MONTANA STATE UNIVERSITY

An evaluation of nontillage and chemical fallow in small grain production

by Daniel Grant Wilson

A thesis submitted in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE in Agronomy
Montana State University

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Date August 26, 1976

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

No-till, annual cropping was evaluated for small grain production. More moisture was stored during the 1973 and 1974 winters due to snow trapping on non-disturbed stubble than where stubble was destroyed by tillage. Glyphosate provided satisfactory vegetation control as a method of seedbed preparation. No-till winter wheat yields were higher than those from conventional tillage; barley yields were not. Continuous winter wheat plots following tillage seedbed preparation exhibited a shift toward downy bromegrass infestation and volunteer grain while wild oats persisted in the continuous barley plots. The benefit of rotating crops for weed control was demonstrated.

Glyphosate in combination with atrazine and metribuzin were most effective of the herbicides evaluated for chemical summer fallow.

INTRODUCTION

Crop-fallow systems are not an efficient means of accumulating moisture since approximately 80% of the moisture received during the fallow period is lost due to evaporation, percolation, and runoff (10). However, effective summer fallow over several years may result in moisture accumulation sufficient to cause the development of saline seep in soils overlaying certain types of underground formations (14,15). Saline seeps are described by Smith (58) as "recently developed salty areas in nonirrigated land that have characteristics of saline or saline-sodic soils." Hence, improved cropland efficiency and a diminution in areas lost to saline seep are possible advantages of the development of alternatives to crop-fallow rotations.

Since one of the prime deterrents to cropping small grains annually in Montana is the lack of an efficient weed control program, the objectives of this experiment were to: 1) develop a system of growing small grains by seeding into untilled grain stubble or other untilled cropped soil in which the vegetation is controlled with chemicals; and 2) evaluate herbicide treatments for control of weeds for fallow, preplant, and in-the-crop situations.

LITERATURE REVIEW

Dryland farming is defined as farming without irrigation in an area where the mean annual precipitation is between 25 and 51 cm (21). Successful wheat production requires a minimum of 30 to 38 cm of water per year for a growing season beginning in May and ending in September (13). Seventy-five percent of Montana's wheat production occurs in the north central and northeast areas which have a 35-year average annual precipitation of 33.8 cm (48). During 1972 and 1973 spring wheat in the north central and northeast portions of Montana produced average yields of 1762 and 1573 kg/ha when average precipitation over the fallow period and crop year equalled 58.1 and 61.3 cm, respectively (48). Brown (13), however, found that approximately 23 cm of water were required to produce 2220 kg/ha of spring wheat. This discrepancy between moisture recorded and that required points to the inefficient use of water by the summer fallow system.

Alternate crop-fallow rotations are commonly used in semi-arid areas of the Great Plains to conserve moisture for more dependable crop production. Annually, about 16,000,000 hectares of land are fallowed in the Great Plains where stubble mulch farming is the most widely used management practice for controlling soil erosion by wind and water (21). This system involves leaving land without a crop for one season, while controlling weeds, to allow moisture storage. Average annual yields based on cropped areas are usually lower with this system than with annual cropping, since half the land area is fallowed (24). However, yields are stabilized over dry years due to the development of a moisture reserve (39).

The summer fallow system was advocated as early as 1880, but was not widely accepted until 40 years later. Krall (38) lists several reasons for its early lack of acceptance: 1) 1915 to 1918 were some of the wettest years on record; 2) during World War I it was unpatriotic to have "idle" land; 3) few annual weeds were serious problems before the 1920's; and 4) effective summerfallow techniques and equipment were not yet developed.

A serious drought in 1919 convinced many that summer fallow was needed to stabilize yields. It led to promotion of summer fallow in the early 1920's by such groups as Bill Reed's "Summer Fallow Club of 1921" (11). By the mid-1920's summer fallow for cereal production was widely practiced in the drier parts of the U.S. dryland farming areas.

The stubble mulch tillage method incorporated into a year-around system the management of plant residues with all tilling, planting, cultivating, and harvesting operations designed to keep a sufficient amount of residues on the surface at all times for soil protection (25). The basic system of stubble mulch farming consists of subsurface tillage with V-sweeps, rod-weeders or the rod-weeder with chisels (17). A sweep machine is the basic tool since it is the most effective for the initial tillage operation (31). Stubble mulch tillage may start immediately after harvest to control weeds in the stubble.

