Designing the Cropping System with the Right Water Intensity

Brian McConkey*, Perry Miller**, Sangu Angadi*, and Y. T. Gan *
*Agriculture and Agri-Food Canada, Swift Current, SK
** Dept. Land Resources and Environ. Sciences, Montana State Univ., Bozeman, MT

Introduction

Mother Nature gives us only so much water to use. It is our task to match our cropping system to the long-term water availability of our location - considering future years in addition to the current year.

Rooting Depth and Water Use

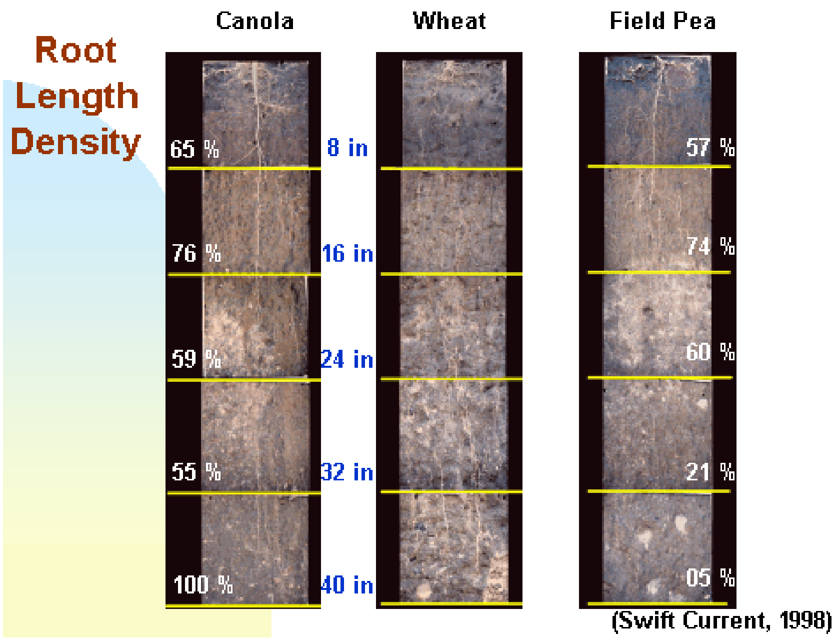

Figure 1. Root Length density of canola, wheat, and pea (percentages are the percent of wheat).

Pea is the shallowest rooting crop commonly grown on the prairies. Canola tends to root a bit deeper than durum or wheat. Our general ranking of rooting depth from deepest to shallowest is:

Sunflower >= Argentine canola = Mustard >= wheat = winter wheat >=barley = chickpea = Polish canola >= flax = lentil >= pea.

When conditions are dry, rooting depths are reduced because of the less vigorous above-ground growth to feed root growth combined with the difficulty for roots to penetrate dry soil. When conditions are wet, rooting depths are also reduced since there is no need for the plant to root as deeply. Deepest rooting depth occurs when there is good early season moisture to produce vigorous above ground growth and the soil is moist with depth but then the weather turns dry so the plant has to obtain its water needs from the soil.

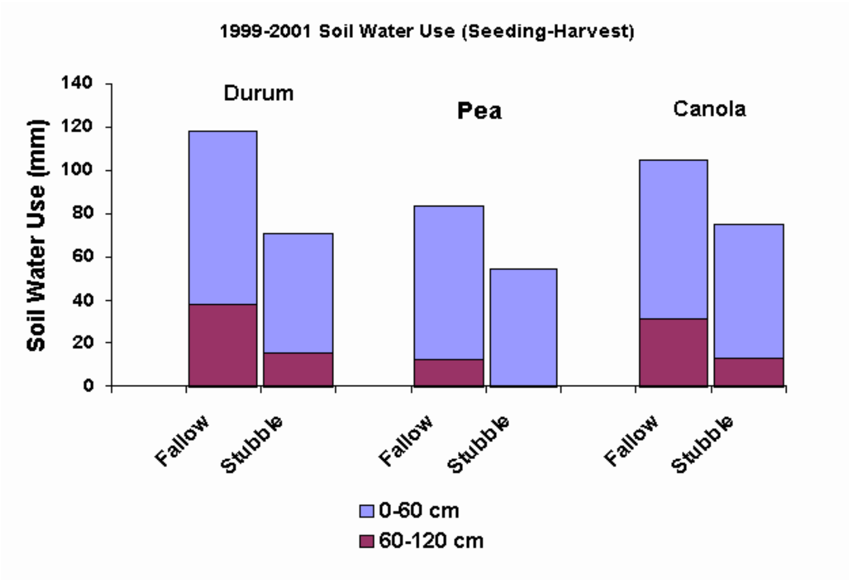

Figure 2. Average soil water extraction from seeding to harvest for durum, pea, and Argentine canola.

