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Effect of Moisture Stress on Plants

By

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With 2 Figures

1 Introduction

The water shortage is the major problem in arid and semiarid regions. In these regions the moisture stress represents the most important factor affecting plants. This article embodies a review of the work done on the effect of moisture stress on growth, productivity and the different aspects of plant water relations. The latters involve water expenditure, water requirements and osmotic pressure of plant sap which is a measure of the water balance and the absorptive capacity of the plant.

Emphasis was also placed on the effect of moisture stress on the mineral composition of plant material as well as the metabolic products that determine the nutritive value of plants.

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2. Vegetative growth

The vegetative growth of plants is greatly affected by the moisture stress. It is greatly reduced by decrease in available moisture before the permanent wilting percentage is reached (Table 1). The permanent wilting percentage which is the lowest limit of available moisture is considered as zero and the moisture equivalent or field capacity is considered as 100. Then the moisture content above the permanent wilting percentage is expressed as percentage of this range of available moisture. The maximum dry weight of any plant species in the different treatments is considered as 100, then the dry weights of plants in the other treatments were calculated as percentage of this maximum (= %maxima).

Table 1

The vegetative growth of some range plants (as shown by dry weight of shoot) under different conditions of soil moisture availability (ABD EL RAHMAN & MONAYERI 1968).

Species	Dry wt./plant (%maxima) as affected by soil moisture availability			
	0–5%	25–30%	60–65%	95–100%
Ononis vaginalis	45	62	76	100
Medicago sativa	55	61	79	100
Chloris gayana	40	55	69	100
Panicum turgidum	32	46	78	100
Panicum antidotale	46	49	67	100
Panicum maximum	38	41	64	100
Panicum coloratum	38	49	80	100
Oryzopsis miliacea	60	74	89	100
Pennisetum dichotomum	46	64	76	100
Pennisetum ciliare	45	52	68	100

Among the investigators who supported this view are DAVIS 1942; FRITTS 1956; KOZLOWSKI 1958; KRAMER & KOZLOWSKI 1960; RICHARDS & WADLEIGH 1952; SLATYER 1957 and STANHILL 1957. The other investigators who opposed this view are DAUBENMIRE & CHARTER 1942; MIGAHID & EL-SHAFEI 1955; VEIHMEYER & HENDRICKSON 1954 and VEIHMEYER 1956.

3. Yield

The effect of moisture stress on yield of cereals is due to (a) magnitude, (b) time and (c) duration of moisture stress.

3.1. Effect of magnitude of moisture stress on yield

As regard the magnitude of moisture stress, experiments were carried on barley and wheat applying different levels of water supply. In the case of barley (*Hordeum vulgare* var. 'Mariutis') a total amount of irrigation water equivalent to 150 mm rainfall is efficient for production of grains in the field under semidesert conditions of the Mediterranean region. The fall in the water supply from the highest level of 350 mm to the lower levels 300, 250, 150 mm caused reduction in the yield to 69, 48 and 30(%) respectively (Table 2). The decrease in yield was more influenced by the number of grains rather than by the weight of grains. This agrees with the findings of HENKEL 1962 and KREEB 1963. The fall in the water supply from the highest to the lowest level, was accompanied by a reduction to about 39 percent in the number of grains and a reduction to about 48 percent in the mean weight of grain (Table 2). The total number of grains per plant is dependent on the number of tillers and ears per plant.

Table 2

Effect of water supply on yield of barley var. 'mariutis' (ABD EL RAHMAN & al. 1967).

Treatment (mm)	Mean number of tillers/ plant	ears/ plant	fertile grains/ ear	plant	Mean weight of grain (mg)	Yield/100 plants g	% of max.
150	1.75	1.05	22.3	23.0	16	60± 3.2	30
250	2.40	1.85	21.3	37.0	26	97± 6.6	49
300	3.10	2.40	19.0	44.8	31	137±10.7	69
350	3.75	3.40	17.9	59.1	38	200±18.2	100

Experiment of the same design was conducted on wheat using cubic wooden boxes with a dimension of 50 cm painted inside and outside and filled with natural desert soil and irrigated with total amounts of water equivalent to 200, 300, 400, 500 and 600 mm rainfall in the different treatments. A total annual rainfall of the order of 200 mm was efficient to produce grains (Fig. 1). The increase in yield with rise in level of water supply is mainly referred to the increase in number of grains per plant rather than to increase in the weight of grain (Table 3). The fall in the level of water supply from 600 to 200 mm caused a reduction in the yield of about 80% associated with a reduction in the number of fertile grains per plant of about 78% and in the weight of grains of about 31%.

Table 3

Effect of water supply on yield of *Triticum vulgare* var. 'Giza' 144 (ABD EL RAHMAN & FAIZA, Flora — in press).

