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Conversion of Conservation Reserve Program (CRP) Grassland for Dryland Crops in a Semiarid Region

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ABSTRACT

Information was needed regarding practices suitable for returning grassland to cropland when Conservation Reserve Program (CRP) contracts expired. A study on Pullman soil (Torrertic Paleustoll) involved seven tillage treatments (no-tillage and reduced, sweep, disk, moldboard plus disk, burn–sweep, and burn–disk tillage) with vegetation retained and the five non-burn tillage treatments with vegetation removed before treatment. Fertilizer (NH_4NO_3) was applied at 0, 34, and 67 kg N ha^{-1} in 1995 and at 0, 67, and 134 kg N ha^{-1} in 1996 and 1997. Initial soil water contents were low, and soil never was filled with water at planting time. Sorghum [*Sorghum bicolor* (L.) Moench] yielded ≤720 kg ha^{-1} in 1995, and the 1995–1996 wheat (*Triticum aestivum* L.) crop failed. Sorghum was not planted in 1996 because of a drought. Sorghum yielded 2260 to 4700 kg ha^{-1} in 1997. Wheat yielded 1410 to 1980 kg ha^{-1} in 1996–1997. Vegetation retention or removal affected yields slightly. Fertilization affected sorghum yields slightly and increased wheat yields. Vegetation control was difficult with no-tillage. Disk tillage to dislodge grass, followed by reduced- or no-tillage, appears best for converting CRP grassland to cropland in this semiarid region. Because of low initial soil water contents, a 90-d period is inadequate for obtaining adequate soil water storage unless precipitation is much above normal. Forgoing planting a crop soon after killing the vegetation when precipitation is low would provide more time for storing soil water and increase the potential for obtaining favorable yields.

One objective for the Conservation Reserve Program (CRP), established as part of the Food Security Act of 1985, was to reduce erosion by taking highly erodible land out of crop production. In Texas, most CRP land is in the semiarid western part where annual precipitation ranges from about 380 to 500 mm. Many producers used bunch-type grasses to control erosion on their land. The CRP contracts were to begin expiring in 1996, with one option for producers being to kill the vegetation and convert the land back to crop production.

Laryea and Unger (1995) converted native grassland to cropland without major problems at Bushland, which is in the semiarid part of Texas. Information regarding conversion of bunch-type grasslands to croplands, however, was not available. Questions needing answers were:

1. Should the CRP vegetation be removed?
2. If removed, should the vegetation be physically removed or burned in place?
3. Can the vegetation be managed in place (as with no-tillage), or should it be incorporated into soil by tillage?

Other questions pertained to the amount of fertilizer needed and the time needed after killing the vegetation to store enough soil water so that good crop yields could be expected.

The study by Laryea and Unger (1995) was on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). This soil is slowly permeable, and precipitation storage as soil water during noncropped periods generally is low (10–35%) under dryland conditions when surface residue amounts are <4.0 Mg ha^{-1} (Jones and Popham, 1997; Unger, 1978, 1994). With more residues, as with an applied mulch or no-tillage after irrigated winter wheat, water storage efficiencies during fallow were 35 to 50% in some cases (Musick et al., 1977; Unger, 1978; Unger and Wiese, 1979).

The low water storage efficiency for Pullman soil is attributable in part to its slow permeability, with precipitation received during a given storm being involved also. For example, precipitation may occur at ≈100 mm h^{-1} for up to 10 min, but for 1522 storms from 1960 through 1979, only 11 resulted in >50 mm and only 73 resulted in >25 mm of precipitation (unpublished data, Conservation and Production Research Laboratory, Bushland, TX). The many small storms lead to high evaporative losses of water in the semiarid region.

According to program regulations (information provided by USDA-Farm Service Agency personnel, Amarillo, TX), producers whose contracts expire on 30 September can begin land preparation on 1 July for a fall-seeded crop (about 90 d before the contract ends). However, because of low storage efficiencies and limited precipitation, 90 d probably would not be enough time to achieve adequate soil water storage for a good crop. Objectives for this study were to determine the effects of some tillage and vegetation management treatments used for converting CRP grassland for dryland grain sorghum and winter wheat production on soil water content and on crop establishment and yield.

MATERIALS AND METHODS

The study was conducted on a producer's field about 7 km west of the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX (35°11′ N, 102°5′ W; 1180 m above mean sea level). Average annual precipitation at Bushland is 475 mm (1939–1996). The study site was on Pullman clay loam with <0.5% surface slope. Pullman soil contains about 170 g kg^{-1} sand, 530 g kg^{-1} silt, and 300 g kg^{-1} clay at the 0- to 0.15-m depth (Unger and Pringle, 1981). Under terms of the CRP contract, the producer established plains bluestem grass [*Bothriochloa ischaemum* (L.) Keng] in 1986 on 172 ha previously used for dryland winter wheat and grain sorghum production.

