Effects of fall subsoiling and snow management on water conservation and continuous spring wheat yields in southwestern Saskatchewan

B.G. McConkey¹, H. Steppuhn¹ and W. Nicholaichuk²

¹Research Station, Research Branch, Agriculture Canada, P.O. Box 1030, Swift Current, Saskatchewan, Canada S9H 3X2; and ²National Hydrology Research Institute, Saskatoon, Saskatchewan, Canada S7N 3H5. Received 27 December 1989; accepted 15 May 1990.

McConkey, B.G., Steppuhn, H. and Nicholaichuk, W. 1990. Effects of fall subsoiling and snow management on water conservation and continuous spring wheat yields in southwestern Saskatchewan. Can. Agric. Engr. 32:225-234. The effects of snow management and one-time fall subsoiling on grain yields and water conservation for continuous zero-till spring wheat (Triticum aestivum L.) were assessed over a four year period in two separate experiments at Swift Current, Saskatchewan. Although snow management practices resulted in a winter snowpack averaging twice that obtained with conventional height stubble, restricted infiltration prevented this water from affecting water conservation or wheat yields. Subsoiling in the fall to a 35 cm depth substantially increased snowmelt infiltration for the first crop year after fall subsoiling. In subsequent years, fall subsoiling did not significantly increase the amount of snowmelt infiltration although it did increase the depth to which snowmelt had penetrated. Water extraction from the root zone was greater between seeding and harvest under subsoiling. For the four crop years following subsoiling, subsoiling increased grain yields over the control treatment by an average of 1% when snow management was practiced. The yield benefit from subsoiling persisted for three years when snow management by tall wheat stubble trap strips retained a snowpack water equivalent of at least 4.9 cm.

Key words: subsoiling, water conservation, spring wheat, Triticum aestivum, snow, Paraplow

INTRODUCTION

Low amounts and variable distribution of precipitation represent the greatest limitation to crop production in the semiarid portion of the Canadian Prairies. Most producers in this region summerfallow the land every second year partly to conserve soil water to increase the probability of having a satisfactory crop the next year. The prevalent wheat-fallow rotation has been linked to soil degradation through erosion from wind and water, soil salinization and decreased soil organic matter (Dumanski et al. 1986). Consequently, reducing the amount of fallow by adopting annual cropping rotations is desired to minimize soil degradation. Unfortunately, the profitability of annual wheat rotations in southwestern Saskatchewan has been lower and more risky than that of a wheat-fallow rotation (Zentner et al. 1984).

De Jong and Steppuhn (1983) suggested that retaining snow on the field offers the greatest potential for increasing the amount of water available for crops on the semiarid Prairies. Snow management, by leaving tall wheat stubble strips, has typically increased soil water conservation over the winter by 1 to 2 cm (Nicholaichuk et al. 1986) and increased the yields and profitability of continuous spring wheat in southwestern Saskatchewan (Steppuhn et al. 1986; Zentner et al. 1988). The two major limitations of snow management have been the frequent occurrence of years with low snowfall and/or poor infiltration of the snowmelt (de Jong et al. 1986; McConkey 1987).

Deep tillage increased conservation of winter precipitation in the northwestern U.S. (Massee and Siddoway 1966; Lindstrom et al. 1974; Pikul et al. 1985; Papendick 1987; Zuzel and Pikul 1987); in the steppes of the U.S.S.R. (Burnatzki and Yarovenko 1961; Larin 1962; Pabat and Gninenko 1987); and in Saskatchewan (Granger and Gray 1986; Patterson et al. 1986; McConkey et al. 1988; Grevers 1988, 1989). However, many early studies showed no water conservation benefit from deep tillage on the Great Plains of the U.S.A. (Duley 1957; Power et al. 1958; Black and Power 1965; Haas et al. 1966) or on the Canadian Prairies (Wenhardt 1950-55; Paterson and Lapp 1964).

The objective of this study was to determine the effects of snow management and subsoiling on water conservation and yields of continuous zero-till spring wheat (Triticum aestivum L.) grown on an Orthic Brown Chernozemic soil in southwestern Saskatchewan over a four year period.

