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Alteration of soil water content consequent to root-pruning at a windbreak/crop interface in Nebraska, USA

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Abstract

Root-pruning is generally recommended as an appropriate treatment to reduce competition for soil water and/or nutrients and suppression of crop yield in areas adjacent to windbreaks. Several recent studies suggest, however, that factors other than soil water might be causing yield reduction at the interface. For two consecutive years, we evaluated root-pruning effects on soil water at the windbreak/crop interface under both cropped (soybean [*Glycine max (L)* Merr.] variety '*Iroquois*', 1997) and non-cropped (1998) conditions in Mead, Nebraska, USA. Volumetric soil water content near the windbreaks was systematically measured at various soil depths, distances from the windbreak, and windbreak exposures using Time Domain Reflectometry (TDR). Overall differences in soil water content between root-pruned and non-pruned plots in soybean were smaller in magnitude at all distances in both the west (windbreak on the east side) and the east (windbreak on the west side) exposures in 1997, compared with the non-cropped condition in the south exposure in 1998. With a soybean crop in 1997, volumetric soil water content in the east exposure averaged 2.3% greater in the top 30 cm of the soil profile at a distance of 0.75H (H = windbreak height) into the field from the windbreak when compared to the non-pruned treatment. In the west exposure, however, the differences were undetectable at corresponding distance and depth. The increase in soybean yield in root-pruned plots corresponded well with the observed differences in soil water content at various distances, especially in the east exposure. Under a non-cropped condition in 1998, soil water content in the root-pruned plots was significantly greater than the non-pruned plots in the top 45-cm profile, averaging 3.3% at 0.75H and 2.2% at 1.0H. Beyond 1.0H, the increase was not significant. These results agree with the previously reported range of crop yield suppression near windbreaks, indicating that soil water competition between the crop and windbreak is highly related to, and probably plays a leading role in yield suppression within the competition zone.

Introduction

Field windbreaks constitute an important component of sustainable cropping systems around the world. With the ever-increasing demand for food production, the limitation on arable land resources, the global change in climate, and deterioration of the environment, windbreak technology provides a vital tool for sustainable agricultural systems (Bagley 1988; Burel 1996; Brandle et al. 2000). Field windbreaks reduce wind speed in the zone behind (leeward) the windbreak. As a result, the potential threat of wind erosion is reduced and microclimate conditions for crop production are enhanced (Van Eimern et al. 1964; Rosenberg 1979; McNaughton 1988). Windbreaks take a portion of the land out of crop production and entail an initial investment for establishment. However, widespread research and overwhelming evidence indicate that windbreaks lead to a net increase in total crop yield and crop quality (Stockeler 1962; Brandle et al. 1984; Kort 1988; Baldwin 1988). As a result, the net economic return is positive, input costs are reduced, and environmental conditions are improved (Brandle et al. 2000).

Although the vast majority of crop studies have indicated a positive response to windbreaks, there appears to be a general reluctance by producers to divert even a small proportion of their field to windbreaks. One reason for this reluctance comes from the variable yield reports in the literature. Another is related to the competition at the interface between the windbreak and the crop (Ong 1991; Ong and Huxley 1996). Although yield suppression exists only within distances extending to 1.0–1.5 times the height of the windbreak (Kort 1988), and yield enhancement beyond this distance more than compensates for this suppression (Brandle et al. 1984, 1992), farmers still cite competition as a major reason not to include windbreaks in their farming systems (Rasmussen and Shapiro 1990). Windbreak root-pruning is an effective way to address farmer's concerns because it alleviates yield suppression in both alley cropping and field windbreak systems over a wide range of geographical regions (Stockeler 1962; Lindquist 1971; Naughton and Capel 1982; Ong 1991).

Kowalchuk and de Jong (1995) reported that competition for soil water, rather than nutrients, constituted the major reason for crop yield suppression of spring wheat in western Saskatchewan in years when growing season rainfall was below normal, but when soil water was abundant the effect was barely noticeable. Lyles et al. (1984) compared root-pruning various types (species) of single-row field windbreaks in Kansas and found significant differences in soil water content adjacent to different windbreak species, especially during fallow years. They further reported that winter wheat yield increased up to 60% following root-pruning. Ssekabembe et al. (1994) reported that black locust (*Robina pseudoacacia* L) hedgerows decreased soil water content between tree rows by 8% to 32% depending on soil type. In contrast, no major differences in soil water content were detected if the tree rows were separated from the cropping area using underground partitions.

Rasmussen and Shapiro (1990) reported that root-pruning increased both soybean yield (32% at 7.5 m from the windbreak) and corn yield (18% at 7.5 m from the windbreak) when all root-pruning treatments were compared with non-pruned plots. Soil sampling for gravimetric water content at various distances from the windbreaks revealed no differences among treatments at three sampling depths and three distances from the windbreak. They attributed the lack of differences to above-normal precipitation.

