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Tillage Requirements of Sweet Corn, Field Pea, and Watermelon Following Stocker Cattle Grazing

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Winter annual grazing combined with vegetable production can potentially improve the sustainability of farming operations, particularly in the Southeast. However, winter grazing creates excessive soil compaction, which can adversely affect yields of subsequent summer crops. We initiated a study to determine the optimal tillage system following winter grazing for production of sweet corn (Zea mays, L.), Southern field pea (Vigna unguiculata L.), and watermelon (Citrullus lanatus L.) on a Wynnville fine sandy loam, in north-central Alabama of the southeastern U.S. from 2001 to 2003. Each fall, all plots were planted to ryegrass (Lolium multiflorum L.) and stocked with 6.7 cattle ha^{-1}. In the spring, three surface tillage treatments (chisel/disk/level, disk/level, no surface tillage) and three deep tillage treatments (no deep tillage, in-row subsoiling, paratill) were arranged in a factorial randomized complete block design with four replications. Sweet corn ear weights responded to a combination of surface and deep tillage in 2002 and 2003. In 2001, the average response to surface tillage was 105% greater than no-surface tillage, compared with only a 14% increase with deep tillage over no-deep tillage in 2001. Southern field pea grown after winter annual grazing yielded 22% greater 2 of 3 years following surface

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tillage with disking; inclusion of chisel plowing with the disking showed no benefit. Watermelon yields following winter annual grazing were 39% and 58% greater in 2001 and 2002 with deep tillage alone, specifically in-row subsoiling, without any surface tillage. The tillage system for vegetable growers who choose to complement their operations with winter-annual grazing varies with the vegetable grown. In general, sweet corn responded best to a combination of surface and deep tillage, Southern field pea required only disking, and watermelon responded to in-row deep tillage with no additional surface tillage.

KEYWORDS conservation tillage, deep tillage, no-tillage, paratilling, soil compaction, vegetables

INTRODUCTION

Prime farmland of the United States is disappearing because it is being converted into urban uses, resulting directly from urban sprawl (Russell, 2006). This phenomenon places more emphasis on remaining farmland, prime or non-prime, to sustain or even exceed current crop production levels while simultaneously minimizing negative environmental impacts. In addition, producers also need their operations to remain profitable under these conditions. To maintain this complex balance, producers must be cognizant of practices previously documented, which involve utilizing crop rotations that include legumes, as well as, adopting modern conservation tillage practices that promote long-term soil productivity (Frye and Blevins, 1989).

Another option that could enhance conservation benefits and producer profits, especially for producers in the southeastern United States, is the integration of animal production with traditional row crops (Katsvairo et al., 2006; Siri-Prieto et al., 2007). One system (i.e., sod-based rotation) involves including a perennial forage in the cropping system to enhance yields, soil quality, and profit. Typically, this forage is present for at least 2 years and is grazed or cut for hay throughout that time once it has been established. This system removes the land from a typical crop production scenario during that time, but once the rotation cycles and the land is back under normal crop production, the potential benefits for the cash crop can be substantial (Katsvairo et al., 2006).

An alternative to taking the land out of crop production for a significant period of time involves planting a winter annual forage following the harvest of the summer crop, which coincides with a typical fallow period for many producers. Mild winters in the Southeast permit significant winter annual forage production between summer cash crops. The forage produced can be utilized by stocker cattle during the winter and spring period, prior to the establishment of the following summer cash crop. Subsequent cattle weight gains during this winter grazing period generate additional revenue, which also contribute to the economic sustainability of a producer's operation.

Ball (1988) reported over 162,000 ha of winter annuals are grazed prior to planting summer row crops. Bransby et al. (1999) reported profits of $170 to $560 ha^{-1} for cattle grazed on ryegrass pastures over the winter months, while Siri-Prieto et al. (2007) reported profits of approximately $200 ha^{-1} for cattle winter grazed on ryegrass or oat (*Avena sativa* L.) preceding planting of peanut (*Arachis hypogaea* L.) or cotton (*Gossypium hirsutum* L.) in the Southeast. These profits illustrate the potential that exists for producers to generate additional income over the winter months following the summer growing season.

