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35 Years of Farming Systems Research in the Texas Blackland

THE TEXAS AGRICULTURAL EXPERIMENT STATION/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

Major Findings

- Rotated grain sorghum produced higher yields than equally fertilized continuous grain sorghum.
- Position of sorghum in a rotation containing cotton, sorghum, and wheat did not influence grain yield.
- Clover fixed adequate nitrogen for the first crop after clover but did not furnish adequate nitrogen for the second crop.
- Wheat grown in a cotton-sorghum-wheat rotation with no fertilizer applied produced lower yields than nonfertilized continuous wheat.
- Cotton grown in a cotton-sorghum-wheat rotation without fertilizer produced higher yields than continuous cotton receiving 45-45-0.
- Rotated cotton resulted in less cotton root rot than continuous cotton.
- Soil organic carbon was increased by manure application or growth of fertilized continuous wheat but was decreased by all other systems measured.
- Soil available phosphorus and potassium were increased by manure application.
- Rate of water infiltration into soil was higher after continuous grain sorghum than after continuous cotton, continuous wheat, and cotton-sorghum-wheat rotation.

Cover photo: Aerial view of the Texas Blackland farming systems in June 1975.

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Summary

Farming system and fertilizer studies were initiated by the Texas Research Foundation at Dallas in 1947 and continued by the Texas Agricultural Experiment Station from 1972 through 1982. The study site was on Blackland Prairie soils consisting of Houston Black clay, Dalco clay, and Austin silty clay. All three soils have high montmorillonite clay content, shrink when dry, swell when wet, and are typical Blackland soils.

The study consisted of combinations of fertilized and nonfertilized continuous cotton, corn, sorghum and wheat, and fertilized and nonfertilized cotton-sorghum-wheat in rotation. A cotton-corn-corn rotation (fertilized) was also included. Seven of the treatments were unchanged during the study. Each treatment was replicated three times in a randomized block design and enough plots were included that each crop would appear every year in a rotation, i.e., cotton-sorghum-wheat required three plots/replication. Conventional farm equipment was used in planting, harvesting, fertilizing, and maintaining the crops; none of the crops received irrigation.

Continuous grain sorghum without fertilization produced an average grain yield of 2,120 kilograms per hectare (kg/ha) (kg/ha × 0.89 =lbs/acre) during the 35-year period. Grain yields were increased by rotation and by fertilizer application. The 35-year average grain yield for sorghum in a cotton-sorghum-wheat rotation fertilized with 45-45-0 (kg N, P_2O_5, K_2O/ha) was 3,716 kg/ha. Rotated sorghum produced higher yields than continuous sorghum, but yield increase due to rotation was partially offset by fertilizer. Position of sorghum in a rotation containing cotton, sorghum, and wheat did not influence grain yields over a 22-year period.

Highest grain sorghum yields during 1971-1981 were obtained from rotated sorghum fertilized with 90-90-0 o

more or from fertilizer plus manure. Substitution of clover for wheat in a cotton-sorghum-wheat system did not influence yields of sorghum if 45-45-0 was applied to cotton and sorghum. If the cotton and sorghum were not fertilized, clover fixed adequate nitrogen (N) for the first crop (cotton) after clover but did not furnish adequate N for the second crop (sorghum). Increased protein production by grain sorghum was generally associated with higher yields.

Wheat grown in a nonfertilized cotton-sorghum-wheat rotation produced significantly less wheat yields than all other systems. Yields from continuous wheat receiving 22-45-0 and rotated wheat receiving 67-45-0 were comparable for the 35-year period, but these fertilizer rates were too low for maximum yields. There was a yearly increase in wheat yield from fertilized rotated systems, probably due to development and use of higher yielding cultivars.

Of the four cotton systems that were not changed during the study, highest lint yield (383 kg/ha) was obtained from cotton-sorghum-wheat rotation with application of 45-45-0. Rotated and nonfertilized cotton produced higher yields than continuous cotton receiving 45-45-0. Increasing the fertilizer application rate above 45-45-0 on rotated cotton produced only a small yield increase (about 6 percent at 90-90-0). During 1971-1981, cotton grown in a cotton-sorghum-wheat rotation and fertilized with at least 45-45-0 produced higher yields than continuous cotton fertilized with 180-180-0.

Rotating cotton with sorghum and wheat resulted in less cotton root rot than did continuous cotton regardless of fertilization rate. The nonfertilized cotton-sorghum-wheat rotation resulted in the least cotton root rot.

Corn grown continuously without fertilizer produced an average yield of 2,065 kg/ha from 1957 to 1982. Rotation of corn with cotton produced higher corn yields than continuous corn, but no definite trends emerged regarding yields as a function of time for any of the treatments involving corn.

Soil organic carbon was increased by several years of manure application or growth of fertilized continuous wheat but was decreased by all other systems measured. All systems measured contained at least 1.5 percent organic carbon after 32 years in the farming system treatments. All treatments measured decreased total soil nitrogen except the rotation receiving manure. Soil from the treatments receiving high N rates during the last 12 years of the study, however, was not analyzed. Nitrogen mineralization rate was a function of applied N and was not influenced by rotated or continuous sorghum. Mineralization rates were 0.47 and 1.6 milligrams per kilogram per day (mg/kg/day) for nonfertilized soils and soils fertilized with 1,620 kg N/ha/11 years, respectively.

Soil available phosphorus (P) and potassium (K) at the 15-centimeter (cm) depth were increased by application of 11,200 kg manure/ha/year. Soil K was very high after 34 years under all treatments measured.

Soil strength was affected by soil depth, cropping system, and location of measurement, but there was not a depth × farming system interaction. Water infiltration rate was higher after continuous sorghum than after continuous cotton, rotated sorghum, and continuous wheat.

Introduction

The Blackland Prairie is one of the major farming regions of Texas. Approximately 5.1 million hectares (12.6 million acres) are included in the Blackland Prairie which extends from the Red River to near San Antonio. About 2.4 million hectares (5.8 million acres) of the Blackland Prairie are the Houston Black-Heiden-Austin association. Other major soil associations in the Blackland Prairie include the Wilson-Crockett-Burleson (Graylands) association, Burleson-Heiden-Crockett association and the Austin-Stephen-Eddy association. Blackland soils are dark colored, high in montmorillonite clay, swell when wet, and shrink when dry. Cracks one meter deep and eight centimeters wide are common during dry periods.

The primary crops grown in the Blackland Prairie are wheat, forages, cotton, grain sorghum, corn, and legumes. Cotton was intensively grown from 1900 to 1960, but cotton acreage has declined and wheat acreage has increased in recent years.

Rainfall limits production of cotton, sorghum, and corn in some years because of low or erratic rainfall during the summer growing period. Small grains are more adaptable to the fall and spring rainfall pattern. A summary of the description and use of Blackland Prairie soils is provided by Godfrey (11).

Continued cropping of the Blacklands and other lands is assumed to be detrimental to productivity probably because of fertility loss and deterioration of soil physical properties. Research was conducted from 1947 to 1982 to study the effects of farming systems and fertilizer practices on crop yield and soil properties.

Materials and Methods

Studies were initiated in the fall of 1947 and spring of 1948 by Texas Research Foundation at Renner, TX (annexed by Dallas in 1970) to evaluate the effects of farming systems and fertilizer treatments on Blackland Prairie soil. The experiment was maintained by Texas Research Foundation, a privately funded research organization, until 1972 when Texas Research Foundation was donated to Texas A&M University. The Texas Agricultural Experiment Station at Dallas maintained the study until it was terminated in the fall of 1982.

Crops involved in the study were those common to the area, namely, cotton, grain sorghum, wheat, and clover. Corn was also included at a later date. The crops, fertilizer treatments, and year that each treatment was initiated are indicated in Table 1 and on the inside back cover. The fertilizer sources used were ammonium nitrate and ordinary or triple superphosphate. Sufficient plots were included so that each crop in a system appeared every year, i.e., cotton-sorghum-wheat required three plots per replication. Treatments were replicated three times in a randomized block design.

Table 1. Description of the farming systems and fertilizer treatments used in the long-term cropping system studies at Dallas, TX, 1948-1982.

System no.	Crops	Fertilizer N-P_2O_5-K_2O (kg/ha/yr)	Year initiated
1	continuous cotton	none	1948
2	continuous corn	none	1956
3*	continuous cotton	45-45-0	1948
4	continuous grain sorghum	none	1948
5	continuous wheat	none	1948
6	continuous wheat	17-100-17, 1948-53 (overseeded with Hubam clover)	1948
		22-45-0, 1954-82	
7	continuous wheat	22-45-0, 1956-58	1956
		50-45-0, 1959-62	
		67-45-0, 1963-82	
8	cotton-sorghum-wheat	none	1948
9	cotton-sorghum-wheat	45-45-0 and 11,200 kg/ha manure/yr cotton & sorghum,	1956
		67-45-0 wheat	
10*	cotton-sorghum-clover	45-45-0, cotton & sorghum	1952
		0-67-0 clover, 1952-79	
		0-67-0 clover, 1980-82	
11	cotton-sorghum-clover	0-67-0 clover, 1952-70	1952
	cotton-sorghum-wheat	180-180-0 cotton & sorghum	1971
		67-45-0 wheat, 1971-81	
12*	cotton-sorghum-wheat	45-45-0 cotton & sorghum	1948
		67-45-0 wheat (plots switched to new location in 1953)	
13	cotton-sorghum-wheat	45-0-0 cotton & sorghum	1961
		67-45-0 wheat	
14	cotton-wheat-sorghum	45-0-0 cotton & sorghum	1961
		67-45-0 wheat	
15	cotton-sorghum-wheat	90-90-0 cotton & sorghum	1971
		67-45-0 wheat	
16	cotton-sorghum-wheat	134-134-0 cotton & sorghum	1971
		67-45-0 wheat	
17	continuous corn	45-45-0, 1957-78	1957
		90-45-0, 1979-82	
18-1**	cotton-<u>corn</u>-corn	45-45-0, 1964-78	1964
		90-45-0, 1979-82	
18-2	cotton-corn-<u>corn</u>	45-45-0, 1964-78	1964
		90-45-0, 1979-82	
19	continuous sorghum	45-45-0	1957
20	continuous sorghum	45-0-0	1960
21	continuous cotton	45-0-0	1971
38	continuous sorghum	134-134-0	1971
39	continuous sorghum	90-90-0	1971
40	continuous sorghum	180-180-0	1971

*Systems 3, 10, and 12 received 22 kg K_2O/ha/yr, 1948-52.

**System 18-1 was first year of corn after cotton; 18-2 was second year of corn after cotton.

In previous publications (2, 19, 20, 23, 24) the experimental site has been referred to as Houston Black clay. However, the area was mapped in detail in 1976 by the USDA Soil Conservation Service and the results indicated the experimental site was about 15 percent Houston Black clay, 35 percent Dalco clay, and 50 percent Austin silty clay. Management techniques, fertilizer, and crops grown are essentially the same for all three soil types. Plots were initially 7.62 × 30.5 meters (m) (25 × 100 ft) but were later changed to 6.1 x 21.3 m (20 × 70 ft). A detailed description of the procedure for establishing the crops and initial treatments was provided by Laws and Simpson (19).

Conventional farming equipment typical for the area was used in planting, maintaining, and harvesting the plots. Insects were controlled as necessary using appropriate insecticides, but herbicides were not applied for weed control. Plant cultivars were changed as new and improved cultivars became available. Cultivars and dates of yearly plantings are indicated in Table 2. These data were not available for the early years of the study.

Soil samples were taken from the 0-15 cm depth of each plot in 1947 and 1966 and stored air dry in cardboard containers. Soils were sampled at various other times for specific analyses. Rainfall data were taken a few meters from the experimental site and the monthly totals are presented in Table 3.

