Eco-physiological Response to Fertility and Landform for Spring Wheat under Rainfed Environment in Hummocky Terrain, Saskatchewan, Canada.

W.Z. Liu*, E. de Jong, L.E. Cowell & D.J. Pennock, Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 0W0

Abstract: The experiment was made throughout the 1992 growing season on upper and lower slope positions at a site near Lanigan,Saskatchewan. Soil water reserves to 120 cm on the footslope was 38% more than on the shoulder at the beginning of the growing period, and the difference decreased gradually with wheat growth. Soil temperature on the lower slope at both the 50 cm depth and 100 cm depth was higher than on the upper slope before mid-July, whereas the opposite was true afterwards. Latent evaporation on the shoulder was higher than on the footslope. Significant differences occurred between slope positions as well as between fertilizer treatments for both the development of leaf area indices and for the accumulation of above ground biomass. Throughout the growing season,leaf water potentials indicated a high level of stress occurred in all treatments,with the shoulder position exhibiting the greatest stress. No significant difference of leaf water potential occurred between fertilizer treatments. Fertilizer application increased both total and grain yields, and raised water use efficiency, on both slope positions. The effect of the amount of precipitation in flowering-filling stage on harvest indices was enhanced with fertilizer application.

Introduction

Studies of soil fertility and crop relationships at the landscape-scale have been made in Saskatchewan (e.g., Pennock &Anderson,1992; Elliott & de Jong,1992; Cowell & de Jong, 1990); however, few investigations have characterized the eco-physiological response of crops in this region as affected by soil fertility and landscape position, which is important to comprehensively understand the relationship between soil quality and crop yield in agricultural landscapes in Saskatchewan. Usually in field research of crop-soil-landform, crop yield, not crop physiological development has been emphasized.

The purpose of this research was to :1) investigate the ecological environment of crops including soil moisture , temperature and atmospheric potential evaporation at different landscape positions ; 2) analyze the physiological development of crops affected by fertility and landform, including leaf area index,biomass, root length, photosynthesis, stomatal conductance ,and leaf water potential,etc.; and 3)clarify the effect of fertilizer application on yield at different parts of the landscape.

Materials and Methods

Plot Establishment

The experiment was conducted in 1992 on the J. Kresse farm near Lanigan, Saskatchewan. The soil is classified as an Oxbow sandy loam. The site was broken in 1910 and recently has been cropped to canola, wheat and barley with summerfallow every third or fourth year. Wheat was cropped in 1991.

Fertilizer treatments were seeded in strips 1.83m wide and 250m long so that each treatment was applied on all landform elements. Three sites with south aspects were selected within the area, each on a different hillslope, on which the measurements were taken. Physiological measurements on plants were made in two fertilizer treatment and two landform elements, that is , 8N+0P_2O_5 kg/ha for low fertility and 80N+40P_2O_5 kg/ha for high fertility, each on a divergent shoulder and a convergent footslope (Pennock etal,1987). Soil temperature was monitored at both backslopes and footslopes. Besides backslopes and footslopes, latent evaporation was also monitored at shoulders . Soil moisture was measured in both control and test plots where physiological measurements were made. High-F , low-F, high-S and low-S will be used to express high and low fertilizer treatments at footslope and shoulder sites, respectively. The thickness of the A horizon in shoulder and footslope was 16cm and 32cm, respectively.

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* Visiting Scientist from Chinese Academy of Sciences

In this paper, the results will be presented by means of the averages of three replicates from three hillslopes except for the data from the high-F, low-F, high-S and low-S positions.

Spring wheat (cv. Katepwa) was seeded at a rate of 84kg/ha. on May 28, and harvested on September 10, 1992.

Plant Ecological Environment Monitoring

Soil moisture content was measured 5 times during the growing period to 120cm depth by oven drying of samples and neutron probes. Soil temperature was frequently monitored at 50cm and 100cm depths with thermocouple thermometer. Soil temperatures at 2.5cm, 10cm and 25cm were continuously recorded with a data logger. Latent evaporation was measured by atmometers. Precipitation, air temperature, humidity and wind speed were recorded by automatic climate station (the data were from Dr.L.Kozak, Agriculture Canada) , but differences between shoulder and footslope were not monitored.

