Killing cover crops mechanically: Review of recent literature and assessment of new research results

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Abstract. *Cover-crop residues left on the soil surface as a mulch in no-till crop production systems protect the soil from erosion, increase water infiltration and suppress weeds. Because many growers using cover crops want to reduce chemical inputs, non-chemical methods of killing or suppressing cover crops are needed. In the first part of this paper we review the current literature and discuss advantages and disadvantages of five mechanical methods for killing cover crops, i.e., mowing, rolling, roll-chopping, undercutting and partial rototilling. We also report on three new studies that broaden the current literature, including planting into freshly killed residue. In the first study, the use of planter attachments to remove surface residues from the planter row improved stands when cotton was no-till planted 2–7 days after mowing cover crops in Mississippi. In the second study, 100% of a rye/vetch cover crop in Missouri was killed by mowing, and greater than 90% was killed by roll-chopping. Cotton stands were reduced by the use of row cleaners that clogged when the cover crop was roll-chopped or mowed on the same day that the crop was planted. The third study evaluated three methods of mechanically killing summer cover crops in North Carolina. Undercutting provided greater than 95% kill for five of six broadleaf species, and two of five grass species. Mowing effectively killed all six broadleaf cover crops, but re-growth occurred with three of five grasses, with the exception of nearly mature German foxtail millet and mature Japanese millet. In general, rolling did not effectively kill broadleaf or grass cover crops, with the exception of nearly mature German foxtail millet, mature Japanese millet and mature buckwheat.*

Key words: crop residues, living mulches, mowing, no-tillage, partial rototilling, rolling, roll-chopping, undercutting

Introduction

Cover crops are used in cropping systems to enhance biological mechanisms and to serve as potential substitutes for chemical inputs. These can be tilled into the soil before planting cash crops, or killed and left on the soil surface as a mulch in no-till crop production. Leaving cover crops as surface mulches in no-till crop production systems has the advantage of conserving soil moisture (Morse, 1993), reducing soil erosion (Langdale et al., 1991), improving soil physical properties (Blevins and Frye, 1993), in some cases, suppressing weeds (Creamer and Baldwin, 2000; Creamer et al., 1996; Teasdale, 1993), inhibiting insects (Zehnder and Hough-Goldstein, 1990), reducing disease (Ristaino et al., 1996) and increasing crop yields (Triplett et al., 1996). In most studies, cover crops managed as no-till mulches have been killed with glyphosate (*N*-[phosphonomethyl]glycine), paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) (Bauer and Reeves, 1999; Raimbault et al., 1990; Reeves et al., 1993; Sarrantonio and Scott, 1988) or mixtures of non-selective, post-emergence and pre-emergence herbicides (Teasdale and Shirley, 1998). Because many growers often want to reduce use of chemical inputs, non-chemical methods of killing or suppressing cover crops are desirable.

Mechanical methods of managing cover crops and leaving them on the soil surface include mowing, rolling, roll-chopping, undercutting and partial rototilling. Generally, the success of these methods is dependent, in part, on the species and growth stage of the cover crop. At certain growth stages, mechanical management can produce rapid desiccation and create an opportunity for utilizing cover-crop residues for weed control. Even where mechanical treatments are inadequate, herbicide requirements for adequate control are often reduced.

In this paper we review the current literature relevant to the management of cover crops with mechanical methods and present new findings that broaden our knowledge base.

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Literature review

Mechanical methods

Mowing. Mowing has been one of the most common methods used by growers to mechanically kill cover crops and leave their residues as surface mulches. For example, Derpsch et al. (1986) reported on successful no-till cropping systems in Brazil (23°S) in which individual cover crops were killed by cutting with a

…e 1. Percent kill by flail mowing various winter annual cover crop species in Louisiana, Mississippi and Ohio.

