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Evaluation of Organic Spring Cover Crop Termination Practices to Enhance Rolling/Crimping

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Abstract: With organic farming hectarage and cover crop interest increasing throughout the United States, effectively timed cover crop termination practices are needed that can be utilized in organic conservation tillage production systems. Four commercially available termination treatments approved by Organic Materials Review Institute (OMRI) were evaluated, immediately following mechanical termination with a cover crop roller/crimper and compared to a synthetic herbicide termination to access termination rates. Treatments included rolling/crimping followed by (1) 20% vinegar solution (28 L a.i. ha^{-1} acetic acid), (2) 2.5 L a.i. ha^{-1} 45% cinnamon (*Cinnamomum verum* L.) oil (cinnamaldehyde, eugenol, eugenol acetate)/45% clove oil (eugenol, acetyl eugenol, caryophyllene) mixture, (3) 0.15 mm clear polyethylene sheeting applied with edges manually tucked into the soil for 28 days over the entire plot area (clear plastic), (4) broadcast flame emitting 1100 °C applied at 1.2 k/h (flame), (5) glyphosate applied at 1.12 kg a.i. ha^{-1} (this non-OMRI-approved, non-organic conservation tillage cover crop termination standard practice was included to help ascertain desiccation, regrowth, and economics), and (6) a non-treated control. Five cover crop species were evaluated: (1) hairy vetch (*Vicia villosa* Roth), (2) crimson clover (*Trifolium incarnatum* L.), (3) cereal rye (*Secale cereale* L.), (4) Austrian winter pea (*Pisum sativum* L.), and (5) rape (*Brassica napus* L.). Three termination timings occurred at four-week intervals beginning mid-March each year. In April or May, organic producers are most likely to be successful using a roller crimper as either a broadcast flamer for terminating all winter covers evaluated, or utilizing clear plastic for hairy vetch, winter peas, and cereal rye. Ineffectiveness and regrowth concerns following cover crop termination in March are substantial. Commercially available vinegar and cinnamon/clove oil solutions provided little predictable termination, and producers attempting to use these OMRI-approved products will likely resort to cover crop incorporation, or mowing, to terminate covers if no other practice is readily available.

Keywords: cinnamon oil; clove oil; cover crop biomass; flame termination; organic agriculture; organic herbicides; roller/crimper; solarization; vinegar

1. Introduction

In 2018, US vegetable farmers produced over 7.53 million hundredweight (cwt; 100 pounds) on over one million hectares, with a value of over US $12.9 billion [1]. On average, per-capita consumption of vegetables was estimated to be 170 kg person^{-1} [2]. As the world's largest market for organic food, organic vegetable production in the United States comprises 8.4% of total vegetable land area, and sales from organic production are more than US $5.5 million [3]. However, as of 2011, only 0.6% of US cropland was certified for organic production due to obstacles such as high management costs, risks associated with operational changes, limited knowledge of organic production methods, and marketing and infrastructure limitations [3].

For organic producers and producers considering transitioning to organic production, there are numerous management practices (e.g., reduced tillage, cover cropping, crop rotation, and intercropping) that are beneficial to soil quality [4,5]. When combined with reduced tillage, cover crops provide many benefits such as reduced soil erosion, utilizing legumes to provide nitrogen, the potential for reduced pesticide use, improved precipitation infiltration and subsequent soil moisture, enhanced soil organic matter, disruption of pest cycles, and weed suppression [6–11]. Integration of reduced tillage in vegetable production can be challenging due to lack of recommended practices, among others [12]. Specifically, loss of weed control provided by tillage and cultivation and integration challenges with polyethylene plastic production systems are the main concerns [5]. However, weed suppression in vegetable production can be attained utilizing residue from a variety of cover crops grown prior to the vegetable crop. Traditionally, in organic conventional tillage systems, winter cover crops are incorporated into the soil through primary and secondary tillage before crop seeding or transplanting [8,13–15]. Weed emergence is reduced while the cover crop is growing, as well as through the release of allelopathic compounds produced after soil incorporation [6,14,16–18]. In reduced tillage organic systems, cover crop residue remains on the soil surface after termination to suppress weed growth through both chemical and physical means [9,19–22]. Common cover crops include fall-planted species such as cereal rye, crimson clover (*Trifolium* spp.), pea (*Pisum* spp.), vetch (*Vicia* spp.), and radish (*Raphanus* spp.) [6,23].

Cover crop termination in organic conservation agriculture is primarily dependent on mechanical practices including rolling/crimping or flail mowing. Flail mowing increases mulch decomposition rate and creates planting issues when using a mechanical transplanter [20]. The Brazilian conservation tillage system, based on terminating cover crops by mechanically rolling/crimping winter covers (forming a dense residue mat on the soil surface into which crop seeds are planted), has been evaluated in many traditional row crop systems [24–27]. This system has also recently been adapted to specialty crop systems into which seedlings are transplanted [12,28]. The relatively flat cover crop biomass mat that is generated would allow for complementary termination methods to be subsequently applied to enhance termination rates (how fast the cover crop biomass desiccates and becomes brittle) [19,26,28,29]. Timely, effective cover crop termination has been cited as a major adoption impedance to producers wanting to integrate conservation tillage practices in organic vegetable or row crops (Steve Li, personal communication).

Integrating Organic Materials Review Institute (OMRI)-approved commercially available organic herbicides, solarization, or flaming following rolling/crimping could help enhance cover crop termination rates and prevent regrowth, similar to the effects of utilizing glyphosate in non-organic systems following rolling/crimping [19]. Vinegar (acetic acid, 20%) and clove (*Syzygium aromaticum* L.) oil (eugenol, acetyl eugenol, caryophyllene, 60%–90%) are marketed organic herbicides and have been evaluated for weed control in sweet corn (*Zea mays* L.), potato (*Solanum tuberosum* L.), and onion (*Allium cepa* L.) [30]. Results reveal that unrealistically high application volumes of 636 L ha^{-1} and 318 L ha^{-1} were needed for vinegar and clove oil, respectively, for marginal initial herbicidal activity on relatively small weeds. Vinegar weed control decreased as weed size increased, application volume decreased, and control decreased over time due to regrowth. Vinegar has been shown to have higher herbicidal activity compared to clove oil, which was shown to be ineffective for weed control. However, these products following cover crop injury due to rolling/crimping may increase the cover crop termination rate, thus conserving soil moisture and facilitating earlier subsequent crop planting opportunities. Flame weeding has been evaluated for weed control before crop emergence or inter-row for onion, sweet corn, and cabbage (*Brassica oleracea* L.) [31–34].

Mechanical cover crop termination may be accelerated utilizing heat-induced cellular membrane disruption, such as flaming or solarization with clear polyethylene to trap solar radiation. Solarization has been utilized throughout warmer climates for weed and other pest control [35]. Synthetic mulches are allowable in organic production systems as long as they are removed from the field at the end of the growing season [36].

