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# Conservation Tillage Tomato Production in California's San Joaquin Valley

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Rising fuel and labor costs and stagnant commodity prices encourage tomato growers to minimize production costs whenever possible. Reducing tillage in crop rotations typically associated with bed-preparation operations may be a means to cut costs in tomato production systems. During the past several decades, a wide range of crop production systems have been developed that minimize or eliminate tillage from crops such as corn, cotton, beans, and wheat (MWPS 2000). By reducing soil disturbance, these systems preserve surface residues, reduce soil erosion, conserve water, and may enable more diverse and intensive crop rotations in areas of limited rainfall. Collectively, these practices have been called conservation tillage (CT) systems. Historically they have been based on various production practices that maintain 30 percent or more of the soil covered by residue at the time of planting (CTIC 2004), the minimum threshold for soil erosion mitigation.

In California's Central Valley, CT approaches are receiving interest as a means to cut costs and reduce dust and diesel fuel emissions from production fields. However, very little information currently exists on using CT for processing tomato production, most likely because of the recognized need for clean bed conditions for planting, harvesting, and incorporating herbicides, as well as the lack of effective CT tomato equipment. This publication summarizes recent advances in the development of CT tomato production and describes what CT tomato systems might look like.

In CT tomato systems, planting beds are not disturbed or reworked following harvest of the crop preceding tomatoes. Two common forms of CT are no-till and strip-till. In no-till, no tillage is done from the harvest of one crop until the next crop is planted; the no-till crop is seeded or transplanted directly into the unworked soil of the previous crop. In strip-till, a narrow zone of soil is cleared, and subsoil layers are loosened prior to planting. This tillage zone is typically 8 to 12 inches wide and 2 to 14 inches deep. Compared with standard tillage (ST), also known as broadcast tillage, in which the entire field is tilled, strip-till decreases both the volume of soil that is disturbed and the amount of dust that is typically generated, and it also reduces fuel, labor, and equipment costs. It provides opportunities for band application of surface-incorporated herbicides and fertilizers at different depths prior to seeding. Because only a relatively small volume of soil is tilled using strip-till, it is often also called zone or vertical tillage. To be successful, strip-till and no-till systems require special implements as well as several other key changes in a cropping system.

**Figure 1.** Dr. Aref Abdul-Baki, USDA Agricultural Research Service, Beltsville Agricultural Research Center, Beltsville, Maryland, examining vetch cover crop mulch in tomato production system. *Photo:* Courtesy Dr. Aref Abdul-Baki.

**Figure 2.** Strip-till transplanted fresh market tomatoes in wheat cover crop, Le Grand, California, 2001. *Photo:* J. P. Mitchell.

Minimum-till systems for tomatoes that rely on reduced-pass bed preparation and that disturb a far greater soil volume than is done in CT are discussed in a companion publication in this series, *Minimum Tillage Vegetable Crop Production in California* (Mitchell et al. 2004).

## EARLY CONSERVATION TILLAGE TOMATO SYSTEMS

The development of the earliest CT tomato production systems is generally attributed to USDA researchers in Beltsville, Maryland (Abdul-Baki and Teasdale 1993). In the early 1990's, Abdul-Baki and Teasdale developed a high-residue, no-till system that used a hairy vetch cover crop mulch to suppress weeds and supply nitrogen to transplanted tomatoes (fig. 1) (Abdul-Baki et al. 1996). Over several years of study, this system has been shown to be more productive and more profitable than the standard black plastic mulch that is common in East Coast production regions (Abdul-Baki et al. 2002; Abdul-Baki and Teasdale 2001). It has been used with considerable success and viability in long-term no-till rotations to reduce soil erosion by Pennsylvania tomato producer Steve Groff (see his Cedar Meadow Farm Web site, http://www.cedarmeadowfarm.com/).

