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CROPPING SYSTEMS

Cropping System Influence on Planting Water Content and Yield of Winter Wheat

David C. Nielsen,* Merle F. Vigil, Randy L. Anderson, Rudy A. Bowman, Joseph G. Benjamin, and Ardell D. Halvorson

ABSTRACT

Many dryland producers in the central Great Plains of the USA express concern regarding the effect that elimination of fallow has on soil water content at winter wheat (*Triticum aestivum* L.) planting and subsequent yields. Our objectives were to quantify cropping system effects (fallow weed control method and crop sequence), including corn (*Zea mays* L.) (C) and proso millet (*Panicum miliacium* L.) (M), on soil water at winter wheat planting and subsequent grain yield, and to determine the frequency of environmental conditions which would cause wheat yield to drop below 2500 kg ha^{-1} for various cropping systems. Crop rotations evaluated from 1993 through 2001 at Akron, CO, were W-F, W-C-F, W-M-F, and W-C-M (all no-till), and W-F (conventional till). Yields were correlated with soil water at planting: kg ha^{-1} = 373.3 + 141.2 × cm (average and wet years); kg ha^{-1} = 897.9 + 39.7 × cm (dry years). Increasing cropping intensity to two crops in 3 yr had little effect on water content at wheat planting and subsequent grain yield, while continuous cropping and elimination of fallow reduced soil water at planting by 11.8 cm and yields by 450 to 1650 kg ha^{-1}, depending on growing season precipitation. No-till systems, which included a 12- to 15-mo fallow period before wheat planting nearly always produced at least 2500 kg ha^{-1} of yield under normal to wet conditions, but no cropping system produced 2500 kg ha^{-1} under extremely dry conditions.

The traditional wheat–fallow production system used in the central Great Plains of the USA was developed in the 1930s as a strategy to minimize incidence of crop failures resulting from erratic precipitation (Hinze and Smika, 1983). The use of herbicides to control weeds in this system reduced or eliminated tillage, and led to greater precipitation storage efficiencies, such that more frequent cropping could be successfully employed (Halvorson and Reule, 1994; Peterson et al., 1993; Anderson et al., 1999; Norwood et al., 1990; Smika, 1990; Farahani et al., 1998).

While more intensive cropping is gradually replacing W-F in the central Great Plains, many producers still express concern regarding the effect that more frequent cropping has on soil water content at planting and subsequent winter wheat yields. Previous research has shown relationships between available soil water and yield of some crops. Nielsen et al. (1999) reported that winter wheat yields were reduced by 79 kg ha^{-1} for every centimeter that soil water at wheat planting was reduced by sunflower (*Helianthus annuus* L.) ahead of wheat in rotation. In southwestern Kansas, Norwood (2000) similarly showed lower winter wheat yields when the previous crop was sunflower or soybean compared with corn or grain sorghum [*Sorghum bicolor* (L.) Moench]. These reductions in wheat yield were related to lower soil water at planting. Lyon et al. (1995) showed that soil water at planting was strongly correlated with yield of short season summer crops [pinto bean (*Phaseolus vulgaris* L.), proso millet] but only weakly related to yield of long season summer crops (sunflower, grain sorghum, corn). They attributed this result in part to shorter season crops having more soil water available at the critical reproductive growth stage than longer season crops, which used much of the initial soil water for stover production and did not have it available for grain development.

In addition to differences in previous crop water use, soil water content at wheat planting can also be affected by differences in tillage and crop residue effects on precipitation storage efficiency. Precipitation storage efficiency increases as tillage is reduced during the summer fallow period before wheat planting (Smika and Wicks, 1968; Tanaka and Aase, 1987; Norwood, 1999). Crop residues reduce soil water evaporation by shading the soil surface and reducing convective exchange of water vapor at the soil–atmosphere interface (Greb et al., 1967; Aiken et al., 1997; Van Doren and Allmaras, 1978). Additionally, reducing tillage and maintaining surface residues reduce precipitation runoff and increase infiltration, thereby increasing precipitation storage efficiency (Unger and Stewart, 1983).

