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Applying butylate- and EPTC-impregnated fertilizer to a cover crop for weed control in no-till corn, *Zea mays*, L.

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Herbicides used for weed control in no-till corn are generally restricted to materials that are applied pre-emergence and postemergence. This study was conducted to determine the effectiveness of preplant-incorporated herbicides when impregnated on dry fertilizer and surface-applied to a winter cover crop at corn planting. Butylate plus atrazine or EPTC plus atrazine impregated on dry fertilizer and surface-broadcast reduced weeds and produced greater grain and silage yields than did untreated areas. Butylate or EPTC applied alone were not as effective as combinations with atrazine but did increase yield and weed control over untreated areas. When impregnated on dry fertilizer and placed in a standing small-grain cover crop, preplant-incorporated herbicides such as EPTC and butylate, when applied in combination with atrazine, reduced weed populations to levels similar to those with surface-applied herbicide combinations such as metolachlor plus atrazine or alachlor plus atrazine.

Keywords: no-till corn; preplant-incorporated herbicides; small-grain cover crop

No-till corn production is increasing throughout the grain- and silage-producing areas of the United States. Many soils are suitable for this management system, but an increase in hard-to-control weed species such as johnsongrass [*Sorghum halepense* (L.) Pers. *SORHA] and shattercane [*Sorghum bicolor* (L.) Moench *SORVU] may occur (Burnside, 1981). Continuous corn production with no-till promotes the development of weed species uncontrolled by surface-applied herbicides (Williams and Wicks, 1978; Witt, 1984; Kells and Meggitt, 1985; Triplett, 1985). Witt (1984) reviewed weed response to changes in tillage and cites Sarpe (1974) as having difficulty in controlling perennial weeds like johnsongrass in no-till systems. Butylate and EPTC, both carbamothioate herbicides, are somewhat volatile, and are generally incorporated into the soil (Hayden and Burnside, 1987). However, these compounds have been used in reduced-tillage corn (Hartwig and Hoffman, 1982; Hart and Ritter, 1986; Buhler, 1987; Hayden and Burnside, 1987) and alfalfa (*Medicago sativa* L.) (Dawson, 1980), producing adequate weed control and optimum crop yields.

Another way to utilize the carbamothioate herbicides would be to impregnate these materials on dry fertilizer and surface-apply this mixture into a small-grain cover crop. The cover crop may reduce wind adequately at the soil surface to prevent volatilization of the herbicides (Danielson, Gentner and Jansens, 1961; Danielson and Gentner, 1964; Ogg, 1987). Desiccation and eventual collapse of the cover crop may further reduce herbicide volatility and provide weed control for the subsequent crop.

Cool soil temperatures are characteristic of conservation-tilled soils and should reduce vapour losses of EPTC compared with the higher soil temperatures of conventional tillage (Danielson *et al.*, 1961; Gray and Weierich, 1965). Conversely, greater moisture in soil with a mulch compared with a conventionally tilled soil may promote thiocarbamate volatility (Gray and Weierich, 1965) and microbial degradation (Obrigawitch *et al.*, 1982; Moshier, 1987; Wilson and Rodebush, 1987).

The objective of this study was to determine corn yield and weed control efficiency of EPTC and butylate impregated on dry fertilizer and surface-applied in no-till corn planted in a small-grain cover crop.

Materials and methods

Experimental sites

Experiments were established at the Mountain Horticultural Crops Research Station, Fletcher, North Carolina. Experimental sites were previously in conventional tillage and did not have a previous history of butylate or EPTC application. The soil series were a Delanco loam (fine-loamy, mixed, mesic Aquic Hapludults) for 1985 and 1986 and a Kinkora loam (clayey, mixed, mesic Typic Ochraquults) for 1987. All sites had high soil potassium, low to medium-low phosphorus (Mehlich III extractant) and soil pH >6.0 (Mehlich, 1984).

Each year a small-grain cover crop was seeded at 75–100 kg ha^{-1} in October after the summer row crop had

*Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, *Weeds Sci.* **32**, Suppl. 2. Available from WSSA, 309 W. Clark St, Champaign, IL 61820, USA been harvested and the soil disced. Barley (*Hordeum vulgare* L.) was used as the cover crop in 1985 and 1986 but was switched to rye (*Secale cereale* L.) in 1987 because of the loss of the barley cover crop location to flooding. Cover crop biomass samples taken at corn planting resulted in 7930, 5600 and 8000 kg ha^{-1} dry matter for 1985, 1986 and 1987, respectively.