Treatment (mm)	tillers/ plant	ears/ plant	Mean number of fertile grains/plant: ear	number	% of max.	Mean weight of grain: mg	% of max.	Yield/100plant: g	% of max.
200	1.04	1.02	9.3	9.5	22	31	69	32.3	20
300	1.50	1.02	19.5	19.9	47	37	82	70.7	45
400	1.62	1.04	23.3	24.2	57	37	82	102.6	65
500	1.94	1.14	29.4	33.5	79	42	93	125.3	79
600	1.94	1.40	35.3	42.3	100	45	100	151.9	100

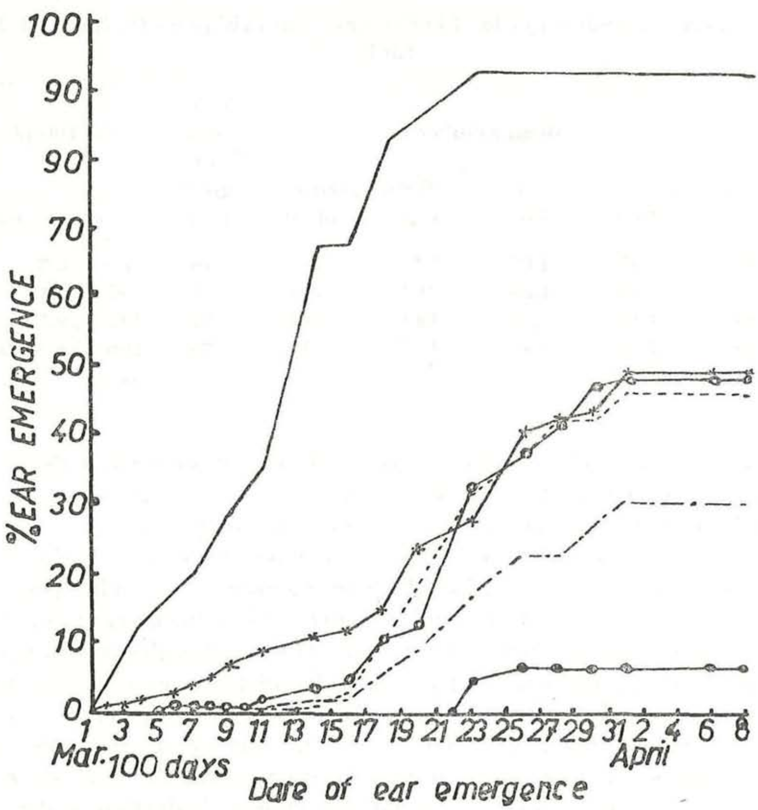

Fig. 1. Ear emergence of barley var. 'mariutis' at different levels and distribution of artificial rain.

3.2. Sensitivity of the different stages of development to drought

It is not only the amount of rain which affects the yield but also the distribution of rainfall. Under desert conditions the rainfall is irregular in its distribution throughout the rainy period. An experiment was designed to cover all the probabilities of the level and distribution of rainfall by using an irrigation regime simulating the natural conditions. In this experiment grains of barley were sown in boxes of the same type mentioned above, filled with desert sandy soil. Six Treatments were used representing different levels of artificial rain and different ways of distribution. Three levels of irrigation were employed. In Treatment I an amount of irrigation water equivalent to 120 mm was given; in Treatment II 210 mm and in Treatment III to VI 310 mm. In the latter 4 Treatments, although the total amount of irrigation water was equal yet the water was distributed in different ways simulating the distribution of rain in nature. Thus in Treatment III, the artificial rain was equally distributed over the growth period. In Treatment IV, the greater part of irrigation water was given in the early stage of vegetative growth; in Treatment V, the greater part was added in the middle stage of vegetative growth, while in Treatment VI, most of the irrigation water was given near the end of the vegetative growth and during ear formation.

Before discussing the yield in the different treatments, it is of interest to follow the ear formation in the different treatments from the beginning of ear emergence till the number of ears became constant. The curves representing the rate of ear emergence lie in four levels. The lowest curve is that of Treatment I, with the lowest water supply. Next is the curve of Treatment II with higher water supply of 210 mm, and then the curves of Treatments III to V receiving the highest water supply of 310 mm which is distributed differently in the three treatments (Fig. 2). The highest curve is that of treatment VI with the highest water supply of 310 mm and in which the greater part of irrigation water was given at the beginning of ear formation. The percentage of ear emergence varied widely in the different treatments between 7 percent in Treatment I and 93 percent in Treatment VI (Fig. 1).

