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Fall Chiseling for Annual Cropping of Spring Wheat in the Intermountain Dryland Region[1]

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ABSTRACT

Comparisons were made among annual cropping, annual cropping with fall chiseling, and a spring wheat-fallow rotation with chiseling after harvest under a climate with near uniform monthly precipitation of 2.5 cm. Because cropping season precipitation averaged only 9.1 cm, soil water storage before planting was necessary to ensure crop production. "Annually cropped" plots averaged 15.0 cm stored available water per 180-cm depth at planting, whereas "annually cropped-fall chiseled," and "cropped-fall chiseled-fallowed" plots averaged 21.3 and 22.9 cm, respectively.

Soil water storage from the spring of the summerfallow year until the spring of the crop year was dependent upon the previous over-winter storage ($r^2 = 0.65$). When this initial storage was less than 23.9 cm per 180-cm depth, water in storage was increased by summer-fallowing. However when the initial storage exceeded 23.9 cm, summer-fallowing resulted in a soil water loss. As crop yields were dependent on soil water storage at planting time ($r^2 = 0.68$), it was possible to estimate in the spring what yields would be with annual cropping, and also what extra water might be stored by fallowing as an alternative practice.

Nonfertilized, "annually cropped" and "annually cropped-fall chiseled" plots contained approximately the same amount of soil NO_3-N at planting, but only the chiseled plots with their extra stored water produced a yield response from fertilizer N. In comparison, nonfertilized fallowed plots contained 1½ times as much NO_3-N, and no yield response was obtained with fertilizer N.

Additional key words: **fallowing, nitrogen fertilizer, soil water storage, tillage, *Triticum aestivum* L. em Thell, water-use efficiency.**

CROP production under dryland agriculture is principally limited by the amount of water available for plant growth (2, 8, 9, 10, 11, 12). To minimize this limitation, summerfallowing is practiced in most dryland areas to store precipitation received during one year to increase the soil water supply for the crop the next year. Fall subsoiling in the Great Plains, where a summer rainfall climate exists, has generally not provided a measurable difference in

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water storage or crop yields (4). Fallowing in northern Montana has reduced the probability of spring grain failure by two-thirds to three-fourths, with yields double those of annual cropping (1).

Various Great Plains workers have evaluated stored soil water at seeding time as an index to predict subsequent spring cereal crop yields. Results of these evaluations have conflicted. Statistical analysis of soil water content, precipitation measurements, and yields of spring cereal crops from 15,000 random locations throughout the Great Plains showed that very little of the yield variation could be attributed to either soil water storage in the profile at seeding time or to precipitation between harvest and seeding time (5). Regression equations expressing spring wheat yields as a function of soil water at seeding time under both annual cropping and fallow cropping conditions at four locations indicated that between 1.3% and 34% of yield variation, depending upon location, could be attributed to soil water available at seeding time (12). At each location, however, growing season precipitation more accurately predicted crop yield than did soil water. When climatological data were used to interpret the effects of preseeding and seasonal water on spring cereal yields in 13 agricultural regions of South Dakota, preseeding water was found to only slightly influence crop yield (10). In this study, the highest correlation coefficients between preseeding water and yield, up to $r^2 = 0.46$, were obtained in areas having less than 25 cm of growing season precipitation. Other work, covering all of the Great Plains, related average spring wheat yields to the depth to which the subsoil was wet at seeding time (3). Yields after fallowing averaged about the same as annual cropping yields, provided the soil water storage at seeding time was similar.

North Dakota research (6) pointed out the inefficiency of fallowing where precipitation was sufficient to permit annual cropping with fertilization. Unfertilized spring wheat yielded twice as much when grown after fallow as when annually cropped. However, with proper fertilization, annually cropped wheat nearly equaled the yield of fallowed wheat.

In a 22-year study in southern Saskatchewan (8), soil water at seeding time was related to expected spring wheat yields in several different growing season rainfall areas. The results showed that with adequate water, annual cropping yields reached a plateau of 1,480 kg/ha, but crop-fallow yields reached 2,020 kg/ha.

In contrast to the Great Plains, good yield predictions were obtained from stored water in the Palouse winter rainfall area of Washington (9). There, under either annual or fallow-cropping systems, with either spring or winter wheat, nearly 60% of yield variation could be attributed to spring soil water. When cropping system was isolated or seasonal rainfall considered, yield predictions improved. Fertilizer nitrogen needs for both annually cropped and fallowed wheat were shown to be governed by the yield potential from stored soil water plus expected seasonal rainfall.