MATERIALS AND METHODS

The research was conducted at the Swift Current Research Station on Swinton loam (Ayres et al. 1985), an Orthic Brown Chernozemic soil (Can. Soil Survey Comm. 1978). These soils have developed from loess veneer overlying loam-textured till. Depth to the B horizon is between 8 and 20 cm (Ayres et al. 1985). The research area has an approximate 1% slope to the south. The soil water content at 4.0 MPa (Table I) was used as an arbitrary lower limit of water availability for calculation of available soil water.

Water conservation and wheat yields for continuous zero-till spring wheat were monitored for four years after subsoiling on two subsoiling experiments: the first experiment subsoiled in October, 1983 and the second experiment subsoiled in October, 1985. Subsoiling was performed on stubble left from...
Table I: Bulk density *, particle sizes **, and water content at 33 kPa+ and 4.0 MPa+ for Swinton loam.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Bulk Density (Mg m⁻³)</th>
<th>Particle Size %</th>
<th>Water Content (% by wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sand</td>
<td>Silt</td>
</tr>
<tr>
<td>0-15</td>
<td>1.24</td>
<td>37.5</td>
<td>42.7</td>
</tr>
<tr>
<td>15-30</td>
<td>1.24</td>
<td>28.8</td>
<td>48.5</td>
</tr>
<tr>
<td>30-45</td>
<td>1.29</td>
<td>32.0</td>
<td>48.7</td>
</tr>
<tr>
<td>45-60</td>
<td>1.42</td>
<td>41.2</td>
<td>37.0</td>
</tr>
<tr>
<td>60-75</td>
<td>1.56</td>
<td>48.2</td>
<td>28.5</td>
</tr>
<tr>
<td>75-90</td>
<td>1.64</td>
<td>46.5</td>
<td>28.2</td>
</tr>
<tr>
<td>90-105</td>
<td>1.64</td>
<td>47.0</td>
<td>28.3</td>
</tr>
<tr>
<td>105-120</td>
<td>1.79</td>
<td>46.0</td>
<td>31.0</td>
</tr>
</tbody>
</table>

* From soil cores.
** By hydrometer method.
+ By pressure plate extraction using disturbed samples.

A hard red spring wheat crop which was grown on fallow. Agronomic management was similar for both experiments. Winter annual weeds were controlled with a late fall or early spring application of 2,4-D. Hard red spring wheat ('Leader') was seeded directly into standing stubble with a prototype offset double disc seed drill (Dyck and Tessier 1986) at a rate of 67 kg ha⁻¹. Fertilizer N was broadcast (as ammonium nitrate) immediately prior to seeding at recommended rates (Sask. Advisory Council 1984-89) based on NO₃-N in the 0-60 cm depth from soil samples taken the previous fall. The average rate of supplemental N was 47 kg ha⁻¹ (range 17-78 kg ha⁻¹). Fertilizer P (as monoammonium phosphate) was applied with the seed at 17 kg ha⁻¹ (as P₂O₅). This rate was generally sufficient to raise soil P₂O₅ to recommended levels (Sask. Advisory Council 1984-89) based on NaHCO₃-extractable P found in the 0-15 cm soil layer in the fall prior to seeding.

Grassy and broadleaf weeds were controlled with a diclofop-methyl/bromoxynil mixture. Occasional spot applications of glyphosate were required prior to seeding to control perennial grasses, principally crested wheatgrass (Agropyron desertorum [Fisch. ex Link] Schult.) and foxtail barley (Hordeum jubatum L.). Seeding and harvest occurred during the first two weeks of May and the last two weeks of August, respectively. Outside of the normal operations of seeding, spraying and harvesting, soil sampling was the only additional traffic. No effort was made to control the pattern of machinery wheel tracks. Precipitation and air temperatures were recorded within 600 m of the experiment sites.

1983 Subsoiling experiment

The six treatments were: control (i.e. no tillage) without snow management (NC), subsoiling with the Paraplow* without snow management (NP), subsoiling with the Du-Al subsoiler without snow management (NR), control with snow management (SC), subsoiling with the Paraplow with snow management (SP), and subsoiling with the Du-Al subsoiler with snow management (SR). At the time of subsoiling, the soil water content of the upper 60 cm of the profile soil was very dry (approximately 11% H₂O by vol.).