Plant Measurement

Leaf area were measured with an Agvision System. Dry weights were taken for aboveground biomass and dried at 65°C. Samples were frequently collected by randomly selecting plants at each position . At harvest a 1m x 1.83m sample was taken at four slope positions and measured for total grain and straw weight. Leaf water potential was measured by leaf press at least once on the same dates as plant sample collected. The upper leaf or adjacent leaf to it was selected. A pressure chamber was used to measure leaf water potential at two times, synchronized with a leaf press, so that a regression equation was obtained between them. Net photosynthesis and stomatal resistance were measured once at flag leaf by use of the Li-6200 Portable Photosynthesis System on August 5. Root samples were collected with aboveground plant material two times in the early days. Dry weights of roots were taken after drying at 65°C. Root length was estimated using the Agvision System.

Results

Latent Evaporation

White atmometers were placed on backslope and footslope positions on June 9,and then additional atmometers were set on shoulders on July 30 (Fig 1). Although the latent evaporation per day in backslope was marginally higher than in footslope for each period, there were significant increases in latent evaporation from backslope to shoulder. For example, the latent evaporation at shoulder, backslope and footslope were 49, 33 and 32 g/atmometer/day, respectively, in the period from July 30 to August 5.

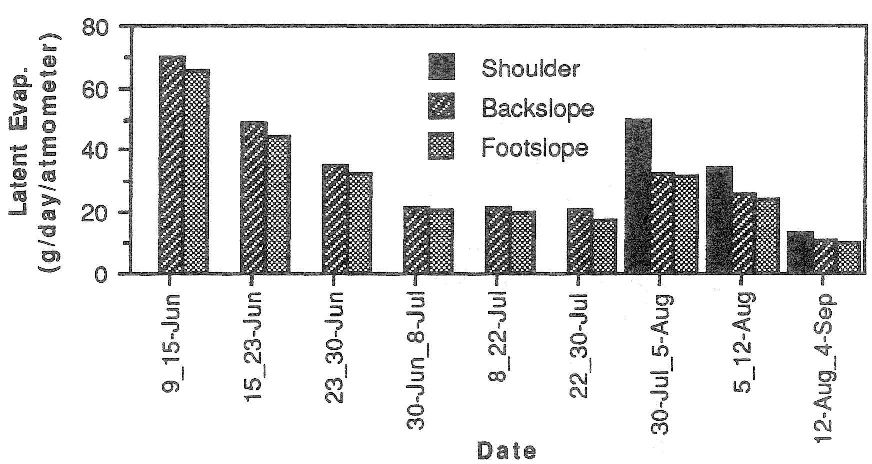

Fig. 1 Latent Evaporation at Different Slope Positions by Atmometers

The biggest latent evaporation occurred in June. It declined gradually through July, but went up again in the early days of August. These variations were related with climatic factors. The correlation coefficient was 0.657 between latent evaporation and air temperature, -0.882 between latent evaporation and air humidity, and 0.852 between latent evaporation and wind speed in backslope; the correlation coefficients in footslope were similar to those in the backslope.

Soil Moisture

There was an obvious increase from shoulder to footslope in June and July(Table 1). More measurements of soil water were done at footslope during the wheat growth period than at shoulder . Soil moisture below 20-40cm at footslope declined gradually with wheat growth before August 19, then increased a little on September 10 because of more rainfall(40.3mm) and lower water consumptive use of wheat from August 19 to September 10.

Table 1 Soil Moisture Data at Different Slope Positions
(mm water /120cm soil)

Date	High-S	Low-S	High-F	Low-F
June 11*	208	208	286	286
July 22	183	177	213	208
July 30			187	200
August 19			135	127
September 10	188	206	195	201

* The data of June-11 were from the control treatment by neutron probe.

