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Weed Management—Techniques

Microencapsulated Herbicide-Treated Bark Mulches for Nursery Container Weed Control

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Nursery container preemergence herbicides must be applied multiple times, usually every 6 to 8 wk, in order to maintain acceptable weed control. Nursery growers have identified extended duration of container preemergence activity as a research priority for reduction of herbicide usage and costs. The objective of this study was to determine if the combination of slow-release (microencapsulated [ME]) formulations of alachlor and acetochlor with wood-based organic mulches could provide extended efficacy and reduced phytotoxicity vs. over-the-top (OTT) sprays or mulch alone. Efficacy and phytotoxicity studies were conducted over 3 yr with various plants. Both acetochlor formulation OTT sprays reduced spirea shoot dry weights at 45 and 110 days after treatment (DAT) compared with the controls, and emulsifiable concentrate (EC) acetochlor OTT spray also reduced shoot dry weights of rose. No herbicide-treated bark mulch (TBM) combination reduced rose or spirea shoot dry weights. EC acetochlor + hardwood (in 2003) was the only treatment to provide 100% weed control at 45 and 110 DAT. The addition of EC or ME acetochlor to mulch reduced phytotoxicity and extended efficacy in 2002 and 2003; alachlor EC or ME TBM did not. Regardless of bark type, 3-yr average EC and ME TBM were 80% more effective than untreated bark mulch (UBM) and 83% and 98% more effective at 45 and 110 DAT, respectively than their comparable OTT sprays. Of the eight treatments that received ratings above commercially acceptable, averaged over dates and years, the three providing the least phytotoxicity and greatest extent, consistency, and duration of efficacy were all TBM combinations: EC acetochlor + Douglas fir or hardwood bark, EC acetochlor + pine, and ME acetochlor + pine. TBM-reduced phytotoxicity compared with OTT sprays.

Nomenclature: Acetochlor; alachlor; Carefree Beauty Rose, *Rosa* × *hybrid* 'Carefree Beauty'; spirea, *Spirea japonica* L. f. 'Little Princess'.

Key words: Douglas fir, shredded hardwood, pine bark.

Los herbicidas pre-emergentes para macetas en viveros deben aplicarse mºltiples veces, usualmente cada 6 u 8 semanas para mantener un control de malezas aceptable. Cultivadores en invernaderos han señalado que lograr una larga duración del efecto pre- emergente de los herbicidas en macetas es una importante prioridad para la investigación, para reducir el uso del mismo así como sus costos. El objetivo de este estudio fue determinar si una combinación de una fórmula de liberación prolongada [micro-encapsulado ("ME")], de alachlor y acetochlor como tratamiento para el pajote orgánico de madera, podría extender la eficacia y reducir la fitotoxicidad cuando comparado con herbicidas aplicados por aspersión (OTT over-the-top) o con sólo el uso del pajote. Los estudios de eficacia y la reducción de la fitotoxicidad se realizaron por más de tres años en diversas plantas. Las dos formulaciones de acetochlor en aspersiones OTT disminuyeron el peso seco de los brotes de la spirea a los 45 y a los 110 días después del tratamiento (DAT) comparadas con los testigos. Los concentrados emulsificables (EC) de aspersión OTT de acetochlor también redujeron el peso seco de los brotes de rosa. Ninguna combinación de pajote de corteza tratada con herbicida (TBM), redujo el peso seco de los brotes de rosa y de spirea. El acetochlor (EC) + corteza de madera dura (2003) fue el único tratamiento que alcanzó el 100% de control de malezas a los 45 y 110 días después del tratamiento (DAT). La adición de concentrados emulsificables (EC) o el acetochlor micro-encapsulado (ME) al pajote, redujo la fitotoxicidad y prolongó la eficacia en 2002 y 2003 pero no se obtuvieron los mismos resultados con el alachlor EC ni con el herbicida micro-encapsulado como tratamiento para el pajote (ME TBM). Sin importar el tipo de madera, el promedio tomado por tres años, demostró que las combinaciones del pajote tratado con el concentrado emulsificable EC y con el herbicida micro-encapsulado fueron el 80% más efectivas que el pajote no tratado (UBM) y también fueron el 83 y 98% más efectivos a los 45 y 110 días después del tratamiento (DAT) respectivamente que las aspersiones OTT. De los ocho tratamientos que tuvieron resultados por arriba de lo comercialmente aceptable, al promediarlos por fechas y años, los tres que proporcionaron la menor fitotoxicidad y la mayor extensión, consistencia y duración de eficacia, fueron combinaciones de pajote tratado: acetochlor + pajote de abeto Douglas u otra madera dura; acetochlor EC + pino y acetochlor ME + pino. El pajote tratado (TBM) redujo la fitotoxicidad comparado con las aspersiones OTT.

Chemical applications of mainly granular preemergence herbicides are currently utilized to control nursery container weeds (Gilliam et al. 1992). U.S. nursery producers apply herbicides every 6 to 8 wk during the growing season (northern nurseries, three times; northeastern, four; or southern, five) to achieve acceptable weed control at a large expense of labor and capital (Barolli et al. 2005; Gilliam et al. 1990; Mathers 2004; Mathers et al. 2007). Half-lives of herbicides are generally less in container media than in field soils (Judge et al. 2002), because leaching, over/misapplication, nontarget losses, and high media temperature increase

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herbicide degradation. Simmons and Derr (2007) found that pendimethalin leached to greater depths in pine bark compared to field soil, resulting in decreased amounts on the surface of containers where it was needed. As much as 86% of applied granular herbicide can fall between containers (Gilliam et al. 1992), depending on pot spacing, pot shape, and crop species. Nontarget herbicide losses contaminate runoff water (Keese et al. 1994), some of which can end up in containment (recirculation) ponds and potentially cause phytotoxicity to crops that are irrigated from these ponds. Bhandary et al. (1997) found that oryzalin concentrations as low as 10 mg/L in irrigation water reduced growth indices of fountain grass (*Pennisetum rupelli* Steud.) and daylily (*Hemerocallis hybrid* L.). Many of the ornamental herbicides have high organic matter adsorption which minimizes their leaching from containers, although it does occur (Horowitz and Elmore 1991; Judge et al. 2002; Wehtje et al. 1993).

