Interactive Effects of Hand Weeding, Tine and Sweep Cultivation for Weed Control in Organic Peanut Production

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ABSTRACT

Previous research has shown that mechanical cultivation is the most effective and affordable method of weed control in organic peanut production. However, growers are in need of more information on specific integrated cultivation regimes for effective season-long weed control with minimal hand-weeding requirements. Therefore, field trials were conducted in 2010–2012 to evaluate the effects of various tine and sweep cultivation treatments combined with or without hand-weeding on season-long weed control, stand establishment, and yield and grade of an organically-managed peanut crop. Tine cultivation treatments consisted of no cultivation or weekly cultivations for 5 wks after planting (WAP). Sweep treatments consisted of no cultivation, weekly cultivations (for 5 WAP), cultivations at 2 and 5 WAP only, or cultivation at 5 WAP only. Hand-weeding treatments were no hand-weeding or hand-weeding of the entire plot. There were numerous significant interactions among tine and sweep treatments on weed control. Initial weed species composition greatly affected cultivation effects on overall weed control. Tine cultivation was most effective at controlling annual grass weeds. Sweep cultivation was effective at reducing weeds (*Amaranthus* spp., southern crabgrass, and Florida pusley), but primarily when tine cultivation was absent. Hand-weeding significantly improved weed control for every weed species every year. Additionally, inclusion of certain cultivation regimes significantly reduced the hand-weeding time requirement over the control. However, cultivation treatments did not improve pod yield or grade in any year. The most significant benefit in cultivation from these data is in the reduction in hand-weeding requirements. Based on this research, a regime consisting of weekly tine cultivations for 5 WAP, combined with two timely sweep cultivations provided the best overall balance of weed control and minimization of hand-weeding. Hand-weeding is the most critical weed control method, followed by tine cultivation, and finally sweep cultivation, which primarily served as an aid in the event of missed tine cultivations or failure.

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Weed control is one of the most limiting factors to organic crop production. Because direct control with synthetic herbicides is prohibited in certified organic systems (USDA, 2005), organic growers must utilize other options for weed control in their production systems. Some organic-approved weed control options are available, including mechanical and cultural practices, along with remedial control of weeds with approved herbicides. These and other techniques have been evaluated for implementation in organic peanut (*Arachis hypogaea* L.) production, but not exhaustively. Approved herbicides are cost-prohibitive and have minimal efficacy for organic peanut production (Johnson and Mullinix, 2008; Johnson *et al.*, 2008) and are not currently considered viable options for the grower.

Cultivation is a well-documented method of weed control, particularly in organic production systems (Bond and Grundy, 2001; Rasmussen, 2004; Reddiex *et al.*, 2001). It has also been an important component for integrated weed management in conventional peanut systems for years (Ferrell *et al.*, 2009; Hauser *et al.*, 1973; Wilcut *et al.*, 1987). Because of the cost and limited efficacy of approved herbicides, cultivation is the keystone for effective weed control in organic peanut systems (Johnson, 2010; Johnson *et al.*, 2012; Russo and Webber, 2012; Wann *et al.*, 2011b). While cultivation-based weed control requires additional trips across an organic field, this is offset compared to conventional production where as many as seven or eight fungicide applications are used. The premiums for the organic crop, combined with the savings from absent synthetic pesticide inputs can offset elevated fuel and labor costs from additional cultivations (Pimentel *et al.*, 2005). This has also been observed in organic peanut systems. Johnson *et al.* (2012) and Wann *et al.* (2011b) reported that varying levels of tine cultivation, combined with sweep cultivation and hand-weeding, provided effective control of various weed species. However, those experiments did not evaluate varying combinations of tine and sweep cultivation, to identify a comprehensive cultivation-based weed control program for organic peanut. Nor did they evaluate the individual effects of hand-weeding versus none. Hand-weeding remains a significant expenditure in non-chemical weed control regimes. Minimizing hand-weeding time requirements could aid in significantly reducing production costs for organic peanut systems. Thus, it is important to identify weed control regimes that provide adequate season-long control of various weed species, while also minimizing hand-weeding. Therefore, the objectives of this research were to 1) evaluate various combinations of tine and sweep cultivation to identify an optimal mechanical weed control program and 2) identify a regime that provides adequate, season-long weed control while minimizing labor inputs for hand-weeding, all under organic management.