Organic carbon was estimated in 1979 on selected plots (from stored and/or fresh samples) by the Walkley-Black method (1), and total soil N was determined in 1979 by digestion, as described by Gallaher, et al. (7), and by conventional distillation and titration. Nitrogen mineralization rate was determined by placing 10 grams (g) of air dry soil in test tubes and moistening it with 3.5 g of water. Moisture level was maintained by weighing every 3 days and adding water if necessary. Tubes were stoppered with loose fitting cotton and incubated for 3 weeks. Nitrate was not removed but was determined initially and again after 3 weeks.

Phosphorus analyses were conducted in 1977 on selected treatments according to the procedure described by Chapman and Pratt (5). Exchangeable K was

Table 2. Cultivar and date of planting for farming systems from 1948-1982.

Year	Cotton cultivar	Planting date	Sorghum cultivar	Planting date	Wheat cultivar	Planting date	Corn cultivar	Planting date
1948			open pollinated	April	Austin			
1949			open pollinated	April	Austin			
1950			open pollinated		Austin			
1951			open pollinated		Austin			
1952			open pollinated		Quanah	10/15		
1953			open pollinated		Quanah	10/20		
1954			open pollinated		Quanah			
1955			open pollinated					
1956			Hybrid TX 601	5/8			TRF 3	3/8
1957			RS 610	3/14	Crockett	10/31	TRF 9	3/13
1958			RS 610	3/22	Crockett	10/2	TRF 9	3/21
1959			RS 610	3/17	Crockett	10/29	TRF 9	3/17
1960			RS 610	3/21	Crockett	10/19	TRF 9	3/22
1961	Lankart 57	4/18	RS 610	4/6	Crockett	10/19/60	TRF 9	3/15
1962	Lankart 57	4/17	RS 610	3/19	Crockett	10/20/61	TRF 9	3/16
1963	Lankart 57	4/9	RS 610	3/18	Crockett	10/18	TRF 9	3/18
1964	Lankart 57	4/7	NK 222	3/17	Kaw	11/7	TRF 9	3/16
1965	Lankart 57	4/14	NK 222	3/16	Kaw	10/28	Asgrow 105W	3/15
1966	Lankart 57	4/13	NK 222	3/15	Caddo	11/1	Asgrow 105W	3/14
1967	Lankart 57	4/20	NK 222	3/9	Caddo	11/2	Asgrow 105W	3/10
1968	Lankart 57	4/8	NK 222	3/28	Caddo	11/20	Asgrow 305W	3/28
1969	Lankart 3840	4/16	NK 222	3/28	Caddo	10/22	Asgrow 305W	3/27
1970	Lankart 3840	4/7	NK 222	3/31	Caddo	11/11	Asgrow 305W	3/31
1971	Lankart 57	4/26	NK 222	3/9	Sturdy	11/12	Asgrow 305W	3/8
1972	Lankart 57	4/26	NK 222	3/1	Sturdy	11/30	Asgrow 305W	2/29
1973			NK 222		Sturdy	11/10	Asgrow 305W	
1974	SP 37	4/8	NK 266A	3/18	Sturdy	N/A	TX 40	3/19
1975	SP 37	4/24	NK 266A	4/4	Sturdy	N/A	TX 40	3/20
1976	SP 37	4/23	NK 266A	3/22	Sturdy	11/18	TX 40	3/2
1977	SP 37	4/5	WAC692R	3/9	Sturdy	11/9	TX 40	3/9
1978	SP 37	4/4	Harpool 8409	3/28	Sturdy	12/2	TX 50	3/22
1979	GP 3755	5/15	Harpool 8409	4/19	Sturdy	10/20	TX 50	4/9
1980	GP 3774	4/17	Harpool 8409	3/20	Sturdy	11/16	TX 50	3/20
1981	GP 3774	4/14	NK 2244	3/27	TAM 106	11/10	NKPX 74	3/24
1982	GP 3774	4/15	NK 2778	3/23	TAM 106	11/19	NKPX 69A	3/15

determined on samples taken in 1981 by extracting with normal ammonium acetate and analysis by atomic absorption. Water infiltration and bulk density measurements were made in April 1981 (soil at approximately field capacity) by procedures described in USDA Handbook 60 (27). Field soil strength measurements were made when soil was wet (field capacity) in 1981 on selected treatments using a soil penetrometer driven by a hydraulic soil sampler. Data were obtained through a transducer-recorder arrangement as described by Gerard and Mehta (9).

Cotton root rot was evaluated at the end of each growing season (1959-1982) by visually estimating the percentage of each cotton plot exhibiting cotton root rot symptoms.

Data were subjected to appropriate statistical analysis, primarily analysis of variance, and regression analysis.

Table 3. Monthly precipitation (cm) during the farming system and fertilizer studies at Dallas, TX.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1947*	3.07	1.14	6.25	10.95	7.06	18.19	0.02	28.88	7.54	7.57	7.54	14.00	112.22
48	1.52	6.40	6.07	3.66	6.81	11.05	5.28	1.65	0.20	2.18	1.40	5.74	51.97
49	21.84	9.04	10.82	4.29	16.05	29.41	0.15	5.54	5.87	17.93	0.13	3.86	124.94
50	13.18	5.31	4.06	10.59	13.31	7.39	10.29	5.76	11.81	0.86	0.25	0.33	83.16
51	4.90	6.58	3.78	2.79	8.99	15.52	7.54	5.18	6.02	5.94	1.88	1.98	71.12
52	4.57	7.39	4.55	14.07	12.65	0	4.95	0.38	0.53	0.08	24.76	8.53	82.47
53	1.63	4.78	9.63	17.17	9.24	1.96	1.80	5.94	5.16	7.95	8.05	3.18	76.48
54	6.15	1.65	1.30	12.80	10.46	4.60	1.78	0.64	5.79	9.58	2.92	2.24	59.89
55	3.84	4.75	4.55	4.57	9.35	10.97	6.60	1.88	7.90	2.59	2.18	0	59.18
56	2.72	9.47	0.23	8.38	8.38	1.22	1.60	1.32	0.25	4.93	8.26	5.99	52.76
57	6.48	2.41	13.94	33.04	22.30	5.77	0.10	1.73	11.89	10.57	9.55	6.65	124.43
58	4.85	1.57	13.72	19.30	9.47	8.18	4.19	1.70	11.25	2.06	6.45	2.26	85.01
59	0.30	4.16	3.18	2.79	5.64	8.81	13.11	2.31	5.23	19.33	4.01	11.02	79.91
60	4.55	5.13	2.29	4.85	13.03	4.39	12.06	10.95	4.27	3.43	1.30	14.68	80.92
61	6.70	6.32	11.43	3.40	3.20	19.00	1.65	0.56	9.91	6.10	9.30	6.22	83.79
62	2.62	5.61	4.24	14.76	3.89	17.04	21.94	4.19	17.80	18.49	7.34	2.11	120.04
63	0.96	0.53	2.24	13.49	11.79	2.62	6.78	0.76	1.42	0.48	4.09	3.99	49.15
64	6.78	3.66	12.17	9.47	14.78	1.24	0.25	9.12	43.61	0.53	15.49	2.39	119.51
65	5.28	13.36	3.66	5.31	24.54	9.96	1.37	3.78	12.22	3.58	5.38	3.76	92.20
66	3.43	5.92	6.07	48.44	2.74	8.81	11.02	16.74	7.49	4.27	1.42	3.43	119.79
67	0.91	1.73	5.89	12.45	16.05	4.27	5.23	0.41	17.93	12.90	2.13	7.29	87.20
68	7.47	3.86	18.52	6.22	10.67	12.42	4.42	9.55	6.81	3.10	10.26	2.87	96.16
69	5.64	5.18	11.20	7.70	23.62	2.39	0.13	2.26	8.41	16.38	2.26	7.75	92.91
70	1.93	12.67	10.06	13.54	11.53	2.69	0.74	7.42	20.32	8.33	1.02	4.06	94.31
71	0.36	5.21	0.76	5.61	9.91	4.75	7.62	11.07	6.86	23.44	4.19	20.17	99.95
72	2.18	0.71	2.72	7.42	4.09	6.45	0.30	2.26	4.47	18.42	7.54	2.46	59.03
73	9.24	5.49	8.41	13.94	18.03	19.23	9.19	0	16.23	17.93	4.04	2.84	124.59
74	4.39	2.79	2.34	11.79	2.46	12.98	4.57	8.76	21.23	14.12	9.07	4.88	99.39
75	11.12	3.56	7.14	9.17	16.81	8.30	10.39	5.18	0.91	0	3.94	3.28	79.81
76	0.71	2.36	6.53	14.22	15.32	4.80	6.17	3.22	5.92	8.53	0.96	7.90	76.66
77	5.77	5.64	18.21	12.75	1.88	5.23	6.02	5.38	5.03	2.51	4.98	0.58	73.99
78	3.81	7.67	5.66	3.96	18.57	1.73	1.83	9.40	4.01	0.76	9.07	3.15	69.62
79	10.57	6.58	18.34	5.38	19.23	3.20	3.50	8.43	3.53	6.45	1.45	7.47	94.13
80	6.86	2.36	3.00	6.35	8.97	4.37	0.13	0	19.63	3.25	3.45	4.55	62.92
81	2.29	5.08	8.15	8.43	16.86	23.42	11.61	3.96	8.71	35.69	3.33	0.46	127.99
82	6.76	4.52	3.33	8.48	28.75	11.66	5.99	1.24	3.00	8.89	11.15	10.87	104.65
83	6.71	3.48	9.32	1.32	13.74	5.97	6.35	7.67	0.30	8.89	5.61	2.74	72.11
Mean	5.19	4.97	7.13	10.62	12.17	8.65	5.32	5.28	8.90	8.60	5.57	5.29	87.69

*1947-1973 data from Brawand, Hans. 1977. Plant Environment Data; long-time measurements and recording at Renner, TX, TAES TR 53. p. 7.

Results and Discussion

Crop Response

Grain Sorghum Yield

There was a distinct influence of cropping system and fertilizer application on grain sorghum yields from systems that were not changed during the entire study period (Table 4). Continuous grain sorghum without fertilization produced an average grain yield of 2,120 kg/ha during the 35-year period. Growing grain sorghum without fertilizer in rotation with cotton and wheat (System 8) increased yields by 815 kg/ha over continuous grain sorghum (System 4), but yields were increased by 1,596 kg/ha if sorghum was rotated and fertilized with 45-45-0 (System 12). Average yearly grain yield for the 35-year period was 3,716 kg/ha for the rotated and fertilized (45-45-0) sorghum. In 1959, Laws and Simpson (19) concluded that rotated sorghum, whether fertilized or not, produced higher yields than nonfertilized continuous sorghum. They also concluded that fertilizer in a farming system was more important than crop rotation for grain sorghum production. Brawand and Hossner (2) reported on the nutrient contents of sorghum leaves and grain as influenced by 13 of the systems described in this publication. They concluded that sufficient information was not available to adequately interpret their data.

Table 4. Influence of farming system and fertilizer practices on grain sorghum yield at Dallas, TX, 1948-1982.

System* no.		Grain yield (kg/ha)
12	cotton-sorghum-wheat 45-45-0	3,716 a**
8	nonfertilized cotton-sorghum-wheat	2,935 b
4	nonfertilized continuous sorghum	2,120 c

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

The effects of cropping system and fertilizer application on grain sorghum during a 22-year period (1961-1982) are indicated in Table 5. Highest yields were from rotated sorghum fertilized with yearly application of 45-45-0 and 11,200 kg manure/ha applied to cotton and sorghum in the rotation (System 9). Average yields for this system were 4,566 kg/ha and were significantly higher than all other systems that were not changed from 1961-1982. During a 22-year period, rotated systems that received 45 kg N/ha produced significantly more grain than continuous systems receiving 45 kg/ha of N/yr. Yield response to P applied to grain sorghum was not significant in rotations (Systems 12 and 13) or with continuous sorghum (Systems 19 and 20). Position of grain sorghum in the rotation did not significantly affect yields during this 22-year period. Sorghum yield following cotton (System 12) was 4,049 kg/ha, and sorghum yield following wheat (System 14) was 4,039 kg/ha. Continuous sorghum grown without fertilizer during 1961-1982 produced lower yields (2,013 kg/ha) than all other systems.