Decreasing the amount of herbicide applied while still maintaining excellent weed control and low phytotoxicity has become the focus of recent ornamental research. Reducing herbicide use also would benefit the environment via decreased herbicide in runoff water from nontarget loss and leaching. There have been many attempts to reduce the amount of herbicides used. One common way is by hand weeding, although it is expensive, costing around $1,367 to weed 1,000 3-L pots over a 4-mo period based on an hourly wage of $14.75 (including benefits) (Darden and Neal 1999). Other methods have included herbicide-coated tablets (Ruizzo et al. 1983), herbicide-coated fertilizers (Crossan et al. 1997), and woven-textile discs (Appleton and French 2000).

Microencapsulation (ME) of herbicides is designed to increase residual activity and decrease volatility compared with the emulsifiable concentrate (EC) formulations. ME formulations are those in which herbicides are enclosed by a matrix that slowly releases the herbicide into the environment. Matrices involving starches have been studied extensively (Carr et al. 1991; Trimnell and Shasha 1990; Wauchope et al. 1990). Polymeric microcapsules of atrazine showed excellent controlled release activity when compared with a dry flowable formulation (Dailey et al. 1993). ME alachlor increased surface concentrations when compared with the EC formulation up to 70 d after treatment (DAT) (Fleming et al. 1992). ME alachlor also increased the total amount of alachlor that was recovered in a column leachate study, with 94% of what was recovered being in the top 5 cm of soil (Fleming et al. 1992). Acetochlor and alachlor are two agricultural herbicides commercially available for corn and soybeans as both EC and ME formulations. There are few ME formulations for use on nursery crops. Controlled release of herbicides using lignin as the matrix were investigated by Oliveira et al. (2000) and offered a promising alternative technology for weed control.

Mulches are another alternative to chemical weed control and are used extensively by the landscape industry. Organic mulches deter weeds by inhibition of weed seed germination and suppression of weed growth (Mathers 2002). Mulches are not used extensively for container production, although several organic mulches have been studied, including Wulpack™,[1] which is pelletized wool left over from sheep trimmings; PennMulch™,[2] a pelletized form of shredded newspaper (Wooten and Neal 2000); and rice hulls (Ahn and Chung 2000). Case and Mathers (2006) investigated pine nuggets, Douglas fir, hardwood, Cypress, PennMulch™, rice hulls, and cocoa shells as mulches for container weed control. Landscape mulches applied at recommended rates have not been shown to provide the weed control desired by commercial and noncommercial landscapers (Somireddy and Mathers 2008). Skroch et al. (1992) found only 50% reduction in weed counts when using 8.9-cm-thick bark mulch, which was not acceptable. Another disadvantage of organic mulches is that they can reduce the amount of readily available nitrogen (Billeaud and Zajicek 1989). Somireddy and Mathers (2008) found mulches needed to be applied at a thickness of 12.7 cm to affectively reduce weed germination and growth; however, these depths were phytotoxic to desired landscape beds. Organic mulches break down with time and the original thickness typically is reduced by 60% after 1 yr. A combination of mulch applied at 6.35 cm along with herbicide was as effective as 12.7-cm-depth mulch, and had reduced phytotoxicity (Somireddy and Mathers 2008).

Herbicide-treated bark mulch (TBM) has been investigated for container weed control (Case et al. 2002; Case and Mathers 2006; Fretz 1973; Mathers 2003; Samtani et al. 2007) and in field and landscape settings (Dunham and Fretz 1967; Fretz and Dunham 1971). TBM has been shown to decrease phytotoxicity in comparison to over the top (OTT) sprays (Case and Mathers 2006; Samtani et al. 2007) while increasing residual container weed control (Case et al. 2002; Case and Mathers 2006; Mathers 2003). TBM can reduce volatility, leaching, and herbicide degradation in container media, thus reducing environmental impacts and costs for nursery producers. Loblolly pine (*Pinus taeda* L.) and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], TBM was effective up to 130 DAT (Mathers 2003) and 310 DAT (Case and Mathers 2003), respectively in nursery containers. TBM could be acting as slow-release carriers for herbicides. With 310 d of weed control in containers, only one application of TBM would be necessary per growing year. In field applications TBM has had longer than 1 yr of efficacy (Somirreddy and Mathers 2008). In 2006 to 2008, formulations of granular herbicides plus mulch became available for the commercial and noncommercial landscape markets, Schultz Premium Mulch with Weed Stop®,[3] Vigoro Premium Mulch Plus Weed Stop®,[4] Preen Mulch® and Preen Mulch Plus® [5] (Mulch and Soil Council 2009). These products offer up to 4 mo of weed control in fields and landscapes, and use granular formulations of dithiopyr (Schultz and Vigoro), or trifluralin + isoxaben (Preen). In studies conducted at The Ohio State University, weed control with Vigoro Premium Mulch Plus Weed Stop diminished after 120 DAT, and Preen Mulch Plus (hardwood) was not effective by 90 DAT (Mathers and Case 2008), whereas liquid TBM formulations were efficacious over 360 DAT (Somireddy and Mathers 2008). The development of TBM using more efficacious herbicides (such as acetochlor and alachlor) with improved, extended, and consistent control would have broad appeal for use in nursery containers, field nurseries, and landscapes. Economic and increasing environmental pressures felt in 2008 to 2009 have increased interest in TBM (which can be used with bioherbicides) for containers to reduce herbicide expense and use and labor (B. Brusse, Sheridan Nurseries, Inc., Georgetown, ON, Canada, personal communication). In Canada, the provinces of Quebec and Ontario banned all cosmetic pesticide applications in 2008 and 2009, respectively. Manitoba has a ban on cosmetic fertilizers but is seeking action from the federal government to ban pesticides for cosmetic uses nationally (Rabson, 2009).