Materials and Methods

Field trials were conducted at the University of Georgia (UGA) Lang-Rigdon, Ponder, and Horticulture Hill Farms near Tifton, GA in 2010, 2011, and 2012, respectively. The trials were conducted on a Tifton loamy sand (fine-loamy, Kaolinitic, thermic Plinthic Kandiudults) with pH between 6.0–6.5 and less than 1% organic matter. All plots were planted with non-treated Foundation seed of cv. Tifguard (Holbrook *et al.*, 2008) with greater than 90% germination each year on 27 May 2010, 13 June 2011, and 14 June 2012 using a 2-row Monosem precision air planter (Monosem, Inc., Edwardsville, KS) at a depth of 6 cm and a seeding rate of 20 seed/m. Tifguard was previously identified by Wann *et al.* (2011a) as displaying excellent potential for use in organic production systems. Individual plots measured 1.8 m × 9.2 m in 2010 and 2012 and 1.8 m × 7.6 m in 2011, with a standard 91 cm row spacing each year. All plots were conventionally tilled (disc harrow, moldboard plow, field conditioner, rotary tiller) before planting and irrigated as needed during the course of the growing season according to UGA Extension recommendations (Beasley *et al.*, 1997). Each test location was subsequently managed according to USDA Certified Organic guidelines for the entire growing season.

The experiment was arranged in a randomized complete block design, with a 2 × 4 × 2 factorial treatment arrangement of tine cultivation, sweep cultivation, and hand-weeding treatments. Tine cultivation treatments included 1) once per week for the first 5 wk after planting (WAP) or 2) no cultivations. Sweep cultivation treatments included 1) five total cultivations (once weekly for 5 WAP), 2) two total cultivations at 2 and 5 WAP only, 3) one single cultivation at 5 WAP only, and 4) no cultivation. Hand-weeding treatments were 1) fully weeded mid-season or 2) no hand-weeding. This design ensured the inclusion of a non-cultivated and non-weeded control for each variable. All treatments were replicated four times across each field location. Tine cultivations were conducted using a flex-tine cultivator (Aerostar, Einböck GmbH & CoKG, Austria) and were initiated 4 d after planting (DAP) (at ground-cracking immediately prior to seedling emergence) in 2010, 2011, and 2012 and continued every seven days until initiation of peanut blooming, or approximately 5 WAP. Sweep cultivations were conducted with a flat-sweep cultivator and the first treatments were initiated 6 DAP, 7 DAP, and 8 DAP in 2010, 2011, and 2012, respectively, and continued every seven days until approximately 5 WAP. Hand-weeding in selected plots was conducted on 6 July 2010, 25 July and 11 Aug. 2011, and 23 Aug. 2012, and the amount of time spent hand-weeding was recorded for each plot. Plant stand estimates were conducted on all plots using a 1.5-m length pole, on 21 June 2010, 5 July 2011, and 5 July 2012, following peanut emergence and stand establishment.

Weed control estimates were conducted each year on prevalent weed species at each location at the end of the season (prior to peanut inversion) to evaluate season-long effects of each weed control regime. This was done using a visual estimate of the percentage of the plot that had the weed present and subtracting from 100 for percent control (i.e. a plot with 5% coverage of the plot with a weed was determined to be 95% control for that weed). In 2010, visual estimates of percent control were conducted for southern crabgrass [*Digitaria ciliaris* (Retz.) Koeler], Florida pusley (*Richardia scabra* L.), redweed (*Melochia corchorifolia* L.), and smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.]. In 2011, estimates were conducted on crowfootgrass [*Dactyloctenium aegyptium* (L.) Willd.], goosegrass [*Eleusine indica* (L.) Gaertn.], redweed, smallflower morningglory, and sorghum-sudangrass [*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Steud.) de Wet ex Davidse].

In 2012, however, the dominant weeds were a mixture of various pigweed species (*Amaranthus* spp.), predominantly consisting of Palmer [*Amaranthus palmeri* (S.) Wats.] with some spiny (*Amaranthus spinosus* L.) and a smaller fraction of redroot (*Amaranthus retroflexus* L.), which suppressed growth of nearly all other weed species. Since pigweed were the dominant weeds in 2012, weed control evaluation was handled differently than in the previous years by using quantitative values instead of control estimates. Pigweed numbers and biomass collection were taken as in-row (23 cm on either side of drill row) or row-middle populations (23 cm on either side of bed center), and the total of this 92 cm span. A 46 cm × 46 cm quadrat was used for these calculations by placing in a random location in each plot centered as described above.

