SOIL MOISTURE CHANGES AND WATER USE EFFICIENCY IN ZERO AND CONVENTIONAL TILLAGE SYSTEMS FOR SPRING WHEAT[1]

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Introduction

Zero or minimum tillage farming systems have the potential ability of conserving soil moisture (Sask. Tillage Committee 1981). Such conservation is obtained by the provision of a standing stubble to retain snow, the reduction of excess tillage, and the concentration of plant residues at the soil surface to provide a mulch. The latter two points are considered important aspects in the reduction of water evaporation from the surface soil during the early part of the growing season, before a full crop canopy develops. Another possibility for improved moisture conservation is the probability of enhanced moisture infiltration, under reduced tillage where the soil surface is protected (Bertrand 1966). Redistribution and movement of water deeper into the soil can prevent evaporation losses of moisture.

The use of mulches to conserve soil moisture by reducing evaporation, however, is dependent on the depth of mulch and frequency of precipitation (Hanks and Ashcroft 1980; Heinonen 1979). Although mulches provide insulation to downward movement of heat into the soil, reduce the quantity of direct solar radiation reaching the soil and reduce the diffusion of water vapour; the cumulative evaporation from the mulched soil can equal or exceed that of the bare soil, given sufficient time without precipitation (Phillips et al. 1980. see Fig.1). Furthermore, studies have shown that, under specific conditions (coarse textured soils), soil porosity characteristics are significantly affected by reduced tillage to increase evaporation in the constant rate phase, especially when residue levels are low (100-300 kg ha^{-1}) (Hamblin and Tennant, 1981). Other studies on a loam to clay loam soil without residue, indicated that increased surface soil cracking, under zero tillage enhanced moisture loss from the surface soil (Darwent and Bailey, 1981).

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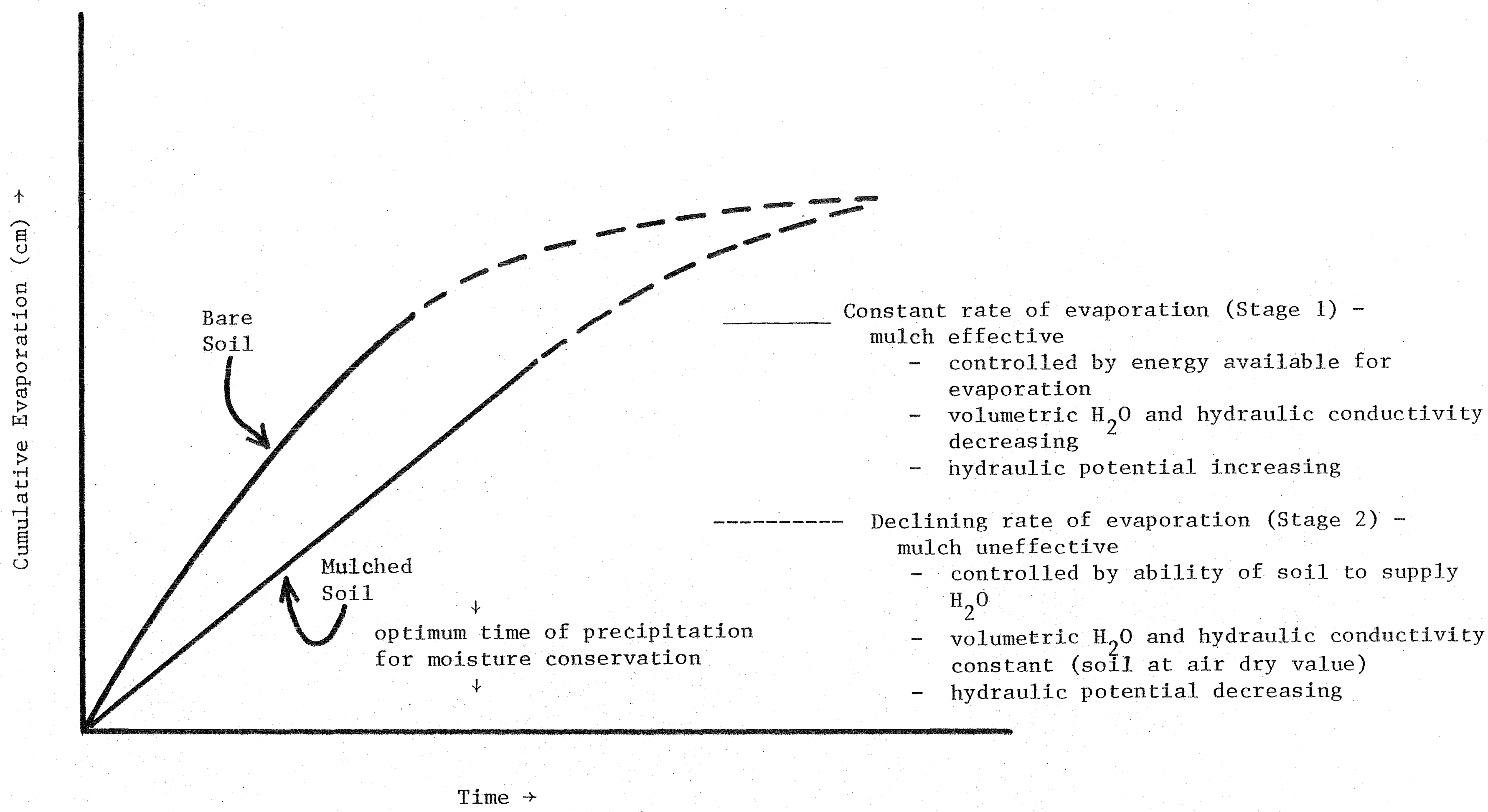

