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EFFECTS OF NITROGEN, RYE COVER AND
ZONE TILLAGE ON THE YIELD OF FRESH MARKET TOMATOES
IN THREE TILLAGE SYSTEMS

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by

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ABSTRACT

EFFECTS OF NITROGEN, RYE COVER AND ZONE TILLAGE ON THE YIELD OF FRESH MARKET TOMATOES IN THREE TILLAGE SYSTEMS

By

Jerome J. Grajauskis

The yield of fresh market tomatoes grown in a no tillage (NT) system was consistently less than conventional tillage (CT). Reduced growth during the 3 weeks after transplanting was very evident and was hypothesized to be the primary factor in reducing total yields. These studies were conducted to determine if this reduction in growth and subsequent yield could be reduced by the implementation of additional cultural practices.

There was no increase in marketable yield as the N rate increased from 140 to 252 $kg \cdot ha^{-1}$ in the NT system. Thus not supporting the hypothesis that limited vegetative growth and yield is not due to lack of available N.

Allowing more rye biomass to be present at the time of tomato transplanting had no effect on early yield, however, there was a trend toward decreased total yield of medium #1 fruit and culls with increased rye biomass. This, coupled with the consistent observation that strip tillage (ST) produced yields intermediate between CT and NT, supports the hypothesis that the rye cover crop is a major contributor to the reduced yields in a NT system.

Zone tillage increased marketable yield by 11% in CT, 24%

in ST and 39% in NT system. The response to zone tillage was evident within 12 days after transplanting for it induced more dry weight accumulation than where the zone tillage was not done. The more extensive root system as a result of zone tillage may help initial tomato plant growth and overall productivity.

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INTRODUCTION

The production of agronomic crops using reduced tillage has been an accepted practice for more than a decade. No tillage (NT) practices reduce erosion and labor, plus conserve soil moisture. The effects on NT or strip tillage (ST) on the yield potential of vegetable crops compared to conventional tillage (CT), has been studied.

Fresh market tomatoes grown in Michigan are generally planted on sandy soils, which are very susceptible to blowing sand. The need for growing tomatoes and other vegetables with reduced tillage and a plant residue on the surface is very important to reduce sand abrasion of the plant and fruit plus preventing soil erosion. Abrasion caused by blowing sand damages leaves, stems, flowers and fruits. The damage may be minor, causing a slight cessation of growth or may cause complete death of the plant. Under proper environmental conditions, even slight abrasion is felt to provide entry points for bacterial diseases, such as bacterial speck; a major disease in most Midwest production areas. Maintaining a vegetative rye cover crop on the soil surface is the simplest way of controlling wind and water erosion. Generally it is planted when the primary crop is harvested, but may include a cover crop planted in strips or between rows to provide protection to young succulent plants. In Michigan many vegetable growers plant rye as a fall cover crop and plow it into the soil as a green manure and also use it as a windbreak for transplanted vegetables.

Previous work by Price and Baughn (1987) has demonstrated that yields of fresh market tomatoes are consisently less in a no tillage (NT) system with a rye cover crop than in a conventional tillage (CT) system. They showed that the initial growth of tomato transplants was considerably less in the NT system and that plants in NT system were never as large as plants in CT. Pik Red, the cultivar used in these experiments has a semi determinant growth habit and produces little vegetative growth after it starts to set fruit. It is very important to obtain good initial plant development prior to fruit set to insure sufficient frame on the plant to produce a full crop.

One hypothesis for this reduced initial growth in the NT system was that surface applied nitrogen did not leach into the root zone in sufficient quantity to stimulate the initial growth and that increased application rates could overcome this limiting factor. The objective was to increase the initial vegetative growth and subsequent fruit from the NT system.

Another possible cause of reduced yields in NT production is that the allelochemicals released by the rye residue as reported by Putnam et al. (1983) are inhibitory to the initial growth of the tomato plants. To test this hypothesis, the rye cover crop was killed at different heights, thus varying the biomass of rye residue and the potential quantity of allelochemicals. Plant spacings were also varied to determine if marketable yield could be increased with increased plant populations of transplanted tomatoes in a rye residue. The objectives were to determine if reduced rye biomass resulted in less inhibition of the tomato plants and whether closer plant spacings would overcome the reduced marketable yields in the NT system compared to CT.

Prior observations also noted with no tillage indicated the soil as being very dense and compacted. It was hypothesized that if the soil was loosened or broken up without being turned over that root development would be improved and yields enhanced. The objectives of these studies were to fracture the soil in conventional tillage, strip tillage and no tillage, to create a better root environment for the growth and development of the tomato plant, along with increasing the yields of the tomatoes in the strip and no tillage system.

This study was designed to determine if a reduction in initial growth and subsequent yield of the tomato is due to 1) limited availability of nitrogen, 2) allelochemicals released by the rye cover crop, 3) reduced root development due to compact soil in the NT system or 4) a combination of these factors.

CHAPTER I

LITERATURE REVIEW

Traditionally, crop production has been characterized by large amounts of soil tillage. Land usually is moldboard plowed, disced two or three times prior to planting and then cultivated from one to three times after planting depending on the crop and the need for weed control. Farmers annually spend vast amounts of money to till, fertilize, irrigate and apply pesticides, all of which modify the plant and root environments. The dynamics of tillage have been studied in the United States since the early 1920's. Increased emphasis was placed on tillage research in the early 1950's as crop production and mechanization expanded. The early 1980's produced new concerns for the use of fossil fuels in agriculture, which brought about new research to increase the efficiency in tillage and other crop production operations.

The current literature dealing with tillage contains terminology that is inconsistent and often times incomplete. The following terms for the different tillage systems, defined by the Soil Science Society of America (1978), will be used in this paper.

> Conventional tillage- the combined primary and secondary tillage operations normally performed in preparing a seedbed for a given geographical area.

Minimum tillage- the minimum soil manipulation necessary for crop production or meeting tillage requirements under the existing soil and climatic conditions.

Reduced tillage- a tillage sequence in which the primary operation is performed in conjunction with planting procedures in order to reduce or eliminate secondary tillage operations.

No tillage- a crop production system whereby a crop is planted directly into a seedbed not tilled since harvest of the previous crop.

Interest in conservation tillage as a means of conserving energy, soil, labor and water has increased greatly. Conservation tillage systems may affect crop yields by their effects on soil temperature, water relationships, mineralization of crop residue, insects, disease, weeds, soil compaction and nutrient availability. Reduced tillage systems have been developed for several agronomic crops (Jones, et al., 1968; Shear and Moschler 1969) but there has been little work with conservation tillage on vegetable crops such as tomatoes. Beste (1973) found that yields of seeded tomatoes grown in a no-tillage system were equal to those grown with conventional tillage. Knavel, et al., (1977) reported that plant survival of transplanted tomato and pepper plants was similar for no-tillage and conventional tillage, but plants in conventional tillage generally out-yielded no-till grown plants.

Many studies indicate that no-tillage agriculture reduces soil erosion to low levels. McGregor, et al. (1975) found that on a highly erodible soil in Mississippi, erosion was reduced from 17.5 metric tons per hectare to about 1.8 tons per hectare when the no-tillage system was used. Moody et al., (1963) reported seven times higher runoff on unmulched plots as compared to mulched plots. This reduction of runoff is a major factor in maintaining a larger supply of soil moisture under the mulched conditions. Even under more erosive practices involving a rotation of corn and soybeans, conservation tillage can reduce erosion by at least 50 percent. Nutrient losses from erosion and possible crop yield reductions are only a part of the costs involved. Erosion may also result in the loss of organic matter, deterioration of desirable soil physical characteristics and degradation of soil tilth.

The benefits of conservation tillage are not limited to reducing erosion brought about by water. In many drier regions of the United States, erosion by wind is a primary cause of soil loss. Crop residues can dissipate wind energy just as they dissipate raindrop impact energy. Soil erosion by wind for wheat production under conservation tillage has been reported to be about 2 metric tons per hectare compared to 32 metric tons under conventional systems (Moldenhauer, et al., 1983).

Wind erosion is a serious problem on soils with fine sand, loamy fine sand or fine sandy loam, in the surface horizon especially when cropped intensively with row crops (Baeumer and Bakermans, 1973). Sand blast injury to plants and fruit is a major dilemma wherever vegetables are grown on sandy soils. Survival studies of cotton (Gossypium hirstum) seedlings (Amburst, 1968), grass and alfalfa (Medicago sativa) seedlings (Lyles and Woodruff 1960), green bean (Phaseolus vulgaris) seedlings (Skidmore, 1966) and tomato (Lycopersicon esculentum) seedlings (Amburst, 1969) all demonstrate the potential damage to seedlings by blowing sand. In all cases growth and yields of each crop were consistently lower.

Soil moisture conservation and utilization are added benefits derived from crop residue management with conservation tillage systems. Phillips, et al., (1980) observed that the average soil water content was consistently higher under reduced-tillage than under conventional tillage systems. Increased soil water content with reduced tillage ranged from 2.0 to 13.5% higher, than with conventional tillage. Phillips also showed that corn (Zea mays L.) transpired approximately 20% more and soil water evaporation was 79% less in reduced tillage systems compared with the conventional systems.

