Weed Science. 1987. Volume 35:407–411

5837

Efficacy of Controlled-Release Formulation of Trifluralin in No-Till Soybeans (*Glycine max*)[1]

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Abstract. A series of experiments were conducted from 1983 through 1986 to determine the efficacy of encapsulated starch formulations of trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine] in conventional and no-till soybean [*Glycine max* (L.) Merr.] production. The encapsulated starch formulations remaining on the soil surface were significantly more effective than the emulsifiable concentrate when applied in February, March, or April. Encapsulated trifluralin products prepared by both the starch xanthate and starch borate processes were as effective as the emulsifiable concentrate even when used in conventional-tillage systems for weed control and for maintaining soybean yields. Our data indicate that an effective and economical herbicide such as trifluralin need not be lost in no-till soybean production if new controlled-release formulation technology is used by the agricultural industry.

Additional index words. Starch xanthates, starch borates, delayed incorporation, weed control, *Setaria faberi*, SETFA.

INTRODUCTION

Weed control is one of the essential elements of reduced-tillage systems (4). Reduced-tillage, and particularly no-till, systems must rely heavily on herbicides for weed control. These herbicides must control all initial vegetation and suppress growth of annual and perennial weed seedlings, but not injure the immediate crop nor leave significant residues to injure subsequent crops (10). These requirements present some unique problems in reduced tillage. A recent review concluded that herbicide activity is generally reduced in reduced tillage because of high levels of organic matter near or on the soil surface which increase herbicide adsorption (11). Likewise, some of the chemical changes typical of these systems, such as lowered soil pH, have reduced herbicide effectiveness. Also major changes in microbial populations due to reduced tillage can increase the rate of breakdown of herbicides such as alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide] and trifluralin (3). For these reasons, some weed scientists have suggested that higher rates of herbicides may be needed for reduced tillage and particularly for no-till (13).

Increased herbicide use becomes less acceptable when costs and environmental impact are considered. Development and adaptations of new technologies appear to be better alternatives. One such technology may be that of controlled-release formulations.

Formulation of herbicides as granules, where the herbicide is entrapped within a starch matrix, has made considerable progress over the last decade (6, 7, 8, 9). Encapsulated starch formulations of volatile thiocarbamates can reduce vapor losses sufficiently to permit delayed soil incorporation (5). Earlier work with encapsulated trifluralin has shown these formulations to have excellent residual activity but lacked immediate activity needed for early-season contol (1, 2). More recently, ways to overcome the lack of initial activity of encapsulated trifluralin were suggested, with delayed incorporation being the most effective (12). The question of how long a delay was needed before incorporation or indeed whether incorporation was essential, was in doubt.

The objective of this study was to determine the efficacy of trifluralin formulated as encapsulated starch granules for use under no-till soybean production. Trifluralin was selected because it is widely used in numerous crops, is normally incorporated under conventional tillage, and previous studies have suggested its potential for surface application.

MATERIALS AND METHODS

Field studies, general. A series of studies were conducted from 1983 through 1986 on a Chalmers silty clay loam soil (fine-loamy, mixed, mesic Typic Argiaquolls) at the Purdue Agronomy Farm. The encapsulated starch trifluralin formulations used were prepared by previously published methods: encapsulated starch xanthates (6, 8) and the encapsulated starch borate (9). In addition, another procedure, called autoencapsulation, was used to encapsulate trifluralin. The autoencapsulated trifluralin was prepared in the following manner: Technical trifluralin was melted onto unmodified corn starch. The product was mixed with KOH and ice in a bladed mixer rotating at 230 rpm for 5 min. The product was removed from the mixer, dried at room temperature, and sieved to pass 20-mesh but not 40-mesh screens. Measurement of trifluralin content in $CHCl_3$ by visible spectroscopy at 400 nm against a standard curve showed 16.4% ai of which 10.82% was adsorbed and 5.58% was encapsulated. After wetting the granules and then drying, the values were 5.25% adsorbed and 11.15% encapsulated.

1983. The experiment conducted in 1983 was a study of three trifluralin formulations under conventional tillage (fall plowed) and no-till, each at two application times. This study used a split-block design with three replications. Half of the area (which was in soybeans in 1982) was fall moldboard plowed and the remaining half was left no-till. On February 1 and May 12, 1983, the emulsifiable concentrate, encapsulated starch borate (15B/12342)[3], and en-

[1] Received for publication August 4, 1986, and in revised form December 29, 1986. Published as J. Paper No. 10755 of the Purdue Agric. Exp. Stn.

