WATER CONSERVATION FOR WHEAT PRODUCTION IN THE
BROWN AND DARK BROWN SOIL ZONES

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That the growth of wheat in the Brown and Dark-brown Soil Zones of the Prairies depends significantly on the occurrence and favourable distribution of limited precipitation, is generally accepted (Gray, J., 1967). Examination of the practices and techniques which offer maximum potential in water conservation and wise use by Prairie wheat crops, involves a cursory review of the pertinent hydrological processes and systems.

The same sun, which grows the wheat, provides the energy sustaining the frequently-cited Hydrological Cycle. Conventionally, water molecules evaporate under solar influence (mostly from oceans), enter the global circulation of the atmosphere, and enjoy a world-wide tour, falling to the earth as precipitation and eventually returning to the sea. Within this grand cycle, exist many less dramatic but important water transfer and circulation systems, such as occur into and from the atmosphere, the surface water, the ground water, and the soil water.

Atmospheric Water

The global atmospheric circulation brings water in solid, liquid and vapour forms hundreds of kilometers inland to the Prairies. Some water originates locally, evaporating from lakes, snow, soil, and vegetation. Adiabatic processes cause release of water from atmospheric storage usually falling as rain or snow (Figure 1).

During the years 1968-1975, the Bad Lake Climatological Station, located between Rosetown and Eston, Saskatchewan (near
Figure 1. ATMOSPHERIC WATER-CYCLE LOCUS

Figure 2. ANNUAL LIQUID WATER CYCLE
the centre of the Brown and Dark-brown Soil Zones), received an annual average precipitation of 318 mm. However, as indicated in Table 1, precipitation not only varied from year to year, but the quantity which fell while the crop grew (15 May - 15 August) averaged only 142.5 mm or 44.8% of the total. Snowfall averaged 32.8% and the remaining rainfall 22.4%. From these data, one may conclude in general that to grow a wheat crop at Bad Lake annually, demanding, say, 250 mm of water, the soil must contain an average pre-seeding water charge of at least 100 mm from snowmelt and previous rainfall.

Figure 2 exhibits the monthly liquid water from rainfall and snowmelt at the Bad Lake Station over the years 1973-75. Snowmelt "spikes" are obvious and form part of the typical annual cycle. Individual storm cycles, although not perceptible in Figure 2, probably do not consistently follow the 100-hour (4.2 day) periodicity of spectral peaks for wind observed over much of North America (Lumley and Panofsky, 1964). Indeed, the time between significant precipitation often extends into weeks, which reflects the regions semi-arid climate.

**Surface Water**

Waters stored in surface loci include those which move very slowly, such as in sloughs, dugouts, reservoirs, etc., and rapidly-travelling waters, as in runoff and streamflow (Figure 3).

The uneven areal distribution of waters over soil surfaces and consequent variance in infiltration significantly limit wheat production. Such lack of uniformity stems from (1) natural topographic relief which causes water to drain toward lowlands
TABLE 1. BAD LAKE PRECIPITATION 1968-75

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall 15 May-15 August</td>
<td>72</td>
<td>142.5</td>
<td>261</td>
</tr>
<tr>
<td>Other Rainfall</td>
<td>44</td>
<td>71.4</td>
<td>154</td>
</tr>
<tr>
<td>Snowfall</td>
<td>51</td>
<td>104.1</td>
<td>176</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>233</strong></td>
<td><strong>318.0</strong></td>
<td><strong>422</strong></td>
</tr>
</tbody>
</table>

Figure 3. SURFACE WATER-CYCLE LOCUS
and (2) an undulating micro-relief resulting from tillage. Both create areal mosaics with soil profiles alternatingly too wet and too dry. Where excessive, soil waters drain downward out of root zones carrying valuable nutrients in solution. Consequently, research into practices which distribute water supplies uniformly over land surfaces appears worthwhile.

Ground Water

Those ground waters most directly affecting the growth of wheat commonly occur in a near-surface location situated immediately over localized impervious material. Transfers into such perched-water zones result from infiltration excesses, while fluxes away from these zones relate to gravity drainage and soil water tensions. If the water status in perched zones remains saturated for extended periods, wheat production suffers, because the optimum moisture-air balance is upset.

As a solvent, water also provides a vehicle for movement of various salts and nutrients. Consequently, ground waters are often rich in soil-leeched solutes, which may aggravate salinity problems especially where these waters migrate near the soil surface.