Both producers and agricultural lenders would like to have a means of assessing the risk level that might be incurred in moving from conventional wheat–fallow production systems to more intensively cropped no-till systems. Part of that risk assessment involves quantifying the effects of cropping system on wheat yields. Therefore, the objectives of this study were to (i) quantify effects of cropping system (crop sequence and fallow-season weed-control method [i.e., tillage vs. no-till]) on soil water content at winter wheat planting and subsequent effects on grain yield, and (ii) determine frequency of environmental conditions that cause wheat

D.C. Nielsen, M.F. Vigil, R.A. Bowman, and J.G. Benjamin, USDA-ARS, Central Great Plains Res. Stn., 40335 County Road GG, Akron, CO 80720; R.L. Anderson, USDA-ARS, Northern Grain Insects Res. Lab., 2923 Medary Ave., Brookings SD 57006; and A.D. Halvorson, USDA-ARS, Soil–Plant–Nutrient Research Unit, P.O. Box E, 301 S. Howes, Ft. Collins, CO 80522. Received 21 Jan. 2002. *Corresponding author (dnielsen@lamar.colostate.edu).

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Abbreviations: CT, conventional tillage; W-C-F, wheat–corn–fallow; W-C-M, wheat–corn–millet; W-F, wheat–fallow; W-M-F, wheat–millet–fallow; NT, no-till.

yields to fall <2500 kg ha^{-1}, a conservative economic yield goal, for various cropping systems in the central Great Plains.

MATERIALS AND METHODS

This study was conducted at the USDA Central Great Plains Research Station, 6.4 km east of Akron, CO (40°09′ N, 103°09′ W, 1384 m). The soil type was a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls). In 1990, several rotations were established to investigate the possibility of cropping more frequently than every other year, as done with the traditional winter wheat–fallow system. The current study analyzes data beginning with the 1993 crop year to provide time for soil water conditions to stabilize and truly manifest rotation, tillage, and previous crop effects. A description of the plot area, tillage systems, and experimental design are given in Bowman and Halvorson (1997) and Anderson et al. (1999). Briefly, rotation treatments were established in a randomized complete block design with three replications. All phases of each rotation were present every year. Individual plot size was 9.1 by 30.5 m, with east–west row direction. Only the following rotations were used in this analysis to determine the influence of tillage and cropping intensity on water content at wheat planting and subsequent wheat yield:

W-F (CT)
W-F (NT)
W-C-F (NT)
W-M-F (NT)
W-C-M (NT)

where W = winter wheat, C = corn, M = proso millet, F = fallow, CT = conventional tillage, and NT = no-till.

Details of the weed control practices used for the CT and NT systems are given in Anderson et al. (1999). Briefly, the CT system employed four to eight sweep plow operations as needed for weed control during fallow. The NT system relied on contact and residual herbicides for all weed control.

Wheat planting occurred between 18 and 28 September in any given year. Wheat variety 'TAM107' was planted for the 1993 to 1996 crops, and 'Akron' was planted for the 1997 to 2001 crops. Row spacing was 18 to 20 cm, depending on the particular drill used. Seeding density was approximately 2.125 million seeds ha^{-1} in all years.

Fertilizer N as ammonium nitrate (34–0–0) was surface broadcast to each plot before planting during the falls of 1992 to 1995, and banded at planting in 1996 to 2000. Application rates were determined according to annual soil tests and a yield goal of 2688 kg ha^{-1}. Actual fertilizer rates varied between 34 and 67 kg N ha^{-1} depending on the plot and the year. Soil profiles were sampled in 30-cm increments to a depth of 180 cm. Phosphorus (11–23–0, N–P–K) was banded with the seed at planting at a rate of 17 kg ha^{-1} P_2O_5.