Unfortunately, winter grazing contributes to soil compaction problems, which negatively affects yields of subsequent summer crops (Mullins and Burmester, 1997; Touchton et al., 1989). Limited research exists to identify tillage requirements to alleviate soil compaction following winter grazing, particularly non-inversion tillage requirements that eliminate compacted layers, minimize surface soil disruption (Busscher et al., 1988; Schwab et al., 2002) and contribute to improving soil physical, chemical, and biological properties of degraded southeastern soils (Langdale et al., 1990). Previous work has primarily focused on tillage requirements related to traditional summer row crops, but knowledge of tillage requirements for vegetable production would also be beneficial.

Producers that have diversified their operations to include vegetable production typically receive higher returns per land unit area than growers who produce only traditional summer field crops. Although the portion of farm operations dedicated to vegetables is generally smaller, vegetables prices are typically much higher. For example, Alabama's 2005 field crops were valued at $198 million across 223,000 ha ($890 ha^{-1}), but vegetable crops were valued at over $12.5 million across only 2,500 ha (~$5000 ha^{-1}) during the same year (NASS, 2005).

Although vegetable growers can supplement their income and reduce economic risk by incorporating winter grazing into their operation, this increase in profitability over the winter months should not be at the expense of vegetable yields the following year. Therefore, the objective of this study was to compare vegetable yields in a sweet corn–watermelon–field pea rotation among various surface and deep tillage combinations following winter annual grazing of stocker cattle (225 to 300 kg).

MATERIALS AND METHODS

This experiment was established at the Alabama Agricultural Experiment Station's Sand Mountain Research and Extension Center in Crossville, AL

(34°17'N, 85°58'W; 352 m above sea level) on a Wynnville fine sandy loam (fine-loamy, siliceous, subactive, thermic Glossic Fragiudults). The experimental area was disked twice and roterred once to level the field, prior to planting wheat (*Triticum aestivum* L.) in the fall of 1999. In early summer of 2000 following wheat harvest, the experimental area was no-till planted into bahiagrass (Paspalum notatum [Fluegge]) for a seed increase, but the stand failed due to dry weather. The area remained fallow until the initiation of the vegetable/grazing experiment in the fall of 2000. Treatments were a factorial arrangement of three surface tillage treatments (chisel/disk/level, disk/level, no surface tillage) and three deep tillage treatments (no deep tillage, in-row subsoiling, paratill) in a randomized complete block design with four replications, established for each of three crops (sweet corn, Southern pea, and watermelon) grown simultaneously.

The chisel plow consisted of a multiple shank implement with each shank approximately 50 mm wide operated to a depth of 20 cm. This disrupted the soil profile to the operating depth across the entire width of the implement (3 m) and at least partially or fully incorporated any plant residue on the soil surface. The disk consisted of two offset rows of circular notched blades 35 cm in diameter mounted on each side of a 4 m wide frame operated 18 cm deep. The first row of blades cut any surface residue present and partially buried that residue, while the second row of blades performed the same operation at the same angle in the opposite direction to the first row of blades. This resulted in complete surface disruption across the width of the implement, 18 cm deep. The level operation consisted of another field operation called a roterra that has a row of small fingers mounted on a drum that is driven by a power take-off and operated at approximately 15 cm. Behind the drum-mounted row of small fingers is another drum designed to firm and level the soil, prior to planting.

Subsoiling consisted of running a parabolic shank, 40 mm wide, to a depth of 35 to 40 cm deep directly under the row just prior to planting the summer cash crop. The subsoiler is equipped with a rippled coulter in front to cut residue and pneumatic tires following the shank to close the subsoil channel. This results in a narrow (15 to 20 cm wide) zone of soil disturbance within the seeding zone. The paratill is a bent-leg subsoiler that lifts the soil from underneath the soil surface with minimal (15 to 20 cm wide) surface soil disturbance offset about 40 cm from the seeding row. The zone of subsurface disturbance using the paratill is 40 cm deep but about 50 cm wide. Both deep tillage implements are designed to eliminate subsurface compaction while leaving crop residues in place on the soil surface to increase infiltration and reduce erosion.