The Paraplow has a 2.54 cm wide shank which is slanted 45° laterally 25.5 cm from the points (Fig. 1). The stated purpose of the lateral bend is to increase lifting and fracturing of the soil (Howard Rotovator Co. 1983). A coulter cuts the soil approximately 7.5 cm deep in front of each shank. The points

Fig.1. Paraplow shanks.

* Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product listed by Agriculture Canada.

226 McCONKEY, STEPUHN and NICHOLAIICHUK
The 1985 subsoiling experiment was located immediately
experiment had shown that it left a poor seedbed for zero-till
ments were NC, SC, NP and SP as previously defined. The
split-block model was used
to analyze 1987 results.

Prior to seeding in 1984, the subsoiled plots were firmed in
one operation with spring tooth harrows and spiral coil pack-
ers. The harrow lines did not penetrate the soil more than 1 cm.

One 60 x 120 m field contained all the treatments with snow
management for 1984 and 1985. The plot size was 10 x 120 m
and SC, SP and SR were randomized within two replicates on
the field. In the 1984 crop year (i.e., Sept. 1, 1983 to Aug. 31,
1984), 60 cm wide x 35 cm high strips of tall stubble spaced 6
m apart were left for snow management. The strips were
oriented N-S; perpendicular to the predominantly westerly
winds. The trap strips themselves were not subsoiled. Over the
winter of 1984-85, 60 cm tall snow fences spaced 11 m apart
were used to retain snow on the field instead of stubble strips
as the stubble was inadvertently cut short at harvest. In 1984
and 1985, NC, NP and NR were randomized within two replicas
within another 60 x 120 m field which was adjacent to
the field with snow management for comparison. This field
had 12 to 25 cm tall wheat stubble over the winter. No snow
management was practiced for the 1986 crop year. For the
1987 crop year, each replicate on both fields was randomly
split into snow trapping and no snow trapping, producing a
split-block experiment with four replicates thus improving the
sensitivity for statistical purposes. Snow trapping during the
winter of 1986-87 was accomplished with 90 cm wide by 40
cm tall stubble strips spaced every 6 m.

Soil water content was determined gravimetrically in 15 cm
increments to 1.2 m from 2 to 4 soil cores per plot taken in
October and again in April approximately 3 to 4 weeks after
snow melt. For SC, SP and SR an equal number of cores were
taken on the trap strip and between the strips. Research on
Swinton loam has shown no effect of subsoiling on average
soil bulk density (McConkey et al. 1988), so constant soil bulk
densities (Table I), determined from 5-cm diameter soil cores
in a nearby field, were used to convert gravimetric to volumet-
ic soil moisture content. Grain yields were determined by
threshing 30 x 6 m windrow segments with a full-size com-
bine. Snow depths were measured with a ruler, and snow
densities with a M.S.C. Type 1 snow sampler (Meteorol.
Branch 1964) in the late winter of 1983-84 and 1984-85.

For statistical analysis of 1984, 1985 and 1986, NC, NP and
NR results were analyzed as one randomized block experi-
ment, while SC, SP and SR were analyzed as a separate
randomized block experiment. A split-block model was used to
analyze 1987 results.

1985 Subsoiling experiment

The 1985 subsoiling experiment was located immediately
southwest of the 1983 subsoiling experiment. The four treat-
ments were NC, SC, NP and SP as previously defined. The
Du-Al subsoiler was dropped because the 1983 subsoiling
experiment had shown that it left a poor seedbed for zero-till
seeding. The experimental design was a randomized complete
block with three replicates. Plot size for 1986 was 45 x 60 m.
In the spring of 1987, each plot was split into two 22.5 x 60 m
sub-plots. One sub-plot received shallow (7.5 cm deep) pre-
seeding tillage, and in the other zero-till seeding was
maintained. Only sub-plots which were untilled since the fall
of 1985 are reported in detail in this paper. All measurements
were made in the centre 10 x 10 m area of each plot, the
remainder of the plot serving as a buffer area.

