Corn-based Extracts to Manage Weeds and Provide Nitrogen in Matted-row Strawberry Culture

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Abstract. The number of herbicides available for use in strawberry (*Fragaria ×ananassa* Duch.) production is limited. Corn gluten hydrolysate (CGH) is a water-soluble extract of corn gluten meal (CGM), a by-product of corn wet-milling. Both CGH and CGM have been shown to inhibit root development of seedlings and can provide nitrogen (N). Four weed control and/or N-containing products were studied: CGH, CGM, urea (46N-0P-0K), and urea applied with DCPA at 8.4 kg-ha⁻¹ a.i. Treatments were applied at N rates of 0, 9.8, 19.5, and 29.3 g-m⁻². The 0 g-m⁻² of N treatment served as the control. During the 1995 establishment season, all treatments were applied in June, July, and August. Treatments were applied in July and August during the 1996, 1997, and 1998 growing seasons. Dicot and monocot weed number and weed shoot dry weights were determined ≈30 days after both July and August treatments. Strawberry yield data were collected in June. Leaf N data were collected during the first week of July, before renovation. When CGH was applied in July, dicot weed number in August decreased in one of four years, but CGH never affected the number of monocot weeds. CGM application in July, reduced the number of dicot weeds found in plots in Aug. 1995 and 1998. Urea had no effect on dicot weed number from 1995 to 1997. However, in 1998, dicot weed number was reduced by as much as 79% as the rate of urea increased. In all study years, dicot weed number was reduced between 86% and 97%, for the high rate of DCPA + urea, compared with control plots. With few exceptions, rate of N had no effect on leaf N or yield. CGH exhibited limited potential as a natural weed control product; it reduced dicot weed number in one year, but did not affect the number of monocot weeds in any year. Strawberry yield in plots receiving CGH showed a linear increase in one year (1998), but did not show an increase in the other 2 years. Chemical name used: dimethyl tetrachloroterephthalate (DCPA)

Few herbicides are available for use in small fruit crop production and there is increased interest in alternatives to conventional herbicides. Weed populations must be kept below economic threshold levels to ensure crop success (Pritts and Kelly, 1997) and to sustain current levels of production quality. Conventional matted-row strawberry production relies on cultivation, mulching, and herbicide sprays to manage weed populations throughout the growing season (Fear et al., 1986). Alternative weed control practices must be developed that meet the challenges of controlling weeds without harming crop plants, and such practices should be environmentally benign and cost-effective. Corn gluten hydrolysate (CGH), a natural weed-control product and nitrogen (N) source, is an environmentally benign product. CGH is a water-soluble extract from corn gluten meal (CGM), a by-product of corn wet-milling. Both CGH and CGM contain several peptides that have been shown to inhibit seedling root development of

both monocotyledonous (monocot) and dicotyledonous (dicot) plants (Christians, 1991; Liu and Christians, 1994, 1996; Liu et al., 1994). CGH contains 10% to 14% N and CGM contains 10% N by weight, which allow the materials to be used both for weed control and as a fertilizer (Christians, 1993; Nonnecke and Christians, 1993). CGH can be sprayed over matted-row strawberry by using ordinary herbicide spray equipment and has the potential to be used as an integral part of weed management programs. The objectives of this study were to determine weed control efficacy of CGH and CGM in matted-row strawberry and to determine the effects on strawberry yield and plant growth.

Materials and Methods

In June 1995, field plots of 'Jewel' Junebearing strawberry plants were established at the Iowa State Univ. Horticulture Station, Ames. Dormant crowns were planted in a Nicollet loam (fine-loamy, mixed mesic Aquic Hapludoll) soil with an organic matter content of 3.3%. The plot was planted with annual ryegrass (*Lolium multiflorum* Lam.) the previous season; the annual ryegrass was tilled under before plants were established in the subsequent spring. The plot size was 3 m × 1 m. Five strawberry crowns were planted 61 cm apart into each plot and allowed to develop into a matted-row ≈0.5 m wide. Rows were

spaced 2 m apart, center to center. Straw was placed over the plots in November for overwintering. When growth resumed in the spring, the straw was repositioned to serve as mulch in and between rows. Renovation of the matted row was performed in 1996 to 1998 and included leaf removal and narrowing of the plant rows (Fear et al., 1986; Pritts and Handley, 1998). Treatments were maintained in the same plots for 4 years.