Fig. 1 Cumulative evaporation rate as a function of time for a bare soil and mulched soil indicating constant and declining rates of evaporation. Conservation of soil moisture will occur in the mulched soil, if precipitation occurs before the two curves cross each other (adapted from Hanks and Ashcroft 1980 and Phillips et al 1980).

Under an optimum frequency of precipitation, long term research has established that zero or minimum tillage can provide an improved moisture regime (Phillips et al. 1980). Studies in Manitoba have shown that soil moisture can be higher under zero tillage in comparison to conventionally tilled areas (Gauer et al. 1980). Such differences were related to reduced evaporation. Furthermore, moisture differences between the two tillage systems were evident to a depth of 135 cm. At Lethbridge, several studies have indicated that improved moisture regimes, at seeding time, can result from a combination of chemical fallow and zero tillage for wheat-fallow and wheat-wheat-fallow systems (Lindwall 1978).

Moisture conservation, under reduced tillage, holds the possibility of enhancing moisture for seed germination, increasing total soil moisture for continuous cropping and maximizing water use efficiency and crop production. The following study, investigated these factors at four zero and conventional tillage systems, for spring wheat, at three locations in western Canada during 1981.

Materials and Methods

Descriptions of the four sites are given in Table 1. The investigations in 1981 on soil moisture, were carried out as part of a larger study on nitrogen utilization under reduced tillage systems.

Within each experimental area (30 x 10 m) four replicate soil samples (3.2 cm diameter cores) were obtained, to a depth of 120 cm, in the spring (at seeding) and fall (at harvest). This procedure allowed the calculation of gravimetric moisture content, undisturbed bulk density and volumetric water content. Estimates of the residue cover and stubble height were also determined for each site (Table 1).

Throughout the growing season soil samples, to a depth of 10 cm, were obtained near the following three growth stages: Feekes 1 (first leaf), Feekes 5 (end of tillering), and Feekes 10 (start of heading). Differences in growth stage, between tillage systems, were also noted at time of soil sampling.

Moisture constants, at -1/3 and -15 bar, were determined to assess the plant available moisture status. No difference in moisture constants between tillage systems could be detected. Since the plant and soil type were identical for each tillage systems, the -15 bar constant was considered equivalent to plant wilting point.