The plots were subsoiled to a depth of 35 cm when the upper
60 cm of soil profile was dry (approximately 15% by vol.).
Over the winter of 1985-86 snow management was accom-
plished with 9 x 15 m rectangular enclosures of 60 cm tall
snow fence. These enclosures were surrounded by 10 to 20 cm
tall soil dikes to impound snowmelt in order to investigate
subsoiling effects on infiltration under conditions of large
potential infiltration. Prior to seeding in 1986, the entire plot
area of NP and SP were leveled and firmed in one operation
with spring tooth harrows and spiral coil packers. Several
passes with the harrows-packers were required to level the
dikes on SC and SP. For the winter 1986-87, the snow fence-
dike method of snow management was replaced with a more
realistic snow trapping system of 40 cm tall stubble strips
spaced every 6 m and oriented N-S. Because of low overall
crop height, for the two subsequent winters (1987-88 and
1988-89), snow management was accomplished with 60 cm
wide x 45 to 60 cm tall trap strips of unharvested wheat spaced
every 6 m. The zone between trap strips and the entire plot area
of NC and NP had 11 to 28 cm tall stubble.

In October 1985 and April 1986, soil bulk densities were
measured to 90 cm (in 2.5 cm increments to 40 cm and 5 cm
increment for 40-90 cm) using the gamma ray transmission
method with two parallel aluminum access tubes spaced 30 cm
apart, straddling a Paraplow furrow for NP and SP. These
access tubes were used also to measure soil water using the
neutron thermalization method. When single access tubes
were reinstalled for the 1987-1989 period, the furrows were
not visible, so the tubes were randomly located which also
served to avoid measuring water content only in the furrow or
between the furrow. The access tubes were placed approximately
midway between the trap strips for SC and SP. Soil
water was measured in 20 cm increments to 1.2 m in late
October, in mid-April, near seeding and at approximately
biweekly intervals thereafter until harvest.

In 1986 and 1987, grain yield was estimated from 3 m long
plant row segments, 6 and 8 per plot, respectively. For 1988
and 1989, grain yields were estimated from 1.37 x 10 m areas
taken with a small plot combine with harvesting done perpen-
dicular to the subsoiling direction and trap strips. Snow depth
and density was determined in January and again in March.

Mean comparisons were made using the Ryan-Einot-Ga-

CANADIAN AGRICULTURAL ENGINEERING
RESULTS AND DISCUSSION

1983 Subsoiling experiment

Other than soil lifting, there was very little disturbance visible at the soil surface from subsoiling with the Paraplow (Fig. 2). The Du-Al subsoiler produced more large clods on the soil surface than the Paraplow, but otherwise the degree of soil disturbance by the two subsoilers was similar.

Where there was no snow management, the subsoiled treatments (NP and NR) had less soil water in the spring of 1984 than NC (Table II). This was attributed to increased evaporation of soil water in the first winter and spring following subsoiling. Patterson et al. (1986) also noted that use of the Paraplow in the fall decreased soil water in the spring compared with untilled soil when there had been very little snow. There was no evidence of soil drying due to subsoiling in 1984 when snow trapping was practiced nor in subsequent years even without snow trapping. In 1984 and 1985, the field with snow trapping had more soil water than the field with conventional height stubble. In 1984, SP and SR had more than 4 cm additional soil water to 1.2 m in the spring than SC which suggested subsoiling increased infiltration of snowmelt for the first year after subsoiling.

Both 1984 and 1985 had below normal growing season precipitation (Table III) and wheat yields (Table I) seemed to be correlated to the amount of soil water present before seeding. In these years, snow trapping appeared beneficial since a one-way analysis of variance revealed the field with snow trapping had higher wheat yields than the field with conventional height stubble (P<0.10, analysis not shown). In addition, in these two drought years, wheat yields of subsoiled treatments averaged 70% more than those of SC. There was no suggestion of any yield effect of subsoiling in 1986 or 1987. There were no differences in wheat yield or water conservation between the Paraplow and the Du-Al subsoiler.

