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SUMMARY

The practice of no-tillage fallow (chemical) showed positive effects. Chemical fallow treatments yielded about 200 and 350 kg/ha of wheat more than subtill and plow treatments, respectively. Yield increases were associated with increased water storage during fallow. An additional 40 mm of water was stored annually under chemical fallow compared to plow fallow. Fallow efficiency (% of precipitation stored during the fallow period) was between 40 and 50% for the chemical system.

It appears that no-tillage fallow improves water storage and erosion control. Successful adaptation of chemical fallow by growers hinges on adequate herbicides, improved application techniques, and equipment that will plant properly in plant residues. Once these problems are solved, chemical fallow should become the norm rather than the exception. It is also likely that development of wheat varieties and cultural practices specifically for this system would enhance its value.

Effects of No-tillage Fallow as Compared to Conventional Tillage in a Wheat-fallow System

C. R. Fenster and G. A. Peterson[1]

INTRODUCTION AND LITERATURE REVIEW

The primary reasons for tillage are weed control, erosion control, residue management, and seedbed preparation. As grain producers have acquired larger power units, more versatile equipment, and a greater knowledge of the effects and responses to reduced soil tillage, interest in improvements in this practice has increased. Tillage in a winter wheat-fallow cropping system presents some unique problems in erosion control, water conservation, and residue manipulation.

Fallowing for a 14-month period is practiced in areas of less than 500 mm of annual precipitation. The purpose of fallow is to accumulate enough water so that a crop can be grown in the following year with the stored water plus the crop year's precipitation. Unfortunately, less than 25% of the precipitation during the fallow period is stored in the soil profile(9). In fact, superior management is necessary to achieve even the 25% fallow efficiency with a bare fallow system. The paradox of fallow has been that tillage is necessary to prevent weed growth while these same tillage operations hasten the loss of soil water by evaporation.

In addition to the water storage problem, windy conditions and intense thunderstorms are common in areas where fallow is practiced. During conventional bare fallow tillage operations designed to kill weeds and prepare a seedbed, the soil is left unprotected and the eroding forces of wind and water remove large amounts of it. Tillage operations such as moldboard plowing can create potentially large erosion hazards and a soil surface subject to great loss of soil water by evaporation.

During the time between 1870 and 1920, a system of "dust mulching" was recommended as a water conserving technique for the fallow system(11). Intensive tillage was used to reduce surface soil aggregates to dust which then would be a protective cover for the moist soil below. There were several disadvantages of this system.

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First, dust mulches are only effective on soils where a water table exists within capillary distance of the surface. Most soils in fallow areas do not have a water table even in the lower root zone. Second, the powdered surface soil crusts easily following even a light rain shower, which then reduces water infiltration and fosters runoff and soil erosion. Third, the powdered surface is extremely erodible by wind—a major problem in most fallow areas. Turelle(11) reports that intentional dust mulching has been totally eliminated in the Great Plains area.

Disadvantages of dust mulching led to work which culminated in the development of the stubble-mulch system in a fallow areas. By 1937, Russel and Duley in Nebraska and Noble in Canada were attempting to develop equipment which would kill weeds but not invert or mix the residues into the soil. Their objective was to have a weed free soil surface but with a large percentage of the crop residues anchored on the soil surface. The surface residues would do two things: (a) provide physical protection for the soil surface from wind and water; (b) reduce evaporation loss by cooling the soil surface due to the insulating effect, light reflection, and reduced direct wind contact provided by the residue. Many research reports are available which contain details on stubble-mulch techniques, Dodds(1), Duley and Fenster(2), Fenster(3), Fenster and McCalla(6), Greb *et al.*(8), McCalla and Army(10), and Fenster and Peterson(4).

Specific water and soil conservation characteristics of stubble-mulching compared to bare fallow systems were reported by Fenster *et al.*(5). They stated that runoff on nonmulched land was more than two times greater than from mulched land during fallow in an eight year experiment at Alliance, Nebraska. Stubble left upright over winter also increases snow catchment. This contributes to water conservation because as Greb *et al.*(8) have shown, 66% of the snow melt moisture was stored in the soil compared to the 0 to 15% for a July rainstorm in the eastern Colorado environment. Use of stubble-mulch techniques improves fallow efficiency. One can normally expect to store 25% or more of the total precipitation during the fallow period if 3360 kg/ha or more of wheat residues are on the soil surface. Soil loss due to wind and water erosion is also greatly reduced by stubble-mulching. Fenster *et al.*(5) reported a six-fold reduction in soil loss from stubble-mulch compared to nonmulched soil.

Stubble-mulch techniques have produced some gains in water conservation and erosion control. However, the need for improved water storage efficiency and further reductions in soil erosion still remains.

Rapid development in herbicide technology has given a new opportunity to improve fallow techniques by fallowing with little or no tilling using herbicides for weed control. Wicks and Smika(12) reported the least weed growth, the most water stored, and the highest grain yields on fallowed land where herbicides replaced tillage.

The amount of water stored annually under stubble-mulch fallow is limited by the fact that moist soil is continually being exposed to the atmosphere during the tillage operation necessary for weed control. Weeds are controlled by burial or desiccation. Moist soil in contact with an atmosphere at less than 100% relative humidity results in evaporation of the soil water. Because relative humidities during the summer months are usually less than 50% in the Great Plains, exposure of moist soil results in rapid and large evaporation losses. Repeated tillage multiplies soil water evaporation losses. Reduction in the number of soil "stirrings and exposures" should enhance water storage by reducing evaporation losses. Any reduction in tillage frequency should also result in more residue remaining on the soil surface. This would reduce soil surface temperature and thus further decrease evaporation. In addition to water storage increases, residue maintenance would also reduce runoff and soil loss by water erosion.

The benefits of reducing tillage by use of herbicides for weed control emphasizes why research was started to study a fallow system where all tillage was replaced by herbicides. Wheat planting was then the only soil disturbing operation. Objectives of the research were to compare the effects of no-tillage (chemical), stubble-mulch and plow (bare fallow) systems of fallow on:

1. Grain yield.
2. Grain protein.
3. Residue retention.
4. Soil NO_3-N accumulation.
5. Soil water accumulations during fallow.

Data presented are in the form of a progress report. These experiments will continue.

MATERIALS AND METHODS

Two sites were selected on the High Plains Agricultural Laboratory located 8.3 km north of Sidney, Nebraska. The soil type at the first site is an Alliance silt loam, a fine silty, mixed, mesic Aridic Argiustoll. Its parent material is mixed loess and loamy calcareous residuum over weathered sandstone. The slope of the land is approximately 1%. The land had been farmed from 1920 until 1957, then seeded to crested wheatgrass for 10 years. In 1967, the land was broken out of sod with a moldboard plow. In 1969, an experiment was started using an alternate wheat-fallow rotation. Chemical properties of the soil in 1969 are given in Table 1. This experiment will be referred to as the "reseeded sod" experiment.

The site was divided into two major blocks; one for fallow and the other for wheat. The blocks were cropped alternately to complete the wheat-fallow rotation. Treatments in each major block were the three fallow methods, bare (no residue on the surface), stubble-mulch and

Table 1. General surface soil properties of the experimental locations at the High Plains Ag Laboratory, Sidney, Nebraska when the experiments were initiated.

