A Comparison of Three Cotton Tillage Systems: Six Year Summary

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Abstract

Two reduced cotton tillage systems, both of which utilize controlled traffic farming techniques, were compared to a conventional tillage system in terms of energy requirements, field work time requirements, crop yield, and operating costs. Six seasons of testing show the Sundance system to have the lowest energy requirement of 31.95 Hp-Hr/Ac, the Uprooter-Shredder-Mulcher the second lowest at 47.16 Hp-Hr/Ac, and conventional tillage the highest at 66.89 Hp-Hr/Ac. Field work times of the two reduced tillage systems were about 58% that of conventional tillage. Costs of the two reduced tillage systems are lower than for conventional tillage. We have never measured a significantly lower lint yield with either of the two reduced tillage systems, relative to conventional tillage.

Introduction

With a conventional tillage system, the farmer spends more than one-half of the annual fuel budget before the crop emerges (Cannon and Stapleton, 1977).

From 1965 to 1973, Cannon and Stapleton (1977) evaluated chisel-list systems for minimum tillage in cotton. These systems saved almost 75% of the fuel and labor costs of plowing down cotton and preparing a new seedbed. They never measured significantly lower cotton yields with these systems; however the main drawback was that chisel-listing resulted in a rough and trashy seedbed that was difficult to plant.

Newer reduced cotton tillage systems are now available which offer potential savings in energy, time, and costs. We conducted this study to measure the energy requirements, field work times, costs, and lint yields of two alternative and one conventional tillage system.

Both of the alternative tillage systems utilize controlled traffic farming techniques. They re-work the existing beds, while confining wheel traffic to certain furrows. The concept is to confine wheel traffic to "traffic lanes" while maintaining uncompacted "production zones" (Williford, 1980; Thacker and Coates, 1993).

Materials and Methods

We began this study with the plowdown of a 1987 cotton crop in Field D-1 of the University of Arizona's Marana Agricultural Center. The soil is a Pima clay loam. The conventional, Uprooter-Shredder-Mulcher (USM), and Sundance systems are replicated four times in a complete randomized plot design. Each plot is twelve 40-inch rows wide, and all data were taken from the center four rows of the plot. In the conventional plots, we had eight guard rows on each side of the plot to provide a turning area for cross-disking and cross-ripping operations.

We have five seasons of cotton crop data from the study. Throughout the study we have maintained a controlled traffic pattern in the Sundance and USM plots. In 1991 we rotated the field to wheat to alleviate the verticillium wilt problem, but even then we maintained the controlled traffic patterns in the Sundance and USM plots. We made no attempt to control wheel traffic patterns in the conventional plots.

We measured the input power of each implement by recording implement draft, tractor speed, and PTO torque and speed as required.

We measured field work times based on travel speeds and effective implement widths. The field work time data were taken with each implement running at full working speed, and the data presented in this report are not adjusted to account for field efficiencies (which would account for turning time and other factors).

We estimated the costs of the 1993-94 tillage operations based on the following facts and assumptions:

- All implements in this study are 4-row, except the USM.
- Field work times are based on the results of this study, adjusted for an assumed field efficiency factor.
- We assumed an 85% efficiency factor for all operations, to allocate 15% of the machinery operating time for turning at ends, adjusting, and other factors.
- Per hour machinery operating costs are from 1993 Arizona Farm Machinery Costs (Daugherty and Wade, 1993). We assumed that the equipment is depreciated straight line. We also assumed that tractors are used 1000 hours per year, that four-row implements are used 200 hours per year, and that two-row implements are used 400 hours per year.
- Labor cost, including FICA, insurance, and benefits was assumed to be $7.00 per hour.
- We assumed that during a ten hour work shift, the machinery would be actually operating in the field for nine hours.

We measured lint yields by machine picking the center two or four rows of each plot and dumping into a trailer on scales.

The sequence of tillage operations varied over the six years of the study, mainly due to weather conditions and with the particular implements that were available to us. At the beginning of the study, most of the equipment we were using was borrowed from various farmers. By the fourth year of the study we had a full complement of donated and purchased equipment. All implements in this study were four-row, except for the USM. The following presents the sequence of tillage operations performed in each treatment:

Conventional:

The sequences of tillage operations for the conventional system are presented in Tables 1, 5, and 9 and are further described as follows.

Shred: In the first three years, we used an International Harvester flail shredder. In the last three years, we used a John Deere rotary shredder.