Hanks and Woodruff (1958) and Russell (1939) propose that mulches conserve water during frequent rainy periods but mulches decrease in value during prolonged dry periods. Soil moisture is normally lost from the plant root zone by evaporation from the soil surface, runoff as surface water, transpiration by growing plants and percolation to depths beyond the normal root zone. Blevins, et al., (1971) reports that moisture is enhanced by increased water infiltration and by the reduction in evaporation loss with a mulch. Soil water conserved by a killed grass sod (no tillage) and straw applied on plots with conventional tillage was found by Jones, et al. (1969) to result in an average increase of 1,932 kg/ha in corn yield.

Soil temperature depends on the thermal conductivity and volumetric heat capacity of a soil and on the amount of heat that enters or leaves the soil surface. Hence, the amount of soil cover and the water and air content of the various soil layers are decisive factors for the temperature regimes of the soil. Bennett, et al. (1973) reported that when corn was planted into grass sod in West Virginia the soil temperature was suppressed by as much as 10°C when compared to conventional tillage. The maximum daily temperature were consistently higher at 2.5 cm. soil depth for the bare, conventionally tilled than for no tillage. The West Virginia data suggest a delay in planting in sods in the northern states would be advisable.

Drost (1983) compared a rye and wheat mulch in a no till tomato system to a conventional tillage system and found no significant differences in soil temperature on an Oshtemo sandy loam. The temperatures were always highest near the soil surface, 5 cm depth, and were near optimum for tomato seed germination. Differences during any week in 1981 or 1982 for the different tillage systems was not greater than 2°C. Soils of sandy loam texture, on which many vegetables are grown, apparently warm sufficiently in the spring to allow early seeding and stand establishment of tomato even under no till conditions.

Fall sown rye provides protection during the winter and gives a faster and larger amount of biomass in the spring than winter wheat (Avena sativa), which makes it an ideal residue for many conservation tillage programs. Putnam, et al. (1983) reported that, when a rye (Secale cereale) cover crop is grown to a height of 40-50 cm, killed by a contact herbicide, and the residue retained on the soil surface, up to 95% control of important agroecosystem weed species was obtained for a 30 to 60 day period following desiccation of the cover crop. Barnes (1981) and DeFrank (1979) also demonstrated significant suppression of weeds achieved by utilizing rye stubble in vegetable cropping systems. They demonstrated that roots and shoots of rye plants give off allelopathic substances that prevent weed suppression.

Friesen (1979) reported that transplanted tomatoes (cv. Springset) kept weed free for 36 days after transplanting, or weeded from the 24th day after transplanting, gave yields equal to those that had been kept weed free throughout the growing season. Conversely, when weeds were allowed to remain in the crop for more than 24 days after transplanting, yields were progressively reduced. Therefore, Friesen concluded that the 'critical period' of weed interference in tomatoes was between 24 and 36 days after transplanting.

Direct changes in the physical and chemical environment resulting from tillage greatly alter the environment supporting microbial growth and stability in the soil. Microbial populations are reported to be larger in the surface soil under reduced tillage than those where crop residues are buried with plowing (Doran 1980). Early research on stubble mulch with winter wheat indicated that populations of fungi, actinomycete and bacteria were significantly higher in the surface 5 cm of plots that were subtilled than in those where wheat residues were plowed under (Norstadt and McCalla, 1969). Doran (1980) also reported that soil microbial populations and enzyme activities in no till compared to plowing were related to changes in soil water content, organic carbon, nitrogen levels, and pH, with water being the primary factor influencing microbial populations. The no till system offers a metabolic status of higher microbial populations which seems to be less oxidative and slower than those under conventional tillage.

Many conservation tillage systems offer a reduction in the amount of energy and labor ordinarily required for conventional tillage (King, 1983). Reduction in trips over the field with heavy machinery can result in lower fuel consumption with no tillage, however, increased expenditures for pesticides, seed and nitrogen fertilizer may be required with the no till system. Taking these points into consideration, no tillage has been reported to reduce the energy input into corn and soybean production by 7% and 18%, respectively. Since primary and secondary tillage may be eliminated with no tillage, investments in tillage implements may also be reduced (Phillips, et al., 1980). Surface applications of fertilizers in no tillage can be as effective, if not more so, than soil incorporation applications in conventional tillage (Shear and Moschler, 1969). Phosphorus availability has been enhanced by surface application in no tillage, whereas, little difference has been found between conventional tillage and no tillage for potassium availability from surface application (Triplett and Van Doren, 1969). Although more managerial skills are required in a conservation tillage system, the use of integrated pest management and crop rotation will also enhance a higher payoff of net profit.

Blevins, et al. (1977) studied changes in soil physical characteristics in a five year planting of continuous no-till corn at various rates of nitrogen applications. They determined that no tillage with moderate rates of nitrogen application most nearly preserved the soil characteristics found under the bluegrass sod present at the beginning of the study.

Deep In-Row Tillage

An increased concern for efficient use of energy and conservation of time, soil and water resources has brought about a shift in attitudes about soil management practices. Each year additional emphasis is placed on reducing tillage and seedbed preparation for cropping. Research has identified effects of various soil physical conditions on root growth. Farm managers, by means of either primary or secondary tillage, routinely alter soil physical properties in an attempt to create optimum conditions for crop planting, seed germination and subsequent crop growth and yield.

Plant root growth and extension through a soil mass are closely related to penetrometer soil strength. Taylor and Gardner (1963) concluded that soil strength was the critical impedence factor controlling root penetration when compared with bulk density. Farm machine traffic and tillage practices affect soil strength and mechanical impedance. Voorhees (1977, 1978) demonstrated that vehicular traffic increases soil compaction and soil strength.

Harvesting equipment operated in the fall, when soil moisture content is often near saturation, compacts many vegetable producing soils. The results are relatively high bulk densities, reduced infiltration rates, a high degree of cloddiness and hard clods, collapse of air pockets and destruction of soil aggregration. Compaction is generally alleviated somewhat during the winter by the freezing and thawing of the soil. Flocker, et al. (1959) reported yields of transplanted tomatoes grown on a moderately compacted fine sandy loam, were not significantly reduced, however compaction delayed the growth processes in the first four weeks after transplanting. Physiological functions of the tomato plant affected by increasing soil density are reduced germination, increased time required for emergence, reduced flower bud formation, reduced root volume and restricted over all growth.

Soils in their natural habitat rarely provide ideal physical conditions for root growth. Soil physical resistance, aeration and water availability are important factors affecting root growth in soil. Root elongation rate is inversely related to soil strength, all other plant growth conditions being nonlimiting (Taylor, 1971).

Deep tillage operations are frequently carried out to loosen, fissure and rearrange compact subsoils and subsurface pans. Carter and Tavernetti (1968) defined the term precision tillage as "subsoiling under the plant row prior to planting". When Carter used this type of tillage with cotton, increases in yield were found to be proportionate to the average soil strength that existed before the precision tillage. These yield increases were particularly significant with soil strengths above 350 psi. Bishop and Grimes (1978) concluded that precision tilling was a practical means of lowering impedance of high strength soils. The more extensive root system used water and nutrients from a larger soil volume resulting in a consistent 6 to 10 percent increase in potato tuber production.

Box and Langdale (1984) conducted a study to evaluate the relationship between in row subsoil and non subsoil tillage treatments on corn grain yields. In row subsoil to a depth of 0.36 meters significantly increased corn grain yield over non subsoiled treatments (8577 and 7820 kg corn grain/ha respectively).

Hegwood, et al. (1978) compared a Stoneville Parabolic Subsoiler and a Stonesville Parabolic Chisel in a minimum tillage system for tomatoes. The subsoiler reached depths of 45 cm. and the chisel reached a depth of 35 cm. on a Bosket fine sandy loam. The two tillage implements were used after raised beds were made. The results showed a yield increase of 1.12 to 3.32 metric tons of marketable fruit per hectare attributed to the subsoil and chisel treatments compared to the control which consisted of a raised bed and no other tillage treatments.

Burpee (1989) reports higher yields of Russet Burbank potatoes grown under zone tillage compared to conventionally tilled plants. Zone tillage caused changes in soil physical properties at the depth of compaction which were reflected in more advantageous soil water and aeration conditions benefitting the potato plant. Zone tillage is the fracturing of the soil directly below where the plant is to be established.

Chapter II

MATERIALS AND METHODS

NITROGEN STUDY

Two field experiments were conducted at the Sodus Horticulture Experiment Station of Michigan State University in 1986 and 1987. The soil type is an Oshtemo sandy loam (coarse-loamy, mixed, mesic Typic Hapludalfs) with 88.6% sand, 5% silt and 6.4% clay and a surface pH of 6.6. Phosphorus and potassium levels were 330 $kg \cdot ha^{-1}$ and 339 $kg \cdot ha^{-1}$ respectively (M.S.U. Soil testing laboratory, September of 1985). Rye (Secale cereale cv. Wheeler) was drilled at 168 $kg \cdot ha^{-1}$ in the fall prior to each planting season.

The experimental design was a split plot, with 4 replications. Tillage treatments formed the main plots and nitrogen levels as the subplots. Each plot consisted of three rows, 150 cm between rows, 9 m long and yield data was obtained by harvesting 10 plants from the center row. Plant spacing within the row was 60 cm (10,800 $plants \cdot ha^{-1}$). The 1987 planting was repeated and the plots were in the same location as in 1986. After the 1986 harvest, the field was disked once to incorporate old plant residue prior to the drilling of the rye cover crop for the 1987 field, experiment.