A. Reseeded sod plowed in 1967:

Alliance silt loam, 0-1% slope

Depth cm	pH	Organic C %	Total N %	C:N	$NaHCO_3$ P ppm
0-10	7.4	1.11	0.107	10.4	11
11-20	7.4	0.88	0.077	11.4	5
21-30	7.4	0.68	0.083	8.2	2

B. Native sod plowed in 1970:

Duroc loam, 0-1% slope

Depth cm	pH	Organic C %	Total N %	C:N	$NaHCO_3$ P ppm
0-10	7.4	2.33	0.188	12.4	27
11-20	7.4	1.55	0.134	11.6	19
21-30	7.5	0.92	0.116	7.9	15

no-tillage (chemical). Each fallow treatment was divided into two equal parts, one with no N fertilizer and one which received 45 kg N/ha. The fallow treatments were arranged in a randomized block design with four replications. Each fallow treatment consisted of a 8.5 m × 72.7 m plot. The N treatments were applied as ammonium nitrate on the growing wheat in April each year. Phosphate fertilizer was applied at seeding according to soil test.

The soil type at the second site is a Duroc loam, a fine silty, mixed, mesic Pachic Haplustoll. Its parent material is mixed loess and alluvium. The slope is approximately 0.1%. The land had remained in native grasses until 1970 when it was broken out of sod with a moldboard plow. The chemical properties of the soil in 1970 are given in Table 1. In 1970, an experiment was started using an alternate wheat fallow system. The experimental arrangement was similar to the first experiment except that a plot of native grass was maintained in each replication, no N treatments were applied, plot size was reduced to 8.5 m × 45.5 m, and only three replications were used. The soil tested high in P, so no phosphate fertilizer has been applied to date. This experiment will be referred to as the "native sod" experiment.

Plots at both sites were tilled with conventional farm machinery. Bare fallow plots were moldboard plowed in the spring, followed by two to three operations of the field culivator, and then one to two operations with the rotary rodweeder. The stubble-mulch fallow plots (subtill) were tilled with 90-150 cm V-Blades from two to four times, then one to two times with the rotary rodweeder. Initial tillage operations were 10 to 15 cm in depth and each subsequent operation was at a decreasing depth to develop a firm mellow seedbed.

For the no-tillage (chemical) fallow system, paraquat, glyphosate, 2,4-D and dicamba were used to control weeds. No residual herbicides have been used thus far. Grassy weeds were controlled after harvest and/or early in the spring with paraquat at 1.1 kg/ha plus 0.25% XX77. Later in the summer grassy weeds were controlled with glyphosate at 0.84 kg/ha. If only broadleaf weeds were present, 2,4-D at 1.1 kg/ha plus dicamba at 0.28 kg/ha was used. Weeds were sprayed when they were 5 to 10 cm tall.

The principle grassy weeds were volunteer wheat (Triticum aestivum), downy brome (Bromus tectorum L.), Witch grass (Panicum capillare L.), Texas tumblegrass (Schedonnardus paniculatus [Nutt.] Trel.), and stink grass [Eragrostis cilianensis (All. Lulati]. The principle broadleaf weeds were Russian thistle (Salsola Kali L. var. tenuifolia Tausch), red root pigweed (Amaranthus retroflexus L.), slim leaf lambsquarter (Chenopodium leptoplyllum Nutt.), tall hedge mustard (Sisymbrium loeselii L.), pitchers sage (Salvia pitcherii L.), wild lettuce (Lactuca scariola L.), and purslanes (Portulaca oleraces L.)

All plots were seeded with an experimental drill capable of seeding in the non-tilled areas. The drill was equipped with large coulters, slot openers for the seed, and press wheels spaced 30 cm apart. Centurk winter wheat was seeded at the rate of 50 kg/ha.

Yield data were taken by harvesting the entire plot with a combine. Moisture data were taken with a neutron probe, using two access tubes in each plot at the beginning and end of the fallow period. Residue reduction was determined by collecting the residues from 3 m^2 in each plot at the beginning and end of the fallow period. Soil nitrates were determined on soil samples taken at 30 cm increments to 150 cm just before or just after fall seeding. The nitrate in the soil was determined by the UNL soil testing laboratory using the phenoldisulfonic acid method. Grain protein was determined by standard Kjeldahl techniques.

RESULTS

1969-70 Reseeded Sod

This was the initial season for this experiment and no weather, soil NO_3^--N and/or soil water data were collected. There was a negative response to the chemical fallow treatment (Table 2). Nitrogen fertilization had no effect on grain yields. Plowing increased grain protein in relation to chemical fallow or subtill treatments (Table 3). No residue reduction measurements were made.

1970-71 Reseeded Sod

Chemical fallow produced higher grain yields than either subtill or plow treatments (Table 2). This response to tillage was consistent over all N treatments, even though N *fertilization reduced yields. Soil*

Table 2. Wheat yields as related to fallow system and fertilizer N treatment at the High Plains Ag Laboratory, Sidney, Nebraska from 1970-77.

A. Reseeded sod broken in 1967:

Fallow system	N	Year 1970	1971	1972	1973	1974	1975	1976	1977	Mean
	kg/ha					kg/ha				
Chemical	0	3026	3362	1009	1815	1345	3698	3160	3093	2564
	45	2824	2958	1210	1815	1748	3833	3227	3093	2588
		2925	3160	1110	1815	1546	3766	3194	3093	2576
Subtill	0	3160	2958	1076	1950	1479	3429	3093	2622	2471
	45	3295	2689	1143	1546	2152	3564	3026	2891	2538
		3228	2824	1110	1748	1816	3496	3060	2756	2504
Plow	0	3026	2891	1143	1412	1614	3093	2824	3160	2395
	45	3026	2622	1143	1748	2421	3160	2891	2891	2488
		3026	2756	1143	1580	2018	3126	2858	3026	2441
Statistical Significance										
Fallow System		10%	10%	N.S.	25%	5%	10%	10%	25%	
N Fertilization		N.S.	5%	25%	N.S.	5%	N.S.	N.S.	N.S.	

B. Native sod broken in 1970:

Fallow system	Year 1972	1973	1974	1975	1976	1977[a]	Mean
				kg/ha			
Chemical	3496	2219	1345	4236	2152	—	2690
Subtill	3295	2219	1479	3765	2017	—	2555
Plow	3295	2152	1614	3429	1815	—	2461
Statistical Significance							
Fallow System	N.S.	N.S.	1%	1%	N.S.		

[a]Winter kill, no data collected.

NO_3^--N accumulations before seeding were low enough that N fertilization was recommended but obviously this was not an accurate recommendation for this growing season (Table 4). A lesser response was expected on the plow treatment due to its higher NO_3^--N accumulation, but the overall negative response was not expected on any treatment.

Grain protein levels were highest on the plow treatment and ranked in direct proportion to soil NO_3^--N accumulation before seeding (Table 3). Nitrogen fertilization increased protein content

Table 3. Grain protein @ 12.5% moisture as related to fallow system and fertilizer N treatment at the High Plains Ag Laboratory, Sidney, Nebraska from 1970-1977.