The mean yield varied widely in the different treatments between 2.9 g per 100 fertile plants in Treatment I and 36.6 g per 100 fertile plants in Treatment VI. A review of the yield in the various treatments expressed as percentage of maximum shows that the yield increased with increase in level of water supply. Although the total amount of irrigation water was equal in Treatments III to VI, yet the yield varied widely between 20 and 100 percent (Table 4). The wide variation in yield is due to the way of distribution of irrigation water. The highest yield was given by the treat-

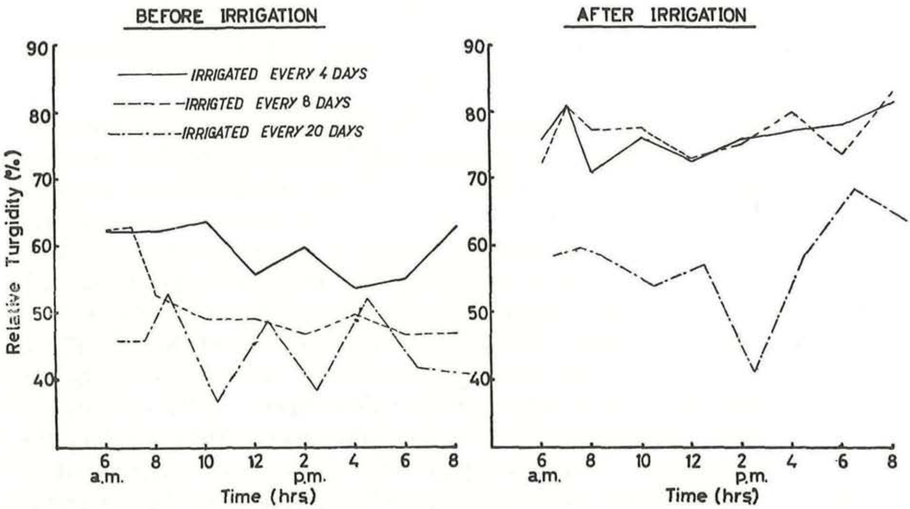

Fig. 2. Diurnal fluctuations in the relative turgidity of leaf tissues of peanut before and after irrigation in treatments with different irrigation intervals.

ment in which a great proportion of irrigation water had been given near the end of the vegetative period and during ear formation. This period was regarded more critical than the early and middle stage of vegetative growth. RUSSEL 1959 mentioned that BARTEL & HOBART in their work on wheat in the arid Salt River Valley of Arizona, showed that water in excess of 6 inches of which 3 inches come from rainfall, early in the life of the crop appears to be more harmful, whilst during the period of maximum growth until the soft dough stage of the grain, the crop has a very considerable water demand. HENKEL 1962 reported that the most marked

Table 4

Effect of water regime on yield of barley var. 'Mariutis' (ABD EL RAHMAN & al. 1967)

Treatment	Mean number of fertile grains/plant	Mean weight of grain (mg)	Yield/100 plants (g)
I	3.2±0.58	9	2.9±0.31
II	3.2±0.41	11	3.4±0.60
III	9.4±0.90	11	10.2±1.37
IV	14.1±0.67	10	14.6±0.96
V	8.0±0.37	9	7.4±0.22
VI	20.9±1.37	18	36.6±2.34

reduction in yield as the result of drought was when the latter occurred in the period of ear formation. With corn, ROBINS DOMINGO 1953 found that maximum yield was reduced by water stress at the tasseling stage and DENMEAD & SHAW 1960 found that a reduction of about 50% was caused by water stress at the silking stage.

3.3 Effect of duration of drought on yield

Wheat plants were subjected to different periods of drought without irrigation for 3, 4, 5, 6, 7 & 8 weeks. Desiccation of the leaves started after a 4 weeks period of drought and proceded till it covered all the leaves after a dry period of 8 weeks. The soil moisture reached the permanent wilting percentage after 7 weeks. Plants growing under this condition

Table 5

The yield and water relations of plants subjected to different periods of drought at the leafy stage (ABD EL RAHMAN & FAIZA, 1972 Flora-In press)

Drought period (weeks)	Soil moisture content (% oven dry weight)	Mean ratio of dry to green leaves	Osmotic pressure of shoot sap (atm)	Mean daily transpir. rate (mg/gh.)	Relative turgidity %	Yield % of maximum
3	1.75	0 : 4	16.33	136.0	68.3 ± 1.33	59.5
4	0.96	1 : 3	24.48	114.9	65.7 ± 2.05	47.8
5	0.60	2 : 2	29.19	108.9	56.5 ± 0.61	19.2
6	0.54	3 : 2	38.11	68.1	55.9 ± 2.51	17.7
7	0.43	6 : 1	—	43.9	51.5 ± 2.68	0.3
8	0.30	6 : 0	—	0	56.9 ± 8.25	0

N. B.: Permanent wilting percentage of soil = 0.4%.

had all their leaves dry except the terminal leaf covering the terminal bud. The plant tissues suffered water deficit of about 50% and still surviving. The osmotic pressure of the plant sap was above 37 atm (Table 5). Plants failed to produce grains and the ears were empty.