Herrero et al. (2001) evaluated no-till processing tomato production in four winter cover crops in Five Points, California. This study demonstrated the feasibility of no-till mulch production for furrow-irrigated production but did not find adequate weed suppression by the cover crop mulches (without soil-incorporated herbicide) compared with a fallow, soil-incorporated herbicide system. In a follow-up 2-year study conducted in Meridian, California, Madden et al. (2004) compared two cover crop mixtures in organic processing tomato production: a mix of legumes, common vetch *(Vicia sativa)*, field pea *(Pisum sativum)* and bell bean *(Vicia faba)*; and a mix of these legumes and rye (*Secale cereale* and *Lolium multiflorum* X *Triticosecale*), annual ryegrass *(Lolium multiflorum* X *Triticosecale)*, and cereal rye *(Secale cereale)*. Tillage included incorporating the cover crops as green manures and using the cover crops as surface mulches in a no-till system. Yields were similar in all systems in the second year of the test but were lower for grass-legume mulch in the second year (due to regrowth of the grass). The total percentage of weed cover was 1.6 to 12.5 times higher in the surface mulch no-till system than in the incorporated cover crop system in the first year, and the percentage was 2.4 to 7.4 times higher in the second year. This indicates that even quite-high-residue surface cover crop mulches are unable to provide effective weed control for CT tomato production compared with traditional tillage systems.

Additional studies of CT tomatoes conducted in commercial production fields in Tracy, Gustine, Vernalis, and Le Grand, California, from 1999 to 2002 evaluated the use of winter cover crops as surface mulches, the feasibility of no-till and strip-till transplanting (fig. 2), and options for in-season weed management (fig. 3). No-till transplanting requires the use of coulters (flat disks that cut through residues ahead of the planter) or some form of

**Figure 3.** High-residue cultivation of strip-till transplanted processing tomatoes, Tracy, California, 1999. *Photo:* J. P. Mitchell.

**Table 1.** Processing tomato yields from 1999 on-farm demonstration in Tracy, CA, and 2000 demonstration in Vernalis, CA

| Tillage or cover crop system | Processing tomato yield (ton/ac) |
|---|---|
| **Tracy, 1999** | |
| strip-till vetch cover crop | 46.6 |
| no-till vetch cover crop | 36.8 |
| no-till winter weeds | 47.3 |
| strip-till winter weeds | 45.5 |
| strip-till winter weeds | 45.3 |
| fallow standard tillage | 47.3 |
| **Vernalis, 2000** | |
| no-till bell bean cover crop | 40.5 |
| no-till vetch and bell bean cover crop | 39.3 |
| no-till berseem clover cover crop | 30.8 |
| no-till pea cover crop | 28.2 |
| fallow standard tillage | 38.7 |

residue management to cut surface residues ahead of the transplanter shoe. In strip-till, a set of coulter or shank implements tills a narrow (6- to 8-inch) band of soil to a depth of a 3 to 14 inches in the line into which transplants (or seeds) will be placed. Results from these preliminary evaluations indicated that planting and harvesting both processing and fresh-market tomatoes is possible with CT. Yields comparable to those attained using standard winter fallow techniques may be achieved with certain reduced-till approaches that do not result in excessive cover crop regrowth or weed competition with the tomato crop. In-season cultivation is possible under these cover crop residue situations. On-farm strip trial data for demonstrations conducted in 1999 in Tracy and in 2000 in Vernalis are presented in table 1.

## REFINING CONSERVATION TILLAGE TOMATO PRODUCTION

Each year since 1999, we have evaluated CT and cover cropping (CC) practices for tomato production in an 8-acre field at the UC West Side Research and Extension Center in Five Points, California (Mitchell et al. 2006). The objective was to compare standard tillage (ST) with and without (NO) winter cover crops on the one hand with CT with and without cover crops on the other to evaluate economics, productivity, soil properties, and dust emissions under tomato and cotton rotation. The study field was divided in half to allow both crops to be grown in each year. A summary of 4 years research is presented below.

The ST systems were managed using farming practices that are traditional in the West Side San Joaquin Valley region. Beds were disked and pulled or reformed following harvest of successive crops. Prior to planting tomatoes, the beds were also shaped with a power incorporator. The ST cover crop system used a triticale-rye-vetch green manure that was disked in each spring before establishing the summer tomato or cotton crops.