The objective of this study was to increase and extend weed efficacy and reduce herbicide application frequency for nursery containers using bark mulch treated with ME and EC formulations of alachlor and acetochlor. Our working hypothesis was that TBM with either formulation or active ingredient would provide extended weed management and reduced phytotoxicity in comparison to untreated bark mulch (UBM), OTT sprays with the two formulations and chemicals, and untreated control. Also, TBM with ME formulations were expected to provide greater extension of efficacy than TBM with EC formulations.

Materials and Methods

Efficacy. Trials were initiated at The Ohio State University, Columbus, OH, on July 1, 2001 (30 C, 0.97 cm of rainfall at 3:00 P.M.), June 7, 2002 (22 C, no precipitation), and May 16, 2003 (23 C, no precipitation). Mulches (pine bark nuggets and Douglas fir bark nuggets in 2001 and 2002, and pine bark nuggets and shredded hardwood in 2003) were laid out one layer thick on a piece of plastic before the herbicides were applied. One layer thickness represents pieces of mulch side by side with minimal overlapping (per Mathers 2003). Mulches were treated once with the following herbicides: ME alachlor (Micro-Tech) 41.5%[6] at 4.26 kg ai/ha, EC alachlor (Lasso) 45%[6] at 4.26 kg ai/ha, ME acetochlor (Degree) 42%[6] at 2.8 kg ai/ha, or EC acetochlor (Harness) 76%[6] at 2.8 kg ai/ha.

The mulches were allowed to dry for 48 h after treatment and then applied to pots at one layer thick. The herbicide-treated mulches were compared to OTT sprays of the same herbicides and rates, untreated mulches, and a nontreated control. OTT sprays and treated mulches were applied to the pots on the same day. A spray volume of 93 L/ha was used to apply the OTT sprays and to treat the mulches using a CO_2-pressurized backpack sprayer[7] equipped with 8002 evs flat-fan nozzles[8] spaced 41 cm apart.

Treatments were applied to 3.8 L (#1) pots filled with 60% pine bark, 20% rice hulls, 10% sand, 5% technigrow[9] (a composted sewage sludge), and 5% stone aggregate. Pots were seeded immediately following treatments with common chickweed [*Stellaria media* (L.) Vill.], spotted spurge (*Chamaesyce maculata* L.), and annual bluegrass (*Poa annua* L.) in 2001 and 2002. In 2003, common groundsel (*Senecio vulgaris* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and annual bluegrass were used because common chickweed and spurge were not available in 2003. Equal amounts of each seed by weight were mixed together, and then 0.6 ml of the seed mixture was applied to each pot. Visual ratings and dry weights were taken 45 and 110 DAT, except for 2001 when no dry weights were taken at 45 DAT. Visual ratings were based on a 0 to 10 scale in comparison to the control with 0 representing no weed control, 10 100% weed control, and ≥ 7 being considered as commercially acceptable. In 2001, all pots were fertilized immediately after planting with 20N–8.8P–16.6K (20–10–20) water-injected Peters Professional fertilizer[10] at 200 mg N/L (200 ppmv), and top-dressed with a 15N–4P–10K (15–9–12) Osmocote[10] fertilizer (8 to 9 mo formulation) 42 g per pot. In 2002 and 2003, Osmocote fertilizer (8 to 9 mo formulation) was preplant incorporated into the potting substrate at 42 g per pot. Pots were watered daily during the test period by timed, overhead sprinklers, applying approximately 0.64 cm per day, regardless of rainfall. Total precipitation for Columbus, OH during the trial was 22.1 cm in 2001, 34.5 cm in 2002, and 44.7 cm in 2003. Average temperatures for each year were 19 C in 2001, 24.5 C in 2002, and 21 C in 2003. Efficacy evaluations were conducted without an ornamental plant in the pot. In 2002, the spurge was cut back between the 45 DAT and 110 DAT evaluations due to excessive growth. The pruned parts of the weeds were dried and the weights were added to the weed shoot dry weights determined at 110 DAT.

Figure 1. Representation of visual ratings on boxwood *Buxus* × 'Green Gem.' Untreated control is at the far left with decreasing visual ratings to the right.

Phytotoxicity. Phytotoxicity was evaluated in a similar manner to efficacy. In 2001 potentilla (*Potentilla fruticosa* L. 'McKays White') was evaluated for phytotoxicity. In 2003, Rose (*Rosa* × *hybrid* 'Carefree Beauty' [modified with an antimicrobial protein gene (Xiangqian et al. 2003)]), spirea (*Spirea japonica* L. f. 'Little Princess'), and boxwood (*Buxus microphylla* var. *koreana* × *Buxus sempervirens* L. 'Green Gem') were evaluated. Average heights of species at the beginning of the trial were 30 cm for potentilla, 25 cm for rose, and 15 cm for boxwood and spirea. Phytotoxicity was evaluated by visual ratings and dry weights 45 and 110 DAT. Phytotoxicity visual ratings were based on a 1 to 10 scale in comparison to the control (Figure 1) with 1 = no phytotoxicity, 10 = death, and ≤ 3 considered as commercially acceptable.

