Impacts of crop sequence and minimum- and no-till cropping systems on soil water in south-central North Dakota, USA.

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As part of a long-term (1993-2011) study near Mandan, ND, we measured soil water at various depths, and together with precipitation and yield data, determined water use efficiency (WUE) and precipitation use efficiency (PUE) for spring wheat grown in different crop sequences under minimum tillage (Min-till) or No-till.

Site and Treatment Description

- The study was located near Mandan, ND, (46°46'12" N, 100°54'57" W), on a predominant soil of Temvik–Wilton silt loam (fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls).
- The design was a split-plot, with crop sequences (R) as whole plots and tillage (T) as subplots.
- Crop sequences (3 replicates) included continuous spring wheat (*Triticum aestivum* L.) with crop residue left on the soil surface (CSW+), or with crop residue removed (CSW–), spring wheat–millet (*Setaria italica* (L.) Beauv.) (SWM), spring wheat–safflower–rye (*Secale cereale* L., a green fallow) (SWSR), spring wheat–safflower (*Carthamus tinctorius* L.)-fallow (SWSF), and spring wheat–fallow (SWF). Each phase of all crop sequences was present every year.
- Minimum tillage utilized one tillage pass with a sweep plow in the spring. The soil surface of no-till subplots was not disturbed except at planting.

Sampling Protocol and Analysis

- We measured profile soil water in 1-foot (30.5 cm) increments at the time of planting (SWP) and harvest (SWH) with a neutron moisture meter (CPN International Inc., model DR503) and used these data together with the amount of precipitation during the growing season (GSP) and spring wheat yield (harvested by combine) to calculate a crop WUE (kg grain ha^{-1} mm^{-1} water used) as:

  WUE= Grain yield/[GSP +(SWP-SWH)] (1).

- We also determined PUE for each crop sequence (kg grain ha^{-1} mm^{-1} precipitation) to account for the effects of fallow:

  PUE= Yield/precipitation since last crop harvest (2),

  where crops included spring wheat, millet, or safflower.

- We used SAS PROC GLIMMIX and a model with R and T as fixed variables and time (Year) as a random variable. We also used orthogonal contrasts to compare the effects of phase number and fallow.
- Figures depict LSMEANS (n=108 for main effects of crop sequences or 54 for R x T interactions). A significant difference between tillage treatments within each crop sequence is denoted by an asterisk while differences between sequences within each tillage treatment are denoted by letters (Tukey adjustment for multiple means, $P < 0.05$).

Fig. 1. Both SWP and SWH were arrayed in complex patterns with the interactions between crop sequence (R) and tillage (T) that varied with depth. Further analyses were conducted on aggregated data from 0-4 feet (0-122 cm), the rooting zone of spring wheat.

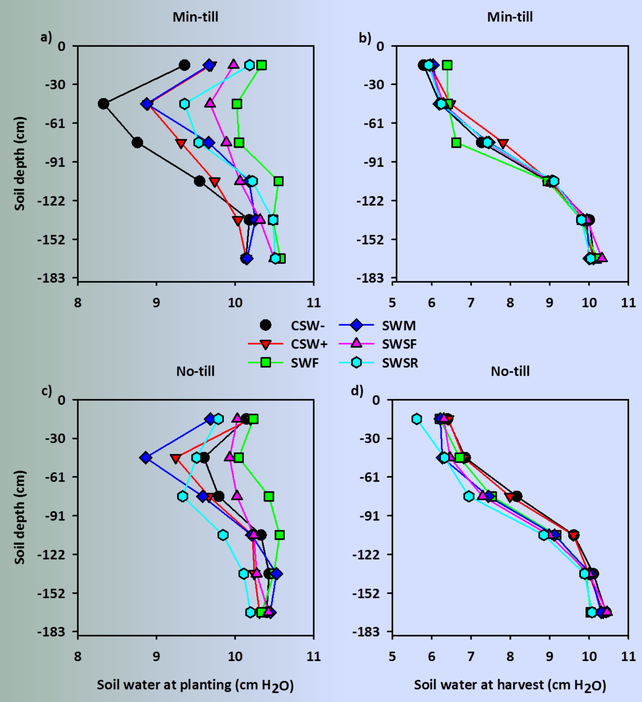

Fig. 2a. Values for SWP were generally highest in crop sequences following a fallow phase (SWF or SWSF) while more intensively cropped sequences, CSW-, CSW+, and SWM, were characterized by lower values. Tillage effects on SWP were negligible for most sequences, but less SWP was recorded for both CSW sequences under Min-till. **Fig. 2b. Values for SWH**, similar for all crop sequences under Min-till, varied under No-till, with more soil water remaining under the CSW sequences and less remaining in the 3-phase sequences that included safflower and a fallow phase. More SWH was observed under No-till for the CSW-, CSW+, and SWF sequences but there was an indication of more SWH under Min-till in the SWSR rotation.