Grassy weeds such as downy bromegrass (*Bromus tectorum*) are a problem in the spring of the fallow year and can markedly reduce yields of the subsequent wheat crop (22). Volunteer wheat growing during the fallow year harbors the leaf curl mite (*Aceria tulipae*) which transmits wheat streak mosaic (59). Destruction of volunteer winter wheat requires tillage in the fall prior to the normal tillage season that begins in May or June in Montana.

The influence of soil surface treatments on moisture storage during the fallow period has been widely studied throughout the Great Plains. However, because of the complexity of evaporation and infiltration processes involved in such storage, conclusions often have been contradictory. Several workers (45,46.47) have indicated that soil moisture storage during a fallow period in the Great Plains is not greatly affected by tillage methods. However, according to Whitfield (62), numerous field measurements show greater moisture penetration on stubble-mulched land than on clean-tilled, one-way cultivated land. In a comprehensive review, Jacks (33) concluded that evaporation is reduced by a mulch where the soil surface is maintained at high moisture content by frequent rains or a high water table. Russel (52) concluded that mulches conserve moisture during periods of frequent rains but have little value for moisture conservation during dry periods. Gardner (27) has stated that a surface mulch or other treatment may have little long-range benefit unless the lower initial evaporation rate with a mulch permits greater downward percolation of water.

Barnes, Bohmont, and Rauzi (5), in Wyoming studies, found infiltration rates on nontilled plots of 3.86 cm of water per hour, on subsurface tilled plots of 2.49 cm of water per hour, and on spring-plowed plots followed by conventional tillage of 3.25 cm of water per hour. Recent studies (66) in the Great Plains indicated that soil moisture storage during fallow periods can be significantly increased with a heavy trash mulch. In studies in Montana, Colorado, and Nebraska, moisture storage efficiency was greatly increased with increasing the amounts of wheat straw up to about 5 tons per acre (36). Black (10), at Sidney, Montana, reported fallow efficiency was 16% with no residue; it increased to 28% with 1.33 metric tons of residue per hectare. Greb (28) at Akron, Colorado reported fallow efficiency was 26% with 1.33 metric tons of residue per hectare, 30% with 1.78 metric tons of residue per hectare, and 33% with 2.67 metric tons of residue per hectare. General research shows that the heavier the mulch, the less surface evaporation, and the deeper moisture penetrates the soil profile (28).

Lee and Alley (41) initiated a study in Wyoming to determine the effectiveness of a single herbicide for weed control in a wheat-fallow system. The weed population consisted of tansy mustard (Descurainia pinnata), Russian thistle (Salsola kali), redroot pigweed (Amaranthus retroflexus), downy bromegrass, and volunteer wheat. Glyphosate at .23 kg/ha in 222 L/ha water carrier was the only treatment which resulted in complete control of downy bromegrass and volunteer wheat; it controlled 97% of all other species in the plots.

Controlling weeds with herbicides during the moisture storage season is called chemical fallow (1,2,3,5). Herbicides have been used with some success in the Great Plains to control annual grassy and broadleaf weeds making chemical fallow farming feasible (6,23,38,40, 41). Chemical fallow is more effective than stubble mulch tillage in protecting the soil from wind erosion (69). Eventually herbicides may be developed that will maintain a weed-free condition during the entire summer of the fallow year without herbicide residue damage to the following wheat crop. Chemical fallow studies in western dryland farming have been underway since 1948 (67). In 1956, Baker (4) concluded from Montana studies that, where chemicals controlled weeds in fallow, grain yields were the same as those obtained from conventional tillage. Since that time additional chemical fallow research has been conducted in an effort to increase soil moisture storage, conserve crop residues, increase weed control, reduce soil crusting, and reduce production costs.

In parts of the intermountain west (southwestern Canada, and parts of Montana, the Dakotas, and Wyoming), however, the summer fallow system has been implicated as a cause of saline seep (26,29,30). This problem was mentioned by Warden (60) about 20 years ago. Annual cropping on virgin prairie uses most of the available water, since metabolizing plants are present during much of the growing season (20). Effective summer fallow during those years of above normal precipitation, however, may cause excess moisture accumulation. This moisture percolates, picking up soluble salts as it moves through the profile; a shale or coal layer causes the formation of a salty aquifer, which emerges or approaches the soil surface at some point down slope (14). When this occurs, a saline seep appears as the water evaporates, leaving enough soluble salts on the soil surface to hinder or eliminate crop production (14). Hence, development of new cropping practices on active and in potential saline seep areas need to be developed.