The mixed results from previous attempts to quantify competition for soil water by windbreaks may have resulted from the confounding effect caused by concurrent crop transpiration, and differences in sampling frequency and numbers. Another factor may have been measurement methodology.

Gravimetric sampling was used for measuring soil water content in most of these studies (Stockeler 1962; Lindquist 1971; Lyles et al. 1984; Rasmussen and Shapiro 1990; Ssekabembe et al. 1994). While direct soil sampling is one of the most accurate methods, there are some obvious limitations, including limited effective sampling volume per sample, small sample numbers, soil disturbance, and the impossibility of repeated measurements. These limitations make gravimetric determination problematic for use in experiments that require frequent measurements. For these reasons, most previous studies have drawn conclusions from a limited number of sample events with a relatively small number of soil samples per treatment (Lyles et al. 1984; Rasmussen and Shapiro 1990; Korwar and Radder 1994).

In recent years, TDR has developed into one of the more reliable methods for indirectly measuring volumetric soil water content (Pearcy et al. 1989). Its working principles and field applications are well-documented (Topp et al. 1984; Dasberg and Nadler 1987). In addition, its ease of use, large effective sensing volume per sample, and ability to provide repeated measurement, made TDR the method of choice for our study.

We hypothesized that tree root-pruning would increase the amount of soil water available to the crop within the windbreak competition zone and consequently enhance crop biomass and yield. However, increased crop biomass can consume the additional soil water saved by restricting extraction of available soil water by roots of the windbreak tree. Consequently, the effect of root-pruning on soil water content may, or may not, be detectable by measuring soil water content depending on the balance of soil water supply and demand, time of measurement, and stage of crop development.

The objectives of this study were to determine the spatial distribution of soil water at the windbreak/crop interface, the effect of tree root-pruning on the seasonal dynamics of soil water content, and to compares the results under cropped and non-cropped conditions.

Materials and experimental design

Field conditions and experimental layout for 1997

The study was conducted at the University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC) near Mead, Nebraska, USA (41°29′ N, 96°30′ W, and 354 m above sea level). The soil was a typical Argiudoll (Sharpsburg silty clay loam), recently reclassified in the Aksarben series (National Cooperative Soil Service, NRCS 1997). The experimental fields were essentially flat with slopes less than 2%.

Three windbreak systems, each with windbreaks along the east, west, and south sides of the field, were used in 1997. Each windbreak consisted of two rows of trees. Within-row spacing was 2 m and between-row spacing was 4 m. One row consisted of alternating pairs of green ash (*Fraxinus pennsylvanica* L.) and Austrian pine (*Pinus nigra* Arnold). The other row consisted of alternating pairs of green ash and eastern redcedar (*Juniperus virginiana* L.). Planted in 1966, the windbreak systems averaged 12 m in height. On 9, May 1997 [DOY (Day Of Year) 129], soybean [*Glycine max (L)* Merr.] variety '*Iroquois*' was planted in rows 76 cm apart, parallel to the windbreaks. No irrigation was applied.

A strip-split-plot design was used with root-pruning and distances from the tree line as the whole plot and split-plot factors. Within each windbreak system, tree/crop interfaces at both the east and west side of a windbreak were subdivided into four pairs of two plots perpendicular to the tree row. One plot from each of the four pairs was randomly selected and root-pruned to a depth of 0.75 m with a single 0.75-meter-long ripper knife at 0.6H from the first tree row (H = windbreak height). Within each plot, soil water sampling locations were systematically arranged along the centerline perpendicular to the windbreak at distances of 0.5H, 0.75H, 1.0H, and 1.25H. At each sampling location, two pairs (30-cm and 45-cm long) of TDR waveguides were vertically installed using a pilot tool, giving an integrated value of volumetric soil water content over a 30 cm or 45-cm profiles, respectively. Volumetric soil water content was measured 7 times at approximately biweekly intervals from DOY 155 (June 4) to DOY 255 (September 12) with a portable TDR system (Trase, Model 6050X1, Soil water Equipment Corp., CA). Precipitation was measured at 5H from the nearest windbreak in each of the three windbreak systems. In a companion study (Nieto 1998), soybean leaf area index was measured using a Licor LAI 2000 Plant Canopy Analyzer (Licor Inc., Lincoln, NE). Biomass was determined at vegetative stage V-6 and reproductive stage R7 (Ritchie et al. 1988). Grain yield at harvest was determined at each soil water measurement location.