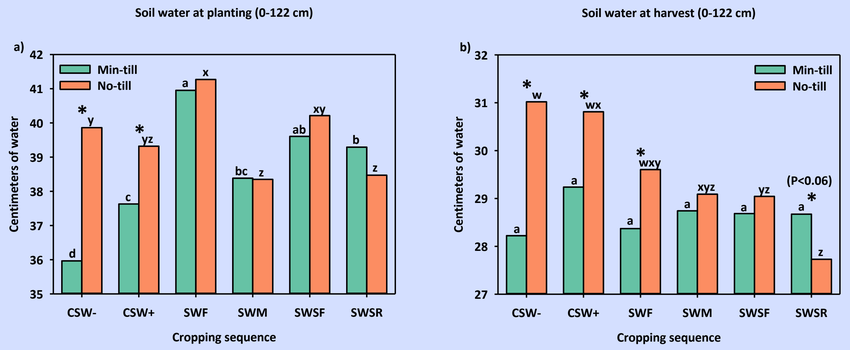

Fig. 3a. Seasonal Water Use varied by sequence, highest when following fallow and lowest for CSW, but was not impacted by tillage. Average precipitation during the growing season (from planting to harvest) averaged 217 ± 13 mm (range 83-380). **Fig. 3b. Yields of spring wheat** were highest when preceded by a fallow phase and lowest in under CSW. Yields under No-till averaged 2452 kg ha^{-1} compared to 2360 kg ha^{-1} for Min-till but differences between tillage treatments were less evident under SWF or SWSF.

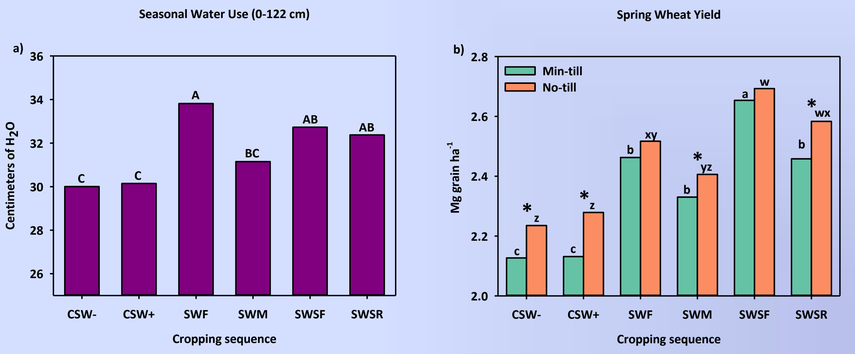

Fig. 4a. Water use efficiencies were not affected by crop sequence under No-till, averaging 8.1 kg grain ha^{-1} mm^{-1} water. In contrast, WUE varied under Min-till, highest for SWSF and lowest for CSW, with tillage effects evident in the latter. **Fig. 4b. Precipitation use efficiencies** were comparatively low and lacking tillage effects for crop sequences with a fallow phase. In contrast, continuously-cropped sequences were characterized by higher (~2x) PUE values, and significant tillage effects (greater in No-till). These patterns are due mainly to differences in the amount of precipitation received during the interval between harvests. Average inter-harvest precipitation for SWM and CSW sequences was 433 and 449 mm, respectively, about 50% that for SWF (896 mm), or SWSF and SWSR (847 mm).

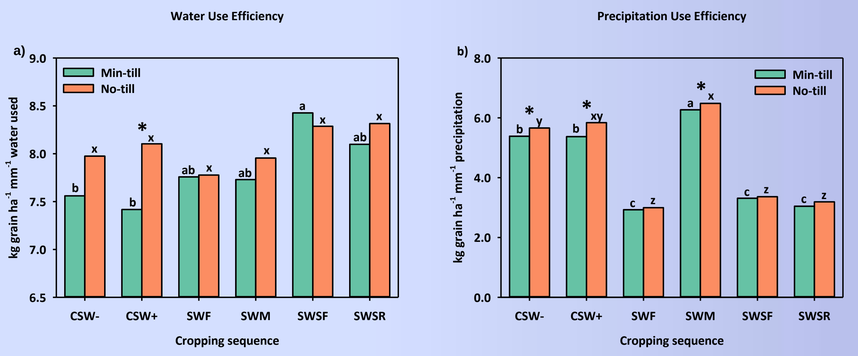

Table 1. Orthogonal contrasts comparing the average effects of phase number and fallow †.

