Influence of Corn Gluten Meal on Squash Plant Survival and Yields

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Summary. **Corn gluten meal (CGM) is a non-selective preemergence or preplant-incorporated herbicide that inhibits root development, decreases shoot length, and reduces plant survival. The development of a mechanized application system for the banded placement of CGM between crop rows (seed row not treated) has increased its potential use in organic vegetable production, especially in direct-seeded vegetables. The objective of this research was to determine the impact of CGM applications (formulations, rates, incorporation, and banded applications) on direct-seeded squash (*Cucurbita pepo*) plant survival and yields. Neither CGM formulation (powdered or granulated) nor incorporation method (incorporated or non-incorporated) resulted in significant differences in plant survival or squash yields. When averaged across all other factors (formulations, incorporation method, and banding), CGM rates of 250 to 750 g·m^{-2} reduced squash survival from 70% to 44%, and squash yields from 6402 to 4472 kg·ha^{-1}. However, the banded application (CGM placed between rows) resulted in significantly greater crop safety (75% survival) and yield (6402 kg·ha^{-1}) than the broadcast (non-banded) applications (35% survival and 4119 kg·ha^{-1} yield). It was demonstrated that banded applications of CGM can be useful in direct-seeded squash production and other organic direct-seeded vegetables.**

Organic vegetable producers rank weeds as one of their most troublesome, time-consuming, and costly production problems (Organic Farming Research Foundation, 1999). Because there are only a few organically approved herbicides, optimizing their application may increase their potential usefulness for organic production systems. Interrow cultivation for the purpose of weed control is not always the ideal choice for organic vegetable production or, because of the soil and weather conditions, may not always be an available option. Additional cultivations can decrease soil organic matter (Dick, 1983; Gallaher and Ferrer, 1987; Johnson, 1986) and soil water holding capacity (Johnson, 1986), increase soil erosion (Logan et al., 1991; McDowell and McGregor, 1984) and nutrient loss (McDowell and McGregor, 1984), and stimulate new weed growth (Pekrun et al., 2003). In conventional, non-organic production systems, herbicides are increasingly used to avoid the detrimental impact of soil erosion. Preventing soil, nutrient, and organic matter losses due to tillage are a fundamental tenant of certified organic production [U.S. Department of Agriculture (USDA) National Organic Standards Board, 2010]. Corn gluten meal (CGM) is an organic herbicide (Bingaman and Christians, 1995; Christians, 1991) that is the byproduct of the wet-milling process of corn [*Zea mays* (Bingaman and Christians, 1995; Quarles, 1999)]. The protein fraction of CGM is ≈60% protein and 10% nitrogen (Quarles, 1999). CGM (Alliance Milling Co., Denton, TX), normally a yellow powder (McDade, 1999), has been used as a component in dog, fish, and livestock feed (Christians, 1991, 1995; Quarles, 1999). CGM can be purchased in the form of powder, pellets, and granulated material (McDade, 1999; Webber and Shrefler, 2007a).

Christians (1993) investigated the weed control efficacy of broadcast soil applied, non-incorporated, applications of corn starch, corn germ, corn seed fiber, corn meal, and CGM. CGM produced the greatest inhibitory effect and reduced root formation in several weed species, including creeping bentgrass (*Agrostis palustris*) and crabgrass (*Digitaria* spp.). Bingaman and Christians (1995) in greenhouse research determined that CGM applied at 324 g·m^{-2} reduced plant survival, shoot length, and root development for the 22 weed species tested, whether the CGM was applied to the soil surface as a preemergence herbicide or mixed into the top 2.54 cm as a preplant-incorporated herbicide. Although plant development was reduced for all weeds tested, the extent of susceptibility differed across species. Plant survival and root development were reduced by at least 70% and shoot length by at least 50% for the following weeds: black nightshade (*Solanum nigrum*), common lambsquarters (*Chenopendium album*), creeping bentgrass, curly dock (*Rumex crispus*), purslane (*Portulaca oleracea*), and redroot pigweed (*Amaranthus retroflexus*). When CGM was applied preplant-incorporated, survival and shoot length of the following weeds were reduced at least 50% and root

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha^{-1}	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha^{-1}	0.8922
33.9057	oz/yard^2	g·m^{-2}	0.0295
6.8948	psi	kPa	0.1450

development reduced by at least 80%: catchweed bedstraw (*Galium aparine*), dandelion (*Taraxacum officinale*), giant foxtail (*Setaria faberi*), and smooth crabgrass (*Digitaria ischaemum*). Barnyardgrass (*Echinochloa crus-galli*) and velvetleaf (*Abutilon theophrasti*) were more tolerant to CGM and plant survival reductions were less than 31%. Field studies with three planting dates (3 July 1998, 20 Aug. 1998, and 8 June 1999) demonstrated that CGM incorporated into the top 5 to 8 cm of soil at 100, 200, 300, and 400 $g \cdot m^{-2}$ reduced weed cover by 50%, 74%, 84%, and 82%, respectively, compared with an untreated control at 3 weeks after treatment (McDade and Christians, 2000).

