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Water Relations of Flax, Cotton and Wheat under Salinity Stress

By

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With 4 Figures

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Summary

EL-SHARKAWI H. M. & SALAMA F. F. 1984. Water relations of flax, cotton and wheat under salinity stress. — Phyton (Austria) 24 (1): 87—100, with 4 figures. — English with German summary.

The effect of salinity stress on some parameters pertaining to the water relations of three important crop plants, flax (*Linum usitatissimum*), cotton (*Gossypium barbadense*) and wheat (*Triticum aestivum*) was studied. Such parameters investigated were: diurnal patterns of transpiration and relative water content of plants adjusted to different levels of soil osmotic water potential, ψ_s, using osmotica of NaCl and $CaCl_2$ at a fixed sodium adsorption ratio (SAR) of $^1/_8$. Correlation analyses of obtained data revealed important facts: 1) Both temperature and VPD of air interfere in action with ψ_s in affecting transpiration, the interference magnitude is very high with cotton and not existant with wheat; 2) The osmotic potential of leaves may serve to maintain high relative water content, indicated by the significant positive correlation between both, in flax and cotton (not in wheat); 3) Soil osmotic water potential, ψ_s, induces significant reduction in transpiration rate, the reduction being dependant on evaporative power of air, especially in flax and cotton. The significance of the results obtained, in practical applications, is discussed.

Zusammenfassung

EL-SHARKAWI H. M. & SALAMA F. M. 1984. Wasserhaushalt von Flachs, Baumwolle und Weizen unter Salzstress. — Phyton (Austria) 24 (1): 87—100, mit 4 Abbildungen. — Englisch mit deutscher Zusammenfassung.

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Die Auswirkungen von Salzstreß auf einige den Wasserhaushalt bestimmende Parameter werden studiert. An Flachs (*Linum usitatissimum*), Baumwolle (*Gossypium barbadense*) und Weizen (*Triticum aestivum*) werden Tagesgänge von Transpiration und relativem Wassergehalt der an verschiedenen Bodenwasserpotentialen ausgesetzten Pflanzen untersucht (die Wasserpotentiale des Substrates wurden mit NaCl—$CaCl_2$-Lösungen eingestellt). Korrelationsrechnungen erbrachten folgende Ergebnisse. 1) Temperatur und Dampfdruckdefizit der Luft bestimmen zusammen mit dem Bodenwasserpotential die Transpiration; diese Interferenz ist bei Baumwolle sehr stark, sie fehlt hingegen bei Weizen. 2) Hohe osmotische Potentiale der Blätter führen bei Flachs und Baumwolle (nicht hingegen bei Weizen) zu hohen relativen Wassergehalten, wie gesicherte hohe Korrelationen anzeigen. 3) Das Bodenwasserpotential verringert in Abhängigkeit von der Evaporation die Wasserabgabe, besonders bei Flachs und Baumwolle. Die Bedeutung der Ergebnisse wird im Hinblick auf praktische Anwendbarkeit diskutiert.

(Härtel transl. et abbrev.)

Introduction

Amelioration of desert lands adjacent to the Nile Valley is already activated in the Nubariya & Salehiya areas which are to be subject to crop cultivation under flood-irrigation practices supplied by Nile tributaries. One of the main prospective problems to be encountered with such type of agricultural practice, in desert areas, is salinization enhanced by excessive evaporation under prevailing evaporative demands of the climate. In this respect, relatively low salt content of the order 0.5% in the surface or subsoil would result in, at least, an osmatic problem to plants dealing with the soil solution. For example at a field capacity not exceeding 25% in the Nubariya area (El-Sharkawi & Salama 1975), the soil solution will have an osmotic potential of about 15 atmospheres when the salt content is 0.5%. Therefore, it seems necessary to be careful about choosing plants which can adjust their water relations to increased osmotic stress in the soil.

The aim of the present work is to investigate the effect of osmotic stress (reduced water osmotic potential) in the soil (ψ_s) on some parameters pertaining to the water relations of three highly considered crop plants, flax, cotton and wheat. The plant parameters tested are: Diurnal changes in transpiration and relative water content of leaves in plants adjusted to different osmotic stress levels, the osmotic pressure of plants at the different levels of treatment as well as the leaf root ratio. Of the effective climatic parameters temperature and vapour pressure deficit of air were concurrently measured, as well as the Piche evaporation for the purpose of comparison with the diurnal transpiration patterns.

