

**CONSERVATION TILLAGE METHODS
FOR CABBAGE PRODUCTION**

by

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(ABSTRACT)

Cabbage (*Brassica oleracea* L.) production in Virginia is concentrated in the mountainous southwest region of the state where soil erosion and soil-moisture deficits are major problems associated with row-crop agriculture. The objectives of this study were to assess the applicability of conservation tillage systems for cabbage production. Four tillage systems (conventional tillage, CT; no-tillage, NT; and two types of strip tillage - Ro-till, RT, and chisel plow, CP) and three planting dates (early, mid and late) were compared in 1985 and 1986. Plants were set with a locally adapted no-till transplanter into a cover crop of cereal rye (*Secale cereale* L.). Under unusually rainy conditions in 1985, cabbage yields with NT were lower than with CT; while with dry weather prevailing in 1986, NT and CT yields were equal for all planting dates. Yields in strip tillage systems were equal or higher than NT and CT with ample or deficit soil moisture. RT out-yielded both CT and NT in 1986. Yield was positively correlated with soil moisture content in 1986, but not in 1985. Once-over resetting was done in all plots resulting in no differences in plant numbers among tillage treatments. Head size was affected by tillage systems and was highly correlated with yield. These data indicate that (i) conservation tillage systems are viable alternatives to CT for production of cabbage, and (ii) available water resources and soil drainage should be important considerations in selection of the most productive tillage system.

DEDICATION

I would like to dedicate this thesis to Mom, Dad, Kenner Phipps, Sarah Kay and Gordon.

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INTRODUCTION

Vegetable growers are becoming more interested in tillage methods that decrease erosion and increase water infiltration and soil moisture retention while maintaining or increasing marketable yields. As a result, experiments testing conservation tillage systems for vegetables have been conducted by several researchers (6, 21, 22, 24, 28, 31). No-tillage (NT) vegetable yields have not always been as good or better when compared to conventional tillage yields. Beste (6) reported no yield differences between NT and conventional tillage (CT) for tomatoes and lima beans; however, CT cucumbers outyielded NT. Knavel et al. (21) observed reduced yields under NT for cucumbers, tomatoes, and peppers and no differences for sweet corn. NT yields were lower than CT because of reduced plant stands and in some cases, lower yields per plant. Morse et al. (31) found higher yields for cabbage, cucumbers, squash, and tomatoes under NT than CT. The increased NT yields were attributed to improvements in soil moisture resulting in increased fruit number per plant rather than average fruit size of the fruiting vegetables. Head size accounted for the increased NT yields with cabbage.

Cabbage in Southwest Virginia is primarily grown on steep slopes where erosion is a major problem (25). An estimated 90 MT/ha of topsoil is lost from land in CT cabbage production in Carroll County each year; however, soil loss often exceeds 180 MT/ha (25). Water deficits are also a problem because of low water infiltration rates. Irrigation is not regularly practiced because of

the lack of proximity to water sources. Conservation tillage which reduces soil erosion and generally increases soil moisture would appear to be a reasonable alternative for cabbage production on steep slopes (5, 7, 8, 17, 19, 22).

Conservation tillage is any tillage and planting system that retains at least 30% residue cover on the soil surface after planting and includes no-till, ridge-till, mulch-till, strip-till and other reduced tillage and planting systems (1). Residue cover may be from meadow, winter cover crop, small grain or row crops (1). No-tillage tends to decrease soil temperature which can lead to poor germination and slow early development of many spring-planted crops (5, 18, 39). Cold, wet soil, especially silts and clays, tends to be less friable under NT systems and when field setting transplants, results in poor soil-root contact (14). Under such conditions with NT, crop growth and potential yield may be reduced compared to CT and possibly strip tillage (ST). Strip tillage is a compromise between conventional and no-tillage which combines benefits of both systems (24, 36, 38). Strip tillage is practiced with varying degrees of soil disturbance and width of the tilled areas. In-row tillage may be accomplished with a rototiller, chisel plow, coulters, row cleaners, etc. (1, 12, 36).

The objectives of this study were to assess the effects of tillage systems and the interaction of planting dates X tillage systems on yield of non-irrigated cabbage.

LITERATURE REVIEW

Data on conservation tillage production of vegetables are limited. However, extensive research has been performed on reduced tillage of agronomic crops; therefore, this review primarily reflects that research.

NUTRIENT AVAILABILITY. No-tillage (NT) agriculture eliminates plowing, thus fertilizer is not incorporated into the soil. With NT, fertilizer is either broadcast, banded or knifed into the soil thus altering the nutrient content in the soil layers compared to conventionally tilled (CT) soils, however, nutrient availability under reduced tillage systems has been shown to be generally adequate for crop growth.