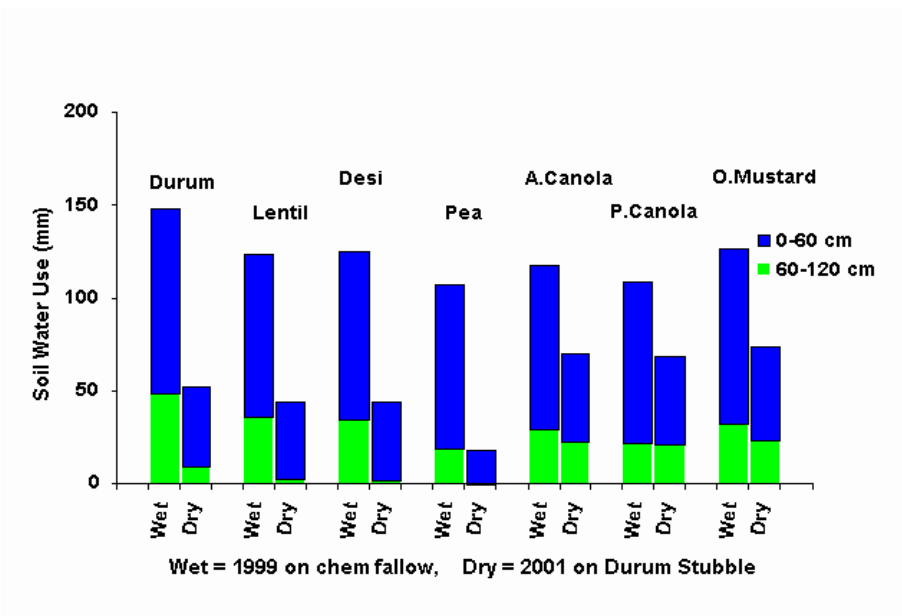

Figure 3. Soil water extraction for upper 2 ft (0-60 cm) and lower 2 ft (60-120 cm) of the soil profile for different crops under wet and dry conditions.

On stubbles that have not been recharged with water, pea confines all its roots near the surface (Figure 2). Under those same conditions, canola and wheat root more deeply. The differences in rooting behavior are more evident when contrasting growth under wet conditions (seeded into moist chem. fallow in a "wet" 1999) versus under dry conditions (seeded into dry stubble in "dry" 2001)(Figure 3). The more aggressively rooting Brassica oilseeds were able to extract more water deeper than durum or the pulses.

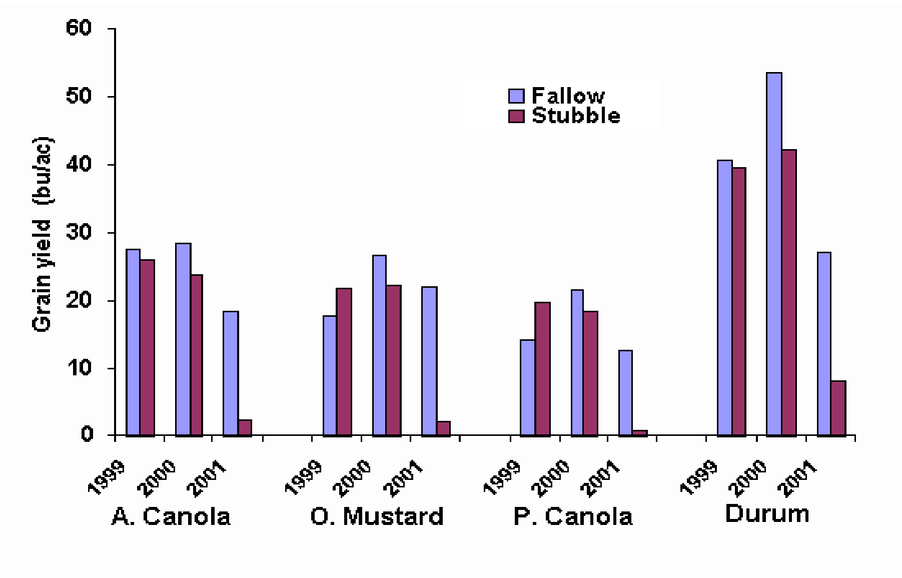

Figure 4. Yield of Brassica oilseeds and durum seeding with low disturbance into chem fallow and into durum stubble.

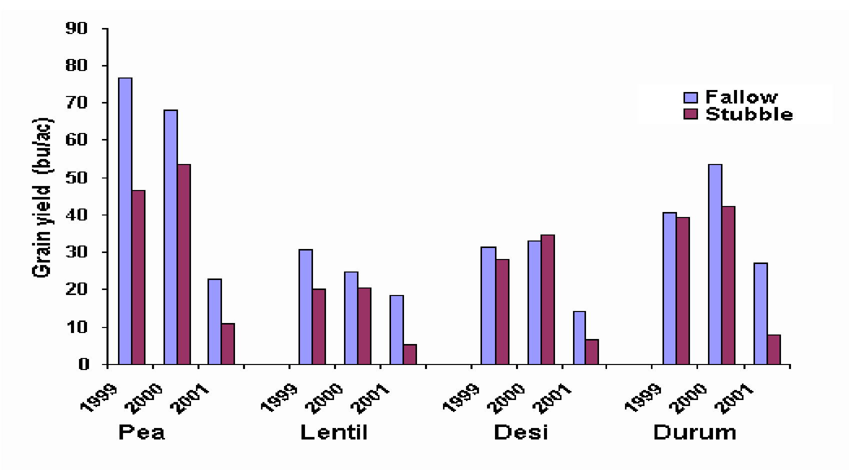

Figure 5. Yield of pulses and durum seeding with low disturbance into chem fallow and into durum stubble.