One of the solutions to the saline seep problem is the elimination of summer fallow, at least during those years when precipitation totals for the preceding 7-8 month period are above normal. Seeding a crop each year is called annual cropping or recropping. Incorporating the no-till method into this program allows winter wheat to be seeded directly into the stubble with minimum soil disturbance. This practice leaves the stubble standing, decreases wind speed near the soil surface, and causes snow accumulation to increase and to be more uniform (36,56,66).

Many studies have been conducted to determine the effect of chemical fallow on various soil properties. Studies in Wyoming and Montana (40,41) show that chemical fallow increases water infiltration rates over conventional tillage.

A Wyoming study conducted during an extremely dry year showed a minimum amount of mechanical tillage is desirable for moisture conservation (1). During periods of near normal precipitation, there was no difference in moisture storage between chemical fallow and stubble mulch tillage.

Small grain yields from annual cropping in areas receiving less than 27 cm precipitation are variable and low (37). Techniques to catch and hold snow, reduce evaporation, and to increase water use efficiency would help to remove some of the risk from annual cropping.

Krall (40) initiated a study at the Southern Montana Agricultural Research Center at Huntley in 1973 to compare various aspects of the no-till seeding versus conventional methods using cereal grains on recropped and fallowed land. The herbicide vegetation control no-till planting yielded 508 to 1155 kg more grain than conventional methods. It was found that to obtain optimum barley yields on recropped land following no-till planting required preplant vegetation control, nitrogen fertilizer, and 2,4-D. Krall (40) estimated yield differences by sampling recropped and fallow spring wheat or barley at ten locations in Montana in 1975. Fallow yielded an average of 8318 kg of small grain while recropped land produced 6251 kg, a difference of only 25%.

The two major grassy weed problems in the northern cereal growing region of the U.S. are downy bromegrass and wild oat (*Avena fatua*) (2,34,55). In addition, some major broadleaf weeds which cause problems in Montana are Russian thistle, Kochia (*Kochia scoparia*), field pennycress (*Thlaspi arvense*), wild mustard (*Brassica* Spp.), wild buckwheat (*Polygonum convolvulus*), sunflower (*Helianthus annuus*), and cow cockle (*Vaccaria segetalis*).

The literature on *B. tectorum* has been reviewed by several workers (22,32,53,64). This grass is usually a winter annual, but can also germinate in early spring. Since *B. tectorum* has little dormancy (19,70), most seed will germinate the first year and the resulting plants may be controlled by spring tillage. Since seeds ripen in June and early July, early treatment with a contact herbicide to prevent seed production was found to be valuable in Canada (53).

Seed dormancy of *A. fatua*, a spring annual, contributes greatly to its persistence (54). Competition by *A. fatua* can reduce yields significantly. Bell and Nalewaja (7) reported that *A. fatua* densities of 77 and 175 seedlings per m^2 reduced wheat yields by 22% and 39%, respectively, and barley (Hordeum distichum) yields by 7% and 26%, respectively in North Dakota. Heavy wild oat infestation may also reduce wheat protein due to competition for nitrogen (7).

Broadleaf weed infestations in cereals are commonly controlled with 2,4-D [2,4-dichlorophenoxy acetic acid], MCPA [[(4-chloro-o-tolyl)oxy] acetic acid], picloram (4 amino-3,5,6-trichloropicolinic acid), dicamba (3,6-dichloro-o-anisic acid), or bromoxynil (3,5-dibromo-4-hydroxybenzonitrile).

A. fatua is selectively controlled with barban (4-chloro-2-butynyl-m-chloro-carbanilate), and triallate [S-(2,3,3-trichloroallyl) diisopropylthiocarbamate] (51). Specific application timing with barban and the necessity for soil incorporation with triallate have restricted their use. New foliage-applied chemicals with less restrictive application requirements are presently being developed.

Chemicals for selective control of B. tectorum in cereals are not presently available. Therefore, non-selective herbicides, tillage and crop rotation must be used as effectively as possible.