	SWP‡ (cm)		SWH‡ (cm)		$H_2$0 Use§ (cm)		Grain Yield (kg ha^{-1})		WUE ¶ (kg ha^{-1} mm^{-1})		PUE# (kg ha^{-1} mm^{-1})	
	Δ	*P*	Δ	*P*	Δ	*P*	Δ	*P*	Δ	*P*	Δ	*P*
Rotation												
2-phase vs 1-phase	1.54	***	-0.87	*	2.41	***	236	***	0.04	NS	-0.90	***
3-phase vs 1-phase	1.20	**	-1.29	***	2.49	***	404	***	0.52	**	-2.34	***
3-phase vs 2-phase	-0.34	NS	-0.42	NS	0.07	NS	168	***	0.48	**	-1.44	***
fallow vs no-fallow	1.72	***	-0.84	**	2.54	***	310	***	0.32	*	-2.69	***
R x T (Min-till)												
2-phase vs 1-phase	2.87	***	-0.17	NS	3.03	***	267	***	0.26	NS	-0.78	***
3-phase vs 1-phase	2.65	***	-0.05	NS	2.68	***	427	***	0.77	***	-2.20	***
3-phase vs 2-phase	-0.22	NS	0.12	NS	-0.35	NS	159	***	0.52	*	-1.42	***
fallow vs no-fallow	2.62	***	-0.16	NS	2.76	***	329	***	0.52	**	-2.58	***
R x T (No-till)												
2-phase vs 1-phase	0.21	NS	-1.57	***	1.79	**	205	***	-0.17	NS	-1.01	***
3-phase vs 1-phase	-0.25	NS	-2.53	***	2.28	***	381	***	0.26	NS	-2.47	***
3-phase vs 2-phase	-0.47	NS	-0.96	*	0.49	NS	176	***	0.44	*	-1.46	***
fallow vs no-fallow	0.81	*	-1.52	***	2.32	***	291	***	0.11	NS	-2.81	***

† the 1-phase crop rotations are CSW- and CSW+, 2-phase rotations include SWF and SWM, and 3-phase rotations are SWSF and SWSR. The rotations without fallow include CSW-, CSW+ and SWM. ‡ Total water in the root zone (0-122 cm) as measured by neutron probe at the time of planting (SWP) and harvest (SWH). § Calculated as GSP +(SWP-SWH). ¶ Water use efficiency (eq. 1). # Precipitation use efficiency (eq. 2). The symbols *, **, and *** indicate significance at the α = 0.05, 0.01, and 0.001 levels, respectively.

Highest cropping intensity was associated with the CSW and SWM sequences in comparison to those that included fallow and multiple phases. Table 1 shows less soil moisture at planting (SWP) in intensively-managed sequences under Min-till. However, intensification had little or no effect on SWP under No-till. Conversely soil water at the time of harvest (SWH) was unaffected by intensification under Min-till but favored by intensification under No-till. Seasonal water use and average yields of spring wheat were lower under continuous cropping, irrespective of tillage. Crop water use efficiency (WUE) tended to be higher for the 3-phase sequences under Min-till but little influenced by intensification under No-till. However, intensified management resulted in markedly more efficient use of precipitation (PUE) over the period of the study.

Key Points

- Profile soil water, measured with a neutron probe, varied as a interaction between crop sequence and tillage. Tillage effects were particularly evident for continuous spring wheat where soil water at the time of planting and harvest were higher under No-till.
- Intensified crop sequences, characterized by continuous cropping and no fallow phase, tended towards relatively low seasonal water use and corresponding yields of spring wheat.
- Water use efficiency was unaffected by intensification under No-till but tended to be higher in 3-phase sequences under Min-till. Tillage effects were most evident for the CSW+ sequence.
- Over the course of this study (1993-2011), the highest precipitation use efficiencies, together with clear tillage effects, were observed for continuously-cropped sequences (CSW-, CSW+ and SWM).
- While crop sequence and tillage management can affect average WUE and PUE, the response to atypical annual or even intraseasonal patterns of precipitation and temperature (perturbation) may be of greater importance in the northern Great Plains.

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