Stand Establishment of Fluid-drilled Tomato in Rye and Wheat Tillage Systems

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Abstract. Tomatoes (*Lycopersicon esculentum* Mill.) were grown in conventional tillage (CT), rye (*Secale cereale* L.) mulch no tillage (RNT), and wheat (*Triticum aestivum* L.) mulch no tillage (WNT). Either germinated seeds (GS) or raw seeds (RS) were fluid drilled on several dates in 1981 and 1982. Tomato stands in no tillage (NT) generally were equal to or higher than in CT, and stands improved with later plantings in each year. Plant stands were unaffected by GS and RS. Time to 50% emergence (T50) was up to 4 days less in NT than in CT and 2 to 3 days less from GS than RS. Yields with CT were twice as high as those with NT for early planting dates. Yields decreased in CT with successive planting dates to levels equal to NT plantings. Use of GS increased fruit yields as compared to RS, regardless of the planting date.

No tillage (NT) compared to conventional tillage (CT) methods of crop production offer the potential of increased soil moisture (Blevins et al., 1971; Gallaher, 1975; Moody et al., 1963), soil conservation (Armburst, 1977; Moody et al., 1963; Van Doren et al., 1984), increased profits through decreased cost (Wittmus et al., 1975), and greater plant protection (Doss et al., 1981). Responses of vegetables to reduced tillage production systems can vary greatly with year (Doss et al., 1981; Patrick, 1971) or crop (Knave et al., 1977; Knave and Herron, 1986). Tomatoes in NT, relative to CT, have given decreased fruit yields (Doss et al., 1981; Knave et al., 1977) or similar yields (Beste, 1973). Problems with stand establishment, crop pests, adequate weed control, and potential phytotoxic substances from decaying mulch residues could affect tomato yields in NT.

Direct field seeding of vegetables can be less costly than transplanting. Cool soils, soil pathogens, and soil crusting all contribute to poor germination and erratic emergence of direct-seeded crops (Hegarty, 1976; Harrington, 1962). Rapid seedling emergence from germinated seeds sown in a gel carrier (fluid drilling) may reduce exposure of seeds and seedlings to adverse environmental factors (low temperatures, high soil moisture levels, and pathogens) that can develop in seedbeds after planting (Currah et al., 1974; Gray, 1981; Lipe and Skinner, 1979; Salter,

1978). Tomatoes respond well to fluid drilling, resulting in denser stands (Bussell and Gray, 1976; Pill and Fieldhouse, 1982) and higher fruit yields (Ghate and Phatak, 1981; Gray et al., 1979). Our study was conducted to evaluate the effects of NT and fluid drilling at several planting dates on the establishment and yield of tomato.

Treatments were CT, rye mulch with no tillage (RNT), wheat mulch with no tillage (WNT), planting dates (early, mid, or late season), and seeding methods of fluid drilled with raw seed (RS) or fluid drilled with germinated seed (GS). All CT plots were sown in the fall with rye, then moldboard plowed and disked twice the following spring. Seeds of the mulch crops (Wheeler¹ rye and 'Tecumseh²' wheat) were sown in all experiments at 134 kg/ha¹. NT plots were sprayed with 1,1-dimethyl 4,4-bipyridinium ion (paraquat) at 1.1 kg a.i./ha 1 week before the first planting date in each experiment. Mulch residue sample from 1 m² of NT plots were collected immediately after the first planting date, dried, and weighed.

Seed germination and fluid-drilling techniques were the same in all experiments. Tomato seeds were enclosed in cheesecloth bags

suspended in aerated water and germinated for 72 h at 25C. The water was changed daily. A tractor-mounted fluid drill delivered the equivalent of 560 g of seed in 220 liters of 1.5% (w/v) Viteria II gel (potassium propenoate propenamide; Napera Chem. Co., Harriman, N.Y.) per hectare. The gel/seed mixture was gravity fed to a peristaltic pump that discharged, the mixture behind the furrow opener. Clumps of gel (10 ml) containing four to six raw or germinated seeds were deposited every 25 to 30 cm in the row for an expected population of 20,000 to 100,000 plants/ha. Covering the gel/seed mixture with soil in the NT was not attempted. Plants were sprayed throughout the growing season to control insect and disease pests as needed.

