Management of Water Use by Crops in Crop Rotations on the Canadian Prairies

Adrian Johnston, Melfort Research Farm
Martin Entz, Dept. of Plant Science, University of Manitoba
Stewart Brandt, Scott Experimental Farm
Guy Lafond, Indian Head Experimental Farm
Con Campbell, Swift Current Research Station

Introduction

While the majority of the earth's surface is covered with water, it is the shortage of water which is the most limiting factor to crop production around the world. The production of crops with irrigation makes agriculture the largest consumer of water. The ever increasing demand of our growing population on fresh water for direct consumption and food production requires that agriculture continue to strive to become more efficient in the use of water for the production of food and fibre, as well as minimize any potentially negative impact on surface and ground water supplies. The study of soil-plant-water relations has received extensive coverage over the years (Begg and Turner, 1976). Understanding evapotranspiration, crop water status, crop growth and development in response to water status, crop response to water deficits, and water use efficiency continue to be a major focus of crop physiology research, particularly in semi-arid regions.

Increases in crop water use efficiency (WUE) have come largely as a result of increases in crop yields rather than from any significant conservation of water use (Pendleton, 1966). Management practices such as tillage and moisture conservation measures, fertilizer application and pest control, all lead to increased grain yields with little change in crop water consumption. Therefore, any cultural practice which overcomes a limitation to yield, which can be attributed to factors other than water, will lead to increased crop WUE (Begg and Turner, 1976). However, in the absence of such cultural practices, it is generally agreed that when biomass yields increase, water use increases (Pierce and Rice, 1988).

The objective of this review will be to evaluate the crop water use characteristics of the crops common to the Canadian prairies, including summer annuals, winter annuals and perennials. From a crop rotation perspective, an attempt will also be made at how these crops could be used in rotation to achieve efficient water use.

Water Use Efficiency - Definition

The efficiency with which water is used in the production of some economic yield is referred to as water use efficiency (WUE) or physiological efficiency (PE). It is calculated as:

WUE = Yield / ET, where

Yield = economic yield of crop
ET = Evapotranspiration, which is the sum of change in soil water between seeding and harvest, plus precipitation.

Pierce and Rice (1988) have proposed a more comprehensive measure of efficiency of water use by crops, Efficient Water Use (EWU). It is calculated as:

EWU = ET / Wa x WUE

ET = as above
Wa = water available during a given period of time (one year, multiple years, etc.)
WUE = as above

This calculation of crop water use using EWU is more comprehensive than WUE in that it considers the recovery of water entering the soil system. In addition, it accounts for the impact of crop management, such as rotation or tillage system, on the traditional WUE measurements. The first term in the EWU equation is often referred to as Recovery Efficiency (RE), representing the portion of available water actually used by the crop.

Crop Rooting Characteristics

The depth of rooting by a crop provides a good indication of the zone of water extraction. Depending on the soil type, water extraction will likely be within 10 to 20 cm of the observed depth of maximum rooting (Entz et al., 1992). In soils with higher clay content, this zone of influence could be even larger.

A wide range of rooting depths have been recorded for spring and winter wheat (Table 1). On average, spring and winter wheat rooted 110 cm. The deep root system of winter wheat, barley, rapeseed, safflower and sunflower were reported by Black et al. (198 1) from East central Montana, and indicates a significantly longer, and warmer, growing season than found in southern and central prairies. Barley was found to have a deeper root system than spring wheat, and intermediate to that recorded for canola. Flax and field pea rooting depth at Indian Head was estimated to be from 61 to 76 cm, considerably shallower than that observed for field pea in southern Manitoba, again a region of higher heat units. Campbell and Zentner (1996) reported that flax left more soil N and water below the 60 cm soil profile than spring wheat, indicating shallow rooting in the semi-arid regions as well.

Within a single growing season, safflower was by far the deepest rooting crop considered, exceeding that observed for sunflower by at least 40 to 50%. Establishment year alfalfa and sunflower were the only crops from the southern prairies which actually showed water uptake below 120 cm. This would lead us to the conclusion that the majority of our annual and winter annual crops are extracting water from the surface 60 to 120 cm.