NITROGEN. Nitrogen is often the most limiting nutrient in NT crop production because it is readily lost from the soil through volatilization, denitrification, or leaching (16, 21, 52). Hoefl and Randall (16) report that nitrogen levels are related to microbial activity which in turn is influenced by soil temperature, moisture and compaction. Surface residue on NT soils increases soil moisture content and decreases soil temperature, which in turn decreases aerobic and increases anaerobic microbial populations. With fewer aerobic microbes, nitrogen mineralization is decreased and nitrogen availability is reduced.

Valiulis (52) cites two conditions with NT that favor nitrogen loss from the soil. First, enhanced soil moisture content increases leaching of nitrogen. Second, soil surface residues increase

the organic matter content which in turn increases urease activity and subsequent ammonia volatilization from surface applied urea.

PHOSPHORUS. Phosphorus is immobile in the soil; therefore, fertilizer phosphorus is generally found in the top 5-10 cm of soil under NT systems (16, 32, 33, 45, 52). In an eleven year continuous study, Moschler et al. (32) found phosphorus levels to be higher under NT in the 0-20 cm soil layer than under CT; however, in the 20-40 cm layer NT and CT had equal phosphorus content. Shear and Moschler (45) reported that total available phosphorus levels were 75% higher under NT than under CT in the 0-20 cm soil layer. Concentration of phosphorus in the upper layer of soil corresponds with the area of soil moisture which allows adequate phosphorus uptake under NT soils and equal or better yields over CT (16, 52).

POTASSIUM. Potassium is slightly mobile and becomes stratified like phosphorus with NT broadcast fertilization (16, 52). Hoefft and Randall (16) found decreased potassium uptake under NT when the soil was abnormally dry and when soil had poor aeration due to compaction. Triplett (49) concluded that potassium nutrition is adequate under NT with broadcast fertilization. Adequate soil moisture near the surface that allows root proliferation is necessary for potassium and phosphorus fertilizer uptake (52).

SOIL pH. Broadcast application of nitrogen fertilizers with NT causes the pH to decrease in the top 3-8 cm of soil over a period of time (16, 45, 52). Hoefft and Randall (16) pointed out that soil pH changes depend on nitrogen rate and placement along with soil type. Acid conditions in the top soil layer decrease the effectiveness of some herbicides, especially the triazine herbicides, and may inhibit root growth (16, 52). Broadcast application of lime may become necessary on continuous NT fields. Valiulis (52) recommends using half the rate of lime recommended for CT applied twice as often. In some cases, liming has also improved yields (45).

SOIL PHYSICAL PROPERTIES. Tillage systems alter the physical properties of the soil. Ketcheson (20) reported higher mechanical resistance under NT than CT. He concluded that higher penetrometer readings corresponded with restricted root growth under NT. The restricted root growth in turn prevented adequate soil moisture uptake which could not be overcome by additional fertilization. Peterson (38) recorded higher bulk density and penetrometer readings under

NT than CT with intermediate values for chisel plow (CP). Knavel et al. (21) studying four different vegetable crops under NT also found higher penetrometer values under NT than CT. Shear and Moschler (45) reported no differences in bulk densities between NT and CT after a 6 year continuous corn study. They concluded that soil compaction is no greater after several years of NT than after CT.

EROSION CONTROL Conservation tillage has become a major factor in providing erosion control on sloping farm land (3, 5, 15, 36, 38, 44). Peterson et al. (38) measured rill erosion and found that NT and CP nearly eliminated soil loss while there was considerable loss under CT. Angle et al. (3) compared NT and CT in a watershed runoff study. Although both treatments had low rates of runoff, CT produced four times as much runoff as did NT. Suspended sediment loss was eleven times greater under CT and soluble solids loss was significantly greater than NT. Although yields may be decreased under NT, most farmers and researchers agree that maintaining a plant cover on hilly terrain to decrease erosion more than offsets the loss in yield (5, 15).

SOIL TEMPERATURE. Soil temperatures are generally lower under reduced tillage than under CT systems (5, 14, 18, 38, 39, 41, 46). Johnson and Lowery (18) reported lower soil temperatures with NT during the early part of the growing season; however, by the end of June, the difference was less than one degree C. No-tillage soils had the highest volumetric heat capacity, CT the lowest, and CP intermediate; therefore, given equal profile heat inputs, NT and CP soils will have lower temperatures than CT. Temperature findings were supported by Potter et al. (41) and Peterson et al. (39) with $NT < ST < CT$.

In a NT tomato and cucumber study, Beste (6) reported the NT plots had slightly higher temperatures at the 5 cm depth than CT plots. He attributed the higher temperatures to a short rye-straw mulch which allowed sunlight to penetrate the soil surface and to reduced soil heat losses by radiation from the soil surface. Also, the mulch helped decrease the cooling effect of the wind. Radke et al. (43) found soil temperatures and soil structure under NT and CT to be similar due to cool weather and rain. Peterson et al. (38) found no difference in soil temperature between CT and strip tillage (ST); however, NT temperatures were 2-3 degrees C lower.