…ocation/cover crop	Scientific name	Growth stage	Date of kill	Percent kill
Louisiana[1]				
Austrian winter pea	*Pisum sativum* L.	<10% bloom	Mid April	86
Rough pea	*Lathyrus hirsutus* L.	<10% bloom	Mid April	82
Hairy vetch	*Vicia villosa* Roth	<10% bloom	Mid April	95
Big flower vetch 'Woodford'	*V. grandiflora* Scop.	Seed development	Mid April	61
Common vetch 'Cahaba White'	*V. sativa* L.	<50% bloom	Mid April	85
Crimson clover 'Tibbee'	*Trifolium incarnatum* L.	Seed development	Mid April	95
Berseem clover 'Bigbee'	*T. alexandrinum* L.	Vegetative	Mid April	27
Red clover 'Chesapeake'	*T. pratense* L.	<50% bloom	Mid April	11
Ball clover 'Segrest'	*T. nigrescens* Viv.	<50% bloom	Mid April	44
Arrowleaf clover 'Amclo'	*T. vesiculosum* Savi	<10% bloom	Mid April	59
Subterranean clover 'Mt. Barker'	*T. subterraneum* L.	Full bloom	Mid April	27
Subterranean clover 'Woogenellup'	*T. subterraneum* L.	Seed development	Mid April	18
Cutleaf evening primrose (volunteer)	*Oenothera laciniata* Hill	<50% bloom	Mid April	18
Wheat 'Coker 916'	*Triticum aestivum* L.	Heading	Mid April	90
Annual ryegrass 'Gulf'	*Lolium multiflorum* Lam.	<50% bloom	Mid April	15
Mississippi[2]				
Hairy vetch	*Vicia villosa* Roth	Vegetative	Early April	94
		Vegetative	Mid April	91
		10–20% bloom	Early May	99
Crimson clover 'Tibbee'	*Trifolium incarnatum* L.	10% bloom	Early April	87
		Full bloom	Mid April	88
		Seed development	Early May	99
Subterranean clover 'Mt. Barker'	*T. subterraneum* L.	<50% bloom	Early April	41
		Full bloom	Mid April	45
		Seed development	Early May	90
Berseem clover 'Bigbee'	*T. alexandrinum* L.	Vegetative	Early April	64
		Vegetative	Mid April	52
		Early bloom	Early May	93
Ohio[3]				
Hairy vetch	*Vicia villosa* Roth	Early bud	27 April 1990	19
		Mid bloom	24 May 1990	93
		Full bloom	18 June 1990	100
		Early bud	30 April 1991	74
		Mid bloom	11 May 1991	100
		Full bloom	June 1991	100

[1] Source: Dabney and Griffin (1987).
[2] Source: Dabney et al. (1991).
[3] Source: Hoffman et al. (1993).

rotary mower at flowering, followed by planting of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.] or kidney bean (*Phaseolus vulgaris* L.). In these systems, white lupin (*Lupinus albus* L.) and hairy vetch (*Vicia villosa* Roth) provided the most benefit for corn, black oat (*Avena strigosa* Schreb.) for soybean, and black oat and oilseed radish (*Raphanus sativus oleiferus* L.) for kidney bean. These cover crops all increased crop yields compared with soils covered with volunteer vegetation during the winter.

Generally, a flail-type mower is preferred over a bush-hog or other rotary-type mower because it leaves cover-crop residues uniformly distributed on the soil surface. Bush-hog mowers tend to leave uneven residue clumps, resulting in less desirable conditions for planting and weed suppression. Also, rotary mowers do not cut as close to the soil surface as flail mowers, so regrowth of cover crops is more likely (Dabney et al., 1991). A sickle-bar mower can be used for some types of cover crops. It severs the cover crop at its base, rather than shredding it into fine pieces. This can yield a thicker, longer-lasting surface mulch and can reduce weed growth (Creamer et al., 1995). However, a sickle-bar mower can be difficult or impossible to use on a viny cover crop, such as hairy vetch, due to tangling in the blades (Creamer et al., 1995). A reel-assisted sickle mower will better handle these conditions if it can be adjusted to avoid creating a windrow. A disk mower can cut close to the surface and through viny crops more efficiently than a sickle-bar mower, but it tends

Table 2. Growth stage of wheat and rye at mowing, and biomass of the regrowth 4 and 8 weeks after mowing in 1992 and 1993 in New York.[1]

	1992			1993		
		Biomass (kg ha^{-1})			Biomass (kg ha^{-1})	
Cover crop	Growth stage	4 WAM[2]	8 WAM	Growth stage	4 WAM	8 WAM
Wheat	First node	2100 a[3]	5320 a	First node	1770 a	5470 a
	Second node	300 b	970 b	Flag leaf	560 b	2240 b
	75% head	90 c	90 c	In boot	450 b	1280 b
	Milky kernel	40 d	10 d	Watery kernel	20 c	20 c
Rye	First node	4340 a	8470 a	Second node	900 a	2820 a
	In boot	200 b	780 b	In boot	610 a	910 b
	100% head	10 c	30 c	100% head	110 b	280 c
				Watery kernel	10 c	0 d

[1] Source: Wilkins and Bellinder (1996).
[2] Weeks after mowing.
[3] Letters denote mean separation within column, year and species using Waller–Duncan *t*-test, *k* ratio = 100. Plant biomass logarithmically transformed before mean separation.

to leave residue in strips separated by bare areas rather than evenly distributed over the surface.