Treatments to convert the grassland to cropland were imposed in October 1994 (Area 1), March 1995 (Area 2), Septem-

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Abbreviations: CRP, Conservation Reserve Program.

ber 1995 (Area 3), and June 1996 (Area 4). Each area consisted of two blocks: one with CRP vegetation retained and one with it mowed (5-cm height), baled, and removed before imposing treatments (Fig. 1). The amount removed (air dry) was ≈8 Mg ha^{-1} from Area 1 plots. Similar amounts were removed from other plots. Because of the 5-cm mowing height, not all vegetation was removed. Therefore, somewhat >8 Mg ha^{-1} of dry matter remained on plots where vegetation was retained.

Treatments on blocks where vegetation remained were no-tillage; reduced tillage (sweep tillage once, then herbicides); sweep tillage; disk tillage; vegetation burned, then disk tillage (burn–disk); vegetation burned, then sweep tillage (burn–sweep); and moldboard plow, then disk tillage (moldboard–disk). The same treatments, excepting those with vegetation burned, were used on blocks where vegetation was removed. Treatments were replicated three times on each block.

The first tillage was about 0.15 m deep in all cases. Later, the same tillage methods were used for additional vegetation control for the first crop and for subsequent crops, except that moldboard plowing was not repeated. Burning also was not repeated for subsequent crops.

Tillage plots were 14 m wide and 45 m long, which permitted using commercially available implements for performing field operations. Implements used were an offset disk (Model 1870, Crust Buster, Dodge City, KS), a sweep plow (Richardson Model AE-4-15-1, Sunflower Manufacturing Co., Beloit, KS), and a moldboard plow (Massey–Ferguson Model 55, AGCO, Norcross, GA).[1] Grain sorghum was planted with a six-row John Deere (Deere & Co., Moline, IL) Max-Emerge planter (Model 7300); wheat was planted with a John Deere drill (Model 750).

All tillage treatments, except those involving burning, were imposed before any vegetation was burned. Vegetation at end and side borders and in alleys between replications also was removed to reduce the potential for problems with burning the vegetation. Burning was done under approved conditions (including wind speed and wind direction), with fire department and other personnel on hand to help control the fire.

The vegetation was dormant when tillage and burn treatments were imposed on Areas 1 and 2. Hence, herbicides were not applied to no-tillage plots until vegetation began growth in spring (May 1995). On Areas 3 and 4, no-tillage plots were treated with herbicides when other treatments were imposed. All vegetation control on no-tillage and reduced tillage (after initial sweep tillage) plots was with herbicides. Herbicides were also applied to tillage treatment plots for growing-season weed control and to borders and alleys for control of field bindweed (*Convolvulus arvensis* L.). A summary of herbicide applications is given in Table 1 and chemical names are given in Table 2.

Soil NO_3^- contents were determined when treatments were imposed on Area 1 and Area 2 plots, with the information serving as a guide regarding the amount of N fertilizer to apply. The determinations were made using an automated spectrophotometric method (Maynard and Kalra, 1993) on core samples obtained at 0- to 7.5-, 7.5- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm depths. Because the NO_3^- content was low, it was assumed to be low also on the other areas, but this was not confirmed directly. Dryland crops in the region do not respond to other fertilizer nutrients (P and K).

Soil water contents were determined gravimetrically (later converted to a volumetric basis) from core samples taken by 0.30-m increments to a 1.8-m depth when treatments were imposed and at planting and harvest of each crop. Plant-available water contents were based on all soil water above the 1.5 MPa value. Precipitation (Table 3) was measured with a standard gauge at the study site.

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-ARS.

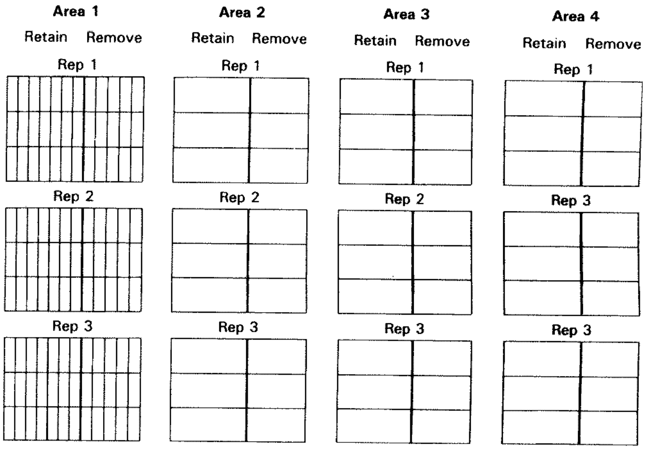

Fig. 1. Arrangement of field areas used for CRP study near Bushland, TX, 1994 to 1997. For each replication within each area, seven tillage treatments were randomly applied where CRP vegetation was retained (left side; shown as 'Retain') and five where it was removed (right side; shown as 'Remove'). Fertilizer treatments were randomly applied within each replication as strips across all tillage treatments within each area. North is to the left. Figure is not drawn to scale.