Soil Temperature

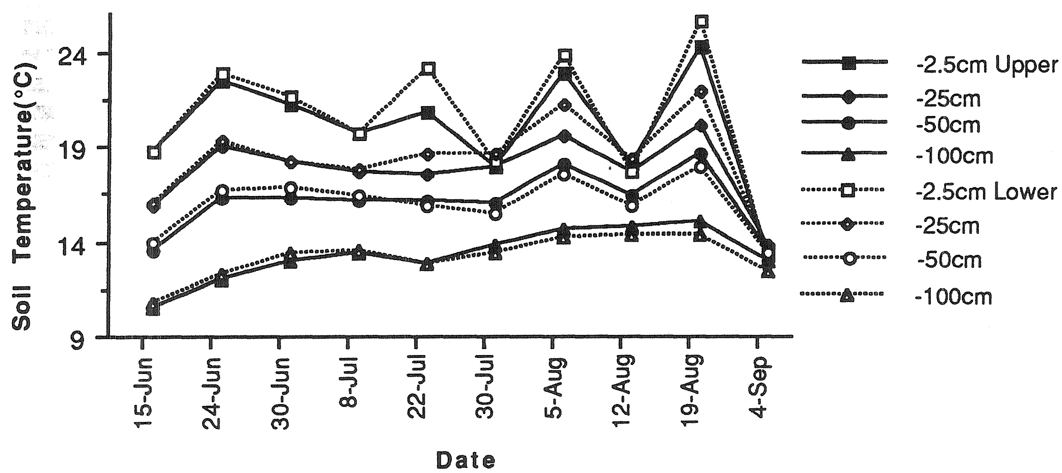

Fig. 2 Soil Temperature Variation during
Spring Wheat Growth Period

The data at 2.5cm and 25cm depths were daily averages, and the data at both 50cm and 100cm depths were results obtained at noon or so, which could approximately be regarded as daily averages because of the limited variation of temperature within one day. At both 50cm and 100cm depths soil temperature on footslopes were higher than on backslope before mid-July,and then smaller than on backslope after this point. At both 2.5cm and 25cm depths the footslope temperature was greater than backslope temperature on most of measurement dates . For all days of measurements, a decrease in soil temperature was associated with increasing soil depth .

Net Photosynthesis and Stomatal Resistance

These properties were measured successfully only once. At 12:00-13:00 on August 5, net photosynthesis rate was 14.41,14.92,18.85 and 15.76 $\mu molm^{-2}s^{-1}$, and stomatal resistance was 4.474, 3.879, 2.822 and 3.923 scm^{-1} for high-S, low-S, high-F and low-F. Based on three replicate measurements, variance analysis showed that differences were significant at p=0.10 between slope position, but not significant at p=0.10 between fertility, for both photosynthesis and stomatal resistance. It can be found that net photosynthesis of high fertility was higher than of low fertility at the footslope, but only a little smaller than low fertility at the shoulder; whereas the opposite was true for the stomatal resistance . On August 5, spring wheat was in the late of filling stage; and air temperature, air humidity and wind speed were 24°C,52% and 3m/s,respectively, at 12:00-13:00; and skies were clear at that time.

Leaf Water Potential

The regression equation between the pressure chamber (Y,bar)and the leaf press(X,psi) was Y = 11.3 + 0.072 X (n=18, R^2= 0.76). Observed endpoints were first appearance of moisture on leaf surface for the leaf press.

Leaf water potential was directly influenced by meteorological factors and soil moisture. It usually changed obviously within one day. Because observations were not taken at a standard time of day, it is difficult to describe the variation of leaf water potential during the wheat growth period . Based on standardization results of each time ((X -Average) /Standard Deviation), variance analysis of all measurements showed differences between slope position were very significant (p=0.001), but differences between fertilizer treatments were smaller (p= 0.114).

Part of the measurement results of leaf water potential are shown in Table 2. On most dates, leaf water potentials indicated a high level of stress occurred in all treatments, and the water stress was more serious in shoulder than in footslope.