Crop water use was calculated by the water balance method using soil water measurements and assuming runoff and deep percolation were negligible. The soil water measurements in the 0- to 30-cm layer were made by time-domain reflectometry. Soil water measurements at 45, 75, 105, 135, and 165 cm were made with a neutron probe. The neutron probe was calibrated against gravimetric soil water samples taken in the plot area. Gravimetric soil water was converted to volumetric water by multiplying by the soil bulk density for each depth. Two measurement sites were located near the center of each plot and data from the two sites were averaged to give one reading of soil water content at each sampling depth per plot.

Available water per sampling depth was calculated as:

$$(\text{Volumetric water} - \text{Lower limit}) \times (\text{Layer thickness})$$

where

Volumetric water = cm^3 water cm^{-3} soil from neutron probe or time-domain reflectometry

Lower limit = lowest volumetric water observed for wheat (Ritchie, 1981; Ratliff et al., 1983)

Layer thickness = 30 cm

The specific values of lower limit used for wheat were 0.090, 0.120, 0.072, 0.061, 0.082, and 0.111 cm^3 cm^{-3} for the 0- to 30-, 30- to 60-, 60- to 90-, 90- to 120-, 120- to 150-, and 150- to 180-cm depths, respectively (Nielsen et al., 1999).

Daily precipitation was recorded as the average of measurements made at two corners of the plot area. Open pan evaporation was measured at an adjacent weather station site about 200 m south of the plot area.

Data were analyzed for treatment (rotation) differences by analysis of variance, with years considered as a fixed variable (Gomez and Gomez, 1984). When treatment differences were significant ($P < 0.05$ from analysis of variance), $LSD_{0.05}$ was computed to perform mean separations. The relationship between available water content at planting and wheat yield was analyzed by linear regression.

RESULTS AND DISCUSSION

There was no significant year × cropping system interaction effect for water content at planting ($p = 0.31$), but the data are presented by year (Table 1) to be complete and consistent with the data presentation for

Table 1. Available water in the 0- to 180-cm soil profile at winter wheat planting from five cropping systems at Akron, CO, for the 1993–2001 wheat crops.

Rotation†	1993	1994	1995	1996	1997	1998	1999	2000	2001	Avg.
	cm									
W-F (CT)	20.7a‡	14.4c	14.8a	11.5b	15.1b	10.0bc	11.0bc	22.8bc	20.1ab	15.6c
W-F (NT)	22.4a	19.8ab	20.5a	22.2a	24.1a	18.2a	20.7a	29.9a	26.5a	22.7a
W-C-F	19.4a	20.9a	17.3a	20.3a	21.3a	20.3a	17.0ab	26.4ab	22.2a	20.6ab
W-M-F	21.1a	16.3bc	17.8a	20.1a	21.9a	16.0ab	14.4b	26.8a	21.0a	19.5b
W-C-M	10.5b	14.5c	6.8b	9.3b	15.5b	3.8c	6.8c	20.1c	10.5b	10.8d
p	0.01	0.01	0.01	<0.01	0.02	0.01	0.01	<0.01	0.06	<0.01

† W = wheat, C = corn, M = millet, F = fallow, CT = conventional tillage, NT = no-till. *p* = probability that the null hypothesis of no differences in profile water content due to rotation is true.

‡ Within columns, means followed by a different letter differ at $P < 0.05$ as tested by LSD.

Table 2. Winter wheat grain yield (at 0.125 kg kg^{-1} moisture content) from five cropping systems at Akron, CO, for the 1993–2001 wheat crops.

Rotation†	1993	1994	1995	1996	1997	1998	1999	2000	2001	Avg.
	kg ha^{-1}									
W-F (CT)	2540a‡	1385	2255	1840b	2140b	1645	2355a	1480b	3495a	2125b
W-F (NT)	3810a	1585	2720	3530a	3445a	1990	3125a	2160a	3925a	2920a
W-C-F	3115a	1490	2770	3755a	4040a	2455	3050a	2200a	3660a	2950a
W-M-F	3720a	1455	2745	3785a	3395a	1960	2845a	1720b	3490a	2790a
W-C-M	925b	1035	2255	1200b	2080b	870	1125b	1150c	2150b	1420c
p	0.02	0.12	0.38	<0.01	<0.01	0.13	0.01	<0.01	0.02	<0.01