Material and Methods

Plants experimented with were a cultivar each of flax (*Linum usitatissimum* L.), cotton (*Gossypium barbadense* cv. G-119) and wheat (*Triticum aestivum*, mexican cultivar max-back). Plants were grown in plastic pots containing 1400 g air dry desert soil. Allowed to grow for ten weeks at soil water potential near field capacity, the plants were twice watered with 100 ml portions of full strength Hoagland-nutrient solution prepared according to HOAGLAND & ARNON (1950). Four plants were allowed in each pot. Soil osmotic water potentials (ψ_s) were chosen at —0.3, —7.0, —10.0, —13.0 and —15.0 bar, in addition to the control ($\psi_s = -1/3$ bar). For each potential level, five pots were assigned at random. Osmotic solutions, prepared according to LAGERWERFF & EAGLE (1960) were used in irrigation to adjust ψ_s to the desired levels. A mixture of $CaCl_2$ and NaCl was used in the preparation of these solutions, in which the sodium adsorption ratio (SAR) was fixed at 12.5% in order to prevent Na^+ toxicity and the effect is thus merely osmotic. Solutions were added to the soil in such a way that the soil solution acquires the assigned potential at field capacity. Treatments of plants began when seedlings were 8 weeks old. On completing the treatment, the plants were watered with distilled water only. In this respect the moisture content of the soil was never allowed to fall far away from field capacity. This was achieved by checking weights of pots twice daily. To ensure homogeneous distribution of moisture in the soil, watering was secured through specially-constructed perforated irrigation tubes inserted 3/4 way down near the center of the pot. The plants were allowed to adjust to treatment for a period of 3 weeks before starting measurements.

Transpiration was measured gravimetrically by weighing the pots at fixed times, the pots being tightly sealed with polyethylene sheets at the level of shoot base of plants. Weighings were carried out during daytime at 7 a.m., 10 a.m., 1 p.m., 4 p.m. and 7 p.m.

Measurement of relative water content (RWC) was carried out by the method of WEATHERLY & BARRS (1962) and the osmotic pressure of leaf sap by the cryoscopic method (WALTER 1949). Since the ionic component of plant osmotic material may change (as accumulation of ions observed or increased synthesis of organic acids may take place), the electrical conductivity (E_c) of the sap was measured. A resistance meter model (CTH/1) was used for this purpose. The partial osmotic pressure due to the ionic fraction was calculated from the equation (BLACK *et al.* 1965):

$$\text{OP (atm.)} = E_c \text{ (mmhos)} \times 0.36$$

The osmotic pressure values measured by the cryoscopic method are referred to as the total osmotic pressure whereas the partial osmotic pressure calculated from conductivity data indicates the ionic fraction.

Appropriate statistical tests were run to elucidate in particular: 1) the influence of reduced soil water osmotic potential (ψ_s) on both transpiration rate (TR) and relative water content (RWC), and 2) the correlation between transpiration and each of leaf relative water content, air temperature and vapour pressure deficit (VPD) of air.

Results

1) Transpiration under decreased osmotic water potential

The diurnal patterns of transpiration in flax, at different soil osmotic water potential (ψ_s), are shown in Fig. 1 A. At ψ_s = —1/3 bar (the control), transpiration fluctuates widely during daytime with a maximum rate, more or less persistant during midday (387—366 mg H_2O/g leaf (f. wt.) hr). Progressive decrease in diurnal fluctations and in magnitude of transpiration took place with decreasing soil water