The CT systems used about 50 percent fewer tillage operations or soil disturbance operations than did ST systems. Tomatoes were no-till transplanted, and cotton was no-till seeded into beds that had not been worked or mowed since the beginning of the study, except for a shallow cotton root undercutting following harvest for pink bollworm management compliance. Preplant tomato beds were rough following the one-pass fall cotton stalk

**Table 2.** Tillage operations used in standard tillage and conservation tillage tomato systems, Five Points, CA, 1999–2005

| Standard tillage (ST) | Conservation tillage (CT) |
|---|---|
| undercut cotton | undercut cotton |
| disk (2 times) | transplant tomatoes |
| rip | |
| disk | |
| list beds | |
| power incorporate beds | |
| tansplant tomatoes | |


**Figure 4.** Cultivating no-till transplanted processing tomatoes in Five Points, California, conservation tillage (high residue) study, 2004. *Photo:* J. P. Mitchell.

**Figure 5.** Applying liquid fertilizer as a side-dress to fresh market tomatoes in Parlier, California, conservation tillage study, 2002. *Photo:* J. P. Mitchell.

management operation, so they were reworked using furrow sweeps at transplanting and during in-season cultivations (see fig. 1). In the CT cover crop systems, the cover crop was sprayed with glyphosate, chopped, and left on the soil surface as a mulch before transplanting tomatoes or planting cotton (see fig. 2). A summary of pretomato tillage operations used in each system is shown in table 2.

## CT Equipment

Certain equipment modifications were made in the CT system during the study: a three-row transplanter sled fitted with 20-inch-diameter coulters ahead of each transplanter shoe; residue-slicing disks in front of each sled; and additional press wheels behind the transplanter drive wheels to seal seedlings into the soil were used (see fig. 3). A Sukup high-residue corn cultivator (Sheffield, IA) was converted to a 3-row 60-inch configuration, and bed-top L-sweep blades were added for tomato bed cultivation (fig. 4). Side-dress fertilizer was applied using Yetter Manufacturing (Colchester, IL) high-residue liquid or dry fertilizer applicators that had coulters fitted in front of the shanks (fig. 5).

## Yields

Processing tomato yields (cv. Heinz 8892) for 2000 to 2004 are shown in table 3. CT-NO yields matched or exceeded those of ST in all 4 years while using considerably less tillage. Yields of CT-CC were lower than the other systems in 2000 and were lower than the CT-NO in each of the next 2 years of the project as well. We observed that tomato plants often grow more slowly early in the season over the heavy CT cover crop mulches; this is perhaps due to the lower temperatures we measured above and below the mulch. As this project has now continued through an additional 4 years, yields of the CT-CC system continue to fluctuate more than those of the other three systems. In some years, plant growth catches up with that of the other systems, but in other years it does not. We speculate that a combination of factors may account for these problems in the CT-CC system, including lower soil and aboveground temperatures, more weed competition, and perhaps nitrogen immobilization. We also observed more surface trash entering the harvester in the CT systems; in years when the cover crop was particularly heavy in the CT-CC system, this forced the tomato harvester to operate more slowly through the field. However, virtually all of this residue was removed by the harvester's suction

**Table 3.** Processing tomato yields from 2000 to 2004 in a field comparison of standard tillage and conservation tillage production, Five Points, CA

| | Processing tomato yield (ton/ac) | | | |
|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 |
| ST no cover | 58 a | 61 b | 46 b | 42 c |
| ST cover crop | 53 b | 63 a | 43 b | 45 b |
| CT no cover | 56 a | 64 a | 56 a | 54 a |
| CT cover crop | 51 b | 61 b | 43 b | 52 a |

*Note:* Letters following each yield number indicate whether there were statistically significant differences between treatments within a given year; different letters in a particular column indicates that the systems likely had significant differences in yield.

**Figure 6.** Transplanting tomatoes into "unworked" cotton beds from previous season in Five Points, California, conservation tillage study, 2005. *Photo:* J. P. Mitchell.

**Figure 7.** Cultivated processing tomatoes in Davis, California, conservation tillage study, 2004. *Photo:* J. P. Mitchell.

cleaning mechanism before the product entered tomato transport trailers.