† W = wheat, C = corn, M = millet, F = fallow, CT = conventional tillage, NT = no-till. p = probability that the null hypothesis of no differences in grain yield due to rotation is true.
‡ Within columns, means followed by a different letter differ at $P < 0.05$ as tested by LSD.

grain yield (Table 2), for which the year × cropping system interaction effect was significant ($p < 0.01$). Available soil water at wheat planting ranged from 3.8 cm (W-C-M, 1998) to 29.9 cm (W-F(NT), 2000). Averaged over the 9 yr of data, reducing tillage in the wheat–fallow system increased available soil water at wheat planting by 46%, with 7.1 cm more available soil water in the NT system. Smika and Wicks (1968) reported somewhat similar results from a 3-yr study in western Nebraska in which soil water storage increased by 37% (8.7 cm) when moving from CT weed control to NT during the fallow period.

When corn was added to the NT production system, there was no significant decrease in available soil water content at wheat planting, even though the fallow period between crops was shortened from 15 mo (W-F) to 12 mo (W-C-F). The W-C-F system eliminates the months of July, August, and September from the fallow period, which on average receives 15.3 cm of precipitation (Table 3). While this is a fairly large amount of precipitation (37% of the avg. annual total), several researchers have shown that precipitation storage efficiencies in W-F (NT) systems are very low during these summer months (−6–46%; Smika and Wicks, 1968; Farahani et al., 1998; Tanaka and Aase, 1987). This low storage efficiency of summer precipitation in combination with the corn stubble's greater ability to catch snow (Norwood, 1999, 2000) are probable reasons for no decrease in available soil water content at wheat planting when corn is added to the W-F cropping system. Farahani et al. (1998) also found no significant effect of crop sequence on soil water at wheat planting when comparing NT systems of W-F, W-C-F, and W-C-M-F in an 8-yr study conducted in northeastern Colorado. Norwood (1994), in contrast, did not find consistent increases from year to year in soil water at wheat planting in western Kansas when moving from CT to NT, but did find significant decreases (15%, 3 cm) in soil water content at wheat planting when changing from W-F (NT) to wheat–sorghum–fallow (NT).

When corn in the W-C-F system was replaced with millet, the average water content at planting was not affected. On the other hand, when fallow in the W-C-F system was replaced with millet, there was a 48% (9.8 cm) decrease in available water content at wheat planting.

The average wheat yields (Table 2) were increased by 37% (795 kg ha^{-1}) when fallow-period tillage was replaced by chemical weed control: W-F(NT) vs. W-F(CT). There were no significant differences in wheat yield among the W-F(NT), W-C-F, and W-M-F production systems. Yield in the W-C-M system was reduced by 52% (1530 kg ha^{-1}) compared with the W-C-F system.

To better understand the significant year × cropping system interaction effect for grain yield, and the influence that planting-time soil water content has on grain yield, we plotted grain yield against soil water content at planting (Fig. 1a). The data fall into two distinct groups, which can be delineated by growing season moisture condition. Upon further investigation, we found 1994, 1998, and 2000 were far below average in April–June precipitation, above average in April–June pan evaporation, and had a >65 cm difference between pan evaporation and precipitation for the same period (Table 3).

Table 3. Precipitation and open pan evaporation at Akron, CO (1992–2001 and 93-yr avg.).