A. Reseeded sod broken in 1967:

Fallow system	N	Year								
		1970	1971	1972	1973	1974	1975[a]	1976	1977	Mean
	kg/ha					%				
Chemical	0	13.9	13.4	11.6	17.0	11.1	—	13.3	—	13.4
	45	13.8	15.3	13.2	16.2	12.5	—	14.0	—	14.1
		13.8	14.4	12.4	16.6	11.8	—	13.6	—	13.8
Subtill	0	12.6	13.6	11.8	16.2	11.3	—	14.6	—	13.4
	45	14.2	15.3	13.4	17.7	13.7	—	13.7	—	14.7
		13.4	14.4	12.6	17.0	12.5	—	14.2	—	14.0
Plow	0	13.8	15.1	12.2	17.3	12.1	—	13.8	—	14.0
	45	15.2	16.6	13.6	18.8	14.5	—	13.7	—	15.4
		14.5	15.8	12.9	18.0	13.3	—	13.8	—	14.7

B. Native sod broken in 1970:

Fallow system	Year						
	1972	1973	1974	1975[a]	1976[a]	1977[a]	Mean
				%			
Chemical	13.0	14.0	12.8	—	—	—	13.3
Subtill	13.2	12.6	12.8	—	—	—	12.9
Plow	12.8	12.4	14.0	—	—	—	13.1

[a]No data collected.

more than 1.5% irrespective of tillage treatment. This particular growing season had grain protein levels which ranked second only to 1973. This may reflect moisture stress during the latter part of the season. It also relates to the yield depression that occurred with N fertilization. Accelerated water use due to N fertilization would have depleted an already short water supply during the critical grain filling period. The slower start of spring growth of wheat plants under chemical fallow would have offset the N stimulus effect and thus saved the stored water for use during grain filling. The higher yields on the chemical fallow treatment support this conclusion. No soil water data were collected in the fallow season before seeding and so no direct evidence of water stresses can be given. Soil temperature data were not available at the High Plains station these initial years and so the slower spring growth under chemical fallow cannot be definitely attributed to lower soil temperatures, although this was the probable cause. No residue reduction measurements were made.

Table 4. Soil NO_3-N in the root zone just prior to wheat seeding as related to fallow system and fertilizer N treatment at the High Plains Ag Laboratory, Sidney, Nebraska.

A. Reseeded sod broken 1967:

Fallow system	N	1970	1971	1972[a]	1973	1974[a]	1975	1976[a]	1977	Mean
	kg/ha					kg/ha				
Chemical	0	57	36	—	11	—	59	—	76	48
	45	64	44	—	12	—	99	—	83	42
		60	40	—	12	—	79	—	80	45
Subtill	0	54	39	—	11	—	57	—	114	55
	45	76	52	—	11	—	62	—	114	63
		65	46	—	11	—	60	—	114	59
Plow	0	84	55	—	13	—	101	—	112	73
	45	90	66	—	39	—	99	—	127	84
		87	60	—	26	—	100	—	120	79

B. Native sod broken in 1970:

Fallow system	1970	1971	1972[a]	1973[a]	1974	1975[a]	1976[a]	1977	Mean
					kg/ha				
Sod[b]	12	1	—	—	3	27	—	18	12
Chemical	76	63	—	—	54	151	—	57	80
Subtill	92	67	—	—	53	263	—	75	110
Plow	134	82	—	—	65	264	—	66	122

[a]No data collected.

[b]Samples taken in growing grass each year.

1971-72 Reseeded Sod

Table 2 shows there were no discernible grain yield responses to tillage treatment in 1971-72. A hail storm in mid-June inflicted great plant damage. Grain protein was increased by N fertilization but tillage treatment had no effect (Table 3). Nitrate accumulation data before seeding, as shown in Table 4, indicated that both a yield and protein increase would result from N fertilization.

Soil water storage during fallow before seeding indicated that the plow treatment stored 40 mm more water than the chemical fallow treatment (Table 5). Since hail destroyed the wheat substantially, it was not possible to assess the net result of this difference in water storage. Fallow efficiencies were 26, 34 and 36% for chemical, subtill

Table 5. Soil water content in the root zone as related to fallow system and fertilizer N treatment at the High Plains Ag Laboratory, Sidney, Nebraska.

A. Reseeded sod broken in 1967:

Fallow system	N kg/ha	8/70	8/71	Δ[a]	4/72	8/72	Δ	8/73	8/74	Δ	8/74	8/75	Δ	8/75	8/76	Δ	8/76	8/77	Δ	Mean Δ
												mm								
Chemical	0	142[b]	244	102	312	348	36	335	526	190	328	584	256	373	620	246	417	652	235	206
Subtill	0	130	267	137	353	353	38	320	432	112	284	490	206	358	541	183	386	651	265	181
Plow	0	135	277	142	317	358	41	328	353	25	302	513	211	338	541	203	429	647	218	160
		PPT=399mm EVAP=1567mm			PPT=244mm EVAP=1212mm			PPT=424mm EVAP=1580mm			PPT=414mm EVAP=1199mm			PPT=320mm EVAP=1400mm			PPT=409mm EVAP=1143mm			PPT=393mm EVAP=1378mm

B. Native sod broken in 1970:

Fallow system	8/70	8/71[c]	Δ	8/71	8/72	Δ	8/73	8/74	Δ	8/74	8/75	Δ	8/75	8/76	Δ	Mean Δ
									mm							
Chemical	119	136	18	269	396	127	325	401	76	262	401	138	290	536	246	121
Subtill	124	142	18	251	429	178	328	472	145	221	307	86	323	467	145	114
Plow	112	132	26	267	404	137	325	424	99	269	340	71	338	447	109	88
	PPT=399mm EVAP=1567mm			PPT=398mm EVAP=1400mm			PPT=424mm EVAP=1580mm			PPT=414mm EVAP=1199mm			PPT=320mm EVAP=1400mm			PPT=389mm EVAP=1395mm

[a]ΔSymbolizes change in soil water during fallow.

[b]Samples in 1970 and 1971 to 4′ only.

[c]Samples in 1970 to 4′ only.

Table 6. Residue reduction during the fallow period on the reseeded sod experiment as related to fallow system and N fertilization from 1971-1977.

Fallow system	N	1971 Loss		1972 Loss		1973 Loss		1974 Loss		1975 Loss		1976[a] Loss		1977 Loss		Mean Loss	
	kg/ha	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Chemical	0	280	9	678	14	0	0	1233	25	1759	59	—		1148	27	850	22
	45	362	9	1347	28	363	10	1567	31	1670	45	—		0	0	885	20
Subtill	0	2778	77	5091	85	2793	77	2460	62	2547	75	—		2173	78	2974	76
	45	2091	66	4988	83	1634	60	3280	83	2413	73	—		2448	79	2809	74
Plow	0	3310	95	5652	95	3070	95	4393	97	4718	100	—		2695	85	3973	94
	45	3121	91	4257	94	4134	93	4317	98	3735	100	—		2925	87	3748	94

[a]No data collected.

and plow treatments, respectively. Air and soil temperatures were measured at the weather station located on the High Plains Ag Laboratory. Temperatures were measured at the 5 cm depth for bare soil and mulched soil with 1680 kg/ha residue. They were about average for the 1972 season.

Table 6 contains data on residue reductions during fallow as related to tillage treatments. Plowing destroyed over 90% of the residues as compared to about 70% and 9% for subtill and chemical treatments, respectively. Nitrogen fertilization had no influence on either total amounts of residue or loss during fallow.

1971-72 Native Sod

Chemical fallow did not significantly affect grain yields as compared to either subtill or plow treatments (Table 2). Since hail damage was minimal at this location, the data could be interpreted accurately. Grain protein also was not significantly affected by tillage treatment (Table 3). This was true even though the plow treatment had accumulated 19 kg/ha of NO_3^--N more than the chemical fallow (Table 4).