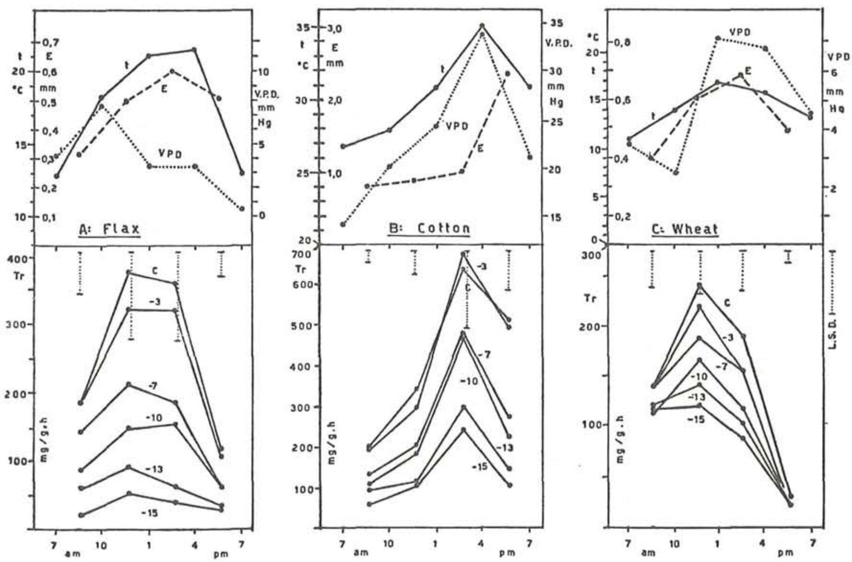

Fig. 1. Diurnal patterns of transpiration in flax (A), cotton (B) and wheat (C) in mg/g f. wt. h at different soil osmotic potentials, compared with the daily changes of temperature (t) and vapour pressure deficit (VPD) of air and with the PICHE-Evaporation (E). The least significant differences (L. S. D.) of transpiration are indicated by perpendicular dotted lines in the lower part of the figures (scale on the right)

potential. Thus, at ψ_s = —7 bar, the maximum ran around 200 mg, almost about half of the amount lost by plants at ψ_s = —$^1/_3$ bar. Likewise, at ψ_s = —15 bar, maximum transpiration was only about 50 mg, a rate which is not very far from attained at either the early morning or late afternoon.

Transpiration diurnal patterns in cotton (Fig. 1 B) showed a progressive increase during daytime. Dependant on evaporative demand of air during late afternoon (4 to 7 p.m.), transpiration in cotton may continue to increase during the afternoon. Temperature and VPD of air seem to be the controlling factors in this respect. Transpiration, however, progressively decreases with decreased ψ_s and the magnitude of this response seems to be dependent on climatic factors as a difference in this response is quite clear from one day to another.

In wheat, transpiration is apparently strongly influenced by changes in diurnal patterns of change in temperature and VPD (Fig. 1 C). Thus, diurnal patterns of fluctuations in transpiration seem to follow closely the fluctuations in climatic parameters specified.

Apart from difference in response of transpiration among the experimental plants with respect to both temperature and VPD, there seems to be a difference in response to decreased ψ_s too. For example, under relatively mild climatic conditions and expectable favourite internal water status (7—10 a.m.), transpiration was significantly reduced at ψ_s below —7 bar in wheat and flax and at ψ_s below —3 bar in cotton. Under conditions favouring high transpiration (10 a.m.—1 p.m.), significant decrease in transpiration immediately started below —3 bar in all plants. At milder climatic conditions and expectedly developed internal water deficits (4—7 p.m.), transpiration was checked immediately at ψ_s = —3 bar in wheat and ψ_s = —7 bar in cotton and flax. The difference in impact of reduced ψ_s on transpiration is clearly reflected in the daily amount of water transpired by the experimental plants (Table 1). Transpirational water output in absence of reduced

Table 1

Average daily amount of H_2O transpired (g/g f.wt.)

ψ_s (bar)	Flax	Cotton	Wheat
−0.3	3.30	4.80	1.85
−3	2.90	4.80	1.33
−7	1.80	3.60	1.27
−10	1.50	3.10	1.10
−13	0.87	2.20	0.97
−15	0.52	1.70	0.90

water potential (control, $\psi_s = -1/3$ bar) widely differs according to species. Cotton plants had the highest output where each leaf lost about 5 times its weight of water during daytime, and wheat had the least output. Salinity stress reduced transpirational water output in various degrees. Thus, at $\psi_s = -15$ bar the output was about half of the amount at $\psi_s = -1/3$ bar in wheat, and only $1/3$ and $1/7$ in cotton and flax, respectively.

