Production & Marketing Reports

# Components of Sustainable Production Systems for Vegetables-Conserving soil Moisture

Ronald D. Morse[1]

***Additional index words.*** conservation tillage, no-tillage, strip tillage, erosion control, cabbage

***Summary.*** Conservation tillage systems offer distinct advantages for crop production under erosive and droughty soil conditions. This report contains 4 years of data on the effects of in situ cereal rye and wheat mulches on yield of cabbage *(Brassica oleracea* L. var. *capitata)* grown under limited-irrigation, conservation-tillage systems. Three tillage systems were studied: conventional plow-disk (CT); strip tillage (ST) and no-tillage (NT). The summers of 1987 and 1990 were characterized by below-average total rain and periods of prolonged (45 days) of dry weather during head enlargement; cabbage yields were highest in the mulched ST and NT plots. In contrast, the 1988 and 1989 growing seasons were above average in total rain and there were no prolonged periods of dry weather. Cabbage yields were unaffected by tillage treatments in 1988, while, in 1989, yields with NT were 65% and 60% lower than with CT and ST, respectively. A combination of abundant rain, soil compaction, and delayed planting retarded plant growth in the 1989 NT plots, resulting in smaller, less-productive plants than in the tilled ST and CT plots. These data show that: 1) conservation tillage and particularly strip tillage systems are viable options for production of cabbage; and 2) rain-irrigation patterns, site selection, and planting dates are major determinants of the relative advantages of conservation tillage compared to conventional tillage systems.

Department of Horticulture, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061-0327.
[1]Associate Professor.

Yield potential of any given crop in a particular field is limited by pest management, soil physical properties, and the availability of plant growth inputs such as $CO_2$, water, and nutrients. Profitability, however, is determined not so much by achieving the yield potential each year as it is through efficient utilization and maintenance of production inputs. Harwood (1990) referred to resource-use efficiency in his definition of sustainable agriculture, "an agriculture than can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species." Indeed, no production system will endure unless it is efficient (profitable) in utilization of available resources. Conservation tillage systems are gaining in popularity throughout the world, in large measure because of their proven superiority in efficient use and maintenance of two of the earth's most precious natural resources-soil and water (Crosson, 1981; Hargrove, 1990). The word "maintenance" in this context refers to protection or retention of these resources in a highly productive (soil tilth and fertility) and environmentally safe (nonpolluted) condition.

A major benefit of conservation tillage systems is increased water-use efficiency (WUE) (Morse et al., 1988; Morse and Tessore, 1984; Wilhoit et al., 1990). This article highlights 4 years (1987-1990) of data on the effects of in situ rye and wheat mulches on available soil moisture and yield of cabbage grown under limited-irrigation conservation-tillage systems. Either wheat *(Triticum aestivum* L.) in 1987 or cereal rye *(Secale cereale* L.) in 1986, 1988, and 1989 were seeded at 112 lb/acre (125 kg·ha$^{-1}$) each year in late September on a Groseclose clay loam soil (clayey, mixed, mesic, typic Hapludult), at the Blacksburg Horticulture Research Farm. Prior to reaching the mature heading stage, the cover crops were mow-killed with a rotary mower in late May and weeds and cover-crop regrowth were desiccated with a 1% solution of glyphosate [N-(phosphonomethyl)glycine] prior to setting cabbage transplants with a modified Holland (Holland Transplanter Co., Holland, Mich.) conservation tillage transplanter. Each year, oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitro-phenoxy)-4-(trifluoromethyl)benzene)] herbicide was applied preplant preemergence at the rate of 0.4 lb a.i./acre (0.45 kg a.i./ha). Fertilizers and pesticides were applied according to standard recommended practices (Virginia Cooperative Extension, 1990) for Carroll County, the largest cabbage-producing area in Virginia. Fertilizer was applied as a liquid starter solution [60 lb/acre (67 kg/ha) of 9N-19P-12K] and a granular sidedressing [712 lb/acre (800 kg/ha) of 15N-13P-12K)] at planting by the transplanter fitted with fertilizer attachments. During the first week after planting, missing and dead plants were replaced in each plot by hand. Other than rain, the plots received only supplementary irrigation during the first 2 to 3 weeks after planting to ensure good plant survival, and occasionally thereafter in some years to maintain growth during periods of severe soil water deficits. This minimum-water supplement system is very common among many vegetable growers in Virginia and other humid regions in the United States where often more land is planted than capacity (water, equipment, and labor) to irrigate in extended droughts (Morse et al., 1988).