Timely spring cover crop termination in organic production systems would allow for increased adoption and retention of conservation tillage practices. Cover crop termination in non-organic conservation agriculture has been primarily and broadly accomplished using glyphosate over decades. Producers transitioning from non-organic to organic systems will likely be familiar with glyphosate's cover crop termination efficacy as well as economics. Thus, the objectives of this experiment were to determine the response of various cover crops species at different spring termination timings, to organic cover crop termination herbicides or practices, and determine their associated costs as compared to glyphosate, the non-OMRI-approved cover crop termination standard practice utilized in non-organic conservation systems [37].

2. Materials and Methods

A two-year cover crop termination experiment was established in the fall of 2013 in Alabama, following summer fallow in both years. The experiment was conducted at the Alabama Agricultural Experiment Station E.V. Smith Research Center Field Crops Unit, near Shorter, AL (32.42 N, 85.88 W) on Compass loamy sand. The experimental design was a randomized complete block design ($r = 4$) with a split block restriction on randomization. This design was chosen for practical reasons because it enabled efficient seeding of cover crops and application of termination treatments at three different application timings. We randomly assigned cover crop termination timings (3 timings) within main blocks. Within each termination timing block, we assigned cover crop species (5 species) to horizontal strips, and termination methods (6 methods) were randomly assigned vertically across strips. Therefore, we had three different sizes of experimental units [38]. The largest experimental unit (termination timing) equals one-third of the block size, the second largest (cover crop species) equals one-fifth of the block size, and the smallest (cover crop × termination treatment × termination timing combinations) equals 1/90 of the block size. This design also led to three different sources of experimental errors catering to each experimental unit. The smallest experimental unit (henceforth called plot) was 4 m wide and 8 m long. Cover crops were planted October 15 and October 5 in 2013 and 2014, respectively.

Three termination timings occurred at four-week intervals beginning mid-March each year. Five cover crop species were evaluated: (1) Austrian winter peas drill seeded at 101 kg ha^{-1}, (2) crimson clover (cv. Dixie) drill seeded at 28 kg ha^{-1}, (3) hairy vetch drill seeded at 22 kg ha^{-1}, (4) rape (cv. Athena) drill seeded at 11 kg ha^{-1}, and (5) cereal rye (cv. Wrens Abruzzi) drill seeded at 101 kg ha^{-1} in October each year. Immediately following a 3.66 m straight bar roller/crimper, six termination treatments were applied: (1) 20% vinegar solution (28 L a.i. ha^{-1} acetic acid), (2) 2.5 L a.i. ha^{-1} 45% cinnamon (*Cinnamomum verum* L.) oil (cinnamaldehyde, eugenol, eugenol acetate)/45% clove oil (eugenol, acetyl eugenol, caryophyllene) mixture, (3) 0.15 mm clear polyethylene sheeting applied with edges manually tucked into the soil for 28 d over the entire plot area (clear plastic), (4) broadcast flame emitting 1100 °C applied at 1.2 km/h (flame), (5) glyphosate applied at 1.12 kg a.i. ha^{-1} (this non-organic, conservation tillage cover crop termination standard practice treatment was included to help ascertain desiccation and regrowth and to make a monetary comparison), and (6) a non-treated control. A non-ionic surfactant at 0.25% (v/v) was included in all vinegar and cinnamon/clove oil treatments. Glyphosate, vinegar, and cinnamon/clove oil were applied with a compressed CO_2 backpack sprayer delivering 140 L ha^{-1} at 147 kPa. Flame was applied with a tractor mounted Red Dragon® Flamer (PL-8750 Poultry House Flame Sanitizer (Figure 1), Flame Engineering, Inc., P.O. Box 577, West Highway 4, LaCrosse, KS, USA, 67548) at 1.2 km ha^{-1} and 345 kPa operating pressure utilizing 382 L/ha (192 kg ha^{-1}) propane. The flame equipment utilized in this experiment used substantially more propane compared to others reported in the literature [31–34].

Figure 1. Rolled/crimped hairy vetch winter cover crop being desiccated by a Red Dragon® Flamer PL-8750 Poultry House Flame Sanitizer, Flame Engineering, Inc., moving at 1.2 k/h and emitting 1100 °C.

Since weather and solar radiation attributes affects cover crop biomass and solarization potential, average daily temperature, precipitation, and solar radiation are reported for each year in Figure 2. At each termination timing prior to rolling/crimping, cover crop biomass samples were collected by clipping all aboveground plant parts close to the soil surface from one randomly selected 0.25 m^2 section in each plot. Plant material was dried at 60 °C for 72 h and weighed. Cover termination ratings were visually estimated over the whole plot, assessing greenness, and recorded on a scale from 0% (no affect compared to non-treated control) to 100% (complete termination) [39]. Three termination ratings were recorded 7, 14, and 21 days after termination (DAT) treatments per plot in both years.

Total variable costs (TVC) were estimated using a partial budgeting approach for each cover crop and termination combination. Only variable costs that differed between treatments were included, and were assumed to be constant across the two years. These costs included cover crop seed and termination costs (labor, machinery repair and maintenance, fuel, and product). Cover crop seed costs were based on actual seed costs paid during the experiment: US \$1.74 kg^{-1} for Austrian winter pea, US \$1.98 kg^{-1} for crimson clover, US \$4.30 kg^{-1} for hairy vetch, US \$3.53 kg^{-1} for rapeseed, and US \$0.69 kg^{-1} for cereal rye. Table 1 displays the termination costs by termination method [40,41]. Cover crop planting (~US \$19 ha^{-1}) and rolling/crimping costs (~US \$13.10 ha^{-1}) were not included since these operations were applied to all plots. Machinery costs were based on a two-wheel drive, 37 kW closed cab tractor with a fuel price of US \$0.57 L^{-1}. Labor costs included both operator (US \$12.55 h^{-1}) and hand labor (US \$9.87 h^{-1}) as applicable.

Mixed models procedures as implemented in SAS® PROC GLIMMIX (SAS Institute Inc., Cary, NC, USA) were used to analyze winter cover biomass and visual termination as a percentage. Winter cover crop, termination timing, and termination treatment were considered fixed effects. Year and the interaction of replication with termination timing and termination treatment were considered random effects. Error terms appropriate to the split design with repeated measures were used to test main effects and interactions at $P \leq \alpha = 0.10$. We chose this α prior to analysis knowing inherent variability in visually estimated data is higher than other quantitative data. Non-transformed data for visual termination evaluations were presented because transformation did not affect data interpretation. Treatment differences were calculated by Tukey–Kramer grouping least square means test.