Lower spring temperatures under NT and ST may explain poorer germination and lower yields than under CT with early planting dates (5, 18, 39). Tessore et al. (46) report cooler soil temperatures under NT to be an advantage in plantings of fall vegetable crops.

SOIL MOISTURE. Researchers have found NT soils to be higher in moisture content than CT soils (5, 7, 8, 17, 19, 22, 30, 38, 43, 46). Several authors cited decreased evaporation from the NT mulch cover as a major factor in increasing moisture reserves especially during the early part of the growing season (5, 7, 8, 43). Blevins et al. (7) report high evaporation losses early in the growing season. As the plants grow, the crop produces a shading effect which decreases evaporation and transpiration becomes the major source of water depletion. Bond and Willis (8) reported lower evaporative potentials under NT. Shaded soil combined with lower temperatures form a temperature gradient causing the water to move from higher to lower temperature areas.

Surface residue increases water infiltration (44, 51). In a three year corn study, Triplett et al. (51) found NT soil with 80% residue to have a greater infiltration rate and total infiltration than did CT soils and NT soils with less residue cover. They attributed the increased infiltration to: 1) physical protection from rain drop impact afforded by the mulch; and 2) difference in structure and stability generated over a three-year period under the mulch. After intense storms, NT with double residue had the highest moisture recharge while NT with residues removed had the lowest recharge. Low intensity storms created no differences in recharge among the treatments because rainfall rates did not exceed infiltration rates.

Peterson et al. (38) compared rotations of winter wheat with crops under NT, CT, and ST. They found no difference in soil moisture between treatments in dry years. In normal years, NT had slightly higher moisture values during the first two months, but this difference disappeared as the crop grew. There was no difference in moisture between conventional and chisel tillage.

Cover crops for NT plantings may deplete soil moisture supply before the crop is planted. Hoyt (17) reports poor kill of rye cover crop to be a factor in removing water from the soil and decreasing broccoli and cabbage yields. In a NT cabbage study, Knavel and Herron (23) reported the effects of killing a Sudan grass cover crop at different heights. Grass allowed to grow 30 cm

high depleted soil moisture and reduced yields; however, killing the grass at 15 cm conserved soil moisture.

WEED CONTROL. No-tillage crop production relies entirely on herbicides for effective weed control (49). New herbicides are being labeled for use on vegetable crops; however, weed pressure is still a major concern for NT farmers.

Herbicides must give initial and residual control on NT crops, and combinations of herbicides are usually needed for satisfactory weed control (49). An effective, non-selective knock-down herbicide applied before planting is an essential part of a weed control program (40). A pre-emergence herbicide with low volatility is recommended (2). Length of herbicide activity is important especially when herbicides are applied several days prior to planting (50). Time and rate of application is important in order to kill the weeds while they are in the vulnerable seedling stage (11, 27, 50). A residual herbicide with good solubility (2), and rain or irrigation soon after application to move the herbicide into the soil is necessary to achieve effective season long weed control. Lack of precipitation often leads to poor weed control (13, 26).

Stubble from cover crops on reduced tillage soils often intercepts and retains herbicides and decreases the rate that reaches the soil, thus reducing their effectiveness (4, 13, 53, 54). Atrazine intercepted by stubble often volatilizes or degrades before reaching the soil (53). Williams and Wicks (53) concluded that broadleaf weeds present at planting time often intercept foliar contact herbicides which allows small underlying grass plants to survive and become a problem later. Other reports also indicate greater grass weed numbers with NT and no difference between NT and CT broadleaf populations (4, 54).

Moomaw and Burnside (26) concluded that greater moisture rather than herbicide retention by the stubble caused weed pressure to be greater under NT. The increased moisture with NT allowed weed seeds to germinate and grow while the CT soil was so dry the weed seeds did not germinate.

Several researchers report problems with perennial weeds after several years of continuous NT (50, 53, 54). The rhizomes are not disturbed so the weeds spread and become a problem.

VEGETABLE YIELD. No-tillage vegetable crop research has provided varied and inconclusive results among different researchers working with the same crop and between different crops.

Table 1 summarizes the findings of this review. Nine studies found no differences between NT and CT; nine found higher yields under NT; and ten found higher yields with CT.

CABBAGE PRODUCTION. No-tillage cabbage production results comparing NT and CT are varied. Knavel and Herron (22) obtained higher head weights and yields with CT than with NT when planting early spring cabbage in March and April. Morse and Seward (29) planted cabbage in June and July and found NT cabbage to have equal or better head weights and yields than with CT.

