Soil Physical Properties and Potato Yield in No-till, Subsurface-till, and Conventional-till Systems

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SUMMARY. Conservation tillage using residue from a cover crop grown before potato (*Solanum tuberosum* L.) production has been infrequently and inconclusively studied. The objectives of this study were to 1) conduct a field study to evaluate soil physical properties, and potato growth and yield, in conventional-tillage (CT), no-tillage (NT), and subsurface-tillage (SST) systems and 2) conduct a greenhouse study to evaluate the effect of soil bulk density (ρ_b) on potato growth and yield. Potatoes ('Atlantic') were planted into residue of sorghum-sudangrass [*Sorghum bicolor* (L.) Moench x *S. sudanense* (Piper) Staph] at two sites in eastern North Carolina—Plymouth into Portsmouth fine sandy loam and Lewiston into Norfolk sandy loam. Potatoes in the NT and SST system emerged more slowly than potatoes

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planted conventionally. There were no differences in plant population or size by 8 weeks after planting at Plymouth, but plant population and size were less in NT and SST systems at Lewiston. Reducing tillage also affected soil compaction, increased soil moisture early in the season at both sites, and increased ρ_b at Lewiston. Yield of U.S. No. 1 potatoes planted in NT and SST systems were comparable to potatoes planted in a CT system at Plymouth, but were less than potatoes planted in a CT system at Lewiston. There were no differences in yield between potatoes planted with NT and SST. In the greenhouse study, ρ_b did not affect leaf area or tuber yield or tuber grade. Specific sites and soils may allow for comparable potato production with no or SST, but further research, conducted on different soil types would promote further understanding of the impacts of reducing tillage in potato production.

In the Coastal Plain region of eastern North Carolina, $\approx 9,000$ ha (22,230 acres) of potatoes are grown for use in the potato chip industry. Conservation tillage could benefit agricultural production in this region by controlling topsoil loss from wind erosion and conserving soil moisture as a reserve against common summer droughts. However, reduction in tillage does have the potential to negatively affect tuber production because of the potato plant's sensitivity to soil physical conditions.

Localized high intensity rainstorms are characteristic of the summer months in eastern North Carolina, and rainfall can be poorly distributed throughout the cropping season (Reicosky et al., 1977). Morse (1993) concluded that the major advantage of conservation tillage in the short term is improved soil moisture, due primarily to residue remaining on the soil surface.

Erosion also presents problems, not just for potatoes, but for all agricultural production. Used with other conservation tools at specific sites, 50% residue cover has been shown to reduce erosion by 83%, and 10% cover can reduce erosion by 30% (Langdale and Moldenhauer, 1995).

The main purpose of tillage in potato production is to control weeds, facilitate planting, and increase the ease of later cultivation and harvest

(Prestt and Carr, 1984). No-till (NT) soils tend to have higher bulk densities (ρ_b) than conventional-till (CT) soils (Naderman, 1991). Increased ρ_b can decrease potato yield (Blake et al., 1960) and make harvest more difficult (Grant and Epstein, 1973).

To plant potatoes in early spring, traditional fall-sown cover crops, like hairy vetch (*Vicia villosa* Roth.) or rye (*Secale cereale* L.), would have to be killed before they produce their greatest amount of biomass. Cover crops, like sorghum-sudangrass, planted the summer before potato production to allow for maximum biomass production, and kept on the field through the winter as mulch, may be an appropriate alternative. However, sorghum-sudangrass used as a green manure crop before potatoes reduced plant growth and yield compared to potatoes following a fallow period or rapeseed (*Brassica napus* L.) (Boydston and Hang, 1995); and sorghum-sudangrass also increased the amount of wireworm (*Melanotus communis* Gyllenhal) damage to potatoes, especially when the cover crop was planted early in the summer (Jansson and Lecrone, 1991).

In addition to conserving topsoil and retaining moisture in the soil, the presence of crop residue or mulch also changes the environment for insects and changes soil temperature fluctuations. Zehnder et al. (1990) found the number of Colorado potato beetles (CPB) (*Leptinotarsa decemlineata* Say), including overwintering adults, egg masses and larvae, was reduced in mulched plots. Soils with crop residue, or a mulch on the soil surface remain cooler for a longer period in the growing season (Cox et al., 1990), which can slow emergence (Grant and Epstein, 1973). However, crop residues or mulches are known to reduce soil temperature fluctuation compared to CT, bare soils (Teasdale and Mohler, 1993), and maximum soil temperatures are lower in soils with a residue cover, compared to bare soils (Creamer et al., 1996).