Crop safety with CGM is a major concern because it is a non-selective organic herbicide. CGM applications for organic weed control did not adversely affect established turf (Christians, 1993). Nonnecke and Christians (1993) did report a decrease in strawberry (*Fragaria* ×*ananassa*) fruit number and weight from four applications of CGM, but it was unclear whether the yield reductions were due to the CGM phytotoxicity or excess nitrogen applications associated with CGM (10% nitrogen). Strawberry leaf area was not reduced as a result of CGM applications (Nonnecke and Christians, 1993). In onion (*Allium cepa*), CGM applications of 400 $g \cdot m^{-2}$ to spring-transplanted onions produced fair (72.1%) overall weed control and good (82.7%) broadleaf weed control through the first 46 d after planting (DAP) (Webber et al., 2007a), without reductions in yields from crop injury (Webber et al., 2007b).

The impact of CGM applications on the plant safety of direct-seeded crops has been investigated by McDade and Christians (2000) and Webber and Shrefler (2007b). McDade and Christians (2000) determined that CGM rates of 100, 200, 300, and 400 $g \cdot m^{-2}$ reduced average seedling survival for eight vegetables by 48%, 65%, 73%, and 83%, respectively. 'Daybreak' sweet corn (*Z. mays*) was the most tolerant to CGM, requiring at least 300 $g \cdot m^{-2}$ of CGM to produce a 26% reduction in stand. CGM applications of 100 $g \cdot m^{-2}$ reduced seedling survival by 35% for 'Ruby Queen' beet (*Beta vulgaris*), 41% for 'Red Baron' radish (*Raphanus sativus*), 59% for 'Maestro' pea (*Pisum sativum*), 67% for 'Comanche' onion, 68% for 'Black Seeded Simpson' lettuce (*Lactuca sativa*), 71% for 'Provider' bean (*Phaseolus vulgaris*), and 73% for 'Scarlet Nantes' carrot (*Daucus carota*) compared with the control. These findings resulted in a recommendation not to apply CGM even at the lowest application rate (100 $g \cdot m^{-2}$) to direct-seeded vegetables (McDade and Christians, 2000). Webber and Shrefler (2007b) determined that broadcast applications of CGM as low as 100 $g \cdot m^{-2}$ significantly decreased the establishment of direct-seeded 'Black Knight' black bean (*P. vulgaris*), 'Apache' pinto bean (*P. vulgaris*), 'Magnum 45' muskmelon (*Cucumis melo*), and 'Allsweet' watermelon (*Citrullus lanatus*) by 66%, 58%, 50%, and 58%, respectively. Webber and Shrefler (2007b) suggested the potential usefulness of CGM application for direct-seeded vegetables by restricting CGM to the interrow area while leaving a CGM-free application area for the direct-seeding of vegetable crops.

A mechanized applicator was developed and evaluated to apply CGM in a banded configuration (Webber and Shrefler, 2007a). The applicator was constructed using various machinery components (fertilizer box, rotating agitator blades, 12-V motor, and fan shaped, gravity-fed, row banding applicators). The equipment was evaluated for the application of two CGM formulations (powdered and granulated), three application rates (250, 500, and 750 $g \cdot m^{-2}$), and two application configurations (solid and banded). Differences between CGM formulations affected flow rate within, and between, application configurations. The granulated formulation flowed at a faster rate, without clumping, compared with the powdered formulation, while the CGM in the banded configuration flowed faster than the solid application. Webber and Shrefler (2007a) demonstrated the feasibility of using equipment, rather than manual applications, to apply CGM to raised beds for organic weed control. The development of equipment to apply CGM in banded configurations created an opportunity to investigate whether banded CGM applications would provide significant crop safety for direct-seeded vegetables. The objective of this research was to determine the impact of CGM applications (formulations, rates, incorporation, and configurations) on direct-seeded squash plant survival and yields.