The experimental design was a factorial arrangement of 16 treatments consisting of four weed control treatments with three rates of N plus control (N at 0 g-m⁻² for each N treatment), in a randomized complete block with four replications. Treatments included CGH, CGM, dimethyl tetrachloroterephthalate (DCPA) plus urea (46N-0P-0K), and urea alone. Treatments were applied at N rates of 0, 9.8, 19.5, and 29.3 g-m⁻². Rates of product were based on equivalent amounts of N for each treatment. DCPA was applied only at the rate of 8.4 kg-ha⁻¹ a.i. Treatment plots that received N at 0 g-m⁻² also received no DCPA. The CGH and DCPA treatments were sprayed directly over the strawberry plants using a pressurized backpack sprayer equipped with a wand with two spray nozzles (T-Jet no. 8006) at 206.8 kPa. The CGH used in 1995 was a refined form that was 14% N by weight; CGH used in 1996 to 1998 was 10% N by weight. CGM and urea were incorporated into the soil to a depth of ≈2.5 cm by raking and hoeing within and around the matted-row.

During the 1995 establishment season, all treatments were applied three times: at transplanting (first week of June); during runner formation (second week of July); and in advance of flower bud formation (second week of August). During the 1996, 1997, and 1998 growing seasons, treatment applications were made at renovation (first week of July) and in advance of flower bud formation (second week of August).

Weed cover percentage and dicot and monocot weed number were determined ≈30 d after treatment applications in July and August from 1995–98. Weed shoot dry weights were determined ≈30 d after treatment applications in July and August from 1996–98. Weed cover percentage was estimated visually over the entire treatment plot and was based on the percentage of ground surface in the plot (excluding strawberry plants) covered by dicot and monocot weeds. Dicot and monocot weed numbers were determined by harvesting all weeds in three randomly placed quadrats (0.25 m²) within the plot. Weed shoots were cut from the roots, dried at 67 °C for 72 h, and weighed. After sample weed data were collected, all remaining weeds were removed from the plots before additional treatment applications.

Fruit were harvested from late May through early July during the 1996–98 growing seasons. Fruit were picked manually, counted, and weighed. Ten randomly selected leaves from each plot were collected in early July before renovation and total N of the leaf blades was determined by Kjeldahl analysis (Bremner and Mulvaney, 1982).

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Year $\times$ treatment interactions occurred, and analysis of variance was computed for individual years. Data were analyzed with the general linear model (PROC GLM) for linear and multiple regression procedures using the statistical analysis system (SAS Institute, 1988).

Results

Weed control results pertain only to data collected in August due to the low number of monocot and dicot weeds present in the treatment plots in September. Monocot weed control exhibited by CGH, CGM, or urea treatments was insignificant ($P > 0.05$) or negligible throughout the study; therefore, monocot weed data are not presented in the results.

The predominant dicot weed species was purslane (*Portulaca oleraceae* L.), which accounted for 70% to 92% of all dicot weeds by number throughout the study. Other common dicot weeds were dandelion (*Taraxacum officinale* Weber), Canada thistle [*Cirsium arvense* (L.) Scop.], and white clover (*Trifolium repens* L.).

CGH did not affect dicot weed number in 1995–97 (Table 1). Dicot weed number showed a linear decline as the rate of CGH increased in 1998, resulting in dicot weed reduction of 59% at the highest rate of CGH compared with plots that received CGH at 0 g·m⁻² (control). CGM applied in July reduced the number of dicot weeds in 1995 and 1998. Urea had no effect on dicot weed number in 1995 to 1997. In 1998 only, as the application rate of urea increased to the highest rate, dicot weed number was reduced by 79% compared with control plots. The DCPA + urea treatment showed a decrease in the number of dicot weeds every year compared with control plots.