Planned initial crops were grain sorghum on Area 1 (planted in 1995), wheat on Area 2 (planted in 1995), grain sorghum on Area 3 (delayed until 1997 because of drought), and wheat on Area 4 (planted in 1996). On Areas 1 and 2, winter wheat and grain sorghum were grown in a rotation that involves 300 to 330 d of fallow between crops and results in two crops in 3 years. For the study, two crops were grown on Areas 1 and 2, and one on Areas 3 and 4. Sorghum was planned as a third crop on Area 1 and as a second crop on Area 4 in 1998, but was not planted because of a drought.

Before planting sorghum and wheat in 1995, 15-m-long subplots were established as strips across the tillage plots to which NH_4NO_3 fertilizer was applied at 34 or 68 kg N ha^{-1}. A check strip was not fertilized. Before subsequent plantings, N was applied at 68 or 134 kg ha^{-1}, with a check strip not fertilized.

Sorghum hybrid 'DK-46' was planted on 13 June 1995 (Area 1) and 3 June 1997 (Areas 2 and 3), at a 0.75-m row spacing. The target population was 86 000 plant ha^{-1}. As already noted, sorghum was not planted in 1996 because of a drought. Sorghum grain yields were determined from head samples harvested by hand from plants on two 1.5- by 3.0-m areas in each fertilizer treatment subplot. Samples were oven-dried at 60°C, then threshed. After removing the head samples, plants from the same areas were cut at 1 to 2 cm above the soil surface to determine stover production. Subsamples were oven-dried at 60°C. Grain and stover yields are reported on an oven-dry-weight basis.

'TAM 107' winter wheat was planted at 45 kg ha^{-1} on 12 Oct. 1995 (Area 2) and 24 Sept. 1996 (Areas 1 and 4) at a drill row spacing of 0.25 m. To determine yields, plants from two 1-m^2 areas in each subplot were cut by hand at 1 to 2 cm above the soil surface. After air drying, total sample weights were determined and grain was threshed from the plants. Grain and straw yields are reported on an air-dry-weight basis.

Data for crops, years, and blocks (vegetation retained or removed) were analyzed separately. For each area, blocks had a randomized split-block design (LeClerg et al., 1962, p. 184–214), with tillage treatments randomly assigned to each

Table 1. Herbicides used for vegetation control on CRP grassland converted to cropland, Bushland, TX, 1994 to 1997.

Date	Plots treated	Herbicide†	Rate
			kg ha^{-1}
Area 1			
15 May 1995	no-tillage	glyphosate + 2,4–D mix	7.6
9 June 1995	no-tillage and reduced tillage	glyphosate	1.7
14 June 1995	all tillage	glyphosate + 2,4–D mix	5.9
24 July 1995	all	dicamba	0.56
2 July 1996	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.8
12 Aug. 1996	no-tillage and reduced tillage	glyphosate	1.7
14 July 1997	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.9
19 Aug. 1997	no-tillage and reduced tillage	atrazine; 2,4–D	3.4; 1.1
1 Oct. 1997	all	2,4–D	0.84
12 May 1997	all	glyphosate + 2,4–D mix	3.9
Area 2			
15 May 1995	no-tillage	glyphosate + 2,4–D mix	7.6
9 June 1995	no-tillage and reduced tillage	glyphosate	1.7
11 Aug. 1995	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.9
13 Sept. 1995	no-tillage and reduced tillage	glyphosate	1.7
11 Oct. 1995	no-tillage and reduced tillage	glyphosate	2.2
3 July 1996	no-tillage and reduced tillage	glyphosate + 2,4–D mix	1.7
17 July 1995	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.9
17 July 1995	all other	2,4-D	1.7
12 Aug. 1996	no-tillage and reduced tillage	glyphosate	1.7
13 May 1997	all	glyphosate + 2,4–D mix	3.8
3 June 1997	all	propazine	1.7
14 July 1997	all	2,4–D	0.84
Area 3			
12 Sept. 1995	no-tillage	glyphosate	1.7
13 Sept. 1995	burn–disk and burn–sweep	paraquat	1.7
23 May 1996	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.9
14 June 1996	no-tillage and reduced tillage	glyphosate	2.2
3 July 1996	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.8
12 Aug. 1996	no-tillage and reduced tillage	glyphosate	1.7
13 May 1997	all	glyphosate + 2,4–D mix	3.8
3 June 1997	no-tillage and reduced tillage	glyphosate	1.7
	all	propazine	1.7
14 July 1997	all	2,4–D	0.84
Area 4			
14 June 1996	no-tillage	glyphosate	2.2
3 July 1996	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.8
12 Aug. 1996	no-tillage and reduced tillage	glyphosate	1.7
14 July 1997	no-tillage and reduced tillage	glyphosate + 2,4–D mix	3.9
19 Aug. 1997	no-tillage and reduced tillage	atrazine; 2,4–D	3.4; 1.1
1 Oct. 1997	all	2,4–D	0.84
12 May 1998	all	glyphosate + 2,4–D mix	3.9

† See Table 2 for chemical names. Mention of a pesticide does not constitute a recommendation for use nor does it imply registration under FIFRA as amended.

block and fertilizer treatments randomly imposed in strips across all tillage treatment plots. Data were analyzed by the analysis of variance technique. When different at the $P = 0.05$ probability level, means were separated by Duncan's multiple range Test (LeClerg et al., 1962, p. 144–146).

