Water use and depletion by diverse crop species on Haplustoll soil in the northern Great Plains

S.D. Merrill, D.L. Tanaka, J.M. Krupinsky, and R.E. Ries

ABSTRACT: In a semiarid-to-subhumid region, water use by crop species can have a considerable impact on both crop production and soil landscape hydrology. Crop production following high water-using crops can be decreased while ephemeral streams and wetlands can be increased by growing lower water-using crops. Water use and soil water depletion were determined with neutron moisture meters in ten crop species (barley, canola, crambe, dry bean, dry pea, flax, safflower, spring wheat, soybean and sunflower) for two years, and measurements are presented for four of these species for one additional year. The observations were made in various species which were grown after spring wheat during crop sequence experiments. Sunflower was the greatest water user, followed by safflower and soybean. Dry pea was the lowest water user, followed in order by barley, crambe, and spring wheat. During an above average precipitation year, the depth distribution of soil water depletion among canola, dry pea, spring wheat, and sunflower was similar. In contrast, during a year of relatively low seasonal precipitation, differences were evident among the four crop species. Sunflower and canola extracted 49 percent and 45 percent of their soil water depletion, respectively, from soil depths greater than 60 cm, while spring wheat and dry pea extracted 33 percent and 27 percent of their soil water depletion from below 60 cm depth. Using a three-year dataset, it was found that water use and soil water depletion were highly correlated with seasonal precipitation, significantly correlated with median depth of water depletion and days from seeding to harvest, but not correlated with root growth parameters. As a general guide to water use by crop species, length of active growing season appears to be the most important factor.

Keywords: Alternative crops, differential water depletion, diverse soil-crop production systems, northern Great Plains, soil water depletion, water use

In a natural soil-plant ecosystem, plant species with higher water use potential will preferentially populate lower portions of the soil landscape where more water is available. This will tend to optimize water use from the landscape as a whole. In modern, monocultural cropping systems, crop choice and rotation will greatly affect water flows through and from agricultural landscapes. The wheat-fallow system in the northern Great Plains has been responsible for increasing the incidence of saline seeps (Black et al., 1981) during periods of higher precipitation. Halvorson and Reule (1980) recommended deep-rooted, higher water-using crops such as alfalfa to control saline seeps.

In a semiarid zone, the choice of crop species can also influence amounts of soil water available the following spring for the next crop. In Kansas, Norwood (2000) showed that amounts of soil water found in the spring following sunflower and soybean were lower than those following corn and sorghum. In eastern Colorado, Nielsen et al. (1999) showed that sunflower used more water, thus leaving less soil water in the profile compared to millet or corn, and have linked lowered winter wheat yields to the lesser amounts of soil water available following a previous sunflower crop.

The small grain—fallow system, which developed in the Great Plains was designed to conserve water and nutrients in one year for use in the next. But inefficiency in storing water under fallow, development of effective chemical weed control, introduction of reduced- and no-tillage practices, and increased use of nitrogen fertilizers have contributed to a decline of fallow and rise of continuous cropping (meaning without fallow) or reduced fallow systems. Farahani et al. (1998) have reviewed the increased precipitation use efficiency resulting from introduction of more intensive cropping systems.

No-till has greatly helped to make the transition from summerfallow to more intensive cropping by conserving soil water and providing better microenvironments for growing crops, especially in seedling stages. The superior effectiveness of no-till compared with conventional tillage for conserving soil water and supporting growth of spring wheat, especially seen under relative drought, has been documented for wheat-fallow by Tanaka (1989) and for continuous cropping by Merrill et al. (1996).

Tanaka et al. (2002) outlined principles of developing cropping systems in the northern Great Plains. They use the term dynamic cropping systems to encompass soil-crop production systems that incorporate flexible, adaptive soil and plant management along with a diversity of crop species to reduce the risk of disease, weeds, and insects. In a given year, progressive producers will use individual crop species that fit needs of soil and land yet meet ever changing environmental (i.e., soil water availability) and marketing system conditions.

Differential water use is one of the most important ways a crop affects a following crop, and such knowledge of comparative water use is important to the design of diverse cropping systems. From previous studies, it is known that crop species in the Great Plains use differing amounts of water. For example, sunflower is a high water user (Stone et al., 2002), and spring wheat uses less water than sunflower (Black et al., 1981). However, comparative studies of water use are needed among a range of crops types. Few such studies exist in the context of dryland agriculture. Anderson et al. (2003), in an earlier

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study, reported high water use for the more deeply-rooted oilseed crops, sunflower and safflower, and the longer-season crop, soybean, compared with the low water use for dry pea and a shorter-season variety of canola. Schillinger and Shelton (1999) determined that under Pacific Northwest conditions, sunflower was a high water user, the mustard family oilseeds were intermediate, and pulses, such as dry pea and lentil, were low water users.

Nielson (1998) presented a comparison of soil water depletion among canola, crambe, and sunflower. In a year of greater soil water availability, soil water depletion of canola and crambe was about 60 percent of that of sunflower. But in a year of less water availability during the growing season, soil water depletion of sunflower was nearly the same while the less deeply rooted canola and crambe crops had increased soil water depletion that was about 80 percent of the sunflower crop.