2) Relative water content under reduced osmotic water potential

Diurnal fluctuations in relative water content in the experimental plants are shown in Fig. 2 A. Patterns of diurnal variations in RWC at different levels of ψ_s obviously differ according to species. Thus, flax plants adjusted to $\psi_s = -13$ to -15 bar retained significantly higher relative water content than those at higher (less negative) water potentials. There was, however, obvious diurnal fluctuations in RWC at all ψ_s levels. Starting with high relative turgidity in the early morning, flax leaves sharply lost turgidity with advance of daytime, but regained turgor to a large degree at late afternoon. It is observed that leaves were apt to partially regain turgor at midday at nearly all ψ_s levels, but apparently this fails to continue for a considerable period. This tendency to regain partial turgor during time of excessive transpiration is quite indicative of developed and efficient root system. Relative turgidity of leaves significantly increased, under mild climatic conditions (at 7 a.m.), when a stress of —13 bar magnitude was developed in the soil. Under relatively severe climatic conditions (at 1 p.m.), significant decrease in turgidity occurred at the same stress level (—13 bar), and turgidity was not significantly changed at lower stress levels (higher water potentials, i. e. less negative ψ_s).

In cotton plants, where sampling for RWC determination was possible only three times a day, stress had no significant effect on RWC in the early morning (Fig. 2 B). At noon time, the significant effect of stress overlapped at the range of ψ_s tested in such a way that, for example, RWC was significantly lower at —7 bar compared to —15 bar but not so with respect to $-1/3$ bar. The same applies to the late afternoon period (7 p.m.).

In wheat (Fig. 2 C) the significant effect of stress on RWC existed in the early morning (7 a.m.) where $\psi_s = -7$ bar significantly decreased RWC. The same level of stress exerted nearly the same effect in the late afternoon (7 p.m.). At midday (1 p.m.) the effect of ψ_s on RWC was overlapping, as it was the case also with cotton. At prenoon (10 a.m.) or early afternoon (4 p.m.) no significant effect of ψ_s on RWC existed.