[2] Res. Agron., U.S. Dep. Agric., Agric. Res. Serv.; Res. Assoc. Weed Sci., Dep. Bot. and Plant Pathol., Purdue Univ., W. Lafayette, IN 47907; and Res. Chem., U.S. Dep. Agric., Agric. Res. Serv., North. Reg. Res. Ctr., Peoria, IL 61604.

[3] Refers to preparation batch number used at USDA-ARS Lab., Peoria, IL.

capsulated starch xanthate (H_2O_2, 45/11997) formulations were applied to individual 3- by 12-m plots. All trifluralin formulations were applied at 1.68 kg ai/ha. These granular formulations were all applied with a calibrated handseeder. The fall-plowed area was prepared for planting with a field cultivator and a Lely roterra[4]. On June 1, 1983, 'Wells II' soybeans were planted. On June 21 and July 26, 1983, weed stand counts were made on all plots. On September 9, 1983, all plots were visually rated for weed control and soybean stand, and on September 29, 1983, all plots were combine harvested.

1984. Two experiments were conducted in 1984. The first was a study of application dates of trifluralin formulations in conventional tillage. The second study was a comparison of the encapsulated starch borate formulation of trifluralin with an untreated check in no-till and no-till with a Fuerst harrow[4].

In the first study, three trifluralin formulations were tested under conventional tillage on ground that had been moldboard plowed in the fall of 1983. The three formulations were the emulsifiable concentrate, a fine granular of encapsulated starch borate (15B/12342), and a coarse granular of encapsulated starch borate (36/12115). The experimental design used was a randomized complete block with three replications, with individual plots 1.5 by 11.6 m. The first application date was approximately 1 month (May 16, 1984) before planting and the second, at planting time, June 12, 1984. All granular formulations were applied with a Gandy[4] applicator and all rates used were 1.4 kg ai/ha. Wells II soybeans were planted following one pass with a field cultivator and one pass with a Lely roterra. Weed and soybean stand counts were taken on August 1, 1984, and visual harvest ratings made on September 16, 1984. On October 3, 1984, all plots were combine harvested.

The no-till study with and without the use of a Fuerst harrow utilized a split-block design with three replications with individual plots 3 by 9 m. The encapsulated starch borate of trifluralin (15B/12342) was applied at 1.4 kg ai/ha on April 10, 1984. The harrow plots received one pass after treatment and just before planting of Wells II soybeans June 5, 1984. All plots received glyphosate [*N*-(phosphonomethyl)glycine] at 0.84 kg ai/ha at planting time. Weed stand counts were taken on June 27 and July 19, 1984. A visual rating was made September 17, 1984, before harvest. All plots were combine harvested on October 4, 1984.

1985. A no-till experiment was conducted in 1985 to evaluate three different encapsulated starch formulations of trifluralin applied at two periods before planting compared to its emulsifiable concentrate. This experiment was no-till soybeans following soybeans.

The study used a split-block design having three replications with individual plots 3.0 by 11.3 m. All herbicides were applied at 1.4 kg ai/ha using a Gandy Air Spred applicator[4] for all the granular formulations. Two of the granular formulations were encapsulated starch borates: 15B/12342 and 36/12115. The third granular formulation was designated as AE (16/12884), a new autoencapsulated granule whose preparation was described above. An early application was made March 29, 1985, and a late application was made May 7, 1985. 'Miami' soybeans were planted on May 21, 1985. Weed stand counts were taken on June 26 and July 23, 1985. A visual harvest rating was made on September 26, and all plots were hand harvested on October 16, 1985.

1986. A no-till experiment was conducted in 1986 to evaluate the encapsulated starch borate (15B/12342) and the autoencapsulated starch (16/12884) formulations of trifluralin compared to its emulsifiable concentrate. This experiment was no-till soybeans following corn.

This study used a randomized complete block having three replications with individual plots 3.0 by 9.1 m. All formulations were applied April 18, 1986, at 1.25 kg ai/ha using a Gandy Air Spred applicator for all the granular formulations. Miami soybeans were planted on May 28, 1986. Weed stand counts were taken on June 25 and July 28, 1986. All plots were hand harvested on October 24, 1986.