Knavel and Herron (23) planted fall cabbage in August. Sudan grass mulch was cut at 15 cm and 30 cm heights and compared to CT treatments. The grass cover in the 15 cm height soon dried out and left little residue. Yield in the 15 cm height was equal to that of the CT plots. The grass in the 30 cm plots depleted the soil moisture supply before planting and thus decreased head weight, yield and number of marketable heads. They concluded that planting fall cabbage in NT Sudan grass cover is of no benefit in terms of moisture conservation.

Knavel and Herron (22) reported greater nitrogen requirements for NT cabbage than CT especially at close spacings. Sidedressing nitrogen increased the NT head weight; however, CT still had greater head weights. Peck (37) reported nitrogen uptake rates of cabbage to be low during the seedling stage, high during midseason and moderate near harvest. Broadcasting or banding at planting with an additional sidedressing of nitrogen increased yield, but decreased quality due to burst heads and tip burn. He concluded that nitrogen uptake is continuous and depends on available soil and/or fertilizer nitrogen in the rhizosphere.

Drew (10) studied the effect of soil moisture on cabbage growth and concluded that the increase in weight of cabbage heads is nearly proportional to the total amount of water applied. The cabbage crops' last three weeks of development seems to be the most critical for irrigation because added moisture during this period may overcome the effect of earlier dry soil conditions. He concluded that the later the dry period, the more the yield was depressed. The moisture effect corresponds to the cabbage growth habit. Cabbage grows slowly in early life, taking from 90-100 days

Table 1. Effect of tillage method on vegetable crop yield.

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Crop	Yield		Authors
	CT	NT	
Acorn Squash	--	*	Morse et al. (28)
Asparagus	--	*	Putnam (42)
Broccoli	* NS	-- NS	Konsler et al. (24) Morse et al. (29)
Cabbage	* * NS --	-- -- NS *	Knavel et al. (22) Konsler et al. (24) Morse et al. (29) Morse et al. (31)
Carrots	NS	NS	Orzolek et al. (35)
Cucumber	* NS* --	-- NS *	Beste (6) Knavel et al. (21) Morse et al. (31)
Lima Beans	NS *	NS --	Beste (6) Mullins et al. (34)
Pepper	*	--	Knavel et al. (21)
Potato	* NS	-- NS	Hoyt (17) Thornton (47)
Snap Beans	NS NS	NS NS	Mullins et al. (34) Tompkins et al. (48)
Sweet Corn	NS *	NS --	Knavel et al. (21) Peterson et al. (39)
Tomato	NS * * --	NS -- -- *	Beste (6) Doss et al. (9) Knavel et al. (21) Morse et al. (31)
Yellow Squash	-- --	* *	Morse et al. (31) Tessore et al. (46)
Zucchini Squash	--	*	Tessore et al. (46)

^z* - significantly higher at the 5% level; NS - no significance at the 5% level.

to reach the grand period of growth. Then cabbage heads double in weight about every nine days and require adequate water supplies to maintain turgor pressure.

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MATERIALS AND METHODS

Experimental sites were located in Carroll County, Virginia, in 1985 on a Chester Glenelg loam soil (pH 6.3) and in 1986 on a Lodi silt loam (pH 6.4) at the Horticulture Research Farm near Blacksburg, Virginia.

The experimental design both years was a split plot with planting dates as main plots (1985, 18.3 x 6.1 m; 1986, 14.6 x 4.9 m), and tillage systems as split plots (1985, 4.6 x 6.1 m; 1986, 3.7 x 4.9 m). Four replications of each planting date were used. Two guard rows and two harvest rows were planted in each sub plot.

Spring, Summer 1985

Cereal rye (*Secale cereale* L.) at 125 kg/ha was seeded in the fall of 1984 as a cover crop. Glyphosate, N-phosphonomethyl glycine at 2.24 kg ai/ha was applied as a knock-down herbicide to the entire field two weeks before the first planting date. The rye was 61-76 cm tall when glyphosate was applied.

Four tillage systems were used: 1) conventional tillage (CT), plowed and disked prior to transplanting; 2) no-tillage (NT), plants set into undisturbed sod; 3) row-tillage, strip tilled with a two row Bushhog Ro-Till (RT) machine with 91 cm row spacing (8, 13); and 4) chisel plow (CP), strip chiseled using a locally constructed tool bar with two chisels spaced 91 cm apart (18). Although RT and CP are types of strip tillage (ST), there is a distinct difference between them. In the RT plots, a subsoiler shank at a depth of approximately 25 cm, a dual-coulter system and a rolling basket were used to thoroughly till a strip 40 cm wide; while in CP a chisel shank opened a narrow slit 20 cm deep leaving an untilled narrow strip approximately 15-20 cm wide. A flat bed free of clods and plant residues resulted from RT, while an uneven depression containing clods and some plant residues occurred with the CP.