Herbicide preparation

Diammonium phosphate (18–46–0) was selected as the herbicide carrier using 1180 kg ha^{-1} in 1985 and 1986, and 780 kg ha^{-1} in 1987. An additional 78 kg N ha^{-1} as ammonium nitrate (34–0–0) was applied in 1987 by surface banding 38 days after planting.

The fertilizer was surface-impregnated with the herbicides by placing the fertilizer (weight required for each plot) in a mechanically driven cement mixer. Undiluted formulations of commercial herbicides were sprayed onto the revolving fertilizer granules using a hand-pumped spray bottle. The materials were mixed for 10 s after herbicide application. Emulsifiable concentrate formulations of butylate and EPTC and a liquid flowable formulation of atrazine were all impregnated by this method. All impregnated fertilizer was placed in plastic bags, tightly sealed, and hand-spread in the field within 3 h of preparation. Butylate and EPTC were applied at 4.5 and 6.7 kg a.i. ha^{-1} (all years) and atrazine at 2.2, 2.2 and 1.7 kg ha^{-1} (for 1985, 1986 and 1987, respectively). Treatments included butylate or EPTC combined with atrazine. Metolachlor and alachlor (both at 2.2 kg ha^{-1} for all years) were not impregnated on the fertilizer, but were applied by backpack sprayer on the same day or the day after the fertilizer-impregnated atrazine was applied. Herbicide treatments were increased each year to expand combinations.

The experiment was established as a randomized complete block design with four replications. Plots consisted of four rows of corn spaced 0.9 m apart and 9.1 m in length. Corn (DeKalb-Pfizer 789, Northrup King PX79, and Dekalb 665 in 1985, 1986 and 1987, respectively) was planted with a no-till planter 5, 1 or 3 days (1985, 1986 and 1987, respectively) after applying the impregnated fertilizer or check treatments. Paraquat was applied at 0.56 kg ha^{-1} to kill the cover crop before corn emergence. Corn population, grain and silage yield in each plot were determined by plant counts and/or harvests in the centre 7.6 m of the two middle rows. Corn vigour ratings were calculated by a visual estimate of plant colour and leaf quality by four independent observers. Rainfall data (*Table 1*) were collected near the field locations.

Table 1. Rainfall before and after impregnated fertilizer application[a]

Rainfall period	Rainfall (cm) 1985	1986	1987
Rainfall in May			
−5 days before application	0	0	0
−4	0	0	0
−3	0	0.2	0.7
−2	0.4	0	0.2
−1	0.7	0.7	0.2
0 herbicides applied	0.4	0.4	0
1	0.3	→ 0.2	0
2	0.3	0	0
3	1.6	0.5	→ 0
4	0.1	0.6	0
5	→ 0	0	0
6	0	1.5	0
7	0.5	4.5	0
8	0.1	1.1	0
9	0	0.6	0.3
10 days after application	0	0	0.8
Total rainfall			
April	8.1	1.5	8.1
May	5.1	12.7	6.4
June	4.1	3.3	33.8
July	16.0	1.8	6.9
August	24.1	16.8	7.9
September	4.8	9.1	18.3

[a]Arrow indicates the date corn was planted (15 May 1985, 21 May 1986 and 8 May 1987)

Results and discussion

1985 cropping season

Low soil moisture conditions before herbicide application and corn planting occurred in 1985. Herbicide plus fertilizer applications were delayed until after 2 days of light rainfall (*Table 1*). Continuous rain for 4 days after application helped move the impregnated fertilizer into the soil. Corn was planted and the cover crop killed 5 days after pre-emergence herbicide applications. Dry weather prevailed throughout May and early June (*Table 1*). Irrigation (2.0 cm) was required by 21 June to alleviate drought stress. Rainfall in July and August was adequate for good crop growth.

Corn plant counts made on 20 June were lower than the seeding rate (60 000 plants ha^{-1}) (*Table 2*). Low plant populations were attributed to the dry spring weather and were not due to the herbicide treatments. A vigour rating taken on 25 June showed no differences due to herbicide treatments.

Herbicide treatments increased grain and silage yields over the weedy check (*Table 2*). Lowest yield was in the untreated check treatment. This treatment lacked weed control and was highest in weed density. The 4.5 and 6.7 kg ha^{-1} rates of butylate plus atrazine controlled annual grasses and broad-leaved weeds equally and provided grain and silage yields similar to those with metolachlor plus atrazine.