Table 5. Influence of farming system on yield of sorghum at Dallas, TX, 1961-82.

System* no.		Grain yield (kg/ha)
9	cotton-sorghum-wheat 45-45-0+manure	4,566 a**
12	cotton-sorghum-wheat 45-45-0	4,049 b
14	cotton-wheat-sorghum 45-0-0	4,039 b
13	cotton-sorghum-wheat 45-0-0	3,965 b
19	*continuous sorghum 45-45-0*	*3,289 c*
20	continuous sorghum 45-0-0	3,144 c
8	nonfertilized cotton-sorghum-wheat	3,053 c
4	nonfertilized continuous sorghum	2,013 d

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Fifteen of the systems involving grain sorghum were not changed during 1971-1981 (Table 6). Highest yields were obtained from rotated sorghum fertilized with at least 90-90-0 (Systems 11, 15, and 16) or 45-45-0 plus manure (System 9). Rotated sorghum fertilized with 45-45-0 (System 12) produced yields as high as any of the continuous sorghum systems receiving up to 180-180-0 (Systems 19, 38, 39, and 40). Substitution of clover, plowed

Table 6. Influence of farming system and fertilizer practice on grain sorghum at Dallas, TX, 1971-1981.

System* no.		Grain yield (kg/ha)
16	cotton-sorghum-wheat 134-134-0	4,222 a**
11	cotton-sorghum-wheat 180-180-0	4,112 a
9	cotton-sorghum-wheat 45-45-0+manure	4,061 a
15	cotton-sorghum-wheat 90-90-0	4,041 a
12	cotton-sorghum-wheat 45-45-0	3,658 b
10	cotton-sorghum-clover 45-45-0	3,654 b
38	continuous sorghum 134-134-0	3,648 b
14	*cotton-wheat-sorghum 45-0-0*	*3,632 b*
40	continuous sorghum 180-180-0	3,618 b
13	cotton-sorghum-wheat 45-0-0	3,521 b
39	continuous sorghum 90-90-0	3,515 b
19	continuous sorghum 45-45-0	2,832 c
20	continuous sorghum 45-0-0	2,767 c
8	nonfertilized cotton-sorghum-wheat	2,660 c
4	nonfertilized continuous sorghum	1,792 d

*For complete system description, refer to Table 1 or the inside back cover.

**Means not followed by the same letter are significantly different at the 0.05 level according to Duncan's multiple range test.

under as green manure, (System 10) for wheat (System 12) did not increase yield of sorghum if 45-45-0 was applied to cotton and sorghum. As indicated in Figure 1, yield of continuous sorghum was less than rotated sorghum at all fertilizer rates during 1971-1981. Parabolic regression equations showed that fertilizer rate accounted for about 87 percent and 92 percent of the variations in rotated and continuous sorghum yield, respectively.

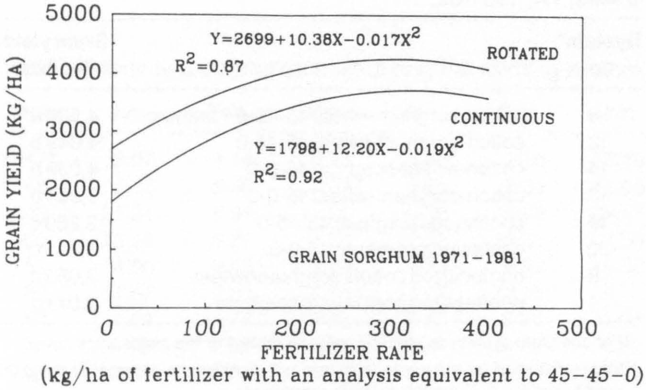

Figure 1. Influence of fertilizer application rate on yield of rotated and continuous grain sorghum.

Data from Table 5 suggest that the yield increases were due primarily to N application. The relationship between fertilizer application rate and increase in yield due to rotation is provided in Figure 2. The greatest yield increase due to rotation over monoculture systems was about 40 percent without fertilizer application. Application of 180-180-0 reduced the effect of rotation on yield to about 15 percent, but the equation describing the relationship between fertilizer application rate and percent yield increase due to rotation suggests that fertilizer rate cannot compensate for rotation at normal fertilizer application rates.

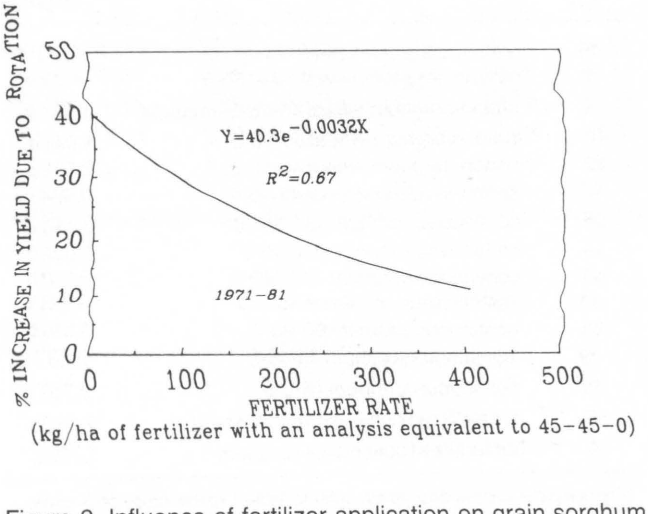

Figure 2. Influence of fertilizer application on grain sorghum yield increase due to rotation.

Yearly grain sorghum yields for the duration of the studies are presented in Table 7. The magnitude of the inherent fertility of the blackland soils used in the study can be gleaned from yearly yield data. After 27 years without fertilization, sorghum produced almost 4,000 kg/ha (System 8) in 1974. Average yields were higher from rotated nonfertilized sorghum than from nonfertilized continuous sorghum every year except 1956 and 1960. A plot of the 5-year average yield (to reduce variation due to weather) vs. years (Figure 3) showed that yields of nonfertilized continuous sorghum changed very little during the experimental period but the yield declined beginning after about 13 years. Yields of rotated nonfertilized sorghum began to decline after about 16 years, while rotated sorghum fertilized with 45-45-0 began to decline after 19 years. The period between 1953 and 1957 was not included in the figure or analysis because of low yields due to severe drought during much of the period.

A comparison of System 10 (cotton-sorghum-clover with fertilizer on cotton and sorghum) and System 11 (nonfertilized cotton-sorghum-clover) from 1952 through 1970 (Table 7) indicates that clover did not fix sufficient N for the subsequent sorghum crop. System 10 with fertilizer applied produced an average of 504 kg/ha/yr more than System 11 (Student's t test = 6.38, significant at 0.001 level). Recent studies indicate that clover grown in blackland soil may furnish adequate N for the first crop after clover but not for the second crop.

Grain Sorghum Protein

Protein production by each of the systems involving sorghum during 1980-1982 is indicated in Table 8. Protein production was closely related to yield because the protein concentrations were not changed as much by treatment as were yield levels. System 9 produced 488 kg protein/ha/yr during 1980-1982. This was more than all the continuous systems regardless of fertilizer rate. The lowest protein yields/ha were produced by the rotated system with no fertilizer or by the continuous sorghum systems. Protein production ranged from 153 to 488 kg/ha. Yearly protein concentration varied considerably (Table 9) ranging from 6.75 percent to 13.52 percent. Low concentrations were generally associated with low N fertilizer levels as suggested by Burleson, et al. (3) or with continuous sorghum.

High rainfall during the growing season can also reduce protein concentration. The relationships between fertilizer applied to sorghum and protein production during 1980-1981 could be described by parabolic regression curves (Figure 4). Fertilizer application accounted for about 53 percent and 67 percent of the variation in protein yields of rotated and continuous sorghum, respectively. The regression curves indicated maximum protein production could be expected with 127-127-0 on rotated sorghum. Extrapolation of the equation for continuous sorghum showed the fertilizer rate for maximum production would be 225-225-0.

Table 7. Influence of farming system and fertilizer practice on grain sorghum yields at Dallas, TX, 1948-1982.

Year	System no.*														
	4	8	9	10	11	12	13	14	15	16	19	20	38	39	40
	kg/ha														
1948	3,163	3,614				3,036									
49	2,331	3,591				3,700									
50	2,335	3,666				4,774									
51	2,026	2,575				4,079									
52	1,597	1,959		2,133	2,006	2,529									
1953	1,670	1,763		1,935	1,721	2,287									
54															
55	2,260	2,648		3,302	2,938	2,342									
56	1,091	925	1,325	1,467	1,003	1,128									
57	1,710	1,857	3,113	2,436	1,785	1,972									
1958	2,712	3,450	4,673	4,839	3,881	3,687									
59	3,054	3,650	3,460	3,632	3,740	3,650									
60	3,813	2,465	4,610	4,185	3,932	3,608									
61	2,990	3,975	5,873	5,454	4,653	4,879	5,511	5,556			4,292	4,173			
62	2,212	4,201	4,852	4,656	4,380	4,640	4,730	4,125			3,586	3,369			
1963	2,080	2,993	4,606	4,112	3,358	4,330	3,689	4,169			3,849	3,284			
64	1,696	3,035	4,262	3,192	2,825	2,876	3,075	3,460			3,238	2,696			
65	3,149	4,097	3,609	4,171	4,029	3,865	4,109	3,432			3,754	3,541			
66	2,830	4,489	6,331	5,980	5,501	5,833	5,385	5,427			4,577	4,587			
67	1,507	3,004	5,807	4,485	3,693	4,760	4,927	5,298			3,386	3,788			
1968	3,177	4,610	6,679	6,153	4,939	6,254	6,487	6,582			5,675	5,189			
69	873	1,807	4,186	2,951	2,349	3,373	3,162	2,951			2,439	2,078			
70	1,746	3,063	5,111	3,910	3,187	3,974	3,920	3,863			3,274	2,511			
71	2,982	3,467	2,894	3,799	4,580	4,420	4,263	4,116	3,808	3,853	3,953	3,468	4,589	4,604	4,399
72	2,228	3,256	5,439	5,087	4,884	5,140	4,140	4,070	4,652	4,721	3,802	3,362	4,146	4,996	4,185
1973	955	1,970	3,709	3,158	3,890	3,085	2,984	3,169	3,597	3,664	2,182	2,078	3,329	3,046	3,894
74	2,879	3,979	5,537	4,160	5,617	4,297	5,167	4,517	5,680	5,816	3,675	4,000	4,608	5,341	5,383
75	1,541	2,506	3,733	3,545	4,532	2,855	3,475	3,939	4,403	4,553	2,503	3,207	4,319	3,347	4,043
76	1,206	2,653	5,027	5,034	5,013	4,919	4,057	4,664	5,215	4,992	3,197	2,827	4,346	4,636	4,581
77	1,645	3,071	4,981	4,033	4,284	4,640	3,876	4,043	4,545	5,061	2,928	2,942	3,611	2,729	3,214
1978	1,987	2,646	2,897	2,565	3,039	2,569	2,771	2,133	3,364	3,339	2,325	2,496	2,671	2,472	2,479
79	1,369	1,942	2,914	2,336	2,379	2,192	1,737	2,514	1,881	3,033	2,055	1,376	2,623	1,846	2,092
80	518	1,656	3,364	2,843	3,254	2,920	2,858	3,079	3,558	3,654	1,419	1,609	2,109	1,835	1,638
81	2,462	2,108	4,180	3,636	3,759	3,202	3,402	3,702	3,750	3,761	3,110	2,075	3,775	3,822	3,888
82	2,240	3,194	4,461	3,752	3,864	4,060	3,503	4,056	4,528	4,975	3,130	3,523	4,426	3,652	3,243

*For complete system description, refer to Table 1 or the inside back cover.