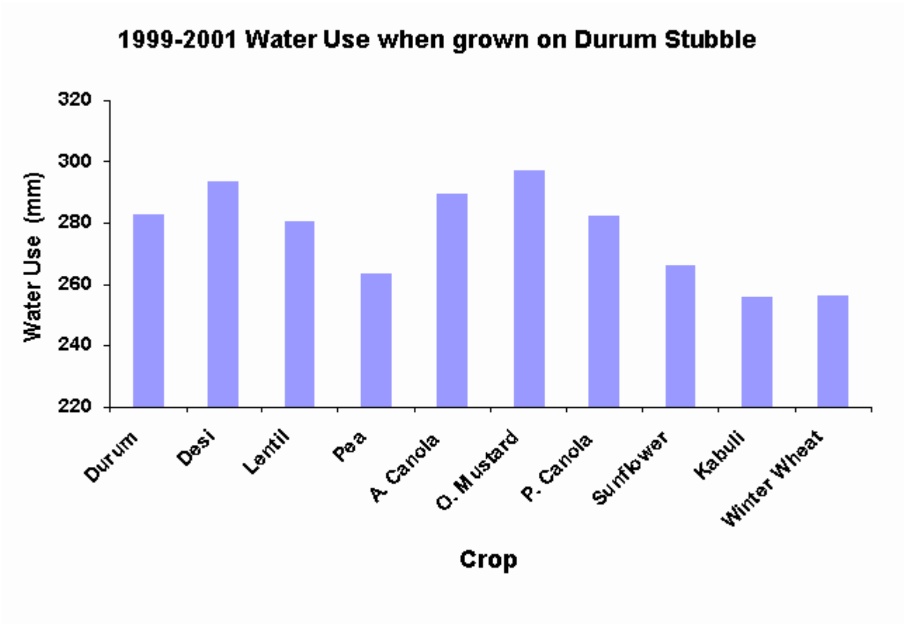

Figure 6. Average water use of different crops seeded with low disturbance directly into durum stubble (except winter wheat on pea stubble).

However, the more aggressively rooting Brassica oilseeds wasted resources extracting small amounts of water under those dry conditions. Not surprisingly, then, its grain yield in 2001 on stubble represented a complete crop failure. In contrast, pea wasted no effort extracting water from dry soil, and, so, relative to its yield on fallow, its yield on stubble in 2001 was highest of all crops (Figure 5). Pea is almost cactus-like under dry conditions. Clearly, it is not a good plan to try and produce deep rooting crops on dry soil.

We defined water use as the change in soil water content between seeding and harvest plus the total precipitation falling over that period. In the Brown soil zone, water use varies little among crop types (Figure 6). Our general water use rankings from most to least are:

Sunflower = Argentine canola = mustard >= wheat = winter wheat >= barley = chickpea = Polish canola >= flax = lentil >= pea

The results shown in Figure 6 are for moisture limited conditions and only for three years so do not perfectly follow the general water use rankings described above. When conditions are wet, water use increases as length of growing period increases and when conditions are dry, water use tends to equal total available water.

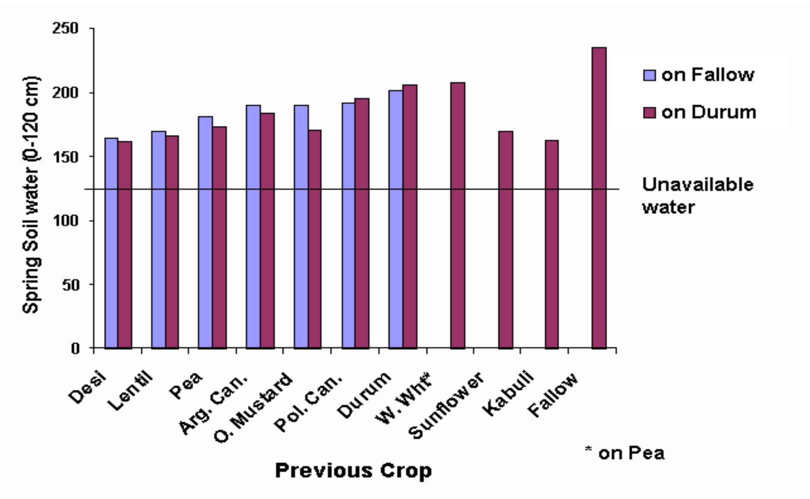

Figure 7. Soil water in the spring after various crops depending on whether the previous crop was seeded on stubble or fallow.

Soil Water Conservation

The previous crop has a strong effect on total soil water in the next spring (Figure 7). Figure 7 also shows the approximate amount of total soil water that is unavailable to plants but the exact amount that is unavailable depends on growing conditions and crop type. Generally, there is not a large amount of additional water available after a crop that was seeded on fallow compared with one seeded on stubble.