1st Disk: This was a 13.5 foot wide disk pulled in the direction of the rows, immediately after shredding. The disk we used in the first three years was a Rhino; in the last three years we used a different, less aggressive disk.

Rip: We always ripped on a 45° diagonal to the direction of the rows, and alternated directions of ripping each year. The ripper had parabolic shanks on 40-inch spacings. We ripped 16 to 18-inches deep.

2nd Disk: This was a 13.5 foot wide disk, run on the opposite diagonal to the direction of the ripping operation.

3rd Disk: This operation was performed only in the last two years of the study, because the disk we were using at the time was not aggressive enough to destroy all of the cotton tap roots in two passes.

Incorporate Herbicide: We applied the pre-plant herbicide on the flat-disked soil, and incorporated it with a pass of the 13.5 foot wide disk. Direction of travel was the opposite diagonal to the previous disking operation.

List: In the first three years of the study, we used a five-bottom moldboard lister. In the last three years, we used a Lilliston disk hipper. The beds were then pre-irrigated.

Mulch: The pre-irrigated beds were mulched with a Sankeen mulcher. In the final year of the study we mulched the beds without pre-irrigating them (the field was to be laser leveled as soon as we completed the study).

Uprooter-Shredder-Mulcher (USM):

The main implement used in this system is the Uprooter-Shredder-Mulcher (USM). It was developed by S. Ben-Dor Automotive Industries Ltd. of Israel. It is a two-row machine which uses sweeps to cut the tap roots about 6-inches below the soil line, then counter-rotating wheels grip and uproot the stalks. The stalks are fed into a shear bar chopper, and then discharged down a chute behind an opener which passes along a furrow between the two cotton rows.

The sequences of operations are presented in Tables 2, 6, and 9 and are described as follows:

USM: Uproot, shred, and bury the stalks. We ran the "injector boot" at a 10 to 12-inch depth to bury the plant residue.

Rip-List: In the first three years of the study, we used an Orthman rip-lister. The ripper shanks were in the centers of each bed, at a 16 to 18-inch depth. The lister was the disk hipper type. In 1990-91 and 1991-92, we used the Sundance disk lister for this. In 1993-94, we returned to using a disk hipper (Lilliston) equipped with ripper shanks to achieve better rip shank penetration.

Bed Shape: We performed this operation in the first year only, and found it unnecessary in subsequent years.

Re-list: We only performed this operation in the 1990-91 year, because the first pass of the lister did not produce a high enough bed (when rip-listing beds, the beds will settle a considerable amount with the pre-irrigation). We performed this operation with a conventional lister without ripper shanks.

Cultivate: Unusually heavy rains in January 1992 caused problems with winter annual weeds, which we killed with a Lilliston rolling cultivator. In this study, we had a tendency to perform all of the tillage operations in a short period of time, because of transportation logistics and work schedules elsewhere. If we had spread the tillage operations out over time, we would not have had as much weed growth.

Mulch: The pre-irrigated beds were mulched with a Sankeen mulcher. We applied and incorporated the herbicide at this time by spraying the herbicide directly into the mulcher. We concentrated the spray pattern on the tops of the beds, where the mulcher knives mixed the chemical with the soil. Because the mulcher scatters the herbicide-treated soil across the entire row we applied the full per acre amount of herbicide, not a reduced amount for a band application. In the last year of the study we did not pre-irrigate the beds before mulching.

Sundance:

This system was developed by Sundance Farms of Coolidge, AZ for tilling cotton with subsurface trickle irrigation. The subsurface trickle irrigation laterals are left in place for several years, hence the beds and furrows must be maintained in the same place from season to season. This requires a tillage system which will meet Arizona's plowdown regulations without destroying the irrigation system. The unique implement used in this system is the uprooter, which uses two converging disk blades per row to grip and lift the tap roots out of the soil.

The sequences of operations are presented in Tables 3, 7, and 9 and are described as follows:

Shred: In the first three years, we used an International Harvester flail shredder. In the last three years, we used a John Deere rotary shredder.

Uproot: There are two ways to utilize the Sundance uprooter. One method is to adjust the implement so that it completely pulls the tap roots out of the soil. Another method is to adjust the implement so that it pulls the roots free from the soil and leaves them standing upright. In the first three years of the study, we pulled the roots and left them standing upright, and then re-shredded to reduce the size of the root residue which gets mixed back into the beds. In the last three years of the study we pulled the roots completely out of the soil with the Sundance uprooter and immediately followed with the Sundance disk lister. In 1990-91 weather conditions and the legal plowdown deadline forced us to perform the uprooting operation in the mud, and we did not collect speed or energy data.