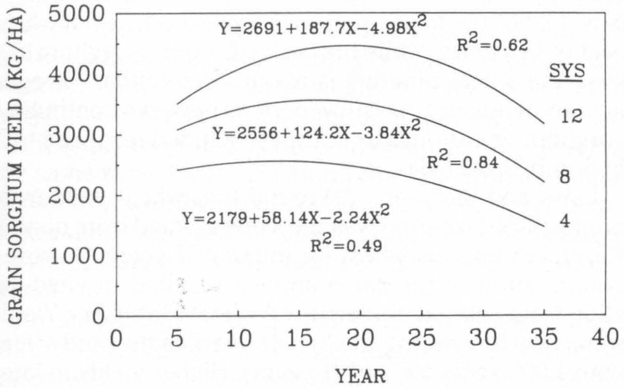

Figure 3. Grain sorghum yield as a function of year for three farming systems (12 is cotton-sorghum-wheat 45-45-0; 8 is nonfertilized cotton-sorghum-wheat; and 4 is nonfertilized continuous sorghum).

Table 8. Influence of farming system and fertilizer on average protein production by grain sorghum at Dallas, TX, 1980-1982.

System* no.		kg protein/ha
9	cotton-sorghum-wheat 45-45-0+manure	488 a**
11	cotton-sorghum-wheat 180-180-0	421 ab
15	cotton-sorghum-wheat 90-90-0	412 ab
16	cotton-sorghum-wheat 134-134-0	389 abc
14	cotton-wheat-sorghum 45-0-0	381 abc
12	cotton-sorghum-wheat 45-45-0	375 abc
13	cotton-sorghum-wheat 45-0-0	325 bcd
10	cotton-sorghum-clover 45-45-0	322 bcd
38	continuous sorghum 134-134-0	307 bcd
39	continuous sorghum 90-90-0	305 bcd
20	continuous sorghum 45-0-0	276 cd
40	continuous sorghum 180-180-0	270 cde
19	continuous sorghum 45-45-0	265 cde
8	nonfertilized cotton-sorghum-wheat	222 de
4	nonfertilized continuous sorghum	153 e

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 9. Influence of farming system and fertilizer on protein concentration in sorghum grain and protein production at Dallas, TX, 1980-1982.

System* no.		1980	1981	1982	1980	1981	1982
		% protein			kg protein/ha		
4	nonfertilized continuous sorghum	12.92	8.52	8.48	65	210	185
8	nonfertilized cotton-sorghum-wheat	12.13	9.43	10.77	197	196	275
9	cotton-sorghum-wheat 45-45-0+manure	12.83	11.96	11.75	431	504	528
10	nonfertilized cotton-sorghum-clover	11.85	10.46	10.31	337	381	250
11	cotton-sorghum-wheat 180-180-0	13.06	12.77	11.58	425	481	358
12	cotton-sorghum-wheat 45-45-0	12.77	10.79	9.85	374	351	400
13	cotton-sorghum-wheat 45-0-0	12.25	7.27	10.87	349	252	375
14	cotton-wheat-sorghum 45-0-0	13.02	6.75	10.93	401	252	490
15	cotton-sorghum-wheat 90-90-0	13.33	11.77	9.81	477	442	317
16	cotton-sorghum-wheat 134-134-0	12.69	7.98	12.81	464	322	382
19	continuous sorghum 45-45-0	12.46	10.00	10.43	171	311	312
20	continuous sorghum 45-0-0	13.21	9.04	9.90	202	281	345
38	continuous sorghum 134-134-0	13.18	11.38	9.92	277	431	213
39	continuous sorghum 90-90-0	13.52	9.98	9.92	248	382	285
40	continuous sorghum 180-180-0	12.36	7.37	9.19	210	302	298

*For complete system description, refer to Table 1 or the inside back cover.

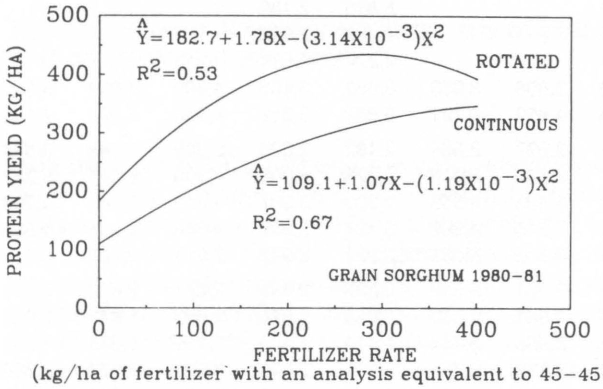

Figure 4. Relationship between fertilizer application rate and protein yield by continuous and rotated grain sorghum.

Wheat Yield

Four of the cropping systems involving wheat were not changed from inception to termination of the study (Table 10). They were Systems 5 (nonfertilized continuous wheat), 6 (continuous wheat with 22-45-0), 8 (nonfertilized cotton-sorghum-wheat), and 12 (fertilized cotton-sorghum-wheat). Average yields for the 35-year period indicated that wheat grown in rotation with cotton and sorghum, in which none of the crops received fertilizer, produced significantly less (1,015 kg/ha) than all other systems. Nonfertilized continuous wheat (System 5) produced 337 kg/ha (5 bu/ac) more than nonfertilized rotated wheat (System 8). Yields from continuous wheat receiving 22-45-0 and rotated wheat receiving 67-45-0 were comparable for the 35-year period.

Table 10. Influence of farming system and fertilizer practice on wheat yield at Dallas, TX, 1948-1982.

System* no.		Grain yield kg/ha
12	cotton-sorghum-wheat 67-45-0	1,979 a**
6	continuous wheat 22-45-0	1,925 a
5	nonfertilized continuous wheat	1,352 b
8	nonfertilized cotton-sorghum-wheat	1,015 c

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

A possible explanation of the higher fertilizer requirement of rotated wheat is the short time between row crop harvest and wheat planting in which N mineralization and moisture accumulation can occur. The fallow time between wheat crops is about 5 months (June 1 - Nov. 1), but the fallow period between cotton and wheat is about 1 month, while the period between sorghum harvest and wheat planting is about 2½ months. Nitrogen accumulation during fallow periods between continuous sorghum or continuous cotton precluded response to N in South Texas (14).

Laws and Simpson (19) found that wheat yield from nonfertilized rotation was the same as yield from nonfertilized continuous wheat for the first 11 years. However, continuation of the same studies resulted in yield decline from rotated nonfertilized wheat (Table 11). Yields were very low during the first 11 years of the study (less than 1,000 kg/ha for 7 of 11 years). Higher yields in later years would be more conducive to manifestation of the difference in the rotated and continuous systems.

Longnecker and Longstaff (24) evaluated the effects of 4 farming systems (5, 6, 8, and 9 of the present study, except System 9 received green manure rather than cow

Table 11. Influence of farming system and fertilizer practices on yearly wheat yields at Dallas, TX, 1948-1982.

Year	System*										
	5	6	7	8	9	11	12	13	14	15	16
	kg/ha										
1948	1,073	1,897		1,232			1,465				
49	54	316		150			248				
50	752	1,277		562			1,098				
51											
52	847	2,397		652			1,624				
1953	1,868	2,789		1,879			2,457				
54	1,436	2,582		1,964			2,079				
55	801	757		625			206				
56	976	1,456	235	645	569		677				
57	688	896	632	1,351	320		934				
1958	1,570	1,736	1,310	2,020	1,335		2,043				
59	2,153	2,276	2,742	1,044	2,645		2,068				
60	1,317	1,960	2,594	1,528	2,834		2,912				
61	1,662	2,209	2,721	1,239	3,138		3,004	3,219	3,017		
62	1,530	1,996	2,162	985	2,650		1,994	2,063	2,755		
1963	1,080	1,593	1,474	475	1,678		1,169	1,357	1,667		
64	2,139	2,273	2,215	1,100	1,964		2,984	2,843	2,560		
65	782	1,028	956	658	813		820	712	1,008		
66	847	1,176	1,644	854	1,290		1,434	1,956	1,915		
67	1,825	2,213	2,596	820	2,493		1,996	2,204	2,137		
1968	1,376	2,009	1,702	896	2,128		1,982	2,372	2,345		
69	1,631	2,715	2,690	831	2,784		2,531	2,789	3,078		
70	1,495	1,682	2,279	1,249	2,352		2,411	2,587	2,513		
71	1,835	2,190	2,199	1,526	3,050	2,880	2,936	3,023	2,692	3,147	3,214
72				771	1,376	1,238	1,286	1,481	1,377	1,542	1,463
1973	2,256	3,089	3,070	1,119	3,683	3,657	3,077	2,979	3,504	3,586	3,571
74	1,644	2,230	2,308	1,260	2,984	2,896	2,692	2,920	2,740	3,137	3,041
75	1,965	2,334	2,605	1,206	3,197	3,303	2,939	2,915	3,246	2,687	3,412
76	1,833	1,793	2,580	759	1,640	1,821	1,662	1,984	1,917	1,886	1,828
77	948	2,599	3,146	513	3,822	3,681	2,337	2,631	2,981	3,228	3,583
1978	998	1,640	1,685	1,043	2,320	2,199	2,222	1,962	2,045	2,277	2,380
79	1,268	1,748	2,141	902	3,672	3,549	2,332	2,962	3,313	3,494	3,695
80	1,834	2,614	3,040	777	2,957	2,975	2,641	2,847	2,562	3,279	3,228
81	1,673	2,610	3,183	1,335	3,073	2,721	3,235	3,550	3,206	3,499	3,169
82	468	1,398	1,662	524	1,868	1,702	1,799	1,877	1,776	1,675	1,595

*For complete system description, refer to Table 1 or the inside back cover.

manure). They found that including fertilizer and green manure in a rotation increased yields over rotation alone. In their study, overseeding continuous wheat with "Hubam" clover increased yields, but the clover crop failed in 3 of 6 years; thus, they summarized that it was not feasible to grow a good crop of wheat and clover at the same time. Laws (18) found that the primary limitation to overseeding small grains with sweet clover in the Blacklands was lack of stand establishment because clover seedlings could not compete with fertilized wheat.

An analysis of systems that were not changed from 1961 to 1982 (Table 12) indicates that wheat grown in rotation with cotton and sorghum and fertilized with 45-45-0 and 11,200 kg/ha manure on row crops (System 9) produced higher yields than all other systems evaluated during the time period. Average yields for the 22-year period for System 9 were 2,497 kg/ha (37 bu/ac). Highest yield for this system was 3,822 kg/ha (57 bu/ac) produced in 1977 (Table 11). The ranking of yields for Systems 5 (nonfertilized continuous wheat), 6 (continuous wheat 22-45-0), 8 (nonfertilized cotton-sorghum-wheat), and 12 (cotton-sorghum-wheat with 67-45-0) was the same as during 1948-1982. However, during 1961-1982 the

Table 12. Comparison of wheat yields at Dallas, TX from farming systems that were not altered during 1961-1982.

System* no.		Grain yield (kg/ha)
9	cotton-sorghum-wheat 67-45-0 + manure	2,497 a**
7	continuous wheat 67-45-0	2,289 b
12	cotton-sorghum-wheat 67-45-0	2,249 b
6	continuous wheat 22-45-0	2,093 c
5	nonfertilized continuous wheat	1,480 d
8	nonfertilized cotton-sorghum-wheat	947 e

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Grain sorghum in the highest yielding system (9 on left) and the lowest yielding system (4 on right) in 1979.

Continuous grain sorghum fertilized with 134-134-0 (left) and rotated sorghum with 134-134-0 (right) in 1979.

Nonfertilized rotated wheat in 1975. This system produced the lowest wheat yields of all treatments.

Nonfertilized continuous wheat in 1975.

Wheat residue from the nonfertilized cotton-sorghum-wheat rotation in 1980.

Wheat residue from the cotton-sorghum-wheat rotation fertilized with 45-45-0 (1980).

Nonfertilized continuous cotton (right) and fertilized with 45-45-0 (left) in 1979.

Nonfertilized continuous cotton (left) and cotton-sorghum-wheat rotation fertilized with 45-45-0 (right) in 1979.

Nonfertilized continuous corn (1981).

Corn in a cotton-corn-corn rotation fertilized with 90-45-0 (1981).

Table 13. Influence of farming system and fertilizer practice on wheat yield at Dallas, TX, 1971-1981.