Soil Water

Although mass water fluxes associated with a volume of root-zone soil are complex, major transfers are often outlined as in Figure 4. Water from rain, snowmelt or surface sources enters a soil system becoming part of the vapour or liquid solution in immediate contact with the mineral and humic aggregates.

The water fraction is held under a range of storage forces which determine resident times and rate of transfer from the
Figure 4. SOIL WATER-CYCLE LOCUS

Figure 5. SOIL MOISTURE-TENSION RELATIONSHIP
system by plant root uptake, surface evaporation, or multi-
directional drainage. Besides gravity, the major forces (ten-
sions) which act on soil waters depend on differential gradients
in salt concentration, capillary pressure, and temperature.
Figure 5 exemplifies the typical inverse shape of the relation-
ship between soil tension and water content. As the soil becomes
dryer, water-forcing tensions increase. However, in opposition
to these forces, under similar conditions, the resistance to
liquid flux also increases with dryness (Figure 6) because, among
other factors, the path of flow increases in length and tor-
tuosity. The efficiency of soil mulches depends on this resis-
tance.

A wheat plant requires water for transpiration and assimila-
tion. Evidence indicates that, during the periods of great
transpiration demand, plants are also capable of sustaining an
advanced rate of assimilation, ie, growth activity. Under this
wisdom, current hypotheses contend that the rapid growth of roots
continualy extends the influence of the plant into a richer soil
water environment. In effect, during rapid transpiration, the
plant "moves" to the water over distances measured in centi-
meters, while soil forces move water to the plant over lengths
scaled in millimeters.

The major factors which limit the quantity of soil water
available to the wheat plant are supply, infiltration, storage,
and evaporation. Water supplies originate from (1) the amount and
character of the rainfall and snowmelt received, and (2) surface
runoff obtained from other areas. To optimize water supplies is
certainly one avenue for research applied to wheat production
systems.
Figure 6. **SOIL MOISTURE-CONDUCTIVITY RELATIONSHIP**

Figure 7. **SOIL WATER STORAGE-TEXTURE RELATIONSHIP**
Another research direction involves increasing the rate and quantity of water which infiltrates into the soil. In general, infiltration quantities in the Brown and Dark-brown Soil Zones follows an inverse function of soil water content. The dryer the soil, the greater the opportunity and volume of infiltration. Infiltration at temperatures which freeze the soil solution follows the same trend, but may be further reduced by possible development of a localized, impervious ice layer at a saturated freezing front. Other conditions which affect infiltration include soil texture, duration and intensity of precipitation, humus content, vegetative cover, and soil tilth.

The amount of water that can be stored in a volume of soil is primarily a function of soil depth, humus, and texture. As observed in Figure 7, the "heavier" textured soils tend to possess greater storage capacities. Given such insight, one might conclude that research in soil water management would prove most beneficial when oriented towards soils rich in silt and clay. Organic matter also increases soil water storage. For example, a Black silty clay loam with 37% clay and 11.7% organic matter has a maximum available water storage fraction of about 20%, which equals that of a Dark-brown heavy clay with 67% clay and 3.6% organic matter (Hutcheon, 1942).

The volume of soil contributing water to a wheat plant naturally increases with root system development. Placed in the upper soil layers, the seed requires little more than immediate contact with a moist medium. Germination uses only a very small volume of the soil solution surrounding the seed. As roots develop, however, the volume of soil from which the water solution
flows to the plant enlarges. With growth, the plant becomes increasingly dependent on the water stored prior to seeding. Unfortunately, as the upper soil layers dry, rain waters from brief showers evaporate from the soil surface contributing little to the water economy of the system.

Often the contributive value of short convective-type rainfall has been overestimated. For example, consider a Dark-brown heavy clay which is capable of holding a maximum of about 20% of its volume as available water (Hutcheon, 1942). If the soil has selectively dried so that the available water storage is 15% in the top 5 cm, 10% between 5-25 cm depth, and 0% below 25 cm, water from a 6.2 mm rain will penetrate less than 5 cm, and a 12.5 mm rain 10 cm deep, while a 25 mm soaking may reach the 22-cm depth. An eight-year rainfall study over the Bad Lake district in Saskatchewan resulted in an average of only 8 storms per year producing greater than 12.5 mm precipitation and only 3 storms in excess of 25 mm. These data included storms occurring prior to seeding. In one of the years, precipitation from only one storm exceeded 25 mm.

