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IMPACTS OF PRECIPITATION AND CROP - TILLAGE DECISIONS ON SOIL MOISTURE REGIMES DURING THE 2002 DROUGHT ON THE SOUTHERN CANADIAN PRAIRIES

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1. INTRODUCTION

The specter of potential environmental change and enhanced variability has implications on countless aspects of land and agricultural management. Of profound importance are systematic and sustained changes in the spatial distribution and timing of climate resources in regions that lie in close proximity to the margins of agricultural production. Further, the existence of increased variability, even without long-term systematic change, will have dramatic seasonal and year-to-year impacts. During 2001 and 2002, widespread concerns about drought and its impacts were realized across the Canadian Prairie provinces (Alberta, Saskatchewan and Manitoba). In response, a complex interaction existed between Prairie agricultural producers and the potentially available environmental resources for annual crop production.

Concerns about the availability of climate resources for sustainable agricultural production are not new. The development and sustainability of agriculture on the Canadian Prairies is an acclamation of human technological and management ingenuity in the face of many difficult hurdles. In the period 1857-1860, an expedition that was sponsored by the British government and the Royal Geographic Society and led by John Palliser assessed the agricultural potential of western Canada. Two natural biogeographical zones were identified. The first was a semi-arid area with short grass vegetation. Lying northward of this was a sub-humid area of tall grass vegetation. Palliser considered the latter to be suitable for agriculture settlement, and it was named the fertile belt (Figure 1). The zone of semi-aridity in southern Alberta and Saskatchewan was deemed essentially unsuitable for agriculture: "forever and comparatively useless". It was viewed to be an extension of the great American desert (to the south), and it was referred to as the dryland belt. This belt, with a slight northward extension acknowledged, is commonly known as Palliser's Triangle. Farming in the fertile belt has traditionally been successful. The dryland belt has a much higher risk associated with cropping. In spite of Palliser's assessment, a 200,000 km^2 area of southern Alberta, Saskatchewan and Manitoba has become one of the world's most productive agricultural regions, despite severe social and economic hardships suffered by its inhabitants during periods that have been punctuated by drought.

Grain farming has been predominant in the dryland zone, and the use of summer fallow (every second or third year) has been traditional for soil moisture conservation and land resource enhancement. In the early 20th century, an agricultural economy on the Canadian Prairies had emerged and it was based primarily upon grain production. Over the past several decades, a number of new and different challenges have arisen for agricultural producers with many of challenges being linked to the international agribusiness marketplace. The first two years of the 21st century witnessed the occurrence of acute environmental difficulties. The year 2001 was characterized by increased aridity throughout the Canadian Prairies, and the widespread impacts of drought were becoming commonplace. There was concern about cumulative effects as the 2002 growing season was about to commence. Soil moisture reserves were low at the end of the 2001 growing season, the winter period of 2001-2002 was one of low snowfall and the winter temperatures were not extremely cold. Although drought was severe and very widespread on the Prairies in 2002, some regions in the traditional dryland belt received sufficient rainfall that permitted agricultural activities to proceed. The usual aridity of the dryland belt was shifted geographically northwards, with the result being that parts of the fertile belt were in the grasp of widespread drought.

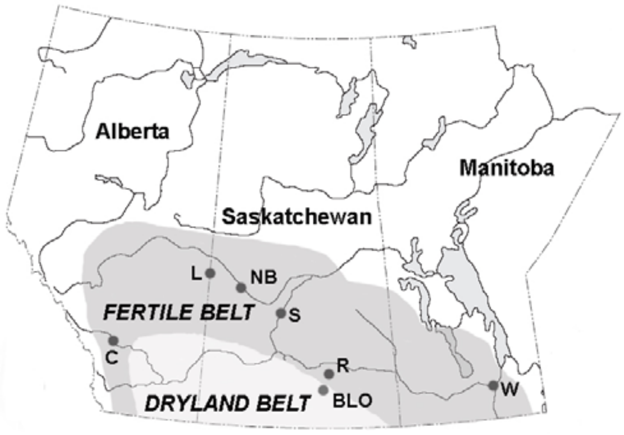

Figure 1. Map of Canada's Prairie provinces showing the approximate location of the dryland and fertile belts, the Bratt's Lake Observatory (BLO) and some Prairie cities. Cities: C - Calgary, L - Lloydminster, NB - North Battleford, R - Regina, S - Saskatoon, W - Winnipeg.

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Research was conducted in southern Saskatchewan (Figure 1) to study the 2002 drought and the aforementioned circumstances. The research site is located near the boundary between the dryland and fertile belts. The research presented herein examines soil moisture regimes over the extended growing season (April to October 2002). Specific attention is given to the impacts of precipitation amount and timeliness on the soil moisture regimes. Supplementing this, matric potential and available water results are employed to examine key aspects of the seasonal trend in moisture availability for crop production. Additionally, the implications of producer decision-making in the anticipation of the 2002 growing season challenges were assessed. Crop - tillage management choices were explicitly considered. For this, two adjacent fields were monitored. One was cropped in wheat and the other field was in summer fallow. The summer fallowing was undertaken by the producer to enhance the conservation of soil moisture for crop production during the following year (2003), and for the control of weeds and volunteer plants through mechanical tillage.

2. STUDY SITE AND METHODS

Research was conducted at the Meteorological Service of Canada’s Bratt’s Lake Observatory (50° 12’ N, 104° 42.7’ W), which is located approximately 25 km south of Regina, Saskatchewan (Figure 1). The Observatory is Canada’s commitment to the Baseline Surface Radiation Network (BSRN). BSRN is a project of the World Climate Research Programme aimed at detecting important changes in the earth's radiation field which may cause climate change. The Observatory is in Canada’s Prairie ecozone and is within the mixed grassland ecoregion. The Observatory is purposefully situated on a working farm and provides the opportunity to examine the dynamic relationships between meteorological, soil and vegetation processes during the seasonality of agricultural activities. The region is commonly referred to as the Regina Plain, the soil type is Regina clay and the landscape is quite typical of southern Saskatchewan. The chernozemic soil is recognized for being among the best wheat lands in Saskatchewan. Over the past one hundred years, the region has been renown in Canada and throughout the world for its quality grain production.