The crops were rotated each year in a Southern pea–sweet corn–watermelon sequence for 3 years. Plot dimensions were 3.4 m wide and 13.7 m long, which allowed four 76 cm rows to be planted within each plot and a 0.3 m buffer between plots. All phases (crops) of the rotation were planted in all three growing seasons. Each replication of each crop phase was sampled separately for pH, P, and K to a depth of 20 cm by collecting 20 soil cores with a probe diameter of 1.9 cm. Initial soil pH, measured in a 1:1 soil/water extract, was 6.3, 6.2, and 6.2 for the watermelon, Southern pea, and sweet corn phases. Phosphorus levels were 'high' and K levels were 'medium' for each phase based on the Mehlich I extractant and Auburn University Soil Testing Laboratory recommendations (Adams et al., 1994).

Ryegrass cv. 'Marshall' was planted at 28–34 kg ha^{-1} with a no-till drill that had row spacings of 19 cm on 14 Sept. 2000, 10 Sept. 2001, and 23 Sept. 2002. At planting, all plots received an average rate of 112 kg N/ha, 112 kg P_2O_5 ha^{-1}, and 112 kg K_2O ha^{-1}. In late February, ryegrass plots were fertilized with 69 kg N ha^{-1} in 2001, 67 kg N ha^{-1} in 2002, and 114 kg N ha^{-1} in 2003 to promote maximum vegetative growth for grazing. Sweet corn and watermelon received approximately 146 kg N ha^{-1} and 67 kg N ha^{-1}, respectively, as ammonium nitrate soon after planting each year.

Beginning in late November to early December, all plots were grazed at a stocking rate of 6.7 cattle ha^{-1}. Cattle were removed early to mid-April each year to facilitate vegetable planting. A set of cone index measurements were collected in the fall of 2002 with a multiple-probe tractor-mounted soil cone penetrometer described by Raper et al. (1999) to a depth of 45 cm. Measurements collected from the no surface and no deep tillage plot areas confirmed the presence of a hard-pan approximately 10 cm below the soil surface and 10 cm thick across the experimental area, which was attributed to winter grazing. Cattle performance was determined each year by weighing each animal prior to grazing and again at the time of removal from grazing. After cattle removal and prior to tillage operations, biomass samples were collected by clipping all aboveground plant material within two 0.25 m^2 areas of each plot, drying in a forced air oven at 55°C for 72 h and weighed. No exclusion cages were used to measure ryegrass biomass production over the winter. Ryegrass was chemically terminated and tillage treatments were administered to designated plots.

Typical cultural practices recommended for each crop by the Alabama Cooperative Extension System for fertilizer, weed control, and insects were utilized throughout the season. Agronomic practices related to specific cultivars, planting dates, seeding rates and harvest dates for each crop are presented in Table 1. Yields of each crop were measured by hand-harvesting all mature vegetables from the two center rows of each plot and summing the weights from each harvest date within a year (Table 1).

Yields were analyzed using the MIXED procedure (Littell et al., 2006) and the LSMEANS PDIFF option to distinguish between treatment means (release 9.1; SAS Institute Inc.; Cary, NC). Data were analyzed with year as a fixed effect in the model, and there were significant year X treatment interactions for yield. Therefore, yields were analyzed within each year, with yield and discussion presented by year. Surface and deep tillage treatments

TABLE 1 Planting Dates, Cultivar, Seeding Rate, and Harvest Dates for Sweet Corn, Southern Field Pea, and Watermelon Grown at the Sand Mountain Research and Extension Center in Crossville, AL during 2001–2003

Crop	Planting dates†	Cultivar	Seeding rate	Harvest dates		
			plants ha^{-1}	2001	2002	2003
Sweet corn	4-26-2001	Silver Queen	64,200	7–19	7–12	7–25
	4-18-2002			7–26	7–19	7–28
	4-15-2003			8–6	7–24	7–31
Southern field pea	5-16-2001	Pinkeye Purplehull	6400	7–24	7–26	8–1
	5-15-2002			7–29	7–30	8–4
	5-29-2003			8–2	8–2	8–6
				8–7	8–7	
Watermelon	5-16-2001	AU Producer	2150	8–24	8–16	8–29
	5-15-2002			8–30	8–23	9–5
	5-29-2003					

†Planting dates represent original planting dates. In 2001, a portion of the sweet corn plots (new plant date; 5-8-2001) and all the southern field pea and watermelon plots (new plant date; 5-25-2001) had to be re-planted due to dry weather. In 2003, sweet corn plots had to be re-planted (new plant date; 5-2-2003) due to poor seed germination.

were considered fixed effects, while replication was considered random. Treatment differences were considered significant if $p \leq 0.05$.