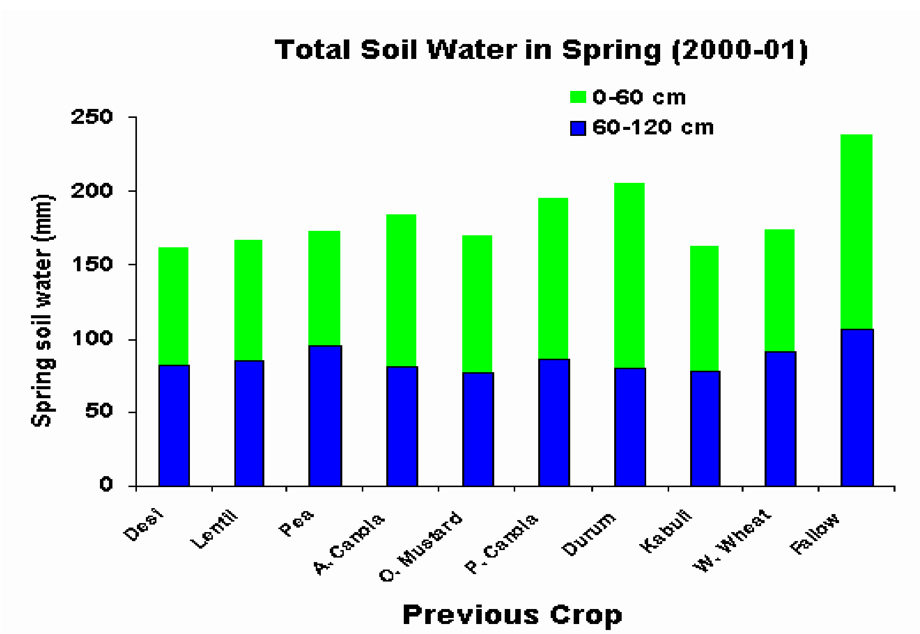

Figure. 8. Total water for upper 2 ft and lower 2 ft in soil at seeding depending on the previous crop.

Water conservation depends on the amount and depth of water used by the previous crop and water conservation from crop maturity until the next spring (Figure 8). Pea stubble has more water at depth than other stubbles reflecting its lower use of water at depth. Although a relatively large water user, by the next spring its stubble and residue provides the best water conservation from harvest until seeding the next year. Chickpea stubble is the driest because it is relatively high water user and produces little residue to slow evaporation or trap snow. Generally we rank the amount of water available the next year from wettest to driest as:

Chem fallow >= tilled fallow >= cereal >= oilseed >= pea >= lentil >= chickpea

Water Use Efficiency

Water use efficiency (WUE) is defined as grain yield divided by water use. The WUE among crops varies greatly (Figure 9). Pea is by far the most water efficient followed by cereals, then pulses, and finally oilseeds. However, that ranking based on grain yield is somewhat unfair because it requires about three times more photosynthesis to produce oil than starch and about two times as much photosynthesis to produce protein than starch. When described on the basis of photosynthetic WUE, the differences among the crop types are reduced considerably. Expressed that way, canola becomes as water efficient as pulses such as lentil and chickpea. Pea remains by far the most water efficient crop commonly grown on the prairies.

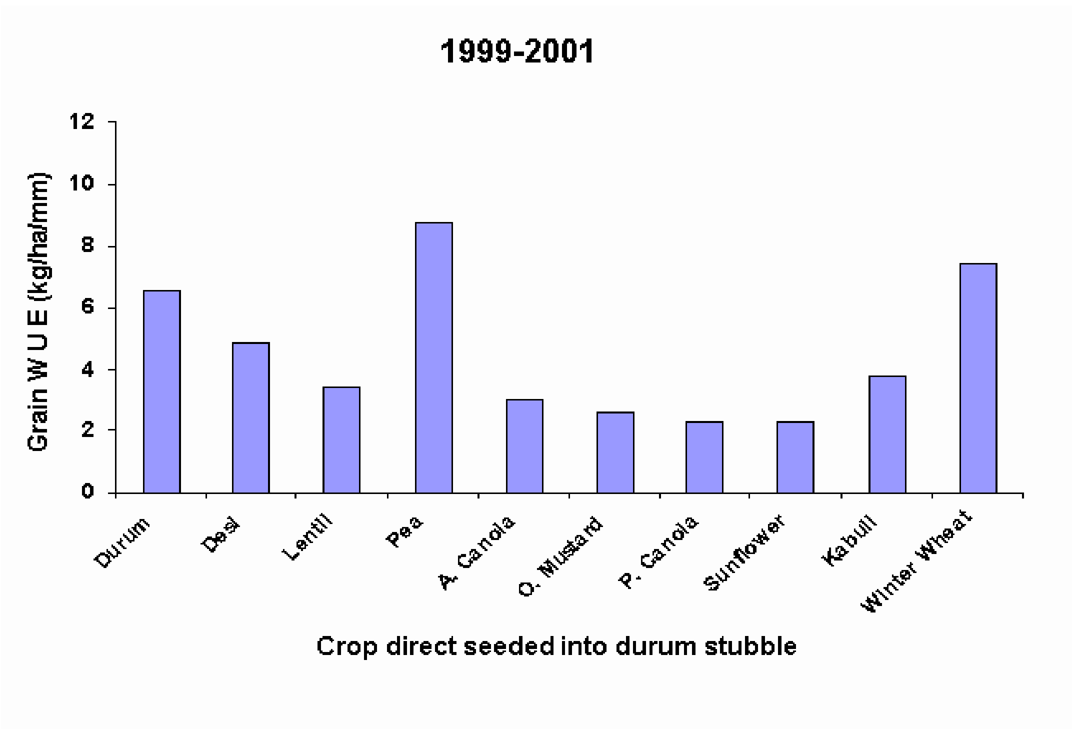

Figure 9. Water Use efficiency (WUE) for various crops.