CGH had no effect on the percentage of weed coverage per plot in 1995–97 (Table 2). Percentage weed coverage increased slightly in CGH plots in 1998 compared with control plots. CGM had no effect on percentage weed coverage in 1995 and 1997. As the rate of CGM increased, percentage weed coverage increased up to 133% and 12% compared with control plots in 1996 and 1998, respectively. Urea had no effect on percentage weed coverage in any year. DCPA + urea had no effect on percentage weed coverage in 1995 and 1997. DCPA + urea reduced percentage weed coverage by 66% in 1996 and 94% in 1998.

CGH had no effect on leaf N (Table 3). CGM had no effect on leaf N in 1996 or 1998, but in 1997 leaf N was increased 16% at the highest rate of CGM compared with control plots. The urea treatment increased leaf N only in 1996, by 32%, compared with control plots. DCPA + urea increased leaf N only in 1997, by 16%, compared with control plots.

CGH had no effect on fruit yield in 1996 or 1997 (Table 4), but as the rate of CGH increased, fruit yield increased linearly (by 173% at the highest rate), compared with control plots in 1998. At the highest rate of CGM, fruit yield decreased 45% compared with control plots in 1996. CGM had no effect on fruit yield in 1997 and 1998. The urea treatment and

DCPA + urea treatment had no effect on fruit yield in any year.

Discussion

CGH and CGM showed dicot weed control efficacy in 1998, a year with the highest weed density (based on the number of dicot weeds in

control plots). The number of dicot weeds per 0.25 m² showed a decreasing linear effect as the rate of CGH increased in 1998. The number of dicot weeds per 0.25 m² showed a quadratic effect as the rate of CGM increased in 1998. CGH and CGM were more effective at N rates of 19.5 and 29.3 g·m⁻², resulting in a lower number of dicot weeds at those rates.

Table 1. Effects of three weed control products (CGH, CGM, or DCPA) and four rates of N from three sources (CGH, CGM, or urea) on number of dicot weeds in 'Jewel' matted-row strawberry, Aug. 1995–98.^z

Source of N ^y	Number of dicot weeds · 0.25 m ⁻²				Linear coefficient Pr > T	Quadratic coefficient Pr > T	<i>r</i> ^{2x}	<i>R</i> ^{2x}
	N rate (g·m ⁻²)							
	0	9.8	19.5	29.3				
1995								
CGH	12	14	7	8	NS	NS	0.06	0.06
CGM	5	7	2	2	**	NS	0.38	0.41
Urea	8	6	6	7	NS	NS	0.01	0.12
DCPA + urea	7	1	0	1	***	**	0.43	0.75
1996								
CGH	12	15	13	5	NS	NS	0.11	0.26
CGM	10	14	9	8	NS	NS	0.04	0.11
Urea	8	13	10	13	NS	NS	0.12	0.16
DCPA + urea	9	1	1	1	***	**	0.52	0.78
1997								
CGH	46	64	66	43	NS	NS	0.00	0.24
CGM	33	40	34	34	NS	NS	0.00	0.02
Urea	44	71	38	37	NS	NS	0.04	0.10
DCPA + urea	33	4	4	1	***	***	0.61	0.83
1998								
CGH	71	65	46	29	**	NS	0.49	0.50
CGM	47	29	32	23	**	NS	0.47	0.51
Urea	75	45	30	16	***	NS	0.65	0.68
DCPA + urea	76	18	12	6	***	*	0.52	0.67

^zMeans of four replications and three 0.25-m² quadrats per replication.

^yCGH = corn gluten hydrolysate, CGM = corn gluten meal, DCPA = dimethyl tetrachloroterephthalate. DCPA applied at 8.4 kg·ha⁻¹ a.i. DCPA was not applied to the 0 g·m⁻² treatment.