RESULTS AND DISCUSSION

Cattle Performance

Cattle performance measured over three grazing periods indicated average total gain was 1000 kg ha^{-1} yr^{-1}, which generated a gross income of \$790 ha^{-1} yr^{-1} (Table 2). Variable expenses were estimated at \$405 ha^{-1} yr^{-1}, excluding fences, water facilities, and rent; producing a net return of \$385 ha^{-1} yr^{-1}, averaged over three winter-grazing periods (Table 2). The 2001–2002 grazing

TABLE 2 Cattle Performance Measured during Three Grazing Periods at the Sand Mountain Research and Extension Center in Crossville, AL

Variable	2000–2001	2001–2002	2002–2003	Mean
Grazing period, days	129	129	138	132
Average daily gain, kg day^{-1}	1.1	1.3	1.0	1.1
Total gain, kg ha^{-1}†	951	1124	925	1000
Gross income, \$ ha^{-1}‡	751	888	731	790
Net returns, \$ ha^{-1}§	346	483	326	385
Cost kg^{-1} gain. \$ kg^{-1}	0.43	0.36	0.44	0.41

†Total gain = Average daily gain × stocking rate of 6.7 cattle ha^{-1} × grazing period.
‡Contract price of \$0.79 kg^{-1}.
§Average variable cost of \$405 ha^{-1}, excluding fences, water facilities, and rent.

period produced the highest total gain and subsequently the highest net return. This could be attributed to a slightly warmer grazing period (10°C for 2001–2002) compared with the other grazing periods (7.6°C average for the 2000–2001 and 2002–2003 seasons). Average rainfall was very similar across all three grazing periods (data not shown). Cover crops grown to maximize residue production can protect the soil from erosion during high rainfall periods, such as the winter months, when precipitation exceeds evapotranspiration and surface runoff is probable. In some cases, a properly managed winter cover crop has also been shown to eliminate deep tillage requirements in fine-textured soils (Raper et al., 2000a, 2000b). However, when the residue is grazed, these potential benefits are minimized or eliminated. If cattle are removed early in the season, there is a period of time for additional biomass production that may be beneficial. However, in our study surface residue was minimal following cattle removal, due to intensive grazing and no time allowed for additional growth before the vegetables were established. In 2001, no biomass measurements were collected, but ryegrass above-ground biomass averaged 400 kg ha^{-1} in 2002 and 970 kg ha^{-1} in 2003, prior to the initiation of tillage treatments.

Sweet Corn

Tillage treatment affected total sweet corn ear weight following winter grazing but results were inconsistent across the three experimental years. Total weights in 2003 were much less than in 2001 or 2002 as a result of wind damage from a tropical storm (Table 3). In 2001, both surface tillage treatments resulted in heavier total sweet corn ear weights compared to the no tillage treatment (Table 3). Although sweet corn ear weights were similar following the use of either deep tillage implement in 2001, only the use of the in-row subsoil implement significantly increased yields relative to those from plots without deep tillage Table 3).

A significant interaction was found between surface tillage and deep tillage in 2002 and 2003 (Table 3). In 2002, both deep tillage operations required some form of surface tillage to maximize sweet corn ear weights (Figure 1). However, surface tillage response varied with type of deep tillage operation. In-row subsoiling resulted in greater sweet corn ear weights when the disk/level treatment was applied, while under the paratill treatment total sweet corn ear weight was greater when combined with the chisel/disk/level treatment. This discrepancy between deep tillage implements may be explained by the fact that the paratill minimized surface soil disturbance and subsequently was inferior to the in-row subsoiler at eliminating surface soil compaction. Indeed, we observed that although the soil was lifted 3 to 6 cm above grade by the paratill, the surface typically remained unfractured and consolidated. This might explain why the chisel/

TABLE 3 Sweet Corn, Southern Field Pea, and Watermelon Yields Measured Following Winter Annual Grazing of Stocker Cattle and Combinations of Surface and Deep Tillage for the 2001, 2002, and 2003 Growing Seasons at the Sand Mountain Research and Extension Center in Crossville, AL