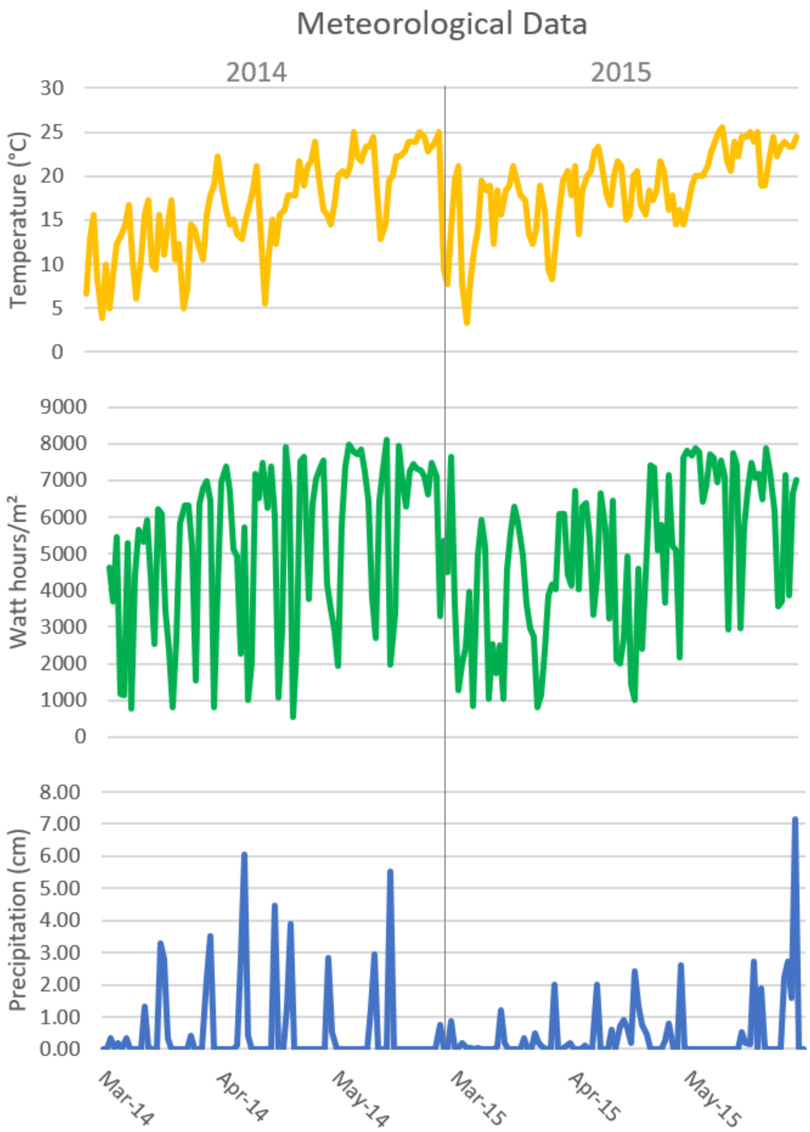

Figure 2. The 2014 and 2015 average daily temperature (°C), solar radiation (Wh/m^2), and precipitation (mm).

Table 1. Total variable costs by termination method ($US ha^{-1}).

Termination Method	Product	Product Application	Total Variable Costs
		$US ha^{-1}	
Non-treated	0	0	0
Glyphosate	5.76	8.93	14.69
Vinegar	1074.54	22.06	1096.60
45% clove/45% cinnamon oil	148.24	22.06	170.31
Clear plastic	790.88	306.73	1097.61
Flame	266.87	76.18	343.05

3. Results and Discussion

3.1. Cover Crop Biomass

ANOVA revealed significant effects for cover crop, termination treatment, and termination timing. ANOVA also showed that the year by species interactions were significant ($p < 0.10$). Therefore, each species is discussed separately by year. In 2014, a maximum May biomass of 8838 kg ha^{-1} was attained in cereal rye plots, followed by Austrian winter peas (7177 kg ha^{-1}), hairy vetch (6213 kg ha^{-1}), and crimson clover (5124 kg ha^{-1}) (Table 2). Rape provided the least biomass (1657 kg ha^{-1}). Terminating covers in April resulted in approximately 50% less biomass in all comparisons, while terminating covers in March resulted in less than 1000 kg ha^{-1} regardless of cover crop. These results are similar to previously reported biomass and are indicative of proper management and environmental conditions (Figure 2) [19,29]. Conservation agriculture specialists consider cover crop biomass amounts exceeding 4000 kg ha^{-1} as 'high biomass' systems [25]. However, for more effective weed suppression, weed scientists recommend >6000 kg ha^{-1} [20–22,29].

In 2015, a relatively warm winter and higher early spring temperatures (Figure 2) resulted in quicker spring cover crop growth compared to 2014 and covers attained maximum biomass at the April (2nd) termination date (Table 2). Similar to 2014, cereal rye attained the highest biomass at 5828 kg ha^{-1} followed by crimson clover and hairy vetch (3995 and 3787 kg ha^{-1}, respectively). Austrian winter pea provided 1623 kg ha^{-1} while rape again resulted in the least biomass (558 kg ha^{-1}) when terminated in April. Again, terminating covers in March again reduced cereal rye and rape biomass by half and decreased the legumes' biomass by a third. Early termination due to planting schedules for early cash crops is a challenge to producing high biomass, especially as you move to more northern latitudes [20].

Table 2. Cover Crop Biomass at Three Termination Timings, E.V. Smith 2014 and 2015.

	Cover Crop Dry Biomass (kg/ha)		
2014			
Cover Crop	**1st Termination Timing [1]**	**2nd Termination Timing**	**3rd Termination Timing**
Austrian Winter Peas	959 ^{hg**}	2587 ^{fe}	7177 ^{b}
Crimson Clover	336 ^{h}	2369 ^{fe}	5124 ^{cd}
Hairy Vetch	928 ^{hg}	3094 ^{e}	6213 ^{cb}
Rape	116 ^{i}	370 ^{h}	1657 ^{fg}
Cereal Rye	719 ^{hg}	4769 ^{d}	8838 ^{a}
LSD (α = 0.10)	634.08	—	—
2015			
Cover Crop			
Austrian Winter Peas	1762 ^{dc}	1623 ^{d}	
Crimson Clover	2408 ^{dc}	3995 ^{b}	
Hairy Vetch	1991 ^{dc}	3787 ^{b}	
Rape	84 ^{e}	558 ^{e}	
Cereal Rye	2453 ^{c}	5828 ^{a}	
LSD (α = 0.10)	448.7	—	

[1] Cover crop biomass was obtained on March 14, April 16, and May 14, 2014; March 11, and April 12, 2015. Cover crop biomass was not sampled in May 2015 as covers had reached maximum maturity in April. ** Mean separations with the same letter are not significantly different.