Weather conditions from 1983 through 1986 were significantly different and could have influenced the various studies. The winter of 1982-1983 recorded the lowest snowfall on record and temperatures considerably above normal for this location. Early spring rains in April and early May 1983 were heavier than normal. From June through September, rainfall was 19.6 cm below normal and temperatures were above normal. The winter of 1983-1984 was the opposite of the previous winter with heavy snowfall and colder conditions. March and April 1984 had cooler temperatures but were dry. Heavy rains in May were followed by drought conditions from June to September with a shortfall of 15.2 cm of rain. The winter of 1984-1985 received normal snowfall followed by heavy rains in March and early April. From mid-April through July, rainfall was 22.9 cm below normal. Heavy rains in August saved the soybean crop in 1985. Fortunately, the dry weather was not associated with excessively high temperatures. The winter of 1985-1986 received slightly lower snowfall than normal followed by a deficit of rainfall of 7.9 cm in March and April. Heavy rains in May (10.7 cm above monthly average) were followed by extremely hot and dry conditions in June, July, and August. The rainfall deficit in this latter period totaled 13.3 cm. The dry conditions during the critical period of soybean growth reduced yields over 60% from average.

RESULTS AND DISCUSSION

1983. An early February application of trifluralin formulated as an encapsulated starch xanthate or borate gave significantly higher soybean yield under no-till than the emulsifiable concentrate formulation and the untreated check (Table 1). When similar formulations were applied 2 1/2 weeks before planting (mid-May) on no-till soybeans, no significant differences in soybean yields were found and

[4] Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Dep. Agric. and does not imply its approval to the exclusion of other products that may also be suitable.

Table 1. The interaction of trifluralin formulations and time of application on the yield of no-till and conventional tilled soybeans, planted June 1, 1983[a].

	No-till		Conventional tilled	
	Application time		Application time	
Trifluralin formulation	2/1/83	5/12/83	2/1/83	5/12/83
(1.68 kg ai/ha)	(kg/ha)			
Emulsifiable concentrate	2118 b	3144 a	2832 a	2609 a
Encapsulated starch borate (15B)	2841 a	3289 a	2781 a	2257 a
Encapsulated starch xanthate (H_2O_2)	2909 a	2764 a	2963 a	2572 a
Untreated check	1890 b	1890 b	1728 b	1728 b

[a]Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 2. The interaction of trifluralin formulations and time of application on weedy grass stands in no-till and conventional tilled soybeans, planted June 1, 1983[a].

	No-till		Conventional tilled	
	Application time		Application time	
Trifluralin formulation	2/1/83	5/12/83	2/1/83	5/12/83
(1.68 kg ai/ha)	(plants/m^2)			
Emulsifiable concentrate	189 a	92 ab	147 b	76 b
Encapsulated starch borate (15B)	88 b	56 b	153 b	43 b
Encapsulated starch xanthate (H_2O_2)	52 b	115 ab	15 c	89 b
Untreated check	158 a	158 a	241 a	241 a

[a]Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

all produced soybean yields significantly higher than the untreated check. Under conventional tillage, all formulations of trifluralin produced significant yield increases over the untreated checks at both application dates (Table 1). There were no differences among formulations.

The stability of the encapsulated granules improved longevity on the soil surface. This contributed to a significant reduction of weedy grasses, mainly giant foxtail (*Setaria faberi* Herrm. #[5] SETFA) in the following growing season in no-till (Table 2).

Both encapsulated starch formulations appeared to be more effective than the emulsifiable concentrate for the midwinter application of trifluralin for no-till soybeans. Why the midwinter application of the emulsifiable concentrate performed better on fall-plowed ground than on no-till ground, based on soybean yield and weed control, is an interesting question. The winter of 1982-1983 had little snowfall. Temperatures were above normal during the winter but apparently not high enough to cause vaporization of the trifluralin. One possible explanation could be the settling action of the rough soil surface by the freezing and thawing in late winter and early spring. This action could have caused a large portion of the emulsifiable concentrate formulation to be shallowly incorporated into the soil surface, thus protecting it from loss by volatilization and photodecomposition.

1984. Use of encapsulated starch borate formulations of trifluralin under a conventional-tillage system applied either approximately 1 month ahead of or at planting time was as effective as the emulsifiable concentrate based on grassy weed control and increased soybean yields (Table 3). The closer to planting the emulsifiable concentrate of trifluralin was applied, the better the weedy grass control. When encapsulated starch borate (15B) was applied at planting time, weed control and subsequent soybean yields were equal to that of the emulsifiable concentrate formulation. This confirms the 1983 data on conventional tillage and indicates that these starch-encapsulated formulations are versatile and not restricted to no-till soybean production.

The encapsulated starch borate (15B) formulation of trifluralin resulted in significantly better giant foxtail control and outyielded the untreated check whether the plots were no-till or received a shallow harrow treatment (Table 4). No emulsifiable concentrate formulation was used in the no-till study in 1986.