The tillage treatments were conventional tillage (CT), strip tillage (ST) and no tillage (NT). Conventional tillage consisted of moldboard plowing when the rye was 15-20 cm high, to a depth of 20-23 cm followed by two trips over the field with a disc (standard practice for field preparation). Strip tillage consisted of incorporating a band of rye 60 cm wide early in the spring, leaving rye between the rows to be dessicated at a later date. The strips in the rye were incorporated with a small rototiller, going over each strip at least twice to insure proper destruction of the rye. The no till treatment was undisturbed and rye was killed with a broadcast spray of Paraquat when it reached a height of 120 cm.

Nitrogen in the form of ammonium nitrate (33-0-0) was broadcast over the rye in all plots in early April at the rate of 56 $kg \cdot ha^{-1}$. This application stimulates the early growth of the rye and allows the mineral form of N to be taken up by the rye that will subsequently be slowly released by mineralization after the cover crop is incorporated or killed. Preplant N was broadcast at 28, 84 or 140 $kg \cdot ha^{-1}$ to subplots within each tillage main plot. Preplant N applications were incorporated in the CT plot with a cultimulcher, but remained on the soil surface in the strip and no tillage plots. An additional 56 $kg \cdot ha^{-1}$ N was sidedressed 3 weeks after transplanting on all treatments. The sidedress was incorporated in both the CT and ST plots, but was placed as a band on the soil surface beside the row in the NT plot.

Tomato seed, (Lycopersicum esculentum L cv. Pik Red) was sown in 72 cell flats filled with a synthetic soil medium, on April 17, 1986 and April 22, 1987. Once the transplants reached the second true leaf stage, Millers soluble fertilizer (12-48-8) was applied once per week at the rate of 70 grams·l water^{-1} per 10 flats, in the greenhouse. The tomatoes were transplanted into the field on June 6, 1986 and May 27, 1987. A conventional single row transplanter with double disk openers and a wide rubber drive wheel was used for transplanting. Millers soluble fertilizer at the rate of 1.4 kg·190 l^{-1} was used in the transplant water. Transplant water was used at the rate of 190 l·0.2 ha^{-1}. Subsequent culture of the tomato plants was by conventional ground production methods (no trellising, training or pruning) and irrigation was not used in either year.

Fungicide applications were applied on a 7-10 day interval, with an insecticide applied only when needed. Paraquat (1,1-dimethyl- 4,4 bipyridinium ion), at the rate of 1.1 kg·ha^{-1} with .5% X-77 surfactant was used to kill the rye in the NT and ST (between the rows) in the first week of May for both years as a broadcast spray. Metribuzin ((4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5-(4H)-one) at the rate of .34 kg·ha^{-1} was used as a broadcast spray for postemergence control of lambsquarter (Chenopodium album L.), red root pigweed (Amaranthus retroflexus L.) and purslane (Portulaca oleracea L.). Dates of application were June 13 and July 24, 1986 and June 10, 1987. Sethoxydim ((2-[1-(ethoxyimino)-butyl]-5-[2-(ethylthio)-propyl]-3-hydroxy-2-cyclohexene-1-one) at the rate of .30 kg·ha^{-1} plus 2.3 l·ha^{-1} crop oil was used as a broadcast spray for postemergence control of large crabgrass (Digitaria sanguinalis L.) and fall panicum (Panicum dichotomiflorum L.). Dates of application were June 25 and July 18, 1986 and June 20 and July 23, 1987.

Yield Data

Fruits were multiple harvested when they reached the breaker stage or riper and subsequently graded by size and external quality. Sizes include, large fruit with a diameter of >67 mm and medium fruit with a diameter of 54-67 mm. External quality consisted of fruit labeled as #2's which have a defect on them but are still marketable. Fruits having blossom end rot, were counted, although weights are included with the cull weights. The plots were harvested twice a week. Six harvests were done in 1986 and 5 harvests in 1987. The 1986 and 1987 yield data were combined and analyzed by analysis of variance.

MANIPULATION OF RYE RESIDUE AND PLANT SPACING

The study was conducted at the Sodus Horticulture

Experiment Station in 1987. Soil type was an Oshtemo sandy loam with a surface pH of 6.5. Soil test from 1986 indicated phosphorus levels were 300 $kg \cdot ha^{-1}$ and potassium levels were 343 $kg \cdot ha^{-1}$. Wheeler rye was drilled at 168 $kg \cdot ha^{-1}$ in the fall of 1986.

The experimental design was a split plot with 4 replications and the rye residue treatments as the main plots and plant spacing as the subplots. Each plot consisted of three rows 60 cm apart, 9 m long and yield data taken from 10 plants, from the center row.

The rye residue treatments were conventional tillage (bare soil), rye killed at 20 cm and 40 cm height. The bare soil was achieved by moldboard plowing the living cover crop on April 20 when it was 20 cm in height, followed by two diskings. The 20 cm high rye was killed April 20 with a broadcast spray of Paraquat (1.1 $kg \cdot ha^{-1}$) plus X-77 (.5%) surfactant. The 40 cm high rye was similiarly killed on May 1.

Plant spacings within the row consisted of 40, 60 and 80 cm treatments. A conventional transplanter manufactured by Mechanical Transplanter was used and the various spacings achieved by changing the sprockets that control the speed of the planting mechanism.

Nitrogen in the form of ammonium nitrate was broadcast at 56 $kg \cdot ha^{-1}$ to the cover crop in the early spring. Another 28 $kg \cdot ha^{-1}$ was applied as a broadcast prior to planting and the final amount of 56 $kg \cdot ha^{-1}$ was sidedressed 3 weeks after transplanting. Applications of nitrogen fertilizer to conventional tillage were incorporated into the soil, however, applications to the rye residue treatments were surface applied.

Tomato seed, cv. Mountain Pride was sown in 72 cell flats on April 20 and after 5 weeks moved from the greenhouse to full sunlight for acclimation before transplanting. Fertilizer treatment in the greenhouse and in the transplant water was the same as that previously mentioned for the nitrogen study. The tomato plants were transplanted in the field on June 2.

Fungicide applications were applied on a 7-10 interval, with an insecticide applied only when needed. Metribuzin (.34 $kg \cdot ha^{-1}$) was applied as a broadcast spray for postemegence broadleaf control of purslane, lambsquarter and red root pigweed on June 15 and 30, and July 24. Sethoxydim (.30 $kg \cdot ha^{-1}$) was applied for postemergence grass control of crabgrass and fall panicum as a broadcast spray on June 25 and July 10.

Yield data

Fruits were multiple harvested when they reached the breaker stage or riper and subsequently graded by size and external quality. Sizes include, large # 1 fruit with a diameter of >67mm and medium # 1 fruit with a diameter of 54-67 mm. External quality consisted of fruit labeled as #2's which have a defect on them but are still marketable. Fruit with blossom end rot were counted, but the weights were included with the cull weights. A total of six harvest were made between August 13 and September 7.

Biomass data

Rye residues were collected in each of the residue treatment plots. The procedure consisted of a wood frame with an inside measurement of 1 m^2 area. The area sampled was picked at random within the plot area on June 1. The rye residues were cut at the soil surface, collected in a bag, dried at 66° C for a minimum of 96 hours and weighed.

ZONE TILLAGE

The studies were conducted at the Southwest Michigan Research and Extension Center. Soil type is a Spinks sandy loam (sandy, mixed, mesic Psammentric Hapludalf) with 87.4% sand, 6.0% silt and 6.6% clay. The surface pH was 6.5 with high levels of available phosphorus, so no additional P was added. Potassium was applied as per soil test in the fall prior to the next growing season. Rye cv Wheeler was drilled at 168 $kg \cdot ha^{-1}$ in the fall prior to each planting season.

The experimental design was a split plot, with 5 replications in 1988 and 4 replications in 1989. Tillage treatments formed the main plots and paratill treatments as the subplots. The plant spacing was 150 cm between rows and 60 cm between plants (10,800 plants·ha^{-1}). Plots consisted of 3 rows, 45 m long in 1988 and 145 m long in 1989 which the data was taken only from the center row.

The 1988 tillage treatments consisted of conventional tillage (CT), strip tillage (ST) and no tillage (NT). Conventional tillage consisted of moldboard plowing when the rye was 15-20 cm high to a depth of 20-23 cm followed by two diskings. Strip tillage consisted of incorporating a band of rye 60 cm wide early in April, leaving rye between the rows to be desiccated at a later date. The no tillage treatment was undistributed and was dessicated when it reached a height of 120 cm.

Paratill treatments (zone tillage) consisted of fall paratill (FP), spring paratill (SP) and no paratill (NP). The difference between the paraplow which was used in the fall of 1987 and the paratill which was used in spring of 1988, was in the design of the two pieces of equipment. The paraplow consisted of 4 subsoil shanks mounted on an angled tool bar similiar in arrangement to a moldboard plow. The paratill consisted of the same 4 subsoil shanks arranged on a straight tool bar. Both tools were set to fracture the soil to a 32 cm depth with no soil inversion and little surface disturbance. The NP treatment didn't receive any zone tillage from the paraplow or paratill.