These results support the potential to produce tomatoes following cotton with considerably less tillage than is currently done in most production fields. The tillage management approach that was pursued in this study sought to reduce primary intercrop tillage and depended on subsequent early-season bed reconditioning with the transplanter and cultivator operations. By doing this, beds were left quite rough during the winter and into the spring, a management strategy that growers may find unacceptable because early-season beds are rather degraded and may not be well shaped (fig. 6). In this study, however, we found that it is possible to establish tomato transplants into these beds, to rebuild the beds using a transplanter and cultivator that are both fitted with "ridging wings" or furrowing tools, and to successfully irrigate and harvest the crop without yield losses. The bulk of fall primary tillage is eliminated in the CT system, but early-season cultivation is needed to recreate furrows and to clean residues out of furrows to improve surface irrigation. While furrow runs at this experimental site were shorter than those used in commercial fields, the early-season "furrowing out" operations would likely enable efficient surface irrigations in larger fields as well.

For our CT tomato system, the largest challenge was to manage weeds consistently. The strategy we pursued involves cultivation, generally two to three times per season, and hand-weeding (fig. 7). However, because herbicides were not incorporated into the soil, the CT systems consistently had many late-season weeds that grew in the furrows. They were not effectively managed because the tomato plants were too big to allow herbicide spraying or cultivation. Thus, weed control must be improved in the CT systems, particularly late in the season. Management options that are currently being evaluated to minimize late-season weed pressure include midseason hooded sprayer applications of appropriate bed shoulder and furrow herbicides that are incorporated using irrigation water, as well as pretransplant broadcast applications of suitable herbicides.

## ECONOMICS OF CONSERVATION TILLAGE TOMATO SYSTEMS

Reducing the number of operations for ground preparation by adopting CT always reduces costs, and profit increases by the same amount that costs decrease. However, adoption of CT may not increase overall profit if it leads to a decrease in income due to yield losses that are greater than cost savings. Even if yields are lower under CT, profit can still increase if the reduction in costs (i.e., increase in profits due to cost savings) is greater than the income loss due to yield reduction (i.e., the decrease in profit from income reduction). However, long-term economics may be much less attractive if CT leads to weed buildup. These potentially negative impacts of CT must be tracked carefully in the future.

In the first year of the ongoing experiment conducted at the West Side Research and Extension Center in Five Points, California, we used preplant tillage practices for all systems. Consequently, the first year showed little difference between ST and CT in the number of times equipment passed over the field or in resource use. We consider this a transition period when permanent beds were established in the CT systems. Consequently, the remaining discussion of CT tomato economics focuses on the 2001 through 2003 results for the systems without cover crops.

In this study, tomato yields were significantly increased from 2001 to 2003 for CT relative to ST (see table 3). From 2001 to 2003 the average increase was 8.4 tons per acre, and for 2003 the increase was 12 tons per acre. For the years following the transition year, the number of times equipment passed over the field was reduced by an average of 6 passes and equalled 9 by 2003. Specifically, CT eliminated a number of diskings, chiseling, triplaning, listing, and bed-shaping operations.

The production practices for the 2001 through 2003 were quite similar. Therefore, the results for 2003 are presented here to illustrate the differences in costs and input use between the two systems (table 4). Also, because of the recent increases in certain input costs, most notably fuel and labor, the costs are expressed in terms of 2007 market values.

**Table 4.** Costs and returns for processing tomato production under standard tillage and conservation tillage, Westside Field Station, 2003 (operations and yield using 2007 input and crop prices)

| | ST | CT | Difference (ST – CT) |
|---|---|---|---|
| | | (ton/ac) | |
| **Yield** | **42.4** | **54.4** | **–12** |
| | | ($/ac) | |
| Gross income at $51.50 per ton | 2,671 | 3,427 | –756 |
| Cultural costs* | 853 | 770 | 83 |
| Harvest cost | 445 | 571 | –126 |
| Total operating costs | 1,298 | 1,341 | –43 |
| Net income per acre above operating costs | 1,373 | 2,086 | –714 |
| Cash overhead: property taxes and insurance | 4 | 2 | 2 |
| Noncash overhead: equipment | 44 | 24 | 20 |
| Total costs | 1,346 | 1,367 | –21 |
| Total net income per acre | 1,325 | 2,061 | –736 |

*See table 5 for details of cultural costs.