2nd Shred: We performed this operation in the first three years of the study, when we left the roots pulled and standing upright. This second pass of the flail shredder cut the roots below the first node, ensuring that they could not re-grow.

Rip-List: In the first three years of the study, we used an Orthman rip lister. The ripper shanks were in the centers of each bed, at a 16 to 18-inch depth. The lister was the disk hipper type. In the last three years of the study we used a Sundance disk lister. On each row, the implement uses pairs of disk blades which split the beds in half, followed by a second pair of disk blades which re-hip the beds. The implement also has parabolic ripper shanks, which were set to run in the middles of the beds at about a 12-inch depth.

Bed Shape: We only performed this operation in the first year, and found it unnecessary in subsequent years.

Re-List: We performed this operation in 1990-91, because the first listing did not produce a high enough bed. We performed this operation with a conventional five-bottom lister without ripper shanks. In 1992-93, we had some initial difficulties in keeping the Sundance disk lister on the row, and had to re-list.

Cultivate: Unusually heavy rains in January 1992 caused problems with winter annual weeds, which we killed with a Lilliston rolling cultivator.

Mulch: The pre-irrigated beds were mulched with a Sankeen mulcher. As with the USM system, we applied the preplant herbicide at this time. In the last year of the study we did not pre-irrigate the beds before mulching.

Results and Discussion

Energy Requirements:

The mean energy requirements for the Conventional, USM, and Sundance systems are presented by operation and year in Tables 1, 2, and 3, respectively. Year-to-year variations in energy use were mostly due to using different implement configurations and due to operating the equipment at different depths or speeds. The most notable changes in energy use over the six years of the study were caused by changing the rip-list implements in the USM and Sundance systems halfway through the study. The Orthman rip-lister we used in the first three years ripped the beds at a 16 to 18-inch depth. None of the rip-listers we have used since the 1990-91 season ripped as deeply, and the energy requirement decreased for this operation.

The mean total energy requirements for each tillage system are presented in Table 4. The USM required significantly less energy than conventional tillage in all years of the study. The Sundance required significantly less energy than both the conventional and USM systems in all years. Over the six years, the USM system required 70% as much energy as conventional tillage and this difference was significant. The Sundance system required 48% of the energy used in conventional tillage, which was significantly less energy than both conventional and USM systems.

Field Work Times:

The mean field work time requirements for the Conventional, USM, and Sundance systems are presented by operation and year in Tables 5, 6, and 7, respectively. As with the energy data, most of the year-to-year variations were due to different implement configurations and operating implements at different depths or speeds. The most notable changes in work time requirements over the six years of the study were caused by the different rip-list implements used in the USM and Sundance systems. The rip-list implement we used in the first three years of the study ripped much deeper and required more work time than the rip-listers we have used since.

The mean total field work time requirements for each tillage system are presented in Table 8. Both of the alternative tillage systems required significantly less work time than the conventional system. In the first three years of the study, the USM system required significantly less work time than the Sundance system. In the last three years of the study, the Sundance system required significantly less field work time than the USM system. This reversal in rankings was due to the fact that in the first three years we were shredding the stalks twice in the Sundance system, and we did not do this in the second three years of the study.

Averaged over the six years of the study, both the USM and Sundance systems required 58% of the field work time requirement of the conventional system. The six year average time requirements for both the USM and Sundance systems were both significantly lower than for conventional tillage, and were not significantly different from each other.

It is important to note that these field work time data are not adjusted for a field efficiency factor (to allow for turning time and other factors). The field efficiency factors published in 1993 Arizona Farm Machinery Costs (Daugherty and Wade, 1993) range from 70 to 90% for tillage operations, and are typically in the 80 to 85% range.

Costs:

Based on the actual field work times from 1993-94 (adjusted for an assumed 85% field efficiency) and per hour cost data from 1993 Arizona Farm Machinery Costs (Daugherty and Wade, 1993), the per acre cost of the conventional tillage system totaled $64.33 (Table 9). The USM system cost $12.46 less per acre than conventional. The Sundance system cost $38.19 less per acre than conventional tillage.