The objectives of this study were to 1) evaluate soil physical characteristics and potato growth and yield in CT, NT, and subsurface-tillage (SST) systems and 2) evaluate the effect of bulk density on potato growth and yield in the greenhouse. Because this experiment was designed to compare different systems, more than one fac-

tor is varied among the NT, SST, and CT plots as is common among systems experiments (Abdul-Baki et al., 1996; Creamer et al., 1996).

Materials and methods

Field study

Experiments were conducted for one production cycle at two sites: the Tidewater Research Station near Plymouth, N.C., and at the Peanut Belt Research Station near Lewiston, N.C. (Abdul-Baki et al., 1997; Franco et al., 1997). The soil in Plymouth was a Portsmouth fine sandy loam (Typic Umbraquults, $\approx 5\%$ organic matter content); and at Lewiston a Norfolk sandy loam (Typic Paleudults, $< 1\%$ organic matter content). Main plots were 21 m (70 ft) long and consisted of four 97-cm (38-inch) wide rows.

CT SYSTEM. Plots were left fallow after corn harvest in August 1996. Just before planting potatoes, plots were disked once before forming hills. Fertilizer ($\text{NH}_4\text{-NO}_3\text{-P}_2\text{O}_5\text{-K}_2\text{O}$) was broadcast by hand at $119 \text{ kg}\cdot\text{ha}^{-1}$ (106 lb/acre) N-P-K. 'Atlantic' seed pieces were planted 11 and 12 Mar. 1997, 10 cm (4 inch) deep and 25 cm (10 inch) in-row spacing in all CT plots. Seed pieces were planted by hand and rehilled mechanically at Plymouth; and planted and hilled mechanically with an Oliver two-row pick planter at Lewiston.

REDUCED TILLAGE SYSTEMS. Sorghum-sudangrass seed was broadcast on preformed beds at $39 \text{ kg}\cdot\text{ha}^{-1}$ (35 lb/acre) in late August 1996, after corn had been harvested and stubble was disked under. At planting of the cover crop, $135 \text{ kg}\cdot\text{ha}^{-1}$ (120 lb/acre) N and $78 \text{ kg}\cdot\text{ha}^{-1}$ (70 lb/acre) P were broadcast at Lewiston and Plymouth, respectively.

The 21.3-m (70-ft) plots with cover crop residue were split into two 9-m (30-ft) lengths with a 3-m (10-ft) border between the NT and SST systems. A modified tiller-transplanter (B&B No-Till Transplanter, Laurel Fork, Va.) was used to cut through the cover residue, open a furrow, place the fertilizer below the seed piece at the rate of $120 \text{ kg}\cdot\text{ha}^{-1}$ (106 lb/acre) N-P-K, and place the seed piece in the row (Morse et al., 1993). 'Atlantic' seed pieces were planted 11 and 12 Mar. 1997, 15 cm (6 inch) deep and at a 25-cm (10-inch) in-row spacing in all reduced tillage plots. Rows were raked by hand to cover seed pieces.

Nt system. In the NT system, a straight fertilizer knife was used to create minimal disturbance of the soil during the planting operation.

Sst system. In the SST system, a winged fertilizer knife was used. The wings on the knife disturbed the soil below the surface to a depth and width of ≈ 20 cm (8 inch).

A side-dressing of $34 \text{ kg}\cdot\text{ha}^{-1}$ (31 lb/acre) N was applied as $\text{NH}_4\text{-NO}_3$ in all plots on 3 May 1997 at Lewiston and on 8 May 1997 at Plymouth. Pests were managed per North Carolina State University recommendations (Sanders and Creamer, 1996) in all plots. Potatoes were harvested mechanically on 23 June 1997 at Plymouth and 30 June 1997 at Lewiston.