Materials and methods

Field studies were conducted to evaluate the effect of formulations, rates, incorporation, and banded applications of CGM on squash survival and yields. The field studies used a factorial treatment structure and were repeated during the 2004 and 2005 growing seasons at Lane, OK. Each year before initiating the research, the Bernow fine-loamy, siliceous, thermic Glossic Paleudalf soil was plowed to incorporate the winter wheat cover crop. Fertilizer was applied according to Oklahoma State University Cooperative Extensive Service recommendations (Motes et al., 2007) and was incorporated before preparing 32-inch-wide raised beds. The randomized complete design experiment with four replications included two CGM formulations (powdered and granulated), two incorporation treatments (incorporated and non-incorporated), three application rates (250, 500, and 750 $g \cdot m^{-2}$), and two application configurations (banded and broadcast) with all treatments included as a full factorial arrangement. The two CGM formulations at three application rates were uniformly applied in banded and broadcast patterns on 18 Aug. 2004 and 19 Aug. 2005 using equipment designed and developed by the USDA and Oklahoma State University (Webber and Shrefler, 2007a). The banded application placed the CGM between rows, creating a 3-inch-wide CGM-free planting zone in the middle of the raised bed. The broadcast application uniformly placed CGM across the entire raised bed surface. The CGM applications were then incorporated into the top 1 to 2 inches of the soil surface with a rolling cultivator or were left undisturbed on the soil surface (non-incorporated). 'Lemondrop' summer squash was direct-seeded into the center of the raised beds. The 20-ft-long plots were kept weed-free throughout the growing season using hand-weeding and between-bed applications of fluazifop-P-butyl (Fusilade®; Syngenta Crop Protection, Greensboro, NC) at 0.5 $kg \cdot ha^{-1}$ a.i. applied at 20 gal/acre and 40 psi with a carbon dioxide-pressurized backpack sprayer equipped with XR8002VS nozzles (Spraying Systems, Wheaton, IL). Plots were kept weed-free to isolate the impact of the CGM formulations, rates, and application configurations on squash plant survival and yields.

Squash yields represent the combined weight of marketable squash fruit harvested during a growing season. Marketable squash fruit (less than 3 inches diameter and 8 inches long) were harvested starting 40 and 38 DAP in 2004 and 2005, respectively. The crop produced marketable fruit for 22 d in 2004 (five harvests) and 24 d in 2005 (six harvests). Squash survival percentages are based on an untreated control within each replication, which had a mean value of 18,880 plants/acre. All data were subjected to analysis of variance and mean separation using least significant difference (LSD) with $P = 0.05$ (SAS, version 9.1; SAS Institute, Cary, NC).

Results and discussion

There were no significant interactions by year and factors; therefore, the data were averaged across years and major factors. Fruit yields were consistently greater in 2005 compared with 2004 (data not shown). The yield advantage in 2005 was most likely a response to an earlier first harvest (2 d), a longer harvesting period (2 d), and an additional harvest.

When averaged across all other factors, there was no significant difference between powdered and granulated CGM formulations or incorporating CGM and leaving CGM on the soil surface (no incorporation) for squash plant survival or yields (Tables 1 and 2). These results are consistent with earlier reports with vegetables (Webber and Shrefler, 2007b), although their research did not investigate broadcast versus banded applications. Webber and Shrefler (2007b), examining CGM application rates of 100, 200, 400, and 800 $g \cdot m^{-2}$, determined that there was no difference in stand reductions between incorporating and not incorporating CGM for direct-seeded vegetables (black bean, pinto bean, muskmelon, and watermelon). If there is no advantage in using the powdered CGM, then the granulated material would be preferred because Webber and Shrefler (2007a) documented that the mechanized application of the granulated CGM was superior to the powdered material. If CGM incorporation does not provide superior weed control (Christians, 1995), and plant stands and yields are not benefited (Webber and Shrefler, 2007b), it would be more cost effective to simply surface apply the CGM without any incorporation.

CGM application rates did affect crop squash survival and yields when averaged across all other factors (Table 3). As CGM rates increased, plant survival and yields decreased. These results are consistent with McDade and Christians (2000) who, when using a broadcast application, reported reductions in seedling survival as CGM application rates increased from 100 to 400 $g \cdot m^{-2}$ for eight vegetables (sweet corn, beet, radish, pea, onion, lettuce, bean, and carrot). Webber and Shrefler (2007b) also reported a decrease in vegetable (black and pinto bean, muskmelon, and watermelon) seedling survival as CGM application rates increased. Seedling mortality percentages at 100 $g \cdot m^{-2}$, averaged across evaluation dates and incorporation methods, were 66% (black bean), 58% (pinto bean), 50% (muskmelon), and 58% (watermelon) (Webber and Shrefler, 2007b). These results were further indication of CGM phytotoxicity, and specifically, its detrimental impact on direct-seeded squash establishment and yields. The midrange rate (500 $g \cdot m^{-2}$) reduced plant establishment by half (51%) [lethal dose 50% (LD_{50}) = 500 $g \cdot m^{-2}$]. This level of stand reduction is not acceptable, but it must be remembered that these results were averaged across banded and broadcast applications.