The agricultural activities preceding, during and following the 2002 growing season were important to this study. The research site employed two agricultural fields. Both fields extended in the west-east direction for 1.6 km, and were bounded by gravel/dirt roads. The field to the south was approximately 270 m wide, whereas the field to the north was approximately 400 m wide. A distinct boundary between these fields ran west-to-east. The character of both fields and their crop - tillage management were essentially indistinguishable from other agricultural production in southern Saskatchewan.

Wheat stubble from the 2001 crop and a residue of discontinuous organic mulch characterized both fields in early 2002. In 2002, with limited moisture availability concerns becoming common knowledge, the producer planted a hard red spring wheat (*Triticum aestivum* L.) (variety AC Barrie) in the north field because of its known drought resistance. Crop - tillage management resulted in a different usage of the south field. It was maintained in traditional summer fallow for the conservation of soil moisture for the 2003 growing season. The wheat field was tilled and seeded on May 18 with packing following on May 19 and 21. The effective growing season terminated in late August. Harvesting of parts of the wheat field commenced on August 24. But as a consequence of weather and other related delays, harvesting was not fully completed until mid-September. The summer fallow field received surface tillage twice throughout the growing season (June 26, July 25) for weed and volunteer plant control.

Starting in mid-April (approximately one week after the disappearance of the 2001-2002 winter snow accumulation) and continuing until mid-October, three interrelated soil moisture programs were maintained. Soil moisture was manually sampled almost every morning in each field. At five locations in each field, vertical soil samples were taken with a corer to a depth of 0.25 m. Upon extraction from the soil, the sample in the corer was sectioned (0.05 m intervals). Additionally, a surface scraping of the 0-10 mm surface layer was taken. Samples were then weighed, dried at 105° C for 24 hours and then re-weighed. Once per week, in each field, sampling was extended down to a depth of 0.50 m (0.05 m intervals). These were done at 5 locations in each field, and a similar methodology to that employed in the 0-0.25 m sampling was used. The method of manual sampling was selected for two reasons. It is the technique that permits the highest quality sampling of the surface zone of the soil profile. This was deemed to be of importance as the observations were also employed in the assessment of soil surface impacts on upwelling radiative fluxes. Further, the methodology is the standard against which all other measurement techniques are calibrated.

A concern about any soil moisture sampling program is the quality of the data in the representation of the subsurface environment. Further, there are often inconsistencies between the scale of measurement and the scale required for process study, modelling and prediction. Hence, the consideration of larger spatial footprints has merit and was undertaken. On 11 dates throughout the growing season, spatial sampling of soil moisture was conducted employing transects. Transects, running west-to-east across each field, were established 50 and 100 m respectively north and south of the boundary between the two fields. Sample locations in the summer fallow commenced at 50 m from the western edge of the field and every 150 m thereafter until the eastern field boundary was reached. In the wheat field, sample locations commenced at 350 m from the western border of the field, and every 150 m thereafter until the eastern field boundary was reached. The reason that sampling did not start at the western boundary of the field was the area had been highly modified several years previous during the site preparation and construction of a meteorological compound. At each transect sample site, a vertical coring to a depth of 0.25 m was taken and thereafter sectioned.

The bulk density of the soil was used to convert gravimetric soil moisture to volumetric soil moisture. Bulk density was sampled in the both fields employing a volume extraction technique. Bulk density was lowest at the surface (0-0.05 m). A rapid increase in density occurs thereafter, with values at depth ranging between 1200 and 1500 kg m^{-3}.

Additionally, soil samples were collected from each field for soil physical property analysis. An extraction technique was employed, and undisturbed soil samples were taken with an aluminium ring that was inserted into the soil. The soil water potential (Ψ_w) in agricultural soils is primarily affected by the matric (Ψ_m) and solute (Ψ_s) potentials. The relationship between the soil's matric potential and volumetric moisture is fundamental to the characterization of water capacity, water retention and the flow of water in soil. Pressure plate analysis of undisturbed soil (Hanks and Ashcroft, 1980; Klute, 1986) yielded a water retention curve between matric potential and volumetric soil moisture at 6 pressures (10, 33, 50, 100, 300 and 1500 J kg^{-1}). Application of water relations curves to volumetric soil moisture data for assessing matric potential was achieved using a semi-physically based modelling approach. Campbell's (1974) power function relationship provides a suitable approach to model the relationship between matric potential Ψ_m and volumetric soil moisture VSM

$$\Psi_m = \Psi_e \ (VSM / Tp)^{-b} \qquad (1)$$

where Ψ_e is the air entry water potential, Tp is the total porosity, and b is the slope of the power function and is often referred to as the Campbell b parameter. Campbell and subsequent researchers demonstrated that b was related to soil texture. Clapp and Hornberger (1978) and subsequent work by Cosby et al. (1984), employing large soil hydraulic property databases, clearly showed the relationship between b and soil texture. For example, for sand, loam and clay soils, with mean clay fractions of 0.03, 0.19 and 0.63 respectively, b had values of 4.05, 5.39 and 11.4. Equation 1 was solved to assess the values of equation parameters for estimating matric potential. The parameters Ψ_m, Ψ_e, VSM and Tp were obtained from the pressure plate determinations of the Ψ_m - VSM relationship and other supplemental analysis. The b parameter was solved using power function regression analysis. The parameters find strong agreement with the literature (Clapp and Hornberger, 1978; Cosby et al. 1984). A b parameter of approximately 12 demonstrates a high degree of correspondence to data for clay soils. Further, for the wheat field, the observed lower bulk density in the surface layer corresponds to a slightly lighter soil, and the analysis shows a decrease in b to 9. This is quite similar to values for clay loam soil in the literature (Clapp and Hornberger, 1978; Cosby et al. 1984). The parameters were used to assess the seasonal trend in the matric potential in the 0-0.25 m soil layer (i.e., an effective depth of the rooting zone).