Table 2. Leaf Water Potential Variation during Growth Period (bar)

Date	Time	High-S	Low-S	High-F	Low-F
15-June	5:15p	17.1	16.8	17.7	16.8
24-June	11:00a	17.1	18.1	16.9	17.5
30-June	8:30a	15.3	15.3	14.1	13.7
8-July	2:00p	22.6	22.1	20.9	20.5
17-July	12:30p	20.2	19.8	18.6	18.3
22-July	4:10p	20.7	20.2	19.2	19.7
30-July	12:50p	25.0	24.3	23.3	22.5
5-August	10:15a	26.8	26.3	25.2	26.0

Leaf Area Index

For all of four positions the leaf area index was very small before mid-June, then increased. The greatest increase occurred in the early of July. The biggest leaf index occurred in mid- to late July. Leaf area index decreased rapidly in August (Fig. 3).At the same time, the highest leaf area index was always in high-F and the smallest one in low-S. Almost equal indices of leaf area occurred in both high-S and low-F. Analysis of variance showed the differences of leaf area index were very significant (p=0.001) both between fertilizer treatments and between slope positions.

Biomass Aboveground

The biggest differences of biomass aboveground occurred between high-F and low-S (Fig. 4). The differences of biomass were very significant (at p=0.001) between fertilizer treatments as well as between slope positions.

In all of four positions, the biomass aboveground was very small before June 30, and increased very fast in July, especially for the high-F. The results of all four positions were used to calculate average growth rate of biomass aboveground from July 1 to August 5, which were 114.5, 57.9, 61.8 and 38.7 kg/ha./day, respectively for high-F, high-S, low-F and low-S.