RESULTS

Precipitation

Precipitation was at or below the long-term average at Bushland in 28 of the 37 months of the study (Oct. 1994–Oct. 1997) (Table 3). Amounts for approximately 10-d periods are given to help illustrate precipitation distribution effects on soil water contents and on crop establishment and yield. Precipitation at the study site was not expected to be the same as at Bushland, because most precipitation (especially during spring, summer, and fall) occurs during localized thunderstorms.

Vegetation Control

The surface soil was dry in most cases when treatments were imposed on a given area (data not shown). As a result, moldboard plowing was difficult and resulted in an extremely rough soil surface. Subsequent disking (part of the treatment) reduced the roughness. Because of the dry soil and type of vegetation (bunch-type grass), all sweep tillage plots were disked once to dislodge the vegetation and loosen the soil before performing subsequent operations with a sweep implement. Disk tillage incorporated some vegetation, but subsequent sweep tillage resulted in most being returned to the soil surface.

The CRP vegetation usually was at various stages of water stress when herbicides were applied. As a result,

Table 2. Chemical names of herbicides used for vegetation control on CRP grassland converted to cropland, Bushland, TX, 1995–1998.

Herbicide	Chemical name
2,4–D	(2,4-dichlorophenoxy)acetic acid
atrazine	6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine
dicamba	3,6-dichloro-2-methoxybenzoic acid
glyphosate	*N*-(phosphonomethyl)glycine
paraquat	1,1′-dimethyl-4,4′-bipyridinium ion
propazine	6-chloro-*N*,*N*′-bis(1-methylethyl)-1,3,5-triazine-2,4-diamine

Table 3. Precipitation at the CRP study site near Bushland, TX.

Year	Month	Precipitation: Days of month 1–10	11–20	21–end	Monthly total	59-yr avg.†
		mm				
1994	Oct.	42	3	0	45	39
	Nov.	4	2	0	6	19
	Dec.	3	0	4	7	15
1995	Jan.	18	0	4	22	13
	Feb.	0	0	0	0	13
	Mar.	0	3	5	8	20
	Apr.	4	0	3	7	28
	May	51	3	56	110	68
	June	49	0	14	63	75
	July	51	27	0	78	68
	Aug.	9	50	7	66	72
	Sept.	0	41	17	58	49
	Oct.	18	0	0	18	39
	Nov.	0	1	0	1	19
	Dec.	0	18	0	18	15
1996	Jan.	0	1	0	1	13
	Feb.	6	0	0	6	13
	Mar.	0	1	1	2	20
	Apr.	0	0	0	0	28
	May	0	0	18	18	68
	June	11	8	12	31	75
	July	6	88	56	150	68
	Aug.	33	0	0	33	72
	Sept.	0	21	5	26	49
	Oct.	0	0	11	11	39
	Nov.	3	8	8	19	19
	Dec.	2	0	2	4	15
1997	Jan.	5	2	0	7	13
	Feb.	2	4	2	8	13
	Mar.	0	0	0	0	20
	Apr.	27	8	81	116	28
	May	9	7	22	38	68
	June	23	0	54	77	75
	July	35	0	0	35	68
	Aug.	67	38	0	105	72
	Sept.	0	0	31	31	49
	Oct.	15	2	2	19	39
	Nov.	4	13	0	17	19
	Dec.	8	0	44	52	15

† Long-term data recorded at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX, 1939 to 1997 inclusive.

vegetation control on no-tillage plots was limited, even though large amounts of herbicides were applied (Table 1). Also, bindweed control required application of additional herbicides to all plots.

Soil Water Content

Plant-available soil water contents when treatments were imposed and at crop planting and harvest are given in Table 4. Fertilizer treatments had no effect on water contents (data not shown).

Pullman soil has a plant-available water storage capacity of 230 mm to a 1.8-m depth. In no case was it filled to capacity during the study period. Initial water contents were low for all areas, even though treatments were imposed at different times of the year (Area 1, October; Area 2, March; Area 3, September; Area 4, June).

Producers could begin land preparation without penalty on 1 July of the year the contract was to end (30 Sept.) if they planned to convert the land to crop production. For wheat, this would provide only about 90 d until planting. In this study, time between imposing treatments and planting the first crop was 235 d on Area 1, 233 d on Area 2, 645 d on Area 3 (sorghum not planted in 1996 due to drought), and 113 d on Area 4. In all cases, except on Area 4, the period greatly exceeded 90 d, but the soil was not filled to capacity with any treatment (Table 4).

Initial soil water contents were similar, whether vegetation was removed or retained. There were no consistent differences for given treatments at subsequent determinations.