	Sweet corn ears			Southern field pea			Watermelon		
Tillage system	2001	2002	2003	2001	2002	2003	2001	2002	2003
				Mg ha^{-1}†					
				Surface tillage					
Chisel/disk/level	21.9	19.7	10.9	6.8	4.1	5.9	70.7	43.1	40.0
Disk/level	20.8	18.6	10.5	6.4	4.1	6.2	69.6	44.1	45.6
None	10.4	14.3	8.3	5.4	4.4	5.0	58.3	39.3	36.6
$LSD_{0.05}$	2.8	1.8	1.7	0.7	NS‡	0.8	NS	NS	NS
				Deep tillage					
In-row subsoil	19.6	17.1	10.5	6.2	4.4	5.8	73.4	53.8	40.4
None	16.2	17.2	8.5	6.0	4.1	5.8	52.7	34.1	40.8
Paratill	17.3	18.3	10.8	6.5	4.1	5.5	72.5	38.5	40.9
$LSD_{0.05}$	2.8	NS	1.7	NS	NS	NS	11.3	12.1	NS
				Analysis of variance (p > F)					
Surface tillage	<0.0001	<0.0001	0.0090	0.0011	0.5597	0.0145	0.0626	0.6905	0.1702
Deep tillage	0.0564	0.3024	0.0241	0.4154	0.6530	0.7230	0.0010	0.0068	0.9922
Surface X Deep	0.3843	0.0135	0.0152	0.1208	0.9858	0.5202	0.0002	0.0172	0.1252

†Yields are the cumulative totals of all the harvest dates within each year.
‡Not significant at the 0.05 level of probability.

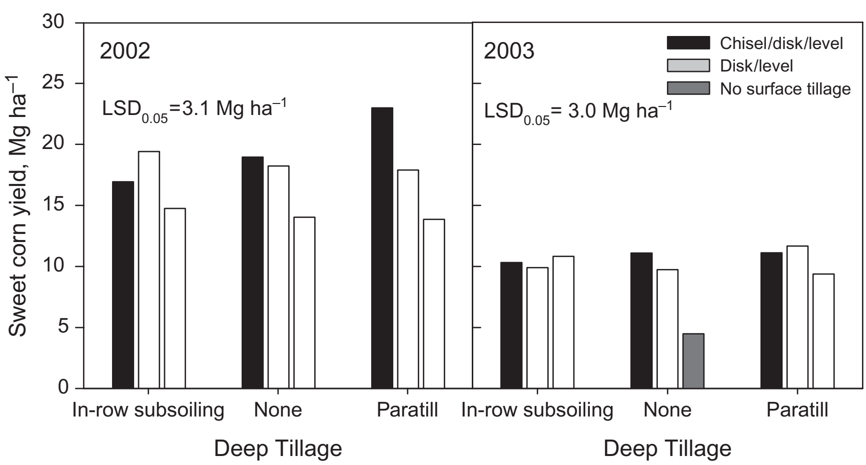

FIGURE 1 Sweet corn yields measured following winter annual grazing of stocker cattle and combinations of surface tillage and deep tillage treatments during the 2002 and 2003 growing seasons at the Sand Mountain Research and Extension Center in Crossville, AL.

disk/level treatment enhanced yields following the paratill operation. The chisel plow clearly disrupted the near surface compaction zone better than did the disk, thereby promoting better seed placement and improved initial root growth. The disk can have a tendency to ride on top of the hard pan compared with the chisel plow that is better designed to stay under the hard pan and actually fracture the compacted zone.

In 2003, surface tillage was required to maximize yields of sweet corn ears when no deep tillage was performed, however there was no benefit to including either form of surface tillage following in-row subsoiling or paratilling (Figure 1). Sweet corn was re-planted during the 2003 crop year on 2 May, which was a much wetter May (26.5 cm rain) compared to May 2001 (8.6 cm) and May 2002 (7.4 cm). It is possible that the additional rainfall in 2003 promoted a shallower root system, which negated any benefit of deep tillage, but another more likely possibility is that the increased soil moisture allowed roots to penetrate the compacted zone easier. As a result, surface tillage was adequate and although deep tillage produced equivalent yields, it was not required in this case.