Cover crop biomass was sampled from NT and SST plots at both sites from 1.0 m^2 (10.8 ft^2) on 5 Nov. 1996, and from 0.60 m^2 (6.4 ft^2) on 11 Mar. 1997 at Lewiston. Percent cover of the residue was estimated using the beaded string method (Sloneker and Moldenhauer, 1977) on 18 Mar. 1997 at both sites. One bulk density sample per replication was taken from the surface 4 cm (1.6 inch) within the crop row with a Lutz soil core on 27 Mar. 1997 at both sites. Emerged sprouts were counted about every 3 d starting on 4 Apr. 1997 at Plymouth and on 7 Apr. 1997 at Lewiston. On 14 May 1997, a 50-cm (20-inch) length of row was harvested to count main stems and measure leaf area (LI-3100 leaf area meter; LI-COR, Lincoln, Neb.). Soil moisture tension at a depth of 10 cm (4 inch) in the potato row was measured in two locations in every plot about every 2 weeks with a 'Quickdraw' Soil Moisture probe (Series 2900; SoilMoisture, Santa Barbara, Calif.). Cone index (CI) to a depth of 64 cm (25 inch) was measured with a manual, semiautomatic cone penetrometer (Mobility Systems Division, Waterways Experimental Station, U.S. Army Corps of Engineers, Vicksburg, Miss.) on 8 May 1997 at Plymouth and on 3 May 1997 at Lewiston; ten probes per potato row were measured.

A total of 6 m (20 ft) of row in each plot was harvested mechanically. Tubers were graded mechanically according to USDA standards, into U.S. No. 1 [>48 mm (1.88 inch)], with 40% >64 mm (2.52 inch)], B grade [<48 mm (1.88 inch)], culls, and greens. Tubers were considered unacceptably green if greater than $\approx 5\%$ of the tuber surface was green.

The experimental design was a randomized, complete block (conventional vs. cover-cropped) with a split-plot (NT vs. SST), with four replications. All data were subjected to analysis of variance. Means were separated with Fisher's (protected) least significant difference (LSD) tests (Wilkinson, 1990).

Greenhouse study

Soil was collected randomly to a depth of 15 cm (6 inch) in mid-October 1996, from a Portsmouth fine sandy loam at the Tidewater Research Station near Plymouth, N.C., and Norfolk sandy loam at the Peanut Belt Research Station near Lewiston, N.C. A randomized complete block design

with four replications, with one pot per replication, was used.

Both soils were packed to two r_b values each by adding a known mass (M) of soil into a known volume (V) in a pot. The r_b values used for the greenhouse study were based on field ρ_b values in CT and NT soils. Soil moisture content was measured gravimetrically, and the r_b of the soil in the pot was then calculated as $\rho_b = (M_{\text{soil}} - M_{\text{water}})/V_{\text{total}} = M_{\text{solids}}/V_{\text{total}}$. 'Atlantic' seed potatoes were planted into 18.9-L (5-gal) pots 17 Dec. 1996. Soil was moistened and packed into each pot around and over the seed pieces. The equivalent of $179 \text{ kg}\cdot\text{ha}^{-1}$ (160 lb/acre) N, $112 \text{ kg}\cdot\text{ha}^{-1}$

Fig. 1. Estimate of residue cover remaining across the plot (AP) and in the potato row (IR) 1 week after planting with no till (NT), subsurface till (SST), and conventional till (CT) at Plymouth and Lewiston, N.C., 1997.

Table 1. Soil bulk densities (ρ_b) ($\text{g}\cdot\text{cm}^{-3}$) in the potato row of no tillage (NT), subsurface tillage (SST), and conventional tillage (CT) at Plymouth (Plymouth fine sandy loam) and at Lewiston (Norfolk sandy loam), N.C.

System	Plymouth ($\text{g}\cdot\text{cm}^{-3}$) ^z	Lewiston ($\text{g}\cdot\text{cm}^{-3}$)
NT	1.18	1.63 a ^y
SST	1.13	1.62 a
CT	1.10	1.42 b
LSD _{0.05}	NS	0.05

^z1 lb/inch³ = 27.7 $\text{g}\cdot\text{cm}^{-3}$.

^yDifferent letters within a column indicate significant differences at $P < 0.05$; NS=nonsignificant at $P < 0.05$.