Available water, that can be extracted from the soil by plant roots, is the difference between the amount of water in the soil at field capacity (water held in the soil against the gravitational force) and the amount of water in the soil at the permanent wilting point (the percentage of soil moisture at which a plant will wilt and not recover in an atmosphere of 100% relative humidity). The concepts of field capacity and permanent wilting point were developed as practical pedological measures to account for the moisture holding capacity of soils and the upper and lower limits of this range. Issues about the concepts have been identified and received attention in the literature (Klute, 1986), and these remain as concerns for a number of soil types and plant environments. Relating field capacity and permanent wilting point to matric potentials has been routinely undertaken and aspects of concern have been also been presented (Klute, 1986). At field capacity, the Ψ_m, is often assessed to range between -10 (sandy soils) to -30 J kg^{-1} (loam and clay soils). The permanent wilting point varies among plant species (-1500 to -5000 J kg^{-1}), but is often arbitrarily set at -1500 J kg^{-1}. Often the water potential at the actual permanent wilting point is usually of minor importance, since over 75% of the available water has been removed from a soil at -500 J kg^{-1}, and very little water is available below -5000 J kg^{-1}. Data from the soil property analysis was used to summarize field capacity, permanent wilting point and available water storage capacity for the wheat and summer fallow fields (Table 1). Given the nature of the Regina clay soil and the crop - tillage system (wheat and summer fallow), the field capacity was assumed to be adequately represented by -33 J kg^{-1} and the permanent wilting point by -1500 J kg^{-1}. The available water storage capacity of the soil was evaluated as the difference between the field capacity and the permanent wilting point.

Table 1. Summary of volumetric soil moisture (VSM) at field capacity and permanent wilting point, and the available water storage capacity.

Site	Depth (m)	VSM at field capacity[1] (%)	VSM at permanent wilting point[2] (%)	Available water storage capacity (%)
Wheat	0.05	41.1	27.8	13.3
	0.20	41.9	29.7	12.2
	0.50	42.2	30.1	12.1
Fallow	0.05	46.7	32.9	13.8
	0.20	46.2	32.8	13.4
	0.50	42.2	30.1	12.1

1. estimated from matric potential at -33 J kg^{-1}
2. estimated from matric potential at -1500 J kg^{-1}

3. RESULTS AND DISCUSSION

Four issues are considered herein: the 2001 and 2002 precipitation regimes and the implications on soil moisture recharge; the 2002 soil moisture regime from mid-April until annual freeze-up in mid-October; spatial soil moisture observations and the representativeness of daily soil moisture sampling; and the available water regimes.

3.1 *Precipitation regimes in 2001 and 2002*

A continental climate prevails over Canada’s Prairie region (Hare and Thomas, 1974). It is characterized by extreme daily and seasonal fluctuations in temperature and low precipitation. In winter, Arctic air masses can often dominate and conditions can be extremely cold. The region’s aridity is not only a consequence of its distance from the ocean, but also the impact of the western cordillera in modifying the trajectory of moisture-laden Pacific air masses. Precipitation is both a crucial and limiting climate resource. Not only is precipitation generally low, it can also vary significantly year-to-year. Sequences of drought years have occurred in the past (in the 1930s - the infamous Dust Bowl conditions and in the 1980s).

The full representation of drought is, at any instance, problematic. When the absence of adequate water availability limits or precludes many agricultural activities, the evidence of drought is obvious. However, the actual character of drought involves the integration of the amount, the timeliness and the spatial attributes of precipitation. The year 2001 was characterized as a drought year across the Canadian Prairies as a consequence of low precipitation over both growing season and annual timescales. In some areas on the Prairies, 2001 was simply another year in a sequence of years with low precipitation. But another aspect was becoming recognizable, the shifting of the aridity of the dryland belt of southern Saskatchewan and Alberta northwards into the fertile belt. This zone through central Alberta and Saskatchewan experienced precipitation values much less than the long-term averages (1971-2000 normals). This situation can be clearly illustrated for three locations (Regina, North Battleford and Lloydminster) that form a southeast-to-northwest transect from the edge of the dryland belt into the fertile belt (Figure 1). Figure 2 presents the cumulative daily total precipitation for these locations for the years 2001 and 2002. Also denoted are the annual totals of precipitation for 2001 and 2002, as well as annual average (1971-2002 normals). The trend in cumulative precipitation for Lloydminster documents low precipitation on both growing season and annual timescales. Both the 2001 and 2002 trends are similar in precipitation amount and timeliness. Annual totals are approximately one-half of the 30 year average. North Battleford, located to the southeast of Lloydminster, usually has slightly less average annual precipitation than Lloydminster. In both 2001 and 2002, North Battleford has more precipitation, but the growing season and annual totals were less than average. The data for Regina, located further to the southeast along the transect, is quite unusual in comparison. The precipitation total for 2001 was close to the annual average, but a substantive