Table II: Snowpack water (SWE, cm), overwinter soil water gain between fall and spring soil sampling (OWG, mm), available soil water to 1.2 m in the spring (SSW, cm), and grain yield (kg ha⁻¹) for the 1983 subsoiling experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>SWE</th>
<th>OWG</th>
<th>SSW</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>4.6</td>
<td>6.0</td>
<td>2.4</td>
<td>4.6</td>
</tr>
<tr>
<td>1985</td>
<td>2.4</td>
<td>4.8</td>
<td>3.7</td>
<td>16.1</td>
</tr>
<tr>
<td>1986</td>
<td>1.8</td>
<td>1.8</td>
<td>5.3</td>
<td>50.9</td>
</tr>
<tr>
<td>1987</td>
<td>4.5</td>
<td>5.3</td>
<td>6.5</td>
<td>1519</td>
</tr>
</tbody>
</table>

* Appropriate comparisons (see text) revealed no significant differences among means (P<0.10).
Table III: Precipitation and mean temperature for the crop years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>5.0</td>
<td>7.8</td>
<td>2.2</td>
<td>4.3</td>
<td>7.1</td>
<td>5.1</td>
<td>4.2</td>
<td>5.1</td>
</tr>
<tr>
<td>1985</td>
<td>1.5</td>
<td>5.8</td>
<td>1.1</td>
<td>1.9</td>
<td>6.7</td>
<td>1.5</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>1986</td>
<td>7.2</td>
<td>8.1</td>
<td>1.3</td>
<td>3.1</td>
<td>1.7</td>
<td>2.5</td>
<td>3.9</td>
<td>27.8</td>
</tr>
<tr>
<td>1987</td>
<td>6.4</td>
<td>6.3</td>
<td>1.4</td>
<td>11.2</td>
<td>5.1</td>
<td>3.2</td>
<td>1.6</td>
<td>35.2</td>
</tr>
<tr>
<td>1988</td>
<td>10.8</td>
<td>5.8</td>
<td>1.3</td>
<td>2.6</td>
<td>4.4</td>
<td>5.9</td>
<td>4.3</td>
<td>35.1</td>
</tr>
<tr>
<td>1989</td>
<td>1.5</td>
<td>4.0</td>
<td>0.2</td>
<td>3.5</td>
<td>7.3</td>
<td>3.5</td>
<td>3.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>


** 2.6 cm on May 30.

1985 Subsoiling experiment

There was no effect of the Paraplow on soil bulk density measured in October 1985 after subsoiling with the Paraplow (not shown) or in April 1986 (Fig. 3). Others (Mukhtar et al. 1985; Hips and Hodgson 1988; Grevers 1988, 1989) also determined that the use of the Paraplow did not affect soil bulk density significantly although Ellington (1986) and Raper and Erbach (1987) found that the Paraplow reduced soil bulk density. The apparent differences in bulk density below 60 cm depth observed in this study were attributed to variations in the amount of small stones which occur at those depths. The soil layer between 10 to 25 cm had a higher bulk density than soil between 25 and 45 cm. Dyck et al. (1977) also detected this denser layer in Swinton loam at a nearby site using 15 cm diameter soil cores. This layer of higher bulk density may be a zone of clay illuviation (Ayres et al. 1985) and/or it may represent a zone which has been compacted from tillage and/or traffic (Voorhees and Lindstrom 1983). Compaction is not believed to be an important problem on the Canadian Prairies (Dumanski et al. 1986) although the potential for soil compaction does exist (Chansy 1989).

Over the winter of 1985-86, the snow fence enclosures were very effective in trapping snow (Table IV). The early January snowpack (data not shown) equalled that measured in early March (Table IV) but the January snowpack was completely melted by chinook winds in that month. The melting of the March snowpack caused water to pond on the soil surface for about 7 to 10 days within the diked areas. Despite the opportunity for infiltration, SC contained no more soil water after snowpack ablation than the treatments without snow management (Table IV). The reason for the restricted infiltration for SC was thought to be the formation of an ice layer at the immediate soil surface during January. SP contained significantly more water than SC indicating that subsoiling increased infiltration into frozen soil under these conditions.