Water storage in 1971-72 was very low in all treatments during the fallow period before seeding. It is likely that there had not been sufficient time to allow the soil of this very dry native sod to be recharged with water. Fallow efficiencies were only 5, 5 and 7% for chemical, subtill, and plow treatments, respectively. No residue reduction measurements were made on this experiment in 1971.

1972-73 Reseeded Sod

Grain yield was increased by about 235 kg/ha by chemical fallow as compared to plowing (Table 2). However, response to N fertilization was not consistent over tillage treatments. Grain protein was highest under the plow system reflecting increased N availability with this system (Table 3). Nitrogen fertilization increased grain protein content for plow and subtill systems but not chemical fallow. No explanation for this is possible with these data. Grain protein produced this year was the highest of all years. It was a year with stress conditions near harvest which may account for the observed protein response.

Water storage during fallow was recorded only from April through August of the year before seeding and so calculation of fallow efficiencies and interpretation of the effects in relation to available water under each system were not appropriate. To support the fact that 1973 was a stress year the temperature data in Appendix Figure IV show temperatures about 2 to 3°C greater than average during the grain filling period (June).

Residue reduction data collected in the fallow preceding this crop year are in Table 6. They were about 95, 84 and 21, *respectively, for*

Table 7. Residue reduction during the fallow period on the native sod experiment as related to fallow system and N fertilization from 1972-1974.

Fallow system	Year							
	1972 Loss		1973 Loss		1974 Loss		Mean Loss	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Chemical	2849	77	0	0	0	0	950	26
Subtill	3579	94	662	26	3188	50	2476	57
Plow	4310	98	2908	91	4935	91	4051	93

the plow, subtill and chemical treatments. Again N fertilization had no influence of residue level.

1972-73 Native Sod

Tillage treatments had no effect on grain yield, but chemical fallow did produce a higher protein level than the other two systems. There was no consistent pattern in water stored. Fallow efficiencies were 29, 41, and 31% for chemical, subtill and plow, respectively. High air temperatures as mentioned for the reseeded sod experiment stressed all of the treatments.

Table 7 contains residue reduction data for the native sod experiment. Losses were highest for the plow treatment (98%), but even the chemical treatment lost more than 75% of its residue. This was the only instance where residue loss exceeded 50% on the chemical treatment. The large loss was probably due to the hail storms during fallow. There was still over 800 kg/ha of residue on the chemical treatments despite the large loss (Appendix Table II).

1973-74 Reseeded Sod

Plowing produced higher yields than either subtill or chemical fallow and chemical fallow was significantly less then subtill (Table 2). Large yield increases were obtained with N fertilization with all systems. These increases were 403, 673 and 807 kg/ha for the chemical, subtill and plow treatments, respectively. Soil analysis in August before seeding (Table 4) indicate very low NO_3^- accumulations during the fallow period, and so the large responses to N fertilizer were expected. Grain protein responded similarly to grain yield. Plowing with an N application afforded the highest grain protein content. The superiority of plowing for higher protein content was consistent with other years in this experiment. Unfortunately, water storage during fallow was not recorded for this cycle of the experiment. The fallow period preceding this crop year was a difficult one for the chemical fallow treatment. Excessive weed growth in the chemical fallow undoubtedly accounts for the poor yields on these treatments in 1974 and probably for the low NO_3^- accumulation during fallow.

Residue reduction for the preceding fallow period is shown in Table 6. As in previous years it ranged from about 94% for the plow treatment to only 5% for the chemical treatment. Nitrogen fertilization had no effect on losses, but N fertilization increased residue amounts on plow and chemical treatments (Appendix Table I).

1973-74 Native Sod

As with the reseeded sod experiment the plow system had the highest grain yield this season (Table 2). The maximum difference, about 250 kg/ha, was between chemical fallow and plowing. Again, the fallow preceding this year had poor weed control in the chemical fallow treatments. Grain protein content was also highest under the plow system. This may reflect higher N availability in the plow system, but no NO_3^--N accumulation data were collected during this cycle to substantiate this point. Data collected in other years supports the point that the plow system accumulates more NO_3^--N during fallow than does the chemical system.

Residue reduction ranged from about 90% for the plow treatment down to 0% for the chemical treatment (Table 7). Subtill treatments had about a 26% loss. These values are in sharp contrast to the 77% and 94% losses from chemical and subtill treatments, respectively, in the previous year on this experiment.

1974-75 Reseeded Sod

In sharp contrast to the yield data collected in 1974, chemical fallow outyielded the plow fallow by about 640 kg/ha (Table 2). This was the first season that chemical fallow had a large advantage over the plow fallow. Response to N fertilization did not occur. Grain protein data were not obtained in 1975.

The advantage of the chemical system was apparent in the water storage data (Table 5). Fallow efficiencies were 45%, 41% and 6% for the chemical, subtill and plow systems, respectively. This was also the first year that water storage differences were so greatly in favor of the chemical system compared to plowing. Air temperatures were near the overall average for the 1974 season.

Residue reduction data in Table 6 show losses of 97%, 72% and 28% for plow, subtill and chemical treatments, respectively. Again N fertilization had no influence on residue losses during fallow.

1974-75 Native Sod

Chemical fallow treatments yielded more than the subtill and plow fallow systems by 470 and 800 kg/ha, respectively (Table 2). Grain protein was not measured this season. Nitrate accumulation during fallow was essentially equal for the three systems. Native sod had very low accumulation as would be expected (Table 4).

Water storage data were somewhat erratic with the subtill substantially exceeding the other systems. Fallow efficiencies of 18, 34 and 23% were calculated for chemical, subtill and plow systems, respectively.

Residue reduction during the fallow period as given in Table 7 ranged from 91% for the plow treatment to 0% for the chemical treatment. Subtilling was intermediate with a loss of 50%.

1975-76 Reseeded Sod

Chemical fallow outyielded the plow fallow by 335 kg/ha, but was about equal with subtill fallow as can be observed in Table 2. Soil NO_3^--N accumulation data are given in Table 4 for the fallow period ending at seeding time in August of 1975. According to current soil test recommendations the chemical and subtill systems had a need for 40 kg/ha of N and the plow system 20 kg/ha. Note in Table 2 that no yield change occurred with the 40 kg/ha N application under any tillage system.

The plow treatment definitely showed higher N availability than the other treatments (Table 4). The rather low grain yields from these plots in 1972 and 1974 apparently allowed NO_3^--N to accumulate because the amounts of residual NO_3^--N were higher in these plots than at any previous time. Grain protein levels were not significantly influenced by either tillage or N fertilization. This is unusual in that the N fertilized plow treatment has historically been significantly higher than other treatments in this experiment.

Soil water storage again favored chemical fallowing, as it stored 40 mm more water than plow fallow (Table 5). Water storage efficiencies were unusually high for all systems being 61%, 50% and 51% for chemical, subtill, and plow, respectively.

Residue reductions for chemical treatments during the preceding fallow were about 50% (Table 6). This is at least double the size of reductions observed in any other year. Reduction with plowing was 100%.

1975-76 Native Sod

Chemical fallowing did not significantly increase grain yields compared to the other treatments (Table 2). Fallow efficiencies were 33%, 21% and 17% for chemical, subtill, and plow, respectively. The lower water storage with plowing coupled with the very high NO_3^--N accumulation (260 kg/ha) with plowing may have stressed this treatment causing a soil water shortage late in the growing season. No grain protein data were collected this year.