Rotation Effects

Crop sequences have a large effect on water available at seeding, crop yield, and water use efficiency. The crop sequence effect is complex and involves effects on soil water, nutrient cycling and availability, soil temperature, soil microbial community, alleopathic and/or growth-promoting substances from crop residues, soil physical structure, previous crop effects on seedbed conditions, insects, weeds, and diseases. These individual effects are non-additive and so it is difficult to quantify exactly the overall crop sequence effect. Hence, scientists often simply refer to the crop sequence effect as the ill-defined "rotation effect".

Previous crop effects on yield are large (Figure 10). Expressing this "rotation effect" with water use efficiencies (Figure 11) shows the effect is not explained simply by water. Generally there is an increase in water use efficiency as the previous crop matured earlier. Fallow is the extreme case of an early maturing previous crop. This benefit of early maturing previous crop is probably related to a partial fallow effect. The greater the time from maturity until seeding the next crop, the more time is available for decomposition of roots and residues from the previous crop. Generally, it appears that this decomposition is beneficial to the next crop for undetermined reasons.

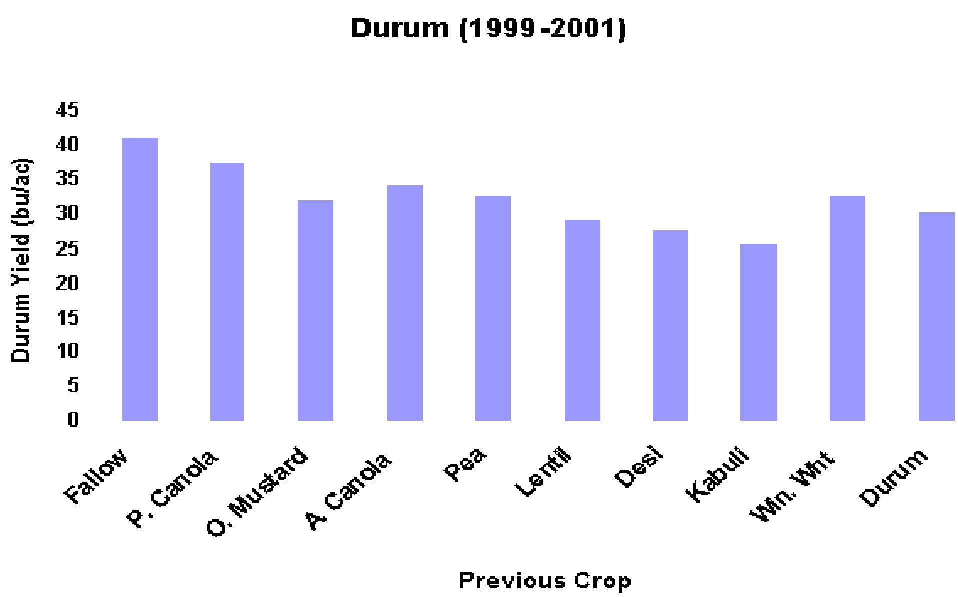

Figure 10. Average yield of durum for different previous crops.

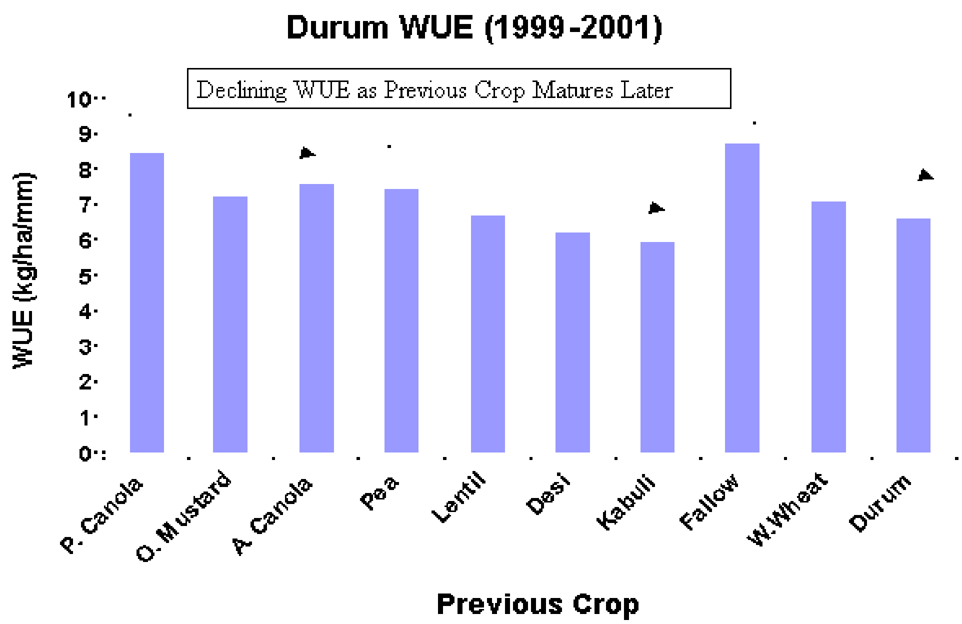

Figure 11. Durum water use efficiency as affected by previous crop.