Month	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Avg.	93-yr Avg.
Precipitation	cm											
January	1.4	0.6	1.0	2.2	0.8	1.3	0.1	0.2	0.6	2.2	1.0	0.8
February	0.5	1.4	0.5	0.9	0.1	1.3	3.2	0.4	0.8	1.1	1.0	0.9
March	5.0	1.3	0.2	2.2	2.9	0.2	0.4	0.8	4.0	2.5	1.9	2.1
April	0.6	4.7	5.3	6.2	1.2	2.2	1.8	5.2	4.1	3.4	3.5	4.2
May	5.7	2.7	2.9	14.5	11.6	5.5	2.5	8.0	2.0	10.7	6.6	7.5
June	7.9	4.5	0.6	12.1	6.5	8.0	1.0	6.2	1.9	3.4	5.2	6.3
July	5.3	11.4	7.0	3.9	8.3	3.1	10.2	4.0	6.6	6.7	6.6	6.9
August	10.2	2.4	3.0	2.0	6.8	6.2	5.6	17.3	5.5	5.8	6.5	5.3
September	0.1	2.3	0.8	5.7	8.6	2.5	0.8	3.9	3.9	4.4	3.3	3.1
October	2.1	9.5	7.3	1.0	1.2	5.9	1.7	1.2	4.9	1.7	3.7	2.3
November	1.9	2.6	2.6	1.5	0.1	0.7	2.7	1.2	0.8	0.5	1.4	1.4
December	0.6	1.2	1.3	0.2	0.1	1.1	0.5	1.5	0.6	0.0	0.7	1.0
Total	41.3	44.5	32.8	52.3	48.0	37.9	30.4	49.8	35.5	42.4	41.5	41.8
Precipitation (April–June)	14.2	11.9	8.8	32.8	19.3	15.7	5.3	19.4	8.0	17.5	15.3	18.0
Pan evaporation (April–June)	76.9	64.2	80.8	50.5	70.3	70.1	85.3	71.1	91.9	69.5	73.1	70.8†
Pan evaporation–precipitation (April–June)	62.7	52.3	71.0	17.7	51.0	54.4	80.0	51.7	83.9	52.0	57.8	52.8

† Pan evaporation data averaged from 1968 to 2001.

These 3 yr, which we would classify as high water stress years, had a yield response to available water at planting of 39.7 kg ha^{-1} cm^{-1} of available water (Fig. 1b), whereas the other 6 yr had a yield response 3.6 times greater (141.2 kg ha^{-1} cm^{-1}, Fig. 1c). The average starting soil water contents in the two sets of years were comparable (17.4 cm in the wet years and 18.7 cm in the dry years). Under the very dry conditions experienced in 1994, 1998, and 2000, the wheat plants made less efficient use of the stored water resource compared with the other years. For comparison, we calculated a wheat yield response to soil water at planting from selected data reported by Norwood (2000) in southwestern Kansas (eliminating years with yield losses due to insects, frost damage, and severe water stress). His data resulted in a yield response of 94.8 kg ha^{-1} for every centimeter increase in available soil water at wheat planting, 33% lower than our high yield response of 141.2 kg ha^{-1} cm^{-1} soil water. A lower yield response to water as latitude decreases (higher pan evaporation) has been reported by Hatfield et al. (1988) and Howell et al. (1995), and is most likely related to vapor pressure deficit differences between locations (Tanner and Sinclair, 1983).