On May 29, tillage systems were established for all planting dates and napropramide, 2-(α -naphthoxy)-N,N-diethylpropionamide, was applied at 1.7 kg ai/ha over the entire field. Bareroot 'Gourmet' cabbage plants (*Brassica oleracea* var. *capitata* L.) were set at a 91 cm between row and 23 cm in-row spacing with a locally modified two row no-till transplanter. The planter was equipped with two fertilizer hoppers, one per row, that surface banded 1600 kg/ha of 10N-4.3P-8.3K approximately 4 cm to the side of the row at planting. A Diazinon, O,O-diethyl O-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate, solution (0.3 g ai/liter) was hand applied at an approximate rate of 200 ml/plant for control of cabbage root maggots. Immediately following planting, all misplaced and missing plants were reset by hand to maximize plant survival and stand uniformity. The second planting was done on July 2 with the same transplanting procedure.

Prior to planting, cover crop biomass estimates were determined by sampling two 61 x 61 cm areas. Rye samples were dried at 70°C and weighed (Table 2). Soil moisture was determined from the top 10 cm by the gravimetric method twice in each tillage treatment for each planting date (7). Soil temperature at a depth of 10 cm was recorded weekly with soil thermocouples for all tillage systems.

Hand weeding was done as necessary and recommended pesticides were applied at regular intervals to control insects and diseases. Plots were harvested twice for each planting date beginning August 8 and September 22 and again two weeks later, respectively, for each planting date. Head number was the number of mature heads per plot at harvest time and was used as an estimate of plant stand because very few plants did not form heads. Total head weight was recorded and weight included 3-4 wrapper leaves. Weight per head was obtained by dividing total head weight by total number of heads.

Spring, Summer 1986

Cereal rye was seeded at a rate of 125 kg/ha in the fall of 1985. Prior to sowing rye, nitrogen was applied at a rate of 34 kg/ha. Most of the cover crop had been lost by the second planting date in 1985; therefore, to assure an adequate cover for each planting date in 1986, only the areas to be planted were killed and tillage methods installed just prior to each planting date. The subsequent areas to be planted were mowed and allowed to continue growing until the next planting date.

Tillage systems and transplanting were the same as in 1985. Paraquat, 1,1'-dimethyl-4,4'-bipyridinium ion, at 0.56 kg ai/ha was used as the knock down herbicide when the rye was 61-76 cm tall and was applied one to two days before establishing tillage methods.

Tillage systems were established and a combination of oxyfluorfen, 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene, at 0.35 kg ai/ha and 1.7 kg ai/ha of napropamide were applied in the morning before planting. The first planting date spray included 0.8 kg ai/ha paraquat due to poor rye kill with the first application. Herbicides were inadvertently applied before tillage treatments were established in the second planting date, necessitating hand weeding particularly in the CT plots. Rates of oxyfluorfen and napropamide were the same as those at the other planting dates.

Table 2. Dry matter yield of rye cover crop (MT/ha).

Table 2. Dry matter yield of rye cover crop (MT/ha).

Planting date ^z	1985	1986
1	3.0 ^y	2.6a ^x
2	---	3.0a
3	---	3.3a

^z Sampling dates were: 1985: 1 = May 30; 1986: 1 = April 21, 2 = May 23, 3 = June 24.
^y 1985 biomass samples were done once - the entire cover crop was sprayed with glyphosate at the same time.
^x Mean separation by Duncan's multiple range test, 5% level.

Bareroot 'Market Prize' cabbage transplants were used for the first two planting dates and 'A & C 5' was used for the third planting date. The transplanting rate of fertilizer and pest control were the same as in 1985. A solution mixture of diazinon (0.3 g ai/liter) and 9N-19P-12K Peters starter fertilizer (6 g/liter) was hand applied after transplanting at approximately 200 ml per plant. After the cabbage plants were set, the plots were irrigated with 4 cm of water to aid plant establishment and incorporate the herbicides. Planting dates were April 24, June 4 and July 8. Once over harvest dates were July 18, August 26 and September 29, respectively.

Soil moisture samples were taken in the plant row three times per planting date in each tillage treatment at a depth of 10 cm using the gravimetric method (7). Soil temperature at a depth of 10 cm was measured weekly in the plant rows. Cover crop biomass was determined by sampling each rep for each planting date using similar procedures as in 1985 (Table 2).

Five cm of irrigation water were applied to all plots on July 22 when the soil became extremely dry due to drought conditions.

Data were statistically analyzed by analysis of variance using the General Linear Models procedure on SAS (23).

RESULTS AND DISCUSSION

YIELD AND YIELD COMPONENTS. Tillage systems significantly affected yield per hectare (Table 3). In 1985, yields with CT equalled RT and CP, and were significantly higher than with NT. In 1986, yield in RT plots was significantly higher than in CT and NT and not significantly different than CP. Strip tillage appeared to be the best alternative tillage method because it combines the benefits of tillage and a mulch cover to produce an excellent growing environment. Individual effects of planting dates and tillage systems for yield and yield components are shown in the appendix (Tables 6, 7, 8).