Results from studies in Louisiana, Ohio and Mississippi investigating the effectiveness of mowing various cover-crop species are summarized in Table 1. Generally, erect-growing or stemmy winter annual broadleaves were killed easily by mowing, although there was a trend for increased kill at later stages of cover-crop growth. Grass cover crops, as compared to broadleaves, were more difficult to kill by mowing.

In the Louisiana study by Dabney and Griffin (1987), cutleaf evening primrose (*Oenothera laciniata* Hill), a weed that dominated the site when a cover crop was not planted, was not killed by mid-April flail mowing. However, most of the cover crops excluded this weed, and could be controlled by mowing. The cover crops with at least 90% kill ratings from mowing included hairy vetch, crimson clover (*Trifolium incarnatum* L.) and wheat (*Triticum aestivum* L.) (Table 1). The authors concluded that mowing could be an economic alternative to herbicides for killing some cover crops. Cover crops that were poorly controlled by mowing included berseem clover (*Trifolium alexandrinum* L.) in the pre-flowering stage, annual ryegrass (*Lolium multiflorum* Lam.) not headed, red clover (*Trifolium pratense* L.) approaching full bloom, and subterranean clover (*Trifolium subterraneum* L.) having stems below the cutting height.

In a study by Dabney et al. (1991) in northern Mississippi, effectiveness of mowing 'Tibbee' crimson clover, 'Mt. Barker' subterranean clover, 'Bigbee' berseem clover, and hairy vetch during early April, mid April, and early May was evaluated for 2 years. Mowing was accomplished with a flail mower set 3.81 cm above ground. Mowing gave a 90% or better kill of hairy vetch (Table 1). When hairy vetch stems exceeded 61 cm in length and at least 36 cm of stem was decumbent on the soil surface, close mowing killed vetch regardless of the reproductive growth stage.

For the other cover crops, percent kill increased as cover-crop maturity increased. When the mower was mistakenly raised to 6.4 cm (versus 3.8 cm) for the mid-April mowing in one year, the percent kill dropped markedly compared to the previous year (87 versus 95% for hairy vetch, 78 versus 91% for crimson clover, 41 versus 49% for subterranean clover, and 23 versus 79% for berseem clover).

In an Ohio study by Hoffman et al. (1993), hairy vetch was flail mowed at early bud, mid bloom and late bloom in each of 2 years. Control was better at later growth stages in both years. The vetch was not completely suppressed by mowing at the early bud stage (late April in Ohio), particularly in 1990, but at least 90% was killed by mowing in mid May or later (Table 1). Percent kill of hairy vetch at the earliest kill date was greater in 1991 due to drought conditions. Similarly, Teasdale (1993) reported that hairy vetch regrowth after mowing was greater in years when the vetch was less mature and had less biomass because of later fall hairy vetch planting dates or earlier spring kill dates.

Wilkins and Bellinder (1996) conducted an experiment to determine the regrowth biomass of winter wheat and rye (*Secale cereale* L.) that were mowed with a sickle-bar mower to a height of 10 cm when each was at various growth stages. In their study, each crop was mowed four times, beginning when the crop reached the first elongated internode growth stage (early May) and continuing at 2-week intervals. Regrowth biomass was measured at 4 and 8 weeks after mowing, by clipping the new growth above the mulch layers. Plant height and growth stage of the regrowth were measured 8 weeks after mowing (WAM). Table 2 shows the growth stage at each mowing date and the amount of regrowth at 4 and 8 WAM. Depending on mowing date, regrowth occurred from different plant parts. Before the boot stage, regrowth came from undamaged tillers. After the boot stage, regrowth was produced from secondary tiller

[Tab]le 3. Percent kill by rolling (Mississippi) and rolling or roll-chopping (Ohio) of various broadleaf winter annual cover crop species.