In 2002, different application volumes were added as treatments. Mulches were sprayed with the herbicides and

Table 1. Weed control and phytotoxicity visual ratings at 45 and 110 d after treatment (DAT) of microencapsulated and emulsifiable concentrate formulations of alachlor and acetochlor when used as a spray and combined with pine bark and Douglas fir compared with an untreated control and untreated mulch in 2001 and 2002 in 3 L pots.

	2001				2002	
	Weed visual ratings[b]		Potentilla visual ratings[c]		Weed visual ratings	
Treatment[a]	45 DAT	110 DAT	45 DAT	110 DAT	45 DAT	110 DAT
Control	0.4 d[d]	0.0 h	2.2 bc	1.4 cd	1.0 i	0.0 e
EC acetochlor	10 a	9.2 a	3.0 ab	3.2 a	9.9 ab	7.2 b
EC acetochlor + Douglas fir	8.2 abc	6.2 cd	3.0 ab	2.4 abc	9.6 abcd	8.7 ab
EC acetochlor + pine	7.0 bc	4.2 de	2.6 abc	1.8 bcd	10.0 a	9.9 a
ME acetochlor	10 a	9.6 a	2.4 bc	2.6 ab	9.2 cd	2.3 d
ME acetochlor + Douglas fir	7.2 bc	3.0 ef	2.2 bc	2.6 ab	7.9 e	3.8 cd
ME acetochlor + pine	9.0 ab	7.4 bc	2.8 ab	2.8 ab	9.1 d	8.2 ab
EC alachlor	9.8 a	7.0 c	2.6 abc	3.2 a	9.3 cd	4.5 c
EC alachlor + Douglas fir	6.8 c	1.6 fgh	2.6 abc	2.0 bcd	6.5 f	2.4 d
EC alachlor + pine	7.2 bc	2.2 efg	3.4 ab	1.0 d	9.6 abcd	7.0 b
ME alachlor	10 a	7.6 ab	3.6 a	2.8 ab	9.7 abc	4.9 c
ME alachlor + Douglas fir	7.4 bc	3.6 ef	1.4 c	2.2 abc	6.0 g	2.5 d
ME alachlor + pine	7.2 bc	2.6 ef	3.0 ab	1.8 bcd	9.4 bcd	4.6 c
Douglas fir	1.2 d	0.2 gh	2.8 ab	2.2 abc	2.5 h	0.0 e
Pine	1.2 d	0.4 gh	3.4 ab	2.6 ab	2.6 h	0.0 e

[a] ME is microencapsulated formulation (42% for acetochlor, 41.5% for alachlor), EC is emulsifiable concentration 76% for acetochlor, 45% for alachlor).

[b] Weed visual ratings based on a 0 to 10 scale with 0 representing no control and 10 representing complete weed control.

[c] Phytotoxicity visual ratings based on a 1 to 10 scale with 1 representing no phytotoxicity and 10 death.

[d] Similar letters in the same column are not significantly different (LSD $\alpha = 0.05$).

rates described above, but with an additional spray volume of 467 L/ha along with the 93 L/ha previously used and 8005 evs flat-fan nozzles were used for these new volume treatments. All trials were conducted as a completely randomized design with five single pot replications per treatment per evaluation date.

Efficacy and phytotoxicity data were subjected to analysis of variance (ANOVA) using the SAS©[11] GLM procedure. Fisher's protected least significant difference test was used to compare means. Visual ratings were subjected to an arc sin square root transformation (Steel and Torrie 1980). Data sets were analyzed and the two analyses (transformed and nontransformed) were compared. No differences were found between the ANOVA of the transformed data. For simplicity, the nontransformed data will be presented. A combined ANOVA using year by treatment interaction as the error term determined that the efficacy data could not be pooled for treatments that were common in all 3 yr. Therefore, results are presented for each year separately with comparisons made between years.

Results and Discussion

In 2002, the lower spray volume of 93 L/ha provided higher efficacy visual ratings and lower weed dry weights than the spray volume of 467 L/ha at 45 and 110 DAT (data not shown). Runoff was observed from the mulch at the time of application with the higher volume spray, which resulted in less overall herbicide adsorption to the mulch. Data in Table 1 are combined over the two volumes for 2002. Even though spray volume main effect was significant, no two-way or three-way interactions were significant (volume by herbicide, spray volume by mulch, or spray volume by herbicide by mulch). The herbicide by mulch interaction was significant in all 3 yr.

Efficacy. In 2001, all treatments except EC alachlor + Douglas fir, the UBM (Douglas fir and pine bark), and control provided commercially acceptable weed control with visual ratings 45 DAT ranging from 7 to 10 (Table 1). At 110 DAT in 2001, five treatments provided commercially acceptable control, the four OTT sprays and ME acetochlor + pine bark (Table 1).

At 45 DAT in 2002, EC acetochlor + pine bark provided 100% weed control, and nine other treatments provided commercially acceptable visual ratings (Table 1). All treatments, except the UBM decreased weed shoot dry weight 45 DAT compared with the control (data not shown). Alachlor and acetochlor are in the herbicide class chloroacetamides which are xylem-transported, shoot-inhibiting herbicides with toxicity symptoms occurring primarily in older foliage (Mathers 2007). In 2002, five treatments, four TBM and one OTT spray (EC acetochlor), provided commercially acceptable efficacy. Treating pine bark with EC and ME acetochlor and EC alachlor increased efficacy to commercially acceptable levels compared with their respective OTT sprays. Douglas fir only was effective for weed control at 110 DAT when it was treated with EC acetochlor (Table 1).