(100 lb/acre) P, and 112 $\text{kg}\cdot\text{ha}^{-1}$ (100 lb/acre) K was mixed into the soil in each pot. High ρ_b pots required hand packing to fit the soil into the desired volume. Seed pieces were placed 10 cm (4 inch) deep and covered with the remaining soil. About 0.5 L (0.1 gal) of water was added to all pots every other day.

Plants were harvested on 23 Mar. 1997. Plant height was measured, from the soil surface to the growing point of the leaves, just before harvest. Stems were cut at the soil surface and leaves, including petioles, removed. Leaf area was measured on a leaf area meter. Leaves and stems were dried 24 h at 65 °C (150 °F) to determine plant dry weight. Actual soil bulk density was measured with a Lutz soil core before removing soil from pots. Tubers were dug from the soil, weighed and evaluated for deformities.

Results and discussion

Field study

RESIDUE BIOMASS AND COVER ESTIMATE. The sorghum-sudangrass cover crop produced $\approx 3.0 \text{ t}\cdot\text{ha}^{-1}$ (1.3 tons/acre) of biomass at both sites, and $\approx 50\%$ of the cover remained at planting at Lewiston the following spring. More than 30% of the soil surface in NT and SST plots was covered with residue (Fig. 1). However, the soil disturbance caused by planting the potato seed decreased residue within the plant row in the NT and SST plots. CT plots were $\approx 90\%$ bare of either residue or weed cover. Primary weeds in all plots were common chickweed [*Stellaria media* (L.) Vill.] and annual bluegrass (*Poa annua* L.).

FIELD BULK DENSITY. There were no differences in ρ_b among the three

systems at Plymouth (Table 1). At Lewiston, CT soil had lower ρ_b than the soil in either NT or SST systems, while no differences in soil ρ_b were observed between SST and NT systems. Yield of U.S. No. 1 potatoes has been negatively correlated with soil ρ_b to a 20-cm (8-inch) depth (Grimes and Bishop, 1971).

PLANT POPULATION AND GROWTH. At Plymouth and Lewiston, plant population early in the season were lower in NT and SST plots than in CT plots (Fig. 2). The seed pieces in NT and SST plots were planted ≈ 5 cm (2 inch) deeper than those in CT plots because postplanting tillage, used to control weeds and tuber greening, was not performed in NT and SST plots. The in-

creased depth at planting most likely slowed sprout emergence (Ivins and Montague, 1958). By 1 month after planting at Plymouth, there were no differences in plant population among the three systems. At Lewiston, final plant population in NT and SST plots were less than final plant population in CT plots. On two of the six sample dates at Lewiston, potatoes in the SST systems had lower plant populations than potatoes in either NT or CT systems.

Midseason, there were no differences in main stem counts at either site, nor were there differences in leaf area at Plymouth (data not shown). At Lewiston, however, the potatoes in the NT and SST plots had less leaf area on 14 May 1997 than those planted con-

Fig. 2. Percent final plant population, based on 10 inch (25 cm) in-row spacing, in no till (NT), subsurface till (SST), and conventional till (CT) rows at Plymouth and Lewiston, N.C. Different letters within a date indicate significant differences at $P < 0.05$. Error bars are equal to $\text{LSD}_{0.05}$. NS=Nonsignificant at $P < 0.05$.

Fig. 3. Soil moisture tension in no till (NT), subsurface till (SST), and conventional till (CT) and precipitation total 1 week before sampling dates at Plymouth and Lewiston, N.C. Different letters within dates indicate significant differences at $P < 0.05$. Error bars are equal to $LSD_{0.05}$. NS Nonsignificant at $P < 0.05$. Conversion factor for soil moisture tension is 1 MPa = 1000 cbar, for rainfall is 1 inch = 2.54 cm.

ventionally; leaf area of plants in NT plots was 2586 cm² (401 inch²), in SST plots was 3499 cm² (542 inch²), and in CT plots was 7043 cm² (1092 inch²) [$LSD_{0.05}$ = 1871 cm² (290 inch²)]. The plants were visibly smaller in NT and SST plots throughout the season; the reduction in plant size could have been due to the greater soil bulk density or later emergence in the NT and SST systems.