Tillage on the conventional systems consisted of cultivation treatments in the fall or spring, to a depth of 5-8 cm, followed by harrowing or rodweeding at seeding. Under fallow systems,

Table 1. Soil and agronomic characteristics of the soils under study

Location	Soil Classification	Soil Series or Association	Rotation Sequence	Years under Zero Tillage	Residue Cover kg ha^{-1} CT	Residue Cover kg ha^{-1} ZT
Lethbridge	Dark Brown Chernozem	Lethbridge	Wheat-Fallow	16	636	1457
Melfort (12)	Black Chernozem	Melfort	Wheat-Fallow	12	198	1860
Melfort (4)	Black Chernozem	Melfort	Continuous Wheat	4	979	2171
Watrous	Dark Brown Chernozem	Elstow	Continuous Wheat†	4	1131	1846

† Wheat-Wheat-Fallow for the conventional tillage system.

Table 2. Precipitation during 1980-81 for the sites under study

Location	% of normal precipitation for Oct.1980-April 1981	Precipitation over the growing season in mm (% of long term average in brackets)				Longest period without substantial (<2.5mm) precipitation (days)			
		May	June	July	August	May	June	July	August
Lethbridge	88	129 (247)	103 (119)	30 (76)	35 (94)	7	8	7	17
Melfort	65	10 (28)	36 (56)	93 (171)	17 (35)	26	9	12	13
Watrous	69	32 (88)	101 (163)	61 (104)	38 (68)	16	9	11	11

practices for weed control consisted of wide blade or cultivator for the conventional tillage and herbicides for the zero tillage system.

Overall winter precipitation (1980-1981) was well below the long term average at all sites (Table 2). Growing season precipitation was generally above average for the Lethbridge site, and well below average until July for the Melfort sites. Precipitation was above the long term average for June and July at Watrous. Periods without substantial precipitation were common at all sites, especially for the Melfort and Watrous sites. However, the importance of this observation is dependent upon the extent of potential evapotranspiration.

Results

At all locations, differences in growth stage were evident between tillage systems. This was expressed by slower growth under zero tillage; such differences ranged from very slight on the Lethbridge soil to pronounced for the 4 year study on the Melfort soil. Little difference in plant density or tillering could be detected between tillage systems. In general, residues levels were low(198-1131 kg ha^{-1}) under conventional tillage and light to medium (1457-2171 kg ha^{-1}) under zero tillage. Standing stubble was sparse (or non-existent) and, except for the Lethbridge site, less than 20 cm tall.

At all sites, except for the Feekes 1 growth stage at Melfort, reduced tillage significantly enhanced (ratio > than 1) the available moisture content of the 0-5 cm depth (Table 3). This difference was maintained from seeding to the development of a full canopy. At the lower depth (5-10 cm) a similar trend was evident but in some cases soil moisture under conventional tillage was enhanced (ratio < 1) in comparison to zero tillage.

Except for the surface 0-15 cm moisture content at Lethbridge, which was greater under zero tillage than conventional tillage, the total moisture content to a depth of 120 cm, measured at seeding time in the spring, did not show any significant difference between tillage systems (Table 4). Differences in total moisture content, however, were present at specific depths, between tillage systems, at the end of the growing season (Table 4). Furthermore, moisture use from spring to fall, compared at specific depths down the soil profile, suggested a trend for increased moisture use at depth for the reduced tillage system.

Comparisons between tillage systems, showed that except for the conventionally tilled wheat following fallow on the Elstow soil, total water use (soil moisture to 120 cm plus precipitation) was greater for the reduced tillage system (Table 5). Yield differences

Table 3. Change in the available soil water content for the 0-5 and 5-10 cm depth over the growing season. Data expressed as the ratio of zero tillage to conventional tillage.

Depth (cm)	Stage of Growth[+] Feekes 1	Feekes 5	Feekes 10
		Elstow CL	
0 - 5	3.64*	4.77*	6.57*
5 - 10	1.22*	1.00	0.75*
		Melfort CL (4 yr. study)	
0 - 5	1.54*	1.61*	1.24*
5 - 10	0.80*	1.42*	1.36*
		Melfort CL (12 yr. study)	
0 - 5	0.23*	1.35*	2.08*
5 - 10	0.91*	1.41*	0.76*
		Lethbridge SiL	
0 - 5	1.21*	3.33*	1.07*
5 - 10	0.81	1.46*	1.00

+ Feekes 1, 5 and 10 represent one leaf, end of tillering and heading, respectively.