While Lafond (1995) reported little difference in soil water extraction between tillage systems for spring wheat, winter wheat, flax and field pea at Indian Head, Borstlap and Entz (1994) found that zero tillage reduced water extraction from deep (50-90 cm) in the soil profile with wheat. However, increased water extraction for canola and field pea was recorded with zero tillage in comparison to conventional tillage. These results from a clay loam soil in Portage, Manitoba indicate that there can be considerable variation between crops in their root development.

Crop Water Use

The amount of water use recorded for a specific crop, in a given growing season, can vary significantly from year to year (Table 2 and 3). However, the conversion of this water into yield, or water use efficiency (WUE), varies little within a given crop species (Fischer and Turner, 1978). As a result, the amount of water available to a crop ultimately governs its yield potential, given that it remains unlimited by nutrient, soil or related environmental factors. An example of environmental extremes are the very low crop water-use values (3.9) recorded for winter wheat in central Saskatchewan during 1988, a year when extreme moisture and temperature stress hastened crop development (Johnston and Fowler, 199 1).

Average WUE for spring wheat was found to be approximately 9.1 kg/ha/mm, with a range from 5.4-16.8 kg/ha/mm (Table 2). The high values recorded in Southern Manitoba were attributed to a) high humidity during the growing season leading to increased WUE, b) crop possibly drawing from high water table, and c) the use of fungicides to control foliar disease in canola and wheat, minimizing any limitation to grain yield. In a review of spring wheat response to water across the prairies, Henry et al. (1986) reported that after the initial 50 mm required for any grain yield, yield increased in response to water at a rate of 10 kg/ha/mm. At Swift Current, Campbell et al. (1988) reported a threshold water requirement for any grain yield of 46 mm on summer fallow and 68 mm on stubble, with yield increasing under both cropping systems at a rate of 10 kg/ha/mm. For soft and Canada Prairie Spring classes of wheat Henry et al. (1986) reported the threshold yield required 75 mm, after which yield increased in response to available water at a rate of 15 kg/ha/mm.

The information presented in Table 2 indicates that winter wheat and barley exhibit a higher average WUE than spring wheat, estimated at 10.5 kg/ha/mm, with a range of 8.6-12.3 kg/ha/mm for barley and 3.9-16.3 kg/ha/mm for winter wheat. These values for barley are similar to those reported by Henry (1989), who suggested that you could expect a range of 10 to 16 kg/ha/mm as one progressed from the dry Brown to the Gray soil zones. On average winter wheat showed a higher WUE than spring wheat. Entz and Fowler (1991) reported that the early season growth habit of winter wheat provided an opportunity for biomass accumulation during a period of cooler air temperatures than are common for spring wheat. As a result, the winter cereal has the opportunity to accumulate higher biomass and in turn, grain yields.

Flax had an average WUE of 4.5 kg/ha/mm, with a range of 3.2-5.5 kg/ha/mm (Table 3). The low values recorded by Lafond et al. (1994) in East Central Saskatchewan were from Loam and light Loam soils with low productive potential. The WUE recorded for canola ranged from 5.0 - 11.7 kg/ha/mm, with an average of 8.2 kg/ha/mm (Table 3). As recorded for spring wheat, the high WUE values from Southern Manitoba reflect superior growing conditions relative to Central Saskatchewan.

A wide range in field pea WUE was recorded (7.6-18.8 kg/ha/mm) with an average WUE of 12.6 kg/ha/mm (Table 3). As with wheat and canola, the high WUE values recorded in southern Manitoba indicate superior growing conditions. Only one reported set of data was obtained for WUE of lentil, from a study under irrigated and dryland conditions at Outlook, Saskatchewan (Table 3). While dryland lentils used considerably less water than those receiving irrigation, they showed superior WUE. The need for the indeterminate growth habit of lentils to have “terminal drought” conditions, resulted in the irrigated lentils favoring biomass production at the expense of seed yield (Livingston et al., 1988).

