

relative importance of deep soil water to alfalfa grown in semiarid environments might be overlooked by agronomists, plant breeders, and crop modellers.

Alfalfa yield has shown a positive linear relationship to evapotranspiration (Sheaffer et al. 1988). Previous alfalfa water relation research done at this location has shown a relationship between pan evaporation and potential evapotranspiration (Pelton and Korven 1969). Prediction of alfalfa forage yield from environmental variables that are closely associated with evapotranspiration would be desirable in deterministic or mechanistic crop modelling. However, the accuracy of such predictions may be greatly reduced if water from deep soil layers contributes significantly to alfalfa production, particularly of newly seeded swards, and this water is not accounted for. Keisselbach et al. (1929) observed that production of newly seeded alfalfa swards was significantly higher than older stands and attributed this to the crop's use of deep soil water. Further, large reserves of soil water at depths below approximately 1.2 to 1.5 m which are unavailable to relatively shallow rooted annual cereals or perennial grasses would be available to deep rooted crops such as alfalfa (Brun and Worcester 1975; Campbell et al. 1993, 1994; Keisselbach et al. 1929).

Sward age is not considered in the long-term forage yield evaluation of alfalfa. The literature and our experience suggest that often sward age is confounded with growing season environmental conditions, and this exerts considerable influence on the variation in forage yields that are observed. Thus to consider the effect of sward age over a large number of observations (growing seasons), a historical database for the Swift Current location was developed.

The objective of this preliminary research was to evaluate the relationship of historical alfalfa yield data with weather variables and sward age (years since establishment) for a semiarid site in southwestern Saskatchewan as affected by alfalfa. The inclusion of sward age in the above relationship has not been developed previously by agronomists, plant breeders or crop modellers but might have significant impacts on interpretation of their results.

MATERIALS AND METHODS

The database of historical alfalfa yields (1951 to 1994) consisted of the cultivar Rambler. Rambler was chosen as the benchmark variety for several reasons. It was registered in 1955 but continues to be included in dryland alfalfa trials since it is a widely known cultivar. This resulted in the largest number of years of available data. It is well adapted and winter-hardy and data from long-term trials were available.

The database was gleaned from old Research Centre reports, Uniform Alfalfa Cultivar Trials (pre-registration tests) and a few agronomy trials. All experiments were spring seeded on previously fallowed soil (Swinton loam; fine, mixed, mesic aridic Haploboroll) located on the dryland research area of the Semiarid Prairie Agricultural Research Centre at Swift Current, Saskatchewan (50° 16'N, 107°44'W, 825 m elevation). Each data point was the mean over the number of replications for that year. If two or more experiments of the same sward age were reported in the

same calendar year, we took the mean for Rambler over experiments. In 1962 and 1985, there were no alfalfa trials harvested due to winter injury of existing experiments. Data from 1955 were discarded as the samples contained a large proportion of weeds.

Harvests were taken as close to 10% bloom stage as possible. Total annual forage yield data were used for years where more than one harvest was recorded.

All alfalfa experiments were located within 0.65 km of the meteorological station. The weather data used in this study included monthly precipitation (mm) from April to August (APR, MAY, JUN, JUL, AUG). Monthly precipitation for the previous September to March were accumulated as Fall and Winter precipitation (FWPPT; water equivalent (mm)). Monthly evaporation (mm) from a Class A pan was used for May through September (EVAPMAY, EVAPJUN, EVAPJUL, EVAPAUG, EVAPSEP). Freezing temperatures from October to April make it impossible to determine evaporation from a Class A pan during that period. Evaporation was considered to reflect several weather variables, such as temperature, wind speed and relative humidity. Water deficit was calculated as the sum of monthly evaporation from May to July minus the sum of monthly precipitation from April to July.

Sward age from 1 to 5 yr was treated as a factor for statistical analysis. Since there were fewer observations for sward ages 6 to 11 yr, all these observations were combined into one category, namely >5 yr sward age. The sample size for each sward age category is listed in Table 1. The GLM procedure and pair-wise *t*-testing of least square means (SAS Institute, Inc. 1985) were used to compare sward age. The STEPWISE procedure (SAS Institute, Inc. 1985) was used for forward multiple regression analysis to predict yield from weather data. The threshold probability for including variables in the model was 0.500. Pearson correlation coefficients between yield and water deficit were calculated with the REG procedure (SAS Institute, Inc. 1985).