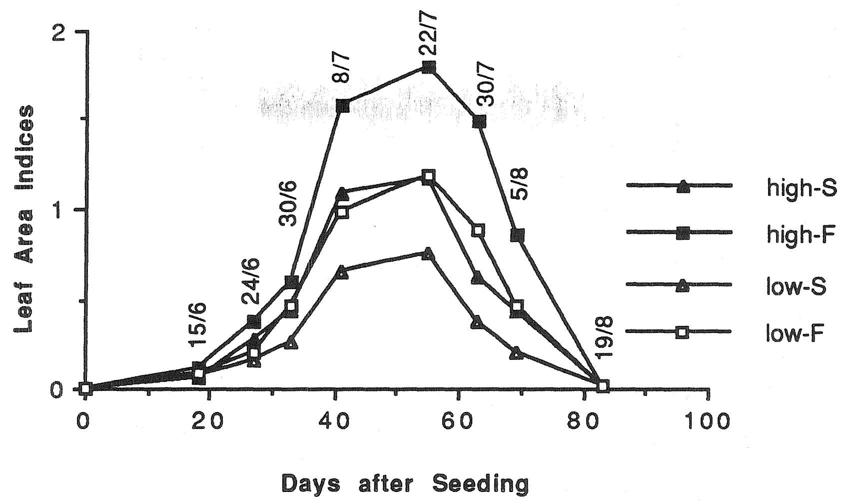

Fig. 3 Leaf Area Index Variation during Growth Period

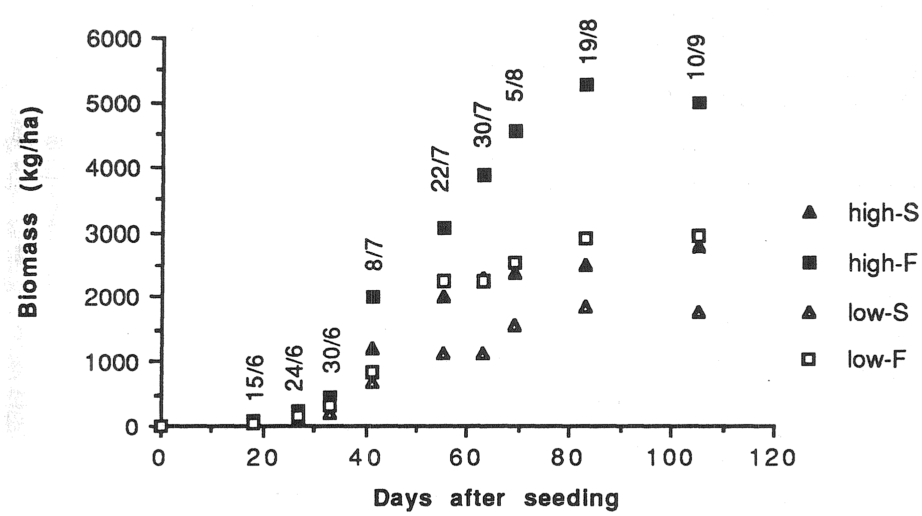

Fig. 4 Biomass Variation during Growth Period

Root Length and Weight

Table 3 Dry Root Weights and Root Length of Seven Plants

Date	High-S	Low-S	High-F	Low-F
		Dry Root Weights(g)		
June 24	0.2478	0.1948	0.3711	0.205
June 30	0.3895	0.2979	0.5146	0.3784
		Root Length (cm)		
June 24	507.3	411	565.5	459.7
June 30	1423.1	892.8	2827.4	1530

Whether on June 24 or on June 30, the biggest value occurred in high-F and the smallest in low-S for dry root weights as well as root length, which were similar to biomass aboveground. From June 24 to June 30, there were bigger increases in aboveground biomass than in root weights, especially for footslope.

Yield and Harvest Indices

Although the significant levels of differences could not be tested by analysis of variance because of only one single sample for each position, the increasing trend was obvious from low fertility to high fertility as well as from shoulder to footslope. The differences of harvest indices between different positions were very small . Grain yield were 1156.9,776.9,2017.5 and 1228.5 kg/ha, and harvest indices were 0.41,0.44,0.40 and 0.42 for high-S, low-S, high-F and low-F, respectively.

Discussion

Rolling terrain causes precipitation to be redistributed from upper slope to lower slope positions. Soil quality differences occur in different slope positions because of erosion and runoff. Micro-meteorological characteristics are changed by rolling terrain itself. All of this influences crop growth.

In the beginning of the spring wheat's growing period ,soil water in 120cm depth of soil in the footslope was 78 mm or 38% more than in shoulder. The soil temperature of the lower slope was greater than the upper slope at 50 cm and 100 cm depths before mid-July , whereas the opposite was true after this. Latent evaporation of shoulder was bigger than of footslope,which subjected the wheat on shoulder positions to a more serious water stress. All of this was of benefit to the wheat in footslope. Under low fertilizer treatment, dry root weights of shoulder and footslope increased by 53% and 85%, root length increased by 117% and 233%, and aboveground biomass increased by 80% and 135% ,respectively, from June 22 to June 30.

Leaf water potential is directly related to soil water regime and latent evaporation. According to several measurements, soil moisture at shoulder was lower than at footslope in the early days, but both of them were far from the level of field capacity after June. Soil moisture at footslope was lower than 40% of field capacity for a time because of heavy water use by wheat. Additionally, there was more latent evaporation in shoulder than in footslope. This was the reason why leaf water potential was low in all of four positions , and lower in shoulder than in footslope during full growing period.

Both fertilizer treatments and slope position had significant effects on biomass aboveground of spring wheat. The differences in average net photosynthesis rates were significant between fertilizer treatments as well as slope positions . However, sometimes the differences of net photosynthesis rates were not significant.

Consumptive use of water in high-F,high-S, low-F, and low-S was 190,120,185 and 102 mm, respectively, from June 11 to harvesting date if runoff was ignored, which showed that the difference between slope positions was large than between fertilizer treatments. Corresponding to the above consumptive use of water, water use efficiencies of four positions were 10.56, 9.64, 6.64 and 7.62 kg/ha/mm, respectively, if water use from seeding date to June 11 was not counted; therefore, water use efficiency increased with fertilizer application. However, the runoff could not be ignored in the calculations of exact water use. The reserve water in the upper 120cm of soil increased by 60mm and 70mm from August 19 to September 10, respectively for high-F and low-F, but precipitation was only 40.3 mm at the same period; the remainder was supplied by runoff from upper slopes . The rainfall intensity reached 3mm/hr. for a time on 4 September, which may have generated runoff.

Almost no precipitation was received for the flowering stage in mid- to late July of 1991 (Pennock & Anderson,1992); however, more than 40mm of rainfall happened in the same period of 1992. The effects of this on harvest indices was obvious in high fertilizer treatment and little in low fertilizer treatment.

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