Average head size among tillage systems was significantly different both years (Table 3) and was the major component responsible for yield differences. The correlation between head size and yield was highly significant with r values of 0.56*** and 0.89*** for 1985 and 1986, respectively.

There were no significant differences in head number among tillage systems either year (Table 3). Head number can be considered the same as plant stand since, with rare exception, all plants produced a marketable head. Resetting misplaced and missing plants resulted in final plant survival (percentage final plant stand with once-over resetting) of over 88% both years (Table 3). Resetting is a standard practice of Carroll County cabbage growers. Even though resetting compensated for planting failures in these experiments, excessive resetting in commercial operations would be un-

desirable because of increased labor costs. Although plant survival was statistically the same for all tillage treatments, plant numbers tended to be slightly higher in RT plots both years

(Table 3). Under windy and/or dry conditions, plant survival would be favored in all three conservation systems, especially in RT where the tilled, friable soil would tend to enhance soil-root contact and rapid root growth (12).

Planting effectiveness (percentage plant stand without resetting) was not recorded in these experiments. However, the numbers and extent of improperly set plants were notably greater with NT and somewhat greater with CP plots than in CT and RT soils. The amount of large clods and plant residues were correspondingly higher in CP and NT plots. It is therefore believed that the relatively impediment-free condition and improved friability of the CT and RT soils would result in greater planting effectiveness than with NT and possibly CP.

The RT would appear to have distinct advantages over NT and CP for conservation tillage cabbage production when wet soils are a potential problem. In this study, the plant beds were flat with all tillage systems; however, raised beds can be established with the RT by a simple adjustment of the dual coulters (12). Raised beds would provide a potential advantage for the RT in situations such as early spring plantings and/or poorly drained soils where excess surface water might be a problem.

SOIL MOISTURE. Except for the second planting in 1985, soil moisture tended to be higher in conservation tillage plots than in CT (Table 4). In 1985, soil moisture and yield were not correlated ($r = -.17ns$). These data are inconsistent with the 1986 findings ($r = .60***$) and the reports of other researchers who have shown a strong positive relationship between yield and soil moisture content (3, 11, 15, 16, 17). Morse et al. (16) found higher fall yields and a corresponding higher soil moisture content with NT than with CT for four vegetables studied--cabbage, cucumber, tomato and squash. Planting date effect on soil moisture content is shown in the appendix (Table 9).

In 1985, after early July soil moisture content was not significantly different between tillage systems and did not affect head yield. Unusually heavy rains in July and August (Table 5) and the

Table 3. Influence of tillage systems on head number, yield and size of cabbage.

Table 3. Influence of tillage systems on head number, yield and size of cabbage.^z

Tillage system ^y	Head no ^x (1000/ha)		Yield (MT/ha)		Head size (kg/head)	
	1985	1986	1985	1986	1985	1986
CT	41.6a ^v	42.1a	61.9a	59.6b	1.5a	1.4b
NT	41.3a	41.6a	52.3b	62.5b	1.3b	1.5ab
RT	43.1a	43.3a	59.9ab	70.8a	1.4ab	1.6a
CP	41.9a	40.8a	58.1ab	64.7ab	1.4ab	1.6a

^zThere were no significant interactions between planting dates and tillage systems.

^yCT = Conventional tillage; NT = No-tillage; RT = Ro-till; CP = Chisel plow.

^xThe theoretical "perfect" plant population at 91 x 23 cm would be 47,778 plants/ha.

^vMean separation within columns by Duncan's multiple range test, 5% level.

small quantity of mulch remaining during the second planting resulted in equal soil moisture content between tillage systems after early July.

Although there were significant soil moisture differences recorded for the first planting (Table 4), these data did not reflect subsequent yield differences because the soil moisture samples were taken on June 13 and 25, which corresponded to the vegetative stage of plant development. During slow development in the vegetative period, cabbage yield is little affected by water deficits. Once the head formation stage is initiated, increases in weight of cabbage heads is nearly proportional to the quantity of water applied (4, 5).

Although actual soil erosion data were not taken in this study, there was no evidence that serious soil losses occurred in the plots either year. Heavy rainfall often results in serious soil erosion in Carroll County (14) and other mountainous Appalachian regions, particularly when heavy rains impact on freshly tilled soil. Probably no soil erosion problems occurred in our plots because the research areas were relatively flat, and the heavy rains of 1985 occurred approximately two months after tillage.

SOIL TEMPERATURE. Tillage systems did not significantly affect soil temperature either year (Table 4). Many authors have reported lower soil temperatures under NT (1, 9, 10, 19, 21, 24). In our experiments, average soil temperature differences between treatments were less than one °C each year. Johnson and Lowery (10) reported lower soil temperatures under NT during the early part of the growing season with differences lessening to less than one °C by the end of June. Radke et al. (22) reported similar soil temperatures under NT and CT due to cool weather and rain. Planting date effects on soil temperature are shown in the appendix (Table 9).