Griffin et al. (2000) measured total sweet corn ear weights of approximately 16.1 to 22.2 Mg ears ha^{-1} across three different rotation cycles and N rates on a silt loam soil in Maine. In two fine sand soils of Florida, Cherr et al. (2006) measured sweet corn marketable fresh ear weights that averaged 10.9 Mg ha^{-1} over two growing seasons with a similar rate of N fertilizer (133 kg N ha^{-1}) utilized in our study. If all the ears were included, instead of only marketable ears, the yields observed in Florida would likely have been similar to our observed sweet corn ear weights.

Southern Field Pea

Southern field pea yields only responded to surface tillage treatments in 2 out of 3 years compared to no-surface tillage, while deep tillage had no effect on yields following winter annual grazing (Table 3). A single disking operation was equivalent to a chisel and disking operation. No specific yields of field pea from the literature were identified for comparisons, but total pod weights were within values reported by Grimmer and Masiunas (2004) for snap pea (*Pisum sativum* L.) following 4 separate harvests on a silt-loam soil in Illinois.

Observed field pea yields were similar across treatments during the 2001 and 2003 growing seasons, but field pea yields measured during the 2002 growing season were much lower. The 2002 field pea growing season received a limited amount of rainfall in contrast to the other growing seasons. Total rainfall amounts for May through August 2002 were only 7.1 cm compared with 9.4 cm in 2001 and 14.0 cm in 2003. Rainfall distribution can also be erratic, especially during critical growth stages, which when combined with low rainfall amounts depress crop yields (Balkcom et al., 2007b). Southern field pea belongs to the cowpea (*Vigna unguiculata* L.) family, which are generally a deep tap-rooted legume tolerant of drought conditions. However, root growth is concentrated in the topsoil under favorable conditions, but the taproot can extend up to 2.4 m to access moisture deeper in the soil profile during dry conditions (Valenzuela and Smith, 2002). During the 2002 growing season, it appears moisture was limited throughout the profile, which depressed yields, regardless of tillage system.

Watermelon

Watermelon yields revealed an interaction between surface and deep tillage treatments during the 2001 and 2002 growing seasons (Table 3). Although not significant, there was a trend ($p \leq 0.12$) in 2003 for an interaction between surface and deep tillage as well. In 2001 and 2002, watermelon yields responded to surface tillage in the absence of deep tillage, but equivalent yields were also obtained with deep tillage treatments without surface tillage (Figure 2). This indicates watermelon yields following winter grazing can be maximized with conservation minded non-inversion deep tillage alone that enhances many physical and chemical benefits for these highly weathered southeastern soils. Although the difference was not significant, watermelon yields responded better to in-row subsoiling compared with paratilling, either alone or combined with surface tillage (Figure 2).

In 2001 and 2002, watermelon yields from the chisel/disk/level treatment were similar within the year whether or not there was associated deep tillage (Figure 2). As previously stated, 2002 was the driest year for the experimental period and water is crucial for watermelon production due to the high water composition of watermelon (Tyson and Harrison, 2000). Watermelon can extend roots deep into the soil profile, but most are found in shallower depths (Tyson and Harrison, 2000). This explanation supports the

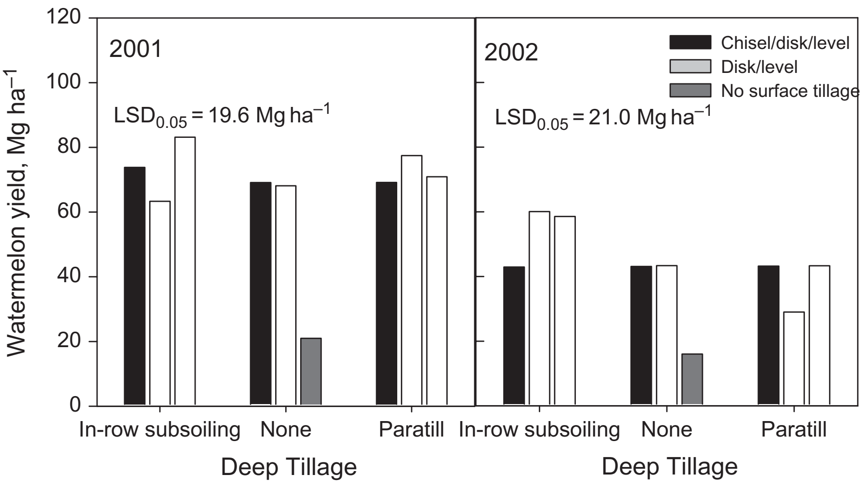

FIGURE 2 Watermelon yields measured following winter annual grazing of stocker cattle and combinations of surface tillage and deep tillage treatments during the 2001 and 2002 growing seasons at the Sand Mountain Research and Extension Center in Crossville, AL.