The goal of annual cropping without tillage is weed control with minimum stubble disturbance. Herbicides used to substitute for tillage should be broad spectrum, thus eliminating field operations, both to reduce stubble trampling and tillage costs. Since chemical residues could reduce yields of subsequent cereal crops, the herbicides should not persist in the soil in a form toxic to cereal grains.

Glyphosphate [N-(phosphonomethyl) glycine] is a water soluble, non-selective, postemergence herbicide produced by Monsanto Chemical Company. It gives outstanding control of perennial grasses (59). It also controls certain perennial broadleaf plants as well as annual grasses and broadleaf weeds, and is now registered for use in cropping systems before emergence of barley, corn, oats, sorghum, soybeans, and wheat (61). Glyphosate has shown promise as a postemergence herbicide in the no-till program with application after harvest and during the fallow period (49). This treatment will control weeds in the fallow and preplant period (3,49). The chemical has not been found to persist in the soil, thus eliminating the fear of of damage to grain seeded later. Hodgson[1/] obtained 99% weed control using glyphosate in combination with 2,4-D in no-till experiments in Montana.

Paraquat (n,n-dimethyl-2,2-diphenylacetamide) as been used as a nonselective contact herbicide during the fallow period (16), but reapplication is needed every few weeks to control vegetation regrowth.

Minimum tillage cropping systems will depend on herbicides as a means to control weeds (41). Herbicides are especially needed to control after-harvest weeds. Species that have proved difficult to control at this stage include kochia, Russian thistle, cheatgrass, wild

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[1/]J.M. Hodgson. 1974. Unpublished data.

J.M. Hodgson

oats, annual foxtail and volunteer cereal grains (47). Few herbicides are available for weed control under minimum tillage conditions. Glyphosate and paraquat are two of the non-selective herbicides available for use in preparing a field for planting (40). The growth habits and life cycles of all of these weeds are quite compatible with that of small grains (68). The incidence of these weeds increases rapidly when small grains are grown continuously on the land. Since small grains would constitute the principal crops used in annual cropping systems in this area, a rapid increase in weed problems could be expected with this practice (10).

Special weed control measures in non-tillage closely parallel those used for other tillage systems. The methods of controlling weeds involve elimination of seed source, timely and effective after-harvest herbicide application, and use of crop rotations.

Soil water supplies for recropping either winter or spring grains depends upon pre- and post-harvest weed control, rainfall, and trapped snow. After an estimate of available soil water is made together with the average growing season (April-July) rainfall for a given locality, a realistic yield goal should be chosen. Nitrogen is the principal soil nutrient deficiency for recropping (10). As available water supplies increase (stored soil water plus growing season rainfall), the need for additional N-fertilizer increases proportionately.

Army (3), Burnside (16), and Wiese (65,69) have all pointed out the importance of learning more about chemical and cultural weed control practices under recropping situations.

METHODS AND MATERIALS

Studies were conducted near Bozeman, Montana in two separate experiments during the periods 1973 to 1975 (Experiment I) and 1974 to 1975 (Experiment II).

Experiment I

Studies were conducted 10 km north of Belgrade, Montana in the Horseshoe Hills area to compare the effect of tillage vegetation control and chemical vegetation control on soil moisture, weed control, and small grain yields.

Plots 12.2 by 12.2 m arranged in a randomized complete block design with four replications were established in September 1973. Plots were located in a 30 cm rainfall area on a Manhattan very fine sandy loam soil. The six rotations involving conventional and chemical seedbed preparation that were compared are listed in Table 1.

Crop Season 1973-74

Chemical and tillage plots were established September 27, 1973 on standing barley stubble. Table 2 lists the vegetation control methods, crop and seeding dates, tillage dates, chemicals and rates with dates of applications. Plots were seeded with a custom-altered Allis Chalmers no-till planter. The planter was set to place all seeds 5 cm below the soil surface in rows 38.1 cm apart. Varieties and seeding rates are listed in Table 3.

Table 1. Type of vegetation control method, crop, seeding date, chemical, application rate and date applied. Horseshoe Hills, 1973.