* Indicates significant increase in soil moisture between tillage systems at the specified growth stage (P=0·05).

Table 4. Changes in total moisture (mm) with depth, between spring and fall, under zero (ZT) and conventional (CT) tillage

	Spring		Fall	
Depth (cm)	ZT	CT	ZT	CT
			Elstow CL	
0 - 15	37	37	26*	21
15 - 30	26	36	20	21
30 - 60	80	85	67	56
60 - 120	232	190	231	204
			Melfort CL (4 yr.study)	
0 - 15	59	64	35	39
15 - 30	62	63	36	41
30 - 60	106	111	85	94
60 - 120	185	200	190	209
			Melfort CL (12 yr.study)	
0 - 15	68	72	38	41*
15 - 30	71	70	41	46
30 - 60	121	128*	78	103*
60 - 120	252	270	215	250
			Lethbridge SiL	
0 - 15	36*	33	23	24
15 - 30	32	30	20*	17
30 - 60	65	73	35	46*
60 - 120	118	128	73	93*

* Indicates significant increase in soil moisture between tillage systems at the same sampling period (P=0.05).

Table 5. Total H_2O used through growing season, yield and water use efficiency parameters under zero (ZT) and conventional (CT) tillage.

Tillage System	Total H_2O used† (cm)	Yield (kg ha^{-1} grain plus straw	WUE‡
		Elstow CL	
ZT	24.5*	3990	163*
CT	27.4	4160	152
		Melfort CL (4 yr. study)	
ZT	21.2	3930*	185*
CT	20.1	4370	217
		Melfort CL (12 yr. study)	
ZT	28.6*	4850	169*
CT	24.6	4780	194
		Lethbridge SiL	
ZT	27.1*	4080	150
CT	25.3	3950	155

† soil moisture to 120 cm plus growing season precipitation

‡ water use efficiency (kg ha^{-1}/total H_2O used)

* significant difference between tillage systems (P=0·05)

were only evident for the 4 year Melfort study, where growth under zero tillage was depressed. Such differences, either in yield or total moisture use, were responsible for the distinctions in water use efficiency (WUE) between tillage systems.

Total moisture use and crop yield were not closely related, suggesting that factors other than moisture, were affecting crop yield.

Discussion and Conclusions

An improved soil moisture regime was evident in the surface soil, under zero tillage in comparison to conventional tillage. This is probably due to the provision of a mulch at the soil surface of the reduced tillage system. Thus, in this study, zero tillage enhanced the moisture characteristics of the seed microclimate.

The lack of any significant difference in total soil moisture conserved, to a depth of 120 cm, between the two tillage systems, indicates the need to ensure adequate stubble management to maximize conservation of over winter precipitation. A combination of reduced tillage and adequate stubble height, to trap snow, is needed to allow improved total moisture reserves under zero tillage farming systems and to encourage continuous cropping. Possible exceptions to this are found in the Chinook belt region, as represented by the Lethbridge soil, where snow management may not be practical (Lindwall 1978).

Differences in moisture content or use with depth have been noted under different tillage systems (Gauer et al. 1980; Phillips et al. 1980). Although no consistent trend is yet available, changes in water infiltration rate and depth of storage may be an important aspect of tillage practices (Bertrand 1966). In this study water use at depth was enhanced by reduced tillage.

The objective of conserving moisture is to allow greater production by recycling of moisture through crops rather than loss by evaporation or other means. Failure to obtain unproved WUE values or observe relationships between water use and yield, probably reflect the existence of other impediments to growth. Such phenomena have been reported for other moisture use studies in Saskatchewan (De Jong and Rennie 1967). Under reduced tillage, decreased WUE has been related to lack of optimum fertility, especially nitrogen deficiency (Lindwall and Anderson 1981; Phillips et al. 1980). Such relationships point to the need for combination of reduced tillage studies with that of soil fertility to ensure the optimum efficiency of any potential moisture conservation.

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