1986 cropping season

Weather conditions at planting for the 1986 season were similar to the 1985 spring season (*Table 1*). Low spring rainfall and high transpiration by the barley cover crop in April and early May resulted in high soil moisture loss. Rainfall on the day of herbicide and fertilizer applications (19 May) may have caused infiltration of these materials into the ground. Continuous light rain through 29 May kept the cover crop foliage and soil surface moist. Light rain in early June provided good early seedling emergence, but continued dry weather in late June and July produced undesirable soil moisture conditions, resulting in low crop yields and limited weed growth early in the growing season in all plots.

Corn plant counts made on 26 June did not differ among herbicide treatments (not shown) and ranged from 55 000 to 60 000 plants ha^{-1}. A vigour rating taken on 24 July showed lower vigour in corn plants in plots that received no atrazine and the low butylate (4.5 kg ha^{-1}) plus atrazine treatment (*Table 3*). This rating may have reflected the effect of weed pressure on corn vigour, as the rating was taken late in the season when low rainfall (*Table 1*) had occurred and the weed population was high.

The various herbicide treatments affected grain and silage yields positively (*Table 3*). As in 1985, the lowest yield was recorded in the weedy check. All herbicide treatments resulted in grain and silage yields greater than the weedy check. No significant differences among treatments with herbicides were seen for silage yields, but contrasts of grain yield means for the butylate-only treatments (4.5 and 6.7 kg ha^{-1} rate) were lower than for butylate (both 4.5 and 6.7 kg ha^{-1} rate) with atrazine (*Table 3*).

1987 cropping season

Weather conditions for the 1987 season produced ideal soil moisture for planting corn. The herbicide-impregnated fertilizer was applied to a dry surface soil and cover crop, with no rain following application for 9 days (*Table 1*). Rainfall for June was heavy, with more than 33 cm of rain falling throughout the month. Rainfall for July and August was slightly below normal, resulting in normal corn yields for this region.

Corn plant counts for 1987 varied and no statistical differences were measured among treatment means (*Table 4*). Soil moisture conditions were ideal, but a heavy rye cover affected seed planting depth and reduced corn stands from 54 000 ha^{-1} to 42 000–47 000 ha^{-1}. Plant vigour ratings taken on 15 June and late-season grain yields did not differ among the herbicide treatments. As in 1985 and 1986, grain yields recorded in the weedy check were numerically lower than in any herbicide treatment.

Table 2. Effect of surface-applied fertilizer impregnated with various herbicides on no-till corn plant vigour and population, weed density, and grain and silage yields, 1985

Treatment			Corn		Corn yield		Weed density[b] (plants per 2 m^2)[c]						
No.	Herbicide	Rate (kg ha^{-1})	Vigour[a] (%)	Population (plants ha^{-1})	Grain (kg ha^{-1})	Silage (kg ha^{-1})	#ECHCG	Total annual grasses	#GASCI	#POROL	#DESPI	#TAROF	Total broad-leaved weeds
1	Weedy check		49	44 100	7800	19 800	3.9	5.5	2.8	10.9	1.3	0.5	20.6
2	Butylate	4.5											
3	Butylate	6.7											
4	Atrazine	2.2											
5	Butylate + atrazine	4.5 + 2.2	69	45 000	9000	24 200	0.0	1.2	0.0	0.0	0.0	0.0	0.3
6	Butylate + atrazine	6.7 + 2.2	61	41 600	9100	23 800	0.0	0.6	0.0	0.0	0.0	0.0	1.4
7	Metolachlor + atrazine	2.2 + 2.2	70	48 400	8600	22 200	0.9	1.3	0.0	0.0	0.0	0.0	2.0
8	Alachlor + atrazine	2.2 + 2.2											
l.s.d	(0.10)		NS[d]	NS	800	2 800	2.8	3.1	2.0	6.0	1.1	0.4	7.9

[a]Vigour rating taken 41 days after planting (0 = poor, 100 = excellent); [b]#ECHCG = barnyardgrass (*Echinochloa crus-galli*); #GASCI = hairy galinsoga (*Galinsoga ciliata*); #POROL = common purslane (*Portulaca oleracea*); #DESPI = pinnate tansymustard (*Descurainia pinnata*); #TAROF = dandelion (*Taraxacum officinale*); [c]weed density measured 22 August; [d]NS, not significant

Table 3. Effect of surface-applied fertilizer impregnated with various herbicides on no-till corn plant vigour, weed density, and biomass and grain and silage yields, 1986