The purpose of this report is to determine the relative water use and soil water depletion by diverse crops grown in the northern Great Plains. Factors useful for predicting relative water use by crop species and relative soil water depletion will be explored. Such factors include length of active crop growth season, depth distribution of soil water depletion, and comparative patterns of root growth in soil.

Methods and Materials

The research was conducted at the Area IV Soil Conservation Districts-Agricultural Research Service Cooperative Research Farm located south of Mandan, North Dakota. The predominant soil type was Wilton silt loam (fine-silty, mixed, superactive, frigid Pachic Haplustolls). Surface soils to approximately 0.6-m depth consist of aeolian-derived material. A transition zone, typically 0.2 m or more thick, and consisting of variably coarser-textured material with lime inclusions, underlies this. The glacial till subsoil is root-penetrable and of finer-textured material. The climate is continental, with approximately 120 to 140 frost-free days, and the mean annual precipitation is 400 mm with the greatest monthly precipitation occurring in June.

Soil water measurements were conducted in two crop sequence experiments that were designed to provide information on interactions between annual species (Krupinsky et al., 2002; Tanaka et al., 2002). The experiments were carried out by seeding ten crop species in strips one year, and seeding the same crops in strips perpendicular to the first set during the following year, creating 100 crop sequences. No-till management was used to carry out the experiments, which had 9 x 9 m subplots and four-fold replication. Seeding was accomplished with a no-till drill (John Deere model 750[1]) at seeding rates and at calendar times common to area producer practice.

Soil water measurements were taken on 10 crop species during 1999 and 2000 in the first of the two crop sequence experiments. A second crop sequence experiment was initiated in 2001 with a new set of crops. Soil water measurements taken in 2002 on the four species (canola, dry pea, spring wheat, and sunflower) that were in common with those grown in the first crop sequence experiment are reported here. Measurements reported were in taken in crops that followed spring wheat. Crop species and varieties monitored were (with years of cultivar usage given if there was a change): barley (*Hordeum vulgare* L., variety Stander); canola (*Brassica napus* L., variety Dynamite ('99, '00), variety 357RR ('02)); crambe (*Crambe abysinnica* Hochst ex R. E. Fr., variety Meyer); dry bean (*Phaseolus vulgarius* L., variety Black Turtle ('99), variety Shadow ('00)); dry pea (*Pisum sativum* L., variety Profi); flax (*Linum usitatissimum* L., variety Omega); safflower (*Carthamus tintorius* L., variety Montola 2000); spring wheat (*Triticum aestivum* L., variety Amidon); soybean (*Glycine max* (L.) Merr., variety Jim); and sunflower (*Helianthus annuus* L., variety Cenex 803 ('99, '00), variety 63M91 ('02)).

As appropriate to no-till management, weed control was by pre-seeding application of glyphosate with additional use of post-emergent herbicides. Granular fertilizer was applied at time of planting through the seeder implement to all crops in 1999 and 2000 at the rate of 67 kg N ha^{-1} and 11 kg P ha^{-1}. In 2002, N was applied at 78 kg ha^{-1} (except that dry pea received no N) in 2002 and P at the same rate as in previous years.

Soil water was measured by CPN International Inc. Model DR503 neutron moisture meter. Steel pipes of 40 mm inside diameter and 2.7 m length were installed in the center of each crop sequence treatment plot of interest, and readings were taken in these access tubes to a depth of 2.1 m at 0.3 m intervals every 7 to 14 days during the crop growth season, and at greater time intervals until ambient temperatures became consistently freezing. Moisture gauge calibration was achieved through comparison of meter readings with volumetric water contents, which combined gravimetric soil water and soil bulk density determinations.

Although evapotranspiration is greatest during active crop growth, pre-seeding or post harvest soil evaporation can be significant. In order to make valid comparisons of soil hydrology among the various crops, soil water depletion and water use for all the crops were calculated between the same set of dates from about May 15 to about September 15 in a given year. The first date was chosen as being generally representative of the seeding dates of the earlier crop species involved, while the later date was representative of harvest dates for the later-harvested crops. Soil water depletion was calculated to a depth of 1.8 m, and water use was determined as soil water depletion plus May 15 to September 15 precipitation. Multiple comparison tests of soil water depletion measurements were based on analysis of variance tolerant of non-balanced datasets (PROC GLM; SAS 1990).

The distribution of soil water depletion with soil depth was analyzed by examining water depletions between the date of greatest soil water accumulation to the date of least water in the soil profile. These dates for the three years of measurement ranged from June 10 to June 19 for greatest water accumulation and from August 6 to August 30 for lowest water in the profile. The median depth of soil water depletion for a crop-year combination was calculated as that depth above which 50 percent of depletion had occurred.

As will be shown below, the level of seasonal precipitation can strongly influence the general level of soil water depletion in a given year. For the purpose of creating a more generalizable index of comparative soil water depletion (SWD) less subject to annual precipitation level, we define differential water depletion (DWD) as the seasonal water depletion of a crop species in a given year minus the average water depletion in that year based on measurements from the entire set of crop species. Thus,

$$DWD_i = SWD_i - SWD_{avg}$$

where:

DWD_i = the differential water depletion for a given crop species in a particular year

Table 1. Precipitation at the sites of experimentation from onsite meteorological devices with long-term means taken from NOAA data.

