, and 100%, respectively, for green foxtail.

Discussion

The results of these greenhouse screenings substantiate that the efficacy of CGM as a herbicide may extend to a broad spectrum of monocotyledonous and dicotyledonous plant species (Christians, 1993). All broadleaf and grass species evaluated exhibited some degree of susceptibility to the herbicidal properties of CGM. Plant responses, however, were variable among treatment levels and species. Application method also affected the reductions in shoot length and root development.

The PPI treatments generally were more effective than PRE applications in reducing shoot length and root development in all species, probably due to increased contact between the CGM and the germinating seedlings with the PPI treatment. The roots and shoots of rapidly germinating species may be developed too fully before the PRE treatments become effective.

The efficacy of CGM for control of a particular weed species in a management system depends on the amount of CGM applied. Broadleaf species were generally more susceptible to CGM than grasses, and reductions in shoot length and root development were larger at the lower CGM levels. Black nightshade, common lambsquarters, creeping bentgrass, curly dock, purslane, and redroot pigweed were the most susceptible species and exhibited ≥75% reductions in survival and rooting and >50% reductions in shoot length with PRE and PPI at 324 g CGM/m^2.

Table 4. Reductions in shoot lengths, relative to the control, of weeds treated with three quantities of soil surface-applied (PRE) and preplan/-incorporated (PPI) corn gluten meal (CGM).[z]

	% Reduction[y]					
	Quantity of CGM					
Weed	324 g•m^{-2}		649 g•m^{-2}		973 g•m^{-2}	
species	PRE	PPI	PRE	PPI	PRE	PPI
Annual bluegrass	27	39	41	29	49	51
Barnyardgrass	0	12	0	30	0	55
Black medic	51	59	73	75	92	87
slack nightshade	66	85	100	100	100	100
Buckhorn plantain	22	67	81	89	90	89
Catchweed bedstraw	11	70	46	100	81	100
Common lambsquarters	70	74	74	95	100	100
Creeping bentgrass	47	58	70	70	95	75
Curly dock	55	75	84	89	90	94
Dandelion	54	81	83	90	100	100
Giant foxtail	21	56	51	72	64	93
Green foxtail	0	62	10	94	100	100
Large crabgrass	0	4	6	49	0	87
Orchardgrass	34	34	45	44	70	88
Purslane	65	100	66	95	83	100
Quackgrass	7	50	27	72	22	94
Redroot pigweed	74	81	81	94	95	100
Shattercane	45	41	19	64	10	84
Smooth crabgrass	44	53	70	71	86	89
Velvetleaf	20	0	42	0	58	79

[z]Least significant difference ($LSD_{0.05}$) = 21 for mean comparisons between PRE and PPI application methods for each species, and $LSD_{0.05}$ = 30 for mean comparisons among CGM quantities for each species.
[y]These data include results of two studies and are the mean percentages of the shoot length reductions relative to the shoot lengths of the control plants (n = 6).

Table 5 Reductions in root development, relative to tbe control, of weeds treated with three quantities of soil surface-applied (PRE) and preplan/-incorporated (PPI) corn gluten meal (CGM).[z]

	% Reduction[y]					
	Quantity of CGM					
Weed	324 g•m^{-2}		649 g•m^{-2}		973 g•m^{-2}	
species	PRE	PPI	PRE	PPI	PRE	PPI
Annual bluegrass	50	70	55	90	95	95
Barnyardgrass	0	35	10	50	30	75
Black medic	80	95	80	95	100	100
Black nightshade	85	100	100	100	100	100
Buckhorn plantain	70	80	95	100	100	100
Catchweed bedstraw	45	80	55	100	100	100
Common lambsquarters	75	100	90	100	100	100
Creeping bentgrass	95	90	100	100	100	100
Curly dock	90	90	100	100	100	100
Dandelion	30	90	95	100	100	100
Giant foxtail	65	85	85	85	95	95
Green foxtail	35	95	85	100	100	100
Large crabgrass	0	80	0	90	45	100
Orchardgrass	50	80	85	95	95	100
Purslane	80	100	80	100	85	100
Quackgrass	25	75	60	95	75	100
Redroot pigweed	95	100	100	100	100	100
Shattercane	5	45	30	75	25	95
Smooth crabgrass	65	90	95	100	100	100
Velvetleaf	40	60	70	75	70	90
Woolly cupgrass	15	60	20	90	35	100
Yellow foxtail	20	90	20	100	60	100

[z]Least significant difference ($LSD_{0.05}$ = 12) for mean comparisons between PRE and PPI application methods for each species, and $LSD_{0.05}$ = 17 for mean comparisons among tbe CGM quantities for each species.
[y]These data include results from two studies and are the mean percentages of tbe root development reductions relative to the root development of the control plants (n = 6).

Turfgrass management systems are restricted to PRE applications of CGM. According to survival, shoot length, and rooting reductions, PRE applications of CGM may provide acceptable control of annual bluegrass, black nightshade, buckhorn plantain, Catchweed bedstraw, common lambsquarters, curly dock, dandelion, giant foxtail, orchardgrass, purslane, redroot pigweed, and smooth crabgrass. In addition, competition from the mature grasses in turfgrass areas may increase the degree of weed control.

Corn gluten meal has the potential to be used as a natural herbicide for the control of many broadleaf and grass weed species. More field trials than those of Christians (1993), however, are necessary to confirm the efficacy of CGM for specific weed species in competitive turfgrass and strawberry production systems.

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