This paper presents comparative results of annual cropping spring wheat, with and without post harvest chiseling, and fallow cropping with post harvest chiseling. Rates of nitrogen application on these cropping systems were also compared. The annual precipitation distribution in the study area was quite uniform as compared to the Great Plains summer rainfall or Palouse winter precipitation pattern.

MATERIALS AND METHODS

The experiment, conducted from 1955 through the spring of 1962, was located on the University of Idaho Tetonia Branch Experiment Station in the dryland area of southeastern Idaho. The latest classification designated the soil type as Tetonia silt loam. It is a deep loessial silt loam with structural horizons grading from weak granular (0-15 cm) to weak prismatic and subangular blockey (15-105 cm) to massive (105-175 cm). The surface organic matter content is 2.5% and cation exchange capacity is 20 meq/100 g. The pH of the surface is 7.3, and free lime is found beginning near the 60-cm depth. Annual precipitation averages 34 cm, and is evenly distributed throughout the year. The monthly average for May and June is 4 cm, whereas that for all other months is near 2.5 cm. The slope was 4%, and while no runoff occurred from summer rainstorms during the experiment, in the early spring when snow melted there was runoff over frozen soil. The quantity of runoff was not measured except as it reflected in soil water stored at planting time.

The experimental design was a randomized complete block with split plots. Main treatments were replicated four times and consisted of (a) annually cropped, (b) annually cropped-fall chiseled, and (c) cropped-fall chiseled-fallowed rotation. No comparison was made of cropping after fallow without chiseling. Plots were chiseled 30 cm deep with diamond points spaced 90 cm apart. Two sets of plots were maintained for treatment (c) so a crop could be raised each year. To get into the cropping sequence, the entire plot site was uniformly cropped in 1954 which delayed the comparative crop results from the "cropped-fall chiseled-fallowed" plots until 1956. Main plots, 18.3 by 24.7 m, were split for nitrogen fertilizer (NH_4NO_3) application, with nitrogen rates of 0, 11, 22, 45, and 90 kg/ha per crop year being applied prior to seeding. A uniform phosphorus application (40 kg/ha of phosphorus as concentrated superphosphate) was applied prior to initiating the experiment to eliminate possible deficiencies.

Either Baart or Thatcher wheat, *Triticum aestivum* L. em Thell, was planted at 45 kg/ha the 2nd week in May, with the exception of 1957, when rains delayed planting until May 28. Weeds were controlled with 2,4-D. A self-propelled combine harvested 2.1-m-wide yield samples lengthwise through the center of each plot during or near the first week in September.

Soil water was determined gravimetrically on zero-nitrogen plots of all cropping methods (including fallowed plots) each spring prior to seeding and after harvest. Four samples per plot were taken at each sampling date in 30-cm depth increments to 180 cm. Bulk density and 15-bar water were determined to convert percent water by weight to available water per soil depth. Nitrate-nitrogen was determined by the phenoldisulphonic acid method (7) on soil samples taken from all plots at 30-cm depth increments to 90 cm in the spring before fertilizing. Kjeldahl procedures were used to determine harvested grain nitrogen content.

RESULTS AND DISCUSSION

Soil Water

Plant root extraction at harvest sampling date was not quite complete (to 15-bars) in the 180-cm soil profile, there being 3.3 cm left unused when averaging all plots and years. The net water stored (Table 1) excludes the individual unused amount so that precipitation may be compared with soil water storage. Also, the net water stored at planting time was so close to soil water portion used for evapotranspiration that this second figure is not re-presented herein.

Storage from harvest until next spring by both "annually cropped-fall chiseled," and "cropped-fall chiseled-fallowed" plots significantly exceeded the amount stored on "annually cropped" plots all years except 9/21/56 to 5/8/57 and 9/23/57 to 5/14/58. In the springs of 1957 and 1958, no runoff was observed, and

Table 1. Precipitation and average net soil water storage (cm) for annually cropped (AC) and annually cropped-fall chiseled (AC-FC) plots for their storage period, and for crop-fall chiseled-fallowed (C-FC-Fallow) plots during three storage periods. St. Anthony, Idaho, 1954-62.