Field conditions and experimental layout for 1998

In 1998, the soil water content patterns were reevaluated using an east-west oriented two-row windbreak under non-cropped conditions. The windbreak was 32 years old, 11-m tall, and 240-m long. Trees in the south row consisted of eastern redcedar alternated with Scots pine (*Pinus sylvestris* L.) on a 2-m within-row spacing. The north row was composed entirely of eastern redcedar on a 2-m within-row spacing. Between row spacing was 4 m. A 40-m-wide strip along the south of the windbreak was kept free of vegetation during the entire study period. At each end of the windbreak a 30-m buffer zone was left to reduce end effects. The remaining area was subdivided into four paired plots (as replications) perpendicular to the tree row. Within each replication, one plot was randomly selected for root-pruning while the other served as a control (non-pruned). Windbreak sections within the four selected plots were root-pruned to a depth of 0.75 m at 6.6 m (0.6H) from the southern tree row. In each of the eight plots, two sets of TDR waveguides (30 cm and 45 cm) were vertically installed at five locations along the centerline perpendicular to the windbreak at relative distances of 0.5H, 0.75H, 1.0H, 1.25H, and 1.5H. Volumetric soil water content was measured 32 times between June and September with the portable TDR system for the 0–30 cm and 0–45 cm soil profiles.

Precipitation was measured at each of the five distances corresponding to soil water sampling points in four replications using plastic rain gauges (Forestry Supplier Inc.) Twenty-two rain events were recorded during the entire study period.

Statistical analysis

Soil water content was the dependent variable and root-pruning, distance from the tree line, and depth of the soil profile, as well as their two- and three-term interactions were examined for fixed effects. With replication as a random variable, the SAS MIXED Procedure was used for the computation of least square means and separation of differences between treatment components and their interactions (SAS Institute 1996).

Given the large differences in soil water content associated with windbreak orientation, separate statistical analyses were conducted on an exposure basis for both 1997 and 1998. With replications as a random factor, the mean soil water content for each treatment factor (pruning, distance, and depth) as well as their high level interactions at 0.75H and 1.0H were separated using the LSMEANS statement with the SAS MIXED Procedure. Degrees of freedom for each least square mean were approximated using Satterthwait's method. Samples of soybean leaf area index, biomass, and yield components were taken at corresponding locations to soil water measurement in each replication. SAS MIXED Procedure was used separating treatment main effects and that of their interactions (Nieto 1998).

Results and discussion

1997

Under a soybean crop in 1997, soil water content profile in the west exposure was consistently greater than in the east exposure ($P \leqslant 0.07$). The volumetric soil water content averaged over all seven measurements (DOY 155, 169, 188, 199, 233, 247, 255) was 2.2% higher in the west exposure due primarily to the higher soil water contents of the 0–30 cm and 0–45 cm profiles at 0.75H (Figure 1). Date of measurement had a significant effect on soil water content profile ($P < 0.0001$), but no significant interaction was found between measuring date and exposure.

Temporal variation in soil water of the 45-cm profile was closely related to the weather conditions preceding the time of sampling and the stage of crop development. For the first set of measurements in early June, the overall soil water content was greater because water accumulated during the non-crop-season was still available and transpiration from the young crop plants was low. As crop development proceeded, leaf area index increased, and hence water uptake increased as evidenced by the decline of mean soil water content during July and early August. By mid- to late-September, the vegetative growth and pod-fill of the soybean plants slowed down and finally ceased, causing an overall decline in water consumption. Subsequent precipitation recharged the soil profile resulting in an overall increase in soil water content (Figure 1).

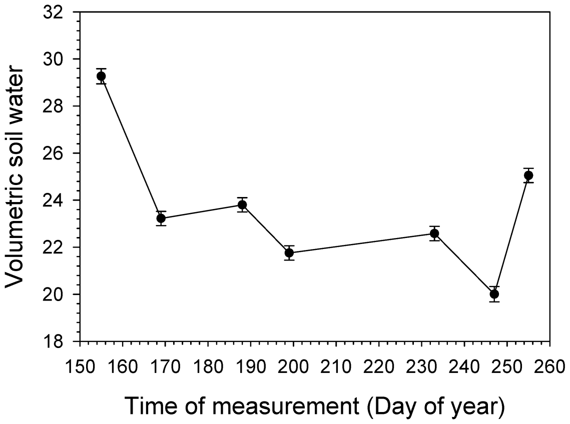

Figure 1. Temporal trend of the mean soil water profile in the 45-cm profile over all measurement locations when soybean crop was involved in Mead, Nebraska, USA in 1997. Error bars represent standard errors for the mean soil waters.

Another temporal trend for both exposures was the consistently greater mean soil water content in the top 45-cm soil profile as compared to the top 30-cm profile (Figures 2A vs. 2B and 2C vs. 2D) ($P < 0.0001$). In the west exposure (Figures 2C and 2D) soil water content for the top 30-cm profile averaged 26.4% in contrast to 29.5% for the top 45-cm profile ($P < 0.001$). The corresponding mean soil water contents for the two profile depths on the east exposure were 24.6% and 26.7% ($P < 0.001$) (Figures 2A and 2B), respectively. While the mean soil water content in the 45-cm profile reflected soybean water extraction patterns at different stages of development, temporal fluctuations observed for the 30-cm profile were most likely due to a greater concentration of fine roots of the crop (Casper and Jackson 1997) as well as more frequent rainfall recharge in the upper soil profile layer.