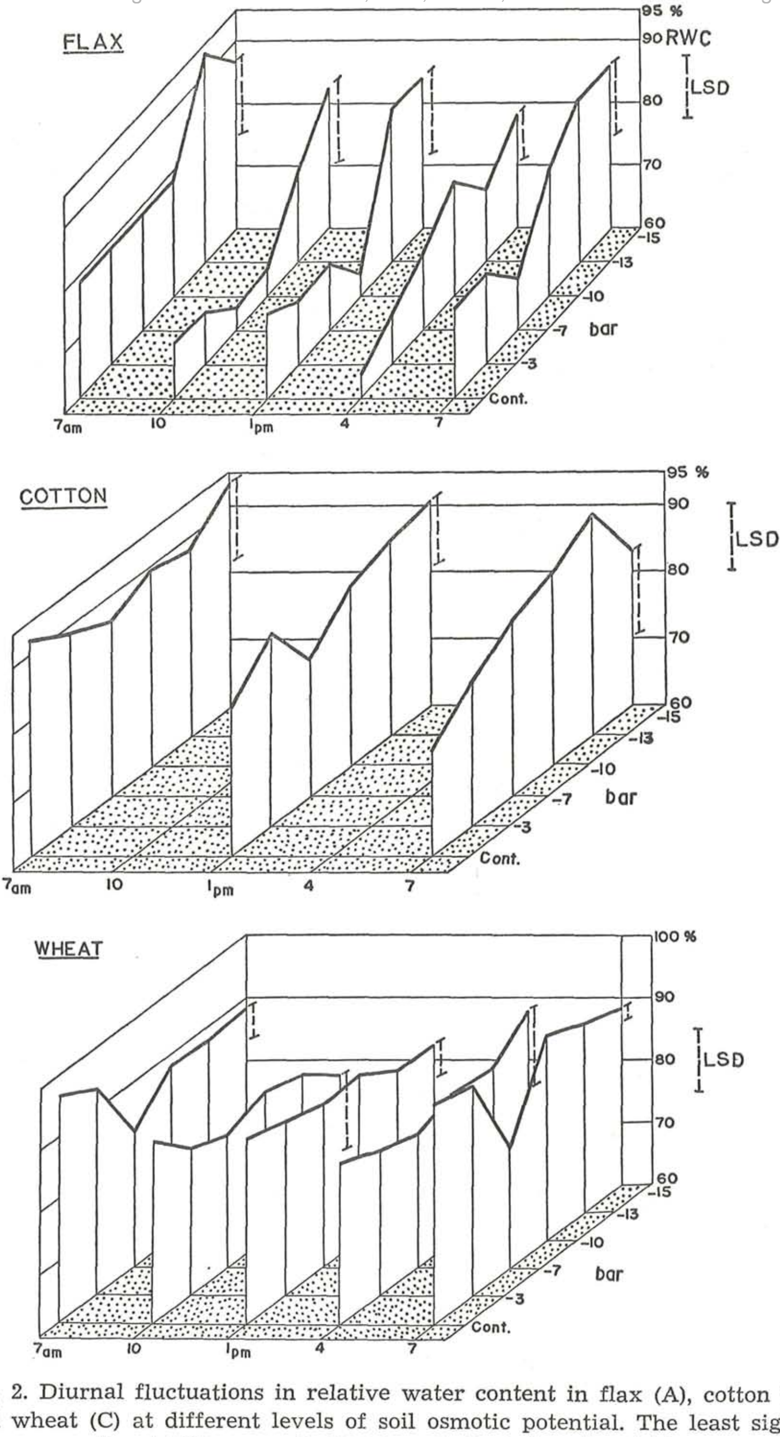

Fig. 2. Diurnal fluctuations in relative water content in flax (A), cotton (B) and wheat (C) at different levels of soil osmotic potential. The least significant differences (L. S. D.) are indicated on the right

3) Changes in osmotic potential (OP) of leaves under decreasing ψ_s

Decreased soil osmotic potential (ψ_s) induced different responses in osmotic potential of leaves in plants under investigation. Although a common trend for increased osmotic potential in plants in response to increased soil osmolality is quite obvious (Fig. 3), yet the maximum plant osmotic potential attained at ψ_s = —15 bar was almost 4 fold that at ψ_s = —1/3 bar in flax (61 vs. 15.5 atm., respectively). In cotton and wheat the increase was only about 1½ fold (18 vs. 29 atm. and 20.5 vs. 28 atm., respectively). In flax and cotton, increasing response of OP

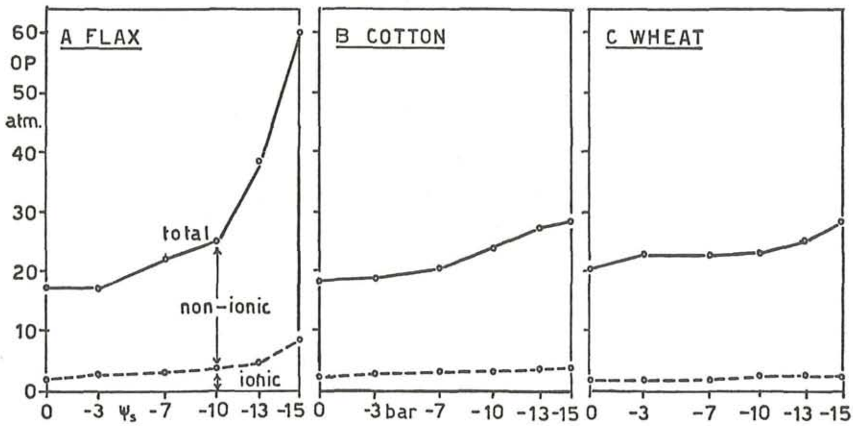

Fig. 3. Osmotic potentials in leaves of flax (A), cotton (B) and wheat (C) at different levels of soil osmotic potential

started at ψs = —3 whereas in wheat it was initiated at ψ_s = —7 bar. The ionic partial osmotic potential in wheat and cotton seems to be unaffected by increased salinity stress. In flax, this fraction increased at ψ_s lower than —10 bar. The metabolic (non-ionic) fraction, therefore, must be responsible for such increases in foliar osmotic potential, in the three plants, in response to increased soil osmolality.