	1999	2000	2002	Long-term mean
	cm			
April	1.9	2.1	2.1	3.8
May	15.4	7.4	1.2	5.6
June	11.4	10.5	3.2	8.4
July	5.3	7.1	6.8	6.6
August	17.2	2.9	1.8	4.6
September	2.7	2.8	1.3	4.1
5-mo. Apr - Aug.	51.3	30.1	15.2	29.0
Annual	60.6	55.1	29.3	40.0

SWD_i = the soil water depletion of that crop during that year's growing season

SWD_{avg} = the average soil water depletion of all crops during that year's growing season

The set of four crops for which data are given in 2002 were found to well represent the 10-crop soil water depletion averages of 1999 and 2000 for purposes of calculating differential water depletion.

Water use, soil water depletion, and differential water depletion were correlated with median depth of soil water depletion, median and maximum root growth depths (from Merrill et al., 2002), seeding date, harvest date, and days from seeding to harvest. From a reduced set of these variables that eliminated similar, mutually correlated ones, multiple linear regression models predicting water use and differential water depletion were constructed using stepwise discriminant analysis (PROC STEPDISC; SAS1990).

Results and Discussion

Water use and soil water depletion results were strongly influenced by seasonal amounts of precipitation received (Table 1). Five-month (April through August) precipitation in 1999 was 77 percent above the long-term mean, 2000 seasonal precipitation was very near the mean, and 2002 precipitation was 48 percent below the mean.

Our results follow the expectation for a semiarid climate that average water use positively correlates with seasonal precipitation. In the above average rainfall year, 1999, water use among 10 crops ranged from 47 cm (sunflower) to 40 cm (dry pea), and from 42 cm (sunflower) to 31 cm (barley, crambe, and dry pea) in the near-average rainfall year 2000 (Table 2). Among the four crops growing in the below-average rainfall year 2002 and for which data are presented, water use ranged from 38 cm (sunflower) to 27 cm (dry pea).

Table 2. Water use (= seasonal precipitation plus soil water depletion (SWD) during the growing season) and differential water depletion (DWD) for diverse crop species: $DWD_i = SWD_i - SWD_{avg}$, where DWD_i is differential water depletion for a given crop species in a particular year, SWD_i is the soil water depletion of that crop during that year's growing season, and SWD_{avg} is the average SWD of all crops during that year's growing season. Numerical values in table result from addition or subtraction of constant values, and thus statistical information given in Figure 1 may be applied.

	Water use			Differential water depletion		
	1999	2000	2002	1999	2000	2002
	cm					
Safflower	45.0	40.8		2.15	6.30	
Sunflower	47.0	42.1	37.5	3.44	7.58	5.39
Spring Wheat	41.7	32.9	29.1	-1.80	-1.63	-3.09
Barley	40.6	30.8		-2.97	-3.66	
Flax	45.9	32.5		2.35	-1.96	
Crambe	41.6	30.9		-1.95	-3.63	
Canola	45.1	32.0	35.3	1.56	-2.48	3.12
Soybean	45.3	36.8		1.82	2.32	
Dry pea	40.0	30.9	26.7	-3.48	-3.59	-5.41
Dry bean	42.4	35.3		-1.10	0.84	

