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Growth and Dry Matter Accumulation Dynamics of Flue-Cured Tobacco under Different Soil Moisture Regimes

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Abstract: A filed research was carried out in the years of 2000, 2001 and 2003 in order to determine the effect of different irrigation regimes and water stress imposed at earlier growth stages on vegetative growth and dry matter accumulation of flue-cured tobacco plant (*Nicotiana tabacum* L.). The field trials were conducted on the fields of Atatürk Soil and Water Resources Research Institute in Kırklareli. A randomised complete block design with three replications was applied and K-326 Virginia tobacco cultivar was used in the experiment. Three levels of irrigation water amount reduction (0, 40 and 60%) were applied at each development stage. Single irrigation was applied during the second part of vegetative stage, while subsequent water applications were done at 50 and 70% depletion level during the yield formation and ripening stages, respectively. Results of this 3-year study show that all vegetative parameters as well as dry matter accumulation processes were significantly affected by water shortage in the soil profile during the earlier growth stages. Water stress in various severity occurring during the rapid vegetative growth and yield formation periods reduced plant height, as well as influenced leaf number and leaf area development. Short-duration water deficits during the rapid vegetative growth period caused 26, 7 and 10; 10, 8 and 9 and 11.3, 8.5 and 9% loss of final dry matter weight of the plants, respectively for the three stress levels in 2000, 2001 and 2003. Losses in the ranges of 40-70, 15-17 and 22-25% could be expected as a result of water stress at three different levels during the yield formation period. Much greater 71, 82 and 71% losses were recorded as result of prolonged water stress during the periods of rapid growth and yield formation.

Key words: Tobacco, stress, growth, leaf formation, dry matter

INTRODUCTION

Irrigation is a factor of vital importance for Virginia tobacco production in Northwest part of Turkey since rainfall is unpredictable and generally unreliable and insufficient during the critical growth stages of the plant. Almost no commercial dry production of tobacco could be considered it the region since the water requirement of the crop is high during the periods of rapid plant growth and leaf expansion.

The importance of irrigation in tobacco production has been described by Gude (1976) and Assimi *et al.* (2004). Many studies related to various aspects of tobacco irrigation have been conducted recently (Moore and Tyson, 1999; Perkins *et al.*, 2001; Sifola and Postiglione, 2002; Liang, 2003; Karaivazoglou *et al.*, 2004; Moustakas and Ntzanis, 2005; Sifola, 2005). Water is involved in all plant growth processes of tobacco plant and continuous water supply is essential for leaf yields of high quality and quantity. There is a wide spread consideration in the literature that growth of tobacco plant is slow during the early establishment and reserves of available soil water should be sufficient for the plant through the first six weeks. Moreover, Volodarskii (1971) and Papenfus (1987) reported that an imposition of drought from 14 to 30 days after transplanting is beneficial in stimulating root development. Though, the availability of water in the soil profile during the later stages of plant growth may permanently affect development of the plant either in leaf yield or leaf quality.

Water requirement and the effect of water deficits in soil profile on flue-cured tobacco plant have been studied by several people. Exists a consensus of opinion that tobacco plants benefit having water available when it is required. It has been shown that water stress occurring at various growth stages of a tobacco plant leads to yield decrease, due to decreased vegetative growth including leaf expansion and dry matter accumulation (Wilkinson *et al.*, 2002).

Doorenbos and Kassam (1979) reported that water deficits during the mid-vegetative (rapid growth) result in reduced growth and smaller leaves, while the severe water

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shortages during the yield formation and ripening stages affect leaf weight and chemical composition of the production.

The purpose of the present study was to evaluate the effect of water deficits in the soil profile during the earlier stages of development on growth, leaf formation and expansion and dry matter accumulation dynamics of flue-cured tobacco plant.

MATERIALS AND METHODS

Experimental site and experimental procedure: Field trials were carried out during 2000, 2001 and 2003 years on fields of the Soil and Water Resources Research Institute in Kirklareli (41°42′N and 27°12′E). The experimental site has a silty loam Entisol soil (Udic Ustifluvent). That is poor (0.9-2.1%) in organic matter and rich in potassium. Values of some soil characteristics related to irrigation are presented in Table 1. Seedlings of K-326 flue-cured tobacco cv, the most popular in the region were transplanted during the second half of May each of each experimental year on a 0.5×1.0 m grid over a total area of 42 plots, ea ch 9.0x6.0 m. Nitrogen fertiliser at 80 kg N ha^{-1} was applied before transplanting each year.

Field trials were laid out in a randomised complete block design, with three replications. In order to prevent the lateral spread of water plots were surrounded with dikes and a distance of 3 m between plots was left bare. Furrows with uniform slope were formed in the experimental plots and used in the irrigation process. Field experiments were laid out on different locations across a larger field in each experimental year.