Due to intense weed pressure in the non-hand-weeded plots in 2011 and 2012, nearly all such plots were unreasonable to dig peanuts and salvage a yield estimate. Therefore, yield data were only collected from the hand-weeded plots those years and will be presented for 2010–2012. All plots that were able to be inverted were harvested 3 Nov. 2010, 22 Nov. 2011, and 21 Nov. 2012. Pod yields were adjusted to 7% moisture. Grade data were also collected from all harvested treatments and analyzed for % total sound mature kernels (Davidson *et al.*, 1982). Statistical analyses were conducted using SAS 9.3 software (SAS Institute, 2011) and all data (plant stand, yield and grade of peanuts, weed control variables, and duration of hand weeding) were analyzed by analysis of variance, using the PROC GLIMMIX procedure. Means were separated via multiple pairwise t-tests at $P \leq 0.05$, or otherwise noted. Correlation analyses of plant stand with yield were performed using PROC CORR in SAS.

Results and Discussion

There were considerable differences in weed species and control among the three years of the experiment. Therefore, analyses were analyzed separately for each year. There were numerous significant two-way interactions involving tine and/or sweep cultivation treatments for many measured variables in each year. Weed control data will be presented for each individual year by discussing important interaction effects and their relevance to the interpretation of the data.

Weed Control. In 2010, when weekly tine cultivations occurred, there were no differences in southern crabgrass (88–92%) or Florida pusley (77–79%) control regardless of sweep treatments (data not shown). However, when tine cultivations were absent, the level of control decreased with decreasing frequency of sweep cultivations (Table 1). For both of these weed species, there was no improvement in control by including tine cultivation as long as at least two sweep cultivations were also used. However, when there was no sweep cultivation, or only one pass of sweep cultivation (at 5 WAP), the use of tine cultivation improved control of both southern crabgrass and Florida pusley by 10–15%. In addition, two or more sweep cultivations improved southern crabgrass control compared to no sweep cultivation when hand-weeding did not occur (regardless of tine cultivation). As expected, there were no differences and effective control (88–92%) regardless of sweep cultivation when hand-weeding was used (data not shown). Likewise, tine cultivation provided no additional control of southern crabgrass when hand-weeding occurred, but there was also no improvement in southern crabgrass control by hand-weeding as long as weekly tine cultivation occurred. Thus, sufficient southern crabgrass control could be achieved with either tine cultivation or hand-weeding, but did not require both for maximized control. This is notable, because annual grasses have been documented to have a significantly negative impact on pod yield (Johnson and Mullinix, 2005) and sufficient control has potential for maximizing pod yields in organic systems. Neither tine nor sweep cultivation had any effect on redweed or smallflower morningglory control (data not shown). However, hand-weeding increased redweed control from 78 to 90% and smallflower morningglory control from 64 to 84% compared to without hand-weeding.

In 2011, sweep cultivation had no effect on weed control for any species present. Interactive effects between tine cultivation and hand-weeding treatments were consistently observed for multiple weed species. The observed trends for these interactions were that hand-weeding improved weed control for all species whenever a difference occurred (only crowfootgrass was effectively controlled by tine cultivation without the need for hand-weeding), and tine-cultivation did not improve control for any species when hand-weeding was used (data not shown). When hand-weeding did not occur, tine cultivation greatly improved control of crowfootgrass and sorghum-sudangrass (Table 2). However, tine cultivation exacerbated smallflower morningglory proliferation, which is consistent with results from Wann *et al.* (2011b). The consistent soil disturbance near the surface may have increased the number of seed achieving good seed-soil contact and excellent germinating conditions, while the small stem and viny growth habit of smallflower morningglory made it difficult to terminate with tines after it emerged.

Despite no interactions, trends were still similar for goosegrass control (data not shown) where hand-weeding improved control regardless of cultivation (from 75 to 93%), and for redweed where hand-weeding improved control from 58 to 89%.

Table 1. Effect of sweep cultivation on southern crabgrass and Florida pusley control when there was no supplemental tine cultivation, Tifton, GA – 2010[a].

Weed species	Sweeps weeks 1–5	Sweeps weeks 2,5	Sweeps week 5	Non-treated control
	%			
Southern crabgrass	88 a	83 ab	78 bc	73 c
Florida pusley	81 a	79 ab	66 bc	64 c

[a]Means within a row followed the same letter are not significantly different according to multiple pairwise t-tests at P = 0.05.

There was also improved redweed control with weekly tine cultivation compared to lack of cultivation (from 70 to 77%; $P \leq 0.10$).