Cover crop	Growth stage	Date of kill	% Kill At coulter spacing 10.2 cm	% Kill At coulter spacing 20.3 cm
Mississippi[1]				
Hairy vetch	Vegetative	Early April	80	62
	Vegetative	Mid April	90	73
	10–20% bloom	Early May	99	98
Crimson clover 'Tibbee'	10% bloom	Early April	44	23
	Full bloom	Mid April	83	56
	Seed development	Early May	93	81
Subterranean clover 'Mt. Barker'	<50% bloom	Early April	26	16
	Full bloom	Mid April	26	21
	Seed development	Early May	61	42
Berseem clover 'Bigbee'	Vegetative	Early April	20	13
	Vegetative	Mid April	31	26
	Early bloom	Early May	53	35
			Roll	**Roll-chop**
Ohio[2]				
Hairy vetch	Early bud	27 April 1990	0	–
	Mid bloom	24 May 1990	56	–
	Late bloom	18 June 1990	97	–
	Early bud	30 April 1991	63	47
	Mid bloom	11 May 1991	87	95
	Late bloom	05 June 1991	99	99

[1] Source: Dabney et al. (1991).
[2] Source: Hoffman et al. (1993).

elongation. After heading, regrowth of both species was limited. The authors suggest that the efficacy of mowing to kill cereal cover crops may be improved by: (1) fall seeding that favors earlier flowering; (2) high seeding rates that cause fewer tillers per plant; (3) consistent planting depth for uniform growth; and (4) nutrient-poor soil during early spring, which reduces the ability of cover crops to recover and renew vegetative growth (Wilkins and Bellinder, 1996).

Rolling and roll-chopping. Mowing may not be the best option for mechanically killing cover crops to optimize weed suppression. The small pieces generated with flail or rotary mowing decompose rapidly, as they have more surface area and are in closer contact with soil microorganisms. Rolling lays the cover crop down intact, flat on the surface, and can be accomplished in various ways, as described below. Roll-chopping is more aggressive than rolling. A variety of designs exist where blades are attached to the roller to cut the cover crop into large sections as it is rolled. Rolling and roll-chopping cover crops, as compared to mowing, creates a longer-lasting surface mulch with longer weed suppression potential. Rolling also has the advantage over mowing of being accomplished at higher speeds, with lower machinery maintenance costs and reduced fossil fuel consumption. Various methods have been used for rolling and roll-chopping cover crops. Depending on conditions, kill can result from breaking, cutting, crushing or crimping stems.

In a study by Morse (1995), in Virginia, well-developed summer cover crops of buckwheat (*Fagopyrum esculentum* Moench) and German foxtail millet [*Setaria italica* (L.) P. Beauv.] were either rolled with a 1.8-m (6-foot) mower on 23 August 1994, just prior to no-till transplanting broccoli (*Brassica oleraceae* L. var. *capitata*). Rolling was accomplished by pulling a disengaged flail mower (weighing approximately 385 kg) across the plots. When the cover crops were rolled, buckwheat had flowered and developed viable seed, foxtail millet had flowered and set immature seed and soybean was in early flower. Rolling effectively killed foxtail millet and buckwheat, but not soybean. Soybean residues remained green but did not interfere with broccoli production. However, some 5% of redroot pigweed (*Amaranthus retroflexus* L.) did survive rolling.

In a study in Mississippi, Dabney et al. (1991) achieved successful rolling of cover crops using a no-till grain drill with 20-cm coulter drill spacing. In one treatment, extra coulters were added between each drill to create 10-cm coulter spacing (Table 3). With this equipment, stems were cut in the direction of travel rather than perpendicular to that direction, as occurs with a roll-chopper. As expected, closer coulter spacing was generally more effective at killing cover crops than wider coulter spacing, and there was a trend for increased kill at later kill dates. As with mowing, hairy vetch control in this study was more related to stem length than to growth stage. Vetch kill by rolling with the 10-cm coulter spacing was more than 90% when stem length exceeded 61 cm. With this stem length, canopy height was only about 28 cm. The rest of the stem lay along the ground, where it was cut by the rolling coulters. In contrast to its utility for vetch, rolling was not an effective kill method for subterranean or berseem clovers at any growth stage evaluated. However, rolling did increase susceptibility of the crops to subsequent herbicide applications (Dabney et al., 1991).