Precipitation history: Daily weather climatic parameters were measured at a weather station located adjacent to the experimental site and precipitation amounts during the experimental years as well as long-term averages are presented on Fig. 1. The last experimental year (2003) was similar to the total yearly precipitation amount averages for a period of 50 years, but 2000 and 2001 were much drier than normal. The experimental years differed in terms of rate and distribution of the seasonal (vegetative) precipitation. The total monthly rainfall amounts during the periods of rapid vegetative growth and yield formation stages (June-August) in the first and second experimental years were 34.8 and 13.4 mm, respectively, much lower than that of 100.6 mm for long-term average rainfall amount. The last experimental year (2003) received a total of 77.9 mm rainfall in this same period.

Irrigation treatments and measurements: Three known stages of the plant, Vegetative (V), Yield formation (F) and Ripening (R), were considered and a total of 14 (including rain fed) irrigation treatments were applied (Table 3). Water applications stages were determined as described by Doorenbos and Kassam (1979) and irrigation periods were given in Table 2. All the experimental treatments were irrigated at the same time as (VFR) irrigated at each growth stage with the amount of water required to fill the 0-90 cm soil depth to field capacity and three levels of water amount reductions (0, 40 and 60%) were done at each development stage. Single irrigation was applied during the second part of vegetative stage, while subsequent water applications were done at 50 and 70% depletion level during the yield formation and ripening stages, respectively.

Table 1: Basic physical and chemical characteristics of the experimental soil

Years	Depth (cm)	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})	Organic matter (%)	Electrical conductivity (dS m^{-1})	pH	Soil texture[a]
2000	0-30	22.10	9.10	1.53	1.93	0.81	7.8	L
	30-60	23.38	10.03	1.49	1.66	0.67	7.9	L
	60- 90	19.36	9.85	1.57	1.31	0.66	7.9	SCL
	90-120	22.37	11.48	1.57	1.49	0.68	7.9	SCL
2001	0-30	22.69	9.73	1.46	2.14	2.34	7.7	L
	30-60	19.81	9.01	1.52	1.45	2.06	7.7	SCL
	60-90	10.79	5.08	1.54	0.94	1.29	7.7	SL
	90-120	13.18	6.68	1.63	0.86	1.58	7.8	SL
2003	0-30	20.25	7.77	1.54	1.18	1.41	7.8	SL
	30-60	22.19	9.47	1.54	1.07	1.56	7.8	SCL
	60-90	22.57	9.49	1.56	0.89	1.80	7.8	SCL
	90-120	23.65	10.79	1.57	0.84	2.04	7.8	SCL

[a] L: Loam; SL: Sandy Loam; SCL: Sandy Clay Loam

Table 2: Periods of water applications during the experimental years

Name of the period	Starting	Ending
Rapid vegetative growth (V)	30 days after transplanting	8-10 leaf stage
Yield formation (F)	8-10 leaf stage	Beginning of flowering
Ripening (R)	Beginning of flowering	4 hand harvest

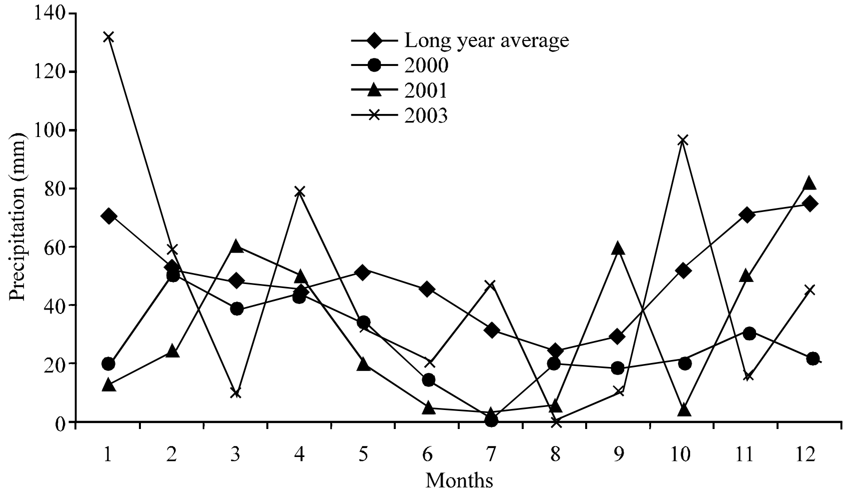

Fig. 1: Precipitation data summary for the corn experiment contrasted to 50-year averages

Table 3: Irrigation programmes included in the experiment

Experimental treatments	Growth stages Vegetative (V)	Yield formation (F)	Ripening (R)
VFR	I	I	I
VF	I	I	0
VR	I	0	I
FR	0	I	I
V	I	0	0
F	0	I	0
R	0	0	I
V_1FR	I_1	I	I
V_2FR	I_2	I	I
VF_1R	I	I_1	I
VF_2R	I	I_2	I
VFR_1	I	I	I_1
VFR_2	I	I	I_2
Rain fed	0	0	0