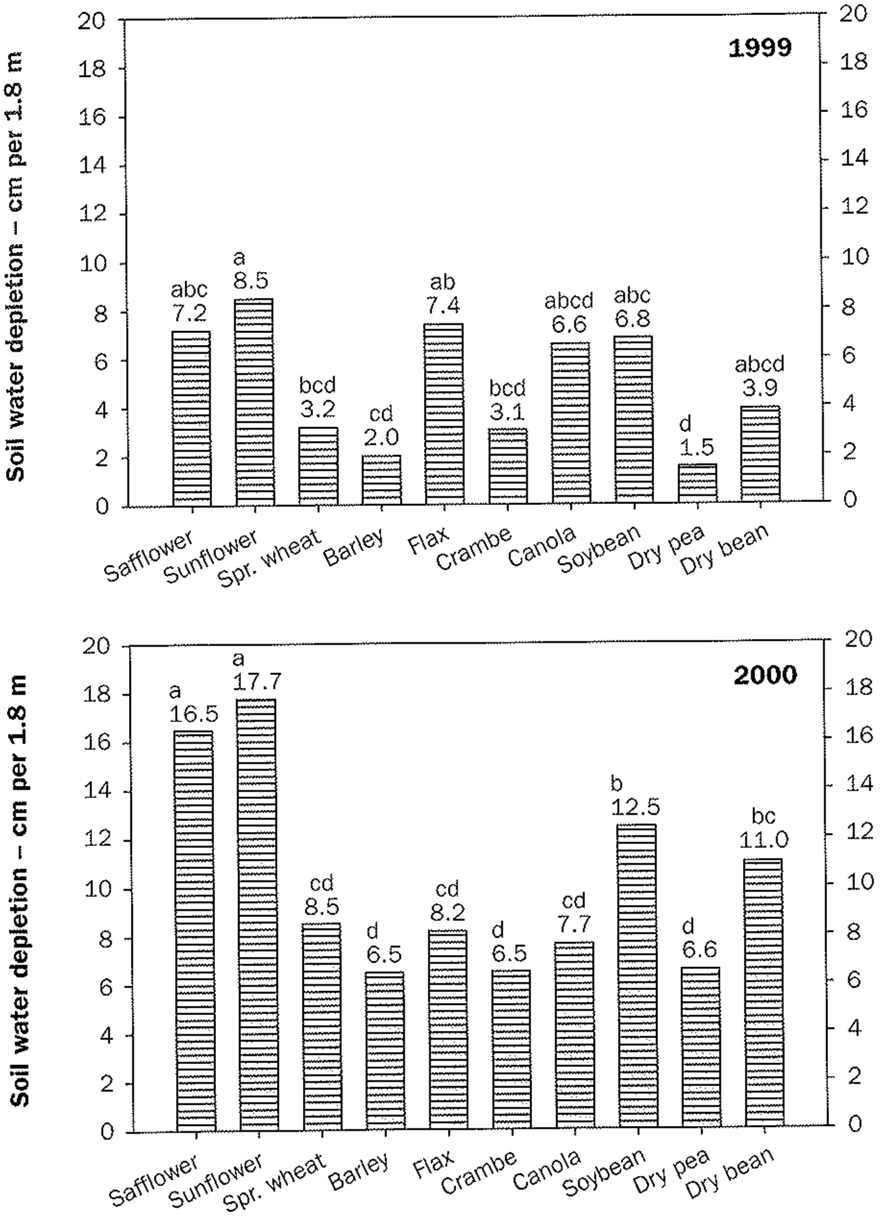
In order to compare the water use of diverse crops in a semiarid-to-subhumid region, the most direct method is to compare the soil water depletion component of use from the time of spring seeding of earlier crops to the time of fall harvest of longer season crops. Considerably greater soil water depletion occurred in 2000, a year of approximately average seasonal precipitation, than in 1999, a year of above average precipitation (Figure 1, Table 1). The only statistically significant separation in 1999 was between sunflower and safflower, which had the highest soil water depletion values, and dry pea and barley, with the lowest soil water depletions. In 2000, the species were statistically separated into three groups with sunflower and safflower exhibiting the highest soil water depletions, and soybean and dry bean forming an intermediate valued group, and six other crops forming a group with lower soil water depletion values. Barley, crambe, and dry pea had the lowest soil water depletion values in 2000 (Figure 1). Overall, sunflower had the highest two-year average soil water depletion value (13.1 cm), followed by safflower (11.9 cm) and soybean (9.7 cm). Dry pea had the lowest two-year average soil water depletion (4.1 cm), followed by barley (4.3 cm) and crambe (4.8 cm). Spring wheat had the 4th lowest two-year average soil water depletion at 5.9 cm.

With one exception, our comparative water use results are similar to an earlier study on the same soil and land type (Anderson et al., 2003). Sunflower and safflower were the highest water users followed by soybean, and dry pea and crambe were relatively low water users. The results with canola varied from the earlier study by Anderson et al. (2003), which reported water use of a *B. rapa* variety of canola to be lower than dry pea, while the present study reports variable but considerably higher water use for two *B. napus* varieties of canola.

Our results with sunflower, measuring soil water depletions of 18 and 21 cm for 2000 and 2002 (Figures 1 and 2), respectively, compare well with those of Nielsen (1998) for the same crop in eastern Colorado, showing soil water depletions of 19 cm for two years. Nielson's measured soil water depletions for canola, 11 and 16 cm, are bracketed by our measurements for 2000 and 2002, 8 and 19 cm, respectively. Soil water depletion for crambe was measured by Nielsen (1998) at 12 and 15 cm, values higher than our soil

Figure 1

Soil water depletion (SWD) for 10 crop species measured over the period of approximately mid-May to mid- to late-September to a soil depth of 1.8 m using a neutron moisture meter. Values bearing the same letter are not significantly different at the P = 0.05 level according to Tukey's Studentized range test.



water depletion of 7 cm measured in 2000 (Figure 1).

Water use results are similar to those obtained in eastern Montana (Black et al., 1981): safflower > sunflower > rapeseed (canola) > spring wheat > barley. Schillinger and Shelton (1999) reported water use in the xeric climate of a Pacific Northwest location to be in the order: sunflower and safflower > mustard crops (canola, etc.) > cool-season grasses (wheat, barley) > pulses (pea, lentil).

The influence of seasonal precipitation on the proportion of water use that consists of soil water depletion as opposed to precipitation is shown in Figure 2 for the four crops that were common to the two crop sequence experiments. Consistently, sunflower with highest soil water depletion values and dry pea with the lowest are at either end of the range for all three years. Soil water depletion, as a percentage of water use, ranged from 18 percent (sunflower) to 4 percent (dry pea) in the relatively wet year 1999. The range was 42 to 21 percent of water use in the average precipitation year 2000, and increased to a range of 57 to 39 percent in the dry year 2002.