Crop Establishment

Planters for sorghum were equipped with double disk openers preceded by a straight coulter. Use of these units resulted in satisfactory sorghum establishment where the soil was loosened by tillage, even though seeding was perceived to be somewhat more difficult on tilled plots where vegetation was retained. Populations tended to be greater where vegetation was removed than where it was retained (data not shown).

Openers on planting units cut through the vegetation on no-tillage plots, even where vegetation was retained. Also, seed placement was satisfactory, but seedling emergence sometimes was poor because the seeding slot in the firm soil was not satisfactorily closed. As a result, plant populations were lower in no-tillage than in tillage plots in some cases (data not shown).

Wheat planting was achieved without difficulty in tilled plots. In no-tillage plots, planting generally was more difficult where vegetation was retained, thus resulting in poorer seedling establishment than in tilled plots or no-tillage plots with vegetation removed (data not shown).

Crop Yield

Grain Sorghum

Grain yields (Table 5) in 1995 were numerically lowest with no-tillage, but not significantly different from yields with some other treatments, both with vegetation removed and retained. Yields with other treatments did not differ in most cases.

Grain yields for sorghum as a second crop on Area 2 were greater with no-tillage than with other treatments for which yields were similar. At planting of the second crop, vegetation had been controlled and crop establishment no longer was a problem. On Area 3 plots, yields were similar with all treatments, whether vegetation was removed or retained (Table 5).

Although initial soil N contents were low, N fertilizer application had little effect on sorghum grain yields (Table 5). On Area 1 with vegetation removed, mean yield was greatest without fertilizer and least with 67 kg ha^{-1} of applied N. Mean grain yield on Area 2 plots with vegetation retained was least without fertilizer and greatest with 134 kg ha^{-1} applied N.

Sorghum stover yield on Area 1 plots was not affected by tillage treatments (Table 5). On Areas 2 and 3, stover yields generally were greater with no-tillage than with other treatments. Fertilizer treatments affected stover

Table 4. Plant-available soil water contents to a 1.8-m depth on CRP land converted to cropland near Bushland, TX, as affected by tillage method and vegetation management.

		Soil water content											
		Vegetation retained							Vegetation removed (mowed and baled)				
Condition	Date	NT†	RT	ST	DT	MB–DT	B–ST	B–DT	NT	RT	ST	DT	MB–DT
		mm											
		Area 1											
Initial	27 Oct. 1994	−9a‡	−1a	−3a	−13a	−11a	−6a	−7a	−16a	−13a	−13a	−20a	−12a
Plant sorghum	19 June 1995	82a	72a	63a	51a	72a	55a	63a	58a	51a	56a	73a	52a
Harvest sorghum	3 Nov. 1995	44a	41a	28a	29a	32a	21a	26a	16a	24a	15a	21a	26a
Plant wheat	1 Oct. 1996	79a	62a	74a	61a	94a	32a	89a	96a	65a	50a	74a	71a
Harvest wheat	9 July 1997	46a	41a	68a	53a	60a	31a	67a	56a	49a	49a	52a	63a
		Area 2											
Initial	27 Feb. 1995	−5a	−13a	−7a	−6a	4a	−10a	−7a	−6a	0a	−5a	−9a	−4a
Plant wheat	17 Oct. 1995	86a	89a	80a	67a	83a	52a	67a	84a	92a	78a	76a	78a
Harvest wheat	26 June 1996	−8a	−17a	−18a	−26a	−21a	−22a	2a	−9a	−15a	−26a	−17a	−21a
Plant sorghum	17 June 1997	178a	122b	111b	110b	110b	112b	117b	172a	132b	118bc	93c	119bc
Harvest sorghum	14 Nov. 1997	44a	41a	28a	29a	32a	21a	26a	16a	24a	15a	21a	26a
		Area 3											
Initial	13 Sept. 1995	−6a	−7a	−6a	−5a	−5a	−7a	−6a	−4a	−5a	−4a	−4a	−5a
Plant sorghum	19 June 1997	195a	128bc	125bc	142b	127bc	106c	105c	129a	108a	119a	104a	115a
Harvest sorghum	21 Nov. 1997	80a	33c	39bc	54b	22c	12c	23c	39a	32a	33a	19a	30a
		Area 4											
Initial	12 June 1996	−14a	−10a	−19a	−9a	−3a	−9a	−8a	−18a	−9a	4a	−19a	13a
Plant wheat	3 Oct. 1996	133a	77b	68b	74b	76b	126a	102ab	76a	66a	69a	66a	30b
Harvest wheat	11 July 1997	51a	12d	8d	13d	16cd	36ab	31bc	41a	16a	11a	14a	15a

† NT, no-tillage; RT, reduced tillage; ST, sweep tillage; DT, disk tillage; MB–DT, moldboard plow + disk tillage; B–ST, burn + sweep tillage; B–DT, burn + disk tillage.
‡ Within rows, means for a given vegetation management (retained or removed) followed by the same letter or letters are not significantly different at the $P = 0.05$ level, based on Duncan's multiple range test.

yields only in 1995 (Table 5). With vegetation retained or removed, stover yields were greater with 67 kg ha^{-1} applied N than with no applied N.