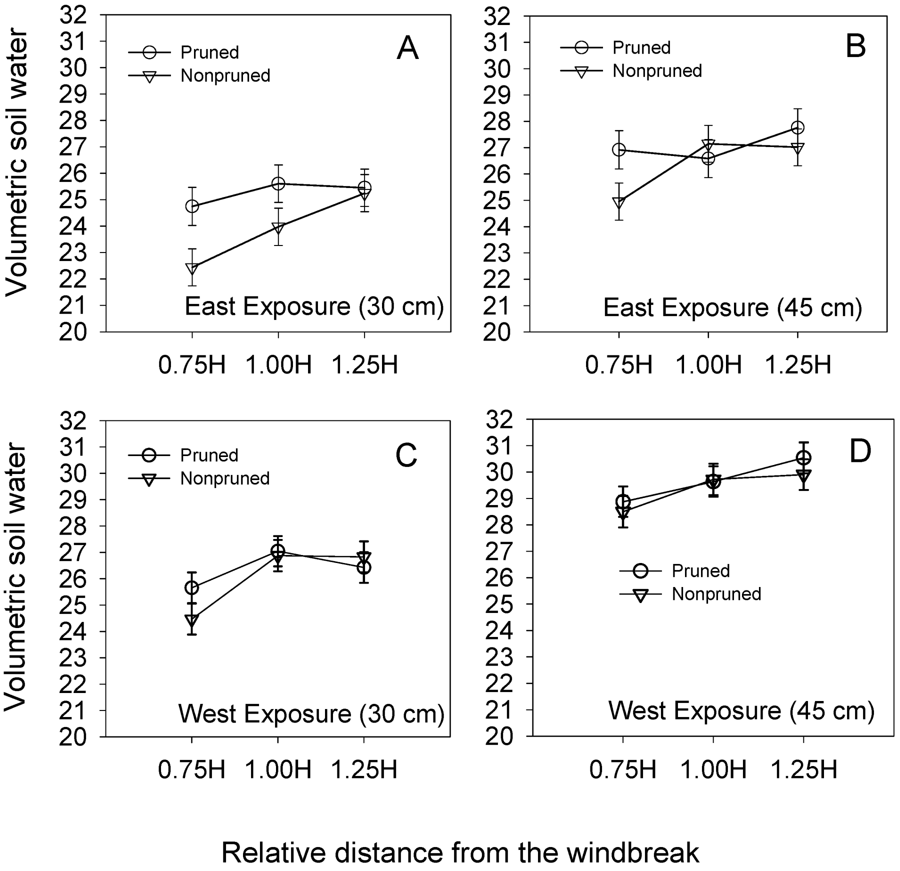

Figure 2. Mean soil water profiles as a function of windbreak exposure, pruning treatment, relative distance from the windbreak, and depth of the soil (30 cm and 45 cm) in Mead, Nebraska, USA in 1997. Data include all seven sampling dates; H = windbreak height; Error bars represent standard errors for the mean values.

Root-pruning effects on soil water content in different exposures

Root-pruning had different effects on soil water content in the two windbreak exposures under cropped conditions in 1997. In the west exposure, no significant moisture profile differences were found at any distance or profile depth in root-pruned plots compared to corresponding locations in the non-pruned plots throughout the season (Figures 2C and 2D). Overall soil water contents for both root-pruned and non-pruned plots were almost identical ($P \leqslant 0.75$). Although mean soil water content at 0.75H for root-pruned plots was 1.2% and 0.3% higher in the 0–30 cm and 0–45 cm profiles, respectively, than that of the non-pruned plots, neither was statistically significant at the 5% level. At 1.0H and 1.25H the effect of root-pruning was undetectable over either profile (Figures 2C and 2D). As expected, distance from the windbreak had a significant effect ($P \leqslant 0.03$). For all measurement dates, soil water content in the profile increased with distance from the tree line in both root-pruned and non-pruned plots. If extraction of water by tree roots contributed to the steeper gradient in non-pruned plots, microclimate variation might be more responsible for the observed soil water gradient in root-pruned plots. Such microclimate variations include windbreak shading and crown effects on rainfall distribution.