3.2. Cover Crop Termination

As previously stated, cover termination ratings were estimated by visually accessing greenness over the whole plot and recorded on a scale from 0% (no affect compared to non-treated control) to 100% (complete termination). ANOVA revealed significant effects for cover crop, termination treatment, and termination timing. ANOVA again showed year by cover crop species interactions were significant ($p < 0.10$). Therefore, each species is discussed separately by year. To facilitate discussion, the 7 (DAT) % termination estimation will be referred to as 'quick' or 'quickly', whereas the 21 DAT % termination estimation will be referred to as 'waiting longer'. As previously stated, rolling/crimping was accomplished on all plots, therefore rolling/crimping alone will be discussed first, followed by the remaining treatments applied immediately following this practice.

Hairy Vetch. In March 2014, rolling/crimping alone provided no quick termination or after waiting longer (Table 3). This result shows additional/alternative practices are required in March to attain termination. The highest (90%) quick termination was attained following flaming; however, regrowth occurred, and termination decreased to 23% after waiting longer. Similarly, significant regrowth was observed in effective quick (90%) glyphosate non-organic comparison treatment after waiting longer, further highlighting hairy vetch resiliency. In March, 95% termination was attained after covering with clear plastic sheeting after waiting longer, and regrowth did not occur following plastic removal (data not shown). In March, other termination practices were not effective quickly or after waiting longer. In April, rolling/crimping alone again provided no termination quickly or after waiting longer (Table 3). Flaming in April resulted in 93% termination quickly, and again following regrowth, only 68% termination was observed after waiting longer. In May, rolling/crimping alone provided 90% termination after waiting longer (Table 3). Cinnamon/clove oil provided a quick 28% increase in termination in April, compared to the ineffective rolled/crimped alone treatment; while vinegar failed to injure hairy vetch. However, regrowth again occurred and negated the control attained with oil. In 2015, likely due to advanced maturity in March, rolling/crimping alone provided 32% termination quickly but did not increase to adequate termination after waiting longer. The addition of flaming provided 93% termination quickly and near complete termination after waiting longer (Table 4). Clear plastic provided 85% termination after waiting longer, with no regrowth after removal (data not shown). In April, hairy vetch termination was 87% following rolling/crimping alone quickly and increased to 99% after waiting longer (Table 4). Similar to 2014, cinnamon/clove oil and vinegar showed little to no substantial activity on hairy vetch in 2015 (Table 4). Thus, when selecting a cover crop proceeding a March- or April-planted cash crop, hairy vetch might not be the best choice if quick termination is needed due to both resiliency and regrowth concerns. If slower termination can be utilized due to subsequent cash crop planting timing, clear plastic will likely be effective in terminating hairy vetch. Overall, hairy vetch termination rates increased, and regrowth was reduced by delaying termination. These results are similar to those reported by Mirsky et al. [42].

Crimson Clover. In 2014, crimson clover response to treatments was similar to hairy vetch in most comparisons (Table 3). In March and April, rolling/crimping alone provided no termination quickly or after waiting longer (Table 3). Flaming clover was less effective in March compared to hairy vetch likely due to the lack of biomass to injure. Clear plastic was also moderately effective in March after waiting longer, and was highly effective in April and May quickly. In April, clover was terminated 42% with cinnamon/clove oil quickly, and this was the second highest susceptibility observed compared to the non-treated, albeit still inadequate, for any species evaluated in this experiment terminated with cinnamon/clove oil. Rolling/crimping alone was 99% effective after waiting 14 d when terminated in May. Vinegar resulted in no termination quickly, or after waiting longer, for any application timing when compared to the rolled/crimped non-treated. In 2015, March clover termination was similar to April 2014 (Table 4). In April, rolling/crimping alone resulted in 87% control quickly and 99% termination after waiting longer (Table 4). Clear plastic was again highly effective in April and May quickly. Similar to 2014, cinnamon/clove oil and vinegar were non-effective at enhancing clover termination quickly or after waiting longer, at any application timing. Thus, similar to hairy vetch, selecting a cover crop proceeding a March-planted cash crop, crimson clover might not be the best choice if quick termination is needed, due to resiliency. If slower termination can be utilized due to subsequent cash crop planting timing, or use in April or later, clear plastic will likely be effective in terminating crimson clover. These results agree with those of Evans and Bellinder [30] that reported termination rates increased with clover maturation.

Cereal Rye. In 2014, rolling/crimping alone provided no termination and no treatment effectively terminated rye in March (Table 3). In April, rolling/crimping alone resulted in 60% termination quickly. Flaming resulted in 97% termination; however, termination decreased to 70% following regrowth after waiting longer (Table 3). Clear plastic covering rye resulted in 97% termination after waiting 14 d. Cinnamon/clove oil increased termination 13 percentage points over rolling/crimping alone after waiting longer. In May, rolling/crimping alone provided 94% termination quickly and increased to 99% after waiting an additional week (Table 3). In 2015, rolling crimping in April alone provided 75% termination quickly and increased to 98% by waiting longer (Table 3). Flaming increased the rate of termination 23% and 11% quickly and after 14 d, respectively. In May rolling/crimping alone provided 99% control quickly, with no additional treatment increasing rye termination (Table 4). Notably, the cinnamon and clover oil mixture increased termination rates for cereal rye in one year after waiting longer. Generally, these results are similar to those reported by researchers that show termination rates following rolling/crimping increase as cereal cover crop growth stage progresses [24,26]. For March-planted cash crops, producers likely would benefit by not choosing cereal rye, as it is relatively hard to terminate at early growth stages. Sequential rolling/crimping or flaming operations would likely be needed.

Austrian Winter Pea. In 2014, March rolling/crimping alone resulted in no termination quickly or after waiting longer (Table 3). Flaming provided 82% pea termination quickly, however aggressive regrowth resulted in only 10% termination after waiting longer. Clear plastic covering peas after waiting longer resulted in 58% termination, with no regrowth after removal (data not shown). Cinnamon/clove oil and vinegar provided no pea termination quickly or after waiting longer at any application timing. In April, rolling/crimping provided 25% termination alone with flaming and clear plastic treatment resulting in 98% termination after waiting 14 d (Table 3). In May, rolling/crimping alone provided 20% termination quickly, however, termination increased to 96% after waiting longer (Table 2). In 2015, rolling/crimping alone provided 48% termination quickly and increasing to 79% after waiting longer, again, likely due to later maturity (Table 4). Cinnamon/clove oil increased pea termination by 23 and 11 percentage points over rolling/crimping alone after 14 d and longer, respectively. Similar to the previous cover crops, March-planted conservation tillage cash crop establishment may be challenging due to insufficient winter pea termination.