Wheat

The 1995–1996 wheat crop on Area 2 failed (mean grain yields <200 kg ha^{-1}; data not shown). Although some soil water contents at planting of the 1996–1997 crop on Area 4 (first crop on the area) were similar to those on Area 2 for the 1995–1996 crop, grain and straw yields were greater than for the 1995–1996 crop (Table 6).

Wheat grain yields on Area 1 (second crop) were similar for treatments with vegetation retained or removed, and similar to yields for the first wheat crop on Area 4. The largest difference was 350 kg ha^{-1} with no-tillage in favor of the crop (second) on Area 1.

Wheat responded strongly to N fertilizer application, with grain yields being greatest with 134 kg ha^{-1} of applied N (Table 6). Wheat straw yields were not affected by tillage treatments, but were influenced strongly by N fertilizer application (Table 6). Harvest index (HI), calculated as grain yield divided by grain plus straw yield, declined with increased rates of N application, with mean values being similar for wheat as a first crop (Area 4) or second crop (Area 1). With vegetation retained, the average HI was 0.38 with no applied N, 0.35 with 67 kg ha^{-1} applied N, and 0.34 with 134 kg ha^{-1} applied N. Similar declines occurred with vegetation removed. On these plots, averages were 0.37 with no applied N, 0.33 with 67 kg ha^{-1} applied N, and 0.33 with 134 kg ha^{-1} applied N.

DISCUSSION

The study was conducted at a location in the semiarid southern Great Plains during a period when precipitation in most months was below the long-term average (Table 3). Low precipitation coupled with low initial soil water contents resulted in low soil water contents at planting time (Table 4). Because dryland sorghum and wheat yields are highly dependent on the stored soil water content at planting (Johnson, 1965; Jones and Hauser, 1975; Jones and Popham, 1997; Unger and Wiese, 1979), the prevailing conditions resulted in low yields in some cases. Yields for the 1995 sorghum crop were limited by the low soil water contents at planting and severe plant water stress during the heading and grain-filling periods. A period of much below average precipitation from October 1995 through June 1996 resulted in failure of the 1995–1996 wheat crop and prevented sorghum establishment in 1996. Similar problems resulted in low crop yields on CRP land converted to cropland for the same period in western Oklahoma (Dao et al., 1996; Stiegler et al., 1996).

Sorghum and wheat yields were greater in 1997, when precipitation amount and distribution were more favorable than in 1995 and 1996. Contributing to the greater yields in 1997 were greater soil water contents at planting time. Greater water contents on Area 3 resulted from the longer time since imposing the treatments (sorghum was not planted as planned in 1996). Sorghum was the second crop on Area 2, and it followed wheat after about 300 d of fallow. These longer times are important for achieving adequate water storage in slowly permeable soils such as the Pullman clay loam,

Table 5. Sorghum yields on CRP land converted to cropland as affected by tillage method, vegetation management, and fertilizer N application rate near Bushland, TX, 1995 and 1997.

	Sorghum yield														
	Vegetation retained								Vegetation removed (mowed and baled)						
N rate	NT†	RT	ST	DT	MB–DT	B–ST	B–DT	Mean	NT	RT	ST	DT	MB–DT	Mean
kg ha⁻¹	kg ha⁻¹														
							Grain, 1995, Area 1								
0	80	680	190	230	350	540	210	320a‡	40	480	430	260	340	310a‡
34	110	620	310	540	520	530	295	420a	0	390	270	300	230	240ab
67	260	720	650	250	490	420	220	430a	10	160	500	50	30	150b
Mean	150b‡	670a	380ab	340ab	450ab	500ab	240b		20b	340ab	400a	200ab	200ab	
							Grain, 1997, Area 2								
0	4410	3220	2730	2350	2460	3030	2650	2980b	3930	3610	3240	2190	3250	3240a
67	4630	3450	3070	3160	2560	2670	2730	3180ab	4470	3500	2940	2110	3670	3340a
134	5070	3340	3750	3190	3320	2710	2350	3390a	3940	3030	3300	2490	3090	3170a
Mean	4700a	3340b	3180b	2900b	2780b	2800b	2580b		4110a	3380b	3160b	2260b	3340b	
							Grain, 1997, Area 3								
0	3930	3150	3410	3210	3580	2820	3420	3360a	3620	3760	3330	3260	2790	3350a
67	4680	3400	4100	3360	3500	3490	3750	3750a	3530	3600	3190	3150	3530	3400a
134	5260	3880	4270	3500	3220	3010	3430	3790a	3680	3950	2600	2390	2610	3050a
Mean	4620a	3480a	3930a	3360a	3430a	3110a	3530a		3610a	3770a	3040a	2930a	2980a	
							Stover, 1995, Area 1								
0	800	1200	700	1300	1100	1400	1700	1200b	700	1500	1200	1600	1700	1400b
34	1000	1000	1000	1500	1200	1600	1600	1300b	600	1400	1600	2100	1900	1500ab
67	1200	1800	2100	1800	2100	1900	2100	1800a	1200	1900	1900	1900	1600	1700a
Mean	1000a	1300a	1300a	1500a	1500a	1600a	1800a		800a	1600a	1600a	1900a	1700a	
							Stover, 1997, Area 2								
0	4000	2900	2800	2800	2600	3000	2800	3000a	4100	3000	3500	2900	3300	3400a
67	4300	3200	2800	2800	3100	3500	2500	3200a	3800	2900	3100	2500	3200	3100a
134	4200	2900	3100	2900	3400	3000	2900	3200a	3500	2600	3100	2500	3400	3000a
Mean	4200a	3000b	2900b	2800b	3000b	3200b	2700b		3800a	2800b	3200ab	2600b	3300ab	
							Stover, 1997, Area 3								
0	3900	3100	3400	3200	3600	2800	3400	3600a	3600	2900	3100	2800	2600	3000a
67	4700	3400	4100	3400	3500	3500	3700	3600a	3600	3100	3000	2800	3300	3200a
134	5300	3900	4300	3500	3200	3000	3400	3700a	4100	3200	2700	2700	2800	3100a
Mean	4600a	3500b	3900b	3400b	3400b	3100b	3500b		3800a	3100b	2900b	2800b	2900b	