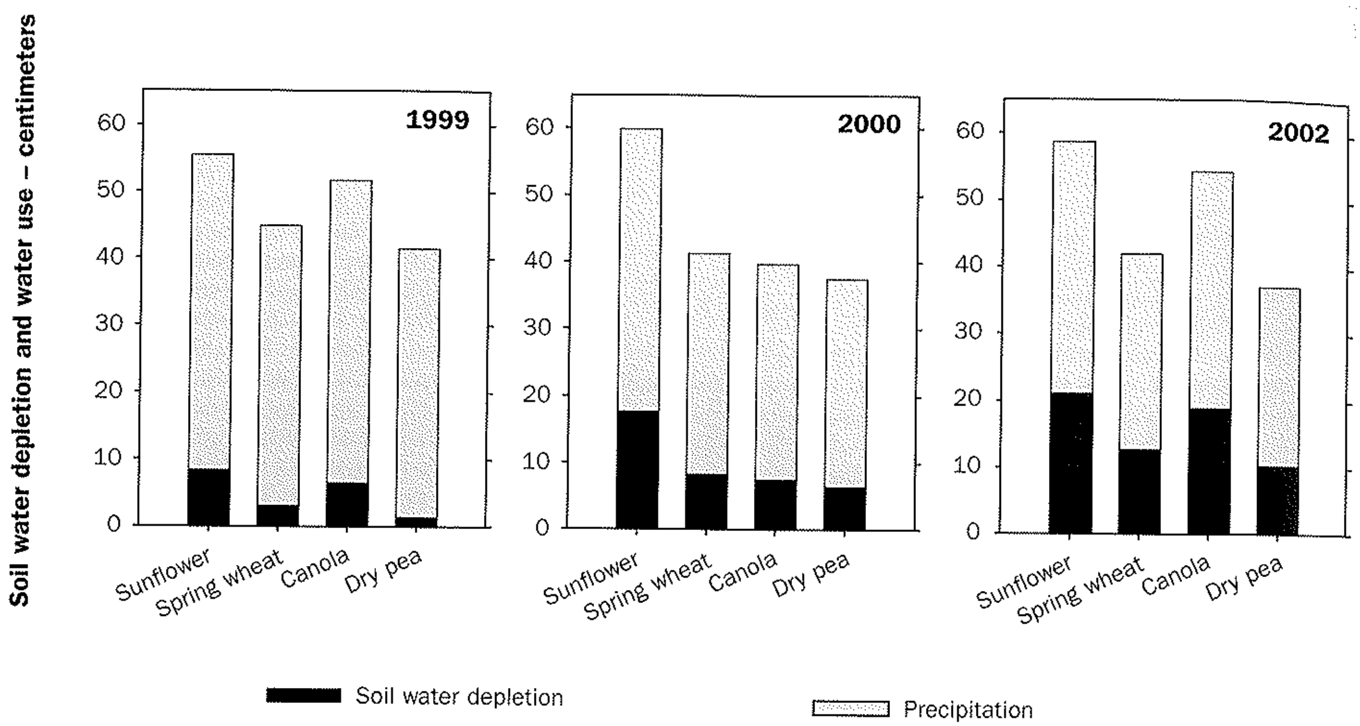
To understand the potential effects of differences in water use among crop species, we must examine the complete annual cycle of soil water changes. Following a spring wheat crop, only random experimental variation is evident in profile water content measurements taken in May 2000 in plots seeded to sunflower, spring wheat, canola, and dry pea (Table 3). After the occurrence of seasonal soil water depletions ranging from 18 cm for sunflower to 7 cm for dry pea, soil under dry pea had 11 cm more water than that under sunflower in September 2000.

Measurements of snow depths were made in February 2001 (data partially given). The stubble of the three pulse crops held less snow than that of the other crops. Dry pea held 8 cm of snow at time of measurement compared with an average of 28 cm for the other three crops (Table 3). In the northern Great Plains region, there are typically a number of mid-winter cycles of snow accumulation and snow loss, and the springtime soil water effects of snow melt are variable. April 2001 measurements showed that snowmelt raised the average water content of soil under all the crops by 10 cm, but soil profiles under sunflower still had 9 cm less water than dry pea soil.

Overall water use and soil water depletion were measured from mid-May to mid-Sept, but as noted above, depth distribution of soil water depletion was measured from times of soil water high to soil water low, from mid-June to sometime in August. The comparative patterns of soil water depletion depth distributions for four crops were different for each of the three years studied (Figure 3). In wetter 1999, with low overall soil water depletions, there was not much difference among the crops in the depth distribution pattern of soil water depletion. In the average rainfall year, 2000, less of the sunflower depletion was in the upper 30 cm of the profile compared with the other three crops, and more of sunflower's depletion occurred at depths of 60 to 150 cm. In the relatively dry year 2002, sunflower and canola had a similar pattern, exhibiting lesser soil water depletion at soil depths above 60 cm compared with dry pea and spring wheat, and much greater depletion at depths of 90 to 180 cm. The

Figure 2

Portions of water use comprised of soil water depletion (SWD) and seasonal precipitation for species common to two crop sequence experiments.



higher soil water depletion measured for canola in 2002 compared with the earlier years (Figure 2) was associated with deeper soil profile depths of soil water depletion but could also be associated with a change of canola variety.