From harvest to next spring					During summerfallow			From post summer-fallow to next spring			Storage, entire fallow period C-FC-fallow
		Storage					Storage			Storage	
Calendar dates	Pre-cip.	AC	AC-FC	C-FC-fallow	Calendar dates	Precip.	C-FC-fallow	Calendar dates	Pre-cip.	C-FC-fallow	
	cm	cm	cm	cm		cm	cm		cm	cm	cm
9/28/54 to 5/4/55	13.9	8.4	15.5	14.9	5/4/55 to 9/16/55	16.7(16.7)	- 1.3	9/16/55 to 5/4/56	27.8	8.8	22.4
9/16/55 to 5/4/56	27.8	8.1	22.8	22.5	5/4/56 to 9/21/56	7.2(4.9)	- 8.1	9/21/56 to5/8 /57	26.5	11.1	25.5
9/21/56 to 5/8/57	26.5	21.0	22.3	24.0	5/8/57 to 9/23/57	15.8(7.1)	- 9.2	9/23/57 to 5/14/58	21.4	8.3	24.7
9/23/57 to 5/14/58	21.4	23.2	20.3	23.4	5/14/58 to 10/16/58	9.6(6.4)	-10.2	10/16/58 to 4/23/59	15.2	7.3	18.3
10/16/58 to 4/23/59	15.2	7.7	9.4	9.2	4/23/59 to 10/5/59	17.5(10.8)	- 1.0	10/5/59 to 5/18/60	18.2	7.9	18.1
10/5/59 to 5/18/60	18.2	9.8	17.0	17.0	5/18/60 to 9/20/60	10.3(8.8)	- 4.6	9/20/60 to 5/12/61	18.7	3.6	16.0
9/20/60 to 5/12/61	18.7	7.6	13.3	11.4	5/12/61 to 8/30/61	11.4(9.1)	- 2.8	8/20/61 to 5/23/62	31.3	6.4	14.9
Average	20.2	12.2	17.2	17.5	Average	12.6(9.1)	- 4.7	Average	22.7	7.6	20.0

* Figures in parenthese denote precipitation that occurred from grain planting to ripe subperiod.

the net storage on "annually cropped" plots was 2.6 times that of other years while precipitation contributing to storage was only 1.3 times greater. The amount of precipitation versus water storage on "annually cropped-fall chiseled" and "cropped-fall chiseled-fallowed" plots from harvest until next spring is shown in Fig. 1. The regression curve in this figure does not include "annually cropped" plots, as these nonchiseled plots had erratic storage. Their storage was presumably related also to runoff, and therefore not significantly correlated with precipitation.

Since planting-to-harvest precipitation (Table 1) ranged from 4.9 to 16.7 cm and averaged only 9.1 cm, the major water source available to the crop was derived from soil storage. The yearly average stored available water by soil depth at seeding time, shown in Fig. 2, is the net storage from harvest (Table 1) plus the carry-over of unused water at harvest. Available water content of "annually cropped" plots averaged 15.0 cm/180-cm soil depth; "annually cropped-fall chiseled" plots averaged 21.3 cm/180-cm depth. The 6.3-cm increase in water stored by chiseling was attributed to increased intake from snow melt due to improved infiltration properties of the soil surface. Available soil water in "cropped-fall chiseled-fallowed" plots, 22.9 cm/180-cm depth exceeded the "annually cropped-fall chiseled" plots by only 1.6 cm. Yearly deviations are not shown as they are so nearly represented by the deviations in Table 1.

The inefficiency of fallowing for water storage was related partly to large evaporative losses during the warm portion of the summerfallow period. Plots to be fallowed contained an average of 20.6 cm of water the spring before summerfallow tillage was started. During the summer of fallow, stored water in the 180-cm soil profile was reduced by an average of 4.7 cm even though 9.1 cm of rain were received during this time. The reduction during the summerfallow period was, within the limits of precipitation that occurred, closely related to the amount of storage at the beginning of the summerfallow season (Fig. 3). The regression equation of this figure also indicates that year-to-year differences in water storage overwinter diminished by fall. For example, a soil containing 1 cm more than average water in the spring would be ex-