***1987.*** A randomized block design with four replications was used to evaluate the effects of two residue levels on cabbage yield. In late May 1987, the rye cover crop was mowed, leaving a heavy cover estimated at 2 tons/acre (4.5 $t\cdot ha^{-1}$) dry weight of coarsely chopped straw on the soil surface. Prior to planting, the straw was removed from half of each replicated plot, leaving a 4-inch (lo-cm) stubble mulch (partial mulch); the straw in the other half was spread out evenly and retained (full mulch). 'Money Maker' cabbage transplants were set 23 June 1987 in double rows 20 inches (50 cm) apart and 28 inches (70 cm) between double rows, with an in-row spacing of 8 inches (20 cm). Soil moisture content of the top 8 inches (20 cm) was determined in all plots throughout the growing season following periods of dry weather, using the gravimetric method (Gardener, 1986). After plant establishment, supplementary irrigation was applied only following periods of prolonged drought in which the soil moisture content of the top 8 inches (20 cm) had been reduced to near the wiltingpercentage (Kovach, 1978). In early fall, marketable size (1 lb and above) heads were harvested and weighed from a 20-ft (5.5-m) double-row section of each treatment plot.

***1988-1990.*** Each year, a randomized-block design with four replications was used to compare three tillage/residue-management regimes: 1) conventional tillage (CT)-cover crop was mowed and the residues incorporated by plowing and disking; 2) no-tillage (NT)-mowed residues averaging 2 tons/acre (4.5 $t\cdot ha^{-1}$) were left undisturbed prior to planting; and 3) strip-tillage (ST)-residues were partially incorporated in a narrow strip using a strip-tillage implement (STE) built at Virginia Tech (Wilhoit et al., 1990). The STE consisted of a ripple coulter mounted in front to cut through the cover crop residues, a chisel to till to a depth of 6 to 8 inches (15 to 20 cm), followed by a pair of fluted coulters to prepare a tilled strip 8 to 10 inches (20 to 25 cm) wide. 'Rio Verde' cabbage transplants were set in all plots with the Holland conservation tillage transplanter on 22 June 1988, 25 July 1989, and 26 June 1990. Plant spacing, fertilizer application, determination of soil moisture content, irrigation, and harvesting procedures were similar to that used in the 1987 experiment.

## Results

***Dry years.*** Average rain in southwestern Virginia is sufficient to produce profitable yields of cabbage; however, because rain is not always distributed evenly throughout the growing season, periods of either excess and/or deficit soil moisture often occur (Table 1). In 1987 and 1990, prolonged periods ofdrought occurred during head development (Table 1), which resulted in soil moisture stress, particularly in the 1987 partial-mulch and 1990 CT plots (Table 2). Cabbage yields were the highest in the 1987 full-mulch and NT plots in 1990. More heads reached marketable size and average head size was largest in the full-mulch and conservation-tillage plots (Table 2). Apparently, plant growth and yield were greatest in these plots because the straw mulches increased water infiltration and reduced runoff and evaporation, providing the plants with a more-extended supply of available soil moisture during head enlargement. Other researchers have reported that, compared to CT systems, yields of vegetables (Love, 1986; Morse et al., 1982; Morse and Seward, 1986) and agronomic crops (Blevins et al., 1971; Crosson, 1981; Moody et al., 1963; Webber et al., 1987) were higher with NT under droughty summer weather conditions similar to that of 1987 and 1990.

***Wet years.*** In 1988 and 1989, irrigation and rain were adequate to sustain plant growth in all plots (Table 1). Cabbage plants showed no visual prolonged soil moisture stress. The differences in growth and yield among tillage/residue-management treatments in 1989 (Table 2) can be attributed to other factors such as poor soil structure. Soil compaction is often higher in NT than CT systems (Blevins et al., 1985; Griffeth et al., 1986; Webber et al., 1987).