System* no.		Grain yield (kg/ha)
16	cotton-sorghum-wheat, 134-134-0 cotton & sorghum, 67-45-0 wheat	2,962 a**
9	cotton-sorghum-wheat, 45-45-0+manure cotton & sorghum, 67-45-0 wheat	2,889 a
15	cotton-sorghum-wheat, 90-90-0 cotton & sorghum, 67-45-0 wheat	2,887 a
11	cotton-sorghum-wheat, 180-180-0 cotton & sorghum, 67-45-0 wheat	2,811 ab
14	cotton-wheat-sorghum, 45-0-0 cotton & sorghum, 67-45-0 wheat	2,689 bc
13	cotton-sorghum-wheat, 45-0-0 cotton & sorghum, 67-45-0 wheat	2,660 bcd
7	continuous wheat, 67-45-0	2,596 cd
12	cotton-sorghum-wheat, 45-45-0 cotton & sorghum, 67-45-0 wheat	2,487 d
6	continuous wheat, 22-45-0	2,303 e
5	nonfertilized continuous wheat	1,626 f
8	nonfertilized cotton-sorghum-wheat	1,019 g

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

rotated system with 67-45-0 applied to wheat (System 12) produced significantly higher yields than the continuous system with 22-45-0 applied to wheat. Rotated wheat and continuous wheat with the same fertilizer rates (Systems 7 and 12) produced comparable yields during the period 1961-1982.

Systems 9, 11, 15, and 16 produced similar yields (2,811-2,962 kg/ha; 42-44 bu/ac) during the period 1971-1981 (Table 13). As in previous years, lowest yields were produced by System 8 (1,019 kg/ha; 15 bu/ac) and the ranking of Systems 5, 6, 8, and 12 was the same as in previous years. The same yield was produced by wheat after cotton (System 14) as by wheat after sorghum (System 13) when 67-45-0 was applied to wheat. Application of phosphorus to sorghum and cotton in a rotation did not increase wheat yield if 67-45-0 was applied to wheat every year (Systems 12 and 13).

The data contained in Figure 5 suggest that 67 kg N applied to wheat was not sufficient for maximum yields because an increase in wheat yield was obtained from residual fertilizer applied to cotton and sorghum. The regression equation obtained shows that maximum wheat yields could be obtained from systems receiving 130-130-0 on cotton and sorghum and 67-45-0 on wheat. The information from Table 13 indicates that the yield increase was due to residual N. The highest fertilizer rate applied to wheat in these studies was 67-45-0 which was not sufficient for maximum yield. Additional but separate studies have indicated that in most years optimum wheat yields can be obtained in the Blacklands with application of 90-45-0. Higher N rates may be required if wheat is grazed and then used for grain production.

Long-term trends for four systems involving wheat are depicted in Figure 6. Wheat yields were averaged throughout 5-year increments to reduce environmental variation. Parabolic regression equations were developed using years in the system (X) and wheat yield (Y). The equations and R^2values obtained were: System 8: $\hat{Y} = 661 + 47.5X - 1.21X^2$, $R^2 = 0.13$; System 5: $\hat{Y} = 173 + 122.4X - 2.56X^2$, $R^2 = 0.70$; System 6: $\hat{Y} = 1223 + 54.7X - 0.79X^2$, $R^2 = 0.45$; and System 12: $\hat{Y} = 636 + 99.8X - 1.36X^2$, $R^2 = 0.67$. Yearly yield increases for the fertilized systems (6 and 12) are assumed to be primarily attributed to higher yielding varieties. Also, wheat yield from nonfertilized systems may have increased with improved cultivars until fertilizer became limiting because of improved production.

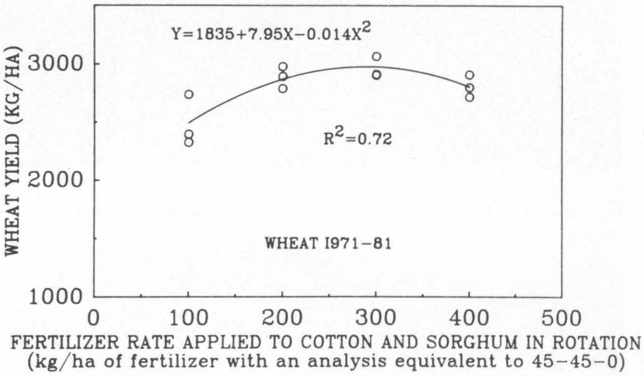

Figure 5. Wheat yield as affected by fertilizer applied to cotton and sorghum in rotation with wheat.

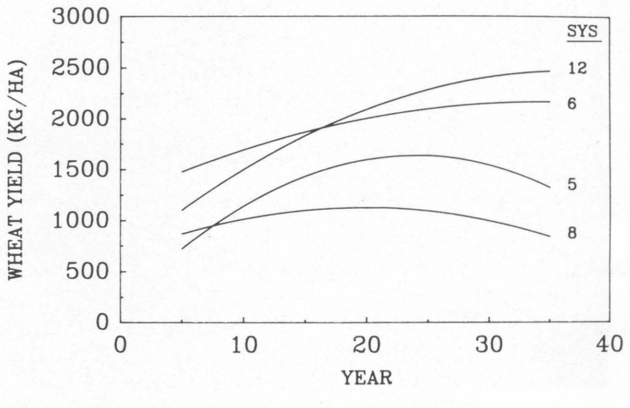

Figure 6. Relationship between wheat yields and number of years in four farming systems (12 is cotton-sorghum-wheat 45-45-0; 6 is continuous wheat 22-45-0; 5 is nonfertilized continuous wheat; and 8 is nonfertilized cotton-sorghum-wheat).

Wheat Protein

Protein concentration in wheat grain generally increased in systems receiving high nitrogen rates on cotton and sorghum in rotation (Table 14). One exception was System 7 which was a continuous system receiving 67-45-0 annually. Nonfertilized continuous wheat contained protein concentrations as high as some systems receiving N. The 5-year average protein concentration for the treatments ranged from 12.7 for System 12 to 14.2 for System 11. Protein production was essentially a function of yield because yield differences due to treatment were much greater than protein concentration differences. As with grain yields, Systems 5, 6, 8, and 12 produced the least protein/ha. The least protein was produced by System 8 (117 kg/ha). Systems 9, 11, 15, and 16 produced almost four times as much protein as System 8. The yearly protein concentrations and protein productions for the period 1978-1982 are presented in Table 15. Protein concentrations and production were less in 1981-1982 than in 1978-1980, regardless of the system.

Cotton Yield

Four systems involving cotton were in effect from 1948 through 1982, and they all produced significantly different yields during the period (Table 16). Highest yields (383 kg lint/ha) were produced by the cotton-sorghum-wheat rotation with application of 45-45-0 to cotton (System 12). The same system without fertilizer (System 8) produced the next highest yield (344 kg/ha), and these yields were higher than those obtained from continuous cotton with yearly application of 45-45-0 (System 3). Continuous cotton without fertilizer (System 1) produced lower yields than all other systems (268 kg/ha).

Application of 45-45-0 to cotton grown in rotation with sorghum and clover (System 10) did not increase yields of cotton over those obtained from the same system with 0-67-0 applied only to clover (Table 17). However, clover did not fix enough N for grain sorghum, which was the second crop after clover.

Table 14. Protein concentration in wheat grain and protein production as influenced by cropping system and fertilizer, 1978-1982.

System* no.	% protein	System no.	kg protein/ha
11	14.16 a**	15	402 a
7	14.11 a	16	399 a
9	14.04 a	9	394 a
15	13.84 ab	11	384 ab
16	13.78 ab	14	344 bc
5	13.48 bc	13	343 bc
14	13.23 cd	7	326 c
13	13.10 cde	12	310 cd
6	12.97 cde	6	268 d
8	12.75 de	5	174 e
12	12.69 e	8	117 f

11 cotton-sorghum-wheat, 180-180-0 cotton & sorghum, 67-45-0 wheat
7 continuous wheat, 67-45-0
9 cotton-sorghum-wheat, 45-45-0+manure cotton & sorghum, 67-45-0 wheat
15 cotton-sorghum-wheat, 90-90-0 cotton & sorghum, 67-45-0 wheat
16 cotton-sorghum-wheat, 134-134-0 cotton & sorghum, 67-45-0 wheat
5 nonfertilized continuous wheat
14 cotton-wheat-sorghum, 45-0-0 cotton & sorghum, 67-45-0 wheat
13 cotton-sorghum-wheat, 45-0-0 cotton & sorghum, 67-45-0 wheat
6 continuous wheat, 22-45-0
8 nonfertilized cotton-sorghum-wheat
12 cotton-sorghum-wheat, 45-45-0 cotton & sorghum, 67-45-0 wheat

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 15. Influence of farming system and fertilizer practice on yearly protein concentration in wheat grain and protein production at Dallas, TX, 1978-1982.

System* no.	1978	1979	1980	1981	1982	1978	1979	1980	1981	1982
	% protein					kg protein/ha				
5	15.80	14.86	15.17	12.07	9.52	158	189	279	202	42
6	15.31	14.23	13.42	11.17	10.24	250	252	357	292	142
7	16.05	15.48	14.55	11.68	12.81	270	331	442	373	212
8	14.32	13.17	15.30	11.25	9.69	149	119	118	150	50
9	15.56	14.84	15.31	12.58	11.93	361	545	453	388	222
11	15.88	15.71	16.02	13.51	9.69	349	561	476	366	166
12	14.95	12.85	14.16	11.29	10.19	332	293	375	367	184
13	15.88	12.70	14.70	11.53	10.68	311	376	418	410	200
14	15.36	13.71	14.89	12.19	9.99	316	452	381	391	179
15	16.01	14.66	15.92	12.84	9.76	365	510	522	450	164
16	15.56	15.30	15.21	13.14	9.65	370	565	491	417	153

5 nonfertilized continuous wheat
6 continuous wheat 22-45-0
7 continuous wheat 67-45-0
8 nonfertilized cotton-sorghum-wheat
9 cotton-sorghum-wheat 45-45-0+manure cotton & sorghum, 67-45-0 wheat
11 cotton-sorghum-wheat 180-180-0 cotton & sorghum, 67-45-0 wheat
12 cotton-sorghum-wheat 45-45-0 cotton & sorghum, 67-45-0 wheat
13 cotton-sorghum-wheat 45-0-0 cotton & sorghum, 67-45-0 wheat
14 cotton-wheat-sorghum 45-0-0 cotton & sorghum, 67-45-0 wheat
15 cotton-sorghum-wheat 90-90-0 cotton & sorghum, 67-45-0 wheat
16 cotton-sorghum-wheat 134-134-0 cotton & sorghum, 67-45-0 wheat

*For complete system description, refer to Table 1 or the inside back cover.

Table 16. Influence of farming system and fertilizer practice on yield of cotton at Dallas, TX, 1948-1982.

System* no.		kg lint/ha
12	cotton-sorghum-wheat 45-45-0	383 a**
8	nonfertilized cotton-sorghum-wheat	344 b
3	continuous cotton 45-45-0	324 c
1	nonfertilized continuous cotton	268 d

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 17. Influence of farming system and fertilizer practice on yield of cotton at Dallas, TX, 1952-1970.

System* no.		kg lint/ha
10	cotton-sorghum-clover 45-45-0	347 a**
11	nonfertilized cotton-sorghum-clover	327 ab
3	continuous cotton 45-45-0	311 b
1	nonfertilized continuous cotton	252 c

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

From 1961 to 1982, application of 11,200 kg/ha manure to cotton and sorghum in rotation did not significantly (0.05 level) increase cotton yields more than rotated cotton fertilized with 45-45-0 (Table 18). Fertilized and rotated cotton (System 12), however, produced higher yields than rotated nonfertilized cotton (System 8). Rotated nonfertilized cotton (System 8) produced higher yields than continuous cotton fertilized with 45-45-0 (System 3).