RESULTS AND DISCUSSION

Forage yield varied from 120 kg ha⁻¹ in 1968 to 4805 kg ha⁻¹ in 1978 (Table 1). The largest variation within a calendar year due to sward age occurred in 1956 with yields ranging from 633 to 4057 kg ha⁻¹. The 1-yr old swards yielded the highest on average; forage yield generally declined with age of sward to 3 yr old but recovered slightly for the >5-yr-old stands. The difference among the sward ages was significant ($P \leq 0.011$) The high average yield for 1- and 2-yr-old swards would support the hypothesis that alfalfa is extracting deep soil water early in its life. This water reserve would decline with use, barring a significant recharge event, and subsequently yields would decline. The recovery of average yield in >5-yr-old stands may be related to the demographics of these data. These old swards must have exhibited reasonable production and plant density to be maintained for such a long period while other trials of similar age had been discarded. Perhaps the persistence of these swards contributed to the recovery of yields observed. These long-term stands were not harvested in droughty years due to low productivity. Had low production years been includ-

Table 1. Historical dryland alfalfa yield at Swift Current, Saskatchewan from 1951 to 1994 by age of stand

Year	Stand age (yr)						SE
	1	2	3	4	5	> 5	
	(kg ha ⁻¹)						
1951	1475						—
1952		1681					—
1953	2744	3002	3943				631
1954	3832	3956	3674	3016			419
1956	4057		633				2421
1957		952					—
1958	1120		605				364
1959		1596		1255			241
1960	896		1101		740		181
1961				340		112 (6) ^z	161
1963	2554						—
1964	638	605					23
1965		2958	3181				158
1966	4551		2246	2509			1262
1967		2274		864	1026		772
1968			255		120		95
1969	1693			2604		1178 (6,7)	722
1970	3812	4321			3841	3388 (7,8)	381
1971	1607	1224	733				438
1972		1396	1231	1100		593 (10)	346
1973	2116		2157	1330	2007	1310 (11)	427
1974	3743	2444		2494		2415 (6)	647
1975	2699	4082	3193		2733		644
1976	3360	4184	3132	3176		3412 (6)	425
1977	4486	2502	2864	3260	2450	3841 (7)	803
1978	4805	2376		1600	2096	1941 (6,8)	1284
1979	1419	3487	2538	1754	2034	1992 (7)	728
1980	2078	1302	1450		1964		380
1981		2942	1701	2109			632
1982			3277	1119		3759 (10)	1406
1983				3467	2843	2907 (11)	343
1984					1394		—
1986	988						—
1987		350					—
1988			200				—
1989		2552		1606			669
1990	2404		2874				—
1991	3698	3735		3808	1063	3558 (6)	1183
1992		1290	724	2259	2900	675 (7)	980
1993			1788			3077 (6)	911
1994					4065		—
Mean	2642A	2400AB	1977C	2087BC	2085B	2259ABC	
SEM	270	250	252	225	286	286	
n	23	23	22	19	15	18	

^zIn > 5 yr column, stand age is listed in parentheses after the yield value. Where two ages are listed, a mean yield is presented for brevity. Individual yields were used in data analysis.

A–C Means followed by the same letter are not significantly different as tested by paired *t*-tests ($P < 0.05$).

ed, this mean value might approach that for the 3- to 5-yr-old swards. We considered the implications of including the yield data for >5-yr-old swards and recognize the bias that selective harvesting has caused in the database. However, we concluded that the value of including yields from old swards was greater than the risk of bias.

As sward age increased from 1 to 5 yr, the ability of the weather variables to explain the variation in yield increased from 50 to 96% (Table 2). The >5-yr-old sward yield prediction was 75%, less than that for the 5-yr-old swards but better than the 1- and 2-yr sward predictions. Again, these data may be skewed by the vigor of the plants. Fall and winter precipitation, April, May, June and July monthly precip-

itation totals were included in at least four of the regression formulae as were monthly evaporation for May, June, July and August.