In 1988, cabbage yield was the same among all treatments (Table 2). Soil tilth in the NT plots was excellent at transplanting in 1988 and plant establishment and growth were similar to that in the CT and ST plots. In 1989, however, cabbage yield in NT plots was 65% and 60% lower than in CT and ST, respectively. The 1989 experimental site appeared to be highly compacted, as evidenced by severe soil

Table 1. Seasonal recorded precipitation, Horticultural Research Farm, Blacksburg, Va.

| Month[z] | Normal[y] | Year 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|
| | | *Precipitation (inches)* | | | |
| June | | | | | |
| 1–15 | --- | 0.52 | 2.31 | 4.88 | 0.15 |
| 16–30 | --- | 0.95[x] | 0.90 | 2.20 | 0.76[x] |
| Total | 3.61 | 1.47 | 3.21 | 7.08 | 0.91 |
| July | | | | | |
| 1–15 | --- | 2.98 | 1.01[x] | 3.07 | 3.76 |
| 16–31 | --- | 0.13 | 4.38 | 1.74[x] | 0.24[x] |
| Total | 3.65 | 3.11 | 5.39 | 4.81 | 4.00 |
| August | | | | | |
| 1–15 | --- | 0.81 | 3.65 | 0.90[x] | 3.19 |
| 16–31 | --- | 0.83[w] | 1.92 | 3.68 | 0.94 |
| Total | 3.53 | 1.64 | 5.57 | 4.58 | 4.13 |
| September | | | | | |
| 1–15 | --- | 5.89 | 1.38 | 1.54 | 1.18 |
| 16–31 | --- | 0.72 | 2.76 | 6.55 | 0.62 |
| Total | 3.48 | 6.61 | 4.14 | 8.09 | 1.80 |
| Total | 14.27 | 12.83 | 17.31 | 24.56 | 10.84 |

[z]Planting dates: 23 June 1987, 22 June 1988, 25 July 1989, and 26 June 1990.
[y]Average rainfall compiled over many years (Virginia Agricultural Statistics, 1991).
[x]Irrigation applied during first 2 to 3 weeks to ensure plant survival.
[w]Supplementary irrigation applied 20 Aug. 1987 after prolonged dry period to sustain growth.

Table 2. Effects of tillage/residue management systems on soil moisture content, marketable cabbage yield, and yield components, 1987-l 990.

| Tillage residue-management treatment[z] | Soil moisture content (%) | Yield (tons/acre)[y] | No. heads (1000/acre)[y] | Head wt (lb)[y] |
|---|---|---|---|---|
| | | *1987* | | |
| Partial mulch | 10.4 a | 11.8 b[x] | 14.1 b | 1.7 b |
| Full mulch | 11.2 b | 18.4 a | 16.5 a | 2.2 a |
| | | *1988* | | |
| CT | 17.2 a | 19.6 a | 12.2 a | 3.2 a |
| NT | 18.1 b | 18.4 a | 11.1 a | 3.3 a |
| ST | 18.1 b | 20.0 a | 12.5 a | 3.2 a |
| | | *1989* | | |
| CT | 20.8 a | 19.6 a | 14.8 a | 2.6 a |
| NT | 20.9 a | 6.8 b | 7.7 b | 1.8 b |
| ST | 21.3 a | 17.1 a | 15.5 a | 2.2 ab |
| | | *1990* | | |
| CT | 12.0 a | 6.2 b | 4.9 b | 2.5 b |
| NT | 12.9 b | 10.8 a | 7.1 a | 3.0 a |
| ST | --- | 8.3 ab | 5.6 ab | 2.8 ab |

[z]Partial mulch = wheat straw removed; full mulch = wheat straw retained; CT = conventional tillage; NT = no-tillage; and ST = strip tillage.
[y]Conversion factors: tons/acre x 2.24 = $Mg \cdot ha^{-1}$; 1000/acre × 2.47 = 1000/ha; lb × 0.45 = kg.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

crusting and poor soil tilth. The transplanter shoe was unable to penetrate and loosen the soil properly in NT plots, resulting in shallow placement of the transplants and poor root-soil contact. Transplant survival, growth, and subsequent yield of cabbage were poor in the NT plots. Even though resetting by hand was done to obtain a uniform plant stand among treatments, the slow early growth and late planting (25 July 1989 vs. 22 June 1988) resulted in smaller, less-productive plants. In contrast, plant establishment and early plant growth were excellent in the tilled soil of the CT and ST plots in 1989. Apparently, late planting was not a limiting factor with the CT and ST treatments and there was sufficient time for the cabbage heads to reach marketable size.