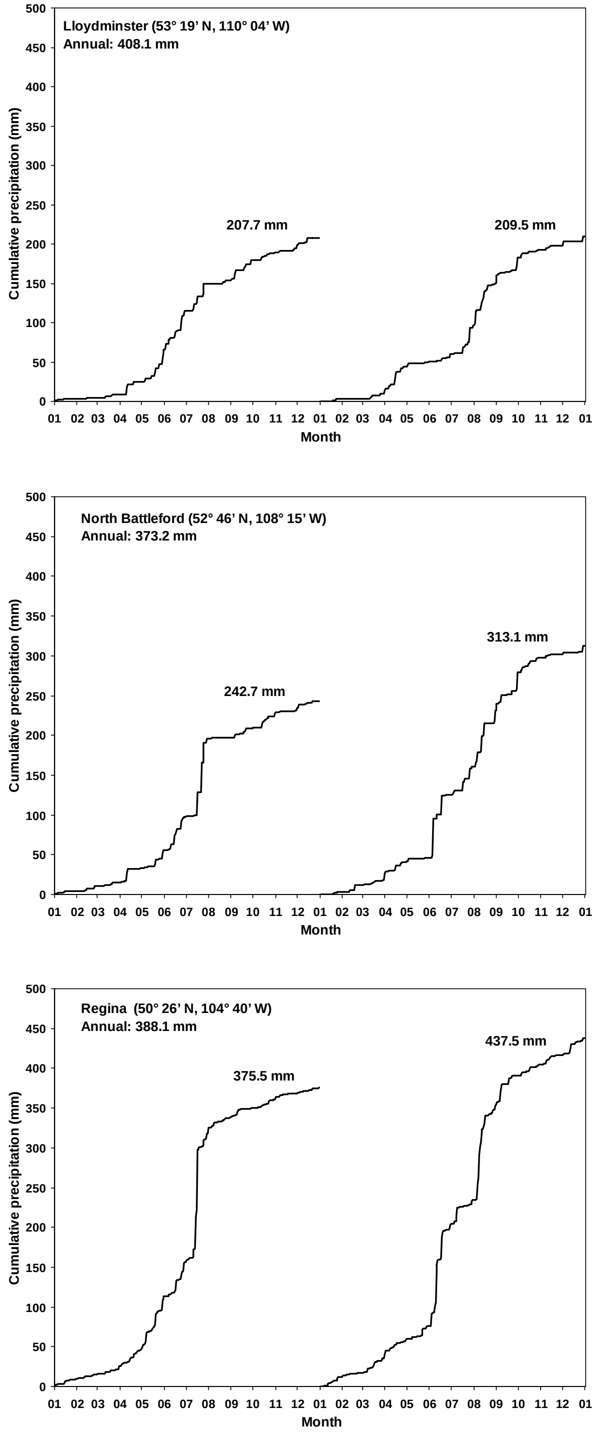

Figure 2. Cumulative precipitation for Regina, North Battleford and Lloydminster for 2001 and 2002. The annual total precipitation for both years is also included for each location, together with the average annual precipitation (1971-2000 normals). Data from the Meteorological Services of Canada archives.

amount of the precipitation input came in a short period in mid-July (124.5 mm over July 14-16). This recharge event is also present in the North Battleford data, but more subdued. It does not appear in the Lloydminster data. The 2002 data reveals an annual total precipitation above the average (437.5 mm) for Regina and two time intervals proved to be critical. A successful growing season start can be directly attributed to precipitation in late May, and the potential for cropping success was maintained by periodic precipitation throughout June. The implications of this recharge become very apparent in the following sections pertaining to soil moisture regimes. Also, later in the growing season (August 6-16 and September 6-7), precipitation occurred. Without the June precipitation, and the two late season events, a low annual total and severe drought conditions would have extended southeast to Regina.

Figure 3 presents the daily temperature and total precipitation for the Bratt's Lake Observatory for the year 2002. The cumulative precipitation trends (not shown) are almost identical to Regina (located 25 km to the north of the Observatory). Several aspects in the annual trend are particularly noteworthy. The winter 2002 temperatures are unusual. Three periods (10 days in total) occur between January 1 and April 1 when average daily temperatures were above freezing. This January - April period was also a time of little precipitation (Figure 3). Three precipitation periods throughout the year are of particular significance, and the implications of these will be the subject of more in-depth consideration in subsequent sections. As for Regina, a sole precipitation event in late May (May 26 with 20 mm) permitted the successful germination of the wheat crop and the start of the growing season. Precipitation during June (9 days with totals exceeding 5 mm) ensured adequate water availability for the 2002 crop year. The late season period was characterized by unusual, over-abundant and untimely precipitation. August had 9 days with totals exceeding 5 mm, followed by September with 3 days with totals above 5 mm. These precipitation amounts were received too late to assist the 2002 growing season water requirements. In many respects, as will demonstrated, it can be considered to be detrimental.

3.2 *Growing season soil moisture regimes*

The trend in soil moisture for the 2002 growing season demonstrates the response of the surface to precipitation input. Also, distinct characteristics arise in the regimes that are directly attributable to crop - tillage decision-making.

Figures 4 and 5 present the volumetric soil moisture from mid-April until mid-October for the wheat and summer fallow fields. The former presents soil moisture at 6 intervals to a depth of 0.25 m from the routine daily sampling; the latter presents the 0-0.50 m depth interval from the weekly sampling program. The surface layer data (0-0.01 and 0-0.05 m depths) shows variation in the seasonal trend that is characteristic of strong surface drying in the near surface layer in response to precipitation input. At intervals of increasing depth (Figure 5), fluctuations in the trend are significantly dampened. The sub-trends in the soil moisture data during the 2002 growing season permit the identification of five distinct periods.