4) The leaf/root dry matter ratio

Dry matter content (as expression of net growth) of both shoots and roots were evaluated in order to have an idea about the effect of disbalance between leaf and root growth on both transpiration and absorption and hence on the development of internal water deficits. Fig. 4 shows the relative dry weights of leaves and roots respectively as well as the leaf/root ratios of the investigated plants at decreasing ψ_s (dry weight of the controls = 100%).

There exist some differences among the three species. For example, in flax the ratio at ψ_s = —15 bar is about 68% of its value at —1/3 bar, in cotton only 52% and in wheat 89%. In flax the decrease of the leaf/root ratio with decreasing ψ_s apparently is due largely to excessively reduced shoot growth than of root growth. At ψ_s = —15 bar, the former is reduced to about a quarter of the control whereas the latter is reduced to a third of the weight of the control. Similarly, in cotton the decrease in this ratio is largely due to excessive decrease in leaf compared to root. In wheat, a low magnitude of stress of the order —3 bar apparently stimulates root growth (accompanied

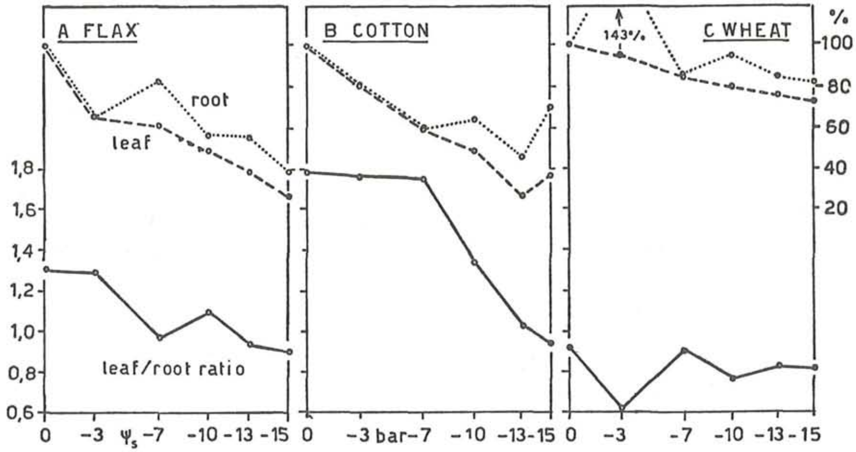

Fig. 4. Relative dry weights of leaves (broken lines) and roots (dotted lines, scale on the right) as well as the leaf / root ratio (straight lines, scale on the lest) of flax (A), cotton (B) and wheat (C) at different levels of soil osmotic potential

by slight decrease in shoot growth, thus resulting in a lower value of leaf/root ratio. However, at —15 bar, the relatively high ratio is the result of excessively reduced leaf growth (about 73% of its weight at —1/3 bar) accompanied by slight decrease in root growth (about 82% of its weight at —1/3 bar).

Discussion

Analysis of transpiration curves, particularly their diurnal behaviour, in plants under salinity- or drought stress has proved to be a useful tool for indicating resistance properties (see, e. g., El-Sharkawi & Salama 1973, 1975). It has been realized by the senior author, however, that the relation between either salinity or drought stress and transpiration is not simply just a binary relation, but it is often modified by interactive effects of climatic parameters such as temperature or VPD of air (EL-SHARKAWI & MICHEL 1975). To evaluate such influences, it was necessary to run correlation tests between transpiration and each of the climatic variables under consideration at every stress level experimented at. This has been feasible in the light of enough (six) replicates used at each stress level. Reference to table 2 indicates a significant positive correlation between transpiration of flax and

Table 2

Correlation coefficients (r values) between transpiration and each of temperature and VPD in the plants adjusted to different levels of ψ_s

ψ_s (bar)	Flax Temp.	Flax VPD	Cotton Temp.	Cotton VPD	Wheat Temp.	Wheat VPD
−0.3	0.46	0.23	0.98 [2])	0.68	0.22	0.05
−3	0.61	0.27	0.96 [2])	0.97 [2])	0.17	−0.002
−7	0.43	0.79 [1])	0.88 [1])	0.91 [1])	0.06	−0.07
−10	0.63	0.27	0.87 [1])	0.90 [1])	0.006	−0.13
−13	0.46	0.37	0.83 [1])	0.86 [1])	−0.15	−0.20
−15	0.83 [1])	0.39	0.78 [1])	0.82 [1])	−0.22	−0.23

[1]) Significant at $P < 0.05$.
[2]) Significant at $P < 0.01$.