Alfalfa forage yield was correlated to annual water deficit (Evaporation less precipitation) for each sward age (Fig. 1). The correlation coefficients were lower at sward ages one and two than for older swards and this was similar to the multiple regression results. It is noteworthy that a cluster of high yields at high water deficits is evident in both 1- and 2-yr-old swards but is not evident in the other ages. We interpret these values as representing swards where soil water has contributed to the yields observed. One datum (■) was excluded from the regression and correlation calcula-

Table 2. Weather variables selected by forward stepwise multiple regression equations for historical alfalfa yield prediction from weather data at Swift Current, Saskatchewan by stand age

Stand age (yr)	Partial correlation coefficient by variable										Model R^2	Prob.	RSD
	FWPPT	APR	MAY	JUN	JUL	AUG	EVAPMAY	EVAPJUN	EVAPJUL	EVAPAUG			
1	—	0.018	0.268	—	0.06	0.03	—	—	0.083	0.045	0.498	0.056	1076
2	0.022	0.023	0.035	0.048	—	—	0.123	0.195	0.023	—	0.469	0.142	1058
3	0.033	0.126	0.08	0.016	0.016	—	0.396	0.119	—	—	0.852	0.001	663
4	0.036	0.041	0.083	0.040	0.126	—	0.149	0.241	—	0.023	0.869	0.002	731
5	—	0.076	0.204	0.282	0.105	—	0.056	0.080	0.020	0.049	0.955	0.006	341
> 5	0.092	—	0.054	0.104	0.046	—	—	0.309	0.041	0.110	0.756	0.017	782

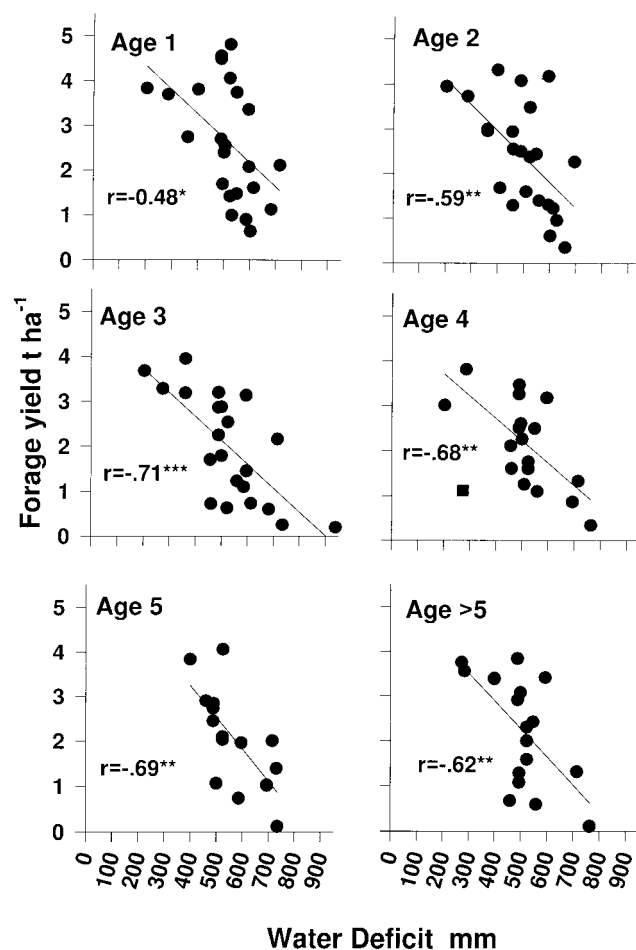


Fig. 1. Alfalfa forage yield as affected by water deficit (Evaporation less precipitation) by age of sward. Lines shown are linear regressions for reference. One datum (■) was excluded from regression and correlation for sward age four. *, **, *** denote $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

tion for age four. In 1982, a 36-cm snowfall from 27 to 29 May resulted in frost damage to all alfalfa cultivars and reduced the yield potential of Rambler. If this datum were included in the correlation, the coefficient would be -0.51 ($P < 0.05$).