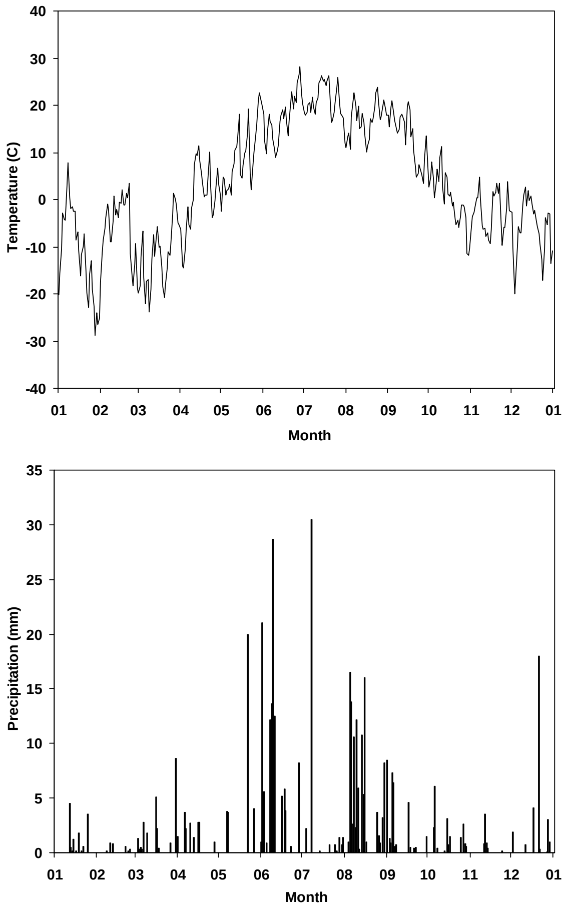

Figure 3. Daily average temperature and precipitation for the Bratt's Lake Observatory for 2002. Data from the Meteorological Services of Canada archives.

a. At the start of the measurement period, in mid-April, both fields were in wheat stubble from the 2001 crop year, and there was abundant crop residue on the soil surface. Deep soil cracks, that usually only arise from very dry soil conditions during late summer, were commonplace in both fields. An arid 2001 growing season, minimal snow accumulation during the 2001-2002 winter period and minimal early spring precipitation in 2002 resulted in dry soil conditions for both fields in the mid-April to the mid-May period. During this period, the soil water potentials in the seeding zone were approaching the permanent wilting point and the available water was in decline (refer to subsequent section). Concerns about wide-spread drought on the Canadian Prairies were receiving extensive coverage in the Canada's national media at this time and the concerns are well captured by the soil moisture data during the early growing season.

b. After the seeding of wheat on May 18, a single precipitation event on May 26 (20 mm) permitted the successful germination and early development of the

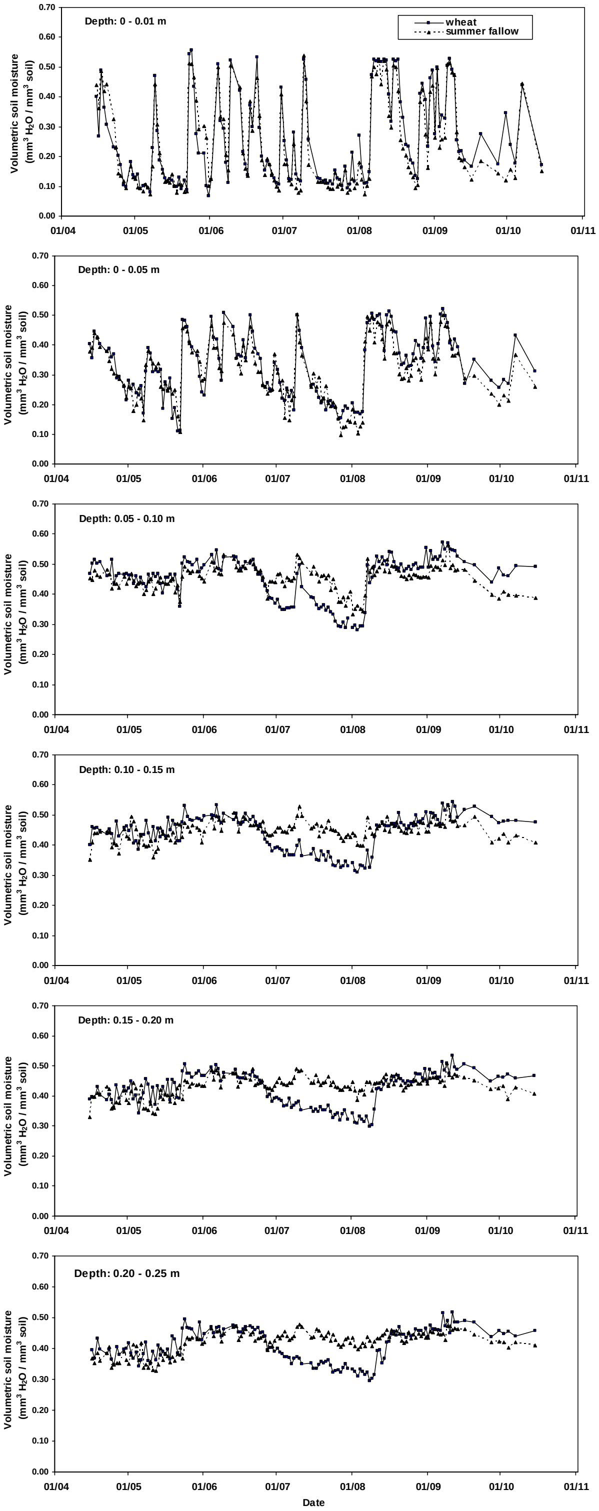

Figure 4. Time series of volumetric soil moisture for the wheat and summer fallow fields for 0-0.01, 0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20 and 0.20-0.25 m depth intervals.