The thermocouple probes used for temperature readings in this study were located between plants within the row. Apparently the disturbance and sloughing aside of plant residues by the conservation planter removed enough in-row cover in the NT plots to minimize any in-row temperature differences between tillage systems. Rapid decomposition of the rye cover prior to planting in 1985 and dry weather during the first planting in 1986 probably contributed to the lack of temperature differences. Beste (2) recorded higher temperatures under NT than under CT. He attri-

Table 4. Effects of planting dates and tillage systems on soil temperature and soil moisture content

Table 4. Effects of planting dates and tillage systems on soil temperature and soil moisture content.

Planting date	Tillage system ^z			
	CT	NT	RT	CP
Soil moisture (%) ^y				
1985				
May 30	18.3c ^x	28.4a	26.9ab	24.8b
July 2	20.6a	20.9a	21.0a	20.6a
Mean	19.5c	24.4a	23.9ab	22.7b
1986				
Apr 24	12.5b	15.3a	13.3b	14.0ab
June 4	15.0a	16.7a	16.7a	16.8a
July 8	14.7a	15.7a	16.6a	16.7a
Mean	14.1b	15.9a	15.5a	15.8a
Soil temperature (C)				
1985				
May 30	19.4a	19.7a	19.5a	20.1a
July 2	23.0a	22.2a	22.8a	22.6a
Mean	21.1a	20.8a	21.0a	21.2a
1986				
Apr 24	20.0a	19.6a	19.6a	19.5a
June 4	22.2a	21.9a	22.2a	21.9a
July 8	20.7a	20.9a	20.7a	20.6a
Mean	21.0a	20.9a	20.9a	20.7a

^z CT = Conventional tillage; NT = No-tillage; RT = Ro-till; CP = Chisel Plow.

^y There was a significant planting date x tillage systems moisture interaction in 1985; however, no moisture interaction occurred in 1986 or temperature interactions either year.

^x Mean separation within rows Duncan's multiple range test, 5% level.

Table 5. Monthly and annual precipitation.

Table 5. Monthly and annual precipitation.

Month	Carroll Co.		Blacksburg	
	1985	Average	1986	Average
	-----mm-----			
Jan	76.2	69.1	29.2	74.9
Feb	90.7	77.5	92.2	74.7
Mar	54.1	88.6	49.5	99.3
Apr	52.3	83.8	37.6	90.2
May	152.4	90.4	168.9	91.9
June	63.2	100.6	32.5	91.7
July	162.8	115.8	99.8	92.7
Aug	249.2	102.1	84.1	89.7
Sept	14.2	97.8	95.5	88.4
Oct	62.7	77.5	62.2	79.8
Nov	231.4	70.4	----	68.1
Dec	28.7	79.8	----	74.2
Total	1237.9	1053.4	751.5	1015.6

buted the higher temperatures to reduced radiation losses of heat and by minimizing the cooling effect of the wind with the straw mulch. This could have also been the situation in these plots.

PLANTING DATES X TILLAGE SYSTEMS INTERACTIONS. Lack of significant yield interactions between planting dates and tillage systems indicates that differences in response of growth determinants such as soil moisture and temperature to tillage systems were similar for all planting dates. In early spring, lower temperatures and wet soils often occur with NT (1, 9, 10, 20). Planting dated X tillage systems interactions frequently occur under cool, wet spring conditions followed by increasing soil moisture deficits as the season progresses (6).

Although significant planting dates X tillage interactions did not occur either year, yield response to tillage varied considerably over the two years and showed a strong relationship with monthly rainfall patterns. In 1985, unusually heavy rainfall in July and August resulted in uniform soil moisture between tillage systems (Table 5). The higher CT yields in 1985, compared to NT, are attributed to observed improvements in soil root contact in tilled plots. In 1986, dry weather occurred during plant establishment and early growth of the first planting, followed by a relatively irregular rainfall pattern throughout the growing season (Table 5). As a result, soil moisture content was consistently higher in NT than CT the entire year (Table 4). The similar yields between NT and CT in 1986 (Table 3) are attributed to counterbalancing effects of higher soil moisture with NT versus improved soil root contact with CT.

If cabbage were planted with NT under cool, wet conditions, poor root-soil contact at planting and slow early plant growth would probably occur resulting in reduced yields (12). The yield difference between tillage treatments and NT in early plantings probably would be greater under high rainfall or when irrigation is applied throughout the growing season. Ample moisture supplies, especially during the rapid head development stage when cabbage requires abundant moisture (5, 6) would tend to offset any potential advantages of NT over the other tillage treatments in conserving soil moisture.