Soil moisture and temperature. Weekly soil moisture levels and daily soil temperatures were monitored in three replications during 1981 and in four replications during 1982 of Expts. 1 and 3, respectively. Moisture contents of two random samples in each tillage system were taken in 7.5-cm intervals to a depth of 30 cm and the gravimetric water content calculated. Total soil volume collected in each tillage system was $\approx 75 \text{ cm}^3$. Weekly soil temperature averages were obtained from sensors placed 5, 15, and 25 cm deep in plots of each tillage system and read daily at 0800, 1200, and 1700 HR.

Tillage system, type of seed, date of planting (Expt. 1). Mulches of wheat and rye were established in Oshtemo sandy loam (Typic Hapludalf) at the Sodus Horticultural Research Station, Sodus, Mich., in 1980. Ammonium nitrate (56 kg N/ha) and potash (185 kg K/ha) were incorporated before mulch establishment. Tillage systems (CT, WNT, and RNT) were the main plots, and a combination of type of seed (GS, RS) and planting dates were subplots. There were four replications. Raw and germinated 'UC 82' tomato seeds were fluid drilled on 7 and 19 May and 2 June 1981. Plots were 18 x 15 m with 1.5 m between rows. Oven-dried rye and wheat residues were 2.97 and 1.67 Mg/ha¹, respectively. All plots were sprayed with 4-amino-6-tertbutyl-3(methylthio)-s-triazin-5(4H) (metribuzin) at 0.37 kg a.i./ha on 2 July and sidedressed with 56 kg N/ha on 8 July. Total number of emerged plants was recorded 28 days after planting (DAP) and analyzed separately. Ripe fruits were

Table 1. Effect of tillage system on plant population of fluid-sown tomato.

Tillage system	Plant population (1000s/ha)						
	Expt. 1		Expt. 2		Expt. 3		Expt. 4
	7 May	19 May	2 June	29 May	8 May	27 May	2 June
Conventional (CT)	54.3	39.8	80.2	31.7	9.9	11.2	53.3
Rye mulch							
no tillage (RNT)	15.0	17.8	76.1	97.2	18.9	23.2	66.5
Wheat mulch							
no tillage (WNT)	15.8	33.8	91.1	76.6	7.8	8.3	---
Contrasts							
CT vs. NT	***	**	NS	***	NS	NS	NS
RNT vs. WNT	NS	**	NS	***	**	***	---

¹Data not recorded.

***, **, NS Significant at $P = 0.01$ and 0.001 or nonsignificant, respectively. Tillage system $\times$ seeding method interaction was not significant, except for 27 May 1982 (Expt. 3).

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Fig. 1. Influence of conventional tillage (CT), rye mulch no tillage (RNT), and wheat mulch no tillage (WNT) on the yield of tomato at three planting dates (Expt. 1, 1981). Vertical bars indicate SE.

Fig. 2. Influence of conventional tillage (CT), rye mulch no tillage (RNT), and wheat mulch no tillage (WNT) on gravimetric soil moisture content (Expt. 3, 1982). Values are the means of four depths and four replications $\pm$ SE.

harvested weekly from 1.5-m sections of row, and weights recorded according to the repeat cumulative method (MacNab and Penny-packer, 1981).

Tillage system, type of seed, cultivar (Expt. 2). Mulches of wheat and rye were established in a Lapeer sandy loam (Typic Hapludalf) at the Clarksville Horticulture Research Station, Clarksville, Mich., during Fall 1980. The design was a split plot with four replications. Tillage systems (CT, WNT, and RNT) were main plots, with a combination of type of seed (GS and RS) and tomato cultivars ('Peto 80' and 'UC82') as subplots. Plots were 10.5 $\times$ 10.5 m with 1.5-m rows. Fertilizer (40N-70P-130K, kg-ha⁻¹) was broadcast over all plots on 27 May and tomatoes were sown on 29 May 1981. Tomato stands were recorded 14 days after planting.