Optimization of Soil Water

Generally, within the Brown and Dark-brown Soil Zones there are many possibilities for optimizing soil water quantities to increase wheat production. There are two main routes that may be taken in this direction. One is to employ conservation measures which will make the best use of water which becomes available at the soil surface. The other is to increase the quantity of water available.
1) Conservation

The most evident soil water conservation practice in Southwestern Saskatchewan is summerfallowing. Its function is to store the precipitation which occurs over a two year period in order to produce one crop. While this practice generally insures a greater supply of initial soil moisture than when cropping annually, its major shortfall, in terms of water conservation, is that some 60% of the precipitation is not used by the crop. It is removed instead by wind, runoff, evaporation and drainage.

Weed control is another means of conserving soil water. Keeping weed growth to a minimum by cultivation and chemicals, whether the soil is fallowed or cropped provides an important reduction in loss of water from soil storage.

A third conservation method is fertilization. It is generally accepted that more water is required to produce more wheat. However, a well fertilized crop will produce more wheat per unit of water used than one which is poorly fertilized. The use of drought resistant wheat varieties operates to a similar advantage.

A less commonly recognized water conservation method is extended rotations or stubble cropping. This practice utilizes a significantly higher percentage of total annual precipitation than does a two year, crop-fallow system. Soils under crop conditions tend to remain dryer than when under fallow conditions, thus increasing their capacity to absorb and retain water. This increased capacity reduces runoff, deep drainage and evaporation of water from rainfall and perhaps even more significantly from snowmelt, when the moist frozen conditions common to fallow may effectively block infiltration into deeper, dryer layers. In
addition, stubble fields exhibit a higher snow retention capacity than fallow fields.

The effect of various tillage methods on soil moisture conservation is not well understood. In terms of water conservation, tillage operations should leave the soil free of weeds, but with a mulch of loose, dry soil covered by organic residue or "trash". The objective is to reduce erosion while decreasing surface evaporation and possibly increasing infiltration by impeding runoff.

2) Soil Water Augmentation

The other route which may be taken to improve soil water quantities is to increase them. There are two possibilities in this direction. One is cloud seeding, the discussion of which is beyond the scope of this report. The other is snow management.

As previously indicated in Figure 2, the relatively large quantity of snow water available for soil recharge leads to questions concerning the usual fate of melted snow. The snow covering a 10.5 km² watershed near the Bad Lake Climatological Station was measured comprehensively at peak accommodation in 1974. Although variably distributed, the mean snow water mass equalled 134 mm. Of this quantity, 32% was measured as runoff either leaving the watershed or forming sloughs within it. If 18% evaporated from water and soil surfaces and 3% percolated below the root zone, slightly less than half became part of the soil solution available for crop growth. The possibility of increasing this available fraction requires consideration.

The snow survey taken prior to the melt period indicated extreme variability of snowcover accumulations in relation to
land use and topography. In essence, at snowmelt time a large portion of the snow water was not in a location where it could infiltrate and become available to a crop. Much of it had accumulated in ditches, farmyards, sloughs and rough uncultivated areas. Also, some of it was situated on fallow fields where the rather wet, impervious and frozen soils prevented much of it from infiltrating, and instead forced it to run off. Where infiltration did occur on the fallow areas there is the probability that it displaced some of the existing soil water and its dissolved nutrients, forcing it below the root zone. Percolated water is not only lost in terms of crop use, but it may also contribute to salinity problems.

In addition to this large loss of potential soil water during the snowmelt period, significant quantities of snow may have been lost by sublimation during redistribution by the wind. In the same winter (1973-74) nipher-shielded precipitation gauges indicated that about 162 mm of water fell over the watershed as snow. Compared to the mean snowcover measurement of 134 mm, indications are that as much as 28 mm of water may have sublimated.

An obvious solution involves the alteration of snowcover distributions such that more accumulates on areas where it has the greatest opportunity for infiltration and storage in the root zone. Generally, these areas would be stubble fields scheduled to be seeded the following spring. Snow management has the potential to produce this redistribution. This potential for effecting control over the areal location of accumulated snow depends on the occurrence of sufficient winds for horizontal transport of
snow. Where winds are adequate, obstructions may be judiciously located to interfere with the wind stream causing a local disruption of snow transport capacity and consequent deposition. There is a number of possibilities for the creation of these obstructions or barriers. Each has relative advantages and disadvantages.

The use of conventional man-made snow fences can, at least presently, be eliminated, in terms of wheat production, for economic reasons. These economic limitations dictate use of naturally available materials for the snow barriers.