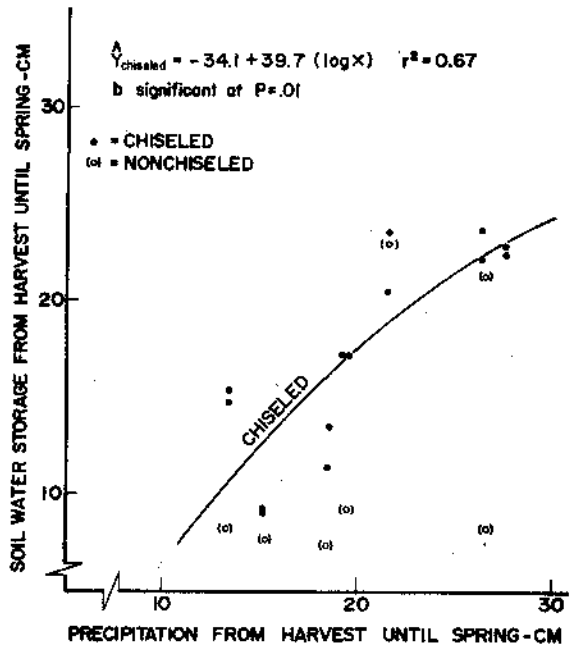

Fig. 1. Relationship between precipitation and soil water storage on chiseled plots, 1955-61.

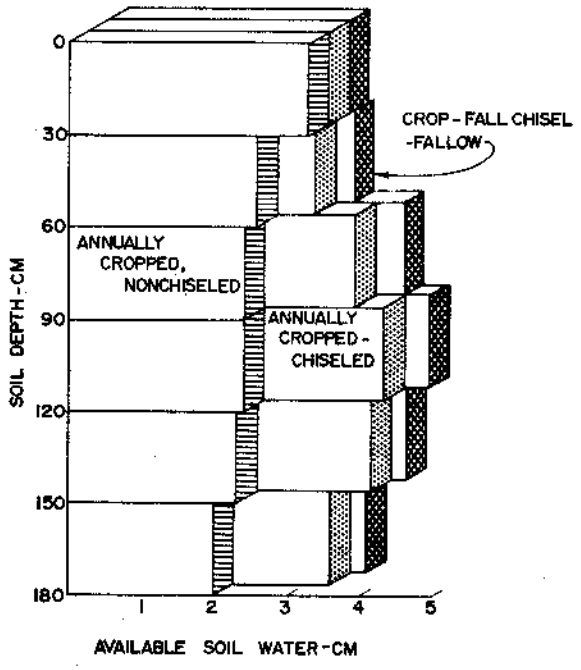

Fig. 2. Available soil water at seeding time for three spring wheat cropping treatments, 1955-61.

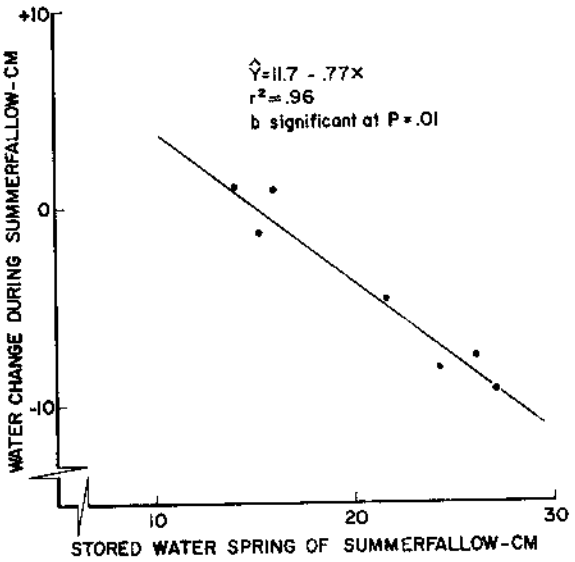

Fig. 3. Relationship between stored water the spring of the summer-fallow year and subsequent change in water stored during the summer of fallow, 1955-61.

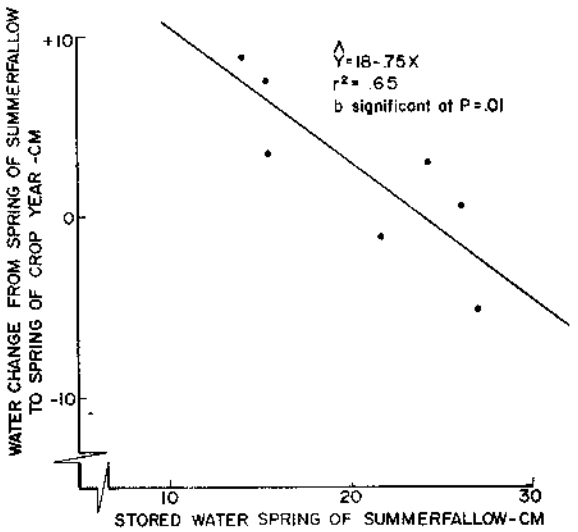

Fig. 4. Relationship between stored water the spring of the summer-fallow year and subsequent change in stored water during remainder of fallow period, 1955-61.

pected to lose 0.77 cm more than average during the summer.