VPD at —7 bar and similarly with temperature at ψ_s = —15 bar. In cotton, a significant positive correlation between transpiration and temperature exists allover the ψ_s range experimented at (the correlation is even highly significant at ψ_s = 1/3 bar). Similarly, a significant positive correlation between transpiration and VPD of air was found at ψ_s ranging between —3 and —15 bar (the correlation is highly significant at ψ_s = —3 bar). In wheat, no significant correlation existed between transpiration and either temperature or VPD at any ψ_s level.

It is quite clear that the role of climatic parameters in affecting transpiration is, to a great extent, species dependant and pertinant to ψ_s level. In this respect, the role of both temperature and VPD of air in increasing transpiration is quite profound in cotton put not in wheat, and in flax their effects are limited to certain ψ_s levels.

Concerning the relation between the internal water status of the plants tested (judged by RWC values) and transpiration in such plants, the data of correlation analysis executed in this respect are given in table 3. It is clear that no significant correlation existed between transpiration and RWC in flax at any stress level. In cotton, a significant positive correlation existed at ψ_s = —13 bar. This indicates a dependence of transpiration rate on the internal water status of such a plant at this level of soil water potential. A significant negative correlation between transpiration and RWC in wheat at ψ_s = —10 bar may signify an influencial controlling effect of reduced RWC in leaves on checking transpiration under such stress conditions. Should this be true, such a variety of wheat must have an efficient stomatal mechanism likely sensitive to changes in internal water status of leaves.

Table 3

Correlation coefficients (r values) for transpiration and relative water content in the investigated plants at different ψ_s levels

plant Level	Flax	Cotton	Wheat
−0.3 bar	0.050	−0.169	−0.421
−3 bar	−0.733	−0.629	−0.789
−7 bar	0.560	0.671	0.723
−10 bar	−0.798	−0.776	−0.941 [1]
−13 bar	−0.358	0.974 [1]	0.677
−15 bar	−0.718	−0.319	−0.861

[1] Significant at $P < 0.05$.

Retention of relatively high leaf water potential is believed to be essential for normal metabolism in the plant (Todd *et al.* 1962, Todd & Webster 1965, Boyer 1970). The impact of transpiration, especially at high rates, on both relative water content and the osmotic pressure of the plant is rather debatable. The interrelations among such important parameters in plant water relations become further complicated when stress conditions develop in either the soil (reduced matric-, = ψ_m, or osmotic-, = ψ_s, water potential) or the atmosphere. Thus, (Oertli 1966), for example, expressed the idea that transpiration data or osmotic pressure measurements give little indication on whether turgidity is maintained at levels not harmful to normal plant metabolism. Contrarily, (Tinklen & Weatherley 1968) confirmed that transpiration affects leaf water potential as soon as the perirhizal soil layer gets dry regardless of high water potential in the soil bulk (even when its water potential is near zero). To the senior author, nothing serves better in clarifying such relation than executing correlation analyses among such parameters. In this respect, in the plants under investigation, it has been realized that the effect of one factor on other plant water relations parameters may exist only under a given set of conditions (such as at certain levels of osmotic-[or matric-]stress in the soil). For example, a highly significant positive correlation between RWC and OP in both cotton and flax at different levels of osmotic stress is indicative of independendence of OP on changes in RWC and that changes in the former must be taking place through metabolic pathways (see El-Sharkawi 1977). Otherwise, there should have been a significant negative correlation. The same explanation applies to the nosignificant correlation between both parameters found in wheat. El-Sharkawi (1977) considered the significant positive correlation between OP and RWC to indicate that increases in the former leads to maintaining tissue turgidity. The relatively higher RWC in *Linum* at $\psi_s = 15$ bar is apparently due to the excessively high soluble protein content accumulation at this level of stress, as revealed in a previous study (El-Sharkawi 1977). Also, a significant positive correlation between soluble protein content and RWC was found to exist in this plant. However, which of the two variables is dependant on the other cannot be determined at the time being, as this needs a detailed study on the enzymology and sequence of protein metabolism in such a plant under stess conditions. Those facts should be considered a point against the views mentioned earlier that leaf water potential is the most important property in plant water relations (unless this potential is largely osmotic, which is not quite true for most crop plants and even to many xerophytes). Such views, however, were criticized by (Oertli 1971, 1976). Alternatively, leaf osmotic potential should be considered as an overriding mechanism in adjustment to increasing soil osmolality. This has been actually observed under matric stress too (El-Sharkawi 1968, El-Sharkawi & Salama 1973, Oertli 1976).