The subsoiled treatments had more soil water in the 20 to 80 cm soil layer than the control treatments in April (data not shown) and at seeding (Fig. 4). A similar tendency was noted in 1984 and 1985 for the 1983 subsoiling experiment (McConkey 1987). Soviet researchers have also reported that fall deep tillage increased the depth of snowmelt infiltration in the soil (Pabat and Gnineko 1987) even when the total quantity of snowmelt infiltration was not increased (Buratzki and Yarovenko 1961). Continuous soil macropores can be very important to infiltration into frozen soil (Harris

Table IV: Snowpack water (SWE, cm), overwinter soil water gain between fall and spring water measurements (OWG, cm) and available soil water at seeding to 1.2 m (SDSW, cm) for the 1985 subsoiling experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>SWE</th>
<th>OWG</th>
<th>SDSW</th>
<th>Treatment</th>
<th>SC</th>
<th>SP</th>
<th>SDW</th>
<th>S*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>4.4b**</td>
<td>5.2b</td>
<td>7.6a</td>
<td>NC</td>
<td>19.0a</td>
<td>16.7a</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2a</td>
<td>3.5a</td>
<td>6.5a</td>
<td>NP</td>
<td>12.9a</td>
<td>12.9a</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>3.8a</td>
<td>3.6a</td>
<td>7.0a</td>
<td>12.1b</td>
<td>12.1b</td>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.4a</td>
<td>3.4a</td>
<td>2.5b</td>
<td>6.5a</td>
<td>6.5a</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.2a</td>
<td>5.2a</td>
<td>6.5a</td>
<td>12.1a</td>
<td>2.5b</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>4.9a</td>
<td>3.8a</td>
<td>7.6a</td>
<td>2.5b</td>
<td>4.9a</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0b</td>
<td>3.0b</td>
<td>7.6a</td>
<td>4.9a</td>
<td>6.5a</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>4.7b</td>
<td>6.4a</td>
<td>6.6a</td>
<td>NC</td>
<td>12.0a</td>
<td>10.2a</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.3a</td>
<td>5.3a</td>
<td>5.8a</td>
<td>NP</td>
<td>6.6a</td>
<td>6.6a</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>3.2b</td>
<td>4.0b</td>
<td>7.6a</td>
<td>6.6a</td>
<td>6.6a</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>5.3a</td>
<td>5.3a</td>
<td>5.1a</td>
<td>7.6a</td>
<td>7.6a</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.9a</td>
<td>4.9a</td>
<td>4.9a</td>
<td>7.6a</td>
<td>7.6a</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Standard error of the mean.
** Means within rows not followed by the same letter are significantly different (P<0.05).
+ Assuming SWE = 0 for all treatments in 1987.

Fig. 3. Soil bulk density for the 1985 subsoiling experiment measured in April 1986 using gamma rays.
1970; Komarov and Makarova 1973; Granger and Gray 1986). Hipps and Hodgson (1988) found that subsoiling with the Paraplow tended to increase soil macropores greater than 60 m and 300 m even though the use of the Paraplow did not increase total soil porosity as a result of lowered bulk density. The trend for more soil water at lower depths in the subsoiled treatments in this study likely was the result of snowmelt moving through macropores, produced by fracturing the soil pan lying between the 10 to 25 cm. Such pans have been identified as a major limitation to water infiltration into frozen soils (Bumatzki and Yarovenko 1961; Pikul et al. 1985). With the exception of the first winter after subsoiling, visual observation suggested that the soil structure near the soil surface, to at least 5 cm, was similar for all treatments. During snowpack

Fig. 4. Soil water distribution for 1985 subsoiling experiment from 1986-89.
ablation this surface layer was probably thawed and saturated with water. The extent of saturation would control the mechanism by which snowmelt was transferred through the soil surface to the subsoil macropores. Consequently, after the first winter, subsoiling did not result in large increases in total snowmelt infiltration because the surface soil layer controlled the amount and rate of infiltration. This proposed mechanism is similar to that identified by Quisenberry and Phillips (1976) who found that macropores do not have to be connected to the surface nor have to be saturated with water to conduct significant quantities of water deeply into the subsoil. The soil water distribution of the subsoiled plots in early July was similar to the check (Fig. 4) indicating that any macropores from subsoiling did not increase the depth of penetration of May and June precipitation. During the growing season, the soil matric potential at the soil surface must have been consistently too low for water movement in subsoil macropores. Poor snowmelt infiltration of the non-subsoiled soil was likely the overriding limitation to snow management in these four years.