The 1989 CT and NT plots were just like those previously mentioned in 1988. The ST plots consisted of chemically treating a strip of rye to width of 60 cm, using a packback sprayer. The desiccated rye residue was left on the soil surface. In 1989 the SP utilized rolling baskets placed on the back of the implement in order to firm the area where the legs of the paratill penetrated and lifted the soil.

1988 and 1989 Planting

Tomato seed, cv. Mountain Pride was seeded in 72 cell flats in the greenhouse in the third week of April for both years. The plants were grown for 4 weeks in the greenhouse prior to moving into full sunlight for acclimation. Transplanting into the field was done in the last week of May for both seasons, with a conventional tomato transplanter equipped with double disk openers ahead of the shoe. Fertilizer in the greenhouse and in the transplant water was done the same as previously stated in the nitrogen study.

Nitrogen fertilizer (33-0-0) at the rate of 56 $kg \cdot ha^{-1}$ was broadcast over the cover crop in the early spring. An additional 28 $kg \cdot ha^{-1}$ was broadcast over the entire plot area prior to transplanting. Three weeks after transplanting an additional 56 $kg \cdot ha^{-1}$ of nitrogen was sidedressed 10-15 cm to the side of the row.

Supplemental irrigation was needed due to unseasonable heat and drought in 1988, however irrigation was applied only once during the 1989 season. Fungicide applications were applied on a 7-10 day interval, with an insecticide applied only when needed. Paraquat at the rate of 1.1 $kg{\cdot}ha^{-1}$ with .5% X-77 surfactant was used to kill the rye in the NT and ST (between the rows) in the first week of May for both years, as a broadcast spray. Metribuzin at the rate of .34 $kg{\cdot}ha^{-1}$ was used as a broadcast spray for the control of lambsquarter, purslane and red root pigweed. Dates of applications were June 24 and July 16, 1988 and June 26 and July 18, 1989. Sethoxydim at the rate of .30 $kg{\cdot}ha^{-1}$ plus 2.3 $l{\cdot}ha^{-1}$ was used as a broadcast spray for the control of large crabgrass and fall panicum. Dates of application were June 21 and July 11, 1988 and June 19 and July 12, 1989.

Zone Tillage Data Collection

Yield

Fruits were harvested and graded as described previously. The plots were harvested every 5-7 days. In 1988, 10 harvests were made starting on August 11 and ending on September 26. Twelve harvests were included in the 1989 data, first harvest on August 10 and lasting until September 19.

Biomass Data

Rye residues were collected 2 weeks after the paraquat application on the rye as described previously. Biomass means were 365 $grams{\cdot}m^{-2}$ for the entire NT plot and between the strips in ST plots for 1988. Residues collected in 1989 were 398 $grams{\cdot}m^{-2}$ for the NT and ST plots. Bare soils were considered as having no residue.

Growth Analysis

In 1989 5 plants from each tillage treatment and each replication were collected 4 times during the growing season. The plant samples were cut at the soil surface and collected 12, 25, 46 and 55 days after transplanting. The third and fourth sampling time, the fruit was collected and counted, then kept seperated from the vegetative plant samples. Dry weights (grams) were taken after the plants dried at 66° C for 96 hrs.

Root Evaluation

In 1988 and 1989 the root systems of tomato plants from each treatment were studied using the "root profile method" as described by Bohm (1979). Pits were dug with a backhoe, large enough to allow two people to visually examine the rooting pattern of the plants. The walls were smoothed with a spade and a scraper prior to spraying the wall to wash a thin layer of soil away from the profile wall and expose the roots. A grid, 1 meter by 1 meter with 5 cm x 5 cm row and column increments was then placed on the wall and the cells having tomato roots was recorded.

The 1989 season included pits, plus root weights from different depths of the soil, with the bucket auger method as described by Bohm (1979). An auger having a bucket 16.25 cm long and 7.5 cm wide was used to collect soil at depths of 0-15, 15-30, 30-45 and 45-60 cm. The samples were placed in water and soaked 1 hour prior to washing the roots and removing all soil. The roots were then dried at 66°C for a minimum of 96 hour prior to determing dry weights.

Pentrometer Readings

In both years soil strength was measured using a soil pentrometer. The measurements were taken within the row between two plants and were recorded from the center row of the plots. Five measurements from each plot were recorded, in units of pounds per square inch, which were converted into $kg \cdot cm^{-2}$ The pressure tests were taken to a depth of 22.5 cm and conducted on July 11, 1988 and June 20, 1989.

Soil Moisture

Soil moisture samples were taken on June 22 and July 6 1989. Samples were taken with a soil sampling probe. Sampling depths were 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm. Wet weights were measured immediately after sampling. The samples were dried at 105° C for a minimum of 96 hours before dry weights were recorded. The difference between the wet wt. and the dry wt. were divided by the dry wt. and multiplied by 100 to give a percent volume in soil moisture content.

Chapter III

RESULTS AND DISCUSSION

Nitrogen study

Tillage method had no effect on total yield of large # 1 size fruit, # 2's or culls, however, the medium size # 1 fruit was reduced by the strip and no tillage treatments. Yields of marketable fruit were not significantly reduced in a NT system, but there was a consistent trend toward reduced yields with the strip and no tillage (Table 1). The CT yielded 25% more large size fruit than ST and 32% more than NT.

Table 1. Effect of tillage methods on total yield of fresh market tomatoes.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	$MT \cdot ha^{-1}$			
Conventional	25.2[1]	17.0	4.2	5.1
Strip Till	18.8	13.9	4.2	5.5
No Till	17.1	13.0	3.3	4.4
LSD (.05)	NS	1.3	NS	NS
CT vs Other	**	**	NS	NS
ST vs NT	NS	NS	*	*

[1]Each figure is the mean of 2 years x 3 nitrogen rates x 4 replications.
(NS)Nonsignificant.
The interaction of tillage x nitrogen rate was NS.
All interactions of year, nitrogen and tillage was NS.

McKeown et al. (1988) reports no effect of tillage on yield of machine harvested processing tomatoes (Lycopersicon esculentum Mill.) in 2 out of 3 years. Yield was reduced in the third year in strip tilled rye plots due to low transplant vigor. These results are similiar to decreases in yields reported by Doss, et al., (1981) and Hoyt (1984) when rye was used as a cover crop.

Increased nitrogen rates did not increase large size # 1 or medium # 1 fruit yields. However # 2's and culls decreased in a linear manner as N rates increased (Table 2). The cause is not understood, but it was not due to blossom end rot.

Since there was no interaction between tillage x N rate this indicates that all tillage systems responded similiarly to increased N rate and increased N was not able to overcome the inhibitory influences of NT on yield. Doss (1981) reports no consistent effect from N rate on marketable tomato yields, the yields from the lower N rate plots (100 $kg \cdot ha^{-1}$) was greater than the higher N rate (200 $kg \cdot ha^{-1}$) in two dry years of 1978 and 1979 and were similar or higher than the higher N rate in the year of more average rainfall in 1977.

Surface applications of nitrogen may not be as efficient as applications which are mixed into the soil. However, ammonium nitrate used in these experiments is very water soluble and should leach readily into the root zone. Because it could not be incorporated the ammonium nitrate form of N was used in order to avoid volatility losses which occur with urea fertilizers. Immobilization of N in the root zone is a possible reason for no response with total yield, especially large size fruit. These results are supported by Knavel and Herron (1981), although working with cabbage they found that 370 $kg \cdot ha^{-1}$ of nitrogen was required to produce the same tonnage by NT as the use of 269 $kg \cdot ha^{-1}$ nitrogen by CT.

Table 2. Effects of N rates on total yield of fresh market tomatoes in three tillage systems from 1986 and 1987.

	# 1			
$kg \cdot ha^{-1}$ N	Large	Medium	# 2	Cull
	$MT \cdot ha^{-1}$			
140	20.3[1]	15.0	4.7	6.1
196	20.9	15.0	3.7	4.8
252	19.8	14.0	3.3	4.2
LSD (.01)	NS	NS	.9	.8
(.05)	NS	NS	1.2	1.1
Linear	NS	NS	**(92)[2]	**(94)
Quadratic	NS	NS	NS	NS

[1]Each figure is the mean of 3 tillage systems x 4 replications.
[2]Percent of the total sum of squares.
(NS)Nonsignificant.
All interactions of year, tillage and nitrogen was NS.

Early yield (the first 2 harvests) of large size # 1 fruit was not affected by rate of N application in 1986 (Table 3). However, the early yield in 1987 decreased in a linear manner as the rate of N application increased. The response in 1987 is typical of the reports of other researchers that excess N does promote excessive vegetative growth and delays fruit maturity (White 1938, Nicklow and Downes 1971, Gomez-

Lepe and Ulrich 1974, Knavel, et al., 1977). In 1986, however, the absence of a response to increased N application may be due to the increased rainfall in that year compared to 1987; 255 mm in May and June of 1986 vs 109 mm for the same period in 1987. The increased precipitation in 1986 may have leached much of the N past the root zone thus not inducing the excessive vegetative growth as in 1987.

Table 3. Effects of N rates on early yield of large size fruit in 1986 and 1987.

	Large # 1	
$kg \cdot ha^{-1}$ N	1986	1987
	-------$MT \cdot ha^{-1}$ ------	
140	5.5[1]	5.5
196	5.9	4.5
252	5.5	3.9
LSD (.05)	NS	1.3
Linear	NS	**
Quadratic	NS	NS

[1]Each figure is the mean of 3 tillage systems x 4 replications.
(NS)Nonsignificant.