In a study by Hoffman et al. (1993), hairy vetch was rolled at early bud, mid bloom and late bloom growth stages (Table 3). Rolling was accomplished with either a smooth, 60-cm diameter, 270-kg, water-filled turf roller, or a 410-kg, water-filled drum roller with full-width steel blades attached (effectively a roll-chopper), similar to that illustrated by Derpsch et al. (1988). Rolling or roll-chopping were more effective at later kill dates than at the early kill dates. In 1990, rolling at early bud stage did not kill the vetch; however, in 1991, a dry year, rolling was more effective. Rolling or roll-chopping at late bloom killed at least 97% of the vetch.

Undercutting. Creamer et al. (1995) designed an undercutter to sever cover-crop roots and flatten the intact, above-ground biomass on the surface of raised beds. The undercutter was designed to kill the cover crop with minimal soil disturbance, while leaving the maximum amount of cover-crop residue on the soil surface. It was developed to improve mechanical control of cover crops without shredding the residue. The standards holding the undercutting blades are placed on the outside of the bed to prevent soil and residue disturbance. A rolling basket follows the blades to flatten and evenly distribute the undercut cover crop, and to aid residue flow through the undercutter.

The undercutter was evaluated in 1992 to determine its effectiveness in killing 17 species of cover crops at two locations in Ohio. Whether a cover-crop species was killed by the undercutter depended primarily on growth stage (Creamer et al., 1995). Rye, hairy vetch, bigflower vetch (*Vicia grandiflora* Scop.), crimson clover, barley (*Hordeum vulgare* L.) and subterranean clover were in mid to late bloom or beyond, and were killed easily. Ladino clover (*Trifolium repens* L.), red clover, yellow blossom sweetclover (*Melilotus officinalis* Lam.), white blossom sweetclover (*Melilotus albus* Medik.), tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), annual ryegrass and perennial ryegrass (*Lolium perenne* L.) were not killed (Creamer et al., 1995).

Successful operation of the undercutter depends on proper soil moisture conditions. This reliance can impede timeliness of cultural operations in the field. The current design consists of one blade (a motor-grader blade turned upside down) designed to cut a 1.5-m wide raised bed. This design has been successful on a wider variety of soil types than the original design with two undercutting blades. Undercutting cover crops, as compared to mowing, leaves a thicker, longer-lasting mulch on the soil surface, and a looser soil that can facilitate transplanting of vegetable crops (Creamer et al., 1995). Undercutting to kill cover crops, as compared to rolling, is a slower operation and requires more horsepower.

Partial rototilling. In living mulch systems, partial rototilling has been shown to be an effective suppression technique for stoloniferous cover crops. In New York, intercropped Dutch white clover (*Trifolium repens* L.) was partially rototilled in sweet corn. Although mowing did not sufficiently suppress the clover, it was effectively suppressed by rototilling well-established clover 2 weeks after corn emergence. Strips of clover roots were left between the tines, resulting in extensive regrowth later in the season. The intercropping system enhanced corn nitrogen nutrition under low nitrogen fertility (Grubinger and Minotti, 1990).

Other impacts of mechanical kill methods

Where residues are heavy and crops are grown in cooler parts of their regions of adaptation, residue removal can result in earlier soil warming, more rapid crop growth and higher yields of no-till planted crops (Kaspar and Erbach, 1998). Cover crops can increase the amount of residue cover, and therefore, increase the benefits of row cleaners (Janovicek et al., 1997).

The method of cover-crop kill has been shown to affect insect populations. Populations of armyworm (Lepidoptera: Noctuidae) were lower (Laub and Luna, 1991), and those of its natural enemies (*Pterostichus* spp. and *Scarites* spp. [Coleoptera: Carabidae]) and wolf spiders (Aranea: Lycosidae) higher (Laub and Luna, 1992), in mowed cover-crop plots as compared with herbicide-treated plots. The authors theorized that the mulch created by mowing provided a more favorable habitat for predators, and that mowing also placed armyworm larvae in a location more susceptible to soilborne predators.

The method of cover-crop kill can also affect weeds that emerge through the killed cover-crop mulches. Regrowth of the cover crop and germination and growth of small weeds in the understory of the cover crop are both a concern. Weeds are more suppressed by living cover crops than by dead cover-crop mulches (Teasdale, 1993). Leaving the cover-crop material intact on the surface, by undercutting or sickle-bar mowing, yielded fewer weeds than when it was chopped into fine pieces with a flail mower (Creamer et al., 1995). The finely chopped cover crop was less thick, allowing more light to reach germinating weed seedlings. In addition, a finely chopped cover decomposes more rapidly than a thick, intact mulch as it is in closer contact with soil microorganisms. This may result in longer-lasting weed suppression by intact mulches.