Annual legumes grown until flowering for green manure at Swift Current were found to extract most of their water from the surface 0.6 m of soil Biederbeck and Bouman, 1994). Their short growth period, approximately 60 days, reduced the total water use recorded. However, the annual legumes showed a high WUE, with the high yielding chickling vetch and feed pea being the most efficient. Finally, the extended growing season and entire biomass harvest of the non-dormant alfalfa (cv. Nitro) grown in southern Manitoba results in a high WUE of 27-35 kg/ha/mm (Table 3). Two cuts of hay, water extraction to a depth of 160 cm and a long growing season resulted in a high water-use efficiency.

Spring Soil Moisture

A major limitation to recropping land in semi-arid and sub-humid regions is the amount of soil water available at seeding to establish a crop. Adequate surface soil water must be available, otherwise fallow would be required. It has been suggested that spring seeded annuals require at least 76 mm of stored soil water in a 120 cm profile (Kresge and Halvorson, 1979). In a review of spring wheat soil moisture use at Swift Current, Campbell et al. (1988) reported that while precipitation was critical to both fallow and stubble seeded wheat during grain filling, precipitation at seeding and crop emergence for stubble seeded wheat was just as important.

Given the variation in growing season, rooting depth and water use of the crops common to the prairies, crop selection and sequence in rotation could have an effect on soil water conditions at seeding. Spring soil moisture in the surface soil was reviewed from a number of studies conducted in Saskatchewan. In an evaluation of alternative crops for stubble production at Scott Experimental Farm, little variation was recorded in surface soil water between the cereal, oilseed and pulse crops at harvest, or the following spring (Table 4). While total soil water increased by an average of 10 mm overwinter for the stubble fields, no change was recorded in fallow soil moisture. Fall tillage proved to be a detriment to over-winter moisture storage at Indian Head, where zero-tillage fields had from 5 to 12 mm of additional water (Lafond and Derksen, 1995). Field pea stubble had the lowest soil water stored on the clay soil at Indian Head, a reflection of the poor snow trapping ability associated with pea stubble. Campbell and Zentner (1996) reported similar levels of spring soil water for both flax and spring wheat stubble at Swift Current, indicating no difference in crop stubble type on soil moisture retention.

Grain legume crops have been widely promoted as a substitute to summer fallow in the semi-arid prairie region (Biederbeck et al., 1995). However, a study in Saskatoon revealed that annual legume green manure crops left the soil with a moisture content similar to that after a crop of spring wheat Townley-Smith et al., 1993) (Table 4). This is the reason why many producers have opted to produce a pulse crop for grain, rather than working it down for green manure. More recently, Biederbeck and Bouman (1994) reported that green manure crops incorporated at full bloom left the soil with 81% of the soil water found in summer fallow, slightly higher than the 68% found with continuous wheat. The legumes for fallow replacement were found to use most of their soil water from the surface 0.6 m.

Summary and Research Opportunities

Plant available water is likely the greatest limiting factor to crop yield in semi-arid and subhumid regions of western Canada. The selection of the crops to be grown in rotation should be based on an understanding of total water supply at seeding, the specific water requirements of the crop, the rooting depth of the various crops and the expected growing season precipitation. The use of annuals, winter annuals and perennial crops in rotation can play a role in how we efficiently manage available water. In addition, the implementation of water conserving techniques should remain of utmost importance. In particular, stubble sculpturing for snow trapping and retention, the elimination of fall tillage and direct seeding can all contribute to additional soil water for the next crop in rotation. The use of short-term perennial forages can be an effective means of using water and nutrients accumulating below the rooting depth of most annual crops. With the development of effective no-till establishment and termination methods for perennial forages, soil water loss with intensive tillage can be avoided.

There is a need to continue to support the evaluation of crops which do not have a production history in semi-arid regions, such as the current research by the Swift Current Research Centre. Understanding the crop water use characteristics of a wide range of cereal, oilseed and pulse crops will help to identify soil water conditions which may limit the full yield expression of individual crops.