Plants subjected to a drought period of 8 weeks had all their leaves dry but the terminal bud was green and protected by the dry leaf sheath. No ears were produced under such condition.

In treatments in which plants were subjected to a long dry period of about 7 to 8 weeks, the failure of grain production may be due to the following: (1) Death of root hairs; (2) Suberization of roots associated with suppression of permeability to water and nutrients (SLATYER 1967); (3) Delayed recovery or incomplete recovery after irrigation. Under the above conditions the formation of new green leaves was extremely limited and took place very slowly. GATES 1955a, 1955b concluded that if the water supply is renewed before death occurs, the recovery to normal metabolic behaviour appears to take several days, even in situations where only a single period of desiccation to the permanent wilting percentage has occurred. In many cases recovery never appears to be complete.

From the above discussion it is evident that failure in production of grains may be attributed to suppression of permeability of roots to water and nutrients together with reduction in assimilating surface and incomplete recovery to normal metabolic behaviour.

The time of irrigation has a remarkable influence on recovery of plant tissues. Plants irrigated after long intervals are subjected to a high water deficit and its tissues could not recover and attain the normal turgidity as plants irrigated after short intervals. This may be reflected on the yield. Peanut plants irrigated after intervals of 4, 8 and 20 days were compared as regard their relative turgidity before and after irrigation. The relative turgidity of plants irrigated at intervals of 4 days fluctuated between a minimum of 54 and a maximum of 64% before irrigation (Fig. 2). In the case of plants irrigated at intervals of 8 days the relative turgidity ranged between a minimum of 47 and a maximum of 63% before irrigation. Plants irrigated after a long interval of 20 days had a relative turgidity varying between 37 and 53% before irrigation. After irrigation, plants irrigated after 4 and 8 days regained a high relative turgidity fluctuating approximately between 70 and 83%. Plants irrigated after 20 days did not attain a high relative turgidity but they suffered a high water deficit even after irrigation. Their relative turgidity fluctuated between 42 and 69%.

The unability of plants subjected to a long dry period without irrigation to regain the normal relative turgidity may be due to the decrease in the efficiency of the absorbing root system.

SLATYER 1967 reported that there is evidence that recovery is delayed firstly by the marked reduction in rates of water absorption caused by death of root hairs, or roots, and increased suberization of the root system, which reduce the permeability of the root to water and nutrients. KRAMER & KOZLOWSKI 1960 concluded that root hairs appear to die at relatively low stress levels and marked root suberization develops as desiccation proceeds.

4. Water requirements

The transpiration intensity is greatly suppressed with the increase in moisture stress. Measurements of the transpiration rate of Barley were made at different levels of water supply in the different months covering the different stages of growth.

Comparison of the daily mean transpiration rate in the different treatments shows a considerable variation in the different months. In December the daily mean transpiration rate was 219 mg/gh.; in treatment C with the highest level of water supply (350 mm) and fell to 184 mg/gh. at the lower level B (300 mm) and to 169 mg/gh. at the level A (200 mm) and to 149 mg in the control with the lowest level of water supply (150 mm).

In January the fall from the highest level of water supply to the lower levels B, A and control was associated with a drop from a mean transpiration rate of 236 to rates of 191, 152 and 96 mg/gh. respectively. Thus a reduction in the daily mean transpiration rate of about 40% accompanied the fall in the water supply from the highest to the lowest level.

In February the mean transpiration rate exhibited a progressive decrease from 261 mg/gh. to 246, 229, and 115 mg/gh. in the successive

Table 6

Effect of water supply on water requirements of tomato (Abd El Rahman & Bierhuizen 1959).

Temperature °C	Level of water supply	Water requirements Calculated	% maximum
26	A	874±49	100
	B	765±32	90
	C	335±30	40
	D	432±17	51
20	A	663±39	99
	B	672±36	100
	C	414± 8	62
	D	388±27	58
16	A	355±42	99
	B	342±18	95
	C	333±25	93
	D	360±22	100
10	A	281±28	90
	B	256±12	82
	C	311±12	100
	D	—	—

N. B.: Treatment A: soil moisture ranged between 20% and 100% available moisture. — B: soil moisture ranged between 40% and 100% available moisture. — C: soil moisture ranged between 70% and 100% available moisture. — D: soil moisture ranged between 95% and 100% available moisture.

treatments from the highest to the lowest levels of water supply respectively. In other words, the mean transpiration rate diminished to about 40% with the fall in the water supply from the highest to the lowest level as in the previous months.