The east exposure exhibited similar soil water patterns to that of the west exposure in terms of distance and depth, but root-pruning caused a complicated effect of interactions (Figures 2A and 2B). Root pruning by distance interaction was stronger compared to those in the west exposure ($P < 0.07$). A close look at the pruning by distance by depth interaction ($P \leqslant 0.18$) indicates that at a distance of 0.75H, mean soil water contents for the top 30-cm and 45-cm profiles were 2.3% and 2.0% greater in root-pruned plots than

Table 1. Soybean mean leaf area index (LAI), mean biomass at V6 and R7 (t ha^{-1}), mean grain yield (t ha^{-1}), and mean yield component (pods per plant) as a function of root pruning (Prun: Pruned plots; Non-P: Non-pruned plots) and relative distance from the windbreaks during 1997 growing season.

Distance/Treatment	LAI		Biomass (V6)		Biomass (R7)		Grain Yield		Pods/Plant	
	Prun	Non-P	Prun	Non-P	Prun	Non-P	Prun	Non-P	Prun	Non-P
0.5H	1.17	0.88	0.35	0.26	1.91	1.91	715.3	567.4	18.6	12.8
0.75H	2.09	1.70*	0.93	0.78*	4.26	3.53[n]	2180.4	1767.0*	31.8	26.3*
1.50H	3.15	3.14[n]	1.33	1.31[n]	7.25	6.85[n]	3098.4	2982.7[n]	38.5	36.6[n]

* Significantly less than those observed at corresponding locations in the root-pruned plots at the 5% level. [n] Not significantly different from those observed at corresponding locations in the root-pruned plots at the 5% level. V6: Soybean phenological stage of sixth node. R7: Soybean physiological maturity.

in the non-pruned plots. By t-test, their associated probability levels were 0.03 and 0.06, respectively. At 1.0H and 1.25H distances, the corresponding differences dropped to 1.6% and –0.6% for the 30-cm profile compared to 0.2% and 0.7% for the 45-cm profile, and neither difference was statistically significant.

Soil water differences between exposures

The differences in soil water content between exposures may have resulted from windbreak shading and consequent differences in leaf area index and crop biomass. Close to the windbreak in the west exposure, total biomass and leaf area index (LAI) at different development stages (V6 & R7) and final yield were lower than for the east exposure (Table 1). Larger biomass would translate into higher water consumption through crop transpiration, resulting in lower soil water content in the east exposure throughout the growing season. Compared to the west exposure, the better soybean growth performance in the east exposure nearer the windbreak (0.5H and 0.75H distances) may have resulted from a more favorable diurnal light pattern (Rosenberg et al. 1983). Moisture stress is relatively less severe during the early morning than in the early afternoon because of lower air temperatures. Less moisture stress, coupled with favorable light conditions create better growth conditions and may result in better use of available soil water for biomass accumulation in the east exposure. In contrast, the west exposure had favorable light conditions beginning later in the morning and mostly in the afternoon when air temperatures were often higher than optimum and there was a greater potential for plant moisture stress (Nieto 1998). In addition, plants close to the windbreak in the west exposure were shaded during the morning when temperatures were more favorable. Consequently, favorable temperature and light conditions were not synchronized in the west exposure and may account for lower yields. Lower crop production would mean lower water consumption, which, in turn, may translate into higher soil water content.

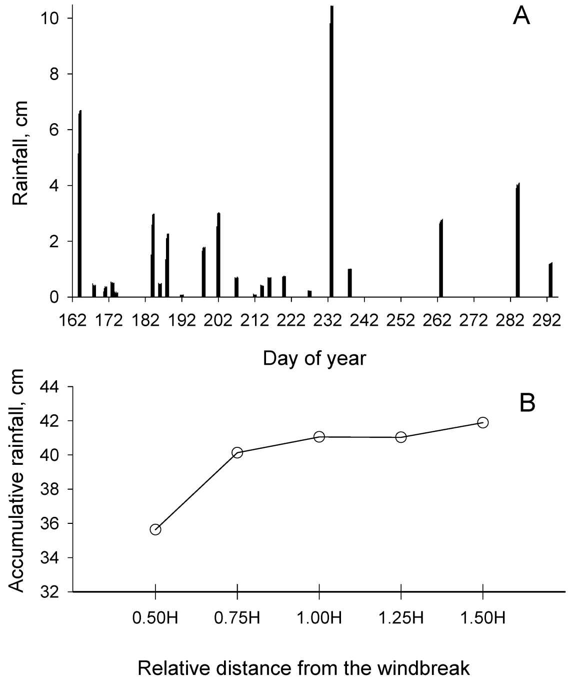

Figure 3. Rainfall distribution as measured in the south exposure from June 12 (DOY 163) to October 24 (DOY 297)(A), and the accumulative precipitation at different relative distances from the windbreak (B) in Mead, Nebraska, USA in 1998. H = windbreak height.