Over the 1986-89 period, the 1985 subsoiling treatment resulted in significantly more water use than the control treatments (Table V). The larger water use was both the result of slightly greater overwinter soil water gains for NP and SP (Table IV) and the tendency for the higher yielding, subsoiled treatments to have less water remaining in the soil at harvest than the control treatments (Fig. 4). This may be an indication of increased rooting, permitting more thorough water extraction from the soil volume. Other researchers have found that subsoiling has enhanced root growth and soil water extraction (Bennie and Botha 1986; Ide et al. 1987; Marks and Soane 1987; Steed et al. 1987).

In June 1986, SP wheat plants appeared more chlorotic, (i.e. yellow or blanched) than the other treatments (not shown) which suggested a nitrogen deficiency possibly due to N loss from leaching and denitrification. The abundant precipitation received during June (Table III) together with the moist initial soil conditions for SP would have encouraged this (Campbell et al. 1984; Malhi and Nyborg 1986). Consequently, although SP had much more water available than the other treatments, it did not have correspondingly higher grain yields in 1986 (Table V). This yield limitation also resulted in SP having a significantly lower water use efficiency (i.e. grain yield divided by growing season precipitation plus soil water decrease between seeding and harvest, Table V). However, overall, fall subsoiling produced a significant yield increase over the controls in 1986 (P<0.05). In 1987 and 1989, the Paraplow treatments had somewhat higher grain yields than the non-Paraplowed areas. Under the hot conditions of 1988 (Table III), SP yielded significantly more than other treatments. The yields during the 1987-89 period from subplots which received preseeding tillage (data not shown) had rankings and significant differences among treatments identical to those presented for the zero-till subplots in Table V.

Table V: Water used (WU, i.e., precipitation plus soil water loss between seeding and harvest, cm), grain yield (kg ha⁻¹), and water use efficiency (WUE, i.e., Yield/WU, kg ha⁻¹ cm⁻¹), for the 1985 subsoiling experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>NC</th>
<th>NP</th>
<th>SC</th>
<th>SP</th>
<th>S_e</th>
<th>Significance Paraplow versus control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>WU</td>
<td>16.6b</td>
<td>19.3b</td>
<td>17.8b</td>
<td>26.3a</td>
<td>2.7</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>2644a</td>
<td>2966a</td>
<td>2744a</td>
<td>2933a</td>
<td>164</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>WUE</td>
<td>159a</td>
<td>155a</td>
<td>154a</td>
<td>112b</td>
<td>13</td>
<td>0.02</td>
</tr>
<tr>
<td>1987</td>
<td>WU</td>
<td>19.6a</td>
<td>18.9a</td>
<td>19.4a</td>
<td>19.4a</td>
<td>0.9</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>1365a</td>
<td>1429a</td>
<td>1123*</td>
<td>1555*</td>
<td>310</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>WUE</td>
<td>69a</td>
<td>76a</td>
<td>58a</td>
<td>8a</td>
<td>17</td>
<td>0.19</td>
</tr>
<tr>
<td>1988</td>
<td>WU</td>
<td>17.3a</td>
<td>15.4a</td>
<td>17.7a</td>
<td>18.7a</td>
<td>1.5</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>311b</td>
<td>354b</td>
<td>388*</td>
<td>569*</td>
<td>66</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>WUE</td>
<td>18a</td>
<td>23a</td>
<td>22a</td>
<td>31a</td>
<td>5</td>
<td>0.04</td>
</tr>
<tr>
<td>1989</td>
<td>WU</td>
<td>27.8a</td>
<td>30.4a</td>
<td>29.9a</td>
<td>31.3a</td>
<td>1.5</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>1941a</td>
<td>1892a</td>
<td>1909a</td>
<td>2172a</td>
<td>224</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>WUE</td>
<td>70a</td>
<td>63a</td>
<td>64a</td>
<td>71a</td>
<td>9</td>
<td>0.90</td>
</tr>
<tr>
<td>1986-89</td>
<td>WU</td>
<td>23.9b</td>
<td>24.2b</td>
<td>22.9b</td>
<td>26.1a</td>
<td>1.3</td>
<td>0.01</td>
</tr>
<tr>
<td>1989</td>
<td>Yield</td>
<td>1565a</td>
<td>1660a</td>
<td>1541a</td>
<td>1805a</td>
<td>223</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>WUE</td>
<td>64a</td>
<td>64a</td>
<td>63a</td>
<td>65a</td>
<td>80</td>
<td>0.56</td>
</tr>
</tbody>
</table>