Materials and Methods

Mechanical cover-crop management systems (including establishment of cash crops into the residue) were evaluated in a combination of replicated-plot and on-farm trials in northern Mississippi (34°N), the Missouri bootheel (36°N) and North Carolina from 1993 to 1996. In Mississippi, hairy vetch, 'Elbon' rye or rye/vetch mixtures were flail mowed at five different times, ranging from 0 to 26 days before no-till cotton (*Gossypium hirsutum* L.) was planted in early May in each of the 3 years. No-till planting occurred on 14 May 1993 at 20 seeds m^{-1}, 10 May 1994 at 20 seeds m^{-1}, and 5 May 1995 at 13 seeds m^{-1}. Three-row plots were used to compare cotton stand establishment, using either standard bubble coulters, or

Table 4. Stand of cotton no-till planted after mow-killing cover crops, as affected by planter and attachments and surface residue biomass at planting (Mississippi, 1995).

	Number of cotton plants m^{-1}		
Mowing time:	<2 days before planting	6–8 days before planting	>14 days before planting
Attachment			
Bubble coulter	6.2 a[1,2]	4.9 b	11.2 c
Acra-plant	3.9 a	10.5 bc	10.2 bc
Martin	10.5 bc	10.5 bc	11.5 c
Yetter	9.5 bc	11.2 bc	11.5 c
	Surface residue dry weight at cotton planting (Mg ha^{-1})		
Mowing time:	<2 days before planting	6–8 days before planting	>14 days before planting
Cover crop			
Rye	1.89 ab	1.52 ab	1.06 a
Rye + vetch	4.00 d	2.04 abc	1.74 ab
Vetch	3.26 cd	2.55 bc	1.51 ab

[1] Averaged over 3 years and cover crops.
[2] Means followed by different letters are significantly different ($P < 0.05$). Note that LSDs vary within and between rows and columns so that some numerically similar differences may have different statistical significance.

commercial tined-wheel row cleaner planter attachments mounted on a John Deere 7300 series no-till planter. In the first year, a Martin Row Cleaner (15-inch interlocking spoked wheels; Martin Industries, Elkton, KY) was compared to the bubble coulter. In the second and third years, the Acraplant Zone Manager (interlocking machined fingers attached to central hubs; ACRA-Plant, Garden City, KS) and Yetter Residue Manager (13-inch spoked wheels mounted on either side of a ¾-inch wavy coulter; Yetter Manufacturing, Colchester, IL) attachments were also evaluated. The cotton stand was determined from the center row of the plots 4 weeks after planting. In 1994 and 1995, gravimetric soil water content in the top 75-mm soil depth was determined at planting and, in 1995, surface residue biomass was measured from duplicate areas (each 0.1 m^2) of each plot. Statistical analysis of variance was conducted using Proc Mixed (SAS Institute, 1996).

Cotton stands were assessed in hairy vetch/rye covers that were killed in different ways in a replicated on-farm trial in Braggadocio, Missouri, in 1996. Cover-crop mixtures were killed by either disking, flail mowing or rolling with a stalk chopper. Plot size was 8 rows wide by 92 m long. The cover crop was either tilled into the soil 3 weeks prior to planting, or was rolled or mowed the same day as planting, on 22 May 1996. Rolling was accomplished with a reel pulverizer (rolling stalk chopper) that comprises the front end of a 'do-all' (Forrest City Machine Works, Forrest City, AR), a secondary tillage implement used commonly in the southern US. A combination of a rolling stalk chopper and harrow, a do-all breaks up clods, levels ridges and prepares a seedbed. In this study, the rear harrows were removed before using the front stalk chopper, so that the cover-crop residues would not drag. The stalk chopper consisted of an array of five blades attached to a central bearing to form a reel 46 cm in diameter. When pulled through the field, it rolled down the rye/vetch cover crop and crimped the stems every 29 cm. The tool cut completely through the stems on the tops of the bedded rows, but cutting was incomplete in the lower row middles. Control in these areas was less complete than from flail mowing, but there was little regrowth or crop competition, possibly because of planter and tractor wheel traffic. Each plot was subdivided into 4-row subplots and replicated four times, with treatments being with or without Martin Row Cleaners attached to a Case/International Early Riser planter. Cotton stands were determined 4 weeks after planting.