- In particular, what impact do deep rooted crops, such as chickpea, dwarf sunflower and safflower, have on the production of subsequent crops in rotation?
- If annual legumes root shallow, will a subsequent cereal crop in rotation be able to make use of unused subsoil water?
- What are the minimum soil moisture requirements for the establishment of the crops we would like in rotation?

In subhumid regions the issues related to soil moisture management and crop production tend to be less related to crop failure and more focused on efficient water management.

- There is a need to continue to evaluate the impact of soil temperature on crop water extraction.
- How do crops differ in their ability to grow in cold soils?
- How does soil texture influence the extraction of soil water beyond the maximum rooting?
- What cropping strategies can we implement to make use of subsoil nutrients and water?
- Can we develop strategies for the management of perennial forages in rotation which will prevent a year of summer fallow after termination?

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Table 1. Depth of rooting of a variety of crops commonly grown on the Canadian Prairies.

Crop	Estimated Rooting Depth (cm)	Comments	Source
Spring Wheat			
- Fallow seeded	107-122	Neutron scatter	Lafond, 1995
- Fallow seeded	120	Method unknown	Black et al., 198 1
- Stubble	91-107	Neutron scatter	Lafond, 1995
- Stubble	110-130	Profile-wall method	Entz et al., 1992
Winter Wheat			
- Stubble	91-107	Neutron scatter	Lafond, 1995
- Stubble	110-130	Profile-wall method	Entz et al., 1992
- Fallow	160-180	Method unknown	Black et al., 1981
Barley	140	Method unknown	Black et al., 198 1
Canola			
- B. napus (cv. Cyclone)	120	Neutron scatter	Angadi and Entz, unpbl. data
- Rapeseed (cv. unknown)	150	Method unknown	Black et al., 1981
Flax	61-76	Neutron scatter	Lafond, 1995
Field Pea			
- Stubble	61-76	Neutron scatter	Lafond, 1995
- Stubble	80-100	Neutron scatter	Borstlap and Entz, 1994
Safflower	2 10-220	Method unknown	Black et al., 1981
Sunflower			
- cv. unknown	200	Method unknown	Black et al., 1981
- Tall hybrid (cv. IS61 11)	160	Neutron scatter and profile wall	Angadi and Entz, Unpl. data
- Dwarf hybrid (cv. SW103)	120-140	Neutron scatter and profile wall	Angadi and Entz, Unpl. data
- Sunola (cv. Aurora)	120-160	Neutron scatter and profile wall	Angadi and Entz, Unpl. data
Alfalfa			
- Tap root (cv. Vernal)	210	Method unknown	Black et al., 1981
- Non-dormant (cv. Nitro)	100-160	Neutron scatter	Entz et al., 1993

Table 2. Water use and water use efficiency of spring wheat, winter wheat and barley.

Crop	Treatment	Water Use (mm)	Water-use Efficiency (kg/ha/mm)	Source
Spring Wheat				
- Central Sask.	Stubble	174-324	5.4-8.6	Entz et al., 1993
- S. Manitoba	Zero-till	146-241	12.4-16.8	Borstlap and Entz, 1994
	Conv-till	156-269	13.2-15.7	"
- Indian Head	Zero-till	373	7.8	Lafond and Derksen, 1995
(on fallow)	Conv-till	366	8.1	"
- Indian Head	Zero-till	310	7.3	"
(on stubble)	Conv-till	287	7.3	"
- Various Sask.	Smf.	-	9.0	Innovative Acres, 1987
Locations	Stb.	-	8.0	"
- Swift Current	Smf. +P	247	6.9	Campbell et al., 1987
	Stb. +N+P	206	5.7	"
	Cont. W +P	195	5.1	"
- Scott	Zero-till	263	7.6	Brandt, 1992
	Conv-till	267	7.0	"
- East-Central	Fallow	260-280	7.1-9.1	Lafond et al., 1994
Saskatchewan	Stubble	240-260	5.9-9.1	"
- Outlook	Dryland	179	7.4	Livingston et al., 1988
	Irrigated	327	8.3	"
Winter Wheat				
- Central Sask.	Stubble	75-277	3.9-13.1	Johnston and Fowler, 1991
- Central Sask.	Stubble	159-315	8.9-16.3	Entz and Fowler, 1991
-Indian Head	Zero-till	272	10.2	Lafond and Derksen, 1995
	Conv-till	269	10.2	"
Barley				
- Various Sask. Locations	Stubble		10.0	Innovative Acres, 1987
-East-Central	Fallow	250-270	8.6-12.3	Lafond et al., 1994
Saskatchewan	Stubble	240-250	9.8-11.7	"