In 2003, none of the OTT sprays provided adequate weed control 45 DAT. EC acetochlor reduced weed dry weights compared with the control; however, the level of control was significantly improved with EC acetochlor TBM (Table 2). Weed control with acetochlor (either formulation) TBM was increased to a commercially acceptable level with hardwood or pine bark (Table 3) vs. their respective OTT sprays. With

Table 2. Weed control and phytotoxicity dry weights of selected ornamentals at 45 and 110 d after treatment (DAT) of microencapsulated and emulsifiable concentrate formulations of alachlor and acetochlor when used as a spray and combined with pine bark and hardwood mulch compared with an untreated control and untreated mulch in 3 L pots in 2003.

	45 DAT				110 DAT			
Treatment[a]	Weed dry weights	Rose shoot dry weights	Boxwood shoot dry weights	Spirea shoot dry weights	Weed dry weights	Rose shoot dry weights	Boxwood shoot dry weights	Spirea shoot dry weights
	g							
Control	9.7 ab[b]	8.1 ab	20.8 f	6.2 bcd	32.5 a	31.4 bcd	16.6 ab	29.5 e
EC acetochlor	6.6 c	5.7 a	13.5 abc	1.1 a	15.7 b	21.1 a	16.9 ab	9.0 ab
EC acetochlor + hardwood	0.4 de	8.6 abc	16.3 bcde	3.4 abc	0.2 c	30.4 bcd	19.4 ab	13.2 bc
EC acetochlor + pine	0.9 de	7.9 ab	14.6 bcde	4.9 abcd	0.8 c	33.0 cd	17.6 ab	22.4 de
ME acetochlor	8.9 abc	8.7 abc	14.7 bcd	1.1 a	32.1 a	27.1 abc	17.8 ab	5.0 a
ME acetochlor + hardwood	0.2 e	8.7 abc	12.2 ab	5.6 bcd	0.6 c	31.0 bcd	20.4 ab	24.7 de
ME acetochlor + pine	0.4 de	8.1 ab	17.1 cdef	6.4 bcd	0.7 c	30.3 bcd	21.6 b	23.2 de
EC alachlor	9.5 ab	8.6 abc	12.9 abc	3.4 abc	8.8 c	28.2 abcd	14.2 a	19.8 cd
EC alachlor + hardwood	1.5 de	9.0 abc	16.2 bcde	7.3 cd	1.2 c	27.0 abc	16.4 ab	24.6 de
EC alachlor + pine	7.4 bc	10.4 bc	12.4 ab	6.7 bcd	3.4 c	34.5 d	19.4 ab	26.1 de
ME alachlor	8.1 abc	7.6 ab	15.2 bcde	2.4 ab	5.6 bc	25.7 ab	17.9 ab	20.9 d
ME alachlor + hardwood	8.2 abc	8.7 abc	18.7 def	8.4 d	3.3 c	29.3 bcd	15.9 ab	24.4 de
ME alachlor + pine	3.2 d	12.9 c	9.5 a	9.1 d	2.3 c	34.3 d	18.2 ab	24.1 de
Hardwood	10.8 a	8.3 ab	19.0 ef	9.1 d	32.9 ac	32.7 bcd	18.3 ab	25.4 de
Pine	8.3 abc	10.5bc	14.5 bcd	8.7 d	30.9 ac	33.2 cd	19.8 ab	26.6 de

[a] ME is microencapsulated formulation (42% for acetochlor, 41.5% for alachlor), EC is emulsifiable concentrate formulation (76% for acetochlor, 45% for alachlor).

[b] Means with similar letters in the same column are not significantly different (LSD $\alpha = 0.05$).

alachlor, however, the two formulations responded differently according to bark type (Tables 2 and 3). Weed control was increased with EC alachlor applied to hardwood bark, but not pine. Results were similar at 110 DAT. Both formulations of OTT alachlor provided minimal weed control, comparable to untreated pine at 45 DAT and ≤ 5 at 110 DAT. Efficacy with ME alachlor was increased when applied to pine bark. UBM did not increase efficacy compared with the untreated control at 45 or 110 DAT, regardless of bark type (Tables 2 and 3).

ME acetochlor + pine bark and EC acetochlor + pine bark were the only two treatments that provided commercially acceptable control all 3 yr at 45 DAT and increased efficacy vs. UBM by 82%. ME acetochlor + pine bark was the only treatment providing commercially acceptable control in all three years at 110 DAT with a 98% increase in efficacy vs. UBM. Acetochlor products had more activity on broadleaf weeds (D. Suttner, Monsanto, personal communication).

Annual bluegrass was more persistent in 2002 vs. 2001, resulting in some year-to-year treatment variations. Annual

Table 3. Weed control and phytotoxicity visual ratings of selected ornamentals at 45 and 110 d after treatment (DAT) of microencapsulated and emulsifiable concentrate formulations of alachlor and acetochlor when used as a spray and combined with pine bark and hardwood mulch compared with an untreated control and untreated mulch in 3 L pots in 2003.