response to deep tillage alone. However, the observed shallow compacted layer is within the operating depth of the chisel/disk/level treatment, which could explain, regardless of with or without deep tillage, why chisel/disk/level yields were similar within years. The disk/level surface treatment was not different from the chisel/disk/level surface treatment, but the observed yields were more inconsistent (Figure 2). Although the chisel/disk/level treatment with no deep tillage produced equivalent yields to either non-inversion deep tillage treatment without surface tillage, a non-inversion deep tillage treatment alone would be recommended to promote benefits associated with residue retention on southeastern soils (Balkcom et al., 2007a).

Best watermelon yields were obtained during the first year of the experiment, while yields were somewhat similar in 2002 and 2003. Comparable watermelon yields were observed on a sandy loam soil by Lu et al. (2003) for three cultivars across high and low management input systems during three growing seasons in Oklahoma. Shogren and Hochmuth (2004) reported slightly lower yields for a single cultivar across fumigation levels and types of mulch in Florida on a fine sand. However, these yields only included marketable fruit as opposed to total fruit and the authors also indicated lower yields than normal, which they attributed to damage by crow (*Corvus brachyrhynchos* Brehm) (Shogren and Hochmuth, 2004).

Combining the yields for all three vegetable crops in the absence of surface or deep tillage resulted in less production than obtained from treatments where there was some tillage. The yield reduction of each crop was attributed to soil compaction associated with winter grazing. No attempt was made to compare yields without winter grazing, but yields obtained following tillage are comparable to other published data for each crop across different locations that had no grazing component. The most suitable type or combination of tillage operations varied according to vegetable crop. In general, Southern pea required only surface tillage; total sweet corn ear weights were greatest following a combination of surface and deep tillage, while watermelon responded to surface tillage alone or non-inversion deep tillage alone. In this case, non-inversion deep tillage would be recommended over surface tillage to promote soil benefits across the region. These findings coincide with rooting depths published by Kemble and Sanders (2000) who provided general estimates for sweet corn and watermelon. Sweet corn rooting depth is estimated at 30–46 cm, while watermelon rooting depth is > 61 cm (Kemble and Sanders, 2000). Rooting depth for field pea, a tap-rooted crop, can be deep (Valenzuela and Smith, 2002), but root length densities differ among species and environment (Fisher and Dunham, 1984). It seems reasonable that root length densities could vary with cultivar, also. Our field pea cultivar, utilized in this experiment, appeared to require only shallow tillage (< 20 cm) to maximize yields.

Winter grazing can provide additional income, but growers interested in adding this component to their operation should be aware that the level of management required for a profitable grazing operation is more intensive (Ball et al., 1991). One aspect that increases the level of management needed is the size of winter grazing operations required to justify adding winter grazing to an existing operation in the first place. Ball et al. (1991) reported that at least 60 calves are required to justify this level of management. Based on the stocking rate we used (6.7 cattle ha^{-1}), a 9 ha area that could be fenced with a water source would be required. In Alabama, as previously reported, vegetable farms typically consist of small land areas (NASS, 2005), which could contrast with size requirements for grazing. On the other hand, a grower that utilizes cattle on a large scale could diversify a portion of the total farm into vegetable production.

CONCLUSIONS

The results of this study confirm that vegetable growers who choose to complement their operations with winter-annual grazing should be aware of potential problems from soil compaction. The results also indicate that the recommended tillage system required to correct the compaction problem varies with the vegetable grown. Sweet corn responded to a combination of surface and deep tillage, although deep tillage produced similar yields to surface tillage during one growing season. Southern field pea only required minimum surface tillage (disk/level) following winter annual grazing. Watermelon yields following winter-annual grazing with only non-inversion deep tillage can be maximized without the need for additional surface tillage. Vegetable growers that incorporate winter grazing into their operations for diversification and additional income can maintain vegetables yields, but traditional tillage practices should be modified to integrate specific combinations of surface and deep tillage for each crop to maintain sustainability of the vegetable and grazing operation.

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