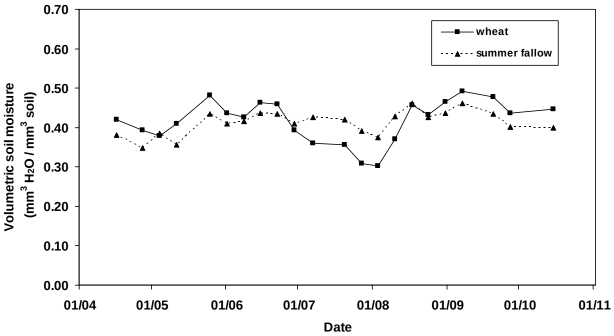

Figure 5. Time series of volumetric soil moisture for the wheat and summer fallow fields for the 0-0.50 m depth interval.

wheat crop. Precipitation that followed in June (9 days with daily totals exceeding 5 mm) ensured adequate moisture for continued crop growth and development. The impacts and significance of the May rainfall and subsequent June recharge is clearly documented in the soil moisture data for all depths. Without this timely yet modest precipitation input, crop success would have been unlikely. To the north, in central Alberta and central Saskatchewan, there were regions that did not receive the late May precipitation (Figure 2), and the 2002 crop successes were very limited at best and, in many cases, non-existent. Throughout this period, both the wheat and summer fallow fields were quite similar in terms of soil moisture amounts and trends.

c. In late June, differences between the soil moisture regimes are evident between the wheat and summer fallow fields. Moisture loss is greater for the wheat field, and some relative moisture conservation is evident in the summer fallow field. This difference would be expected given the summer fallow management employed. Distinctness in the regimes between the two fields continues until early to mid-August.

d. A sequence of rainy days occurred in mid- to late August (9 days with daily totals exceeding 5 mm). This resulted in substantive moisture recharge for both fields. In fact, for a period of approximately one month, there are no discernable differences between the two fields. Any soil moisture conservation, achieved using summer fallowing, completely vanished in response to the late growing season precipitation.

e. In early to mid-September, a reversal in the soil moisture regimes between the wheat and summer fallow fields becomes apparent. Soil moisture in the wheat field exceeds that of the summer fallow field. This situation, the fallow field having less moisture than the cropped and harvested field, continues through until the annual soil freeze-up (in mid- to late October).

The spring soil moisture regime demonstrates the critical role of timely precipitation input and the impacts on soil and crop management schemes. Without the precipitation that occurred in late May throughout southern Saskatchewan, the drought that encompassed central Alberta and central Saskatchewan would have extended geographically much further south. With such an occurrence, any potential success for agricultural producers in southern Saskatchewan would have been severely limited.

The mid-summer and autumn soil moisture regimes are noteworthy and clearly link the vagaries of precipitation input with crop - tillage decision-making and management (summer fallow). Summer fallow is practiced throughout the world in farming regions that are characterized by arid and semi-arid climate zones. Summer fallow has been a traditional tillage and agronomic practice on parts of the Canadian Prairies for many years. Its most important function is the storage of moisture, in the belief that during the year following summer fallow, higher crop yields will result from the accumulated soil moisture availability. Traditionally, it has been thought that summer fallow promotes nitrification, increases available soil nutrients, and permits the control of volunteer plants and noxious weeds by mechanical or other means. For the producer, it is implicit that any summer fallow operations must be accomplished at minimal cost.

In mid-summer, the soil moisture in the wheat field is lower than the summer fallow field. Several interrelated processes readily explain this. The field with the wheat crop loses water from the surface soil zone through three processes: soil evaporation, crop transpiration and infiltration to depth. For this soil, the latter is relatively small given the high clay content present, and is only significant immediately following heavy rainfall events. The recharge of deeper soil layers throughout the growing season, as illustrated by Figure 5, is subtle. For a cropped surface, evaporative losses from the soil surface will usually be minimal (Figure 4) given the low net irradiance levels at the soil surface and the minimal surface soil moisture availability. The exception would be immediately after precipitation events. Wheat transpiration is controlled by a complex interplay between radiant energy inputs and the water availability to the crop. For a developing crop with its expanding leaf area, large bulk stomatal conductances and adequate soil moisture availability (refer to the following section), transpiration losses can be significant when compared to a fallow field. Further, during the summer, the fallow field had weeds present, although the leaf area index was substantially less than for the wheat crop. In addition, the fallow field was subjected to mechanical tillage several times for weed control. This minimized the foliage area for transpiration and also resulted in the creation of a soil mulch. The mechanical stirring of the soil surface can assist in the modest conservation of subsurface soil water. Loose, dry and open soil surfaces provide an effective cap to the soil column and will reduce soil surface evaporation. Upward movement of water by capillarity to appreciable heights becomes minimal, and this upward movement decreases as the soil moisture decreases. Research on the northern Canadian Prairies (Darwent and Bailey, 1981) has documented the role of surface tillage, and the additional and modest conservation of soil moisture that results.

For the 2002 growing season, the producer sought soil moisture conservation through the use of summer fallowing. For periods of time during the 2002 growing season, this objective was fully realized. However, the rainfall during August eliminated any soil moisture difference between the two fields. Also, additional concerns about summer fallow practices remain and merit statement: carbon inputs into the soil during the year when there is no crop are reduced; frequent tillage during summer fallowing increases the rate of decomposition of available organic matter; soil aggregation can be disrupted and the susceptibility to erosion can be increased; and available nitrogen may be more readily lost from the soil.

Another important feature in the 2002 soil moisture regime became evident in the late season (early to mid-September). For all depth intervals, the wheat field had higher soil moisture than the summer fallow field. The combination of the wheat stubble and the organic residue on the soil surface resulted in the relative conservation of soil moisture. During the periods of crop maturation, senescence and subsequent harvesting, crop transpiration was essentially eliminated from the field's water balance regime. The crop residue from the wheat harvest, in addition, formed a physical barrier that served to effectively decouple the soil from the atmosphere in terms of water efflux. Additionally, the wheat stubble and crop residue increased the surface zero plane displacement. Hence, wind velocity and turbulent mixing at the soil surface were reduced when compared with the summer fallow field. The result was minimal water efflux from the soil surface of the former wheat field. Evaporative losses from the summer fallow field continued into the autumn season, albeit at subdued rates. As a result, soil moisture values for the previously cropped field were found to be higher than those in summer fallow tillage management.