CONCLUSIONS

1. All conservation tillage systems performed well under the conditions of this study.
2. In 1985, when soil moisture was not limiting, CT outyielded NT probably because of observed improvements in soil- root contact with CT. Under the intermittent deficit soil moisture conditions found in 1986, conservation of soil moisture by the plant residues resulted in improved NT yields, equalling those with CT.
3. Yields with strip tillage (RT and CP) equalled or were higher than with NT or CT both years. Strip tillage appeared to be the best overall tillage choice under either ample or deficit soil moisture. The combination of in-row tillage for improved planting efficiency and soil physical condition and between-row cover for moisture and soil conservation make strip tillage an excellent compromise between NT and CT.
4. In situations where soil erosion is a major concern, NT would probably be the preferred tillage treatment over strip tillage, unless the grower paid strict attention to proper contour planting procedures. Because of the relatively small fields and irregular terrain in mountainous Appalachia, contour farming is not a well established practice. Studies are needed to evaluate the effects of different strip tillage systems on soil erosion.
5. Planting dates X tillage yield interactions did not occur either year. Abnormally heavy summer rainfall in 1985 and dry spring weather in 1986 probably accounted in large measure for the lack of yield interactions.

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APPENDIX

Table 6. Individual effects of planting date and tillage system on head number, yield and size of cabbage in 1985.

Table 6. Individual effects of planting date and tillage system on head number, yield and size of cabbage in 1985.

Tillage system ^z	Planting date	
	May 30	July 2
	Head no (1000/ha)	
CT	41.9a ^y	41.3a
NT	38.3a	44.2a
RT	44.4a	41.7a
CP	40.6a	43.3a
	Yield (MT/ha)	
CT	63.8a	60.1a
NT	51.2a	53.3a
RT	63.6a	56.3a
CP	58.3a	58.0a
	Head size (kg/head)	
CT	1.5a	1.5a
NT	1.3a	1.2b
RT	1.4a	1.3ab
CP	1.4a	1.3ab

^z CT = Conventional tillage; NT = No-tillage; RT = Ro-till; CP = Chisel plow.

^y Mean separation within column by Duncan's multiple range test, 5% level.

Table 7. Individual effects of planting dates and tillage systems on head number, yield and head size of cabbage in 1986.

Table 7. Individual effects of planting dates and tillage systems on head number, yield, and head size of cabbage in 1986.

Tillage ^z system	Planting date		
	Apr 24	June 4	July 8
		Head no (1000/ha)	
CT	41.1a ^y	42.6a	42.3a
NT	41.8a	42.6a	40.0a
RT	43.4a	43.2a	43.4a
CP	41.5a	40.4a	40.6a
		Yield (MT/ha)	
CT	50.1a	57.4b	69.0b
NT	54.0a	65.4ab	67.2b
RT	55.4a	75.0a	82.0a
CP	53.0a	67.4ab	70.8ab
		Head size (kg/head)	
CT	1.2a	1.4b	1.6a
NT	1.3a	1.5ab	1.7a
RT	1.3a	1.8a	1.9a
CP	1.3a	1.7a	1.7a

^zCT = Conventional tillage; NT = No-tillage; RT = Ro-till; CP = Chisel plow.
^yMean separation within column by Duncan's multiple range test, 5% level.

Table 8. Influence of planting date on head number, size and yield of cabbage.

Table 8. Influence of planting date on head number, size and yield of cabbage.^z

Planting date ^y	Head no (1000/ha)		Yield (MT/ha)		Head size (kg/head)	
	1985	1986	1985	1986	1985	1986
1	41.3a ^x	42.0a	59.2a	53.3b	1.4a	1.3b
2	42.6a	42.2a	56.9a	66.3ab	1.3a	1.6ab
3	----	41.7a	----	72.6a	----	1.7a

^zThere were no significant interactions between planting dates and tillage systems.
^y1985: 1 = May 30, 2 = July 2; 1986: 1 = April 24, 2 = June 4, 3 = July 8.

^xMean separation within columns by Duncan's Multiple range test, 5% level.

Table 9. Influence of planting dates on soil moisture and soil temperature.

Table 9. Influence of planting dates on soil moisture and soil temperature.

Planting date ^z	Soil moisture (%)		Soil temperature (°C)	
	1985	1986	1985	1986
1	---- ^y	13.8b ^x	19.7b	19.7c
2	----	16.3a	22.7 ^w a	22.0a
3	----	15.9a	----	20.7b

^z1985: 1 = May 30, 2 = July 2; 1986: 1 = April 24, 2 = June 4, 3 = July 8.

^yThere was a significant soil moisture interaction between planting dates and tillage systems in 1985; see Table 3.

^xMean separation within columns for each main effect by Duncan's multiple range test, 5% level.

^wOnly two plantings were established in 1985.

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