	Visual ratings[b,c]							
Treatment[a]	Weed[z]	Rose[y]	Boxwood	Spirea	Weed	Rose	Boxwood	Spirea
	45 DAT				110 DAT			
Control	0.0 g[d]	2.6 bcd	1.0 d	3.0 efg	0.0 f	1.6 bc	2.8 abc	1.0 b
EC acetochlor	4.0 c	4.4 a	3.8 ab	7.2 ab	4.6 d	3.8 a	2.4 abc	4.6 a
EC acetochlor + hardwood	10.0 a	3.6 abc	2.8 bc	5.4 cd	10.0 a	2.4 abc	1.6 bc	5.0 a
EC acetochlor + pine	9.2 a	2.6 bcd	3.4 abc	3.6 def	9.2 ab	1.0 c	2.6 abc	2.0 b
ME acetochlor	2.2 cdef	4.0 ab	3.2 bc	8.0 a	2.0 e	2.4 abc	2.2 abc	6.2 a
ME acetochlor + hardwood	10.0 a	3.2 abcd	3.2 bc	3.0 efg	9.4 ab	1.0 c	3.2 ab	1.4 b
ME acetochlor + pine	9.2 a	3.2 abcd	2.2 bcd	2.6 efgh	9.2 ab	2.4 abc	2.2 abc	1.6 b
EC alachlor	2.6 cde	3.0 abcd	3.0 bc	4.2 cde	4.4 d	2.4 abc	3.8 a	2.4 b
EC alachlor + hardwood	6.8 b	3.0 abcd	2.6 bcd	1.8 gh	8.2 bc	1.0 c	2.8 abc	2.4 b
EC alachlor + pine	3.8 cd	2.0 cd	3.0 bc	3.0 efg	7.2 bc	2.4 abc	1.3 bc	1.8 b
ME alachlor	2.0 def	3.6 abc	2.6 bcd	5.8 bc	4.8 d	2.4 abc	2.2 abc	2.2 b
ME alachlor + hardwood	3.4 cd	3.2 abcd	1.8 cd	2.2 fgh	4.3 d	3.0 ab	1.2 c	1.6 b
ME alachlor + pine	6.0 b	1.8 d	5.0 a	1.2 h	7.0 c	1.0 c	2.8 abc	1.2 b
Hardwood	0.6 fg	3.4 abcd	2.4 bcd	1.8 gh	0.0 f	1.4 bc	2.0 bc	1.8 b
Pine	1.0 efg	3.0 abcd	2.4 bcd	2.2 fgh	0.0 f	1.6 bc	2.2 abc	1.4 b

[a] ME is microencapsulated formulation (42% for acetochlor, 41.5% for alachlor), EC is emulsifiable concentrate formulation (76% for acetochlor, 45% for alachlor).

[b] Weed visual ratings based on a 0 to 10 scale with 0 representing no weed control and 10 complete weed control.

[c] Phytotoxicity visual ratings based on a 1 to 10 scale with 1 representing no phytotoxicity and 10 death.

[d] Means with similar letters in the same column are not significantly different (LSD $\alpha = 0.05$).

bluegrass prefers moist conditions; the hot/dry conditions of 2001, plus the late trial initiation in July probably decreased its vigor. All TBM except ME alachlor + pine bark controlled annual bluegrass both years. Acetochlor and alachlor controlled the spurge in 2001 and 2002, either as a spray or when combined with mulch, indicating their excellent efficacy. Prostrate/spotted spurge [*Chamaescyce maculata* (L.) Small or *C. humistrata* (Englem ex. Gray) Small] in nursery containers has been identified as one of the four most difficult weeds to control (Gilliam et al. 1990) and one of the six most dominant weed species (Penny and Neal 2000). Mathers (1999) also found spurge to be one of the most competitive weeds. Spurge growing in Oregon nursery containers resulted in significant growth and quality reductions in Evergreen Azalea ('Rosebud' [*Rhododendron* × 'Rosebud']) and Common Juniper (*Juniperus communis* 'Gold Cone') (Mathers 1999). Prostrate/spotted spurge also dominates containers in mid- to late summer (Penny and Neal 2000). Spurge is a warm-season weed (Mickler and Ruter 2001) that germinates later than many container weeds. Temperatures of 25 to 30 C and light are required for its germination (Krueger and Shaner 1982). Spurge often germinates when most spring preemergence herbicides have dissipated. Several researchers have found that of registered nursery products, only combination herbicides such as oxyfluorfen + pendimethalin (OH2) can provide spurge control after 30 to 45 DAT (Fare and Robinson 2001; Judge and Neal 2000) because they offer longer control. In 2001, with reduced bluegrass competition and selectivity for spurge control, the OTT sprays provided no additional benefits of TBM. In 2001, OTT sprays were superior or equal to most TBM treatments with the exception of ME acetochlor + pine bark.

In 2003 when large crabgrass and common groundsel management were studied, neither acetochlor nor alachlor were effective when used as OTT sprays, regardless of formulation. Common groundsel was abundant 45 DAT, but by 110 DAT it had completed its life cycle. Neither herbicide is labeled for common groundsel control. Large crabgrass is on the label of both acetochlor and alachlor in agronomic field crops; however, in this trial large crabgrass was not adequately controlled by either herbicide when using OTT sprays. Annual grasses including large crabgrass are common container weeds in some regions of the United States (Singh et al. 1980; Wilcut et al. 1989) but control with conventional herbicides is inconsistent. The inconsistency is attributed mainly to dose response and the extended germination potential of species such as large crabgrass (Judge et al. 2002). Again, in containers, half-lives of field herbicides are reduced and longer release potential of the herbicide is intensified. Smith and Verma (1977) found that controlled release of alachlor from plaster-of-paris tablets controlled crabgrass up to 7 mo after treatment by extending the dosing of the alachlor. Walker et al. (1991) found in field soils that alachlor provided control of large crabgrass 20 DAT, but by 35 and 50 DAT, control was diminished to 30 and 16%, respectively. Judge et al. (2002), working with trifluralin, found that herbicide dose was important for large crabgrass control. In our study, 4.26 kg ai/ha of alachlor and 2.8 kg ai/ha of acetochlor seemed to have been insufficient rates for extended crabgrass control as OTT sprays. Applying herbicide onto mulch or perhaps increasing the amount of active ingredient in the formulations would help with crabgrass control in containers. The addition of more active ingredient, however, would probably increase phytotoxicity which was already above acceptable levels with most OTT sprays at 45 DAT (Table 3).