In the drought year of 2001, the previous crop had a dramatic effect on durum yield (Figure 12). Water was only a part of this effect as the water use efficiencies were also dramatically affected by the previous crop (Figure 13).

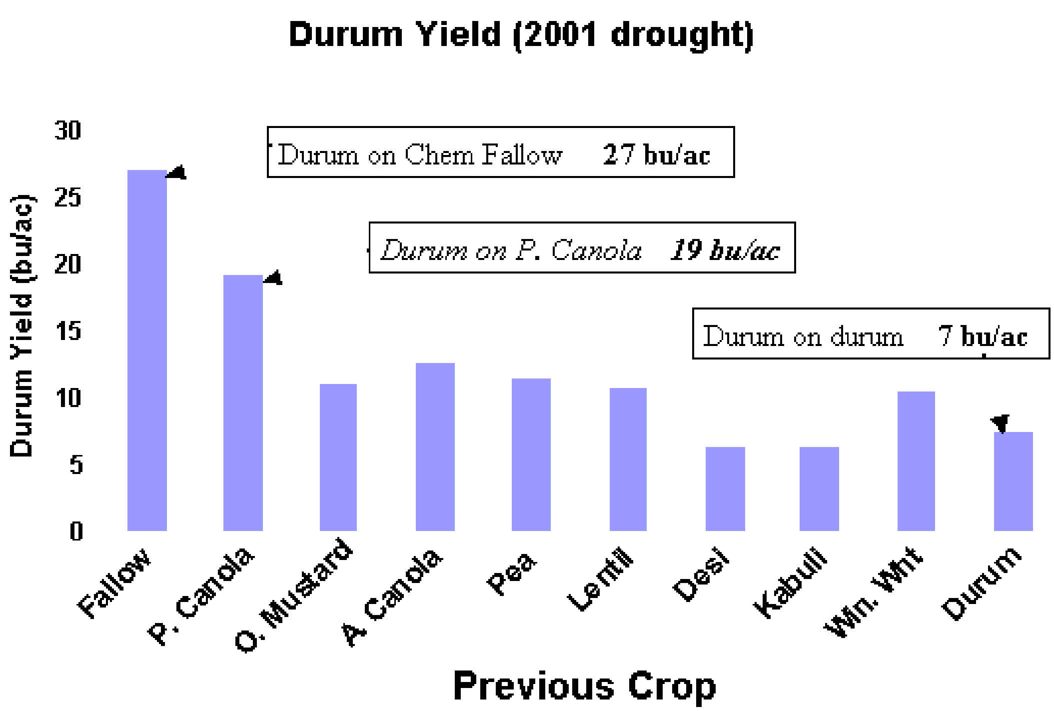

Figure 12. Durum yields in 2001 as affected by the previous crop

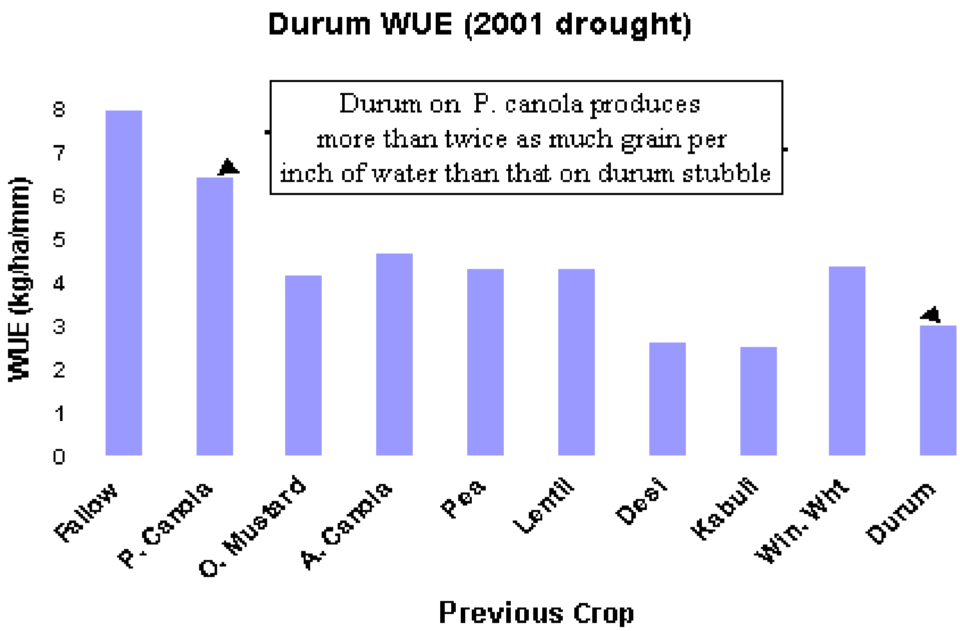

Figure 13. Durum water use efficiency in 2001.