SOIL MOISTURE. At Plymouth, soil moisture tensions varied among treatments at two sampling dates early in the season (Fig. 3). Less negative soil moisture tension is equivalent to higher soil moisture content. Soil in SST was more moist than CT on both dates. Moisture levels in NT plots were the same as CT on the first sampling date and greater on the second sampling date. There was 2 cm (0.75 inch) less

rainfall in the week before the second date than in the week before the first sampling date, suggesting that the residue on NT and SST soils may have reduced evaporation from the soil surface and/or allowed more water to infiltrate the surface compared to the CT soils. Later in the season, there were no differences among the systems in soil moisture tension.

At Lewiston, differences in soil moisture also existed early in the season. CT soils were drier than either NT or SST soils. The plants in the CT plots were larger and more vigorous than plants in the NT and SST plots, and may have been using more water for growth, and losing more water through transpiration. There was also low rainfall early in the season, suggesting that the NT and SST soils may have been able to conserve more moisture than CT soils, as has been previously documented (Creamer et al., 1996; Morse, 1995). On two dates, SST plots were more moist than NT plots, which may be a result of better infiltration in the SST soil. More moisture could have entered the soil and been conserved by the surface residue.

CONE INDEX (CI). At Plymouth, SST soils had a significantly lower CI between the soil surface and 20 cm (8 inch) deep than either NT or CT soils, which were not different. There were no differences in CI among the three systems below 20 cm (8 inch).

At Lewiston, there was little difference in CI of the soils among the three systems to a depth of 25 cm (10 inch) (Fig. 4). Below 25 cm (10 inch), soil in NT and SST systems had lower CI than soil in the CT system. The differences in CI between soil in CT and soil in NT and SST plots below 25 cm (10 inch) at both sites may have been due to the reduction of downward pressure from tillage equipment in the NT and SST soils where less tillage was performed (Raper et al., 1994).

YIELD. There were no differences in yield at Plymouth (Table 2). The CT system at Lewiston produced higher yields than either NT or SST, which were not different from each other. There were no differences at either site among systems on the incidence of internal heat necrosis and hollow heart (data not shown) or on the percentage of As that were green. Also, there were no differences among systems in misshapen tubers at either site.

Fig. 4. Cone index of no till (NT), subsurface till (SST), and conventional till (CT) at Plymouth and Lewiston, N.C. * Significant at $P < 0.05$ or 0.01, respectively; 1 MPa = 1000 cbar.

Grant and Epstein (1973) found no statistical differences in potato yield among tillage systems. However, they did encounter difficulties with planting, maneuvering of equipment, weed control, delayed emergence, tuber sunburn, and tuber greening with minimum tillage. Reduced postplanting tillage did not reduce yield of potatoes in a study by Dallyn and Fricke (1974), but tended to increase yield with the use of an appropriate herbicide. Bennett et al. (1975) found that yields were increased by planting potatoes with

NT into a preformed bed of ryegrass (*Lolium multiflorum* × *L. perenne* L.) sod, with two applications of herbicides. Yield, quality, and available moisture all increased when potatoes were planted NT into cereal rye residue (Morse, 1997). In New York, a reduced tillage system into cereal rye residue reduced potato yield 1 of 4 years and had no effect on yield the other 3 years (Lanfranconi et al., 1993). There was also greater weed pressure in the reduced tillage systems without herbicide applications than in similar

conventional systems without herbicide applications.

Tilling a small width of row, while leaving the space between rows covered with residue (strip tillage), improves planting efficiency and soil physical properties for plant growth. The area between rows left undisturbed protects the soil from erosion and conserves moisture for the crop (Morse, 1995). In-row soil loosening improved transplanted cole crop yields compared to CT, due to the moisture conservation of the mulch between rows, and stabilized yields compared to NT by improving the conditions for transplant establishment (Morse, 1995).

Greenhouse study

There were no differences in plant height or plant dry weight at harvest (data not shown), leaf area, or tuber weight (Table 3) due to ρ_b treatment. This is not consistent with field studies that have shown a decrease in tuber yield with an increase in ρ_b (Blake et al., 1960; Grimes and Bishop, 1971). Other factors associated with an increase in ρ_b , such as air permeability, moisture holding capacity, and soil strength (CI), may have more of an impact on plant growth and yield than ρ_b alone. Also, the differences in ρ_b in the greenhouse may not have been sufficient to elicit differences in plant growth, even though the r_b values did correspond to those found in the field study.