Although a different evaluation method was used for pigweed in 2012 compared to the weed escapes in previous years, similar trends were still observed as the weed control estimates in 2010 and 2011 in several instances. The total number of pigweed present was zero or statistically equal to zero in all hand-weeded plots. Yet when hand-weeding was absent, the total number of pigweed across the entire row + middle span (92 cm) was reduced by nearly 40% with two sweep cultivations, and by over 52% with weekly sweep cultivations. However, the total number of pigweed was not reduced with a single sweep cultivation at 5 WAP compared to the non-treated control (Table 3). When separated by in-row (46 cm) compared to row-middle (46 cm) pigweed populations, this exact trend was reflected in the row middles, where sweep cultivation should be affecting weeds (Table 3). There was no difference in pigweed populations regarding frequency of sweep cultivation when either hand-weeding or tine-cultivation or both occurred in combination with sweeps. Since pigweed grows very rapidly, the root system was already well established by 5 WAP, so one sweep cultivation at that stage of growth had no effect on controlling this weed. Although, when coupled with one additional sweep cultivation 3 wk earlier, pigweed was able to be effectively controlled all season in the row middles with no additional weed control (canopy closure assisted with mid and late season weed control beyond the final cultivation at 5 WAP).

The total biomass of pigweed was also affected by interactions involving sweep cultivation. With no tine cultivation coupled with no sweep cultivation, pigweed biomass was largest, although not statistically greater than when sweeps were run weekly (Table 3). The primary reason that this phenomenon occurred was as a result of the average biomass weight per pigweed. Despite half as many pigweed per plot where sweep cultivations were maximized, the average weight per pigweed plant was 3.5 times that of the pigweed plants in the non-treated areas (Table 3). This was most likely a compensation mechanism by the plant where less plant competition allowed each individual plant to grow much larger (there were several instances where only one plant was present per sample, in which that individual plant flourished to a robust size).

Hand-Weeding Duration, Plant Stand, Yield, and Grade. The amount of time spent hand-weeding exhibited a significant tine × sweeps treatment interaction in 2010 and 2012, thus were subsequently separated and analyzed for their interaction in each year. In both years, when tine cultivation occurred weekly, the amount of time needed for hand-weeding was not different for any sweep treatment. However, when tine cultivation was absent, there were large differences in labor among the various sweep treatments. In both years, the amount of hand-weeding was greatly reduced when sweeps were run at least twice, compared to only a single Week 5 cultivation or non-treated (Table 4). Likewise, the inclusion of a weekly tine cultivation significantly reduced the duration of hand-weeding compared to not using tine cultivation

Table 2. Effect of tine cultivation on crowfootgrass, smallflower morningglory, and sorghum-sudangrass control when no hand-weeding occurred, Tifton, GA – 2011[a].

Weed species	Non-treated	Weekly tines
	%	
Crowfootgrass	57 b	88 a
Smallflower morningglory	60 a	44 b
Sorghum-sudangrass	31 b	70 a

[a]Means within a row followed the same letter are not significantly different according to multiple pairwise t-tests at P = 0.05.

Table 3. Effects of sweep cultivation on pigweed (*Amaranthus* spp.) density and biomass, Tifton, GA – 2012[a].

Sweep cultivation	Pigweed density (total) [b]	Pigweed density (row middles) [c]	Pigweed biomass (total) [d]	Average biomass (total) [b]
	No./m^2	No./m^2	g dry matter/m^2	g dry matter/plant
Weeks 1–5	17.4 c	0.0 b	810 ab	207 a
Weeks 2,5	22.1 bc	1.2 b	390 b	58 b
Week 5	32.3 ab	16.7 a	520 b	29 b
Non-treated	36.5 a	20.3 a	1530 a	59 b

[a]Means within a column followed by the same lowercase letter are not significantly different according to multiple pairwise t-tests at $P = 0.05$.

[b]Interactive effect of sweeps by hand-weeding, values are for treatments with no hand-weeding, averaged over tine cultivation spanning entire 92 cm row plus middle.

[c]Interactive effect of tines by sweeps by hand-weeding, values are for treatments with no tine cultivation and no hand-weeding spanning row middle only (23 cm on either side of bed center).

[d]Interactive effect of Tines by Sweeps, values are for treatments with no tine cultivation, averaged over hand-weeding treatments spanning entire 92 cm row + middle.

when sweeps were operated fewer than twice (ranging from a 51–75% reduction in labor), but did not reduce hand weeding time when sweeps were used at least twice. In 2011, there was not an interaction between tine and sweep cultivation for hand-weeding duration, and only the tine cultivation effect was significant in reducing hand-weeding. Weekly tine cultivations reduced the amount of time spent hand-weeding by over 38% (from 1115 to 686 hr/ha) in that year compared to not having tine cultivation.