When taken together, these results suggest that yields from 1- and 2-yr-old swards of dryland alfalfa do not accurately reflect long-term forage productivity at this semiarid site. This is consistent with Brun and Worcester's (1975)

observation that 1- and 2-yr-old swards of alfalfa had 120 to 150 mm of available soil water (at tension ≥ 1.5 MPa) at 1.22 to 2.44 m deep in the profile, while 6-yr-old swards had zero available soil water at that depth. They also reported that 3- and 4-yr-old swards had 50 mm of additional soil water stored. However, from our results of long-term yields three year old swards were as low in productivity as 5-yr-old swards. Using the 56 to 73 mm H_2O t^{-1} dry matter conversion factor determined by Sheaffer et al. (1988), our yield data suggest that between 37 and 48 or 24 and 31 mm more soil water was used by 1 or 2-yr-old swards, respectively, compared to 3-yr-old alfalfa swards. The preceding crop management used on areas included in our database ranged from wheat-fallow rotation (slow recharge of deep soil water) to 2 or more years of continuous fallow (fast recharge of deep soil water). If alfalfa had been grown previously on a trial site, there may have been little or no recharge of deep soil water (Kiesselbach et al. 1929). This may explain, in part, the wide range of variation within individual years to sward age.

The practical importance of these results is twofold. Regional cultivar trials are conducted for 3 harvest years in Saskatchewan prior to recommendation to producers. Yield decline with stand age should be considered in the evaluation of new cultivars to avoid over estimation of a cultivar's yield potential. Deep soil water utilization (to 3 m soil depth) by alfalfa must be documented in alfalfa productivity research such as agronomy or modelling. If soil water use is not documented, dryland alfalfa yields will be skewed high when yield trials are grown on land not previously seeded to deep rooted crops, i.e. the yields claimed will be misleading and not a true reflection of long-term dryland yields. Once deep soil water reserves have been exhausted, dryland alfalfa yields will depend upon annual soil water reserves added by infiltration of snow melt from the previous winter and growing season precipitation — a true dryland situation. One suggestion would be to report yields, or yield advantages, in water use efficiency terms, i.e., dry matter yield per unit of water used. Assessments of the long-term productivity of dryland alfalfa must consider yield decline with stand age and the longevity of the stand as factors in the analysis.

Brun, L. J. and Worcester, B. K. 1975. Soil water extraction by alfalfa. *Agron. J.* **67**: 586–589.

Campbell, C. A., Zentner, R. P., Selles, F. and Akinremi, O. O. 1993. Nitrate leaching as influenced by fertilization in the Brown soil zone. *Can. J. Soil Sci.* **73**: 387–397.

- Campbell, C. A., Lafond, G. P., Zentner, R. P. and Jame, Y. W. 1994.** Nitrate leaching in a Udic Haploboroll as influenced by fertilization and legumes. *J. Environ. Qual.* **23**: 195–201.
- Cutforth, H. W., Jefferson, P. G. and Campbell, C. A. 1991.** Lower limit of available water for three plant species grown on a medium-textured soil in southwestern Saskatchewan. *Can. J. Soil Sci.* **71**: 247–252.
- Cutforth, H. W., Jones, K. and Lang, T-A. 1993.** Agroclimate of the Brown soil zone of southwestern Saskatchewan. Research Branch, Agriculture Canada Research Station, Swift Current, SK. Publ. no. 379MOO88.
- Goplen, B. P., Baenziger, H., Bailey, L. D., Gross, A. T. H., Hanna, M. R., Michaud, R., Richards, K. W. and Waddington, J. 1980.** Growing and managing alfalfa in Canada. Agriculture Canada Publ. 1705. Ottawa, ON.
- Kiesselbach, T. A., Russel, J. C. and Anderson, A. 1929.** The significance of subsoil moisture in alfalfa production. *J. Amer. Soc. Agron.* **21**: 241–268.
- Pelton, W. L. and Korven, H. C. 1969.** Evapotranspiration estimates in a semiarid climate. *Can. Agric. Eng.* **11**(2): 50–61.
- Sheaffer, C. C., Tanner, C. B. and Kirkham, M. B. 1988.** Alfalfa water relations and irrigation. Pages 373–409 in A. A. Hanson, D. K. Barnes, and R. R. Hill, Jr., ed. *Alfalfa and alfalfa improvement*. Agronomy no. 29. American Society Agronomy, Madison, WI.