Manipulation of rye residue and plant spacing

Plowing living rye into the soil or killing it at different heights and leaving it on the soil surface had no effect on early yield of transplanted tomatoes. However there was a downward trend of large size fruit as more residue is left on the soil surface (Table 4). Total yield of medium # 1 fruit and culls was decreased when rye was allowed to grow to 40 cm before it was killed (Table 5). No effect on total yield of large size fruit was evident, however, there is a trend toward a decrease in yield as more rye was left on the soil surface. It was hypothesized that increased rye residues on the soil surface that more allelochemicals are released. These compounds have a detrimental effect on tomato plants which cause a reduction in yield. This observation is supported by the work of Barnes and Putnam (1983) which demonstrated that root exudates from a rye cover crop left on the soil surface reduced tomato seedling growth. The interaction between rye residue treatments and plant spacing was not significant indicating that the plants responded similiarly for all residue treatments regardless of plant spacing.

Rye residues were collected one month after the rye was killed. Means for each plot were conventional having zero residue, 20 cm high rye having 35 g of dry matter per square meter and the 40 cm rye having 81 g of dry matter per square meter collected.

There was a negative correlation between the amount of residue on the soil surface and early yield of large size fruit ($Y=7.3-.02x$, $r=.98^{*}$).

Table 4. Effects of rye residue on early yield of fresh market tomatoes 1987.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	---MT·ha⁻¹---			
Conventional	7.2[1]	2.8	.5	.8
20 cm high rye	6.7	3.1	.6	.8
40 cm high rye	5.4	2.5	.3	.8
LSD (.05)	NS	NS	NS	NS
CT vs 20 rye	NS	NS	NS	NS
40 cm vs other	NS	NS	NS	NS

[1]Each figure is the mean of 3 plant spacings x 4 replications.
(NS)Nonsignificant.

Table 5. Effects of rye residue on total yield of fresh market 1987.

Tillage	# 1 Large	# 1 Medium	No 2	Cull
	---MT·ha⁻¹---			
Conventional	26.4[1]	23.7	5.1	7.3
20 cm high rye	27.4	21.4	4.3	5.3
40 cm high rye	22.4	20.0	3.5	4.6
LSD (.01)	NS	3.2	NS	1.8

[1]Each figure is the mean of 3 plant spacings x 4 replications
(NS)Nonsignificant.

Increasing plant spacing within the row decreases the early yield of large and medium size # 1 fruit (Table 6). The variance due to plant spacing on large # 1 and medium # 1 fruit, is in a linear downward trend, 96 and 95 percent of variance is accounted for respectively. Plant spacing had no effect on early yield of # 2's and culls.

Table 6. Effect of plant spacing on early yield of fresh market tomatoes.

Plant Spacing	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
40 cm spacing	7.4[1]	4.2	.7	.8
60 cm spacing	6.3	2.5	.4	.8
80 cm spacing	5.7	1.7	.3	.7
LSD (.05)	1.4	.7	NS	NS
Linear	*(96)[2]	**(95)	NS	NS
Quadratic	NS	NS	NS	NS

[1]Each figure is the mean of 3 tillage methods x 4 replications.
[2]Percent of the total sum of squares.
(NS)Nonsignificant.

Total yields responded similiarly, however the increase in yield with increased plant population is much more dramatic with the medium sized fruit compared to the large size fruit (Table 7). This is a critical factor with fresh market tomatoes for the primary market is for the large size and market for the medium size is very limited. Thus, it is evident that for the cultivar Mountain Pride there is no advantage to have spacings closer than 60 cm.

Table 7. Effect of plant spacing on total yield of fresh market tomatoes.

	# 1			
Plant Spacing	Large	Medium	No 2	Cull
	MT·ha^{-1}			
40 cm spacing	25.9[1]	28.3	4.3	7.2
60 cm spacing	26.7	20.0	4.2	5.5
80 cm spacing	23.2	16.7	4.4	4.5
LSD (.01)	NS	3.2	NS	1.2
(.05)	2.6	4.3	NS	1.7
Linear	* (53)[2]	** (94)	NS	** (98)
Quadratic	NS	NS	NS	NS

[1]Each figure is the mean of 3 rye residues x 4 replications.
[2]Percent of the total sum of squares.
(NS)Nonsignificant.

It is thus concluded that increasing plant spacing in a NT system does not increase yields of tomatoes. This observation is supported by Knavel and Herron (1981) working with spring cabbage; cabbage grown in a NT did not yield as well as that grown by CT, regardless of spacing. Doubling the plant population reduced head size and total tonnage was never greater for NT than for CT.

ZONE TILLAGE

Yield, 1988.

Rainfall in 1988 was only 92 mm (average 284 mm) during the months of May, June and July, which is the critical time period for actively growing transplants to get established and develop a framework for subsequent fruit set. If fruit set commenses prior to development of this framework the yield potential is reduced. The tomato plants were exposed to 37 days of 29° C or higher temperatures within the period of June and July. These temperatures are sufficient to cause severe stress to tomato plants and have detrimental effects on fruit set. High temperatures cause poor pollen viability and stylar extension beyond the anther cone before pollen is released, thus preventing pollination. Flower abortion (blasting) is generally the result of this type of heat stress. Consequently yields in 1988 were very low for all treatments.

Early yield (Table 8) of large # 1 fruit was the same for CT and ST, however, yields for NT was only 27% of that from CT. Similiarly, yield of medium size and # 2 fruit was reduced by NT. Total yield (Table 9) was reduced in a similar manner by NT treatment; total yield of strip tillage plot was intermediate between CT and NT.

Doss et al. (1981) reported similar results from a three year study with tomatoes, when there were significant differences due to tillage effects, the highest yield was found on plants grown in conventional tillage, followed by strip tillage.

Table 8. The influence of tillage on early yield of fresh market tomatoes in 1988.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Conventional	6.4[1]	5.5	1.5	3.6
Strip Till	5.3	3.6	1.3	3.8
No Till	1.7	1.6	.4	2.6
LSD (.05)	1.5	1.2	.4	NS

[1]Each figure is the mean of 3 paratill treatments x 5 replications.
(NS)Nonsignificant.
[2]The interaction of tillage x paratill treatments was NS.

Table 9. The influence of tillage on total yield of fresh market tomatoes in 1988.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Conventional	13.2[1]	11.1	3.8	9.8
Strip Till	11.2	7.4	3.7	10.2
No Till	4.9	4.0	1.7	7.6
LSD (.05)	6.8	1.2	1.8	NS

[1]Each figure is the mean of 3 paratill treatments x 5 replications.
(NS)Nonsignificant.
[2]The interaction of tillage x paratill treatment was NS.

The NT plots were exposed to drier conditions prior to planting than the ST and CT plots because the rye in the NT was not killed until the first week of May and only 30 mm of rain was received prior to planting. The severe yield inhibition due to NT may be due to lack of soil moisture due to the rye or the allelochemicals produced by the rye were not leached from the root zone of the tomato plant.

Doss et al. (1981) reported that marketable yields tended to be greater on no-rye plots than on rye plots, with yields averaging 2.2 MT/ha higher for no-rye plots. The reduced yields from plots with rye cover crop may have been eliminated by killing the vegetation earlier in the spring. This would have allowed more time for the soil profile water to be recharged by rainfall without the offsetting influence of evapotranspiration by a vigorously growing rye crop.

The paratill treatments in 1988 had no effect on early or total yield of any size or grade of tomato fruit (Tables 10 and 11). Although there is a trend in higher marketable yield there were no differences at the 5% percent level. Only at the 11% significance level did the spring paratill show an increase in yield over the no paratill treatment. This data corresponds to the work of McKeown et al. (1988) in a study on the influence of strip tillage and conventional tillage of machine harvested tomatoes; found that subsoiling did not increase yield of marketable fruit 2 years.

Examination of the root profile of tomatoes planted in the paratilled plots showed deeper and more extensive development than where the paratill was not used. The soil in the paratill zone was loose and friable which was more conducive to rapid root development.

Table 10. The influence of zone tillage on early yield of fresh market tomatoes in 1988.

Paratill[2]	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha⁻¹			
Spring	5.1[1]	3.2	1.1	3.3
Fall	4.5	4.0	1.1	3.5
None	3.7	3.6	1.1	3.3
LSD (.05)	NS	NS	NS	NS
Paratill vs None	NS	NS	NS	NS
Spring vs Fall	NS	NS	NS	NS

[1]Each figure is the mean of 3 tillage treatments x 5 replications.
(NS)Nonsignifcant.
[2]The interaction of tillage x paratill treatment was NS.

Table 11. The influence of zone tillage on total yield of fresh market tomatoes in 1988.

Paratill[2]	# 1 Large	# 1 Medium	No.2	Cull
	MT·ha⁻¹			
Spring	11.4[1]	7.1	3.4	9.2
Fall	9.6	8.2	3.1	9.6
None	8.4	7.1	2.7	8.8
LSD (.05)	NS	NS	NS	NS
Paratill vs None	NS	NS	NS	NS
Spring vs Fall	NS	NS	NS	NS

[1]Each figure is the mean of 3 tillage treatments x 5 replications.
(NS)Nonsignificant.
[2]The interaction of tillage x paratill treatment was NS.