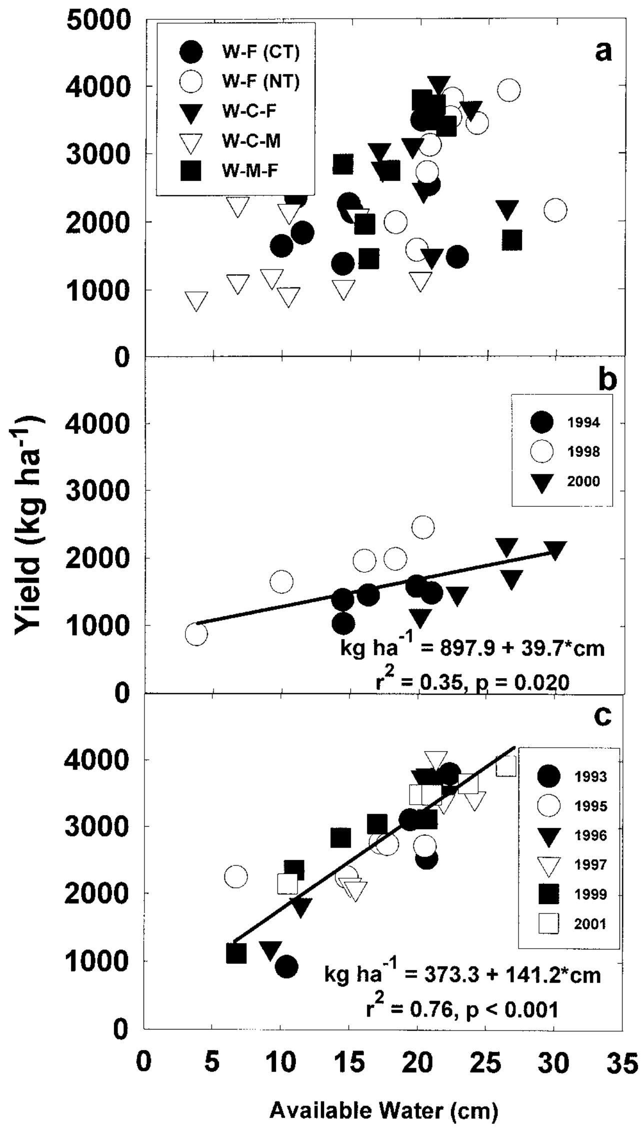

Fig. 1. Winter wheat yield as affected by available soil water content at planting (in 0–180 cm depth) at Akron, CO. (*a*) All data (1993–2001) by crop rotation; (*b*) data from dry years (April–June Pan evaporation − Precipitation >65 cm); (*c*) data from average and wet years (April–June Pan evaporation − Precipitation <65 cm).

The very dry conditions (Pan evaporation − Precipitation >65 cm [April–June]) have occurred in 13% of the years of record (Fig. 2). To quantify the risk in moving from the traditional wheat–fallow production system to one with more frequent cropping, we assumed a yield goal of 2500 kg ha^{-1}. This is somewhat higher than the average W-F (CT) yield (2125 kg ha^{-1}) found in the present study and the average wheat yield for eastern Colorado (2122 kg ha^{-1}; Liles and Fretwell, 2000). The higher yield goal of 2500 kg ha^{-1} provides a more conservative evaluation of the frequency of years under the various cropping systems in which sufficient soil water would be present at planting to ensure production of an economic yield. An economic wheat yield for northeastern Colorado, assuming 5-yr average price and direct costs of production, would be 2289 kg ha^{-1} (Kaan, 2001). Linear extrapolation of the relationship defined in Fig. 1b suggests that 40.4 cm of soil water at planting would be needed to produce 2500 kg ha^{-1} in very dry years. This amount of soil water at planting was never observed during the course of the study, and would be highly unlikely to ever occur at this site. Therefore, in 13% of years the yield goal of 2500 kg ha^{-1} could not be realized with any of the cropping systems.

During the other 87% of the years, with average or wet environmental conditions, the higher yield response to water content at planting should apply (Fig. 1c). The relationship defined in Fig. 1b indicates 15.1 cm of available soil water at planting was needed to produce 2500 kg ha^{-1} in years with average to wet conditions. Using the available soil water data shown in Table 1, we generated cumulative frequency distributions to determine how often the various cropping systems had sufficient soil water at planting (≥15 cm) to produce a 2500 kg ha^{-1} yield (Fig. 3). This figure shows, for any given amount of available soil water, the percentage of years

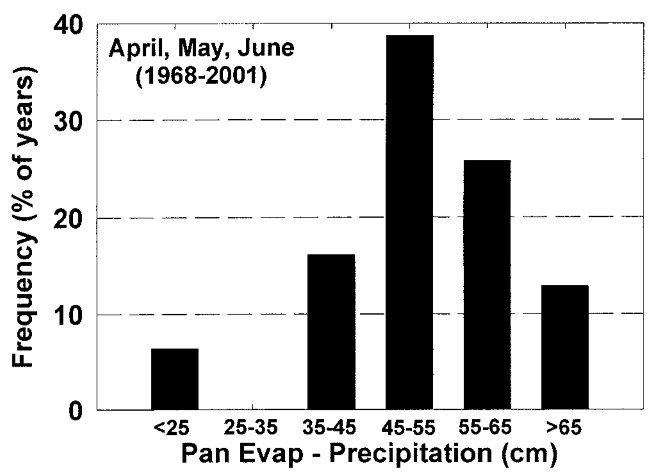

Fig. 2. Frequency distribution of Pan evaporation − Precipitation summed over April, May, and June at Akron, CO (1968–2000).