No residue reduction data were collected for the preceding fallow period.

1976-77 Reseeded Sod

Grain yields for the chemical and plow fallow systems were equal but significantly greater than yields from the subtill fallow (Table 2). Nitrogen fertilizer effects were not detectable. Grain protein data were not collected this season. Soil water storage during fallow was largest under chemical fallow and efficiencies were 77%, 57% and 63% for the chemical, subtill, and plow systems, respectively. These efficiencies are extremely high for any of these systems. No residue reduction data were collected for the preceding fallow period.

1976-77 Native Sod

No data were obtained because of winter kill.

DISCUSSION

Grain Yield

Overall effects of tillage on grain yield are depicted in Figure 1 for both experiments. There was a consistent advantage of about 200 and 350 kg/ha for chemical fallow over subtill and plow treatments, respectively. To obtain a clear view of the direct effects of tillage on grain yields, results were omitted in years where hail damage occurred or where weeds were not controlled in the chemical fallow.

The years omitted from the reseeded sod experiment summary were: 1970, the initial experimental year when weed control was not effective in the chemical fallow; 1972, a year of severe hail damage; 1974, a year with heavy weed infestation in the prior fallow period. The 1974 data were also omitted from the native sod experiment due to weed infestations in the prior fallow period. In the early years of these experiments small changes in time of application greatly affected herbicide effectiveness. With the chemicals now available the weed infestations that affected the 1970 and 1974 yields would not have occurred. Because the objectives of these experiments were to determine the effects of fallow systems on various crop and soil parameters and not the determination of how to best practice chemical fallow, the omission of these data was necessary to allow proper interpretation of the results.

These yield increases were directly related to soil water stored during the preceding fallow. Figure 2 depicts the water storage differences in terms of actual quantity and also in terms of fallow efficiency. It is interesting that the saving of an additional 40 mm of water in the chemical fallow treatment resulted in a 350 kg/ha yield increase over plowing. This relationship was found for both experiments as is shown in Figure 2A.

Figure 2B displays the relative storage efficiencies of the fallow systems. These are of particular interest for *two reasons: (a) chemical*

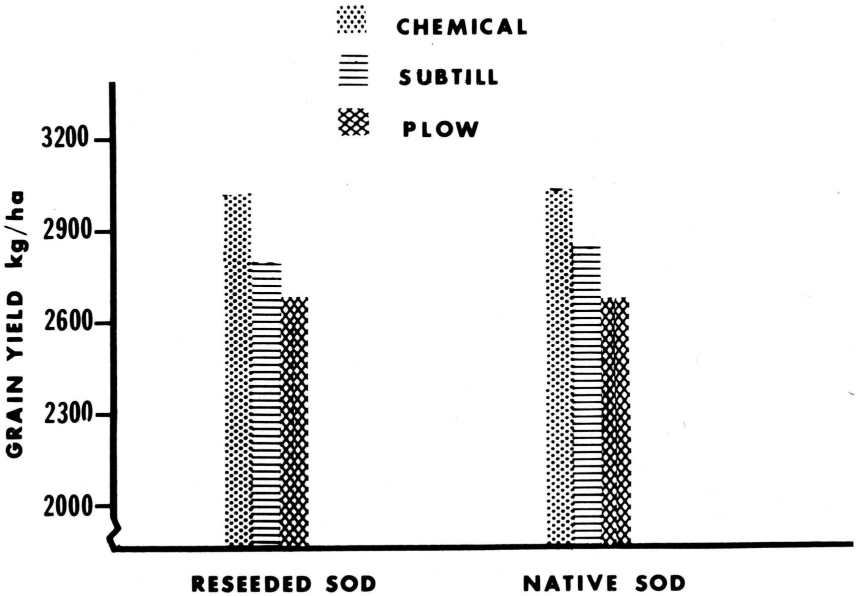


Figure 1. Grain yields as affected by fallow system in the reseeded sod and native sod experiments. (Yields averaged over all years with one hail year and two weed problem years omitted.)

fallow allowed achievement of a very high efficiency, 40% to 50% in the two experiments, and (b) efficiencies obtained with the plow treatment, 42% and 27%, were above that usually obtained in the Great Plains. These findings, coupled with the yield data in Figure 1, translate into two conclusions: (a) chemical fallow will result in increased water storage which results in yield improvement over conventional fallow systems, and (b) chemical fallow is likely to result in even greater yield responses compared to conventional systems when practiced on a field basis by wheat producers. The latter is true because producer attainment of 25% to 40% fallow water storage efficiency with plowing or subtillage is unlikely at best (9), whereas the 40% efficiency figure could be relatively easily reached by a producer using chemical fallow.

Nitrogen fertilization effects on the reseeded sod experiment averaged over all years are shown in Figure 3. In years when soil NO_3^--N accumulation was small, as in 1974, a large positive response occurred (Table 2). In general, however, N fertilization had no effect on grain yields. This finding is disconcerting because in all years when soil NO_3^--N analyses were made, they indicated that fertilization would be beneficial. This was especially true for the chemical fallow treatments which on the average had 25 kg/ha less NO_3^--N accumulated during fallow than the plow system. At the present time no

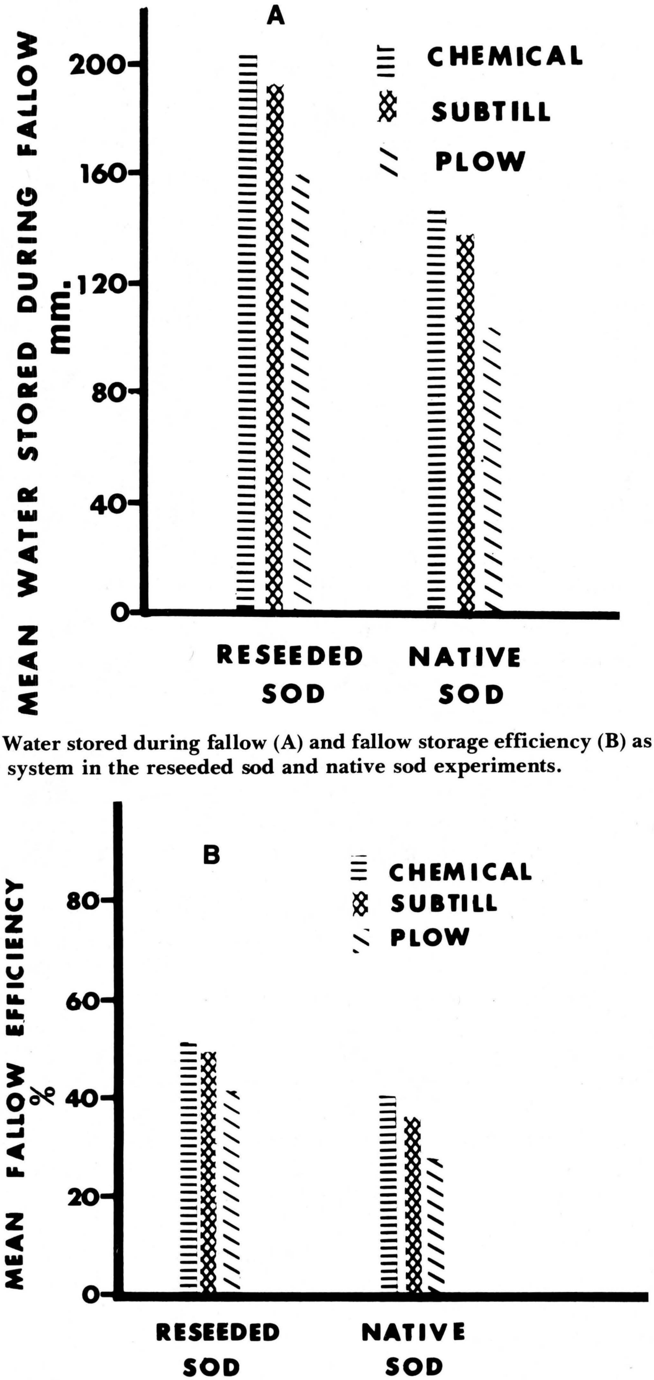


Figure 2. Water stored during fallow (A) and fallow storage efficiency (B) as affected by fallow system in the reseeded sod and native sod experiments.