Yield, 1989.

In the 1989 season there was 293 mm of rainfall during the months of May, June and July compared to 1988 which had only 97 mm during the same months and daily maximum temperatures were lower than in 1988.

Early and total yield of large # 1 fruit were reduced by NT (tables 12 and 13), however, there was no difference in yield between CT and ST. This supports prior years observations of a period of delayed fruit set in NT and that plots never reach the yield potential of CT and ST. The CT yielded 16% more large fruit than ST and 42% more than NT.

Not only does NT delay the start of harvesting, but the fruit production is reduced (Figure 1). The slope of the log phase of fruit accumulation for CT and ST is the same and both are greater than NT.

Reduced tillage such as NT results in less yield than CT with ST treatment being intermediate. This observation is supported by the work of Doss et al. (1981) who reported that marketable tomato yields decrease with reduced tillage; yields form complete tillage plots during a 3 year period averaged 2.9 $MT \cdot ha^{-1}$ higher than yields from strip tillage plots and yields from strip tillage plots were 1.0 $MT \cdot ha^{-1}$ higher than yields from no tillage plots.

Figure 1. Yield log transformation of large size fruit from three tillage systems.

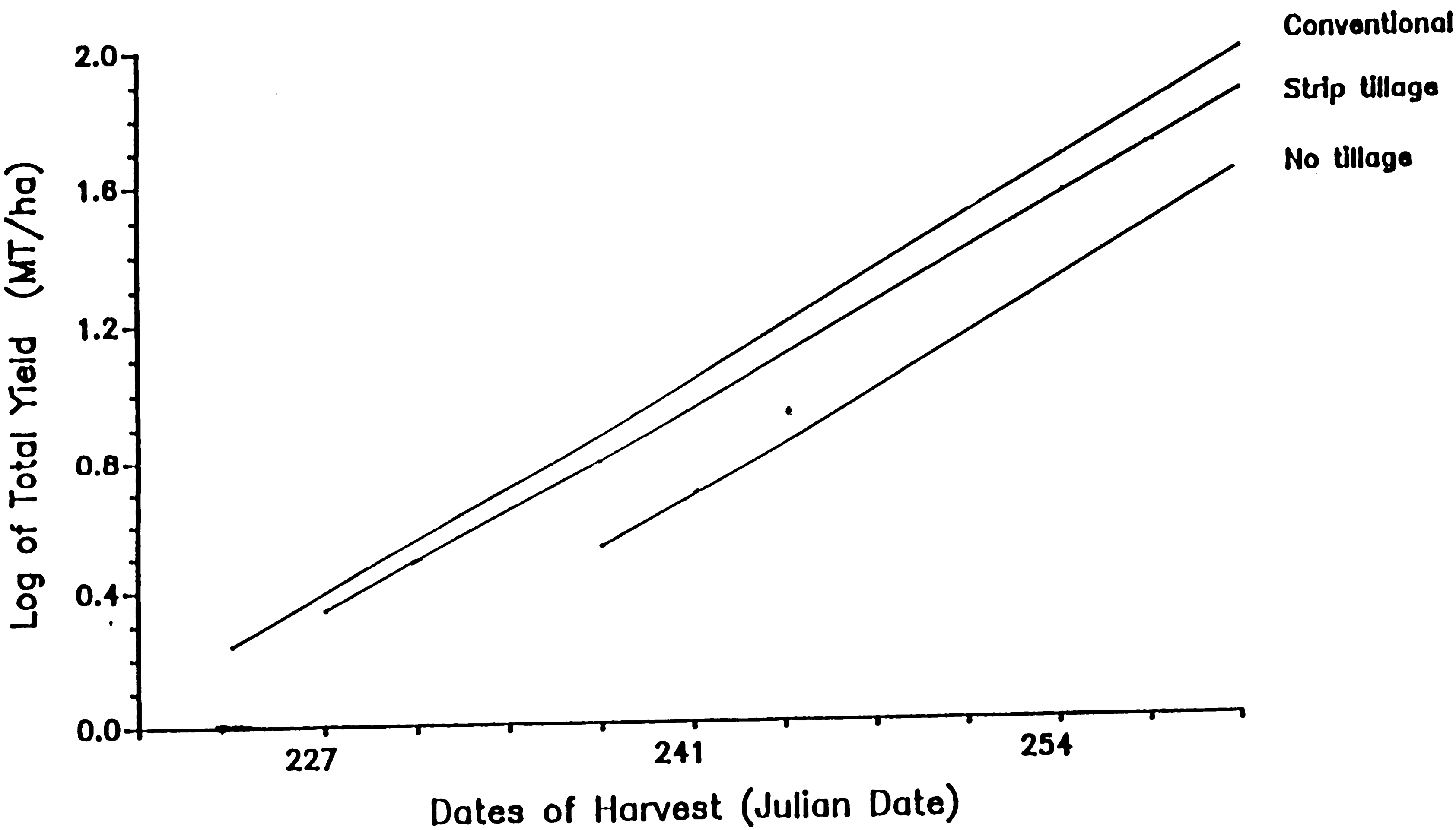

Conventional
Strip tillage
No tillage
Log of Total Yield (MT/ha)
2.0
1.6
1.2
0.8
0.4
0.0
227
241
254
Dates of Harvest (Julian Date)

Table 12. The influence of tillage on early yield of fresh market tomatoes in 1989.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Conventional till	6.2[1]	1.1	.45	1.7
Strip till	4.3	1.1	.25	1.2
No till	1.2	.4	.04	.5
LSD (.01)	NS	.5	NS	.9
(.05)	3.9	.3	NS	.6

[1]Each figure is the mean of 3 paratill treatments x 4 replications.
(NS)Nonsignificant.
The interaction of tillage x paratill treatment was NS.

Table 13. The influence of tillage on total yield of fresh market tomatoes in 1989.

Tillage	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Conventional till	50.8[1]	17.9	7.8	10.3
Strip till	42.8	19.7	5.5	9.4
No Till	29.4	12.8	3.4	5.6
LSD (.01)	17.4	NS	2.7	NS
(.05)	11.5	NS	1.8	NS

[1]Each figure is the mean of 3 paratill treatments x 4 replications.
(NS)Nonsignificant.
The interaction of tillage x paratill treatment was NS.

The early yield (first 4 harvests) of large size # 1 fruit was increased where the soil was disturbed by use of the paratill in either the spring or the fall prior to planting (Table 14). Yields from the spring paratill plots were equal to the fall paratill treatments.

Table 14. The influence of zone tillage on early yield of fresh market tomatoes in 1989.

Paratill	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Spring	4.3[1]	1.1	.2	1.3
Fall	4.6	.7	.4	1.2
No	2.8	.7	.1	.2
LSD (.05)	NS	NS	.2	.4
Paratill vs None	*	NS	*	*
Spring vs Fall	NS	NS	*	NS

[1]Each figure is the mean of 3 tillage treatments x 4 replications.
(NS)Nonsignificant
The interaction of tillage x paratill treatment was NS.

Total yield of large size fruit was also increased by zone tillage in both the spring and fall treatments (Table 15). Although culls are increased with paratill, the increase in yield of large size fruit was much more important. Plants in all tillage systems responded similiarly to the paratill treatments, however, the percent increase due to spring paratill is greater for the NT and ST than the CT (Table 16).

The data presented is not consistent with McKeown (1988) who reported on the influence of strip tillage and conventional tillage of machine harvested tomatoes. They found that yield of marketable fruit was not affected by subsoiling in a two year study.

Table 15. The influence of zone tillage on total yield of fresh market tomatoes in 1989.

Paratill	# 1 Large	# 1 Medium	# 2	Cull
	MT·ha^{-1}			
Spring	46.3[1]	17.4	6.1	9.3
Fall	41.0	17.0	5.7	8.6
No	35.6	16.0	4.9	7.3
LSD (.01)	6.7	NS	NS	NS
(.05)	4.9	NS	NS	1.6

[1]Each figure is the mean of 3 tillage treatments x 4 replications.
(NS)Nonsignificant.
The interaction of tillage x paratill treatment was NS.

Table 16. Influence of spring paratill on 3 tillage systems on large size fruit.

	No Paratill	Spring Paratill	% increase yield
	MT·ha^{-1}		
Conventional	45.5	51.3	11
Strip Till	37.9	49.6	24
No till	23.3	38.0	39

Growth Analysis, 1989.

The dry weight accumulation is most rapid in CT, intermediated in ST and most reduced in the NT (Table 17). It is evident that within 12 days after transplanting, the NT was inhibiting the growth of the tomato plants. The NT plants are always smaller through the coarse of the growing season, even up to 55 days after transplanting, when the plants are in the fruit production stage.

Table 17. Plant dry weight accumulations in 3 tillage systems.

Tillage	Days after transplanting 12[1]	25	46	55
	----------	----------	g ----------	----------
Conventional Till	5.3	49.5	299.0	765.0
Strip Till	5.6	36.6	172.8	635.0
No Till	2.9	10.7	58.6	392.0
LSD (.01)	2.2	NS	207.3	NS
(.05)	1.5	26.4	136.9	245.9

[1]Each figure is the mean of 3 paratill treatments x 5 plant samples x 5 replications.
(NS)Nonsignificant
The interaction of tillage x paratill was NS.