Between the soil water sampling done in the fall on summerfallow and the next spring, fallow plots gained only 7.6 cm water out of 22.7 cm of precipitation for a storage efficiency of 30%. Although there was already 16.5 cm available water stored in the profile at the fall date, the low efficiency is not attributed to lack of storage space for water as the 180-cm soil profile had a waterholding capacity of 37.1 cm of available water at 1/3-bar suction. Undoubtedly the relatively moist and frozen surface had a low infiltration capacity which contributed to snowmelt being lost by runoff. Also, as standing stubble had been eliminated by summer tillage, winds had a chance to blow the snow from the plots which reduced the source of water for storage.

Of the 7 fallow years shown (Table 1), two of these (5/24/55 to 5/4/56 and 4/23/59 to 5/18/60) provided quite substantial increases in stored water by fallowing and one (5/14/58 to 4/23/59) induced a substantial loss. In other years, gains, and one loss, were less pronounced. These gains and losses were correlated with the quantity of available water present the spring of the summerfallow year (Fig. 4). On the average (from regression), when the initial stored water was less than 23.9 cm/180-cm soil depth, water in storage was increased by summerfallowing or lost when the initial storage exceeded 23.9 cm. Therefore, except for nutrient release, weed control, and phytotoxic effects from the preceding crop, there was no advantage to fallowing if the quantity present after the initial overwinter storage period was equal to or greater than the 23.9 cm.

Effect of Fertilizer N and Cropping System on Soil Nitrates and Nitrogen Uptake

Soil NO_3-N per 90-cm depth is reported herein as kg/ha N found the spring of the crop year before N fertilization was done. By excluding the initial crop year, the results include any carry-over from previous fertilizer applications. As there was only slight variation among years, the quantitative carry-over for more than one crop year was not significant. The "annually cropped" and "annually cropped-fall chiseled" plots were very similar, and also within these main plots, split plots receiving 0, 11, and 22 kg/ha fertilizer N were all similar, averaging 12 kg/ha NO_3-N. The plots that received 45 and 90 kg/ha of fertilizer N averaged 18 and 32 kg/ha of NO_3-N, respectively. The "cropped-fall chiseled-fallowed" plots with 0, 11, and 22 kg/ha fertilizer N applied were similar to each other, averaging 19 kg/ha NO_3-N, whereas with 45 and 90 kg/ha fertilizer N they averaged 25 and 38 kg/ha NO_3-N, respectively.

The nitrogen content of the harvested grain from "annually cropped" plots averaged 23.1 kg/ha and from "cropped-fall chiseled-fallowed" plots there was 35.6 kg/ha. Fertilizer N applications did not change these quantitative amounts as slight increases in percent nitrogen of grain were offset by slight reductions in yield. However, with the "annually cropped-fall chiseled" plots, where yields and protein content were increased simultaneously with nitrogen fertilizer, grain-nitrogen uptake increased from 23.2 kg/ha with no fertilizer to a maximum of 32.6 kg/ha with the 90-kg/ha N rate.

Wheat Yields

The average yield of 837 kg/ha (Table 2) from the "annually cropped" tereatment was 257 kg/ha below the "annually cropped-fall chiseled" yield of 1,094 kg/ha. The "cropped-fall chiseled-fallowed" yield, 1,331 kg/ha, was 665 kg/ha when placed on a yearly basis, the lowest of the three treatments.

To determine the regression of yield on 0- to 60-, 60- to 120-, and 120- to 180-cm soil profile water and growing season precipitation, the data were analyzed by stepwise multiple regression. There were 12 possible combinations of the independent variables—soil water and crop season precipitation. Yield was best expressed, when using only one independent

Table 2. Effect of cropping method and nitrogen fertilizer on spring wheat yields, 1955-61.

Cropping method	Wheat yield, kg/ha					
	0 N	11 N	22 N	45 N	90 N	Avg
Annual crop, (nonchiseled)	815	903	822	856	788	837
Annual crop-fall chiseled	977	1,037	1,152	1,125	1,179	1,094
Crop-fall chiseled-fallowed*	1,334	1,354	1,293	1,354	1,320	1,331
Average	1,042	1,098	1,089	1,112	1,096	1,087

LSD .01 cropping method = 160
LSD .05 nitrogen = 49
LSD .01 among N treatments with same cropping method = 112

* Includes missing plot values for 1955.

variable, as a function of available water in the 180-cm profile in the spring of the crop year:

$$\hat{Y} = 84 + 50X$$
$$b \text{ significant } P = 0.01$$
$$r^2 = 0.68$$

When the 0- to 180-cm water was separated into 0- to 120-cm and 120- to 180-cm water as separate variables and analyzed by multiple regression analysis, the r^2 value was also 0.68. This indicated total available water alone was as good a criterion to estimate yields from as using two water variables.