One type of barrier consists of permanent trees, shrubs or tall grass. Shelterbelting is a relatively old and well known practice. While it tends to effectively redistribute snow, it has one major disadvantage. The large size of the barriers necessitates rather wide spacings, to avoid excessive allocation of land for the barriers themselves. Their large size tends to accumulate excessive snow just leeward of the barrier. The result is very uneven snow distribution, too much near the barriers and too little in the large spaces between them. Tall grass barriers minimize the size problem and have proven quite successful in Montana where they have been adopted by farmers to some degree. However, both of these permanent barrier type methods present the problem of interference with machinery operation especially in view of the trend towards larger field equipment.

A related method but one which is employed on an annual basis is the seeding of a tall species of plant (such as sunflowers) in narrow, widely spaced rows, either with a seeded crop
or on a fallow field. As with permanent barriers the problem of machinery interference exists.

Snow ridging is another snow collecting endeavour which has been tried from time to time. It has probably been used more as a means of preventing snow clogged farm yards and roadways and for increasing water yield for ponds and dugouts, than it has for soil moisture improvement. While field trials by members of the Division of Hydrology have indicated increases of up to 70% in soil moisture above that of unridged fields, 3 out of 5 trial years produced no significant difference. In addition to the extra costs involved ridging presents a number of other problems. Firstly, an appreciable amount of snow must be present before a ridging operation is possible. Therefore, the opportunity to advantageously manipulate the first few blowing snow events must be foregone. Secondly, snow ridges do not make very effective snowfences. Being non-porous they do not produce the most efficient type of turbulence for snow collection. A third problem common to the southern parts of the Prairies, involves the mid-winter melting of the ridges which may necessitate two or more field operations.

The most promising of barrier types utilizes part of the previously grown crop itself to create the barriers. A fairly widespread practice in this regard is alternate height double swathing in situations where applicable. Another is straight combining, which usually permits leaving taller stubble than normal swathing. Both of these methods will increase snow accumulation potential. However, the increase is limited by the stubble height which can be obtained. One of the major advantages
of this type of barrier is that there is no cost involved. The barriers are created as part of normal harvesting operations.

Still another system which utilizes the existing crop is leave-stripping during harvest. A leave strip is simply a narrow width (20-40 cm wide) of grain which is left unharvested at spacings of one, two or three header widths. Advantages of leave-stripping include; 1) ease of establishment, 2) a taller barrier, 3) flexibility in choice of spacings and strip width for optimization under various conditions, 4) permanency throughout the winter (as compared to ridging), 5) no interference with machinery operation since the strips are not maintained after snowmelt, and 6) low cost (less than 5% of the crop). Two possible disadvantages are 1) the extra seed source provided by the strips resulting in unwanted plants in the next crop and 2) lodging of the plants left in the strips, reducing the snow trapping efficiency per unit of investment.

During the 1975-76 winter we compared snow accumulation in plots of durum wheat harvested conventionally and with leave strips. One foot strips spaced 18, 36 and 54 feet apart accumulated snow water quantities which averaged about 80% (5 cm of water) greater than that in conventional stubble. Further experimentation with leave-stripping is currently underway by the Division of Hydrology in cooperation with the Crop Science Department, University of Saskatchewan, the Agriculture Canada Research Station at Swift Current and a number of Saskatchewan farmers. Leave strips are being evaluated for the 1977-78 winter in 5 field sites and 3 plot sites in various locations within the province.
Recommendations For Future Research

In view of the items which have been considered in this review, several areas of applied research appear worthy to fill some major water-related gaps in wheat production technology. One of these is field measurements of soil moisture. Current limitations relate to 1) the large number of observations required to make accurate areal estimates of soil moisture quantities and 2) the availability of suitable portable field instruments. A strong need exists for an inexpensive, easily operable measuring device that is simple and reliable enough to be used by either scientist or farmer. The value of such an instrument will manifest itself in better research and better moisture-related management decisions by farmers.

Another area of useful research relates to the actual quantities and rates of water use by wheat plants during growth, coupled to definitions of pertinent water sources and fluxes. Knowledge of these items would give insight into those aspects of wheat production hydrology offering the greatest potential return for research investment.

Thirdly, the Prairie snow resource offers considerable opportunity for farmer management to optimize soil water sources. Therefore, snow management research should logically be continued.
Literature Cited


Literature Cited