Zone tillage appears to alleviate some stresses on the tomato plant during the time immediately after transplanting. transplanting. The fall and spring paratill induced more plant dry weight accumulation, which is evident after 12 days and continues throughout the growing season (Table 18). The looser soil with zone tillage may induce more rapid development of roots and thus facilitate uptake of water and nutrients for early plant development.

Table 18. Plant dry weight accumulation in 3 paratill treatments from 1989.

Paratill	Days after transplanting			
	12[1]	25	46	55
	g			
Spring	5.1	35.4	192.0	618.0
Fall	4.9	37.5	202.4	633.0
None	3.9	23.8	135.9	540.0
LSD (.01)	.9	11.1	NS	NS
(.05)	.7	8.1	50.0	NS

[1]Each figure is the mean of 3 tillage treatments x 5 plant samples x 5 replications.
(NS)Nonsignificant.
The interaction of tillage x paratill treatment was NS.

Fruit were present on plants in all 3 tillage treatments by 46 days after transplanting (Table 19), however, by 55 days after transplanting the number of fruit on the NT treatments were greatly reduced compared to the CT or ST. There was no difference in the number of fruit set between the CT and ST.

There was no difference in number of fruit on plants from the fall and spring paratill plots at 46 and 55 days after transplanting, however, both were greater than that of the paratill treatment (Table 20). Bishop and Grimes (1978) working with potatoes, report impedence to the extension of potato roots in a high strength soil was reduced by chiseling with a subsoil shank directly in the center of the potato bed (precision tillage). The more extensive root system used water and nutrients from a larger soil volume and was associated with a consistent 6-10% increase in tuber production.

Table 19. Fruit number recorded from 3 tillage treatments.

Tillage	Fruit Number[1] 46[2]	55
Conventional	8.1	29.6
Strip Till	8.5	27.2
No Till	3.9	4.3
LSD (.05)	NS	18.9

[1]Each figure is the mean of 3 paratill treatments x 5 plant samples x 5 replications.
[2]Days after transplanting.
(NS)Nonsignificant.

Table 20. Fruit number recorded from 3 paratill treatments.

Paratill	Fruit Number[1] 46[2]	55
Spring	8.8	24.6
Fall	7.4	19.9
None	3.9	16.4
LSD (.05)	2.2	6.8

[1]Each figure is the mean of 3 tillage treatments x 5 plant samples x 5 replications.
[2]Days after transplanting.
(NS)Nonsignificant.
The interaction of tillage x paratill treatment was NS.

Root Evaluation, 1989.

There was no difference in the dry weight of roots collected from soil samples taken at the 0-15 cm depth (Table 21). At the 15-30 cm depth, however, the weight of roots recovered from the no paratill plot was less than the paratill treatments. At the 30-45 cm depth, the no paratill treatment had virtually no roots compared to the paratill treatments which had many roots penetrating to this depth. Below 45 cm there were few roots for any of the treatments and the root weights measured were extremely variable. It is evident that both spring and fall paratill treatment are effective in increasing the depth of rooting the tomatoes under these growing conditions.

Table 21. Root weight data 1989.

	Soil Depth (cm)			
Paratill	0-15	15-30	30-45	45-60
	g			
Spring	.40[1]	.27	.19	.12
Fall	.33	.19	.20	.12
None	.33	.14	.09	.06
LSD (.05)	NS	NS	.08	NS
Paratill vs None	NS	NS	**	*

[1]Each figure is the mean of 7 sample dates x 3 tillage treatments.
(NS)Nonsignificant.
The interaction of tillage x paratill was NS.

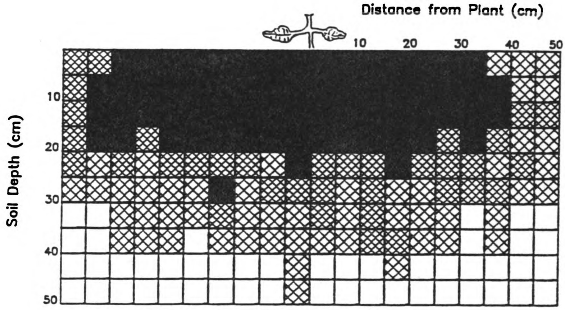
Tomato transplants have no tap root, because while the plant is growing in cells of synthetic soil, the tap root is destroyed. Once transplanted to the field, the plant produces a very fibrous root system, thus making it difficult to quantify root number from the field.

Root observations from the wall profile root examination are expressed diagramatically by shading grids that represent the root system (Figures 2-7). Three seperate pits were dug for each different tillage and paratill treatment. Once the wall was smoothed with a spade, the 1 m by 1 m grid was placed on that wall and each cell was given a plus sign when roots appeared in that area. When all the pits from the same treatment were examined the grids were put together to from a single grid for each of the tillage and paratill treatments. The cells which are fully shaded is where the highest amount of fine roots occured, or roots were found 3 out of 3 sampling times in which there was a plus sign in that particular area. The other cells which have the cross hatching represent the areas where the roots were only found 2 out of 3 times or 1 out of 3 times. When the cells are blank no roots were present in any of the three pits examined.

In each tillage system it is evident that the use of the paratill facilitated deeper and more extensive root development. Those plots receiving the paratill had much more extensive root development into the B_t horizon then where fracturing did not occur.

Figure 2. Rooting pattern for conventional tillage with zone tillage 1989.

Figure 3. Rooting pattern for conventional tillage without zone tillage 1989.


Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50

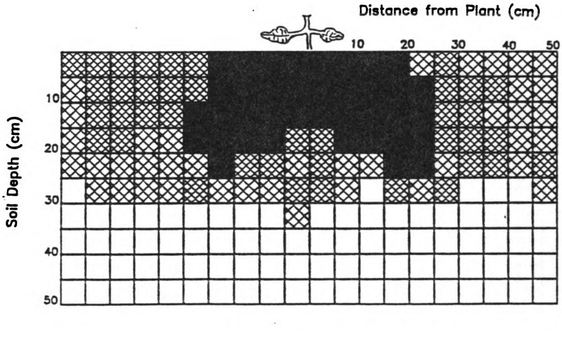
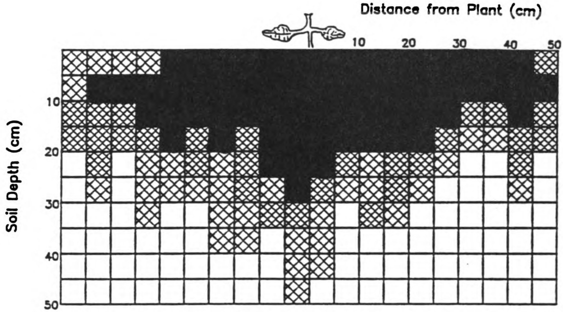

Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50

Figure 4. Rooting pattern for strip tillage with zone tillage 1989.

Figure 5. Rooting pattern for strip tillage without zone tillage 1989.


Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50

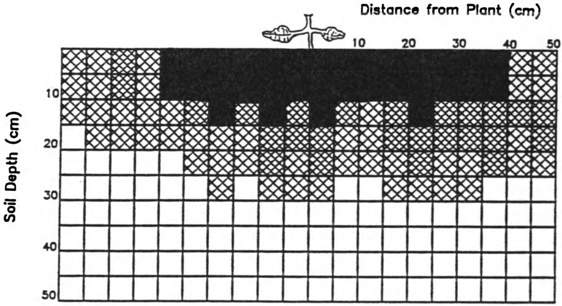
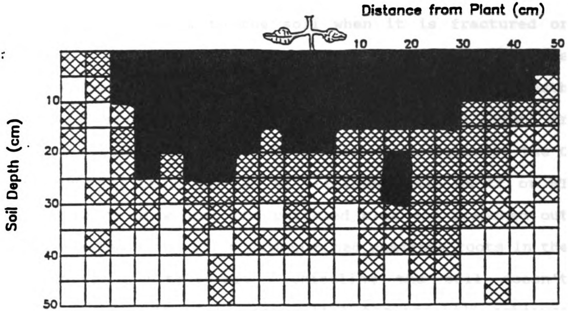
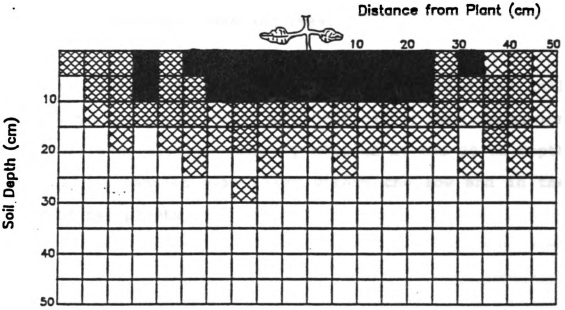

Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50

Figure 6. Rooting pattern for no tillage with zone tillage 1989.

Figure 7. Rooting pattern for no tillage without zone tillage 1989.


Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50


Distance from Plant (cm)
10
20
30
40
50
Soil Depth (cm)
10
20
30
40
50

It is concluded that tomatoes that are transplanted into the field do respond to the soil when it is fractured or loosened. Doss et al. (1981) working with no tillage tomatoes, chiseled to a depth of 40 to 50 cm directly beneath the row observed little effect from treatment on amount or depth of rooting except that there were fewer roots in the 0 to 15 cm soil depth on the NT treatment than on CT or ST plots. Roots grew down the chiseled slot and branched out into the subsoil and all treatments had numerous roots in the soil profile down to 60 cm. Chiseling the soil doesn't provide the amount of loosening that the paratill achieves this probably the reason for the lack of effect seen by Doss et al.