Root-pruning and soybean yield

Leaf area index, biomass, yield, and yield components for soybean were significantly increased as a result of root-pruning (Table 1). Overall soybean yields in root-pruned plots were 81 kg ha^{-1} and 154 kg ha^{-1} greater in the west and east windbreak expo-

Table 2. Comparison of daily mean soil water (%) and the associated probability levels between root-pruned and non-pruned plots in the top 45-cm profile at various relative distances from the windbreak in 1998. H = windbreak height, T is T-Value, and Pr < ¦ t ¦ represents the probability of t statistics greater than the observed T-Value.

DOY	Distance	Non-pruned	Pruned	Difference	SE	Pr < ¦ t ¦
224	0.75H	26.84	29.44	2.59	1.72	0.1382
	1.00H	28.66	31.19	2.53	1.72	0.1483
	1.25H	29.86	31.10	1.24	1.72	0.4739
225	0.75H	26.77	29.86	3.09	1.82	0.0968
	1.00H	28.81	31.28	2.46	1.82	0.1825
	1.25H	30.13	31.68	1.55	1.82	0.3979
226	0.75H	26.62	28.66	2.04	1.62	0.2136
	1.00H	29.63	32.10	2.46	1.62	0.1351
	1.25H	29.53	32.23	2.71	1.62	0.1014
227	0.75H	26.79	29.73	2.93	1.71	0.0927
	1.00H	28.88	31.24	2.35	1.71	0.1745
	1.25H	31.61	33.08	1.46	1.71	0.3948
254	0.75H	26.04	29.88	3.84	1.23	0.004***
	1.00H	28.42	29.95	1.53	1.23	0.2204
	1.25H	30.68	32.07	1.39	1.23	0.2624
255	0.75H	25.93	29.99	4.06	1.24	0.002***
	1.00H	28.84	30.72	1.88	1.24	0.1356
	1.25H	30.72	31.68	0.95	1.24	0.4456
256	0.75H	26.15	29.77	3.62	1.34	0.01***
	1.00H	28.73	31.44	2.71	1.34	0.0498**
	1.25H	31.97	32.36	0.40	1.34	0.8306

** Significant at 5% level; *** Significant at 1% level. SE = Standard error.

sures than in the corresponding non-pruned plots. At distances of 0.75H, yield was up to 192 kg ha^{-1} and 874 kg ha^{-1} greater, corresponding to 12.2% and 40.8% in the west and east windbreak exposures, respectively. At distances of 1.50H, the yield responses to root-pruning were not statistically significant at the 5% level in either windbreak exposure. These soybean yield responses corresponded well with the measured soil water content patterns with respect to root-pruning, distance from the tree line, and windbreak orientation. The similar patterns for soil water content and soybean yield suggest that soil water extraction by the trees was responsible for the crop yield suppression at the windbreak/crop interface. They also indicate that the degree of windbreak/crop competition for soil water was a function of windbreak orientation as well as distance from the windbreak. In this particular study, the reduction in soil water content due to extraction by windbreaks was most severe within a distance of 1.0H and was more prominent in the east than in the west exposures.

1998

Distribution of precipitation at the interface

Daily rainfall distribution by distance for the 22 rain events recorded from June to October are shown in Figure 3. Because no significant differences were observed beyond 1.0H distances, the average precipitation values recorded at distances of 1.0H, 1.25H, and 1.5H were used as the reference for comparing precipitation reductions at 0.5H and 0.75H. Statistical analysis indicated that cumulative rainfall at 0.5H and 0.75H was 14% ($P < 0.001$) and 2.9% ($P < 0.05$) less, respectively, than the average at 1.0H, 1.25H, and 1.5H distances.

Of the 22 rain events, mean rainfall at 0.5H was below the average for the 1.0H, 1.25H, and 1.5H sampling locations for 10 events ($P < 0.05$), while the other 12 events showed no significant differences between distances. Darnhofer et al. (1989) suggested that rainfall modification by windbreaks usually occurs within one-tree height of the windbreak, depending on wind direction. The majority of the events during this study occurred with southwesterly or southeasterly winds, which have less effect on southfacing than north-facing interfaces. Because the 0.5H distance was located inside the pruning line and usually does not contribute to yield production, precipitation was considered to play a marginal role in soil water content at the other distances during the 1998 field experiment. Nevertheless, the windbreak edge effect on precipitation could intensify and extend deep into the field depending on the windbreak height and orientation with respect to the dominant wind direction during rain events and on how much lateral movement of soil water occurred.