The annual ranges of water use and soil water depletion values were considerably shifted to higher or lower values depending on seasonal precipitation (Table 2). Construction of the differential water depletion (DWD, see Methods and Materials) measure substantially removes this influence of seasonal precipitation. The higher water using and depleting species sunflower, safflower, and soybean have positive DWD values. The lower water using and depleting species dry pea, barley, and spring wheat show negative DWD values. And a crop like canola that had significant annual variation in water use and soil water depletion due to cultivar and climatic differences exhibits DWD values ranging from positive to negative (Table 2). Higher seasonal precipitation will lower the numerical range of DWD values, as shown by a range of 6.9 cm for above average 1999 compared to ranges of 11.2 and 10.8 cm for average to below average years 2000 and 2002, respectively.

In order to find predictors of water use and depletion measures, a series of correlations between measured water variables and various soil, agronomic and climatic variables were calculated. Ranges of variables not shown included: (a) median soil depth of soil water depletion, 65 to 36 cm, sunflower to crambe, 2000; (b) maximum root growth depth, 164 to 99 cm, safflower to dry pea and soybean; (c) median root growth depth, 92 to 46 cm, safflower to dry bean; (d) seeding date, day-of-year 153 to 116, dry bean (1999) to dry pea (2002); (e) harvest date, day-of-year 284 to 198, sunflower (2000 and 2002) to dry pea (2002); and (f) number of days from seeding to harvest, 139 to 81, sunflower (2000) to canola (2002). Root growth depth data were taken from a previous study that was conducted on the same soil and land type (Merrill et al., 2002).

Both water use and soil water depletion were highly correlated with seasonal precipitation ($P < 0.001$), soil water depletion was strongly correlated with median water depletion depth ($P < 0.01$), and water use was significantly correlated with median water depletion depth (Table 4A). Both water use and soil water depletion were correlated with seeding-to-harvest days, but water use was highly correlated with seeding date and harvest date while soil water depletion was not correlated with either seeding date or harvest date. Neither water use nor soil water depletion showed significant correlations with root growth parameters.

Table 3. Annual cycle of soil water dynamics for sunflower, spring wheat, canola, and dry pea from May 2000 to April 2001. Soil water was measured to a depth of 1.8 m.

	Soil water 26 May 2000	Soil water depletion May to Sept.	Soil water 15 Sept. 2000	Snow depth measured Feb. 2001	Soil water 18 Apr. 2001
	cm				
Sunflower	57.0	17.7	39.3	23.1	51.0
Spring wheat	55.4	8.5	46.9	30.4	56.0
Canola	55.6	7.7	47.9	29.1	56.3
Dry pea	56.4	6.6	49.9	8.3	59.6

Table 4. Results of simple and multiple linear regressions of water use (WU), soil water depletion (SWD), differential water depletion (DWD) and median water depletion depth (MedWDD) against various variables.

Part A: R-squared values for simple regressions. Value range of model F-statistic indicated as: not significant, ns; 0.1 - 0.05, +; < 0.05 - 0.01, *; < 0.01 - 0.001, **; < 0.001, ***. N = 24 for all regressions.

Dependent variable	May through August precipitation (cm)	Median water depletion depth (cm)	Maximum root growth depth (cm)	Median root growth depth (cm)	Seeding date (DOY)	Harvest date (DOY)	No. of days, seeding to harvest
Water use	0.644***	0.204*	0.111ns	0.079ns	0.690***	0.567***	0.234*
Soil water depletion	0.532***	0.350**	0.147+	0.081ns	0.094ns	0.080ns	0.237*
Differential water depletion	0.000ns	0.669***	0.326**	0.206*	0.243*	0.617***	0.612***
Median water depletion depth	0.002ns		0.436***	0.292**	0.128+	0.282**	0.261*

Part B. Progressive construction of multiple linear regressions for WU and DWD as guided by results of stepwise discriminant analysis. Harvest date, HarvD; median water depletion depth, MedWD; and seasonal (May - Aug.) precipitation, SPrcp. N = 24 for all regressions.

Equation	R-squared value
WU = -5.908 + 0.1824*HarvD	0.567
WU = -5.657 + 0.1301*HarvD + 0.4262*SPrcp	0.896
WU = -7.513 + 0.0853*HarvD + 0.4810*SPrcp + 0.2407*MedWD	0.954
DWD = -17.714 + 0.387*MedWD	0.669
DWD = -28.642 + 0.264*MedWD + 0.069*HarvD	0.841
DWD = -28.464 + 0.236*MedWD + 0.083*HarvD - 0.075*SPrcp	0.868

Construction and use of the DWD parameter completely removed any correlation with seasonal precipitation as found with water use and soil water depletion (Table 4a). Also in contrast to water use and soil water depletion, DWD was strongly correlated with both median water depletion depth ($P < 0.001$) and maximum root growth depth ($P < 0.01$), and was significantly correlated with median root growth depth. DWD was significantly correlated with seeding date and highly correlated with harvest date and seeding-to-harvest days. Removal of correlation with seasonal precipitation through the definition of DWD is apparently associated with the gaining of significant correlations with parameters unassociated with climate, such as the indices of root growth.