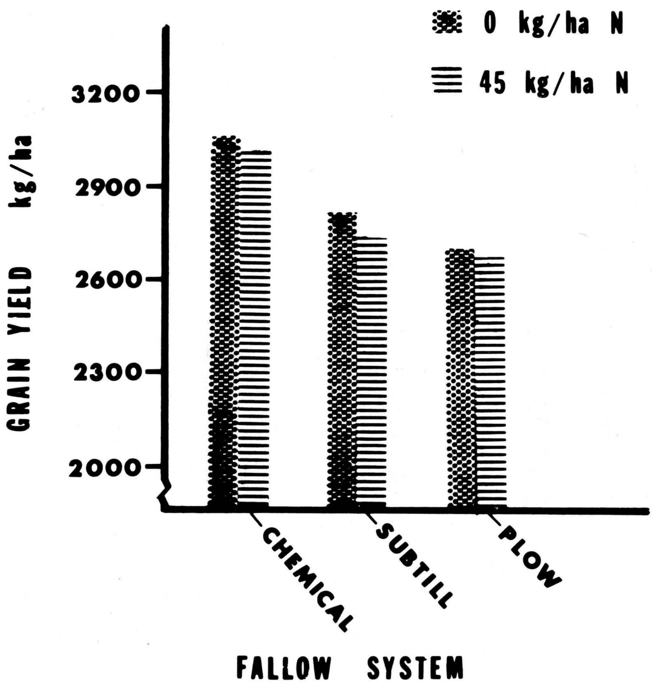


Figure 3. Grain yields on the reseeded sod experiment as affected by fallow system and N fertilization. (Yields averaged over all years with one hail year and two weed problem years omitted.)

explanation is available for the finding. It does suggest that the N soil test may not be correctly calibrated for the soils under study. The recent grass sod history of the reseeded experiment may also be a factor.

It would appear that NO_3-N accumulations under chemical fallow will be consistently less than with plow or subtill (Table 4). This effect was very dramatic in the case of the native sod experiment. Apparently, there is continuous N immobilization in the residues during fallow. Since the drilling equipment does not incorporate very much of the residue, this immobilization may continue through the cropping year too. This in turn may influence N recommendations for wheat grown in chemical fallow systems.

Grain Protein

As shown in Figure 4, the plow system had a slight advantage in protein content in the reseeded sod experiment. Nitrogen fertilization on the reseeded sod experiment increased protein content over all fallow systems. This increase was largest with the plow treatment, 1.5%, and smallest for the chemical fallow treatment, 0.1%. This dif-

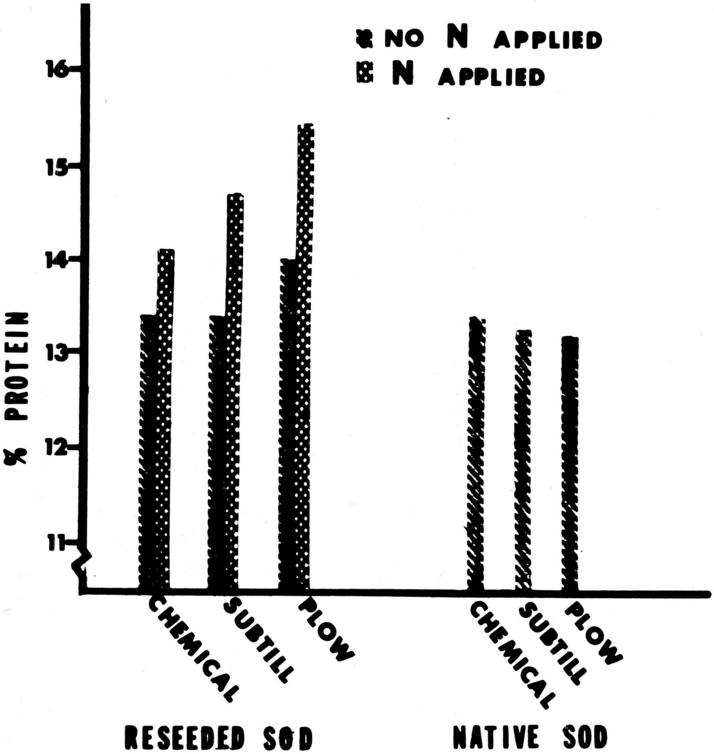


Figure 4. Grain protein as affected by fallow system in the reseeded sod and native sod experiments and by N fertilization in the reseeded sod experiment. (All years included where data were collected.)

ferential in protein content can be accounted for by the fact that the chemical fallow treatment yielded more than the plow treatment and thus total grain protein was diluted. In other words, total weight of protein produced was constant over both fallow system and N treatments.

Protein levels were generally very high. No treatment averaged less than 13.2% in either experiment. These levels reflect an abundant N supply because they were attained at average to above average yield levels, 2600-3000 kg/ha. In relation to the NO_3^--N accumulation data in Table 4 this level of protein at these yields was unexpected in the reseeded sod experiment. Data reported by Gass *et al.*(7) indicates that N absorbed late in the growing season is transferred directly to the grain in corn. Thus, late season N availability had a large effect on corn grain protein content. Since the experimental areas were recently in sod it may well be that soil organic N mineralization is supplying enough late season N to result in higher than expected protein

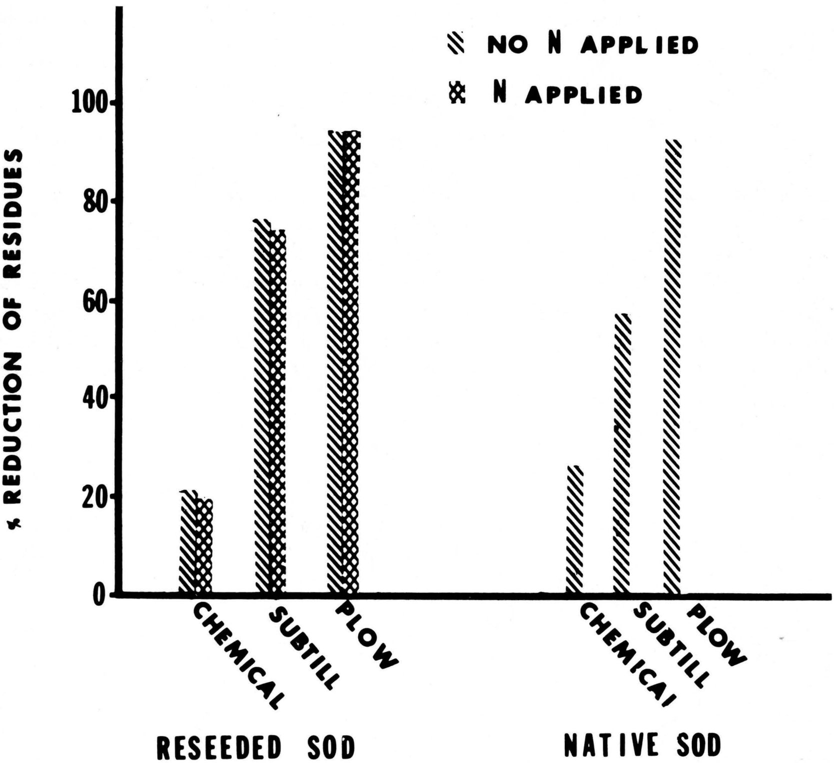


Figure 5. Residue reduction as affected by fallow system in the reseeded sod and native sod experiments and by N fertilization in the reseeded sod experiment. (All years included where data were collected.)

levels. This may also account for the lack of response to N fertilizer observed in the reseeded sod experiment.