^x*r*² = square of the correlation coefficient; *R*² = square of the multiple correlation coefficient.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Table 2. Effects of three weed control products (CGH, CGM, or DCPA) and four rates of N from three sources (CGH, CGM, or urea) on percentage weed coverage in 'Jewel' matted-row strawberry, Aug. 1995–98.^z

Source of N ^y	Weed cover·m ⁻² (%)				Linear coefficient	Quadratic coefficient	<i>r</i> ^{2 x}	<i>R</i> ^{2 x}
	0	9.8	19.5	29.3				
1995								
CGH	12.0	7.4	14.5	10.6	NS	NS	0.00	0.00
CGM	14.0	9.9	9.4	12.7	NS	NS	0.01	0.10
Urea	11.6	11.8	9.3	13.9	NS	NS	0.01	0.03
DCPA + urea	9.8	6.3	6.9	9.1	NS	NS	0.00	0.03
1996								
CGH	1.8	6.1	6.2	6.5	NS	NS	0.20	0.28
CGM	3.0	4.2	3.9	7.0	*	NS	0.34	0.39
Urea	2.9	3.9	3.9	3.8	NS	NS	0.05	0.09
DCPA + urea	3.8	1.8	0.9	1.3	*	NS	0.35	0.49
1997								
CGH	3.4	9.5	8.8	7.3	NS	NS	0.08	0.27
CGM	4.8	4.7	7.2	11.0	NS	NS	0.22	0.26
Urea	2.6	5.7	9.1	7.3	NS	NS	0.21	0.29
DCPA + urea	4.3	0.8	2.7	0.8	NS	NS	0.13	0.16
1998								
CGH	30.5	32.3	32.4	31.4	NS	*	0.08	0.43
CGM	27.8	31.9	31.8	31.0	NS	*	0.17	0.41
Urea	28.8	31.7	29.9	28.3	NS	NS	0.01	0.10
DCPA + urea	30.9	2.3	3.2	1.7	***	***	0.61	0.91

^zMeans of four replications.

^yCGH = corn gluten hydrolysate, CGM = corn gluten meal, DCPA = dimethyl tetrachloroterephthalate. DCPA applied at 8.4 kg·ha⁻¹ a.i. DCPA was not applied to the 0 g·m⁻² treatment.

^x*r*² = square of the correlation coefficient; *R*² = square of the multiple correlation coefficient.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

The surviving weeds tended to be larger due to the N present in CGH and CGM, thereby increasing percentage weed coverage, compared with control plots. The improved weed control by CGH and CGM at N rates of 19.5 and 29.3 g·m⁻² is consistent with previous research on strawberry and turfgrass with CGM and on bioassays with CGH on weed seeds (Bingaman and Christians, 1995; Liu and Christians, 1997; Liu et al., 1994).

At a low rate the herbicidal activity of CGH and CGM may not be effective, at least in bare-ground field conditions of a matted-row strawberry planting. Possibly, the surviving weed seedlings may use the N present in CGH and CGM to enhance growth. Optimal conditions for weed seed germination and development may continue until CGH and CGM reach a threshold level at which their herbicidal activ-

ity inhibits weed seedling development.

The presence of N near germinating seedlings may induce damage from N toxicity (Tisdale et al., 1999). It is also possible that the critical point at which weed survival begins to decline is due to the increased N level. Dicot weed number was reduced as the N rate of urea increased in 1998, and may reflect a biological response to N. Dicot dry weight increased at the two lowest CGH rates and then declined at the highest rate in 1997 (data not presented). This raises the question of whether dicot weed number reduction is obtained through the herbicidal activity of CGH at higher rates, N toxicity, or a combination of these factors.

Because CGH is a water-soluble product, moderate to heavy rainfall may cause it to leach out of the zone of weed establishment and lose its weed-control activity. Conceiv-

ably, weed suppression may be reduced when extended rainfall events follow application of CGH. Rainfall in the July to September period, however, was below normal or was close to normal for most of the years of the study (data not presented). The rate of microbial breakdown may play an important role reducing the persistence of CGH in the soil as well.