Treatment				Corn yield		Weed density[b] (plants per 2 m^2)[c]						
No.	Herbicide	Rate (kg ha^{-1})	Corn vigour[a] (%)	Grain (kg ha^{-1})	Silage (kg ha^{-1})	#ELEIN	#DIGSA	Total annual grasses	#PHBPU + #IPOHE	Total broad-leaved weeds	Total weeds	Weed biomass[c] (g m^{-2})
1	Weedy check		38	4500	8 500	35	37	78	2	4	82	161
2	Butylate	4.5	48	5300	9 900	2	17	27	7	7	34	120
3	Butylate	6.7	50	5400	10 100	1	10	19	10	11	30	48
4	Atrazine	2.2	61	5800	10 700	0	4	28	8	15	43	17
5	Butylate + atrazine	4.5 + 2.2	47	5900	10 700	1	12	33	12	14	47	25
6	Butylate + atrazine	6.7 + 2.2	71	5900	10 400	0	4	10	9	14	24	10
7	Metolachlor + atrazine	2.2 + 2.2	59	5800	10 600	0	0	9	10	15	24	17
8	Alachlor + atrazine	2.2 + 2.2	60	6000	10 300	0	4	19	4	5	24	5
l.s.d (0.10)			13	800	1 400	21	NS	24	NS	NS	24	53
Contrast of herbicide treatment means[d]												
Control (1) vs all others (2, 3, 4, 5, 6, 7, 8)				**	**							
2, 3 vs 5, 6				†	NS							
4 vs 5, 6, 7, 8				NS	NS							
5, 6 vs 7, 8				NS	NS							

[a]Vigour rating taken 64 days after planting (0 = poor, 100 = excellent); [b]#ELEIN = goosegrass (*Eleusine indica*); #DIGSA = large crabgrass (*Digitaria sanguinalis*); #PHBPU = tall morningglory (*Ipomoea purpurea*); #IPOHE = ivyleaf morningglory (*Ipomoea hederacea*); [c]weed population and biomass taken 45 days before harvest; [d]NS, not significant; **significant at $p = 0.01$; †significant at $p = 0.10$

Table 4. Effect of surface-applied fertilizer impregnated with various herbicides on no-till corn plant vigour, population, grain yield, and between-row weed density, 1987

Treatment			Corn			Weed population (plants per $2m^2$)					
						30 days after planting			30 days before corn harvest		
No.	Herbicide	Rate (kg ha^{-1})	Vigour[a] (%)	Population (plants ha^{-1})	Grain yield (kg ha^{-1})[b]	Misc. broad-leaved weeds	Misc. annual grasses	Total weeds	#SORVU[c]	Misc. broad-leaved weeds[d]	Total weeds
1	Weedy check		55	41 900	7600	7.0	30	37	8	8.0	15.8
2	EPTC	4.5	46	43 000	7900	4.5	14	19	0	1.8	1.8
3	EPTC	6.7	48	42 600	8000	5.5	13	18	3	6.8	10.0
4	EPTC + atrazine	4.5 + 1.7	46	44 200	8100	1.0	5	6	3	1.8	4.5
5	EPTC + atrazine	6.7 + 1.7	46	43 000	8600	1.5	3	5	0	0	0
6	Atrazine	1.7	57	41 000	7900	0.5	5	5	14	0.3	13.8
7	Butylate + atrazine	4.5 + 1.7	53	44 000	8800	0.5	5	6	1	1.5	2.8
8	Butylate + atrazine	6.7 + 1.7	53	47 100	9600	0.5	1	2	1	0.3	0.8
9	Metolachlor + atrazine	2.2 + 1.7	49	41 500	8400	0	3	3	4	0.5	4.0
10	Alachlor + atrazine	2.2 + 1.7	49	43 000	8100	1.0	3	3	4	0.8	4.8
l.s.d.	(0.10)		NS	NS	NS	4.1	NS	NS	NS	4.7	8.8