Residue Reduction during Fallow

Residue retention during fallow is the objective of both the subtill and chemical fallow systems. Data obtained in these experiments are summarized in Figure 5. Chemical fallow systems lost only 20% to 25% of their residues during the 14-month fallow period. This is in contrast to losses of 55%-75% and 90%-95% for subtill and plow systems, respectively. Obviously, the chemical fallow treatment provided excellent protection from both wind and water erosion. Even the most sandy soils should be adequately protected if managed with a chemical fallow system.

Nitrogen fertilization had no effect on residue reduction during fallow. As can be observed in Appendix Tables I and II the amount of residue was occasionally increased by fertilization, but amount of reduction was not influenced by it.

SUMMARY

The practice of no-tillage (chemical) fallow showed very positive effects overall. It resulted in increased water storage and improved protection against erosion during fallow. Grain yields were increased by this practice in years when adequate weed control was obtained. It appears that the successful adaptation of chemical fallow to farmer use hinges on adequate herbicide application techniques and seeding in no-till residues. Once these problems are solved, chemical fallow should become the norm rather than the exception. It is also likely that development of wheat varieties and cultural practices specifically for this system would enhance its value.

Appendix Table I. Wheat residues at the beginning and end of fallow period under three fallow systems in a wheat-fallow rotation on the reseeded sod experiment at the High Plains Ag Laboratory, Sidney, Nebraska.

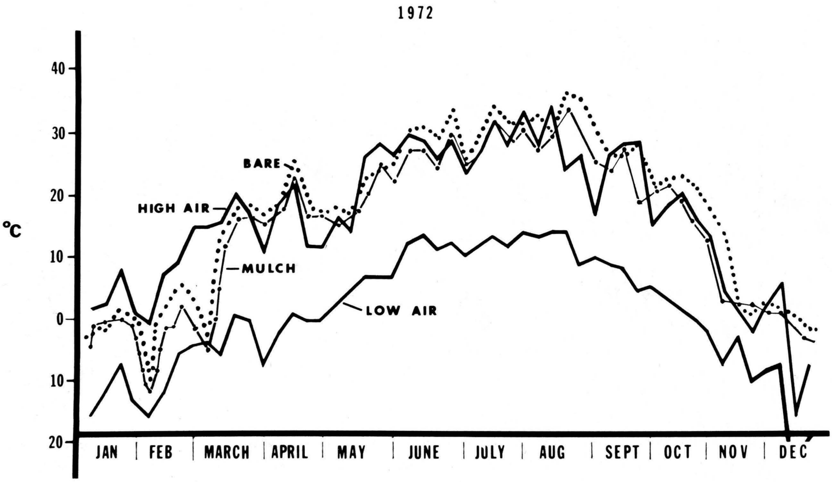
Fallow system	N	Year							
		1970-71		1972-73		1974-75		1976-77	
		Initial	End	Initial	End	Initial	End	Initial	End
	kg/ha	kg/ha							
Block A[b]									
Chemical	0	3220	2940	3172	3215	3589	1830	4237	3089
	45	3946	3584	3970	3607	3732	2062	3433	3940
Subtill	0	3598	820	3613	820	3417	870	2776	603
	45	3178	1087	2721	1087	3316	902	3105	657
Plow	0	3486	176	3252	176	4718	0	3164	468
	45	3414	291	4426	292	3735	0	3343	418
Block B[b]		1971-72		1973-74		1975-76[c]		1977-78	
		Initial	End	Initial	End	Initial	End	Initial	End
Chemical	0	4970	4292	4966	3733	—	2477	4298	2015
	45	4741	3394	4994	3427	—	2388	6104	1821
Subtill	0	5872	853	3987	1527	—	388	2761	597
	45	6017	1029	3966	686	—	269	2624	550
Plow	0	5907	318	4550	157	—	30	2806	0
	45	4519	262	4419	102	—	134	2955	0

[a]Block A. Wheat harvested in even years and fallowed on odd years.
[b]Block B. Wheat harvested in odd years and fallowed on even years.
[c]Data not collected.

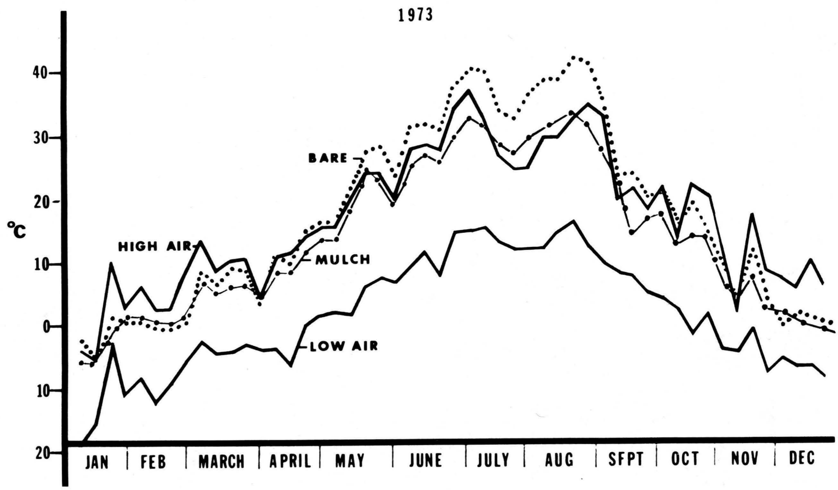
Appendix Table II. Wheat residues at the beginning and end of fallow period under three fallow systems in a wheat-fallow rotation on the native sod experiment at the High Plains Ag Laboratory, Sidney, Nebraska.