Rape. In March and April 2014, rolling/crimping provided no termination quickly or after waiting longer (Table 3). Flaming provided 95% termination quickly, however, rape recovered completely after waiting longer (Table 3). Clear plastic provided 58% termination after waiting longer, with no regrowth after removal (data not shown). Cinnamon/clove oil and vinegar provided no termination at any application timing quickly or after waiting longer. In April, flaming provided only 33% termination quickly and did not increase after waiting longer (Table 3). Clear plastic provided 48% termination quickly, increasing to 78% after waiting longer. In 2015, rolling/crimping in March provided no rape termination quickly or after waiting longer (Table 3). Clear plastic was very effective, providing 95% termination quickly increasing to 99% after waiting longer, likely due to increasing solar radiation and relatively high air temperatures. Flaming provided 99% termination quickly, however, termination decreased to 70% after waiting longer due to regrowth. Similar to 2014, cinnamon/clove oil and vinegar provided no rape termination at any application timing quickly or after waiting longer.

Table 3. Cover crop response to termination method by termination date in 2014.

Cover Crop	Termination Method	1st Termination Date (March) 7 DAT	14 DAT	21 DAT	2nd Termination Date (April) 7 DAT	14 DAT	21 DAT	3rd Termination Date (May) 7 DAT	14 DAT	21 DAT
		% Termination *								
Hairy Vetch	Non-treated [1]	3^{cb}	0^{c}	0^{c}	0^{c}	0^{c}	0^{b}	37^{b}	78^{b}	90^{a}
	Glyphosate [2]	13^{b}	90^{a}	60^{ba}	43^{bc}	72^{b}	83^{a}	58^{b}	98^{a}	99^{a}
	Vinegar [3]	2^{cb}	2^{c}	0^{c}	0^{c}	0^{c}	0^{b}	53^{b}	80^{ba}	81^{a}
	Clove/cinnamon oil [4]	8^{cb}	0^{c}	0^{c}	28^{bc}	8^{c}	5^{b}	62^{ba}	85^{ba}	93^{a}
	Clear plastic [5]	1^{c}	3^{c}	95^{a}	66^{ba}	97^{a}	66^{a}	99^{a}	99^{a}	99^{a}
	Flame [6]	90^{a}	63^{b}	23^{bc}	93^{a}	73^{b}	68^{a}	98^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	6.7	9.4	29.5	29.5	6.1	34.9	22.8	11.8	11.4
Crimson Clover (Dixie)	Non-treated	2^{b}	0^{c}	0^{c}	0^{c}	0^{c}	0^{c}	67^{b}	99^{a}	99^{a}
	Glyphosate	57^{a}	98^{a}	98^{a}	38^{b}	93^{a}	97^{a}	78^{ba}	99^{a}	99^{a}
	Vinegar	3^{b}	2^{c}	2^{bc}	2^{c}	0^{c}	0^{c}	57^{b}	99^{a}	99^{a}
	Clove/cinnamon oil	5^{b}	5^{c}	10^{bc}	42^{b}	33^{b}	30^{b}	57^{b}	66^{a}	66^{a}
	Clear plastic	8^{b}	3^{c}	72^{a}	82^{a}	93^{a}	97^{a}	99^{a}	99^{a}	99^{a}
	Flame	67^{a}	68^{b}	52^{ba}	96^{a}	96^{a}	96^{a}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	23.0	14.3	31.0	18.6	11.0	10.6	17.2	34.0	34.0
Cereal Rye (Wrens Abruzzi)	Non-treated	0^{c}	0^{c}	0^{b}	60^{ba}	63^{b}	67^{ba}	94^{b}	99^{a}	99^{a}
	Glyphosate	48^{a}	98^{a}	69^{a}	97^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Vinegar	0^{c}	0^{c}	0^{b}	45^{b}	53^{b}	53^{b}	94^{b}	99^{a}	99^{a}
	Clove/cinnamon oil	8^{c}	0^{c}	0^{b}	75^{ba}	85^{a}	80^{ba}	96^{ba}	99^{a}	99^{a}
	Clear plastic	2^{c}	2^{c}	48^{ba}	82^{ba}	97^{a}	96^{a}	98^{ba}	99^{a}	99^{a}
	Flame	28^{b}	15^{b}	12^{b}	97^{a}	96^{a}	70^{ba}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	8.0	3.5	31.5	24.3	12.6	22.8	2.7	****	****
Austrian Winter Peas	Non-treated	0^{c}	0^{b}	0^{b}	27^{b}	28^{b}	25^{b}	20^{c}	87^{a}	96^{ba}
	Glyphosate	67^{ba}	98^{a}	99^{a}	60^{ba}	95^{a}	98^{a}	72^{b}	99^{a}	99^{a}
	Vinegar	31^{bac}	17^{b}	10^{b}	28^{b}	28^{b}	28^{b}	32^{c}	88^{a}	93^{b}
	Clove/cinnamon oil	27^{bc}	20^{b}	25^{b}	27^{b}	28^{b}	25^{b}	57^{b}	97^{a}	99^{a}
	Clear plastic	9^{c}	11^{b}	93^{a}	62^{ba}	98^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Flame	82^{a}	68^{a}	10^{b}	98^{a}	98^{a}	98^{a}	98^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	31.2	23.5	18.9	35.8	15.4	15.0	13.3	7.8	3.4
Rape (Athena)	Non-treated	0^{c}	0^{b}	0^{b}	0^{c}	0^{c}	0^{c}	2^{c}	0^{b}	0^{c}
	Glyphosate	48^{b}	96^{a}	69^{a}	80^{a}	97^{a}	98^{a}	47^{b}	90^{a}	94^{ba}
	Vinegar	2^{c}	0^{b}	0^{b}	0^{c}	0^{c}	0^{c}	2^{c}	0^{b}	0^{c}
	Clove/cinnamon oil	2^{c}	0^{b}	0^{b}	7^{bc}	0^{c}	0^{c}	2^{c}	0^{b}	0^{c}
	Clear plastic	0^{c}	1^{b}	58^{ba}	48^{ba}	63^{b}	78^{a}	95^{a}	99^{a}	99^{a}
	Flame	95^{a}	95^{a}	3^{b}	33^{bc}	37^{b}	33^{b}	99^{a}	70^{a}	70^{b}
	LSD (α = 0.10)	27.3	1.6	36.5	25.7	16.5	17.8	24.0	22.5	16.9

[1] No herbicide or other termination method was used to kill the cover crop other than mechanically rolling/crimping. [2] Mechanically rolling/crimping followed by glyphosate (not Organic Materials Review Institute (OMRI)-approved) applied to covers at 1.12 a.i. kg/ha. [3] Mechanically rolling/crimping followed by 20% vinegar solution applied to covers with an application volume of 140.25 L/ha. [4] Mechanically rolling/crimping followed by 2.5 L a.i. ha^{-1} 45% cinnamon (*Cinnamomum verum* L.) oil (cinnamaldehyde, eugenol, eugenol acetate)/45% clove oil (eugenol, acetyl eugenol, caryophyllene) mixture. [5] Mechanically rolling/crimping followed by clear plastic laid over the entire plot 3.7m × 3m area for 28 days. [6] Mechanically rolling/crimping followed by broadcast flaming emitting 1100 °C applied at 1.2 k/h. **** Mean separations with the same letter are not significantly different within a cover crop and termination timing. Treatment differences were calculated by Tukey–Kramer grouping least square means.