Soil water content in the pruned and non-pruned treatments

Mean daily soil water contents in the root-pruned plots were on average 2.04–4.06%, 1.53–2.71%, and 0.4–1.75% greater at the 0.75H, 1.0H, and 1.25H locations, respectively, than in the corresponding non-pruned plots. For some days of measurement, the differences in soil water content at the 0.75H distance were statistically significant at the 5% level while those at the 1.0H and 1.25H locations were not significant (Table 2). Between June and September, the mean soil water content in both pruned and non-pruned treatments followed a similar trend in both the 30-cm and 45-cm profiles (Figure 4). No treatment differences in soil water content were detected in the 30-cm profile. These results differed from those in 1997 and were most likely related to windbreak orientation and lack of a crop cover. On the other hand, mean soil water contents in the 45-cm profile in the root-pruned plots were consistently greater at the 0.75H and 1.0H locations than at the corresponding locations in the non-pruned plots. But, the effect of root pruning was not as significant at the 1.25H distance.

The effect of root pruning on soil water content in the 30-cm and 45-cm profiles may be related to differences in cultivation and/or bare soil evaporation. The spring cultivation in 1998 may have disturbed the upper layer of the soil, reducing the number of fine tree roots and making it less likely that the windbreak thoroughly exploited this region of the profile. Fine roots immediately below the cultivation zone may have remained undisturbed in the non-pruned treatment, leading to a significant decline in soil water content caused by the extraction of windbreak roots. This hypothesis was supported by observations of the vertical distribution of tree roots in four, 75-cm-deep access pits dug at each 0.75H locations, which showed that fine root densities were greater in the 30–45 cm soil layer than in the top 30-cm profile. With no crop cover and no other vegetation, soil evaporation from the upper profile could become a dominant factor that could easily overshadow the treatment effect, especially as the time since the last rainfall event increased.

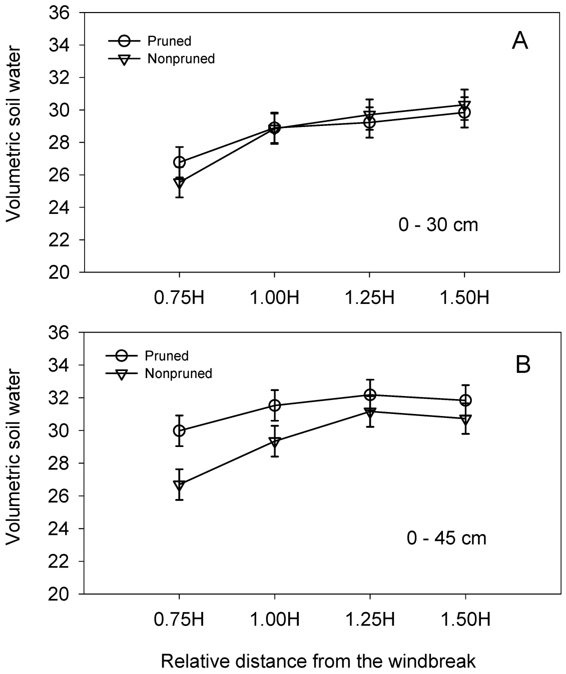

Figure 4. Mean soil water as a function of pruning treatment, relative distance from the windbreak, and depth of the soil profile in the south exposure in Mead, Nebraska, USA in 1998. Means calculated with SAS mixed procedure for all measurements taken over the entire season. Error bars represent standard errors for the means. H = windbreak height.

Daily soil water content for the period from August 13 (DOY 225) through September 13, 1998 (DOY 256) illustrates the similarity of the 0.5H and 1.5H distances for pruned and non-pruned plots (Figures 5A and 5B). Root-pruning showed a limited effect on soil water dynamics at 1.5H and 0.5H. Because the 0.5H location was inside the pruning line, it appears that the bulk of the tree root system may not extend out to distances of 1.5H in the adjacent field. The soil profile at the 0.5H location, on the other hand, was most likely occupied by an extensive tree root system capable of exhausting available soil water and maintaining soil water content at low level for most of the time except immediately follow rainfall events capable of fully recharge the soil profile. Between distances of 0.75H and 1.5H, however, the moisture gradient in non-pruned plots dropped nearly