There were no differences in plant stand or grade (% total sound mature kernels) in any year for any treatment effect. Although, plant stands were higher in 2010 (11.3 plants/m) than in 2011 or 2012 (6.6 and 6.7 plants/m, respectively). Similarly, there were no differences in yield for any treatment effect in 2010 or 2011 (average 2370 and 1320 kg/ha, respectively), while there were yield differences among sweep cultivation treatments in 2012 (Table 4). However, these results were not consistent with any weed control factors. Yields were highly correlated (positively) with plant stands in 2012 ($P \leq 0.0001$, $R^2 = 0.396$), but were not correlated with stands in 2010 or 2011. This correlation is a more likely explanation of yield differences observed, as it was also observed in Wann *et al.* (2011a). Yields were relatively low in these experiments compared to some other recent organic peanut experiments (Wann *et al.*, 2011a; 2011b). This was likely due to the substantial weed pressure that was present at each test location, and reduced plant stands in 2011–2012. Price premiums are available for organic peanut, which can allow some tolerance for lower yields compared to conventional management and contracts. However, assuming contract premiums ($1100/Mg) and hourly wages ($9.12/hr) used in Wann *et al.* (2011b), the only year with the potential for positive net revenue based strictly on yield and hand labor requirements to produce the crop was 2012. This is indicative of how important it is for management of weed seedbank populations prior to the establishment year of peanut in order to suppress potential weed density and pressure (Bàrberi, 2002).

Summary and Conclusions

These data are significant in that there appeared to be a hierarchy of effectiveness for weed control

Table 4. Effects of sweep cultivation on hand-weeding and pod yield, Tifton, GA – 2010–2012[a].

Sweep cultivation	Duration of hand-weeding[b] 2010	Duration of hand-weeding[b] 2012	Pod yield 2012
	Hrs/ha	Hrs/ha	
Weeks 1–5	518 b	200 b	2175 a
Weeks 2,5	627 b	130 b	1500 b
Week 5	1485 a	371 a	1872 ab
Non-treated	1390 a	316 a	2083 a

[a]Means within a column followed by the same lowercase letter are not significantly different according to multiple pairwise t-tests at $P = 0.05$.

[b]Interactive effect of Tine × Sweeps, values are for treatments with no tine cultivation.

in organic peanut production. Hand-weeding cannot be replaced by cultivation, whether tine or sweep or both, and is still the foundation of organic weed control systems. Peanut harvest could not even occur in plots where weeds were not removed by hand. However, by including various combinations of tine and sweep cultivation, there was enough overall weed control to warrant a significant reduction in total hand-weeding. This is notable because labor costs for hand-weeding represent one of the greatest expenditures by organic growers. Reducing the need for hand-weeding has great potential for increasing the economic viability of the system.

Tine cultivation had a more consistent effect on weed control than sweep cultivation, and should be considered an important supplement to hand-weeding. In addition, even though sweep cultivation did not give consistent supplemental weed control for any given weed when tine cultivation was present, the fact that there were reductions in some species of weeds by some levels of sweep cultivation when tine cultivation was not present is still relevant. Sometimes weather conditions or equipment malfunctions or breakdowns may prevent or delay the ability to run equipment through the field. Having sweep cultivation in combination with tine cultivation would allow for some level of weed control and reduction in hand-weeding requirements in the event a tine cultivator could not be used consistently. These data consistently showed improved results with weekly sweep cultivations, or at minimum two cultivations occurring 2 and 5 WAP to ensure improved weed control and/or reduction in hand labor in the event of tine-cultivation failure.

Successful weed control depends on initial species composition at a location (Faircloth *et al.*, 2008; Rasmussen, 2004; Wann *et al.*, 2011b). A large proportion of annual grasses in an area will likely respond greater to cultivation than areas with heavy dicot weed populations. As outlined by Bàrberi (2002), any weed control regime for a given growing season needs to be a component of a long-term weed management program that utilizes a variety of other cultural methods (i.e. cover cropping, crop rotations, stale seedbeds, etc.) in addition to cultivation for direct control. Additional research is needed to determine optimum timing of hand-weeding efforts. Several well-timed trips through the field to eliminate weeds while they are small and easily pulled may require the equivalent amount of time as one single rescue event after weeds have become robust and firmly established. However, an integrated weed control regime has the potential to provide season-long, non-chemical control of weeds, thereby maximizing production in an organic peanut system. Based on these results, the most optimum combination of weed control and minimization of hand labor included weekly tine cultivation for 5 WAP combined with at least two flat-sweep cultivations (approximately a week after emergence, and just prior to pegging), followed by in-season hand weeding to remove weed escapes.

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