In March at the end of the vegetative period there was a progressive diminution in the mean transpiration rate with the fall in the water supply, but the difference between the various treatments was less pronounced than in February. A reduction in the mean transpiration rate to about 66% took place with the fall in water supply from the highest to the lowest level.

The magnitude of variation in transpiration rate with change in moisture stress is controlled by the atmospheric conditions. Comparison of the transpiration rate of irrigated and nonirrigated plants of *Agave sisalana* showed that the variation was more pronounced in summer months when the evaporative power of the atmosphere was greater than in the winter months when the evaporative power of the atmosphere was lower (Abd El-Rahman & al. 1968).

The water requirements based on the amount of water lost per gram dry matter produced are greatly suppressed by increase in moisture stress under higher temperatures but at lower temperatures the effect of moisture stress is minimised. Abd El-Rahman & Bierhuizen 1959 working on the water requirements of tomato arrived to the conclusion that the effect of water supply on the water requirements is noticeable at high temperatures and disappears at the lower ones. At the highest temperature (26° C), the fall in the water supply from the highest to the lowest level was accompanied by a reduction in the water requirements to 51% (Table 6). At the 20° C, the fall in the water supply from the highest to the lowest level was associated with a reduction in water requirement to 57%. At the lower temperatures 15° and 10° C, the variation in the water requirement at the different levels of water supply was irregular and less remarkable.

5. Effect of moisture stress on mineral composition of plant material

The deficiency in soil moisture favours the decrease in accumulation of some ions and the increase in accumulation of others. Experiments were conducted on 8 range plants grown at different levels of water supply using a total amount of irrigation water equivalent to 125, 200, 275 and 350 mm during the whole life period of plants. In these treatments plants were subjected to soil moisture ranging between the permanent wilting percentage and moisture equivalent.

It is evident from the results presented in Table 7 that in all the studied range species the deficiency in soil moisture favours more accumulation of K, Na, Ca, Mg, Cl and less accumulation of P and Fe in plant tissues of all the studied species in a regular manner.

A review of the work done by other investigators shows that most of their findings are in general agreement with the above results. OELBERG 1956 in his discussion of the factors affecting the nutritive value of forage plants, reported that increased precipitation resulted in an increase in P content and a decrease in Ca content of forages and vice versa. The results of JENNE & al. 1958 showed no effect of soil moisture stress on the P percentage of whole corn plants. However, percentage of K, Ca and Mg in corn plants increased as the supply of available soil moisture decreased. KILLMER & al. 1960 concluded that the P content of eight forage species increased as soil moisture increased. WILSON & MCKEEL 1961 concluded that moisture stress altered the relative distribution of the translocated P within the plant. Plants with adequate moisture accumulate a higher concentration of P than did plants exposed to moisture stress. SMOLIAK & BEZEAU 1967 in their study on chemical composition of range forage plants of the *Stipa-Bouteloua* association of the prairie have shown that phosphorus content increased during moist than in dry years.

On the other hand WADLEIGH & RICHARDS 1951 reported that for a given level of fertility, a decreasing soil moisture is associated with a definite decrease in K, content and variable effects upon content of P, Ca and Mg.

Examination of Table 7 reveals that the majority of ions (K, Ca, Mg, Cl and Na) increase with decrease in soil moisture, whereas the minority (P and Fe) diminished with deficiency in soil moisture. The sum of total ions accumulated in the plant tissues increases with increase of soil moisture stress. This is accompanied by accumulation of more salts in the cell sap and rise in osmotic pressure. It is evident from Table 7 that in all the range species, the rise in osmotic pressure with decrease in water supply is associated with increased in total salt content. Therefore one can arrive to the conclusion that the accumulation of salts together with the other changes such as the increase in water deficit of tissues and increase in the concentration of sugars and osmotically active carbohydrate breakdown products may account for the rise in osmotic pressure of plants subjected to deficiency in soil moisture.

6. Metabolic products in relation to soil moisture stress

It is well known that plants grown with a reduced water supply often show differences in physiological processes or generally in chemical composition when compared with those grown with abundance of water supply. This was discussed in some details by STOCKER 1956, 1960, 1961, HAGAN & al. 1957, RUSSEL 1959, KRAMER & KOZLOWSKI 1960, COYNE & SERRANO 1963, HENKEL 1964 and KOZLOWSKI 1964. They have shown that water deficits in plants, brought about by high soil moisture tension greatly modifies their metabolic products.

Table 7

The relation between the mineral ion accumulation in the plant material and the osmotic pressure of the plant sap in the advanced leafy stage under different conditions of water supply. (ABD EL RAHMAN & al. 1971).