## Discussion

***Short-term benefits (one season).*** To benefit from using a particular tillage system, the grower must have a specific combination of growing conditions that maximize the advantages and minimize the disadvantages of this production system. Data presented in this report and other research strongly indicate that the major short-term (one season) advantage of using conservation tillage systems is improved soil moisture. Most studies have shown increased growth and yield benefits as mulch biomass increases (Blevins et al., 1971; Hargrove, 1990; Morse et al., 1988). Improved yield resulting from increased soil moisture commonly occurs when conservation tillage is practiced on hillsides (Moldenhauer et al., 1991). When water-use efficiency (WUE) increases in conservation tillage systems (Morse and Tessore, 1984), profitability may be enhanced two ways: 1) by increasing yields under soil-moisture deficit conditions, thus increasing WUE of rain (Morse and Tessore, 1984); and 2) by reducing the amount of irrigation water needed, thus increasing the WUE ofirrigation (Wiese and Unger, 1974). The question may arise, "should conservation tillage be used when soil moisture is not limiting"? For each farmer or production situation, the answer is based on the erosion potential of the farm site, plus the extent to which the advantages of conservation tillage other than erosion offset the disadvantages.

***Long-term benefit (many years).*** Whether conservation tillage systems increase crop yield depends on many factors and interactions over time (Crosson, 1981). Over the long term (many years or decades), lower rates of erosion can give conservation tillage a decisive yield advantage relative to conventional tillage. Continued use of conservation tillage systems often result in soil improvement and enhanced soil productivity (Hargrove, 1990). On highly erosive soils, conventional tillage practices over many years can lead to severe decline in soil productivity.

***Conservation tillage is not for everyone.*** Even the most enthusiastic supporters of conservation tillage do not claim it to be the most appropriate system under all conditions. Indeed, many factors offset the advantages of conservation tillage systems compared to conventional tillage. A conscientious land steward must, whenever possible, consider both short-term yield effects as well as long-term, sustainable effects on soil productivity. Factors that offset the advantages and discourage the use of conservation tillage include soil compaction and drainage problems, delayed planting dates caused by reduced soil temperatures or other factors, and deleterious effects of plant residues on crop establishment and pest management. In humid areas when rain is abundant accompanied by frequent periods of excessive downpour, NT systems are often not recommended, especially on nonerosive soils (Crosson, 198 1). Thus, when considering conservation tillage systems, rain-irrigation patterns, site selection, and planting dates are extremely important. The data in 1989 illustrate this point. The site used in 1989 was flat and relatively compacted and planting was delayed 1 month later compared to 1987, 1988, and 1990. The combined effects of abundant or possibly excessive rain, compacted soils, and delayed planting are believed to account for the poor yield response in the NT plots in 1989.

***Strip tillage.*** Based on these data and previous studies (Love, 1986; Morse, 1989), strip tillage appears to be the best overall tillage system for many soils under either ample or deficit soil moisture. The combination of in-row tillage for improved planting efficiency and soil physical properties and between-row cover for moisture and soil conservation make strip tillage an excellent compromise between NT and CT. An important question or consideration associated with conservation tillage systems for vegetables is "how much tillage or soil loosening is necessary to alleviate compaction in undisturbed (unplowed) soils"? Work is underway at Virginia Tech to answer this question using a new Subsurface Tiller Transplanter (SST-T) to loosen in-row subsoil and set transplants in heavy residues (Feigenoff, 1992). The SST-T has a high clearance design to function in heavy residues with reduced disturbance of surface soil and cover crop residues, thereby improving weed control and conservation of soil and water.