Table 4. Cover crop response to termination method by termination date in 2015.

Cover Crop	Termination Method	1st Termination Date (March) 7 DAT	14 DAT	21 DAT	2nd Termination Date (April) 7 DAT	14 DAT	21 DAT
		% Termination *					
Hairy Vetch	Non-treated [1]	32^{c}	37^{b}	38^{b}	87^{a}	99^{a}	99^{a}
	Glyphosate [2]	63^{b}	93^{a}	98^{a}	98^{a}	99^{a}	99^{a}
	Vinegar [3]	32^{c}	40^{b}	35^{b}	88^{a}	99^{a}	99^{a}
	Clove/cinnamon oil [4]	17^{c}	15^{b}	15^{b}	90^{a}	99^{a}	99^{a}
	Clear plastic [5]	65^{b}	87^{a}	85^{a}	90^{a}	99^{a}	99^{a}
	Flame [6]	93^{a}	92^{a}	98^{a}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	15.3	18.0	25.4	7.7	****	****
Crimson Clover (Dixie)	Non-treated	5^{b}	3^{c}	3^{c}	99^{a}	99^{a}	99^{a}
	Glyphosate	77^{a}	82^{ba}	96^{a}	99^{a}	99^{a}	99^{a}
	Vinegar	0^{b}	0^{c}	0^{c}	99^{a}	99^{a}	99^{a}
	Clove/cinnamon oil	10^{b}	8^{c}	8^{c}	99^{a}	99^{a}	99^{a}
	Clear plastic	30^{b}	58^{b}	5 8^{b}	98^{a}	99^{a}	99^{a}
	Flame	90^{a}	94^{a}	88^{ba}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	19.7	20.6	21.8	****	****	****
Cereal Rye (Wrens Abruzzi)	Non-treated	75^{bc}	87^{b}	98^{a}	99^{a}	99^{a}	99^{a}
	Glyphosate	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Vinegar	73^{c}	90^{ba}	98^{a}	99^{a}	99^{a}	99^{a}
	Clove/cinnamon oil	83^{bac}	92^{ba}	96^{a}	99^{a}	99^{a}	99^{a}
	Clear plastic	67^{c}	91^{ba}	93^{a}	99^{a}	99^{a}	99^{a}
	Flame	98^{ba}	98^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	13.7	6.2	5.6	****	****	****
Austrian Winter Peas	Non-treated	48^{a}	50^{a}	79^{a}	98^{a}	99^{a}	99^{a}
	Glyphosate	62^{a}	67^{a}	69^{a}	98^{a}	99^{a}	99^{a}
	Vinegar	40^{a}	50^{a}	72^{a}	99^{a}	99^{a}	99^{a}
	Clove/cinnamon oil	50^{a}	80^{a}	90^{a}	99^{a}	99^{a}	99^{a}
	Clear plastic	57^{a}	73^{a}	79^{a}	99^{a}	99^{a}	99^{a}
	Flame	96^{a}	97^{a}	98^{a}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	****	****	****	****	****	****
Rape (Athena)	Non-treated	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Glyphosate	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Vinegar	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	Clove/cinnamon oil	99^{a}	99^{a}	99^{a}	97^{b}	99^{a}	99^{a}
	Clear plastic	99^{a}	99^{a}	99^{a}	95^{c}	99^{a}	99^{a}
	Flame	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}	99^{a}
	LSD (α = 0.10)	****	****	****	****	****	****

[1] No herbicide or other termination method was used to kill the cover crop other than mechanically rolling/crimping. [2] Mechanically rolling/crimping followed by glyphosate (not OMRI-approved) applied to covers at 1.12 a.i. kg/ha. [3] Mechanically rolling/crimping followed by 20% vinegar solution (28 L a.i. ha^{-1} acetic acid). [4] Mechanically rolling/crimping followed by 2.5 L a.i. ha^{-1} 45% cinnamon (*Cinnamomum verum* L.) oil (cinnamaldehyde, eugenol, eugenol acetate)/45% clove oil (eugenol, acetyl eugenol, caryophyllene) mixture. [5] Mechanically rolling/crimping followed by clear plastic laid over the entire plot 3.7m × 3m area for 28 days. [6] Mechanically rolling/crimping followed by broadcast flaming emitting 1100 °C applied at 1.2 k/h. * Mean separations with the same letter are not significantly different within a cover crop and termination timing. Treatment differences were calculated by Tukey–Kramer grouping least square means. **** Indicates no significance.

3.3. Cover Crop Termination Economics

Cover crop seed costs drive cover crop establishment costs. Austrian winter peas had the highest per unit seed costs, and at a seeding rate of 101 kg ha^{-1}, it was the highest cost cover crop. Hairy vetch and cereal rye were also more expensive due to seed costs and seeding rate, respectively. However, since one of the main objectives of cover crops is to produce adequate biomass, the cover crop seed cost per 100 kg of dry biomass was calculated to compare the production potential in terms of dollars spent (Table 5). At the early termination date (March), rape had the highest cost per 100 kg of biomass, with biomass averaged across both years; however, at the later termination dates (April and May), there was little numerical difference between Austrian winter peas and rape. Biomass from Austrian winter peas and rape was the most expensive to produce across all three termination dates. Crimson clover and cereal rye consistently had lower seed costs per 100 kg produced biomass.

Glyphosate was the least expensive treatment option compared to non-treated; however, it obviously does not meet organic production standards (Table 6). Of the organic methods, cinnamon/clove oil was the least expensive and one of the least effective termination methods. Vinegar, along with clear plastic, had the highest costs as driven by product costs and application rates; however, in general, vinegar was not an effective termination method, while expensive, clear plastic was an effective termination method after waiting longer. Clear plastic also requires additional labor and machinery time as compared to the other treatments. Furthermore, there may be disposal costs associated with clear plastic, which were not accounted for in this analysis. The cost of flame termination was almost four times the cost of glyphosate; however, it proved to be an effective termination option for most covers evaluated in April or May. However, there may be additional costs if regrowth occurs after termination. Furthermore, the cost to purchase the equipment and ownership costs were not included since they differ greatly between farms. From an economic perspective, organic farmers should look at their operations, goal and objectives, and potential constraints, such as labor, before deciding on the most appropriate termination methods.