Species	Water supply level (mm)	Plant sap O.P.*) (atm)	Mineral ions accumulation (mg-equival)							
			Na	K	Ca	Mg	P	Fe	Cl	Total
Chloris gayana	125	19.1	70	48	92	35	7.4	2.7	113	369
	200	17.0	59	39	67	32	7.8	2.8	102	310
	275	14.5	51	35	62	26	9.4	3.2	100	287
	350	13.4	45	33	45	24	9.5	4.1	100	261
Panicum turgidum	125	18.6	44	45	89	54	9.4	2.8	81	325
	200	15.5	35	42	83	50	10.8	3.0	80	304
	275	12.3	29	40	70	46	10.4	3.2	70	268
	350	11.3	25	37	56	40	11.0	3.6	50	223
Panicum antidotale	125	18.7	46	60	70	50	7.9	2.2	90	326
	200	16.5	38	53	60	40	11.1	2.6	87	292
	275	14.2	30	57	52	38	11.8	2.9	60	252
	350	11.2	24	50	38	32	12.0	3.3	60	219
Panicum maximum	125	17.2	70	52	86	52	8.9	2.4	71	344
	200	15.0	57	47	72	45	9.4	2.7	49	282
	275	12.1	47	41	62	40	9.7	3.3	43	249
	350	11.1	40	38	54	36	10.3	3.6	39	202
Panicum coloratum	125	15.6	57	51	65	45	8.9	2.9	105	335
	200	13.7	52	41	54	42	10.2	3.2	100	302
	275	11.5	46	37	46	38	10.5	3.6	97	279
	350	10.4	38	36	37	35	10.7	3.7	80	240
Oryzopsis miliacea	125	21.5	36	44	70	35	6.7	2.3	71	265
	200	17.7	32	40	62	28	8.9	2.4	49	222
	275	14.7	26	39	60	24	10.2	2.8	41	203
	350	13.4	20	35	56	21	10.5	3.1	32	178
Medicago sativa	125	19.2	41	56	108	71	9.4	2.4	80	366
	200	16.7	32	51	97	64	9.8	2.7	80	337
	275	13.4	27	48	90	52	9.2	2.9	65	294
	350	11.6	24	45	80	46	10.4	3.0	60	268
Crotalaria aegyptiaca	125	13.5	32	40	100	63	8.4	2.8	78	324
	200	12.4	25	38	93	55	9.6	3.1	78	302
	275	10.4	23	34	90	50	10.1	3.1	52	262
	350	9.2	20	30	83	46	10.5	3.3	48	241

*) O. P. = *osmotic pressure.*

Studies were made on the metabolic products of range plants which determine their nutritive value under different conditions of water supply. Also the crude fibre content which affects the palatability of range plants was analysed under different moisture conditions.

6.1 Total Available Carbohydrate Content

Examination of the results obtained reveals that the total available carbohydrates (soluble sugars and acid hydrolysable polysaccharides including only starch and pentosans) increased with deficiency in soil moisture in all the species and in the different stages of development. The range of variation in carbohydrate content with change in water supply differs in the different species and also in the various stages of development (Table 8). The widest range was demonstrated by *Medicago sativa* in the three successive stages viz.: preflowering, end of flowering, and fruiting. In these stages, the fall in the level of water supply from the highest to the lowest level was accompanied by the increase in the total carbohydrate content from about 4.8 to 9.0%. Thus the deficiency in moisture content causes an increase in the carbohydrate content that reaches in some cases double the value recorded under conditions of optimum water supply. In the other species the magnitude of variation in the carbohydrate content with change in water supply was more or less equal to that of *Medicago sativa*. The results obtained are in agreement with the findings of the following authors: GRANFIELD 1943, JULANDER 1945, EATON & ERGLE 1948, 1953, SIMONIS 1947, 1952, BERNSTEIN & AYERS 1953, TADROS & IBRAHIM 1960, STOCKER 1960, EVENARI 1962, SWIFT & SULLIVAN 1962 and HENKEL 1964.

On the other hand the results obtained by other investigators are in disagreement with the above findings. Among these authors are MAGNESS & al. 1935, WADLEIGH & AYERS 1945, WOODHAM & KOZLOWSKI 1954 and COYNE & SERRANO 1963.

6.2 Total Nitrogen Content

The effect of water supply on the nitrogen content is very prominent (Table 9). The decrease in water supply is accompanied by increase in the total nitrogen content in the different stages of life cycle in all the species. Comparison of the total nitrogen content in *Chloris gayana* in the highest and lowest levels of water supply shows that in the early leafy stage it varied between 2.01 and 2.72%; in the advanced leafy stage between 2.19 and 3.16%; in the preflowering stage between 0.93 and 1.87%; at the end of flowering stage between 1.26 and 2.40% and in the fruiting stage between 1.06 and 2.18%. Thus the deficiency in soil moisture results in a considerable rise in the nitrogen content of the plant which reaches in some cases double the value at optimum water supply.