Table 3. Water use and water use efficiency of canola, flax, field pea and lentil.

Crop	Treatment	Water Use (mm)	Water-use Efficiency (kg/ha/mm)	Source
Canola				
- S. Manitoba	Zero-till	161-263	7.8-l 1.4	Borstlap and Entz, 1994
	Conv-till	171-268	8.4-l 1.7	"
- Various Sask.	Fallow		5.0	Innovative Acres, 1987
Locations	Stubble		5.0	"
Flax				
- Indian Head	Zero-till	320	5.5	Lafond and Derksen, 1995
	Conv-till	295	5.0	"
- Various Sask.	Stubble	-	4.0	Innovative Acres, 1987
- East-Central	Fallow	260-330	3.2-4.6	Lafond et al., 1994
Saskatchewan	Stubble	250-320	3.3-4.5	"
- Scott (canola	Fallow-ZT	289	4.6	Brandt, 1992
& flax)	Fallow-CT	282	4.5	"
	Stubble-ZT	243	5.2	"
	Stubble-CT	252	5.3	"
Field Peas				
- S. Manitoba	Zero-till	220-278	12.5-18.8	Borstlap and Entz, 1994
	Conv-till	202-288	11.8-17.2	"
- Indian Head	Zero-till	323	7.6	Lafond and Derksen, 1995
	Conv-till	290	7.6	"
Lentil - Outlook	Dryland	244	6.8	Livingston et al., 1988
	Irrigated	361	3.7	"
Alfalfa				
- Montana	1 st/2nd/3rd yr	178/305/5 13	-	Black et al., 1981
- S. Manitoba	3rd. year stand	-	26.9-34.6	Entz et al., 1993
Legume Green Manure				
- Swift Current	Black lentil	156	15.1	Biederbeck and Bouman, 1994
	Tangier flatpea	152	14.8	"
	Chickling vet.	153	18.4	"
	Feed pea	165	18.7	"

Table 4. Spring soil moisture following a variety of crops grown on the prairies.

Scott 1991-1995 (Brandt, personal comm.)		
Stubble	Fall Soil Moisture (mm/15 cm)	Spring soil water (mm/15 cm)
Summer fallow	33.8	33.8
B. rapa (Tobin	27.0	35.0
B. napus (Cyclone)	25.6	37.4
B. juncea (Cutlass)	23.6	33.4
Flax (Vimy)	22.9	34.7
Sunflower (XF223)	23.1	33.4
Spring Wheat (Makwa)	27.6	35.9
Oats (Derby)	26.2	37.9
Lentil (Laird)	25.5	34.2
Field Pea (Radley)	28.1	35.6
Indian Head 1987-1994 (Lafond and Derksen, 1995)		
Stubble	Tillage	Spring soil water (mm/30cm)
Winter wheat (Norstar)	Zero-till	120
	Conv-till	108
Spring wheat (Katepwa)	Zero-till	120
	Conv-till	110
Field Pea (Radley)	Zero-till	112
	Conv-till	107
Summer fallow	Zero-till	121
	Conv-till	116
Saskatoon 1983-1986 (Townley-Smith et al., 1993)		
Stubble	Spring Soil moisture (mm/100 cm)	
	Incorporated	Desiccated
Field pea	145	143
Lentil	142	138
Tangier flat pea	136	143
Faba Bean	141	145
Alfalfa	138	130
Wheat	140	
Summer fallow	175	