[a]Vigour rating taken 38 days after planting (0 = poor, 100% = excellent). [b]Herbicide treatment grain yield means did not differ significantly (p = 0.10) for the following contrasts: 1 vs all others; 2, 3 vs 4, 5; 6 vs 4, 5, 7, 8, 9, 10; 4, 5, 7, 8 vs 9, 10; [c] #SORVU = shattercane (*Sorghum bicolor*); [d]includes horsenettle (*Solanum carolinense* L., #SOLCA), tall morningglory (#PHBPU), common cocklebur (*Xanthium strumarium* L., #XANST), redroot pigweed (*Amaranthus retroflexus* L., #AMARE), common pokeweed (*Phytolacca americana*, #PHTAM) dandelion (#TAROF), pinnate tansymustard (#DESPI), prickly lettuce (*Lactuca serriola* L., #LACSE), *Paulownia tomentosa*, and Philadelpha fleabane (*Erigeron philadelphicus* L., #ERIPH) (no individual species was significant among treatment means)

Weed populations

Weed counts made in 1985 showed the greatest level in the weedy check (*Table 2*). Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. #ECHCG] was most numerous in the weedy check. The herbicide treatments also reduced other annual grassy weeds in number to levels below the weedy check. Broad-leaved weed species were also greatest in the weedy check treatment. Common purslane (*Portulaca oleracea* L. #POROL), pinnate tansymustard (*Descurainia pinnata* (Walt.) Britt. #DESPI], hairy galinsoga [*Galinsoga ciliata* (Raf.) Blake #GASCI] and dandelion (*Taraxacum officinale* Weber in Wiggers #TAROF) were all controlled by herbicide treatments.

The field site for 1986 contained high annual grass populations (*Table 3*). Fewer broad-leaved weeds were counted in the weedy check than in the herbicide treatments, possibly because the annual grasses competed more efficiently than broad-leaved weeds for soil water. Fewer annual grassy weeds in the herbicide treatments reduced competition and increased populations of broad-leaved weeds. Goosegrass [*Eleusine indica* (L.) Gaertn. #ELEIN] and large crabgrass [*Digitaria sanguinalis* (L.) Scop. #DIGSA] dominated the weedy check. All the herbicide treatments controlled goosegrass but lowered large crabgrass numbers.

Fall panicum (*Panicum dichotomiflorum* Michx. #PANDI) and barnyardgrass populations were low and varied in number for all treatments in 1986. They were included in the total annual grass population counts. A large selection of broad-leaved weeds {common purslane, dandelion, common chickweed [*Stellaria media* (L.) Vill. #STEME], yellow rocket (*Barbarea vulgaris* R. Br. #BARVU), common pokeweed (*Phytolacca americana* L. #PHTAM), common vetch (*Vicia sativa* L. #VICSA), and broad-leaved dock (*Rumex obtusifolius* L. #RUMOB)} were found throughout the test site, with tall morningglory [*Ipomoea purpurea* (L.) Roth #PHBPU] and ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq. #IPOHE] the dominant broad-leaved weeds.

Weed biomass was measured late in the growing season in 1986 and reflects herbicidal control of weeds. The weedy check and the 4.5 kg ha^{-1} butylate treatment were greater in weed biomass than the other herbicide treatments, suggesting the addition of atrazine with butylate to control the varied weed population.

The site selected for the 1987 corn growing season had a history of shattercane. This location had been cropped to corn for over 15 years, with shattercane developing within the last 5 years. Weed counts 30 days after corn planting showed high populations of broad-leaved weeds and annual grasses in the weedy check (*Table 4*). Greater numbers of broad-leaves and grasses also were counted in the two herbicide treatments without atrazine than those with atrazine, indicating the effectiveness of atrazine in weed control.

High variability within the treatments prevented statistical differences in total and miscellaneous annual grass weed counts among the treatments. Weed densities recorded in early September (30 days before corn harvest) reflect the good control herbicide treatments provided during the summer. Shattercane counts in the weedy check and atrazine-only treatments reflect the lack of control by atrazine on shattercane germination and the high variability in weed numbers.

Broad-leaved weed species were too few to separate by species, so a total miscellaneous broad-leaf count was analysed This analysis showed the greatest number of broad-leaved weeds in the weedy check, with all atrazine herbicide treatments providing lower counts than the untreated weedy check. Overall weed control ratings (total weeds) for treatments with either EPTC plus atrazine or butylate plus atrazine were statistically lower than the weedy check treatment, indicating that the combination of both materials was necessary for adequate weed control.

These experiments show that, when impregnated on dry fertilizer and placed in the standing small-grain cover crop, preplant-incorporated herbicides (EPTC or butylate) plus atrazine can reduce weed populations to levels similar to those with surface-applied labelled materials (metolachlor plus atrazine or alachlor plus atrazine). Butylate or EPTC alone was not as effective as these materials combined with atrazine but did increase yield and weed control over the weedy check.

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