The effectiveness of mowing, rolling or undercutting summer cover crops was assessed in Plymouth, North Carolina, during September 1995. In North Carolina, summer cover crops have the potential to be incorporated into cropping systems between spring and fall vegetable crops. Plots consisted of three 1.5-m wide raised beds each 6.1 m long, split by method of cover-crop kill and replicated four times. Eleven different summer cover crops were treated on 1 September 1995, and percent kill was rated visually 3 weeks later. A 1.5-m wide flail mower was used for the mowing treatment. Undercutting was accomplished with the implement described in the literature review, while rolling was accomplished by lifting the blades of the undercutter out of the ground and placing downward pressure on the rolling basket. Data were subjected to analysis of variance, and least-significant difference (LSD) tests were used to separate means (SAS Institute, 1989).

Results and Discussion

In Mississippi, when the standard bubble coulter was used, cotton stands improved if planting was delayed at least 2 weeks after mowing the cover crops (Table 4). All functioning row cleaners that removed residues from in front of the planter's double-disk openers caused less 'hairpinning' of residues than did standard bubble coulters, and this improved the cotton stands. The Martin and Yetter planters improved stands when cotton was no-till planted 2 or fewer days after mowing cover crops. In contrast, the Acraplant attachment quickly became plugged with fresh cover-crop residues and stopped turning, resulting in seed drop on the soil surface, and thus, reduced stands. Although the row cleaners differed in their ability to handle cover-crop residues without plugging, all worked effectively when residues were dry and brittle. With reference to the Missouri study discussed below, none of the row cleaners was satisfactory when cover-crop residues were heavy and fresh.

In the Mississippi study, mowing at the earliest date (14–19 April) allowed regrowth of rye and vetch; moreover, some winter weeds resumed growth so that these plots had green vegetation by planting time each year (data not shown). At later dates, mowing killed both rye (heading) and vetch (vegetative). Mowing also caused rapid drying of cover-crop residues. Because of rainfall during the month preceding planting (113 mm in 1994 and 140 mm in 1995) there were no significant differences in gravimetric soil water content at cotton planting between cover-crop kill dates (average 0.24 g/g in 1994 and 0.26 g/g in 1995). Residue cover on the soil surface increased as the interval between cover-crop mowing and planting was reduced (Table 4). This trend is due both to termination of growth by mowing and residue decomposition after mowing.

In the Missouri field study (Table 5), the Martin Row Cleaners did not work on a large scale when mowing and planting were done the same day, because they became wrapped with the moist and flexible vegetation. In this study, no-till cotton stands were improved by using the planter without the row cleaner in areas where the rye/vetch cover crop was roll-chopped rather than mowed. Residues oriented in the direction of planter travel were more easily displaced by the planter's double-disk opener than where the cover crop had been mowed. Similarly, in the Mississippi study, an additional treatment conducted only in 1993 showed that use of the bubble coulter prior to mowing resulted in a better stand (9.5 plants m^{-1}) than planting after mowing (Table 4), possibly because there was less randomly oriented mulch on the soil surface. Ratings made 4 weeks after planting showed 100% kill of the cover crop from tillage or mowing, and 90% kill from roll-chopping (data not shown).

Table 6 shows percent kill of 11 summer cover crops rated 3 weeks after treatment in the 1995 North Carolina study. In general, undercutting greatly improved mechanical killing of all the broadleaf cover crops not killed by rolling alone and provided greater than 90% kill for five of the six broadleaf cover crops. Grass cover crops were better controlled by undercutting, except for the two species that were killed by all three methods. Without exception, the broadleaf cover crops were easily killed by mowing, even in the vegetative stage. Pearl millet [*Pennisetum glaucum* (L.) R.Br.], sorghum-sudangrass [*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf] and sudangrass (*Sorghum sudanense* L.) initiated regrowth 3 weeks after mowing. Mowing killed Japanese millet [*Echinochloa frumentacea* (Roxb.) Link] that had already formed mature seed, and German foxtail millet in the green seed stage. Rolling provided little control of the summer cover crops, except for nearly mature German foxtail millet, mature Japanese millet and mature buckwheat.