Vegetation control methods	Crop	Date Seeded	Chemical[1/]	Rate kg/ha	Date Applied
Chemical seedbed preparation plots	Winter wheat	9/27/73	Glyphosate 2,4-D	.55 .60	9/27/73 6/11/74
	Spring grains	4/29/74	Glyphosate 2,4-D	.55 .60	4/29/74 6/11/74
Tillage seedbed preparation plots	Winter wheat	9/27/73	Double disced 2,4-D	-- .60	9/27/73 6/11/73
	Spring grains	4/29/74	Double disced 2,4-D	-- .60	4/29/74 6/11/74
Chemical summer fallow plots	None	--	Glyphosate	.55	5/7/74 7/11/74
Tillage summer fallow plots	None	--	Double disced	--	9/27/73 6/10/74 8/15/74

[1/] Chemical applied in 222 L/ha of water

Table 2. Type of vegetation control, crop and seeding date, chemical, application rate, and application date. Horseshoe Hills, 1974.

Vegetation control methods	Crop	Date seeded	Chemical[1/]	Rate kg/ha	Date Applied
Chemical seedbed preparation plots	Winter wheat	9/16/74	2,4-D	.60	6/2/75
	Spring grains	5/24/75	Glyphosate	.55	5/24/75
			2,4-D	.60	6/2/75
			picloram	.28	6/2/75
Tillage seedbed preparation plots	Winter wheat	9/16/74	Double disced	--	
			2,4-D	.60	6/2/75
	Spring grains	5/24/75	Double disced	--	
			2,4-D	.60	6/2/75
			picloram	.28	6/2/75
Chemical seedbed fallow plots	None	--	Glyphosate	.55	9/24/74 7/7/74
Tillage summer fallow plots	None		Double disced	--	9/24/74 6/22/75 7/17/75

[1/] Chemical applied in 222 L/ha of water

Table 3. Crop varieties and seeding rates. Horseshoe Hills

Crop	Variety	Seeding rate (kg/ha)
Winter wheat	Winalta	55.5
	Cheyenne[1/]	66.6
Spring wheat	Fortuna	74.4
Barley	Shabet	62.2

[1/] Seeded during the 1974-75 crop season

The tillage seedbed preparation plots were doubled disced twice before planting. All grain plots received a treatment of 2,4-D to control broadleaf weeds. Chemical summer fallow plots were treated with glyphosate as necessary to control vegetation. Tillage summer fallow plots received three double discing operations to control vegetation during the summer.

A "Chain" small plot combine was used to harvest a 1.5 m by 6.1 m area from each plot; winter wheat was harvested Aug. 1, 1974 and spring grains August 15, 1974. The samples were cleaned and the bulk density of grain was determined with a Boerner test weight apparatus.

One soil core sample was taken from each plot with a "Giddings" core sampler on May 1, 1974. Moisture from samples taken at 30-cm intervals to a 1.52 m depth was measured by determining the weight loss after oven drying for 36 hours at 100°C.

Crop Season 1974-75

The second crop year began September 16, 1974. Due to a misunderstanding and a change in farm operators, the entire experiment was cultivated and seeded to winter wheat. Plot boundaries and crop rotations were reestablished with the use of glyphosate to control winter wheat plants on plots to be seeded to spring grain. As a result of cultivation, an area next to the main plots provided continuity for winter moisture storage data on disturbed and undisturbed stubble. All plot operations were carried out as in 1973-74. All plots received 72.2 kg/ha of 8-46-0 fertilizer. Plots were hand harvested from a 1.22 by 2.44 m area. Samples were threshed and the bulk density of grain was determined as in 1973.

Experiment II

Plots 3.3 x 6.1 m were established as a split block, replicated four times, on standing winter wheat stubble on October 4, 1974. All herbicides were applied with a backpack sprayer delivering 222 L/ha on October 10, 1974. The tillage treatment consisted of double discing for vegetation control to a depth of 12 cm. 'Fortuna' spring wheat was planted May 17, 1975 with the Allis Chalmers no-till planter at 74.4 kg/ha. The seeds were placed to an approximate depth of 7.6 cm.

Selective broadleaf weed control was accomplished with MCPA [(4-chloro-o-tolyl)oxy] acetic acid at the rate of .66 kg/ha June 22, 1975; and July 22, 1975 1.1 kg/ha of 2,4-D amine was applied in 222 L/ha of water to control Canada thistle.