A review of the work done by other investigators shows that decreasing soil moisture is associated with definite increase of nitrogen content of the tissue (Wadleigh & Richards 1951, Richards & Wadleigh 1952, Kramer 1959, Kramer & Kozlowski 1960, Kozlowski 1964, Tadros & Ibrahim 1960, Stocker 1960, Killmer & al. 1960, Evenari 1962, Chen & al. 1964, Bernet & Naylor 1966, Ben-Zioni & al. 1967 and Singh 1967).

Table 8

Effect of water supply on the total available carbohydrates (% dry weight) of different species at different stages of developments. (Abd El-Rahman & al. 1971).

Water supply (mm)	Weeks after emergence	Species*) A	B	C	D	E	F	G	H
125	6	9.32	10.70	8.95	8.26	8.73	7.92	9.05	7.93
	8	8.53	8.72	10.43	7.83	11.08	9.28	9.40	8.83
	10	9.83	9.28	9.91	9.48	9.43	7.33	8.98	9.43
	12	9.55	9.36	9.78	9.53	9.57	7.20	8.99	8.46
	14	9.40	9.42	9.66	9.00	9.30	7.20	8.90	8.68
200	6	7.21	8.26	6.67	6.20	7.76	6.10	7.55	7.32
	8	7.05	8.12	9.40	6.73	10.28	8.27	8.62	8.58
	10	8.90	8.82	8.56	7.98	8.40	6.18	7.71	8.53
	12	8.87	8.22	8.45	8.40	8.27	6.14	7.50	8.33
	14	8.23	7.96	8.29	8.26	8.38	6.00	7.46	7.83
275	6	5.88	6.89	4.61	4.62	6.65	5.02	6.37	6.45
	8	5.57	7.22	8.54	5.50	8.81	7.23	7.75	8.33
	10	7.72	7.78	7.15	7.43	7.72	5.29	6.26	7.10
	12	7.50	7.61	6.80	7.20	7.22	5.38	6.16	7.41
	14	7.03	6.92	6.37	7.23	7.16	5.23	6.27	7.30
350	6	5.02	5.53	4.04	4.15	5.13	4.10	5.80	5.83
	8	5.21	6.42	7.75	4.73	7.36	6.59	7.07	8.02
	10	6.00	6.53	6.63	5.60	6.64	4.68	4.84	6.25
	12	6.47	6.45	6.00	5.51	6.36	4.60	5.06	6.63
	14	6.12	6.43	5.71	5.93	6.19	4.63	5.03	6.97

*) A = *Chloris gayana*, B = *Panicum turgidum*, C = *Panicum antidotale*, D = *Panicum maximum*, E = *Panicum coloratum*, F = *Oryzopsis miliacea*, G = *Medicago sativa*, H = *Crotalaria aegyptiaca*.

6.3 Crude Fibre Content

Crude fibres consist almost entirely of cellulose and lignin together with some resistant hemi-cellulose. The moisture stress exhibits a slight effect on the crude fibre content in the different stages of development. There is a tendency towards an increase in crude fibre content with increase in soil moisture.

The nutritive value of range plants as determined by the total available carbohydrates, total nitrogen, Ca, Mg; and P contents is highly influenced by soil moisture conditions. Plants subjected to higher moisture tension,

Table 9

Effect of water supply on the total nitrogen content (% dry weight) of different species at different stages of development (ABD EL-RAHMAN & al. 1971).

Water supply (mm)	Weeks after emergence	Species*) A	B	C	D	E	F	G	H
125	6	2.72	2.32	2.25	2.43	2.86	2.84	3.20	2.35
	8	3.16	2.60	2.34	2.70	2.74	2.60	3.32	3.00
	10	1.87	2.12	1.82	2.18	1.65	1.93	2.63	2.20
	12	2.40	1.84	1.68	1.92	1.90	1.80	2.61	2.18
	14	2.18	1.87	1.60	1.90	1.72	1.72	2.61	2.44
200	6	2.65	2.07	2.00	1.90	2.60	2.33	3.11	2.15
	8	2.83	2.40	2.10	2.38	2.36	2.25	3.16	2.77
	10	1.48	1.63	1.46	1.51	1.45	1.02	2.23	1.39
	12	1.57	1.42	1.34	1.38	1.30	1.50	2.50	1.94
	14	1.58	1.52	1.35	1.35	1.26	1.65	2.42	2.26
275	6	2.30	1.73	1.86	1.75	2.32	2.20	2.56	1.78
	8	2.54	2.16	2.00	1.86	2.16	2.14	2.93	2.60
	10	1.20	1.30	1.32	1.30	0.91	0.75	1.84	1.65
	12	1.42	1.10	1.13	1.12	0.96	1.43	2.32	1.57
	14	1.40	1.14	1.03	1.02	0.83	1.26	2.06	1.87
350	6	2.01	1.50	1.73	1.62	2.13	2.11	2.26	1.60
	8	2.15	1.80	1.75	1.64	1.95	1.85	2.53	2.35
	10	0.93	0.92	1.02	11.0	0.75	0.58	1.41	1.50
	11	1.26	0.90	0.94	0.84	0.86	1.21	1.95	1.32
	14	1.06	0.75	0.88	0.83	0.80	1.17	1.64	1.40