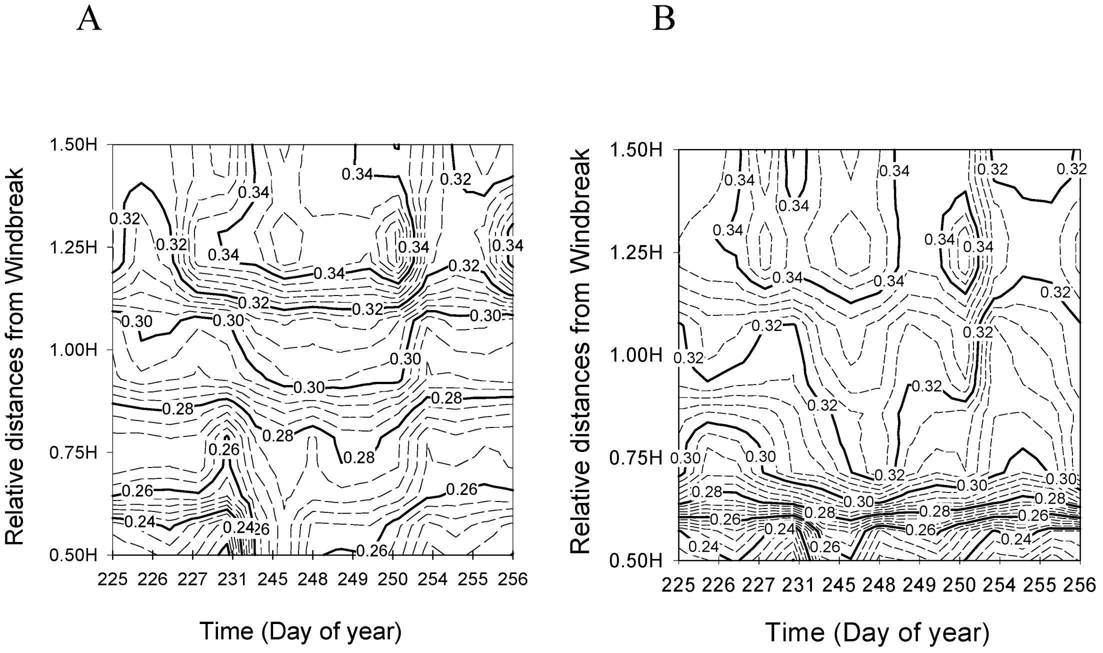

Figure 5. Mean soil water as a function of relative distance from the windbreak and date of measurement in the top 45-cm soil profile of the non-pruned (A) and pruned plots (B) in Mead, Nebraska, USA in 1998. Contour lines represent mean soil water. Inverse distance weighting was used for interpolation between sampling points. H = windbreak height.

3% more than at corresponding distances in the root-pruned plots. The average soil water content at the 0.75H location for root-pruned plots was 3.3% higher than non-pruned plots ($P < 0.05$). As a result, for the majority of dates, soil water contents in root-pruned plots at the 0.75H distance were similar to levels at 1.25H in the non-pruned plots. At 1.0H the difference declined to 2.2% ($P < 0.1$). Beyond the range of one-tree height the differences were smaller and statistically non-significant.

Strong bare soil evaporation could have dampened or even overwhelmed the effect of root-pruning on soil water content, especially for measurements taken in the upper soil profile and/or under persistent drought conditions. With no crop cover in 1998, we examined the effect of root-pruning only to the south of the windbreak where bare soil evaporation was highest among all four windbreak directions due to high net radiation and dominant south and southwest wind at the test location. Consequently, the magnitude of soil water enhancement due to root pruning found in this study could be more pronounced if directions other than the south were included.

Conclusions

The two-year study under cropped or non-cropped conditions indicated that root-pruning of windbreaks altered the spatial distribution of soil water in the root zone within the windbreak/crop interface. Root-pruning decreased extraction of available soil water by the windbreak trees and prompted an increase in crop biomass, which, in turn, induced an increase in water consumption through crop transpiration. The repartitioning of available soil water between the windbreak and the adjacent crop may not be reflected in a net increase of soil water content in the root-pruned zone as assumed in previous studies, but rather in the increase in the biomass of the adjacent crop.

When a soybean crop was involved, a statistically significant increase in soil water content (2.3%, $P < 0.03$) in root-pruned plots was detected only in the top 30-cm profile at the 0.75H distance in the east exposure. The differences in the 30-cm profile at other measurement locations and in the 45-cm profile were less obvious or undetectable for most times during the growing season. Soybean leaf area index, biomass, and grain yield, on the other hand, increased substantially as a consequence of root-pruning. When the confounding effect of crop transpiration was removed by excluding crop vegetation, soil water content in the root-pruned plots was consistently higher than non-pruned plots and the magnitude of differences was greater than that of the cropped condition. The most significant soil water increase in root-pruned plots occurred in the 45 cm (3.3% at 0.75H and 2.2% at 1.0H) rather than in the 30-cm soil profile as observed when a soybean crop was involved possibly because of the strong effect by direct soil evaporation.

Both cropped and non-cropped experiments indicated that severe competition for soil water between the windbreak and the crop existed up to 1.0H from the tree line, which in turn led to a significant yield reduction in this competition zone. In root-pruned plots, soybean yield increased up to 48% while soil water content was 3.3% higher at the 0.75H distance when crop transpiration was excluded. We suggest that this result occurred because root-pruning reduced or eliminated the soil water gradient immediately beyond the pruning line and diverted additional available soil water from the windbreak to the crop.

Soil water competition was the major reason for yield suppression at the windbreak/crop interface, as evidenced by the increment of crop biomass and yield components and by a significant increase in soil water content when crop transpiration was excluded. Thus, root-pruning can effectively reduce yield suppression at the windbreak/crop interface.

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