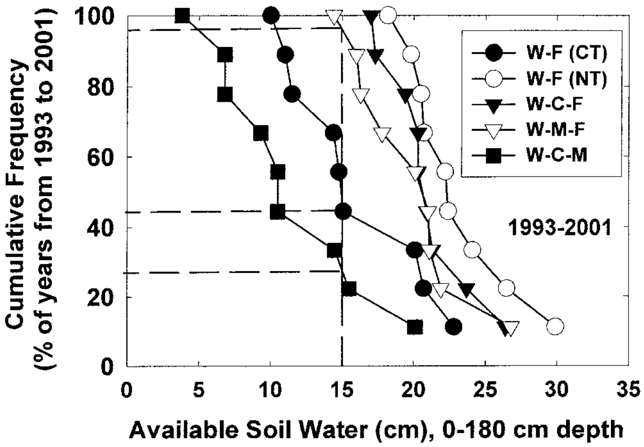

Fig. 3. Cumulative frequency distributions of available soil water at wheat planting as influenced by rotation (1993–2001) at Akron, CO.

from 1993 through 2001 with that given amount of soil water or more. Therefore, the figure shows that the W-F(CT) system had sufficient soil water at planting (≥15 cm) to produce 2500 kg ha^{-1} in 44% of the years if conditions during April through June were normal to wet, as defined earlier. With the wheat–fallow system under no-till conditions (W-F(NT)), 100% of years had ≥15 cm of available soil water at planting. Adding corn ahead of the fallow period prior to wheat planting (W-C-F) did not decrease the frequency of occurrence of years with >15 cm of available water at planting. With millet as the crop ahead of the fallow period prior to wheat planting (W-M-F), there was a small decrease in the frequency of years with >15 cm of available water at planting (96% of years). Soil water at planting for the W-C-M rotation was only >15 cm in 28% of years.

CONCLUSIONS

Available soil water content at winter wheat planting was significantly higher in W-F systems when NT weed control replaced tillage during the fallow period. Intensifying the NT system by inserting a crop (corn or millet) between wheat and the fallow period did not significantly affect available soil water at wheat planting nor subsequent wheat yield. Elimination of the fallow period (W-C-M) significantly reduced available soil water at wheat planting and subsequent wheat yield. Wheat yields increased linearly with increasing available soil water at wheat planting, but the response was much lower when conditions were very dry (Pan evaporation − Precipitation > 65 cm in April, May, and June). In eastern Colorado, these very dry environmental conditions occur about 13% of the time. When these very dry conditions occur, it is extremely unlikely that there will be enough stored soil water to result in a grain yield greater than 2500 kg ha^{-1}. In the other 87% of the years (average to wet conditions), W-F(NT), W-C-F, and W-M-F will nearly always have sufficient soil water at wheat planting to produce a grain yield of at least 2500 kg ha^{-1}. Under these conditions, the available soil water at wheat planting will be sufficient to produce a 2500 kg ha^{-1} grain yield 44% of the time with a W-F(CT) system and 28% of the time with a W-C-M system. Producers should have little concern regarding reduced available soil water and subsequent wheat yields when intensifying cropping systems from W-F to W-C-F or W-M-F. On the other hand, elimination of the fallow period in the W-C-M system significantly reduced available soil water at wheat planting and subsequent wheat yield, and producers will need to carefully consider the total system production and economic returns compared with other less intensive systems. We encourage producers to evaluate available soil water at planting and make necessary changes in crop management plans when insufficient soil water is present to produce economical wheat yields.

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