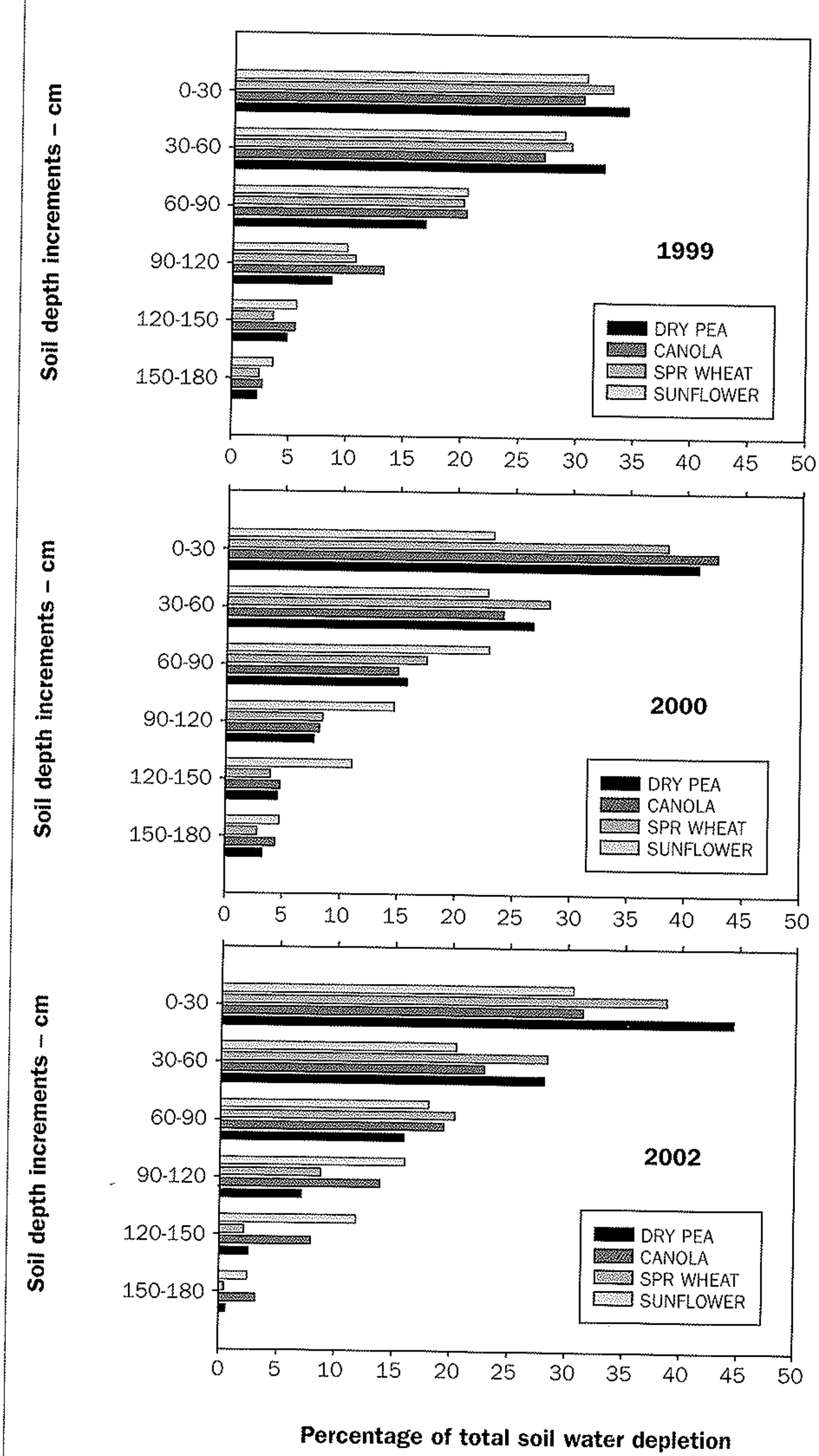
Many dryland soil and crop studies have inferred root growth depth from depth profiles of water depletion. Johnston et al. (2002) found that rooting depths of three oilseed crops inferred by neutron moisture meter measurements were greater than rooting depths observed with minirhizotron microvideo technology by Merrill et al. (2002). In the present study, we found a higher R^2 value for the regression of median water depletion depth versus maximum root growth depth ($R^2 = 0.44, P < 0.001$; Table 4a) than for the regression of median water depletion depth versus median root growth depth ($R^2 = 0.29, P < 0.01$).

In order to better understand the characteristics of the DWD measure, we have compared it to water use by constructing multiple regression predictive equations for both parameters. The set of independent variables used for these equations was reduced from the total found in Table 4a by using harvest date to represent the similar and highly correlated length-of-season group consisting of seeding date, harvest date, and seeding-to-harvest days. Similarly, the better-correlated maximum root growth depth was used rather than median root growth depth.