Conclusions

Research on reducing tillage in potatoes appears periodically in the United States (Bennett et al., 1975; Dallyn and Fricke, 1974; Grant and Epstein, 1973; Lanfranconi et al., 1993; Morse, 1997). In this study, we found that the success, solely in terms of potato yield, of reduction of pre-plant tillage in potato production systems depended largely on the soil type and specific site of production. At Lewiston, in a sandy soil, with low organic matter, potatoes did not produce well in NT and SST systems. At Plymouth, in a finer sandy soil, with higher organic matter, potatoes in NT and SST systems yielded as high as potatoes in CT systems. The difference in organic matter and fineness of soil texture, between the two soils may mediate changes in ρ_b and soil tilth to improve conditions for potato growth.

There are some constraints that

Table 2. Yield of 'Atlantic' potatoes in no tillage (NT), subsurface tillage (SST), and conventional tillage (CT) at Plymouth and Lewiston, N.C.

	Yield ² (t·ha ⁻¹)							
	Plymouth		Green (%)	Total	Lewiston		Green (%)	Total
	A	B			A	B		
NT	27.7	2.5	1.20	31.1	19.3 b ^x	3.6 b	1.89	24.3 b
SST	25.4	3.0	3.30	30.0	19.4 b	3.8 b	0.57	24.4 b
CT	27.3	2.8	4.86	32.3	25.9 a	5.4 a	1.07	32.7 a
LSD _{0.05}	NS	NS	NS	NS	3.4	0.8	NS	3.3

²A is yield of U.S. Grade A potatoes [>48 mm (1.88 inch)], with 40% >64 mm (2.52 inch)]; B is yield of U.S. Grade B potatoes B grade [<48 mm (1.88 inch)]; Percentage green is percentage of total yield that had $>5\%$ of surface area with discoloration; 1 ton/acre = 2.24 t·ha⁻¹.

³Different letters within a column indicate significant differences at $P < 0.05$; ^{NS}nonsignificant at $P < 0.05$.

Table 3. Final bulk densities (ρ_b) and potato (var. 'Atlantic') plant growth characteristics of high and low ρ_b targets for soil [no tillage (NT), subsurface tillage (SST), and conventional tillage (CT)] from Plymouth (Portsmouth fine sandy loam) and Lewiston (Norfolk sandy loam), N.C., in the greenhouse.

	ρ_b		Leaf area (cm ²) ^y	Tubers (g) ^x
	Target/field 1997 (g·cm ⁻³) ^z	Greenhouse (g·cm ⁻³)		
Plymouth				
High (NT)	1.18	1.16	1497	231
Low (CT)	1.10	1.07	2103	235
Lewiston				
High (NT)	1.63	1.54	1545	217
Low (CT)	1.42	1.45	1253	201
LSD _{0.05}			NS	NS

^z1 lb/inch³ = 27.7 g·cm⁻³.

^y1 inch² = 6.45 cm².

^x1 oz = 28.4 g.

^{NS}Nonsignificant at $P < 0.05$.

need to be overcome for reduced tillage systems to be used on a large scale by growers. Equipment has been developed for small plot work, but modifications would have to be made on larger commercial equipment, including addition of coulters or other devices able to cut through heavy plant residue, strong press wheels to close the furrow over the seed pieces, and a way to mechanize planting to reduce the number of people necessary for this operation. Also, a method for consistently planting cover crops on pre-formed beds, sufficient for potato production, needs to be developed. A crucial component for many growers of the success of reducing tillage in potato production would be the recognition of site specific limitations. Fields with high weed populations, fields with compaction and/or drainage problems, soils with high sand contents that do not hold soil moisture well, or fields with many rocks should all be avoided. Despite these

limitations, NT and SST in potatoes has the potential to be considered as a viable management option by potato growers in the southeastern U.S. Future research on NT and SST in potatoes should focus on production in different soil types to determine what soils are best suited for these production techniques.

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