When averaged across all other factors, the banded application resulted in significantly greater crop safety (75% plant survival) and yields (6402 $kg \cdot ha^{-1}$) than the broadcast applications (35% plant survival and 4119 $kg \cdot ha^{-1}$) (Table 4). Before this current research, it was not feasible to use CGM for preemergence weed control in direct-seed crops because broadcast applications of CGM reduced direct-seeded seedling survival of beans, muskmelon, and watermelons by 98%

Table 1. Effect of corn gluten meal formulations on plant survival and squash yield averaged across all other factors: incorporation method (incorporated and no incorporation), application rate (250, 500, and 750 $g \cdot m^{-2}$)^z, application method (banded between crop row and broadcast), and year (2004 and 2005).

Formulation	Plant survival (%)	Squash yield ($kg \cdot ha^{-1}$)^z
Powdered	53 a^y	5319 a
Granulated	57 a	5354 a

^{z}1 $g \cdot m^{-2}$ = 0.0295 oz/yard^2, 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
^{y}Means in a column not significantly different based on a least significant difference test at $P = 0.05$.

Table 2. Effect of corn gluten meal incorporation methods on plant survival and squash yield averaged across all other factors: formulation (powdered and granulated), application rate (250, 500, and 750 $g \cdot m^{-2}$)^z, application method (banded between crop row and broadcast), and year (2004 and 2005).

Incorporation method	Plant survival (%)	Squash yield ($kg \cdot ha^{-1}$)^z
No incorporation	55 a^y	5461 a
Incorporation	55 a	5061 a

^{z}1 $g \cdot m^{-2}$ = 0.0295 oz/yard^2, 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
^{y}Means in a column not significantly different based on a least significant difference test at $P = 0.05$.

Table 3. Effect of corn gluten meal application rates on plant survival and squash yield averaged across all other factors: formulation (powdered and granulated), incorporation method (incorporated and no incorporation), application method (banded between crop row and broadcast), and year (2004 and 2005).

Application rate ($g \cdot m^{-2}$)^z	Plant survival (%)	Squash yield ($kg \cdot ha^{-1}$)^z
250	70 a^y	6402 a
500	51 b	4966 b
750	44 c	4472 c

^{z}1 $g \cdot m^{-2}$ = 0.0295 oz/yard^2, 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
^{y}Means in a column not significantly different based on a least significant difference test at $P = 0.05$.

Table 4. Effect of broadcast and banded corn gluten meal applications on plant survival and squash yield averaged across all other factors: formulations (powdered and granulated), incorporation method (incorporated and no incorporation), application rate (250, 500, and 750 $g \cdot m^{-2}$)[z], and year (2004 and 2005).

Application method	Plant survival (%)	Squash yield ($kg \cdot ha^{-1}$)[z]
Banded	75 a[y]	6402 a
Broadcast	35 b	4119 b

[z]1 $g \cdot m^{-2}$ = 0.0295 oz/yard², 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
[y]Means in a column not significantly different based on a least significant difference test at $P = 0.05$.

(Webber and Shrefler, 2007b). These results demonstrate the benefits of using a CGM-free strip (banded application) to increase squash plant survival and yields for direct-seeded squash. McDade and Christians (2000) warned against using CGM for direct-seeded vegetables, but this research demonstrates that CGM applications can be safely used if applied in a strip between vegetable rows. These results also have potential implications for all direct-seeded organic vegetables, not just direct-seeded squash. McDade and Christians (2000) and Webber and Shrefler (2007b) reported phytotoxicity differences across various vegetables, therefore, future research should determine the optimum CGM application rates and CGM-free strip width for specific vegetables to maximize crop safety, yields, and weed control efficacy.

Conclusions

Before this research, it was determined that CGM was phytotoxic when used as a preplant or a preplant-incorporated organic herbicide. It was also known that as a non-selective material, CGM would not only kill and inhibit weed growth, but also would negatively impact direct-seeded crop establishment, seedling vigor, and yields. Therefore, previous researchers suggested that CGM applications be restricted to established crops (turf and transplants) rather than direct-seeded vegetable crops. This research determined that a CGM-free planting strip (CGM applied between crop rows) provided increase crop safety for direct-seeded squash compared with broadcast applications. Furthermore, these results have implications for all direct-seeded organic vegetable crops once the optimum CGM application rates and CGM-free strip width can be determined for specific vegetables to maximize crop safety, yields, and weed control efficacy.

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