Using stepwise discriminate analysis to progressively construct the equations (Table 4b), it can be seen that harvest date entered the equation for water use first, while median water depletion depth entered the equation for DWD first. Seasonal precipitation entered the water use equation second and harvest date entered the DWD equation second. Significantly, maximum root growth depth entered neither equation. We can speculate that this was because several relatively less deeply rooted pulse crops (Merrill et al., 2002) were relatively higher water users/depleters, such as soybean in 1999 and both soybean and dry bean in 2000 (Figure 1).

Results with both simple and multiple linear regressions (Table 4) indicate that the combination of length-of-season data, such as harvest date as used here, and depth of soil water depletion information is effectively predictive of water use and soil water depletion. Harvest date was used here due to higher correlation with water use and DWD, but seeding-to-harvest days may be as or more useful for use with other studies and datasets. Root growth parameters are not effectively predictive of water use and SWD, provided the other input parameters are available for use. Information about depth of soil water depletion has been published for many soil and crop science studies in contrast to root growth information, which is expensive and difficult to obtain, and sparse to nonexistent for many alternative crop species.

Figure 3
Distribution with soil depth of total soil water depletion observed in four crop species that were common to the two crop sequence experiments.



The differential water use by crops has immediate economic consequences for agricultural producers in the semiarid-subhumid northern Great Plains region, where precipitation is the most limiting factor for crop production. Bauer and Black (1991) reviewed regional literature to show that every additional cm of effective soil water evapotranspired beyond the point of zero seed yield will produce on average 130 kg ha^{-1} spring wheat yield. If it is assumed that the average seasonal difference in water use between sunflower and dry pea reported here, 9.7 cm, is 30 percent attenuated by spring soil water acquisition (there was 20 percent attenuation overwinter in 2000/2001), the following spring, land seeded to dry pea will have 6.8 cm more water than land seeded to sunflower. If it is assumed that conditions are critically water-limited, and this land is subsequently seeded to spring wheat, then this differential translates into a gross spring wheat return differential of \$116 ha^{-1} to \$148 ha^{-1} for spring wheat prices of \$0.129 kg^{-1} to \$0.165 kg^{-1} (\$3.50 bu^{-1} to \$4.50 bu^{-1}).

In a natural system, higher water-using members of the plant community will be populating portions of the landscape where flow networks make more water available. However, in an agricultural monoculture, there can be important hydrological and water quality consequences from the dry pea vs. sunflower type of crop choice. In terms of agro-ecosystem environments, these effects may be categorized as: (a) effects at the immediate field scale on water availability for subsequent crops; (b) effects at field scale on the portion of land that is wet to the extent of trafficability problems and crop drowning; (c) effects on hydrologic flows on- and off-field influencing water impoundments for animal use; (d) effects propagating through successively higher environmental scales relating to movement of nutrients and agrochemicals off-field.

Weather patterns in the Great Plains region feature chaotically appearing multiyear droughts. Farmers tend to continue nitrogen fertilization programs into drought periods, and as documented by Halvorson et al. (2000), large accumulations of inorganic N in the soil profile can result. Seeding of lower water-using crops such as dry pea can accelerate fluxes of nitrogen from an agricultural landscape when drought periods are followed by years of average or greater precipitation. Excess nitrogen in the environment is a global biogeochemical problem (Follett and Hatfield, 2001).

The present study contributes to information about and understanding of the potential consequences of differential water usage by crop species in a dryland soil-crop production system. But such information and understanding is based on simplified, conventional, one-dimensional conceptualizations of agroecosystems. Effective and real scientific progress will be made to the extent that future studies are designed and carried out so that soil water dynamics are observed and quantified on a soil-landscape basis.

Summary and Conclusion

The most effective means for observing differential water use by crop species in a semiarid/subhumid region is by measuring differences in soil water depletion (SWD) over a set time period from spring to autumn. Soil water depletion measurements over three cropping years showed that, on average, sunflower had greatest water use, safflower the second greatest, and soybean the third. Dry pea had the least water use, followed in order by barley, crambe and spring wheat.

Low precipitation caused the greatest differences among species in soil depths at which soil water depletion occurred. During a year of below average precipitation (2002), sunflower and canola extracted 49 percent and 45 percent of soil water depletion, respectively, from depths below 60 cm, while spring wheat and dry pea extracted 33 percent and 27 percent of soil water depletion below 60 cm. Water use and soil water depletion were highly correlated with seasonal precipitation, significantly correlated with median depth of water depletion and days from seeding to harvest, but not correlated with root growth parameters. Length of active growing season appears to be the most generally useful factor for predicting the relative amount of water use among crop species.

Differences in water use between crops with the greatest use, such as oilseeds, and least water-using crops such as pulses (e.g., dry pea) and small grains will reduce yields of succeeding crops, especially under limited precipitation, and will have significant economic impact on producers. Crop species' water use differences must be expected to have significant impact on soil landscape hydrology, and soil and land functionalities dependent on such hydrological dynamics, including percentage of cropland area trafficable by agricultural equipment or serving as ephemeral wildlife habitat.

Endnote

[1]Inclusion of branded product information is for the benefit of the reader and does not imply preference nor endorsement by the U.S. Department of Agriculture, Agricultural Research Service.

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