During the period from 1961 to 1982, continuous cotton receiving 45-0-0 (System 21) produced significantly higher yields than continuous cotton receiving 45-45-0 (System 3). Reasons for the slight decrease in cotton yield due to P application on continuous cotton was not evident from these studies. Phosphorus has induced micronutrient deficiencies in some crops (4). Micronutrient deficiencies were not visible on any cotton plots during 1977-1982, but plants were not analyzed for micronutrient concentration. Phosphorus did not decrease yields of rotated cotton.

Table 18. Influence of farming system and fertilizer practice on yield of cotton at Dallas, TX, 1961-1982.

System* no.		kg lint/ha
9	cotton-sorghum-wheat 45-45-0+manure	408 a**
12	cotton-sorghum-wheat 45-45-0	388 a
8	nonfertilized cotton-sorghum-wheat	352 b
21	continuous cotton 45-0-0	343 b
3	continuous cotton 45-45-0	318 c
1	nonfertilized continuous cotton	263 d

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Analysis of lint yield for the time period 1971-1981 (Table 19) showed that cotton grown in a cotton-sorghum-wheat rotation receiving at least 45 kg N/ha or in a cotton-sorghum-clover rotation produced higher yields than continuous cotton regardless of fertilizer application. Cotton grown in the rotation cotton-corn-corn (System 18) produced lower yields than cotton grown in a cotton-sorghum-wheat rotation (System 12). Nonfertilized continuous cotton produced lower yields than cotton in other systems.

Table 19. Influence of farming system and fertilizer practice on yield of cotton at Dallas, TX, 1971-1981.

System* no.		kg lint/ha
16	cotton-sorghum-wheat 134-134-0	396 a*
13	cotton-sorghum-wheat 45-0-0	375 ab
15	cotton-sorghum-wheat 90-90-0	365 bc
11	cotton-sorghum-wheat 180-180-0	365 bc
9	cotton-sorghum-wheat 45-45-0+manure	363 bc
10	cotton-sorghum-clover 45-45-0	342 cd
14	cotton-wheat-sorghum 45-0-0	341 cd
12	cotton-sorghum-wheat 45-45-0	340 cd
8	nonfertilized cotton-sorghum-wheat	320 de
21	continuous cotton 45-0-0	306 e
18	cotton-corn-corn 45-45-0	304 e
3	continuous cotton 45-45-0	295 e
1	nonfertilized continuous cotton	258 f

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

The data contained in Figure 7 indicate a slight increase in lint yield due to increased fertilizer application to cotton grown in a cotton-sorghum-wheat rotation. The polynomial regression equation obtained using fertilizer application rate (X) and lint yield (Y) showed 314 kg lint/ha could be produced without fertilizer. Application of 90-90-0 only increased yields to 371 kg/ha. Although the R^2 value obtained for the regression equation was statistically significant, it indicated that only 35 percent of the variation in yield can be accounted for by application rate of fertilizer.

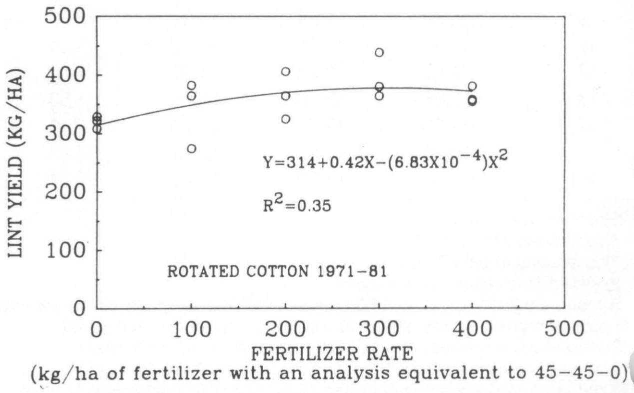

Figure 7. Influence of fertilizer application rate on lint yield from cotton in a cotton-sorghum-wheat rotation.

Table 20. Influence of farming systems and fertilizer practices on cotton yield at Dallas, TX, 1948-1982.

Year	System no.*												
	1	3	8	9	10	11	12	13	14	15	16	18	21
	kg lint/ha												
1948	283	243	330				249						
49	500	528	390				492						
50	394	597	464				723						
51	267	383	304				501						
52	183	260	226		242	244	251						
1953	376	405	387		379	273	448						
54	201	253	270		267	245	276						
55	285	307	315		298	289	331						
56	130	118	155	158	161	150	173						
57	228	257	273	291	253	269	261						
1958	262	338	419	392	362	323	420						
59	297	390	466	242	283	330	327						
60	202	286	317	422	304	319	406						
61	316	475	546	631	577	504	616	596	534				508
62	491	389	590	694	656	664	771	791	900				638
1963	255	328	357	455	329	402	352	507	500				430
64	260	339	334	372	401	302	392	326	301				271
65	292	402	380	437	393	365	458	423	418				333
66	304	483	530	610	569	408	519	629	409				522
67	193	233	208	289	273	251	258	269	246				253
1968	190	255	293	421	372	358	358	407	463				344
69	140	184	190	221	206	205	195	206	212				167
70	183	229	256	271	264	220	301	269	248				224
71	222	221	238	264	268	267	270	288	266	215	285	191	223
72	354	470	380	497	410	422	435	486	461	465	454	390	436
1973	247	220	304	373	355	467	441	457	335	418	469	327	354
74	163	161	225	158	193	219	182	179	153	169	213	156	191
75	189	220	292	369	371	441	270	431	394	470	406	320	298
76	319	344	331	432	358	392	410	365	320	397	465	337	339
77	292	337	342	388	349	306	394	369	367	363	386	339	296
1978	183	159	152	171	179	144	166	178	158	152	204	151	159
79	340	496	519	575	522	537	521	583	494	530	622	515	454
80	204	214	230	238	216	211	187	230	265	242	262	185	187
81	329	404	510	528	536	606	464	554	544	593	587	434	429
82	323	427	527	588	532	566	564	576	522	589	633	525	482

*For complete system description, refer to Table 1 or the inside back cover.

Yearly cotton yields for each of the systems involving cotton are provided in Table 20. These data indicate that in addition to cropping system and fertilizer, factors such as weather, insects, and root rot have an influence on cotton yields in the North Texas Blacklands. Blackland prairie soils have high inherent fertility. This is evidenced by the fact that cotton in a nonfertilized rotation produced 45 kg/ha more lint during years 31-35 than it did during the first 5 years of the study. Nonfertilized rotated cotton produced an average of 388 kg lint/ha during the last 5 years of the experimental period. All systems produced relatively high yields during years 32-35. Cotton yield could not be predicted by a first or second order regression equation using years as the independent variable because of low correlation.

Cotton Root Rot

Cotton root rot, caused by *Phymatotrichum omnivorum*, was extremely variable from year to year regardless of the cropping system (Table 21). Estimation of percent of each plot showing root rot symptoms at maturity from 1959 through 1982 indicates that the percent root rot ranged from 0 to 99.7 for nonfertilized continuous cotton (System 1) and ranged from 0 to 51.0 for the nonfertilized rotated cotton (System 8). Statistical analysis of root rot data obtained between 1959 and 1982 showed that cotton grown in a nonfertilized rotation with sorghum and wheat (System 8) resulted in significantly less root rot than all other systems except cotton grown in a cotton-sorghum-wheat rotation fertilized with 45-45-0 (System 12 in Table 22). Rotation with sorghum and wheat or sorghum and clover resulted in significantly less root rot than continuous cotton regardless of fertilizer rate. Root rot incidence may be slightly increased by fertilizer rate on rotated systems (System 12).

Table 21. Influence of farming system and fertilizer practice on cotton root rot incidence at Dallas, TX, 1959-1982.

Year	System no.*					
	1	3	8	9	10	12
	% Root rot					
1959	72.0	47.0	4.3	7.0	1.0	50.0
60	50.3	69.3	20.0	29.7	24.3	16.7
61	20.0	9.3	0	1.7	4.3	1.0
62	63.3	68.3	26.7	33.3	25.0	8.3
63	71.0	66.0	33.3	44.0	40.7	44.0
64	1.3	3.0	1.7	2.7	1.7	0.7
65	28.3	6.3	2.3	4.7	3.0	1.0
66	76.7	49.0	21.7	24.3	50.7	40.3
67	36.7	23.0	12.7	11.0	16.7	5.3
68	75.0	80.7	49.0	52.3	47.0	54.3
69	1.0	0	0.3	0.7	0	0.3
70	12.0	2.0	1.7	1.3	3.3	0
71	99.7	98.3	51.0	58.0	68.3	47.0
72	6.3	3.3	1.7	4.3	1.3	20.0
73	—	—	—	—	—	—
74	51.0	42.7	6.3	23.0	35.0	17.3
75	82.7	81.3	14.3	50.0	46.7	40.0
76	3.0	26.7	0.7	7.3	18.3	8.0
77	2.0	1.7	0	1.7	3.3	0
78	0	0.3	0	5.7	2.0	1.7
79	34.0	28.7	0.7	10.3	11.7	2.7
80	7.0	3.7	0	5.0	3.0	2.0
81	29.0	18.3	0.7	36.3	13.7	12.0
82	38.7	42.0	0	25.0	15.0	4.0

1 nonfertilized continuous cotton
3 continuous cotton 45-45-0
8 nonfertilized cotton-sorghum-wheat
9 cotton-sorghum-wheat 45-45-0+manure
10 cotton-sorghum-clover 45-45-0 1959-79, no fertilizer on cotton 1980-82
12 cotton-sorghum-wheat 45-45-0

*For complete system description, refer to Table 1 or the inside back cover.

Table 22. Influence of farming systems and fertilizer on cotton root rot incidence on Blackland soil at Dallas, TX, 1959-1982. (Arc Sin Transformation for analysis).

System* no.		% of plot showing root rot symptoms
1	nonfertilized continuous cotton	37.4 a**
3	continuous cotton 45-45-0	33.9 a
9	cotton-sorghum-wheat 45-45-0+manure	19.1 b
10	cotton-sorghum-clover 45-45-0 1959-79 no fertilizer on cotton 1980-82	18.9 b
12	cotton-sorghum-wheat 45-45-0	13.6 bc
8	nonfertilized cotton-sorghum-wheat	10.8 c

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

However, in a 3-year study, Jordan, et al. (17) found that cotton root rot incidence was decreased by the application of nitrogen and was increased with the application of phosphorus to Wilson soils. The effects of fertilizer on root rot were not consistent on Houston Black clay in their study. Rotated systems with 45-45-0 and manure and cotton-sorghum-clover with 45-45-0 applied to cotton resulted in significantly more cotton root rot than nonfertilized cotton-sorghum-wheat rotation. Continuous cotton resulted in significantly more root rot than all other systems evaluated. Garrett (8) suggested that monoculture promotes development of specialized pathogens, such as *P. omnivorum*, while rotation with taxonomically different plants starves the specialized pathogens.

The data from System 8 (cotton-sorghum-wheat rotation) in Table 21 suggest that culture of cotton under this system might result in elimination of the symptoms of cotton root rot after a long period of time.

Corn Yield

Corn grown continuously without fertilizer (System 2) produced an average of 2,065 kg/ha during 1957-1982 (Table 23). This was significantly (0.05 level) lower than the 2,745 kg/ha produced by fertilized continuous corn (System 17).

Corn yields for the period 1964-1982 are presented in Table 24. Corn from the fertilized system of cotton-corn-corn (Systems 18-1 and 18-2) produced higher yields than fertilized continuous corn (System 17). Nonfertilized continuous corn produced an average of 1,958 kg/ha for the 19-year period. Fertilization of continuous corn with 45-45-0 from 1957-1978 and with 90-45-0 from 1979-1982 resulted in 680 kg/ha higher yield than nonfertilized continuous corn during the same time period.

Table 23. Influence of fertilizer on yield of continuous corn at Dallas, TX, 1957-1982.

System* no.		Grain yield kg/ha
17	continuous corn 45-45-0	2,745 a**
2	nonfertilized continuous corn	2,065 b

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 24. Influence of farming system and fertilizer practice on corn yield at Dallas, TX, 1964-1982.