A high leaf/root ratio value, in essence, is considered as favourable for normal plant functioning, especially when un-impaired absorption of water (if no considerable decrease in root growth occurs) and unaffected photosynthetic activity for the individual plants occurs (if no serious water deficit develops in the leaves as the shoot growth is greatly decreased). Based on such assumption, the relatively high ratio maintained at $\psi_s = -15$ bar in wheath is indicative of tolerance to salinity. Similary, the decreased ratio in cotton at $\psi_s = -15$ bar is indicative of low tolerance properties.

From the data and points discussed above, it is quite clear that: 1) Temperature and VPD of air greatly interfere with the effect of decreasing ψ_s on transpirational water loss especially in cotton and flax. It is therefore advisable, when cropping in fairly saline soils, to limit this to areas with relatively mild climates (such as northern lower Egypt). 2) Cotton and flax have the physiological advantage, when grown under salinity stess, to maintain high relative water content necessary for normal metabolism. This is apparently attained through the high osmotic potential these plants can maintain. This potential, apparently, is regulated through metabolic process and not by increased ion absorption. 3) Wheat, particularly the cultivar tested, is the most fit for saline soils even under climatic aridity.

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Recensio

VETTERLI Luca 1982. Alpine Rasengesellschaften auf Silikatgestein bei Davos mit farbiger Vegetationskarte 1 : 2500. — In: Veröffentlichungen des Geobotanischen Institutes der Eidg. Techn. Hochschule, Stiftung Rübel, in Zürich. 76. Heft. — 8°, 92 Seiten, 10 Abbildungen, 10 Beilagen (Vegetationskarte, Tabellen) in Tasche; brosch. — Geobot. Institut ETH, Stiftung Rübel, Zürichbergstr. 38, CH-8044 Zürich. — sfr. 38,—.

Das pflanzensoziologisch und standortskundlich untersuchte Gebiet in der Umgebung von Davos (Graubünden, Schweiz) ist ca. 10 km² groß, und liegt größtenteils zwischen 2300 und 2500 m (³/₄ der Aufnahmen stammen aus diesem Höhenbereich). Saure Silikatgesteine herrschen bei weitem vor, kleinflächig treten auch Kalkschiefer auf. Ein 56 Hektar großes Gebiet („Kerngebiet") wurde unter Zuhilfenahme von Luftbildern kartiert.

Die für die Geländearbeit und die anschließende Auswertung angewandte Methodik und der Vergleich mit den Methoden von BRAUN-BLANQUET und OBERDORFER machen einen wesentlichen Teil des Bandes aus und beherrschen auch die Diskussion. Während BRAUN-BLANQUET charakteristische Artenkombinationen aus der Beobachtung der Vegetation erkannt hat und sich davon bei Auswahl und Größe der Aufnahmeflächen sowie der Tabellenarbeit leiten ließ, wurde hier versucht, die verschiedenen Rasengesellschaften durch kontinuierliche Flächenwahl möglichst vollständig zu erfassen; erst danach wurden die Aufnahmen unter Verwendung mathematischer Methoden nach Ähnlichkeit geordnet und Vegetationseinheiten abgegrenzt. Von den 13 unterschiedenen und beschriebenen Vegetationseinheiten decken sich sechs mit entsprechenden, in der Literatur beschriebenen Assoziationen, während die übrigen mit mehr als der Hälfte der Aufnahmen in Übergangsbereichen zwischen diesen liegen.

H. TEPPNER