Table 5. Stand of cotton planted after tilling, mowing or roll-chopping a rye/vetch cover crop in Braggadocio, Missouri, in 1996.

	Plants m^{-1} 4 weeks after planting	
Management	Row cleaner	No row cleaner
Till	10.5	10.2
Mow	6.2	7.8
Roll-chop	6.9	9.2

LSD (0.05) = 2.3.
Cover crop biomass: 5.6 ± 0.3 Mg ha^{-1}.

Table 6. Percent kill of various summer cover crop species by mowing, undercutting, or rolling in North Carolina in 1995.

Cover crop	Scientific name	Growth stage	Mow	Undercut	Roll
Broadleaves					
Cowpea 'Iron clay'	*Vigna unguiculata* (L.) Walp.	Vegetative	98	85	5
Sesbania	*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hall	Vegetative	100	100	34
Lablab	*Lablab purpureus* (L.) Sweet	Vegetative	96	98	25
Velvetbean	*Mucuna deeringiana* (Bort) Merr.	Vegetative	100	95	52
Soybean 'Young'	*Glycine max* (L.) Merr.	Early bloom	100	99	12
Buckwheat	*Fagopyrum esculentum* Moench	Mature seed	100	100	100
Grasses					
Pearl millet	*Pennisetum glaucum* (L.) R.Br.	Heading	0	73	18
German foxtail millet	*Setaria italica* (L.) P. Beauv.	Green seed	100	100	100
Japanese millet	*Echinochloa frumentacea* (Roxb.) Link	Mature seed	100	100	100
Sudangrass	*Sorghum sudanense* L.	Green seed	0	84	28
Sorghum-sudangrass	*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf	Mature seed	0	89	25

LSD (0.05) = 54.

though cowpea [*Vigna unguiculata* (L.) Walp.] was easily killed in this study, considerable regrowth occurred when mowed in 1997 and undercut in 1998 2 weeks earlier in the season (Creamer, unpublished data).

Summary

Many summer and winter cover crops can be effectively killed using mechanical methods other than tillage or with herbicide application. Winter annual broadleaves and grass cover crops can be effectively killed by mowing, although there is a trend for increased kill at later growth stages, and, in the case of hairy vetch, with longer stem lengths. Lower mower height can also increase kill. Summer annual grasses, as compared to winter annuals, are more difficult to kill by mowing. However, depending on the time of year and cash crop, regrowth of the cover crop may not reduce yields of the cash crop. Mowing is an attractive management option because most growers already have mowers on their farms. However, mowing generates small residue pieces that decompose quickly, and thus may result in less weed suppression by the cover-crop residue. Flail mowing, as compared to other mowing methods, distributes plant residues more evenly, lessening subsequent planting difficulties and enhancing weed suppression. Because cover crops frequently have considerable decumbent stem length on the soil surface, a low cutting height usually improves cover-crop kill by mowing, unless the soil surface is not level. When a cover crop is mowed, the pieces lie on the ground in a random orientation, and double-disk planter openers are likely to hairpin some pieces in with the seed. Where residues are dry, the use of row cleaner planter attachments that move the residue away from the drill can reduce this problem and improve stands of direct-seeded crops.

Although rolling alone is sometimes not an effective method of cover-crop kill, roll-chopping has increased effectiveness and has several potential advantages over mowing. Rolling or roll-chopping provides a more persistent mulch, and orients the residues to facilitate planting. Both rolling and roll-chopping are also faster, and therefore less expensive, than mowing. It is often recommended that no-till planting into herbicide-killed cover crops be delayed for several weeks after treatment to avoid stand establishment problems (Dabney et al., 1996; Teasdale and Shirley, 1998). This delay reduces the weed control benefits that may be obtained from the cover-crop mulch subsequent to planting, and may possibly be shortened with rolling. Assessing the benefits of integrated management systems that use no-till seeding and direct transplanting prior to or after rolling cover crops warrants more research.

Undercutting has many of the same advantages as rolling and roll-chopping; however, it is more dependent on soil moisture conditions, and thus, timeliness of cultural operations may be an issue. As compared with rolling, undercutting requires more horsepower and the operation is slower. In the studies reviewed herein, undercutting was more effective than rolling in killing both broadleaf and grass cover crops. The soil is loosened by the operation, which may facilitate subsequent transplanting and early growth of vegetable crops.

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