[5]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

1985. Visual ratings at harvest for both early and late treatment dates indicated that for overall weed control there were no significant differences among treatments, and only the untreated check was significantly different from all treated plots. Giant foxtail stands were a good indicator of degree of weed control since it was the predominant weed (Table 5). When herbicides were applied in late March, the emulsifiable concentrate and untreated check had significantly higher foxtail stands than all treatments except the coarse borate formulation (starch xanthate 36). However, when applied

Table 3. Effect of trifluralin formulation and application time on soybean yields and giant foxtail stands in conventional tilled soybeans, planted June 12, 1984[a].

	Yield		Giant foxtail stand	
	Application time		Application time	
Trifluralin formulation	5/16/84	6/12/84	5/16/84	6/12/84
(1.4 kg ai/ha)	(kg/ha)		(plants/m²)	
Emulsifiable concentrate	2535 a A	2488 ab A	100 b A	34 b B
Encapsulated starch borate (15B)	2495 a A	2542 a A	46 b A	39 b A
Encapsulated starch xanthate (36)	2529 a A	2219 bc A	44 b A	62 b A
Untreated check	2031 b A	2031 c A	324 a A	324 a A

[a]Means within a column followed by the same lower-case letter, or within a row in yield or stand followed by the same capital letter, are not significantly different at the 5% level according to Duncan's multiple range test.

Table 4. Effect of a trifluralin formulation on soybean yields and giant foxtail stands in no-till soybeans, planted May 24, 1984[a].

	Yield		Giant foxtail stand	
Treatment	No-till	No-till + harrow	No-till	No-till + harrow
(1.4 kg ai/ha)	(kg/ha)		(plants/m²)	
Trifluralin, encapsulated Starch borate (15B)[b]	2495 a	2603 a	10 b	17 b
Untreated check	1500 b	1426 b	70 a	125 a

[a]Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Applied April 10, 1984.

Table 5. Effect of trifluralin formulation and time of application on soybean yield and giant foxtail stands in no-till soybeans, planted May 21, 1985[a].

	Yield		Giant foxtail stand	
	Application time		Application time	
Trifluralin formulation	3/29/85	5/7/85	3/29/85	5/7/85
(1.4 kg ai/ha)	(kg/ha)		(plants/m²)	
Emulsifiable concentrate	2165 b A	3107 ab B	32 a A	13 b B
Encapsulated starch borate (15B)	3262 a A	3329 a A	5 b A	7 b A
Encapsulated starch xanthate (36)	3174 a A	2448 ab B	21 ab A	11 b A
Autoencapsulated starch	3201 a A	3013 ab A	10 b A	14 b A
Untreated check	2381 b A	2340 b A	33 a A	35 a A

[a]Means within a column followed by the same lower-case letter, or within a row in yield or stand followed by the same capital letter, are not significantly different at the 5% level according to Duncan's multiple range test.

Table 6. Effect of trifluralin formulations on soybean yields in no-till soybeans, planted May 28, 1986[a].

Treatment[b]	Yield
(1.25 kg ai/ha)	(kg/ha)
Emulsifiable concentrate	653 b
Encapsulated starch borate (15B)	2208 a
Autoencapsulated starch	2437 a
Untreated check	1023 b

[a]Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Treatments applied April 18, 1986.

2 weeks before planting, all trifluralin treatments caused significant reduction of giant foxtail compared to the untreated check.

Soybean yields were significantly different within each application time and within treatments across application times (Table 5). In the March application, the yield from the emulsifiable concentrate formulation equaled the untreated check and was significantly lower than the other herbicide treatments. The new autoencapsulated formulation of trifluralin was as effective as the starch borates. In the May treatment, differences were not significant among herbicide formulations.

1986. When applied in April, the starch borate (15B) and the autoencapsulated starch formulations of trifluralin gave effective weed control and produced no-till soybean yields significantly higher than the emulsifiable concentrate and untreated check (Table 6).

These data from 1983 thru 1986 show that the encapsulated starch borate formulation of trifluralin (15B) was effective in controlling giant foxtail sufficiently to increase soybean yields when applied in no-till situations from February to May. In the early applications (February, March, and April), the starch borate was significantly better than the emulsifiable concentrate under no-till conditions. Two years data with the new autoencapsulated starch formulation indicate that this new formulation may be as effective as the starch borate (15B) under the same conditions. These data also indicate that these formulations work as well in conventional as in no-till systems of soybean production. In conventional-tillage systems they work as well as the emulsifiable concentrate. With the option for application in late winter or early spring, these new formulations give farmers opportunity to reduce the work load near or at planting time.

Our data indicate that effective herbicides presently available for conventional-tillage systems, such as trifluralin which normally requires incorporation, can have a place in no-till production systems if new controlled-release technology is employed. Encapsulated starch formulations may be a viable approach.

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