Lint Yields:

Overall yields in the study were below the County average in most of the years due to problems unrelated to tillage; namely a devastating infestation of lygus and pink bollworm in 1990, a hailstorm destroyed 60% of the crop in 1992, and a heavy infestation of verticillium wilt in all of the years. Yields with the USM and Sundance systems were never significantly lower than with conventional tillage.

Conclusions

Both the USM and Sundance systems offer significant energy and field work time savings over conventional tillage. Costs of both systems are lower than with conventional tillage, and we never measured a significantly lower yield with either of the alternative tillage systems.

Acknowledgments

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Table 1. Energy requirements by year and operation for the conventional tillage system at the Marana Agricultural Center, 1987-94.

	Energy Requirement, Horsepower Hours per Acre								
	Shred	1st Disk	Rip	2nd Disk	3rd Disk	Inc. Herb	List	Mulch	Total
1987-88	2.56	9.13	27.91	8.26		7.43	5.19	7.82	68.30
1988-89	4.99	9.13	26.73	8.26		7.96	5.02	7.86	69.95
1989-90	8.39	10.05	23.86	8.80		9.63	7.22	7.11	75.05
1990-91	5.39	6.17	20.17	6.10		6.89	4.99	5.42	55.11
1992-93	9.91	6.60	20.48	5.44	5.33	6.53	3.13	9.01	66.42
1993-94	8.49	7.23	24.84	6.40	5.79	5.82	2.62	5.36	66.52

Table 2. Energy requirements by year and operation for the Uprooter-Shredder-Mulcher (USM) tillage system at the Marana Agricultural Center, 1987-94.

	Energy Requirement, Horsepower Hours per Acre						
	USM	Rip-List	Bedshape	Re-List	Cultivate	Mulch	Total
1987-88	30.10	11.76	3.52			11.88	57.26
1988-89	26.38	14.19				4.46	45.04
1989-90	24.34	12.83				6.28	43.44
1990-91	28.98	9.32		4.70		5.33	48.33
1992-93	25.73	6.82			2.40	9.02	43.97
1993-94	32.82	7.82				4.30	44.93

Table 3. Energy requirements by year and operation for the Sundance tillage system at the Marana Agricultural Center, 1987-94.

	Energy Requirement, Horsepower Hours per Acre								
	Shred	Uproot	2nd Shred	Rip-List	Bedshape	Re-list	Cultivate	Mulch	Total
1987-88	2.56	4.51	2.07	14.48	3.17			11.96	38.76
1988-89	4.69	5.12	2.19	17.24				4.79	34.02
1989-90	5.71	3.37	1.91	16.45				5.01	32.46
1990-91	4.53	*		8.38		5.55		4.36	22.81
1992-93	8.45	3.00		9.74		5.90	2.17	9.10	38.35
1993-94	9.94	3.16		8.00				4.18	25.28

*Due to weather conditions, this operation was performed in the mud and we did not collect energy or speed data.

Table 4. Mean tillage energy requirements of conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1987-94.

	Energy Requirement, Horsepower Hours per Acre						6-Year Average	
	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	Hp-Hr/Ac	% of Conv.
Conventional	68.30 a*	69.95 a*	75.05 a*	55.11 a*	66.42 a*	66.52 a*	66.89 a*	100
USM	57.26 b	45.04 b	43.44 b	48.33 b	43.97 b	44.93 b	47.16 b	71
Sundance	38.76 c	34.02 c	32.46 c	22.81**c	38.35 c	25.28 c	31.95 c	48
LSD 0.05	1.32	2.13	1.86	3.65	5.02	6.47	6.78	
OSL †	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
CV% §	1.4	2.5	2.1	5.0	5.9	8.2	9.9	

* Means followed by the same letter within a column are not significantly different at the 95% confidence level.
** Does not include the energy requirement of the uprooting operation, which was performed in the mud that year.
† OSL = Observed Significance Level.
§ CV = Coefficient of Variation.

Table 5. Field work time requirements by operation and year for the conventional tillage system at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency to allow for turning time at ends and other factors.