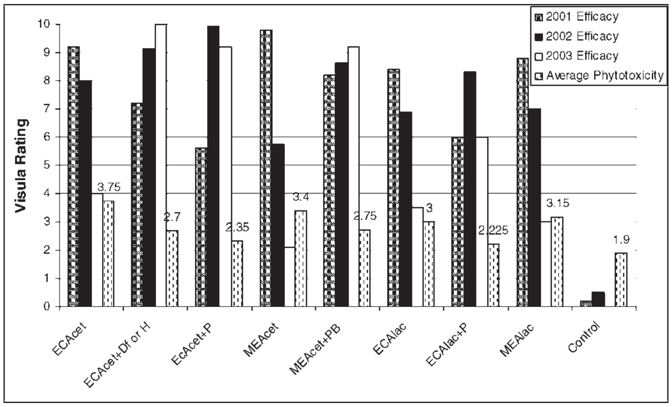

Figure 2. Best eight treatments (for commercially acceptable efficacy) evaluated 2001 to 2003 at The Ohio State University, Columbus, OH with comparative phytotoxicity ratings averaged over potentilla, spirea, rose, and boxwood. ME is microencapsulated formulation (42% for Acet [acetochlor], 41.5% for Alac [alachlor]), EC is emulsifiable concentrate formulation (76% for acetochlor, 45% for alachlor). Df is Douglas fir bark, P is pine bark. Efficacy visual ratings are based on a 0–10 scale with 0 representing no weed control, 10 complete weed control and ≥ 7 being commercially acceptable. Phytotoxicity visual ratings are based on a 1 to 10 scale with 1 representing no phytotoxicity, 10 death, and ≤ 3 being commercially acceptable.

The efficacy of TBM was influenced by formulation and bark type. ME acetochlor did not persist to 110 DAT when combined with Douglas fir. However, EC acetochlor provided weed suppression through 110 DAT. EC alachlor was slightly more effective than ME alachlor when combined with pine bark; however, neither formulation of alachlor performed well with Douglas fir. Duration of efficacy was not increased by treating mulch with ME formulations vs. EC formulations. However, efficacy and duration of efficacy of either TBM was generally superior to OTT sprays. Generally, acetochlor TBM was superior to alachlor TBM, representing three of the best eight treatments in the study, respectively (Figure 2).

Data indicate that TBMs are more effective for weed control than the OTT sprays of either product or formulation or UTM. TBM could be acting as slow-release carriers for herbicides, providing weed control up to 115 DAT (Case and Mathers 2003, 2006) and 130 DAT (Mathers 2003). However, combining slow-release formulations (ME) with a slow-release carrier (bark) in this experiment resulted in no additional extension in efficacy. The results of this study concur with Case and Mathers (2003, 2006) and Mathers (2003) suggesting that mulches can increase the duration of weed control. This study also concurs with Case and Mathers (2006) in that some herbicide-mulch combinations are highly effective, whereas others are not.

Phytotoxicity. Six treatments had phytotoxicity ratings ≤ 3 with potentilla at 45 DAT in 2001, including the untreated pine bark. The control had a rating of 2.2. These plants were shipped bareroot from Oregon and the hot, dry growing season and July planting in 2001 caused some injury at the initiation of the trial; however, by 110 DAT the plants had recovered. Because phytotoxicity was evaluated compared with the control (Figure 1), the injury rating was a relative measure. The pine bark might have increased phytotoxicity by repelling water that did fall as rainfall or irrigation. By 110 DAT, potentilla controls had recovered and only one treatment, EC acetochlor, ≤ 3 at 45 DAT, was still ≤ 3 at 110 DAT (Table 1). At 110 DAT in 2001, the OTT spray of EC acetochlor and EC alachlor caused unacceptable phytotoxicity to potentilla. Several EC formulation labels indicate injury can be more severe if plants are heat- or drought-stressed (Vegetation Management, LLC, Raleigh, NC).

EC acetochlor was the only treatment providing higher visual ratings than the control for rose at both 45 and 110 DAT in 2003 (Table 3). No treatments lowered shoot dry weights for rose (Table 2) at 45 DAT. EC acetochlor as an OTT spray reduced rose shoot dry weights at 110 DAT compared with the controls (Table 2). It is recommended that irrigation events occur before and after applications of EC formulations to minimize injury (J. Derr, personal communication).

All treatments except ME acetochlor + pine bark, ME alachlor + hardwood, and untreated hardwood were phytotoxic and decreased shoot dry weight of boxwood in 2003 at 45 DAT (Table 2). Control plants at 110 DAT were smaller than those in the 45 DAT evaluations (Table 2) and no treatments differed from the controls at 110 DAT. At 45 DAT, ME alachlor + pine bark was the most phytotoxic treatment with a visual rating of five (Table 3) and dry weight of 9.5 g vs. the boxwood control 20.8 g (Table 2 and Figure 1). Eight other treatments also provided visual ratings ≥ 3 compared with the boxwood controls at 45 DAT (Table 3).