Table 5. Cover crop seed costs per 100 kg of biomass averaged over 2014–2015.

Cover Crop	Cover Crop Seed Costs per 100 kg of Biomass ($US 100 kg^{-1})		
	1st Termination Timing	2nd Termination Timing	3rd Termination Timing
Austrian Winter Peas	5.23	3.38	0.99
Crimson Clover	1.64	0.71	0.44
Hairy Vetch	2.67	1.13	0.63
Rape	16.00	3.45	0.97
Cereal Rye	1.79	0.54	0.32

Table 6. Total variable costs (including seed and termination method costs) by cover crop and termination method ($US ha^{-1}).

Cover Crop	Termination Method				
	Glyphosate	Vinegar	45% Clove Oil/45% Cinnamon Oil	Clear Plastic	Flame
	$US ha^{-1}				
Austrian Winter Peas	212	1272	346	1273	519
Crimson Clover	92	1152	226	1153	399
Hairy Vetch	133	1193	267	1194	439
Rape (Athena)	76	1136	210	1137	383
Cereal Rye	106	1167	240	1168	413

4. Conclusions

Five winter cover crops were evaluated, however, the *Brassica* (rape) never attained biomass at any termination timing that would benefit either soil quality or weed suppression. Because of the very low biomass produced, it was the most expensive to produce on a weight basis. In addition, Austrian winter pea was also expensive to produce on a weight basis. Crimson clover and cereal rye were both relatively less expensive on a weight bases and produced adequate biomass to both affect soil quality and provide weed suppressive qualities.

Organic producers seeking to terminate winter covers would most likely be successful using a broadcast flamer on most any winter cover in April or May, or utilizing clear plastic in hairy vetch, winter peas, or cereal rye, as ambient temperature increases along with solar radiation, both following a roller/crimper. Obvious limitations to using plastic include cooler climates, and/or higher latitudes. Termination rates increase as cover crops mature, thus, producers with early crop planting timing that necessitate early cover crop termination timings will likely need to use multiple recurrent practices to terminate most cover crops. Commercially available vinegar and cinnamon/clove oil solutions provided little predictable termination. Producers attempting to use these OMRI-approved products will likely resort to utilize cover crop incorporation, or mowing, to terminate covers if no other effective practice is readily available, and these practices fail to adequately terminate the cover.

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References

1. Anonymous 2018. Vegetables 2018 Summary. United States Department of Agriculture, Agricultural Marketing Service. Available online: https://downloads.usda.library.cornell.edu/usda-esmis/files/02870v86p/gm80j322z/5138jn50j/vegean19.pdf (accessed on 5 September 2019).
2. Well, H.F.; Bond, J.K. Vegetables and Pulses Outlook. VGS-357. United States Department of Agriculture, Economic Research Service, 2016. Available online: https://www.ers.usda.gov/publications/pub-details/?pubid=93032 (accessed on 5 September 2019).
3. Ferreira, G.; Turk, Z. Vegetables and Pulses Outlook: An Overview of Organic Vegetables and Production in the United States. VGS-357-SA2. Department of Agriculture, Economic Research Service, 2016. Available online: https://www.ers.usda.gov/webdocs/publications/74639/vgs-357.pdf?v=0 (accessed on 5 September 2019).
4. Kornecki, T.S.; Arriaga, F.J. Impact of different cover crops and types of transplanter mounted subsoiler shanks on tomato yield. *Hortscience* **2011**, *46*, 715–720. [CrossRef]
5. Singh, B.P.; Granberry, D.M.; Kelley, W.T.; Boyhan, G.; Sainju, U.M.; Phatak, S.C.; Sumner, P.E.; Bader, M.J.; Webster, T.M.; Culpepper, A.S.; et al. Sustainable vegetable production. In *Vegetables: Growing Environment and Mineral Nutrition*; Dris, R., Ed.; WFL Publisher: Helsinki, Finland, 2005; pp. 1–38.
6. Clark, A. *Managing Cover Crops Profitably*, 3rd ed.; Sustainable Agriculture Research and Education (SARE): College Park, MD, USA, 2007.
7. Balkcom, K.S.; Arriaga, F.J.; van Santen, E. Conservation systems to enhance soil carbon sequestration in the Southeast U.S. Coastal Plain. *Soil Sci. Soc. Am. J.* **2013**, *77*, 1774–1783. [CrossRef]
8. Peoples, M.B.; Herridge, D.F.; Ladha, J.K. Biological nitrogen fixation: An efficient source of nitrogen for sustainable agricultural production? *Plant Soil* **1995**, *174*, 3–28. [CrossRef]
9. Reeves, D.W. A Brazilian model for no-tillage cotton production adapted to the southeastern USA. In Proceedings of the Second World Congress on Conservation Agriculture-Producing in Harmony with Nature, Iguassu Falls, Paraná, Brazil, 11–15 August 2003; pp. 372–374.
10. Sarrantonio, M.; Gallandt, E. The role of cover crops in North American cropping systems. *J. Crop Prod.* **2003**, *8*, 53–74. [CrossRef]
11. Wang, K.; McSorley, R.; Gallaher, R.N.; Kokalis-Burelle, N. Cover crops and organic mulches for nematode, weed and plant health management. *Nematology* **2008**, *10*, 231–242. [CrossRef]
12. Duzy, L.M.; Kornecki, T.S.; Balkcom, K.S.; Arriaga, F.J. Net returns and risk for cover crop use in Alabama tomato production. *Renew. Agric. Food Syst.* **2014**, *29*, 334–344. [CrossRef]
13. Brennan, E.B.; Smith, R.F. Winter cover crop growth and weed suppression on the Central Coast of California. *Weed Technol.* **2005**, *19*, 1017–1024. [CrossRef]
14. Norsworthy, J.K.; Malik, M.S.; Jha, P.; Riley, M.B. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate—producing cover crops in organically grown bell pepper. *Weed Res.* **2007**, *47*, 425–432. [CrossRef]
15. Treadwell, D.D.; Creamer, N.G.; Schultheis, J.R.; Hoyt, G.D. Cover crop management affects weeds and yield in organically managed sweetpotato systems. *Weed Technol.* **2007**, *21*, 1039–1048. [CrossRef]
16. Cornell Cooperative Extension (CES). Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production. Cornell Cooperative Extension Publication, 2009. Available online: http://www.nysaes.Cornell.edu/recommends/11frameset.html (accessed on 23 April 2018).
17. Price, A.J.; Stoll, M.E.; Arriaga, F.J.; Bergtold, J.S.; Balkcom, K.S.; Kornecki, T.S.; Raper, R.L. Effect of cover crop extracts on cotton and radish radicle elongation. *Commun. Biometry Crop Sci.* **2008**, *3*, 60–66.