**Table 5.** Cultural costs for standard tillage (ST) versus conservation tillage (CT) for processing tomato, Westside Field Station, 2003 (operations expensed at 2007 input prices)

| Cultural costs | ST | CT | Difference (ST – CT) |
|---|---|---|---|
| | | ($/ac) | |
| fertilizer | 79 | 79 | 0 |
| seed | 176 | 176 | 0 |
| herbicide | 76 | 70 | 6 |
| insecticide | 0 | 0 | 0 |
| water | 163 | 163 | 0 |
| labor (machine) | 36 | 19 | 17 |
| labor (irrigation) | 110 | 110 | 0 |
| labor (hand weed) | 84 | 84 | 0 |
| fuel | 58 | 21 | 37 |
| lube and repair | 34 | 16 | 18 |
| interest | 36 | 31 | 5 |
| total cultural | 853 | 770 | 83 |

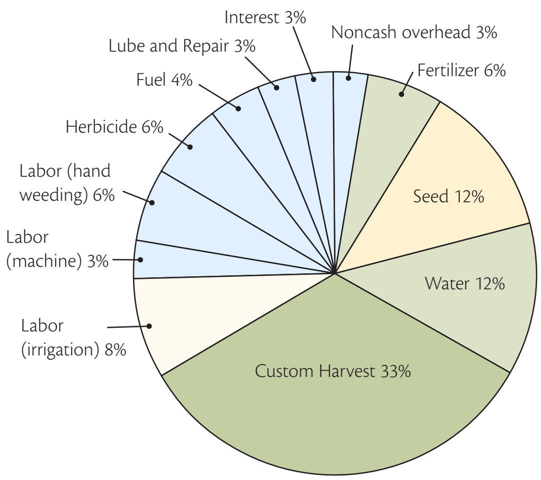


**Figure 8.** ST tomato production costs without a cover crop. The blue-shaded costs can be reduced by eliminating tillage operations, comprising 36 percent of total costs for the ST system without a cover crop. All other costs remain the same regardless of tillage practices.

**Table 6.** Comparison of labor and fuel inputs under standard tillage and conservation tillage for processing tomato, Westside Field Station, 2003

| Input | ST | CT | Difference (ST – CT) |
|---|---|---|---|
| equipment passes over the field | 19 | 10 | 9 |
| labor hours (total) | 21 | 19 | 2 |
| machine hours (tractor operator) | 2 | 1 | 1 |
| non-machine hours (hand-hoe and irrigate) | 18 | 18 | 0 |
| fuel (gal) | 25 | 9 | 16 |

Although CT reduced the number of operations by half, the cultural cost of tomato production was reduced by only about 10 per cent (table 5). This is because one-third of the costs are for harvest and another third are for seed, fertilizer, and water, and these two-thirds are identical between systems. Only one-third of total costs are for preplant tillage operations that are affected by the choice of tillage systems (fig. 8).

CT's reduction of 9 equipment passes over the field translated into a reduction of 16 gallons of fuel and 1 hour of tractor labor (table 6). The value of the savings from reducing labor and fuel increased as labor rates and fuel costs per gallon increased. For example, at a price of $1.12 per gallon of fuel in 2003, the fuel savings per acre were $18, but at a price of $2.32 in 2007 the savings were $37; at $3 per gallon the savings would be $48. The 1-hour decline in tractor labor saved $9 per acre in 2003 and $17 at 2007 wage and benefit rates.

Using the 2003 results and 2007 input costs, CT reduced fuel, lube, and repair costs by $55 per acre compared with ST. Herbicide costs were also lower in CT by $6 per acre because of the types and amounts of materials used. Machine labor costs in CT were reduced by $17 per acre (1 hour) due to the fewer number of trips across the field. However, hand-weeding and irrigation labor costs were the same under CT and ST. Finally, the interest on the operating loan was lower in CT due to its smaller operating budget. The total saving in cultural costs was $83 per acre (see table 5). CT also had lower noncash overhead costs (capital recovery costs) by $20 per acre because of the reduced amount of equipment used, the reduced tractor hours, and the commensurately lower taxes and insurance (see table 4). Therefore, if the yields for the two systems had been identical, the difference in profit would have been $106 per acre in favor of CT.

**Figure 9.** Transplanting fresh-market tomatoes in conservation tillage field, Sun Pacific Farms, Firebaugh, California, 2003. *Photo:* J. P. Mitchell.

**Figure 10.** Triticale cover crop planted on bed tops in conservation tillage field, Sano Farms, Firebaugh, California, 2005. *Photo:* J. P. Mitchell.