Tillage system, type of seed, date of planting (Expt 3). Wheat and rye were sown in Marlette fine sandy loam (Glossoboric Hapludalf) at the Michigan State Univ. Horticultural Research Farm, East Lansing, in Fall 1981. A split-plot design with six replications was used with a combination of planting dates (7 and 27 May 1982) and type of seed (GS and RS) imposed on tillage systems (CT, WNT, and RNT). Plots were 6.1 $\times$ 7.6 m with 1.5 m rows. Ammonium nitrate (50 kg N/ha) was applied to all plots before seeding 'UC 82' tomato. Residue of rye and wheat averaged 0.88 and 0.27 Mg-ha⁻¹, re-

spectively. Daily emergence counts were taken until no more seedlings emerged for three consecutive days. Total emergence and time to 50% emergence (T50) was calculated for each treatment. Analyses for planting dates were conducted separately. Three 900-cm² areas in each plot were sampled to evaluate the effects of mulch on weed population and biomass. The dominant broadleaf and grass weed species were counted and dried for 48 h at 60C before being weighed.

Tillage system and type of seed (Expt. 4). Fall-sown rye was compared to CT at the Michigan State Univ. Horticultural Research Farm in 1981. Main plots were CT and RNT and subplots were type of seed (RS and GS). There were three replications. Plots were 4.5 $\times$ 7.6 m with 1.5-m rows. Rye residue in the NT averaged 2.9 Mg-ha⁻¹. 'Chico III' tomato was planted on 2 June 1982. Emergence criteria and weed populations were recorded as described in Expt. 3.

Plant stands in all experiments were generally not affected by sowing method (data not shown). Fluid-drilled raw and germinated tomato populations for the early planting dates in 1981 and 1982 varied from 10,000 to 30,000 plants/ha, while late planting dates averaged from 60,000 to 80,000 plants/ha. These results are different from those of Gray et al. (1979), where sowing germinated seeds increased plant stands compared to raw seeds. Sowing germinated seed compared to untreated seed had little effect on percent emer-

gence when soil moisture levels were adequate (Finch-Savage and Pill, 1990); however, fewer seedlings emerged from germinated seeds when seedbed conditions were poor (Finch-Savage, 1987). Late planting dates have been reported to improve tomato stand establishment from both raw and germinated seed (Gray et al., 1979). Improved establishment with later planting dates may be due to increased soil temperatures or decreased toxicity associated with decomposing crop residues (Patrick, 1971).

There was no interaction between tillage system and type of seed in Expt. 1. Plant stands were significantly lower in the NT than the CT for 7 and 19 May in Expt. 1 (Table 1). Stands in the RNT and WNT sustained up to 50% losses due to cutworm compared to 3% to 4% losses in the CT (data not shown). The black cutworm is the most serious pest of seedling corn in reduced-tillage systems in the north-central United States (Gregory and Musick, 1976). Tomato stands in CT and NT from the 2 June planting were similar in Expt. 1. Allelopathic leachates from mulches can influence seed germination and seedling emergence (Barnes and Putnam, 1983; Guenzi et al., 1967; Unger, 1978). Patrick (1971) noted that the toxicity of decomposing residues declined with increasing decomposition until little or no phytotoxicity was observed. Allelopathic compounds also may have contributed to the reduced seedling emergence in early plantings but had no influence on late plantings.

In Expt. 2, plant populations increased by 200% and 140% for RNT and WNT, respectively, compared to the CT (Table 1). There was no interaction between tillage system, cultivar, or type of seed in Expt. 2. Other environmental factors also influenced stand establishment in the tillage systems. Heavy rains after planting caused considerable soil crushing in CT plots in Expt. 2, which restricted seedling emergence. The higher stands in NT systems with high residue levels may reflect decreased soil crusting. NT systems have been shown to maintain surface soil structure and improve seedling emergence (Larson, 1970). Stand establishment for 'Peto 80' increased by 125% relative to 'UC 82' (data not shown). Cultivar differences may also be important for tomato stand establishment in NT and should be investigated further.