† NT, no-tillage; RT, reduced tillage; ST, sweep tillage; DT, disk tillage; MB–DT, moldboard plow + disk tillage; B–ST, burn + sweep tillage; B–DT, burn + disk tillage.

‡ Within a given area, year, or yield factor, row or column means for a given vegetation management (retained or removed) followed by the same letter or letters are not significantly different at the $P = 0.05$ level, based on Duncan's multiple range test.

especially when precipitation is limited. However, even with the longer periods, the soil was not filled to capacity with any treatment during the study.

For the southern Great Plains, water storage efficiencies for between-crop periods are highly variable, but mean efficiencies generally are low (Jones and Popham, 1997; Unger, 1984). For example, mean storage efficiencies for winter wheat and grain sorghum cropping systems generally ranged from 15 to 30% with sweep and disk tillage when surface residues were limited or incorporated by tillage. With no-tillage, more residues are retained on the surface, and 35 to 50% storage efficiencies have occurred (Musick et al., 1977; Unger, 1984; Unger and Wiese, 1979). However, when annual precipitation averages 470 mm (as at Bushland), even with 50% storage as soil water about 1 year would be needed to fill the Pullman soil profile with water. With lower efficiencies or less precipitation, more time would be needed. This was the case, because the soil was not filled to capacity with any treatment. Total precipitation was 449 mm in 1995, 301 mm in 1996, and 505 mm in 1997.

Soil water contents due to tillage treatments generally did not differ, except that they were or tended to be greater with no-tillage at sorghum planting in 1997 and at wheat planting in 1996. Greater soil water storage and crop yields are common with no-tillage on the Pullman soil when residues are retained on the soil surface (Jones and Popham, 1997; Unger, 1984; Unger and Wiese, 1979).

Vegetation removal or retention before imposing treatments had little effect on soil water contents, apparently because most vegetation was incorporated with soil by tillage, except with the no- and reduced-tillage treatments. For these treatments, soil water contents in some cases were greater where vegetation was retained than where it was removed. Increased water storage under no- or reduced-tillage conditions occurred in other dryland studies in the Great Plains (Greb et al., 1967, 1970; Unger, 1978).

With vegetation retained, crop establishment was difficult with no-tillage, even though the planter used provided for satisfactory seed placement. Poor crop establishment resulted from limited slot closure and lack of timely rain after planting.

Planting was more successful on no-tillage plots with vegetation removed, but yields were still low, because of low soil water contents at planting and little rain during heading and grain-filling periods. Poor vegetation control due to plant water stress when herbicides were applied undoubtedly contributed to the low yields with the no-tillage treatment. Stiegler et al. (1996) en-

Table 6. Wheat yields on CRP land converted to cropland as affected by tillage method, vegetation management, and fertilizer N application rate near Bushland, TX, 1997.