**Figure 11.** Strip-tilling centers of processing tomato beds in conservation tillage field, Sano Farms, Firebaugh, California, 2008. *Photo:* J. P. Mitchell.

However, in the 2003 trial, CT yielded 12 tons per acre more than ST. Using a crop value of $54.40 per ton, the gross return was higher by $756 per acre with CT. Custom harvest is charged on a per ton basis; therefore, the higher yield in 2003 for CT resulted in an additional harvest cost of $126 per acre. The increase in revenue per acre offset by the increase in harvest cost meant an increase in net returns over harvest cost of $630 per acre. Adding the savings in cultural costs and overhead costs ($106) to the increase in revenue adjusted for the increase in harvest cost ($630) gives a bottom line of an increase in profit of $736 per acre for CT.

The custom harvest cost per ton would perhaps be slightly higher in the CT cover crop system because the harvester must go slower to separate trash and soil clods from fruit in years when large amounts of cover crop biomass persist on the soil surface through the growing season.

## CONSERVATION TILLAGE PRODUCTION AT SAN JOAQUIN VALLEY TOMATO FARMS

Two commercial variations of the CT and cover crop systems described above were recently featured as part of the San Joaquin Valley Conservation Tillage 2005 conference farm tours. One was Sano Farms, a processing tomato and cotton farm, and the other was Sun Pacific's fresh-market tomato farm, both in Firebaugh, California (fig. 9). Both of these farms currently use winter cover crops and spring strip-till to mix cover crops and incorporate herbicide in the transplant line (figs. 10, 11, 12, and 13). In one CT tomato farm, subsurface drip irrigation was carefully managed to avoid wetting the soil surface and to control weeds. At the other, over-the-top herbicide was used. More details about these farms may be obtained at the CT Workgroup's Web site, http://groups.ucanr.org/ucct/index.cfm (see also Mitchell et al. In press).

**Figure 12.** Strip-tilled triticale cover crop beds, Sano Farms, Firebaugh, California, 2008. *Photo:* J. P. Mitchell.

**Figure 13.** Strip-tilled transplanted fresh market tomatoes in barley cover crops, Sun Pacific Farms, Firebaugh, California, 2003. *Photo:* J. P. Mitchell.

## FUTURE CONSERVATION TILLAGE TOMATO SYSTEMS

Reducing tillage in production systems may yield more long-term economic and resource conservation benefits than can be obtained from conventional systems. To develop sustained no-till rotations that include tomatoes, a number of changes must be made to optimize management of the overall production system. Current systems, including the approach we pursued in this study, rely primarily on surface, or gravity, irrigation systems that require clean furrows for efficient and uniform water application. If the irrigation water delivery system is changed to subsurface drip or low-pressure overhead delivery (fig. 14), production costs may be lowered more, surface residue may be left in place, soil disturbance may be avoided, and weeds should be better controlled with minimal tillage (fig. 15). These management systems, as well as other management alternatives, are now being evaluated by the UC Conservation Tillage Workgroup and the agricultural industry.

An additional modification of today's standard production systems that may further facilitate CT alternatives would be the use of controlled traffic harvest trailers that track only in permanent furrows and not on bed tops. By restricting heavy loads to the furrows, optimal crop growth zones might be preserved across the beds due to less compaction. Also, ideal cover crops should be developed for CT systems that are inexpensive, fast to establish so that weeds are suppressed, and easily destroyed mechanically or with herbicides as needed before transplanting.

**Figure 14.** Overhead low-pressure irrigation system used for no-till corn production field, Pierre, South Dakota, 2005. *Photo:* J. P. Mitchell.

**Figure 15.** Fresh-market tomato field with barley cover crop residue, Firebaugh, California, 2003. *Photo:* J. P. Mitchell.

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| foot (ft) | 0.3048 | 3.28 | meter (m) |
| acre (ac) | 0.4047 | 2.47 | hectare (ha) |
| pound (lb) | 0.454 | 2.205 | kilogram (kg) |
| ton (T) | 0.907 | 1.1 | metric ton (t) |
| pound per acre (lb/ac) | 1.12 | 0.89 | kilogram per hectare (kg/ha) |
| ton per acre (T/ac) | 2.24 | 0.446 | metric ton per hectare (t/ha) |

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