For spirea at 45 DAT in 2003, three OTT sprays and one TBM (EC acetochlor + hardwood) (Table 3) had phytotoxicity ratings greater than the control. The 2003 rose and spirea came out of cold storage from Minnesota and suffered from transplant shock. The controls were rated 2.6 and 3.0, respectively. Again, ratings were made relative to the controls and only those treatments with statistically significant greater phytotoxicity ratings are discussed. By 110 DAT both species were recovered. At 45 DAT, all TBM spirea treatments provided lower visual ratings than their respective OTT sprays (Table 3). Spirea dry weights at 45 DAT, regardless of bark type, show that ME acetochlor and ME alachlor decreased phytotoxicity compared with the OTT sprays (Table 2), supporting our hypothesis. By 110 DAT, shoot dry weights of spirea were decreased by all OTT sprays compared with the control. EC acetochlor + hardwood was the most phytotoxic TBM at 110 DAT by spirea dry-weight evaluations (13.2 g vs. control at 29.5 g) (Table 2) or visual rating (5) (Table 3).

Granular preemergence herbicides generally cause less phytotoxicity than liquid formulations (Kalmowitz and Whitwell 1988) due to herbicide placement. We expect TBM can have the same benefits as granular formulations and more. With TBM, herbicide contact is limited to around the stem or possibly exposure to shallow roots. Our working hypothesis was that TBM lowers phytotoxicity compared with OTT sprays. Neither acetochlor nor alachlor are labeled for ornamental use. All the crops evaluated were previously untested with these herbicides, so some phytotoxicity with OTT sprays was expected. However, finding minimal phytotoxicity with these unlabeled products when combined with bark mulch was a veritable test of our hypothesis. Alachlor as a component of Rout GL (oxyfluorfen + alachlor, Scott's Miracle-Gro Co.) was found effective in some container crops (Duray and Davies 1989) and nonphytotoxic to azalea (*Rhododendron obtuseum* Planch. 'Richardii') at rates up to 45 kg/ha when released from plaster-of-paris tablets (Smith and Verma 1977). Rout GL no longer is available commercially. Evaluations at 110 DAT show that TBM decreased phytotoxicity on potentilla, rose, and spirea compared with the OTT sprays. Physical and chemical interactions between herbicides and mulch can result in superior combinations to others for reduction of phytotoxicity (Case and Mathers 2006). In this study EC acetochlor + pine bark caused no reduction in spirea growth, but EC acetochlor + hardwood did.

Case et al. (2002), Fretz (1973), and Mathers (2003) have indicated that mulches can act as slow-release carriers and produce positive, sometimes synergistic interactions with herbicides. Even though the herbicide is slowly released from the mulch, the amounts often provide superior efficacy and low phytotoxicity. Data from this trial indicate that there is sufficient herbicide released from some TBMs to control weeds up to 110 DAT. Results also indicate TBM has particular application in controlling weeds with extended germination times where longer persistence is required. Herbicide-treated mulches can have many advantages and applications for the nursery and landscape industry. One application per year could result in significant savings in time and money. They could also reduce the amount of herbicide lost by leaching or misapplication to ground water, containment ponds, and surface water. Of the best eight treatments (ratings ≥ 7) averaged over dates and years, the three providing the least phytotoxicity and greatest extent, consistency (over years) and duration of efficacy were all TBM combinations (EC acetochlor + Douglas fir or hardwood bark, EC Acetochlor + pine, ME acetochlor + pine bark), indicating that mulches with herbicide combinations can be very advantageous in terms of lowered phytotoxicity and a longer duration of efficacy (Figure 2). Annually, acetochlor TBM could reduce applications of conventional ornamental preemergence herbicides by 6.16 kg ai/ha (8.96 kg ai/ha to 2.8 kg ai/ha). At an estimated cost of $110.00/kg ai, that would represent a savings of $677.60/ha of containers, representing over $1.7 million in herbicide savings alone across the U.S. nursery container industry. More work needs to be done on characterizing release from the mulches and mulch-herbicide interactions to determine what herbicides and rates work best with various mulches. Data from this study also could be used for studies conducted in a field setting for landscape and field nursery use.

Sources of Materials

[1] Walpack^{TM} organic mulch, Hortifeeds, Kettlethorpe, Lincoln LN1 2LD United Kingdom.

[2] PennMulch™ organic mulch, Lebanon Seaboard Corporation, Lebanon, PA 17042.

[3] Schultz Premium Mulch with Weed Stop®, Schultz Co., Bridgeton, MO 63044.

[4] Vigoro Premium Mulch Plus Weed Stop®, Spectrum Group, St. Louis, MO 63114.

[5] Preen Mulch™ and Preen Mulch Plus™, Mulch Manufacturing, Reynoldsburg, OH 43068.

[6] ME alachlor (Micro-Tech), EC alachlor (Lasso), ME acetochlor (Degree), EC acetochlor (Harness), Monsanto Co., St. Louis, MO 63167.

[7] CO$_2$-pressurized backpack sprayer, R&D Sprayers, Opelousas, LA 70570.

[8] 802 evs flat-fan nozzles, Spraying Systems Co., Wheaton, IL 60189–7900.

[9] Technigrow composted sewage sludge, Kurtz Bros. Inc., Groveport, OH 43125.

[10] Peters Professional fertilizer and Osmocote, Scott's Miracle-Gro Co., Marysville, OH.

[11] GLM statistical procedure, SAS Institute Inc., Cary, NC.

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