In summary, any moisture conservation advantage from summer fallowing vanished when rainfall occurred during the August - October period. This situation was further exacerbated by the late season conservation of soil moisture for the wheat field after harvesting took place. Additionally, the wheat field yielded a harvestable crop; the fallow field did not yield any agricultural production for the 2002 crop year. At the time of freeze-up, the soil moisture reserves in the summer fallow field were less than those for the field that was cropped.

3.3 *Soil moisture transects*

Figures 6 and 7 present a time series summary of soil moisture transect data for the wheat and summer fallow fields. Of the 11 sample dates, six are presented for illustrative purposes. These dates were selected to provide approximate monthly intervals throughout the growing season. The changes in the west-to-east transects with date are in agreement with the previously identified temporal sequences in daily soil moisture (Figures 4 and 5). The soil moisture losses in the wheat field in July are particularly evident. Although there is variation across each west-to-east transect, very few abrupt or repetitive changes in soil moisture with position are discerned. For some sample locations, a subtle relationship to the general topography of the fields is perhaps suggested. Slightly higher values may be associated with very shallow depressions, and lower values are found for gentle undulations in elevation;

however, this is not always the case. To further explore this issue, a much more refined and extensive spatial sampling scheme would be required (Western et al., 1998; Western and Bloschl, 1999). Sampling methodology, measurement quality, differences in soil surface hydraulic properties for all individual sample sites, etc. would require much further attention. In particular, any additional activity would require considerably more spatial samples. Experience from soil moisture spatial sampling programs elsewhere (Western et al., 1998; Western and Bloschl, 1999) and in other environments (Bowers, personal communication) suggest that more complex spatial patterns may potentially exist, but that the ability to identify and attribute an explanation to the variability would remain quite challenging.

The soil moisture data from transects also provide a means for examining the routine daily sampling of soil moisture for quality and particularly any systematic bias. Figure 8 presents a comparison of soil moisture derived from the west-to-east transects (average values; for both the wheat and summer fallow fields) and the soil moisture from the routine daily sampling. The intercomparison illustrates that all data points are clustered along the 1:1 line, and the best fit line (not shown in the figure) has an intercept approaching zero and a slope approaching unity. Intercomparison of the coefficients of variation (also not shown) also yields a cluster of data points about a 1:1 line. For the daily soil moisture data, the mean and range of the coefficients of variation are 4.97% and 6.45%. For the soil transect data, the values are 6.00% and 7.15%. This suggests that the routine daily sampling employed for volumetric soil moisture can be utilized with a sense of confidence. Further, that the daily data can be also be considered to represent of the behaviour of the larger field environments. Three primary reasons for this can be suggested: the landscape at the Bratt's Lake Observatory is topographically very level and all surface undulations are minimal; the soil being studied (Regina clay) is quite uniform and has generally homogeneous characteristics; and, although there was variability within each of the two fields in terms of surface cover (wheat and summer fallow) during the 2002 growing season, within each field, the surfaces demonstrate a generalized uniformity.

3.4 *Soil water relations and available water*

The seasonal trend in available soil water is presented in Figure 9, where the available water is presented as a percentage of the maximum available water storage capacity. The seasonal trends displayed in the data complement the previously presented soil moisture regimes. For both fields, the arid spring period is evident. The impact of the late May precipitation recharge is strikingly apparent. During both of these periods, the two fields behave quite similarly. Commencing in late June and continuing through until early August, there are greater moisture losses from the cropped field. In fact, in late July, the available water falls below 20%, denoting significant moisture limitations. The August precipitation events recharge the soil moisture for both fields. Thereafter as previously noted, the cropped field at the termination of the growing season has considerably more

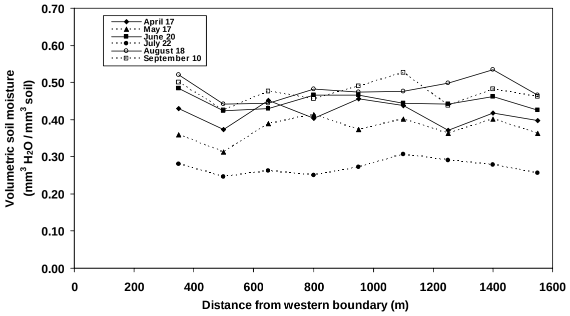

Figure 6. West-to-east transects of volumetric soil moisture for six dates during 2002 for the wheat field. The transect location is 50 m north of the field boundary, and the depth of sampling is 0-0.25 m.

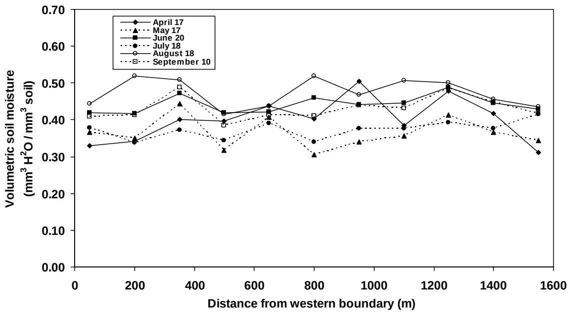

Figure 7. West-to-east transects of volumetric soil moisture for six dates during 2002 for the summer fallow field. The transect location is 100 m south of the field boundary, and the depth of sampling is 0-0.25 m.