System* no.		Grain yield (kg/ha)
18-1	cotton-corn-corn 45-45-0	2,922 a**
18-2	cotton-corn-corn 45-45-0	2,876 a
17	continuous corn 45-45-0	2,694 b
2	nonfertilized continuous corn	1,958 c

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Corn produced higher yields when rotated with cotton, but it did not seem to matter whether corn was the first or second crop after cotton (Table 24). Yields of first year corn after cotton were 2,922 kg/ha, while corn grown the second year after cotton produced 2,876 kg/ha. Both of these were significantly higher than the yield from continuous corn, whether fertilized or not.

Nonfertilized continuous corn produced an average of 1,584 kg/ha (Table 25) during the last 5 years of the study (years 23-27). This yield is very close to the 29 bu/ac that Smith, et al. (25) suggested as the equilibrium yield level of nonfertilized corn grown on Blackland soil.

Yields were low during the entire study period, but the low yields did not appear to be entirely related to fertilizer application rate. Increasing the N application rate from 45 to 90 kg/ha on continuous or rotated corn during the last 4 years of the study did not increase the yield over that obtained during the first 15 years for rotated corn or for the first 22 years for continuous corn (Table 25). There were no definite trends regarding continual increase or decrease of corn yield as a function of years for any of the systems.

Table 25. Influence of farming system and fertilizer on yearly yield of corn at Dallas, TX, 1956-1982.

Year	System*			
	2	17	18-1	18-2
	kg grain/ha			
1956	288			
57	2,022	2,051		
58	2,668	2,737		
59	2,760	2,528		
60	2,193	2,584		
61	2,242	4,029		
1962	2,850	3,700		
63	1,765	2,555		
64	1,666	2,693	3,006	3,155
65	780	985	1,349	1,215
66	3,115	3,797	3,818	3,840
1967	1,541	2,703	3,276	2,661
68	3,096	4,708	5,400	4,376
69	914	1,533	1,152	2,306
70	2,120	2,348	2,597	2,469
71	2,603	3,458	3,040	3,238
1972	2,312	3,000	3,036	3,180
73	2,187	2,638	3,558	3,428
74	2,327	3,293	3,374	3,345
75	2,266	3,257	3,926	3,634
76	2,229	3,627	3,949	3,681
1977	2,122	2,546	2,546	2,312
78	1,666	2,070	2,275	2,070
79	1,344	1,961	2,038	2,051
80	1,206	1,459	1,390	1,549
81	1,430	1,906	2,584	2,384
82	2,275	3,197	3,211	3,742

2 nonfertilized continuous corn
17 continuous corn 45-45-0
18-1 cotton-corn-corn 45-45-0
18-2 cotton-corn-corn 45-45-0

*For complete system description, refer to Table 1 or the inside back cover.

Soil Properties

Organic Carbon

Carbon is a major component of soil organic matter. Organic carbon is commonly determined and multiplied by a factor of 1.724 to obtain an estimate of soil organic matter. The carbon content of organic matter is highly variable however, and this factor does not always approximate organic matter. Because of these variations, results from these studies are reported as organic carbon. Trends of the effects of cropping systems on soil organic carbon content are depicted graphically in Figure 8. Organic carbon decreased with time under Systems 1, 3, 4, 5, 8, 12, and 19. After 32 years, System 1 had the lowest concentration of soil organic carbon for all treatments measured.

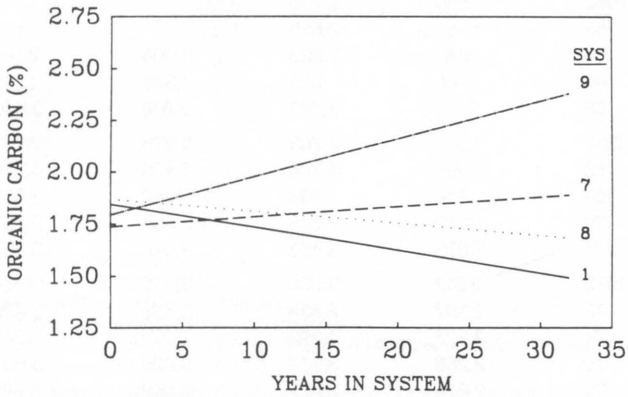

Figure 8. Relationship between soil organic carbon percent and years in four different farming systems (9 is cotton-sorghum-wheat 45-45-0 + manure; 7 is continuous wheat 67-45-0; 8 is nonfertilized cotton-sorghum-wheat; and 1 is nonfertilized continuous cotton).

For System 1 (nonfertilized continuous cotton), the relationship between years in system (X) and soil organic carbon percentage (Y) was linear with a negative slope. The equations developed for Systems 1 and 8 (nonfertilized cotton-sorghum-wheat) were $\hat{Y} = 1.81 - 0.011X$ ($R^2 = 0.67$) and $\hat{Y} = 1.87 - 0.006X$ ($R^2 = 0.12$), respectively (Figure 8). System 9 (cotton-sorghum-wheat, fertilizer, and manure) affected soil organic carbon more than any other system measured. The linear increase in organic carbon due to System 9 was described by the equation $\hat{Y} = 1.80 + 0.018X$ ($R^2 = 0.92$). The increase in organic carbon from this system was due to the 11,200 kg/ha of manure applied yearly to cotton and sorghum because the same system without manure resulted in a decrease in organic carbon.

Laws (20) found that about 4,000 kg/ha of residue must be returned to Blackland soil to maintain organic matter levels. These studies showed that organic matter changes were extremely slow in the Blackland soils studied, and it would not be economically feasible to increase soil organic matter. Smith, et al. (25) determined that Blackland soils reached an equilibrium of about 2 percent organic matter (approximately 1.16 percent organic carbon) under continuous nonfertilized corn. All systems measured in these studies were higher, as they contained at least 1.5 percent organic carbon after 32 years.

Total Nitrogen

Changes in total soil N concentration were similar to those of organic carbon in that total N increased with time under System 9 but decreased under Systems 1, 3, 4, 5, 7, 8, and 12. Typical total N changes with time are depicted in Figure 9. System 9 was the only treatment measured that resulted in increased N. However, treatments that received high amounts of N between 1971 and 1981 were not measured. The regression equation obtained for System 9 was $\hat{Y} = 0.18 + 0.00094X$ ($R^2 = 0.62$) (Y = % total N, X = years in system), and for System 1 the regression equation was $\hat{Y} = 0.20 - 0.0015X$ ($R^2 = 0.71$). The equation for System 1 (nonfertilized continuous cotton) resulted in the largest negative slope of all systems measured. This indicates that total N was depleted at a faster rate under this system than all other systems measured. The increase in N under System 9 was attributed to manure since the same system without manure (System 12) resulted in less N after 32 years than initially.

About 30 kg/N/ha/yr was removed from soil with nonfertilized grain sorghum treatments (Table 8). This would amount to about 960 kg N/ha over a 32-year period (1948-1979), and should reduce the total soil N concentration by 0.043 percent if all N was removed from the top 15 cm of soil and none was returned by N fixation or other processes. The actual reduction in the average N of Systems 8 and 4 was 0.040 percent (Figure 9 and data not shown for System 4). Approximately the same amount

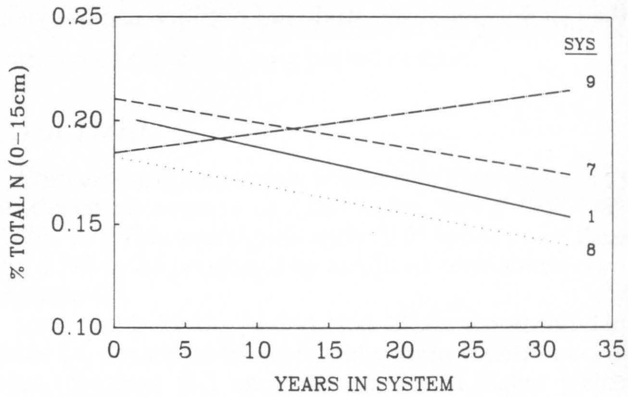

Figure 9. Relationship between total soil N and number of years in four farming systems (9 is cotton-sorghum-wheat 45-45-0 + manure; 7 is continuous wheat 67-45-0; 1 is nonfertilized continuous cotton; and 8 is nonfertilized cotton-sorghum-wheat).

of soil N (976 kg/ha) was removed by continuous nonfertilized wheat during the same period (Table 14). Total N for this system changed from 0.18 percent in 1948 to 0.15 percent in 1979.

Nitrogen Mineralization

Nitrogen mineralization was a function of applied N (Figure 10), but the rate was similar whether the cropping system was continuous sorghum or cotton-sorghum-wheat rotation. Applied N accounted for 88 percent of the variation in N mineralization rate when rotated and continuous treatments were combined. Nitrogen mineralization rates estimated from the curvilinear equation obtained were 0.47 mg/kg/day with no N applied, to 1.6 mg/kg/day with 1,620 kg N/ha applied over an 11-year period.

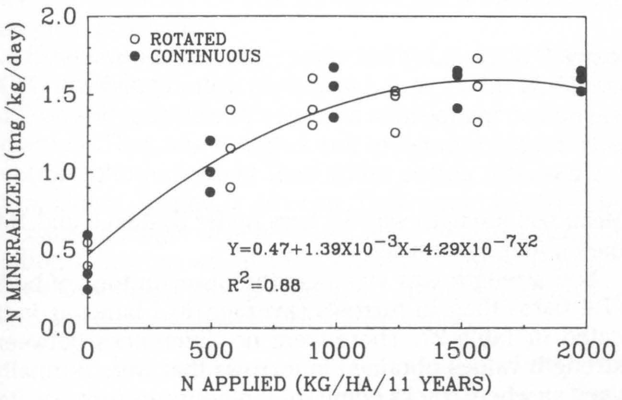

Figure 10. Soil nitrogen mineralization rate as influenced by N applied to Blackland soil.

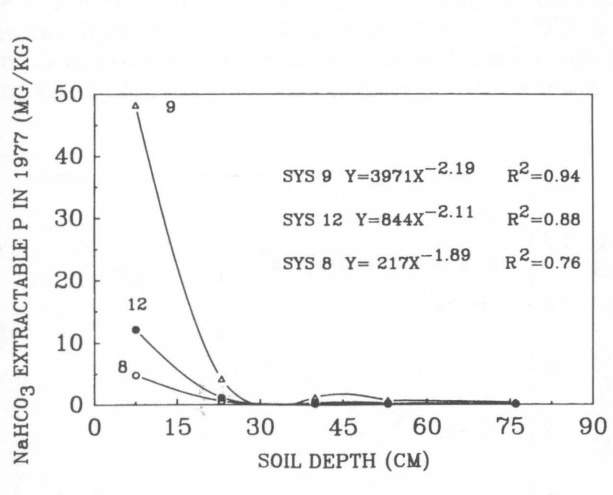

Figure 11. Relationship between extractable soil phosphorus and soil depth as a result of three farming systems (9 is cotton-sorghum-wheat 45-45-0 + manure; 12 is cotton-sorghum-wheat 45-45-0; and 8 is nonfertilized cotton-sorghum-wheat).

Soil Phosphorus

Soil P extractable with $NaHCO_3$was greatly increased at the 0-15 cm depth by yearly application of manure (System 9, Figure 11) over the same system without manure (System 12, cotton-sorghum-wheat with 45 kg P_2O_5/ha/yr). Extractable soil P was 48, 12, and 5 mg/kg at the 0-15 cm depth for Systems 9, 12, and 8, respectively. Soil phosphorus concentration for all other systems measured (Systems 11 and 16) were similar to that of System 12. As indicated by Figure 11, a small amount of the P applied in System 9 moved to the 15-30 cm depth. Phosphorus concentration at 15-30 cm depth was about 3 times higher under System 9 than under Systems 8 and 12.