18. Reberg-Horton, S.C.; Burton, J.D.; Danehower, D.A.; Ma, G.; Monks, D.W.; Murphy, J.P.; Ranells, N.N.; Williamson, J.D.; Creamer, N.G. Changes over time in the allelochemical content of ten cultivars of rye (*Secale cereale* L.). *J. Chem. Ecol.* **2005**, *31*, 179–193. [CrossRef] [PubMed]
19. Price, A.J.; Norsworthy, J.K. Cover crop use for weed management in Southern reduced-tillage vegetable cropping systems. *Weed Technol.* **2013**, *27*, 212–217. [CrossRef]
20. Reberg-Horton, S.C.; Grossman, J.M.; Kornecki, T.S.; Meijer, A.D.; Price, A.J.; Place, G.T.; Webster, T.M. Utilizing cover crop mulches to reduce tillage in organic systems in the Southeast. *Renew. Agric. Food Syst.* **2011**, *27*, 41–48. [CrossRef]
21. Teasdale, J.R. Contribution of cover crops to weed management in sustainable agricultural systems. *J. Prod. Agric.* **1996**, *9*, 475–479. [CrossRef]
22. Teasdale, J.R.; Mohler, C.L. The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci.* **2000**, *48*, 385–392. [CrossRef]
23. Creamer, N.G.; Baldwin, K.R. An evaluation of summer cover crops for use in vegetable production systems in North Carolina. *HortScience* **2000**, *35*, 600–603. [CrossRef]
24. Ashford, D.L.; Reeves, D.W. Use of a mechanical roller crimper as an alternative kill method for cover crop. *Am. J. Altern. Agric.* **2003**, *18*, 37–45. [CrossRef]
25. Derpsch, R.; Roth, C.H.; Sidiras, N.; Köpke, U. *Controle da Erosão no Paraná, Brazil: Sistemas de Cobertura do Solo, Plantio Directo e Prepare Conservacionista do Solo*; Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH: Eschborn, Germany, 1991.
26. Price, A.J.; Arriaga, F.J.; Raper, R.L.; Balkcom, K.S.; Kornecki, T.S.; Reeves, D.W. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. *J. Cotton Sci.* **2009**, *13*, 238–245.
27. Price, A.J.; Monks, C.D.; Culpepper, A.S.; Duzy, L.M.; Kelton, J.A.; Marshall, M.W.; Steckel, L.E.; Sosnoskie, L.M.; Nichols, R.L. High residue cover crops alone or with strategic tillage to manage glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Southeastern Cotton (*Gossypium hirsutum*). *J. Soil Water Conserv.* **2016**, *71*, 1–11. [CrossRef]
28. Price, A.J.; Williams, J.; Duzy, L.; McElroy, S.; Guertal, B.; Li, S. Effects of integrated polyethylene and cover crop mulch, conservation tillage, and herbicide application on weed control, yield, and economic returns in watermelon. *Weed Technol.* **2018**, *32*, 623–632. [CrossRef]
29. Price, A.J.; van Santen, E.; Sarunaite, L. Cover crop residue amount influences weed suppression in Abdurakhmonov. In *Cotton Research*; Intech Press: Rijeka, Croatia, 2016.
30. Evans, G.J.; Bellinder, R.R. The potential use of vinegar and clover oil herbicide for weed control in sweet corn, potato, and onion. *Weed Technol.* **2009**, *23*, 120–128. [CrossRef]
31. Diver, S. Flame Weeding for Vegetable Crops. 2002. Available online: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=110 (accessed on 23 April 2018).
32. Ghantous, K.M.; Sandler, H.A. Effects of timing and frequency of flame cultivation for dewberry control. *Weed Technol.* **2016**, *30*, 751–757. [CrossRef]
33. Knezevic, S.Z.; Stepanovic, S.; Datta, A. Growth stage affects response of selected weeds species to flaming. *Weed Technol.* **2014**, *28*, 233–242. [CrossRef]
34. Ulloa, S.M.; Datta, A.; Knezevic, S.Z. Tolerance of selected weed species to broadcast flaming at different growth stages. *Crop Prot.* **2010**, *29*, 1381–1388. [CrossRef]
35. Pullman, G.S.; DeVay, J.E.; Garber, R.H.; Weinhold, A.R. Soil solarization and thermal death: A longarithmic relationship between time and temperature for four soilborne plant pathogens *Verticillium dahliae*, *Pythium ultimum*, *Rhizoctonia solani*, *Thielaviopsis basicola*. *Phytopathology* **1981**, *71*, 954–959. [CrossRef]
36. Anonymous 2018. Allowed Mulches on Organic Farms and the Future or Biodegradable Mulch. United States Department of Agriculture, Agricultural Marketing Service, 2018. Available online: https://www.ams.usda.gov/sites/default/files/media/5%20Mulches%20incl%20biodegradable%20FINAL%20RGK%20V2.pdf (accessed on 23 April 2018).
37. Anonymous 2014. Plant Enhancement Activity—PLT20–High Residue Cover Crop or Mixtures of High Residue Cover Crops for Weed Suppression and Soil Health. United States Department of Agriculture, Natural Resource Conversation Service, 2014. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1243440.pdf (accessed on 5 September 2019).
38. Steel RG, D.; Torrie, J.H. *Principles and Procedures of Statistics*; McGraw: New York, NY, USA, 1960.

39. Kornecki, T.S.; Arriaga, F.J.; Price, A.J. Evaluation of visual and non-visible light active sensors methods to assess termination rates of cover crops. *Trans. ASABE* **2012**, *55*, 733–741. [CrossRef]
40. Mississippi State University (MSU). Traditional Vegetable 2015 Planning Budgets. Budget Report 2014-08. Department of Agricultural Economics, Mississippi State University (MSU), 2014. Available online: http://www.agecon.msstate.edu/whatwedo/budgets/docs/MSUVEG15.pdf (accessed on 23 April 2018).
41. Sanders, D.; Granberry, D.; Cook, W.P. Plasticulture for Commercial Vegetables (AG-489). North Carolina Cooperative Extension Service, 1996. Available online: https://content.ces.ncsu.edu/plasticulture-for-commercial-vegetables# (accessed on 23 April 2018).
42. Mirsky, S.B.; Ackroyd, V.J.; Cordeau, S.; Curran, W.S.; Hashemi, M.; Reberg-Horton, S.C.; Ryan, M.R.; Spargo, J.T. Hairy Vetch Biomass across the Eastern United States: Effects of Latitude, Seeding Rate and Date, and Termination Timing. *Agron. J.* **2017**, *109*, 1510–1519. [CrossRef]