Fallow system	Year							
	1971-72		1973-74		1975-76[c]		1977-78	
	Initial	End	Initial	End	Initial	End	Initial	End
	kg/ha							
Block C[a]								
Chemical	3694	845	6247	6633	—	—	2408	1433
Subtill	3390	218	6357	3169	—	—	2209	358
Plow	3930	92	5433	498	—	—	627	0
Block D[b]	1972-73		1974-75		1976-77			
	Initial	End	Initial	End[c]	Initial[c]	End		
Chemical	2893	3653	4967	—	—	2836		
Subtill	2566	1904	4948	—	—	527		
Plow	3190	282	4584	—	—	209		

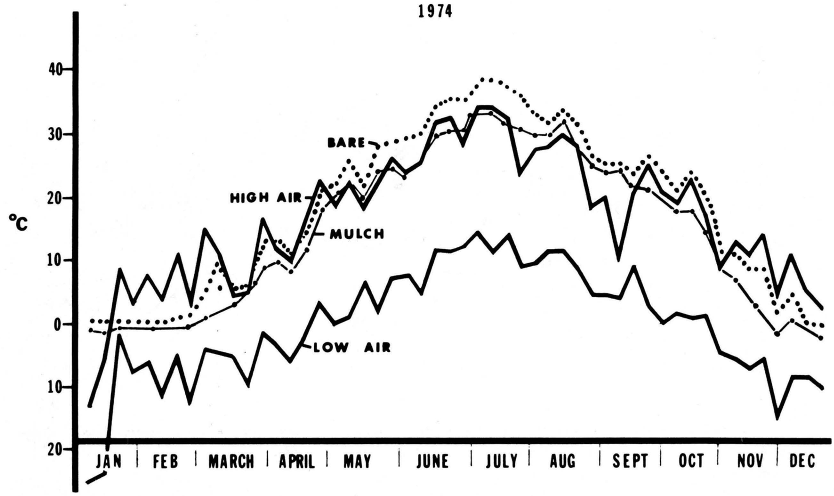
[a]Block C. Wheat harvested in odd years and fallowed in even years.
[b]Block D. Wheat harvested in even years and fallowed in odd years.
[c]No data collected.



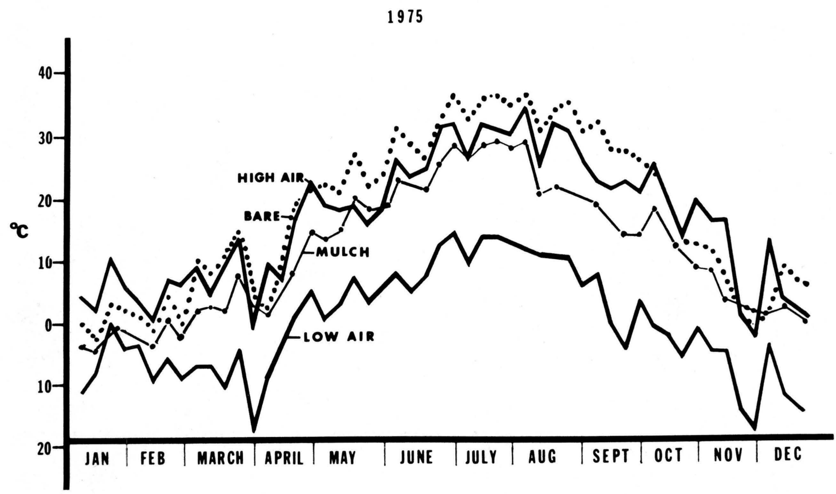
Appendix Figure 1. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1972 at the High Plains Agricultural Laboratory, Sidney, Ne.



Appendix Figure 2. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1973 at the High Plains Agricultural Laboratory, Sidney, Ne.

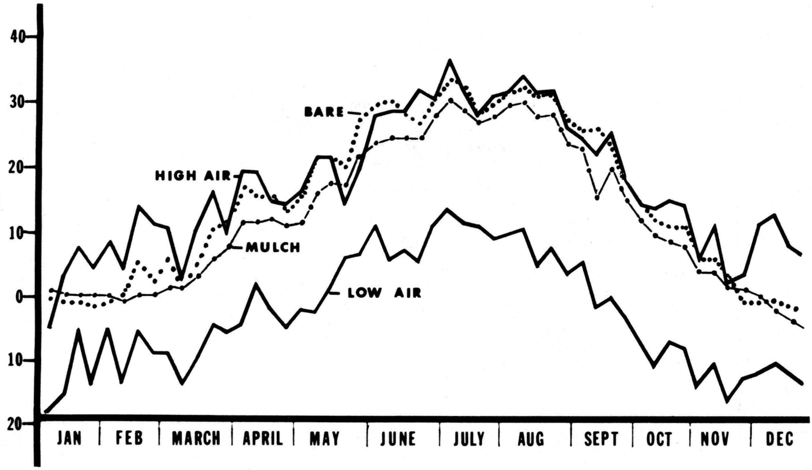


Appendix Figure 3. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1974 at the High Plains Agricultural Laboratory, Sidney, Ne.



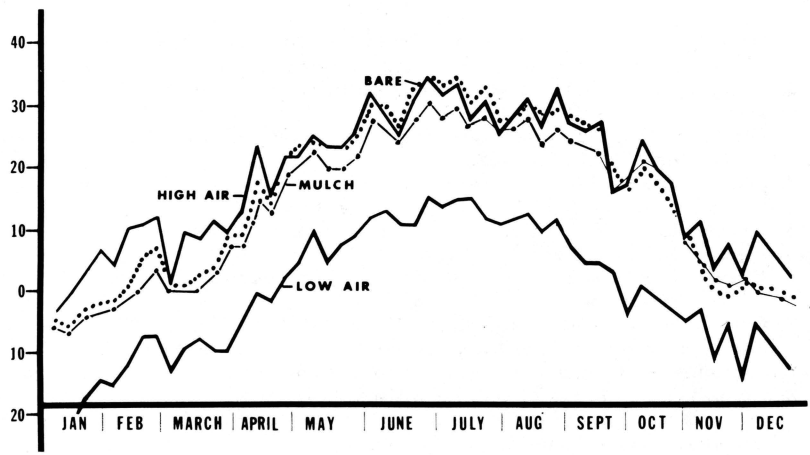
Appendix Figure 4. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1975 at the High Plains Agricultural Laboratory, Sidney, Ne.

1976

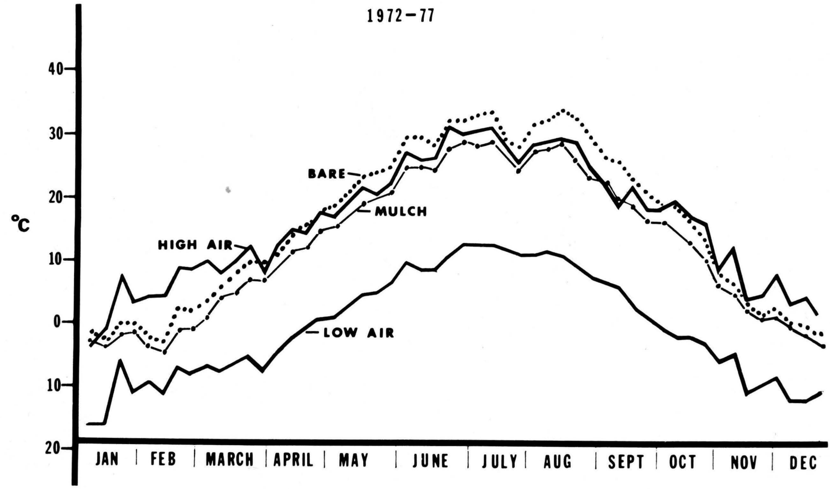


Appendix Figure 5. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1976 at the High Plains Agricultural Laboratory, Sidney, Ne.

1977



Appendix Figure 6. Maximum and minimum air temperatures and soil temperatures at the five centimeter depth as affected by mulching during 1977 at the High Plains Agricultural Laboratory, Sidney, Ne.



Appendix Figure 7. Mean maximum and minimum air temperatures and soil temperatures at the five centimeter soil depth as affected by mulching for the period 1972 through 1977 at the High Plains Agricultural Laboratory, Sidney, Nebraska.

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