	Field Work Time, Hours per Acre								
	Shred	1st Disk	Rip	2nd Disk	3rd Disk	Inc. Herb	List	Mulch	Total
1987-88	0.14	0.12	0.42	0.21		0.22	0.12	0.25	1.47
1988-89	0.15	0.12	0.48	0.21		0.15	0.15	0.19	1.44
1989-90	0.23	0.11	0.65	0.19		0.15	0.13	0.20	1.65
1990-91	0.25	0.12	0.40	0.12		0.14	0.16	0.21	1.37
1992-93	0.19	0.12	0.43	0.13	0.14	0.13	0.13	0.19	1.45
1993-94	0.20	0.12	0.49	0.13	0.14	0.14	0.16	0.20	1.57

Table 6. Field work time requirements by operation and year for the Uprooter-Shredder-Mulcher (USM) tillage system at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency to allow for turning time at ends and other factors.

	Field Work Time, Hours per Acre						
	USM	Rip-List	Bedshape	Re-List	Cultivate	Mulch	Total
1987-88	0.33	0.31	0.21			0.24	1.08
1988-89	0.30	0.29				0.20	0.79
1989-90	0.27	0.26				0.19	0.72
1990-91	0.36	0.14		0.15		0.21	0.85
1992-93	0.47	0.18			0.15	0.19	0.97
1993-94	0.46	0.16				0.20	0.82

Table 7. Field work time requirements by operation and year for the Sundance tillage system at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency to allow for turning time at ends and other factors.

	Field Work Time, Hours per Acre								
	Shred	Uproot	2nd Shred	Rip-List	Bedshape	Re-list	Cultivate	Mulch	Total
1987-88	0.14	0.08	0.15	0.33	0.21			0.24	1.15
1988-89	0.16	0.08	0.15	0.31				0.20	0.89
1989-90	0.16	0.06	0.14	0.26				0.19	0.82
1990-91	0.27	*		0.14		0.15		0.21	0.77
1992-93	0.19	0.11		0.14		0.15	0.15	0.19	0.92
1993-94	0.20	0.11		0.14				0.20	0.65

* Due to weather conditions, this operation was performed in the mud and we did not collect energy or speed data.

Table 8. Mean field work time requirements to plow down cotton and prepare a seedbed for a subsequent cotton crop with conventional, Uprooter-Shredder-Mulcher (USM) and Sundance tillage systems at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency to allow for turning time at ends and other factors.

	Field Work Time, Hours per Acre						6-Year Averages	
	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	Hrs/Ac	% of Conv.
Conventional	1.47 a*	1.44 a*	1.65 a*	1.37 a*	1.45 a*	1.57 a*	1.49 a*	100
USM	1.08 c	0.79 c	0.72 c	0.85 b	0.97 b	0.82 b	0.87 b	58
Sundance	1.15 b	0.89 b	0.82 b	0.77** c	0.92 c	0.65 c	0.87 b	58
LSD 0.05	0.06	0.02	0.06	0.03	0.03	0.03	0.08	
OSL †	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
CV% §	2.9	1.0	3.1	1.8	1.4	1.9	10.0	

* Means followed by the same letter within a column are not significantly different at the 95% confidence level.
** Does not include the time requirement for the uprooting operation, which was performed in the mud that year.
† OSL = Observed Significance Level.
§ CV = Coefficient of Variation.

Table 9. Per acre operating costs of conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1993-94.

CONVENTIONAL		USM		SUNDANCE	
Operation	Dollars per Acre	Operation	Dollars per Acre	Operation	Dollars per Acre
Shred Stalks	7.02	USM	36.96	Shred	7.02
Disk	5.55	Rip-List	6.85	Uproot	3.77
Rip	18.27	Mulch	8.07	Rip-List	7.27
Disk	6.02			Mulch	8.07
Disk	6.48				
Inc. Herb.	6.48				
List	6.44				
Mulch	8.07				
Total	64.33	Total	51.87	Total	26.14
Savings Over Conventional			12.46		38.19

Table 10. Lint yields with Conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1988 - 1993.

	Lint Yield, Pounds per Acre					
	1988	1989	1990	1992	1993	5-Year Average
Conventional	778 a*	929 a*	325 b*	601 a*	1108 a*	749 a*
USM	730 a	1030 a	367 ab	597 a	1059 a	757 a
Sundance	888 a	969 a	433 a	623 a	1054 a	794 a
LSD 0.05	N.S.	N.S.	82	N.S.	N.S.	N.S.
OSL †	0.069	0.543	0.049	0.722	0.238	0.165
CV% §	9.7	12.6	12.6	7.9	4.1	10.2

* Means followed by the same letter within a column are not significantly different at the 95% confidence level.
† OSL = Observed Significance Level.
§ CV = Coefficient of Variation.