Water Intensity of the Cropping System

The basic concept is to match the water intensity of the cropping system to the long-term water availability of your location. Mother Nature has done this with the communities of native vegetation. Water intense cropping systems purposely use a lot of water and require a lot of water to be successful. In contrast, cropping systems that are not water intense purposely do not use all the water available in one year to conserve water for the next year. Non-intense systems also conserve water through practices like low disturbance direct seeding and leaving as tall as stubble as feasible. Insufficient water intensity results in too much soil water as indicated by frequent seeding delays due to wet soil, full sloughs, water ponding for prolonged periods, much runoff, soils too wet in fall, and salinity. Excessive water intensity results in too little soil water as indicated by good performance in wet years but disappointing yields under average conditions, very low yields under dry conditions, and fallow (to reduce intensity) starts to looks economically attractive in many years.

	Climate	Required Intensity
Wet	Red River Valley	Very Intense
	Dark Gray	Intense
	Moist Black	
Moist	Black	Moderately intense
	Thin Black	
	Dark Brown	Less intense
	Brown	
Dry	Dry Brown	Non-intense

Required Intensity	Crops and Practices
Very Intense	Perennial forages in rotation, post-harvest cover crops, tillage, long-season crops, deep rooted crops
Moderately intense	Mix of practices from above and below
Not intense	Short-season crops (hay/silage better than grain),winter cereals, low-disturbance direct seeding, tall stubble, early seeding, fallow

Examples of Water Intensity Choices for the Brown Soil Zone

Chickpea, especially late-maturing cultivars, is a relatively water intense crop for the Brown soil zone. Not surprisingly, reduced yields following chickpea are commonly reported. Pea, the least water intense crop available, may be a reasonable choice to put on chickpea stubble (Figure 14).

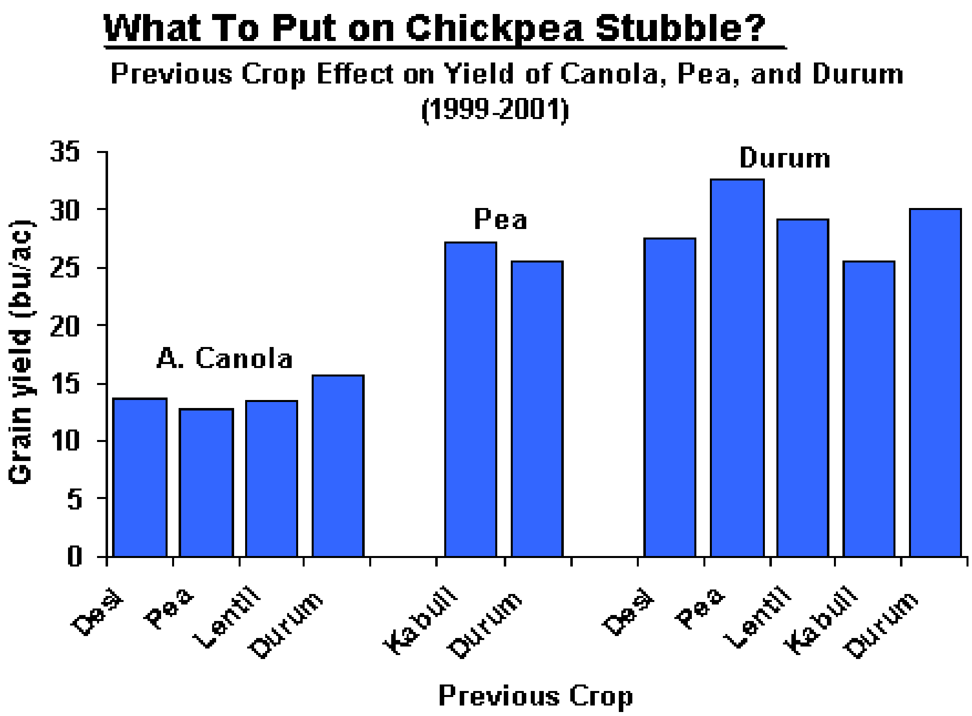

Figure 14. Yield of Argentine canola, pea, and durum on chickpea and other stubbles.

Sunflower is a very water intensive crop being both deep rooted and late maturing. Sunflower will even extract some soil water below 4 ft (Figure 15).

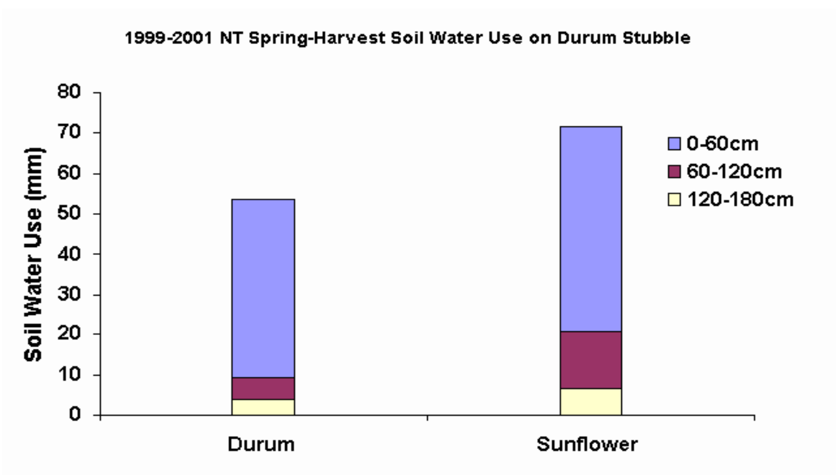

Figure 15. Average soil water extraction for durum sunflower seeded directly into durum stubble.