During the years of this experiment, precipitation was fairly constant among most years. Therefore, regression of yield on precipitation did not account for a significant portion of the yield variation.

To determine if some stored soil water or precipitation variables were correlated with a N-fertilizer response, the data were again analyzed by stepwise regression using ratio of N-fertilized wheat yield to unfertilized wheat yield as the dependent variable. The simple regression equation that accounted for the most variation in yield from the three cropping treatments was 120- to 180-cm soil water available in the spring:

$$\hat{Y} = 0.82 + 2.74X$$
$$b \text{ significant } P = 0.05$$
$$r^2 = 0.22$$

Realizing that the fallowed plots had more NO_3-N in the spring at planting time and had not responded to fertilizer, the "cropped-fall chiseled-fallowed" plots were excluded from the next regression analysis, which again estimated N-fertilizer response versus 120- to 180-cm soil water:

$$\hat{Y} = 0.80 + 3.78X$$
$$b \text{ significant } P = 0.05$$
$$r^2 = 0.31$$

Although this procedure produced a slight increase in r^2 value, over two-thirds of the variation in yield changes due to fertilizer remained unexplained.

Water-Use Efficiency

Water-use efficiency (WUE) is defined here by the ratio: grain yield Y (kg)/evapotranspiration of soil water ET (cm). ET was computed as precipitation plus the decrease in soil profile water between planting and harvest. Drainage out of the profile and runoff during cropping was considered insignificant. An insight as to how WUE varied with ET can be gained by first observing how Y varied with ET in the regression equation of Fig. 5. When Y = 0, that is when there was not sufficient water available to produce grain, ET is equal to 11.3 cm. Assuming linearity, each centimeter of ET above 11.3 cm is equivalent, within experimental limits, to 66 kg/ha of wheat. It is obvious that WUE is low when Y is low because there is an ET plateau below which no wheat is produced. For instance, extrapolating from the data in Fig. 5, if growing season precipitation were the only source of water for crop growth (averaging 9.1 cm), crop failures would be normal, which is indicative of the major role that stored water plays in spring wheat production in this climatic environment. The highest WUE, 55.8 kg/cm, measured during the experiment was from the highest yielding plot; the lowest WUE, 22.2 kg/cm was from the lowest yielding plot. On "annually cropped-fall chiseled" plots where nitrogen fertilizer enhanced yield, it also increased WUE. For instance, the additional 6.3 cm of water stored by chiseling was sufficient, according to the regression equation showing yield as a function of soil stored water, ($\hat{Y} = 84 + 50$ X), to increase yield by 315 kg/ha. As shown in Table 1, yields without nitrogen averaged only 162 kg more than "annually cropped" plots. However, when 22 kg/ha N were applied, they averaged 330 more than the nonchiseled plots or close to the regression equation prediction.

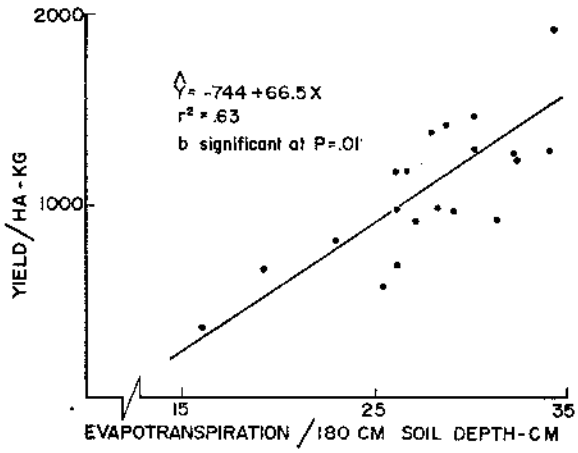

Fig. 5. Relationship between evapotranspiration per 180-cm soil depth and spring wheat yield, 1955-61.

Because WUE as computed here excluded nonstored fallow precipitation, "cropped-fall chiseled-fallowed" plots had the highest WUE. However, if WUE included precipitation during noncrop periods, then "annually cropped-fall chiseled" plots could be shown to be nearly twice as efficient as "cropped-fall chiseled-fallowed" plots.

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