Pentrometer Readings, 1988 and 1989.

Soil penetrometer measurements showed spring and fall paratill treatments to result in significantly less compaction than where zone tillage wasn't practiced at the 20 cm depth (Table 22). Samples were taken within the row and in the center of two plants.

Table 22. Soil penetrometer readings from 1988 and 1989.

	kg·cm^2	
	1988[1]	1989[2]
Spring Paratill	5.4	4.6
Fall Paratill	8.0	7.8
No Paratill	16.8	14.7
LSD (.01)	5.3	2.4
(.05)	3.8	1.8

[1]Each figure is the mean of 3 tillage x 5 replications x 5 readings.
[2]Each figure is the mean of 3 tillage x 4 replications x 5 readings.

The soil where zone tillage was practiced was very loose and friable. This supports observations that were made while studying root development. The top 10 cm of the loosened zone was firm, but not compacted and beneath this zone is where the soil was loose.

Soil Moisture, 1989.

Soil moisture data was taken twice during the 1989 growing season. The samplings were taken in the drier periods of the summer, when the availability of water was most critical for the development of the plants. The potential loss of capillary movement of soil water to the root zone was a concern.

At the first sampling date (Table 23) the NT and CT plots had the highest amount of soil moisture per volume of soil in the top 15 cm of the soil profile. The reason for the ST having the lowest soil moisture is not understood. All 3 tillage treatment had the same soil moisture below 15 cm. The fall and spring paratill treatments contained greater soil moisture below 15 cm than where the paratill was not used. At the 0-7.5 cm depth only the fall paratill contained more moisture than no paratill. The zone tillage thus contains higher soil moisture on a per volume basis (Table 24) than the treatment which didn't receive zone tillage. The interaction of tillage x paratill was not significant in either of the two sampling dates.

Table 23. Influence of tillage treatment on volumetric soil moisture content of soil from 4 depths June 22.

	Soil Moisture[1]			
	Depth (cm)			
Tillage	0-7.5	7.5-15	15-22.5	22.5-30
Conventional	5.36[2]	7.85	6.24	7.38
Strip Till	3.96	6.51	6.54	5.83
No Till	5.51	8.63	8.24	7.29
LSD (.05)	.79	1.55	NS	NS

[1]Volumetric soil water content (%).
[2]Each figure is the mean of 3 paratill treatments x 4 replications.
(NS)Nonsignificant.

Table 24. Influence of paratill treatment on volumetric soil moisture content of soil from 4 depths June 22.

	Soil Moisture[1]			
	Depth (cm)			
Paratill	0-7.5	7.5-15	15-22.5	22.5-30
Spring	4.89[2]	8.26	6.87	7.75
Fall	5.76	7.96	7.60	7.38
None	4.18	6.78	5.69	5.36
LSD (.05)	1.05	NS	.88	.96

[1]Volumetric soil water content (%).
[2]Each figure is the mean of 3 tillage treatments x 4 replications.
(NS)Nonsignificant.

The second sampling date shows NT having more soil moisture in the 15 to 22.5 and the 22.5 to 30 cm depth than CT or ST (Table 25). The reason that strip tillage had the least amount of soil moisture in all four depths is not clearly understood. The paratill treatments had no effect on soil moisture (Table 26) at this sampling date. The interaction between tillage system x paratill treatments was not significant in either of the two sampling dates.

Table 25. Influence of tillage treatment on volumetric soil moisture content of soil from 4 depths on July 6.

	Soil Moisture[1]			
	Depth (cm)			
Tillage	0-7.5	7.5-15	15-22.5	22.5-30
Conventional	2.78[2]	5.11	4.28	4.15
Strip Till	2.29	4.21	3.24	3.18
No Till	2.61	5.95	6.07	5.81
LSD (.05)	NS	1.28	1.49	1.30

[1]Volumetric soil water content (%).
[2]Each figure is the mean of 3 paratill treatments x 4 replications.
(NS)Nonsignificant.

Table 26. Influence of paratill treatment on volumetric soil moisture content of soil from 4 depths on July 6.

	Soil Moisture[1]			
	Depth (cm)			
Paratill	0-7.5	7.5-15	15-22.5	22.5-30
Spring	2.90[2]	4.90	4.79	4.04
Fall	2.31	5.46	4.70	5.30
None	2.46	4.89	4.10	3.81
LSD (.05)	NS	NS	NS	NS

[1]Volumetric soil water content (%).
[2]Each figure is the mean of 3 tillage treatments x 4 replications.
(NS)Nonsignificant.

Chapter IV

SUMMARY AND CONCLUSIONS

Increasing the rate of nitrogen from 140 $kg \cdot ha^{-1}$ to 252 $kg \cdot ha^{-1}$ did not increase the large or medium size # 1 fruit, however # 2's and culls decreased linearly as more nitrogen was applied. Since low yields of the NT treatment were not overcome with increased N, N was eliminated as being a limiting factor. No tillage was not significantly different than CT or ST, however CT had 25% more large size fruit than ST and 32% more than NT. The upper limit of nitrogen needed is 140 $kg \cdot ha^{-1}$ using the three tillage systems investigated. The ST treatment was intermediate between CT and NT in yield and appears to be the most feasible treatment for a minimum tillage system.

Plowing living rye into the soil or killing it at different heights and leaving it on the soil surface had no effect on early yield of transplanted tomatoes, however, a downward trend of large size fruit was evident as more residue was left on the soil surface. Total yield of medium # 1 fruit and culls was decreased when the rye was allowed to grow to 40 cm before it was killed. This plus the fact that ST is better than NT supports the hypothesis that the rye is inhibitory to the tomatoes. No effect on total yield of large size fruit was evident, however a decrease in yield occurred as more rye was left on the soil surface.

Increasing plant spacing from 40 to 60 to 80 cm within the row decreases early yield of large and medium size # 1 fruit. Plant spacing had no effect on early yield of # 2's and culls. However, as plant spacing increased total yield of large and medium size # 1 and culls decreased linearly. The 60 cm spacing is best suited for the cultivar Mountain Pride, growing in a dessicated rye residue due to the highest yield of large # 1 fruit.

Zone tillage proved to be beneficial to the tomato transplant in a minimum tillage system, more so in a normal year like 1989 than in a hot, dry year like 1988. Total yield of large size fruit was increased by zone tillage. Zone tillage appears to alleviate some stresses on the tomato plant during the time immediately after transplanting. The fall and spring paratill treatments resulted in more plant dry weight accumulation, which is evident soon after transplanting and continues throughout the growing season. The looser soil achieved with zone tillage may induce more rapid development of the roots and thus facilitate uptake of water and nutrients for early plant development.

Destruction of the tap root on a tomato plant grown in the greenhouse and transplanted to the field, only allows the plant to produce a very fibrous root system and with zone tillage fracturing the soil to a 30 cm depth allowed the fibrous roots to explore more of the B_1 horizon.

Zone tillage is beneficial when growing tomato transplants in a minimum tillage system. The most efficient way of growing tomatoes with a conservation tillage program is with strip tillage and using the paratill either in the fall or spring when the soil is the driest. The soil is fractured best when the soil is dry because a wet soil will not fracture and could create more of a compaction problem.

The rye cover crop cv. Wheeler which was used in all experiments, resulted in reduced yields indicating a possible toxic effect on the tomato plants from allelochemicals released from the rye. In almost all cases the CT treatments had the highest yield, followed by ST and NT especially of large size fruit, however, the yields were not statistically different in all cases. The ST plots where part of the rye is mixed in the soil or chemically killed in a band early in the spring, has greater potential than the complete NT system. The literature on NT vegetables and the data presented have shown, that when a year has uniform rainfall throughout the course of the growing season, that ST and NT work well and yields from these systems are greater than CT, however the reverse is true when lack of rainfall occurs or when the rainfall pattern is not very uniform.

Strip tillage and no tillage production of fresh market tomatoes continues to be a viable method of production. The benefits of reduced water erosion, sand abrasion and wind damage are very important aspects of conservation tillage. Yields of marketable fruit in ST and NT are comparable to CT, however continued research in this area is needed on tomatoes and other vegetables.

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APPENDIX

WEATHER DATA

Date		1986 GDD	1986 Precipitation	1987 GDD	1987 Precipitation
May	1-15	83	19	73	31
	15-31	81	139	169	33
June	1-15	138	69	167	21
	15-30	159	28	193	24
July	1-15	169	46	199	17
	15-31	233	68	234	64
Aug.	1-15	149	24	200	82
	15-31	136	56	149	83
Total		1148	449	1384	355

GDD=Growing Degree Day base 10° C.

Date		1988 GDD	1988 Precipitation	1989 GDD	1989 Precipitation
May	1-15	54	10	16	9
	15-31	118	21	107	9
June	1-15	136	1	120	90
	15-30	191	8	157	34
July	1-15	194	21	195	60
	15-31	213	36	183	91
Aug.	1-15	256	48	159	70
	15-31	162	93	169	38
Total		1324	238	1106	401

GDD=Growing Degree Day base 10° C.