* Standard error of the mean.
** Means within rows not followed by the same letter are significantly different (P<0.05).
+ Does not account for the approximate 10% of grain left unharvested for trap strips.
The yield increases due to use of the Paraplow were fairly consistent from year to year. There was no significant (P < 0.10) year by treatment interaction (analysis not shown). The yield advantage of SP over NC or SC ranged from 180 to 430 kg ha⁻¹ over the four year period, SP outyielded NC and SC by 16%.

In 1988 the subsoiled treatments had a significantly higher water use efficiency than the non-subsoiled treatments (P<0.05). Increased crop water use efficiency as a result of subsoiling has been noted elsewhere (McEwen and Johnston 1979; Bennie and Botha 1986; Grevers 1989).

Longevity of subsoiling

Large (i.e. >4 cm) increases in overwinter soil water gain occurred only for the first year after subsoiling since this was the only time the sub-soiler furrows were open to the soil surface. However, these furrows also aggravated soil drying when the water equivalent of the late-winter snowpack was less than 4 cm and the spring had below-normal precipitation. After the first crop year following subsoiling, the trend over time of the yield increases from subsoiling suggested a gradual reconsolidation of the soil. For the second year after subsoiling, soil reconsolidation from wheel traffic and natural forces had sealed furrows at the soil surface. The higher yields on the subsoiled treatments in this year likely occurred because additional snowmelt was conducted into the subsoil through numerous macropores from near the soil surface to the depth of subsoiling. In the third and fourth years after subsoiling, there was no evidence of a yield increase from subsoiling unless the snowpack water equivalent was at least 4.9 cm (assuming the 1986 snowpack water equivalent on the 1983 subsoiling experiment equalled that on conventional height stubble on the 1985 subsoiling experiment). This trend can be attributed to a reduction of the number of subsoil macropores as a result of soil reconsolidation so that appreciable snowmelt was necessary to increase the amount of soil water in the subsoil. A late winter snowpack water equivalent of 4.9 cm or more using snow management can be expected only two out of three years at Swift Current (McConkey 1987).

Significant yield increases from subsoiling the Chernozemic soil did not extend beyond three years. This agrees with other research which has found that the effects of subsoiling are greatly diminished after 3 to 6 years (Trouse and Humbert 1959; McEwen and Johnston 1979; Ellington 1986; Soane et al. 1987; Ide et al. 1987; Papendick 1987; Steed et al. 1987).

CONCLUSIONS

Restricted infiltration of snowmelt was apparently the major limitation to the value of snow management without subsoiling. Fall subsoiling to a 35 cm depth substantially improved snowmelt infiltration for one crop year even when soil surface conditions were very unfavorable for infiltration. In subsequent years, the fall subsoiling did not significantly increase the amount of snowmelt infiltration but increased the depth of penetration of snowmelt. Water extraction from the 1.2 m soil profile was greater where the soil had been subsoiled. The only negative effect of subsoiling was increased soil water evaporation before seeding in the first crop year after subsoiling, but this only occurred when the spring had below-normal precipitation and snow management had not been practiced.

Overall, a single fall subsoiling increased grain production from a 4-yr continuous zero-till spring wheat rotation in southwestern Saskatchewan by 7% with conventional height stubble and by 20% with snow management practices. The improved moisture regime provided by subsoiling plus snow management were most beneficial in drought years (1984, 1985 and 1988) when the average yield was more than twice that of conventional height winter stubble without sub-soiling. However, the overall profitability of one-time fall subsoiling remains to be determined.

ACKNOWLEDGEMENT

We acknowledge the careful attention of Don Reimer in collecting and processing the data, as well as the conscientious field management by Del Jensen and his crew. We are indebted to Drs. C. Campbell and J. Clarke for their helpful suggestions for improving the manuscript.

REFERENCES


McCONKEY, STEPPUHN and NICHOLAICHUK


CANADIAN AGRICULTURAL ENGINEERING 223