Tomato stands were similar in NT and CT for the 8 May planting date in Expt. 3 (Table 1), with stand establishment improved by sowing in RNT compared to WNT. Tillage system and type of seed interacted significantly in influencing stand from the 27 May 1982 planting (Table 2). NT did not improve stand establishment compared to CT when sowing RS, though RNT had a higher plant population than WNT. However, sowing GS in RNT increased plant populations compared to either CT or WNT. Sowing GS instead of RS improved tomato stands in RNT but had little effect on populations in either CT or WNT. Rye mulch residues appear beneficial in improving stand establishment. Overall stand establishment was poor in Expt.

Table 2. The interaction of tillage System and type of seed used for fluid drilling on tomato plant population. Data for 27 May 1982 planting date in Expt. 3.

Tillage system	Plant population (1000s/ha)	
	Raw seeds (RS)	Germinated seeds (GS)
Conventional (CT)	13.6	8.2
Rye mulch no tillage (RNT)	16.4	29.7
Wheat mulch no tillage (WNT)	5.0	11.3

LSD_{0.05} = 10.0 between seeding methods for the same tillage system and 10.3 between seeding methods at different tillage systems and same seeding method at different tillage system.

Table 3. Effects of tillage system and type of seed used for fluid drilling on the days to 50% emergence (T50) of fluid-sown tomato.

Treatment	T50		
	Expt. 3 8 May	Expt. 3 27 May	Expt. 4 2 June
Tillage system			
Conventional (CT)	11.0	12.7	8.9
Rye mulch no tillage (RNT)	8.7	10.1	8.3
Wheat mulch no tillage (WNT)	8.7	8.4	---
Contrasts			
CT vs. NT	***	**	*
RNT vs. WNT	NS	NS	---
Type of seed			
Raw	11.1	11.9	9.6
Germinated	7.8	9.0	7.6
LSD _(0.05)	1.7	2.1	0.8

*Data not recorded.

***, **, NS Significant at $P = 0.05$, 0.01 , and 0.001 or nonsignificant, respectively. Tillage system $\times$ seedling method interaction was not significant.

3. Plant stands in CT and WNT were less than half the targeted population. Dry soil conditions at planting and below-average rainfall contributed to the reduced stands. Low residue levels and failure to cover the seed in WNT may have exposed the gel/seed mixture to desiccating conditions that reduced emergence. Results with onion (Finch-Savage, 1986) and carrot (Finch-Savage and Pill, 1990) demonstrated that if high soil moisture levels in seedbeds are maintained, a high percent emergence and a low spread of emergence can be achieved. Furthermore, when seedbeds are dry at sowing, more seedlings emerge from raw seed than from germinated seed (Finch-Savage, 1986), with soil moisture stress being a major factor in seedling loss from germinated seed (Finch-Savage, 1987). There was no difference in tomato stands for tillage systems or type of seed in Expt. 4 (Table 1).

The time to 50% emergence (T50) was as much as 3 days less in NT compared to CT (Table 3) and 2 to 3 days less for GS than RS in Expts. 3 and 4 (Table 3). There was no difference in T50 values between RNT and WNT. Finch-Savage (1986 and 1987) and Gray et al. (1979) reported earlier and more uniform emergence from fluid-drilled GS than from RS. Seedbed conditions at

sowing can significantly influence stand establishment. As seedbed moisture levels decreased, T50 increased (Finch-Savage, 1987). Low moisture levels in CT may contribute to the increased T50 noted.

Redroot pigweed (*Amaranthus retroflexus* L.) and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] were the dominant weed species in CT and NT in Expts. 3 and 4 during 1982. The number and weight of pigweed plants were higher in CT than in NT regardless of the planting date (data not shown). The effects of rye and wheat on reducing broadleaf weed population densities and biomass confirm reports of improved weed control with these mulches (Barnes and Putnam, 1983). Allelopathic compounds in the residues of rye and wheat may have contributed to the reductions noted in weed growth. The density and biomass of large crabgrass was unaffected by CT or NT in Expt. 3; however, RNT had fewer crabgrass plants than CT in Expt. 4 (data not shown). Annual grasses may be a worse problem in NT (Larson, 1970). Mulches of rye and wheat had only a minimal effect on crabgrass populations and biomass.