Fruit yield increased as CGH treatment rate increased in 1998 only. CGM reduced fruit yield as N rate increased in 1996, but CGM had no effect in other years. Urea or DCPA + urea treatments had no effect on yield in any year. Variable results such as these can be expected due to soil and fertility differences (Archbold and MacKown, 1988). Yearly climatic changes also may play a role in such differences. In cases where soil N is adequate to support plant growth without the addition of fertilizer, the application of fertilizer had no effect on yield (Blatt, 1981). Organic matter was 3.3% in the plots before the experiment began and was 3.1% when completed. Leaf N sufficiency levels for strawberry range between 2.0% and 2.8% N for plants sampled in midsummer after renovation (Pritts and Handley, 1998). We collected leaf samples before renovation and, as expected, our leaf N values were lower, ranging from a high of 2.08% in 1997 to a low of 1.09% in 1998. Leaf N levels are typically lower at the end of the fruiting season and before the addition of N at renovation.

Our results indicate that the preemergence weed control efficacy of the corn-based extracts, CGH and CGM, is limited and is not as effective as the conventional herbicide application of DCPA for use in matted-row strawberry production in Iowa. The results, however, demonstrated that some dicot weed control could be achieved by using CGH or CGM. These products may be of use in combination with other cultivation techniques in production systems where synthetic herbicides are not used. Further research should seek to improve the residual period of CGH and CGM in the soil and to understand the fate of N that they provide.

Table 3. Effects of three weed control products (CGH, CGM, or DCPA) and four rates of N from three sources (CGH, CGM, or urea) on leaf nitrogen from 'Jewel' matted-row strawberry, Aug. 1996–98.^z

Source of N ^w	N (%) ^y				Linear coefficient ^x Pr > T	Quadratic coefficient ^x Pr > T	<i>r</i> ^{2v}	<i>R</i> ^{2z}
	0	N rate (g·m ⁻²)						

^zMeans of four replications.

^yLeaf nitrogen measured as total Kjeldahl nitrogen (TKN), % N of dry weight.

^wCGH = corn gluten hydrolysate, CGM = corn gluten meal, DCPA = dimethyl tetrachloroterephthalate. DCPA applied at 8.4 kg·ha⁻¹ a.i. DCPA was not applied to the 0 g·m⁻² treatment.

^vr² = square of the correlation coefficient; R² = square of the multiple correlation coefficient.

NS, *, **, ***Nonsignificant or significant at P ≤ 0.05, 0.01, 0.001, respectively.

Table 4. Effects of three weed control products (CGH, CGM, or DCPA) and four rates of N from three sources (CGH, CGM, or urea) on strawberry fruit yield in 'Jewel' matted-row strawberry, 1996–98.^z

Source of N ^x	Fruit yield·m ⁻² (g)				Linear coefficient ^y	Quadratic coefficient ^y	r ^{2w}	R ^{2o}
	N rate (g·m ⁻²)							
	0	9.8	19.5	29.3	Pr > T	Pr > T		
1996								
CGH	296.2	261.6	223.6	315.9	NS	NS	0.00	0.23
CGM	339.8	358.1	312.7	185.2	*	NS	0.30	0.42
Urea	220.2	304.9	313.9	265.8	NS	NS	0.03	0.13
DCPA + urea	266.7	333.8	357.6	185.8	NS	NS	0.04	0.30
1997								
CGH	130.3	227.0	157.7	223.2	NS	NS	0.06	0.06
CGM	242.0	154.4	124.8	160.1	NS	NS	0.08	0.16
Urea	120.6	164.2	175.0	181.0	NS	NS	0.05	0.06
DCPA + urea	192.4	250.6	202.6	223.2	NS	NS	0.01	0.04
1998								
CGH	321.4	405.6	358.6	878.0	*	NS	0.26	0.35
CGM	577.2	562.9	713.6	970.7	NS	NS	0.18	0.23
Urea	241.2	437.1	620.7	518.3	NS	NS	0.13	0.20
DCPA + urea	529.4	755.4	735.8	481.2	NS	NS	0.00	0.10

^zMeans of four replications.

^sCGH = corn gluten hydrolysate, CGM = corn gluten meal, DCPA = dimethyl tetrachloroterephthalate. DCPA applied at 8.4 kg·ha⁻¹ a.i. DCPA was not applied to the 0 g·m⁻² treatment.

^wr² = square of the correlation coefficient; R² = square of the multiple correlation coefficient.

NS, *, **, ***Nonsignificant or significant at P ≤ 0.05, 0.01, 0.001, respectively.

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