Soil moisture data were collected on the chemical fallowed plots with a neutron probe at 30-cm intervals to a depth of 1.8 m on three treatments: 1) cyanazine; 2) glyphosate + atrazine; and 3) No chemical check. Readings were taken weekly from July 22, 1975 through harvest.

Herbicide residue injury was evaluated by counting wheat seedlings in one meter of row per plot. Weeds were identified, counted and harvested from a m^2 area. Grain yields were obtained by hand harvesting a 1.2 by 2.4 m area. Samples were threshed with a gravity "Vogel" thresher. Grain bulk density was determined as in Experiment I.

RESULTS AND DISCUSSION

Experiment I

Precipitation for the 1973-74 cropping season (September 1973 through August 1974) was variable. Above normal readings were recorded during September through December and in March and May, while January, February and April received less moisture than average. The biggest variation for the season occurred in June when precipitation was 6.1 cm less than normal. Precipitation during 1974 totaled 30.8 cm which is 4.5 cm less than normal (Table 4). The second cropping season was abnormally wet, although less than normal moisture was recorded during four months--April, June, August, and September. Abundant July rainfall more than made up for the deficiency in June and contributed greatly to the above normal grain yields. Precipitation for 1975 totaled 45.9 cm-10.6 cm above normal (Table 4).

More moisture was found on May 1, 1974 in the top 91.5 cm of soil under standing stubble than when stubble was disced. These same differences were also reflected in the 1975 results, although moisture penetrated slightly deeper under undisturbed stubble (Figures 1 and 2). Standing stubble stored an extra 1.97 cm and 2.00 cm moisture during the winter of 1973-74 and 1974-75, respectively (Table 5) to a depth of 1.52 m. This additional moisture was attributed to snow trapping by the standing stubble. The winter precipitation (September

Table 4. Total precipitation and departure from normal 1973, 1974, and 1975 (Belgrade FAA Airport, Montana)

Month	Total precipitation and departure from normal[1] (cm)					
	1973		1974		1975	
	Precip	Depart	Precip	Depart	Precip	Depart
Jan	.55	-1.12	.68	- .99	3.30	1.63
Feb	.29	- .75	.38	- .66	3.86	2.82
Mar	.95	-1.26	2.74	.53	2.67	.46
Apr	2.03	- .92	1.22	-1.73	2.18	- .76
May	.73	-4.61	6.20	.86	5.38	.05
June	4.01	-2.78	.69	-6.10	4.08	-2.69
July	.18	-2.61	2.69	- .10	7.54	4.74
Aug	5.23	2.31	4.47	1.55	2.64	- .28
Sept	4.70	1.16	3.18	- .36	1.93	-1.60
Oct	3.73	1.19	3.28	.74	8.05	5.51
Nov	2.51	.46	2.13	.08	2.46	.41
Dec	1.37	.87	2.18	1.68	1.83	.33
Total	26.28	-8.06	30.83	-4.49	45.95	10.62

1/ Climatological Data Montana

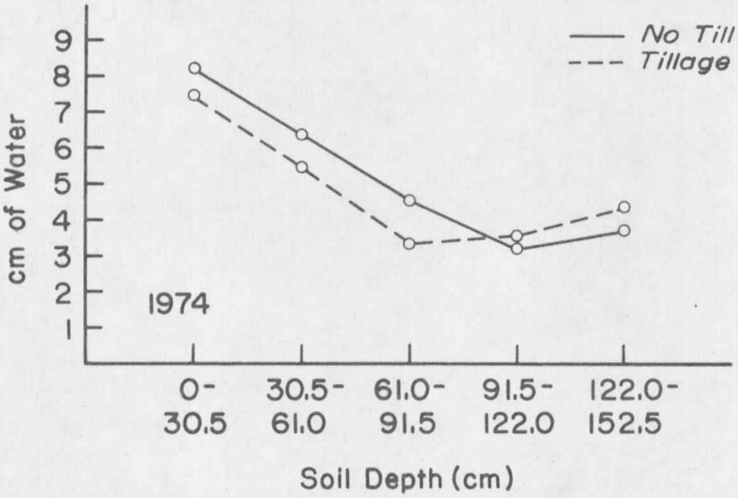

Figure 1. Soil water on May 1, 1974 at five soil depths as influenced by stubble treatment, Experiment I.