	Wheat yield													
	Vegetation retained								Vegetation removed (mowed and baled)					
N rate	NT†	RT	ST	DT	MB–DT	B–ST	B–DT	Mean	NT	RT	ST	DT	MB–DT	Mean
kg ha^{-1}	kg ha^{-1}													
	Grain, Area 1													
0	1450	1370	1280	1790	1410	1570	1820	1530c	1340	1660	1810	1580	1610	1600b
67	1940	2030	1730	1960	1910	1750	1870	1890b	2050	2070	1820	1990	2110	2010a
134	2300	1950	2100	2180	2420	2290	1850	2160a	2000	1890	1940	2090	1890	1960a
Mean	1900a	1780a	1700a	1980a	1910a	1870a	1850a		1800a	1870a	1860a	1880a	1870a	
	Grain, Area 4													
0	1010	1100	1120	1190	1250	1220	1090	1140c	760	1070	1020	1100	1300	1050b
67	1580	1780	2000	1670	1810	2190	1950	1850b	1560	1810	1790	1860	1990	1800a
134	2050	2100	2150	2350	2090	2500	2500	2250a	1910	2030	1990	2030	1800	1950a
Mean	1550a	1660a	1760a	1740a	1710a	1970a	1850a		1410a	1640a	1600a	1670a	1700a	
	Straw, Area 1													
0	2500	2600	2300	2900	2400	2600	3000	2600c	2400	2900	2800	3000	3000	2800b
67	4300	3900	4000	4100	3600	3300	3700	3800b	3800	4100	3900	4300	4400	4100a
134	4800	5200	4400	4700	4300	4500	3300	4500a	4400	4000	4000	4000	3300	3900a
Mean	3800a	3900a	3600a	3900a	3400a	3500a	3300a		3500a	3700a	3600a	3800a	3600a	
	Straw, Area 4													
0	1600	1800	1700	1900	1900	1900	1800	1800c	1400	1300	1700	1900	2100	1800c
67	3000	3100	3300	3200	3400	3400	3500	3300b	3500	3900	3500	3600	3700	3600b
134	4200	4000	3900	4300	4200	4500	4400	4200a	4200	4400	4100	4100	3700	4100a
Mean	2900a	3000a	3000a	3100a	3200a	3200a	3200a		3000a	3400a	3100a	3200a	3200a	

† NT, no-tillage; RT, reduced tillage; ST, sweep tillage; DT, disk tillage; MB–DT, moldboard plow + disk tillage; B–ST, burn + sweep tillage; B–DT, burn + disk tillage.
‡ Within a given area, year, or yield factor, row or column means for a given vegetation management (retained or removed) followed by the same letter or letters are not significantly different at the $P = 0.05$ level, based on Duncan's multiple range test.

countered similar problems in Oklahoma. Under such conditions, it may be advisable to kill the vegetation by tillage, then switch to a no-tillage system after the first crop.

Although tillage would destroy most surface residues and, hence, subject the soil to erosion, the wind erosion potential on the CRP land at 2 to 3 years after killing the vegetation was slight (Unger, 1998). Also, the water erosion potential is slight on Pullman soil. These results suggest that killing the CRP vegetation with tillage would overcome the initial problems of no-tillage without subjecting the land to a high erosion potential. Subsequent conversion to a reduced- or no-tillage system would achieve the water conservation and erosion control benefits widely acclaimed for these practices.

Although soil N contents were low when treatments were imposed, N fertilizer applications had little effect on sorghum yield in most cases. A possible reason for the sorghum grain yield difference on Area 1 is that early plant growth was greater with applied fertilizer, which resulted in greater extraction of soil water than with the no fertilizer treatment. As a result, plant water stress was greater during the heading and grain-filling periods on fertilized plots, which resulted in the lower yields.

Wheat yields increased with increasing amounts of applied N fertilizer. Declining HIs with increasing N application rates suggest that wheat grain yields were limited by plant water stress late in the growing season due to greater early soil water use on plots that received fertilizer than on nonfertilized plots. Differential responses of sorghum and wheat to applied N possibly resulted from seasonal differences (summer vs. winter crops) and precipitation amount and distribution.

CONCLUSIONS

Results of the study suggest the following conclusions for a semiarid region.

1. Soil water contents at times for killing well-established CRP vegetation usually are extremely low. As a result, the 90 d allowed to prepare the land for the first crop are totally inadequate to achieve adequate soil water storage for a dryland crop, even with near-normal precipitation. Providing more than 1 year for water storage with near-normal precipitation did not result in a soil profile filled with water. Therefore, forgoing planting a crop soon after killing the CRP vegetation when precipitation is low may be a viable option because it would provide more time for soil water storage, thus increasing the probability of obtaining greater yields.
2. CRP vegetation removal by burning or mowing and baling has little effect on soil water storage and crop yields where tillage is used to kill the vegetation and loosen the soil.
3. Under no-tillage conditions, seedling establishment and, hence, crop yields, are reduced by the difficulty in closing the seeding slot in the firm soil. Rain soon after planting would reduce this problem.
4. Nitrogen fertilizer application increases wheat yields, but has limited effect on grain sorghum yields under conditions similar to those of the study.
5. Conservation Reserve Program vegetation is difficult to control with herbicides under no-tillage conditions. Factors affecting herbicide effectiveness are large amounts of surface materials present that

intercept herbicides and limited precipitation, which often results in plant water stress when herbicide application is most desirable.

6. Low effectiveness of herbicides for killing CRP vegetation under no-tillage conditions, even when large amounts of herbicides are applied, suggests that killing the vegetation with tillage may be a cost-effective and satisfactory alternative. Although tillage destroyed the surface residues, a companion study on the same areas showed that the wind erosion potential was low on all plots (the water erosion potential is known to be low). Hence, the initial crop could be established through use of tillage without incurring a high potential for erosion. Subsequent crops then could be produced through use of reduced- or no-tillage, thus achieving the water conservation and erosion control benefits widely acclaimed for these practices.

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