*) A = *Chloris gayana*, B = *Panicum turgidum*, C = *Panicum antidotale*, D = *Panicum maximum*, E = *Panicum coloratum*, F = *Oryzopsis miliacea*, G = *Medicago sativa*, H = *Crotalaria aegyptiaca*.

or deficiency in soil moisture, are richer in total nitrogen (or generally crude proteins) as well as available carbohydrates, Ca and Mg contents, and poorer in P content. This phenomenon is manifested in all the 8 studied species (Tables 7, 8, 9).

The total value of the nutritive constituents per plant is not only determined by the percentage of these constituents in the dry material, but also by the dry matter production per plant. The latter is greatly suppressed with deficiency in soil moisture.

7. Summary

The moisture stress influences the vegetative growth of the studied species within a range extending above and below the permanent wilting percentage. The effect of moisture stress on yield of cereals is due to (a) magnitude, (b) time and (c) duration of moisture stress.

The transpiration intensity is greatly suppressed with increase in moisture stress. Its magnitude of variation is controlled by the atmospheric conditions. The water requirements based on the amount of water lost per gram dry matter produced are greatly suppressed by increase in moisture stress under higher temperatures, but at lower temperatures the effect of moisture stress is minimised.

The deficiency in soil moisture favours the decrease in accumulation of some ions (P and Fe) and the increase in accumulation of other ions (K, Ca, Mg, Na and Cl). The sum of total ions accumulated in the plant tissues increases appreciably with increase in soil moisture tension. This is accompanied by accumulation of more salts in the plant cell sap and the subsequent rise in osmotic pressure. The other factor causing the rise in osmotic pressure is the increase in water saturation deficit as a result of moisture deficiency.

In the case of fodder plants the nutritive value of the shoot is highly influenced by soil moisture conditions. Plants subjected to higher moisture tension are richer in total nitrogen as well as available carbohydrates, Ca and Mg content and poorer in P content. The total values of the nutritive constituents per plant is not only determined by the percentage of these constituents in the dry material, but also by the dry matter production per plant; the latter is greatly reduced with deficiency in soil moisture.

8. Zusammenfassung

Für die untersuchten Arten beeinflußt der Wasserzustand der Pflanzen das vegetative Wachstum innerhalb eines Bereiches, der über und unter dem Prozentsatz des Dauerwelkens liegt. Der Ernteertrag von Getreide hängt ab von (a) Größe, (b) Zeit und (c) Dauer des Wasserzustandes der Pflanzen.

Das Transpirationsausmaß wird bei erhöhtem Wasserzustand stark unterdrückt. Dessen Variationsgröße ist von atmosphärischen Bedingungen abhängig. Der Wasserbedarf, bestimmt durch das vorhandene Wasser je Gramm Trockengewicht, ist viel geringer bei erhöhtem Wasserzustand und höherer Temperatur; aber bei niedrigerer Temperatur ist der Einfluß des Wasserzustandes herabgesetzt.

Der Mangel an Bodenwasser begünstigt die Abnahme des Anreicherns bestimmter Ionen (P und Fe) und die Zunahme anderer (K, Ca, Mg, Na und Cl). Die Summe aller Ionen nimmt merklich zu mit dem steigenden Dampfdruck des Bodenwassers. Dieser geht Hand in Hand mit dem Anreichern von Salzen im pflanzlichen Zellsaft und dem daraus folgernden erhöhten osmotischen Druck. Dieser wird auch als Folge von Wassermangel durch das ansteigende Wassersättigungsdefizit verursacht.

Bei Futterpflanzen ist der Nährwert des Materials durch Bodenfeuchtigkeit stark beeinflußt. Unter höherem Dampfdruck sind die Pflanzen reicher an N und verfügbaren Kohlehydraten, Ca und Mg, hingegen ärmer an P. Der gesamte Nährwert je Pflanze ist nicht nur von dem Prozentsatz dieser Stoffe in der Trockensubstanz bedingt, sondern auch von der Menge der jeweils von der Pflanze erzeugten Trockensubstanz; diese sinkt mit der mangelnden Bodenfeuchtigkeit.

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