Exchangeable Potassium

Exchangeable soil K is assumed to be available for plant use. Exchangeable K determinations for Systems 1 (nonfertilized continuous cotton) and 9 (cotton-sorghum-wheat with fertilizer and manure) in 1981 showed that K levels were still very high in both systems, although K had not been applied to System 1 since the initiation of the study (Figure 12). System 1 contained about 5,600 kg/ha of available K in the 0-90 cm depth (0-3 ft) after 34 years cropping with cotton. Manure application (System 9) increased extractable K to about 2.4 and 1.6 milliequivalents (meq)/100 g (1 meq K/100 g = approximately 780 lbs/acre 6 ins.) in the 0-15 and 15-30 cm depth, respectively. Exchangeable K extracted from soil under Systems 8 and 12 was slightly higher (approximately 0.2 meq/100 g) than that of System 1 in the 0-30 cm depth but was similar to System 1 at lower depths. These Blackland soils, as well as several other Texas soils, have been found to have an extremely high K supplying capacity (6, 12, 13, 21, 22, 26).

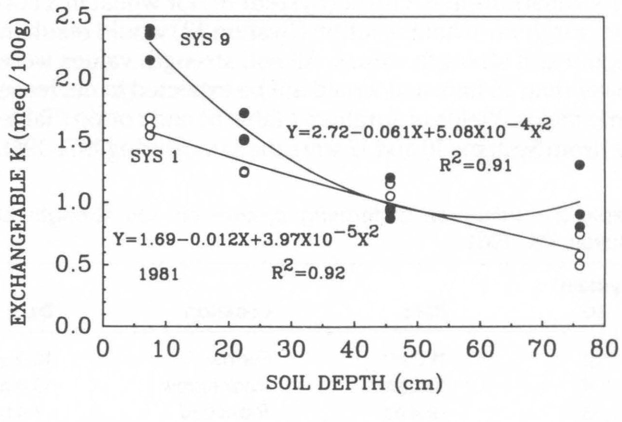

Figure 12. Exchangeable soil K under two farming systems as influenced by soil depth (9 is cotton-sorghum-wheat 45-45-0 + manure and 1 is nonfertilized continuous cotton).

Table 26. Average soil strength values for selected farming systems at Dallas, TX, March 1981.

Soil depth		Bottom of furrow					Top of bed					Bottom of wheel track furrow				
		System*					System					System				
ins	cm	3	4	9	10	12	3	4	9	10	12	3	4	9	10	12
		bars														
2	5.1	10.1	10.5	9.6	12.4	10.5	0.9	1.8	3.4	1.2	1.4	10.8	9.5	8.8	10.0	9.8
4	10.2	8.4	8.6	8.0	9.7	8.2	2.8	3.6	5.4	3.9	3.3	8.8	7.9	8.2	9.3	8.2
6	15.2	8.5	8.5	7.5	9.3	7.9	4.9	5.7	5.7	5.7	5.0	8.3	8.3	7.5	9.0	8.0
8	20.3	9.4	8.9	7.7	10.3	8.1	5.6	6.0	6.4	6.0	6.1	8.6	8.7	7.8	8.8	7.7
10	25.4	10.2	9.7	7.7	11.8	8.6	6.4	6.4	7.1	7.2	6.7	9.2	9.5	8.1	10.1	7.2
12	30.5	10.8	11.1	8.3	11.8	9.5	6.6	7.3	7.2	8.7	7.2	9.1	9.9	8.3	11.5	8.4
14	35.6	11.5	12.2	8.8	12.5	10.9	7.2	8.6	7.8	9.8	7.6	9.9	11.2	9.3	13.1	10.1
16	40.6	12.2	13.4	9.1	13.7	11.3	7.7	9.5	8.8	11.1	8.4	11.1	12.3	10.5	14.4	11.4
18	45.7	13.0	14.6	9.2	13.9	11.9	8.1	10.6	9.5	12.4	9.4	12.3	13.5	11.4	16.0	12.1
20	50.8	13.7	15.5	9.4	14.5	12.5	9.3	11.8	10.3	13.4	10.6	13.3	14.6	11.6	15.8	12.4
22	55.9	14.0	16.4	9.7	15.5	12.8	10.4	13.2	11.6	14.5	11.3	13.6	15.6	11.8	16.1	13.2

	Pr > F	
Sys	0.0001	3 continuous cotton
Depth	0.0001	4 continuous sorghum
Sys × Depth	NS	9 cotton-sorghum-wheat + manure
Loc	0.0001	10 cotton-sorghum-clover
Sys × Loc	0.063	12 cotton-sorghum-wheat
Depth × Loc	0.011	

*For complete system description, refer to Table 1 or the inside back cover.

Soil Strength

Root growth is normally reduced and tillage is more difficult in soils with high soil strength values. Gerard, et al. (10) found that soil strength values greater than 25 bars were required to restrict cotton root growth in clay soils. Soil strength values obtained from measurements made in 1981 indicated that soil strength was affected by depth, cropping system, and location of measurement (bed or furrow), but there was no interaction between depth and system (Table 26). Of the treatments measured, Systems 9 and 12 resulted in lower soil strength values than Systems 10 and 4 (Table 27). It is not clear why substitution of clover (System 10) for wheat in a cotton-sorghum-wheat rotation (System 12) would result in higher soil strength values. All soil strength values were lower than 25 bars and would not be expected to decrease crop yields. Yields of sorghum (Table 6) and cotton (Table 19) from Systems 10 and 12 were the same during 1971-1981. Mean soil strength was 8.5 bars under System 9 and 11.0 bars under System 10.

Soil strength was significantly lower on tops of beds (7.4 bars) than in furrows (average 10.7 bars) as indicated in Table 27. There were no differences between strength values obtained in furrows that were normally used as wheel tracks compared to nontrack furrows. Because depth influenced strength, but there was not a significant system × depth interaction, soil strength (Y) was plotted as a function of depth (X) (Figure 13). The relationship between depth and strength was parabolic with a positive slope between 0 and 60 cm soil depth. The regression equation developed ($\hat{Y} = 6.76 + 0.027X + 0.0017X^2$, $R^2 = 0.29$) indicated that soil strength values of about 7 bars could be expected between 0 and 15 cm regardless of cropping system. Soil strength at 55 cm

Table 27. Influence of farming system on soil strength at Dallas, TX, 1981.

System* no.	Bars	Location	Bars
10	11.0 a**	Furrow	10.9 a
4	10.2 ab	Track furrow	10.6 a
3	9.4 bc	Top of bed	7.4 b
12	9.0 c		
9	8.5 c		

10 cotton-sorghum-clover 45-45-0 cotton & sorghum, 0-67-0 clover
4 nonfertilized continuous sorghum
3 continuous cotton 45-45-0
12 cotton-sorghum-wheat 45-45-0
9 cotton-sorghum-wheat 45-45-0 + manure

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by the same letter in a column are not significantly different at the 0.05 level according to Duncan's multiple range test.

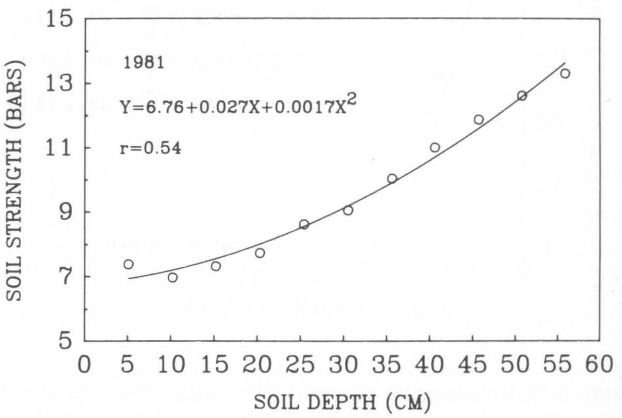

Figure 13. Strength of Blackland soil as affected by soil depth.

was about 13.4 bars for all systems. Average soil strength values for systems 3, 4, 9, 10, and 12 at three measurement locations are given in Table 26. Soil strength at 0-5.1 cm was very low (<3.4 bars) on tops of beds for all systems while strength at the same depth in furrows was about 10 bars. This condition is generally visible to the naked eye at the time of bedding.

Bulk Density and Water Infiltration

Soil bulk density at 0-15 cm ranged from 1.00 to 1.08 g/cubic centimeter (cc) under Systems 1, 4, 5, and 12 after 34 years of treatment (Table 28), but these differences were not different at the 0.05 level of significance. Water infiltration rate into soil was higher after 34 years under System 4 (continuous sorghum) than it was after 34 years under Systems 1 (continuous cotton), 5 (continuous wheat), or 12 (cotton-sorghum-wheat). Continuous grain sorghum grown on a similar soil in South Texas increased water infiltration and was important in salinity management (15) and nitrogen requirements of subsequent crops (16).

Extensive studies were conducted by Laws and Brawand (23) involving cotton (Systems 1, 8, 9, 11, 13, 14, 15, and 18) on soil moisture storage and subsequent cotton production. They found higher soil moisture content when cotton followed wheat than when cotton followed cotton, clover, sorghum, or corn. This would be expected because a longer time is available for moisture accumulation following wheat than the other crops. However, they concluded that cotton yield could not always be explained on the basis of moisture supply.

Table 28. Influence of farming system on water infiltration and soil bulk density of Blackland soil at Dallas, TX after 34 years of treatment.

System* no.	Crop	Bulk density (g/cc at 0-15 cm)	Infiltration rate (cm/hr)
1	continuous cotton	1.08	0.3 a**
4	continuous grain sorghum	1.06	1.2 b
5	continuous wheat	1.00	0.6 a
12	cotton-sorghum-wheat	1.02	0.4 a

*For complete system description, refer to Table 1 or the inside back cover.

**Means followed by different letters are significantly different at the 0.05 level according to Duncan's multiple range test.

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Description of the farming systems and fertilizer treatments used in the long-term cropping system studies at Dallas, TX, 1948-1982.

System no.	Crops	Fertilizer N-P_2O_5-K_2O (kg/ha/yr)	Year initiated
1	continuous cotton	none	1948
2	continuous corn	none	1956
3*	continuous cotton	45-45-0	1948
4	continuous grain sorghum	none	1948
5	continuous wheat	none	1948
6	continuous wheat	17-100-17, 1948-53 (overseeded with Hubam clover)	1948
		22-45-0, 1954-82	
7	continuous wheat	22-45-0, 1956-58	1956
		50-45-0, 1959-62	
		67-45-0, 1963-82	
8	cotton-sorghum-wheat	none	1948
9	cotton-sorghum-wheat	45-45-0 and 11,200 kg/ha manure/yr cotton & sorghum,	1956
		67-45-0 wheat	
10*	cotton-sorghum-clover	45-45-0, cotton & sorghum	1952
		0-67-0 clover, 1952-79	
		0-67-0 clover, 1980-82	
11	cotton-sorghum-clover	0-67-0 clover, 1952-70	1952
	cotton-sorghum-wheat	180-180-0 cotton & sorghum	1971
		67-45-0 wheat, 1971-81	
12*	cotton-sorghum-wheat	45-45-0 cotton & sorghum	1948
		67-45-0 wheat (plots switched to new location in 1953)	
13	cotton-sorghum-wheat	45-0-0 cotton & sorghum	1961
		67-45-0 wheat	
14	cotton-wheat-sorghum	45-0-0 cotton & sorghum	1961
		67-45-0 wheat	
15	cotton-sorghum-wheat	90-90-0 cotton & sorghum	1971
		67-45-0 wheat	
16	cotton-sorghum-wheat	134-134-0 cotton & sorghum	1971
		67-45-0 wheat	
17	continuous corn	45-45-0, 1957-78	1957
		90-45-0, 1979-82	
18-1**	cotton-corn-corn	45-45-0, 1964-78	1964
		90-45-0, 1979-82	
18-2	cotton-corn-corn	45-45-0, 1964-78	1964
		90-45-0, 1979-82	
19	continuous sorghum	45-45-0	1957
20	continuous sorghum	45-0-0	1960
21	continuous cotton	45-0-0	1971
38	continuous sorghum	134-134-0	1971
39	continuous sorghum	90-90-0	1971
40	continuous sorghum	180-180-0	1971

*Systems 3, 10, and 12 received 22 kg K_2O/ha/yr, 1948-52.

**System 18-1 was first year of corn after cotton; 18-2 was second year of corn after cotton.

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