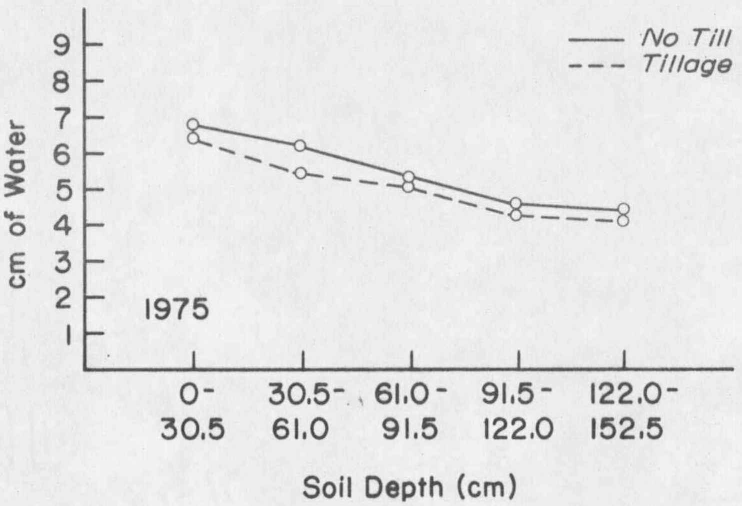

Figure 2. Soil water on May 24, 1975 at five soil depths as influenced by stubble treatment, Experiment I.

Table 5. The effect of stubble treatment on winter soil moisture storage. Horseshoe Hills, 1974 and 1975.

Soil depths (cm)	cm of water 1974[1/]					cm of water 1975[2/]				
	Replications					Replications				
	1									
No-Till										
0-30.5	7.92	8.38	8.00	8.51	8.20 a	6.73	7.11	6.54	7.21	6.90 a
30.5-61.0	6.37	6.55	6.19	6.48	6.40 c	5.89	5.97	6.12	6.90	6.22 b
61.0-91.5	4.39	5.53	4.33	4.57	4.71 e	5.10	5.33	5.41	5.56	5.35 c
91.5-122.0	3.46	3.09	3.04	2.82	3.10 f	4.59	4.41	4.24	5.51	4.69 e
122.0-152.5	4.19	3.70	3.96	3.68	3.88 f	4.62	4.77	4.24	4.29	4.48 f
Total					26.29					27.64
Tillage										
0-30.5	7.87	7.87	7.73	6.68	7.54 b	6.70	6.45	6.65	6.19	6.50 b
30.5-61.0	5.46	5.81	5.89	5.52	5.67 d	5.94	6.22	4.14	5.74	5.51 c
61.0-91.5	3.70	3.07	2.89	3.53	3.30 f	4.87	5.15	5.02	5.23	5.07 d
91.5-122.0	3.54	2.84	3.68	3.93	3.50 f	4.47	4.59	4.06	4.44	4.39 f
122.0-152.5	4.39	3.95	4.42	4.54	4.33 ef	4.64	4.49	4.36	3.20	4.17 f
Total					21.34					25.64

1/ Sampled May 1, 1974
2/ Sampled May 24, 1975
3/ Means within a column followed by a common letter are not significantly different at the P.05 level using Duncan's Multiple Range Test

through sampling date totaled 17.33 and 22.78 cm, respectively, for the two years.

In evaluating the reduced tillage cropping system, crop moisture requirement must be considered. Winter wheat requires 27 cm of moisture to produce a 1090 kg/ha yield (13). In a 35 cm mean annual rainfall area such as the study site, part of this must come from stored moisture, since half of the expected precipitation occurs during the growing season (May through August) (13). Assuming 17.5 cm of moisture fell during the growing season, and that 90% of it was available to the crop (18), 17.25 cm would be required from stored soil moisture. In a year with 35 cm of precipitation, that would require 64% moisture storage efficiency during the winter months.

The 1973-74 total soil moisture stored over the winter on standing stubble increased from an average of 10.4 cm in the top 152 cm on September 18, 1973 to an average of 26.29 cm through May 1, 1974, an increase of 15.89 cm (Table 6). Precipitation during this period totaled 17.33 cm; a moisture storage efficiency of 91%. Soil under double disced stubble stored 14.22 cm resulting in a moisture storage efficiency of 82%.

The moisture storage efficiency values for the second winter period were 68 and 73 percent, respectively, for tilled and non-tilled stubble (Table 6).