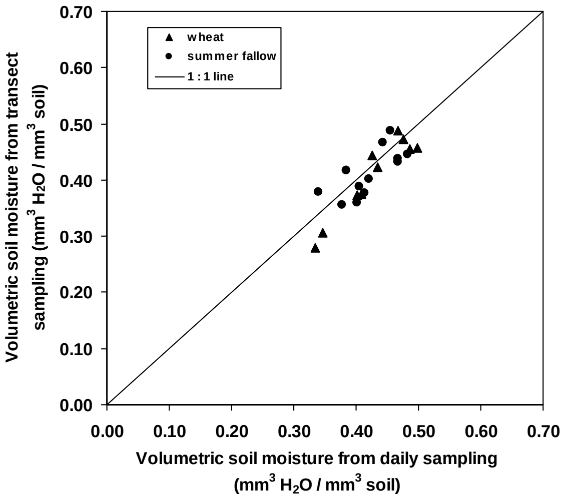

Figure 8. Comparison of the volumetric soil moisture for the wheat and summer fallow fields from routine daily and the spatial transect sampling. The depth of sampling is 0-0.25 m. The linear equation through the data points (not shown) is y = 0.9946 x - 0.0123, with r = 0.8559 and n = 22.

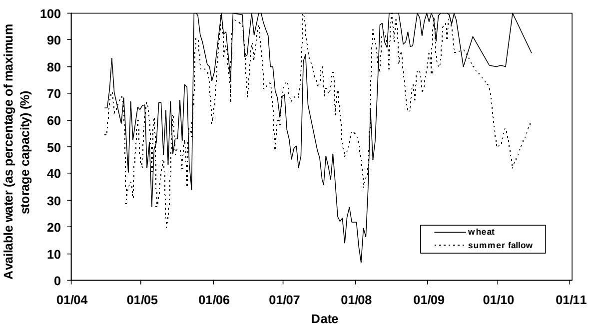

Figure 9. The 2002 seasonal trend in available water (as a percentage of maximum available water storage capacity) for 0-0.25 m depth for the wheat and summer fallow fields.

available water than was realized through summer fallowing.

This reinforces the observation that summer fallowing in 2002 did not achieve additional soil moisture storage. Rather, the late season data demonstrate that the summer fallow field lags behind the cropped field in terms of moisture storage going into the 2002-2003 winter season.

4. CONCLUSIONS

A number of interrelated aspects that lie beneath the overarching specter of drought on the Canadian Prairies have been examined. Data show that growing season and annual precipitation in central Alberta and Saskatchewan was less than average in 2001 and 2002. Timely precipitation that was required for the commencement of the 2002 spring planting season and crop germination period was minimal or unavailable. To the south, modest yet timely precipitation allowed the cropping season to commence. A single precipitation event in late May proved to be absolutely critical. Further precipitation in June ensured sufficient moisture resources through the mid-summer drought period. Late season rain commenced in early to mid-August and continued into September. Although these rains helped recharge soil moisture, they had very little positive impact on 2002 production. Crops were already at maturity, the completion of harvesting was delayed, available human and machinery resources were unused due to delays and then later over-taxed as the autumn harvest window closed, and poor harvest weather reduced crop quality. The latter is a particular concern given difficult international markets.

The soil moisture and available water data both communicate a unified story for the wheat crop. Soil moisture reserves were low at the start of the 2002 growing season. Soil moisture response from a single precipitation event in late May was critical for the seeding depth zone (refer to Figure 4, top 0.10 m of the soil). June precipitation helped ensure sufficient moisture for the growing season, and substantive drying in June and July was evident. Late season precipitation recharged soil moisture. However, detrimental aspects also arose as noted above.

The summer fallow soil moisture regime during 2002 is unique. Soil moisture regimes were similar to the wheat crop from the commencement of the spring season until late June / early July. With transpiration losses at a minimum, the summer fallow field demonstrated a conservation of soil moisture reserves throughout July and early August. This advantage abruptly vanished in late August during a series of rainy days. Further, after wheat crop harvesting, the combined impacts of stubble and a crop residue on the soil surface allowed the moisture in the wheat field to exceed that of the summer fallow regime. At season end (freeze-up in mid-October), soil moisture was less in the summer fallow field, and the primary goal of water conservation was not achieved. When coupled with other concerns about summer fallow (carbon inputs into the soil during the year when there is no crop are reduced, frequent tillage during summer fallowing increases the rate of decomposition of available organic matter, soil aggregation can be disrupted and the susceptibility to erosion can be increased, and available nitrogen may be more readily lost from the soil), more study is merited into the appropriate utility of this tillage approach.

Many studies of soil moisture also acknowledge both explicit and implicit concerns about the quality of the data in representing subsurface environments, and particularly spatial representativeness. When compared with spatial transect data, the daily sampling herein can be employed with confidence. Increasing the quality of the spatial regime for more in-depth insight would require considerably more observations and significantly impact the required measurement resources.

In Robert Bone’s (2000) textbook "The Regional Geography of Canada", he speaks with insight about farming in the dry continental climate of western Canada. He points to it being a risky undertaking for producers. Prairie farmers often describe grain farming as ‘Next Year Country’ - crops may do poorly this year, but the hope is for better next year. A sequence of dry years, potential climate change and sustained warming without increases in precipitation and a geographical expansion of the dryland belt northwards are all serious threats to current western Canadian agricultural infrastructure. The crop - tillage, precipitation and soil moisture research results herein document some of the underpinnings of ‘Next Year Country’. On a particularly cautionary note, such adages may well be overly optimistic in the years ahead. Faced with demanding environment challenges, Prairie agricultural producers have increasingly serious and somber decisions in land management and crop choices. Agribusiness success, and perhaps survival itself, dictate the optimum utilization of increasingly variable and scarce resources.

5. ACKNOWLEDGEMENTS

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