## Literature Cited

*Blevins, R.L., D. Cook, S.H. Phillips, and R.E.* Phillips. *1971.* Influences of no-tillage on soil moisture. Agron. J. 63:593-596.

*Blevins, R.L., W. W. Frye, and M.S. Smith. 1985.* The effects of conservation tillage on soil properties, p. 99-110. In F.M. D'Itri (ed.). A systems approach to conservation tillage. Lewis, Chelsea, Mich.

*Crosson, P.R. 1981.* Conservation tillage and conventional tillage: A comparative assessment. Soil Conservation Soc. Amer., Ankeny, Iowa.

*Feigenoff, C. 1992.* Curbing erosion. Amer. Farmland (Summer) p. 16-17.

Gardener, *W.H. 1986.* Water content, p. 493-544. In: A. Klute (ed.). Methods of soil analysis, Part 1. Agron. Mngr. 9. Amer. Soc. Agron., Madison, Wis.

*Griffith, D.R., J.V. Mannering,* and *J.E. Box. 1986.* Soil and moisture management with reduced tillage, p. 19-57. In: M.R Sprague and G.B. Triplett (eds.). No-tillage and surface-tillage agriculture. Wiley, New York.

*Hargrove, W.L. 1990.* Role ofconservation tillage in sustainable agriculture, p. 28-32. In: J.P. Mueller and M.G. Wagger (eds). Proc. Southern Reg. Conservation Tillage Conf. 16-17 July 1990. North Carolina State Univ. Spec. Bul. 90-l.

*Harwood, R.R. 1990.* A history of sustainable agriculture,p. 1-19. In: C.A. Edwards et al. (eds.). Sustainable agriculture systems. Soil and Water Conservation Soc., Ankeny, Iowa.

*Kovach, S.P. 1978.* Effect of irrigation regime and nitrogen rate on tomato yield and quality in a humid climate on a siltloam soil. PhD Diss., Virginia Polytechnic Inst. and State Univ., Blacksburg.

Love, *V.A. 1986.* Conservation tillage methods for cabbage production. MS thesis, Virginia Polytechnic Inst. & State Univ., Blacksburg.

*Moldenhauer, W.C., N.W.* Hudson, *T.C. Sheng and S.-W. Lee (eds.). 1991.* Development of conservation farming on hillslopes. Soil and Water Conservation Soc., Ankeny, Iowa.

*Moody, J.E., J.N, Jones, Jr., and J.H. Lillard. 1963.* Influence of straw mulch on soil moisture, soil temperature and *growth* of corn. Soil Sci. Soc. Amer. Proc. 27:700-703.

*Morse, R.D. 1989.* Strip tillage is good conservation tillage method. Amer. Veg. Grower 37(2):32-33.

*Morse, R.D. and D.L. Seward. 1986.* No-tillage production of broccoli and cabbage. Applied Agr. Res. 1(2):96-99.

*Morse, R.D. and C.M. Tressore. 1984.* Efficient water use: Conservation of soil moisture with no-tillage. Veg. Growers News 39(1):2,4.

*Morse, R.D., C.M. Tressore, W.E. Chappel, and C.R. O'Dell. 1982.* Use of no-tillage for summer vegetable production. Veg. Growers News 37(1): 1.

*Morse, R.D., D.H. Vaughan, and J.H. Wilhoit. 1988.* Low-input production systems conserving soil moisture with mulch tillage. Veg. Growers News 42(4):34.

*Virginia Agricultural Statistics Service. 1991.* Virginia Agr. Stat. Serv. Bul. 63.

*Virginia Cooperative Extension. 1990.* Commercial vegetable production recommendations. Virginia Coop. Ext. Publ. 456-420.

*Webber, C.L., III, M.R. Gebhardt, and H.D. Kerr. 1987.* Effect of tillage on soybean growth and seed production. Agron. J. 79:952-956.

*Wiese, A.F. and P. W. Unger. 1974.* Soil water storage and use. Symp. proc. on limited and no-tillage crop production, USDA Southwestern Great Plains Res. Center. p. 17-26.

*Wilhoit, J.H., R.D. Morse, and D.H. Vaughan.* 1990. Strip-tillage production of summer cabbage using high residue levels. Applied Agr. Res. 5(4):338-342.