Tillage system interacted with planting date to influence tomato fruit yield in Expt. 1 (Fig. 1). Yield in CT decreased with successive plantings, while yields in RNT and WNT were unaffected by planting date. Yields in RNT and WNT were significantly less than CT for the 7 May planting. By 19 May, only the yields in RNT were less than CT. Fruit yield for the 2 June planting was similar for all tillage systems. There was no difference between CT and NT for number of fruit per plant and average fruit weight (data not shown). Poor plant stands in NT compared to CT for the early plantings in Expt. 1 significantly reduced tomato fruit yields since fruit count per plant and average fruit weight were unaffected by tillage system. Cutworm damage to early plantings was a factor in stand reductions in NT. Tomato fruit yield reductions from plants transplanted in NT have been due to dry soils at establishment (Doss et al., 1981) and greater weed reinfestation during crop growth (Knavel et al., 1977). Beste (1973) reported that with adequate weed control, yields of direct-seeded tomatoes were the same in both tilled and NT areas. We did not consider weed pressure to be serious in Expt. 1 and soil moisture and temperatures were adequate for tomato establishment. Yield reductions associated with late planting dates in CT were due to insufficient time available for fruit ripening even though plant populations were high (Table 1). Fruit yields were significantly higher for all planting dates when sown with GS compared to RS (data not shown). Fruit yields averaged 32 and 22 Mg-ha⁻¹ for GS and RS, respectively. Gray et al. (1979) also reported significantly higher yields from fluid-sown GS than for RS for all planting dates. There was no interaction between tillage system and type of seed for fruit yield (data not shown). Sowing GS not only speeds seedling emergence (Table 3), but also increases yield compared to fluid-drilling RS.

Due to poor plant stands in Expt. 3 and heavy weed pressure in Expts. 2 and 4, yields were not recorded.

There was no difference in soil moisture between the tillage systems in 1981 (data not shown). Soil moisture levels in 1982 were higher in the RNT than the CT at all dates (Fig. 2). There was no difference between the WNT and the CT at the first three samplings in 1982, but by 30 days after planting, WNT had higher moisture levels than the CT. The surface of the soil was drier than lower depths (data not shown), with the highest moisture levels occurring at 15 to 22.5 cm. Dry soil conditions in CT (Fig. 2), deep seed placement, and low residue levels in WNT (0.27 Mg-ha⁻¹) all contributed to poor stand establishment in Expt. 3. Rainfall during May 1982 was 47 mm, 31 mm below normal. Dry soils can draw moisture from the gel, causing the germinated seed to desiccate before rainfall replenishes soil moisture. Low plant stands of GS sown in CT may reflect increased sensitivity of germinated seeds to low soil moisture (Table 3, Expt. 3). Furthermore, in a year of low rainfall, early desiccation of the growing mulch may be necessary to minimize soil moisture depletion. Mulches have been shown to reduce evaporation and improve water infiltration (Blevins et al., 1971; Gallaher, 1975; Moody et al., 1963). Even small amounts of mulch conserved soil moisture (Fig. 2) and likely produced a favorable microclimate for seedling emergence.

Soil temperatures were similar in all tillage treatments during plant establishment in 1981 and 1982, and they were highest near the surface and decreased with depth (data not shown). Soil temperatures at 5 cm averaged 15C on 8 May 1982 and increased to 19C by 27 May. Low soil temperatures can reduce tomato emergence and adversely affect plant growth (Gray et al., 1979). Soil temperatures in the different tillage systems were adequate for seedling emergence and did not appear to influence stand establishment.

In three of four experiments, stands of NT direct-seeded tomatoes were equal to or higher than those in CT. Fluid-drilling GS into NT systems reduced emergence time but did not improve plant populations. Further work is needed to understand the influence of mulches and soil environmental factors on stand establishment and tomato yield in NT systems. Furthermore, pest and weed pressure in NT needs to be carefully monitored if stands and yields are to be maximized.

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