We observe reduced yields the first and second year after sunflower (Figure 16 & 17). Sunflower is too water intense for the Brown soil zone and should only be grown if its economic returns are much better than less water intense crops - that has generally not been the case in recent years.

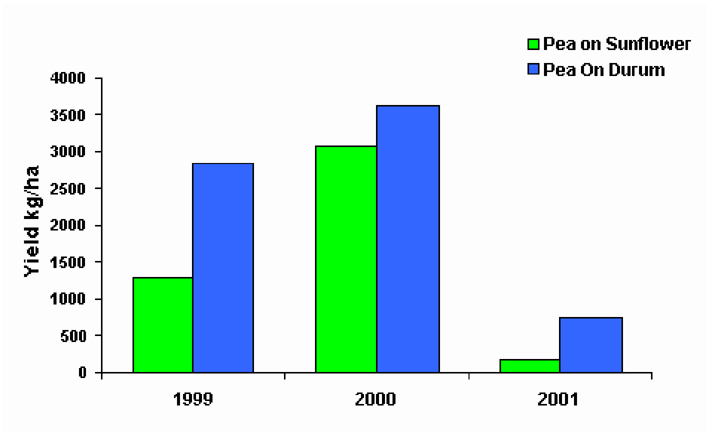

Figure 16. Pea yields after durum and after sunflower.

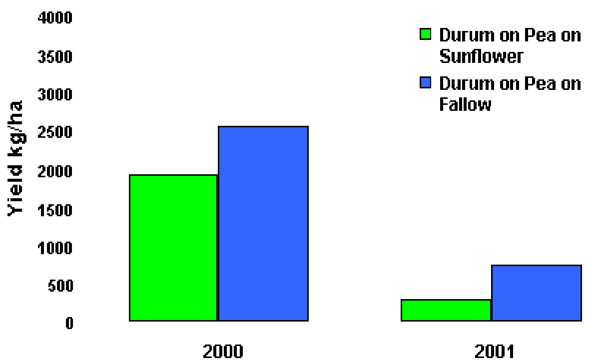

Figure 17. Sunflower appears to reduce yield two years later.

Short-season crops grown for hay or silage are the ultimate in hastening maturity and reducing water intensity. This will benefit the subsequent crop under dry conditions (Figure 18). Note that if the hay or silage is taken off early so that it also removes weeds before they set seed, there can also be a weed control benefit to this practice in subsequent years.

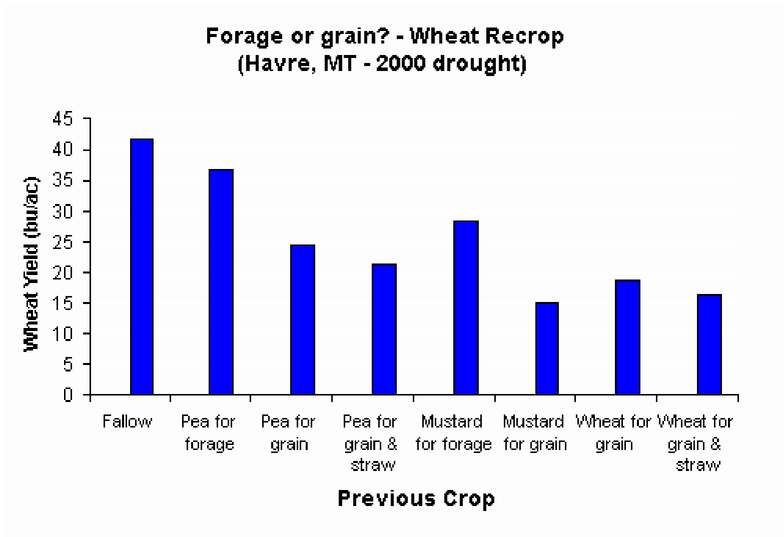

Figure 18. Taking a short-season crop for forage reduces water intensity and benefits the subsequent crop under dry conditions.

Summary

On the Canadian prairies water is generally the greatest limitation to crop production. Through choice of crop type, crop sequences, and production practices, we can adjust the water intensity of the cropping system to best match the water availability of the climate. Many cropping systems in wet areas are not sufficiently water intensive and have been running into excess soil moisture conditions. Conversely, many cropping systems in the semiarid prairie are too water intense with several long-season and/or deep-rooted crops in a continuous rotation and have run into problems when conditions turned dry. Most prairie farms lie somewhere intermediate in terms of water availability and appropriate water intensity of the cropping system. In these situations, the cropping system will require a mix of practices. Water conserving practices such as low-disturbance direct seeding and tall standing stubble are valuable to support more water intense crops. Cropping systems with intermediate water intensity will also alternate between low water intensity crops and high water intensity crops. For example, a water intense deep-rooted crop would be put on soil that was left relatively moist by the previous low-water intensity crop

Crop sequences have a huge impact on how effectively crops use available water to produce grain. Within a cropping system of appropriate water intensity, it is also important to use beneficial crop sequences that can greatly improve economic returns at little cost.