I: Full irrigated at a given stage; I_1 and I_2 irrigated at a given stage with reduced water amounts of 40 and 60%, respectively; 0: Irrigation omitted

Table 4: Irrigation water quantities applied to full irrigated flue-cured tobacco at different stages of the experimental years

Year and stage of development	Water application	Vegetative (V)	Yield formation (F)	Ripening (R)
2000	App. Date[b]	33	49/55/62	72/81/91/103/116
	Irr. Water, mm	125.2[c]	90/90/90.5	106/115.5/111/116/101.5
2001	App. Date	29	53/60/67/74	83/93/104/128
	Irr. Water, mm	129,1	92/76,7/77/81,1	90,2/94/90/85,2
2003	App. Date	33	52/57/69	76/95/117
	Irr. Water, mm	72,2	70,8/74,5/75	69/125/100

[b]Days after transplanting; [c]40 and 60% less water applied to treatments I_1 and I_2, respectively

Individual treatments were treated similarly except for omitting the irrigation application or reduction the irrigation water amount at a specific growth stage. Water applied to each experimental plot was measured using a flowmeter connected to an irrigation pipe. The irrigation water amount applied to each experimental treatment to be irrigated at a given stage, as well as data concerning the application date are presented in Table 4. Soil moisture content of the plots was monitored (from transplanting to last harvest) for the layers of 0-30, 30-60, 60-90 and 90-120 cm with a neutron probe (CPN, 503 DR),using one access tube located at the center of each plot.

Plant height development was determined by measuring (from soil surface to growing tip) five labeled plants for each plot prior to the first irrigation application, followed by weekly measurements. The number of leaves with length around 15 cm and more was determined for each labeled plant at the same time with plant height measurements. Three plants, from rows 2 and 8 of the 9 row plot, were cut at ground level, leaves were separated from the stalk and their shapes traced and area measured using a planimeter. The sum of the area of all leaves on a plant was considered as a total leaf area of the plant. Leaf dimensions as length and diameter were measured on leaf shape trace for all the leaves on a given plant cut from the experimental plots. Leaves were considered as one sample and the rest of the plant as the other, were cut into pieces, oven dried at 70°C to a constant weight. The sum of dry weight of leaves and other parts was assumed to be the Total Dry Matter (TDM) of the plant. Observations and measurements related to leaf and dry matter accumulation dynamics were started prior to first irrigation application and ceased prior to first harvesting date each year.

The data obtained from field measurements and laboratory observations were subjected to an analysis of variance using the procedure given by Yurtsever (1984) and the Duncan mean separation test procedure was applied.

RESULTS AND DISCUSSION

The effect of water stress on plant growth: Irrigation applied at the earlier two growth periods (vegetative and leaf formation) affected plant height growth significantly (Fig. 2). The growth of stalk was very slow during the first month after transplanting and the height of the plant was recorded to be 7.7, 4.8 and 6.0 cm at measurements taken at 29, 27 and 26 Days After Transplanting (DAT) of 2000, 2001 and 2003 years, respectively. Water application at the beginning of rapid growth (33, 29 and 33 DAT) accelerated the plant height of all the treatments receiving water at this time and the effect was obvious as early as several days after the application. While plant height values of control irrigated plants at the end of the period reached up to 32, 14 and 30 cm, the corresponding plants under stress during the rapid vegetative stage were 20.3, 8.0 and 20.25 cm, respectively for the first, second and third experimental years. On the other hand, plant height growth was statistically decreased by the partial moisture stress imposed by 40 and 60% decreasing in irrigation water amount applied during this period of 2000 and 2001 experimental years (Fig. 2).

Additional water applications started at 49, 53 and 52. DAT of 2000, 2001 and 2003 and renewed at 50% depletion during the period of yield formation (F) made the differences among irrigation programmes more evident. Measurements taken at 54, 61 and 68. DAT (2000), 68, 75 and 81 DAT (2001) and 54, 64 and 71 DAT (2003) showed that the plan height is higher for treatments fully irrigated during the both irrigation periods and reaches up to 117, 98 and 119.8 cm for the last observation date of 2000, 2001 and 2003, respectively. Steady but statistically significant decrease in growth rate was recorded for treatments irrigated at the period of rapid vegetative growth and exposed to severe or moderate water stress during the yield formation period. On the other side, plant height of the treatments exposed to water stress during the period of rapid vegetative growth and receiving their first irrigation at the beginning of yield formation (8-10 leaf stage) was dramatically increased after the applications and reached 88, 75 and 90 cm at last observation dates of 2000, 2001 and 2003, respectively.

Due to on going internode elongation processes, plant growth was seriously affected by water applications following the period of yield formation. The effect of water available in the soil profile during this period was especially visible for the treatment (R) not irrigated during the previous two application periods and irrigation programmes including omitted irrigation (VR) or 60%

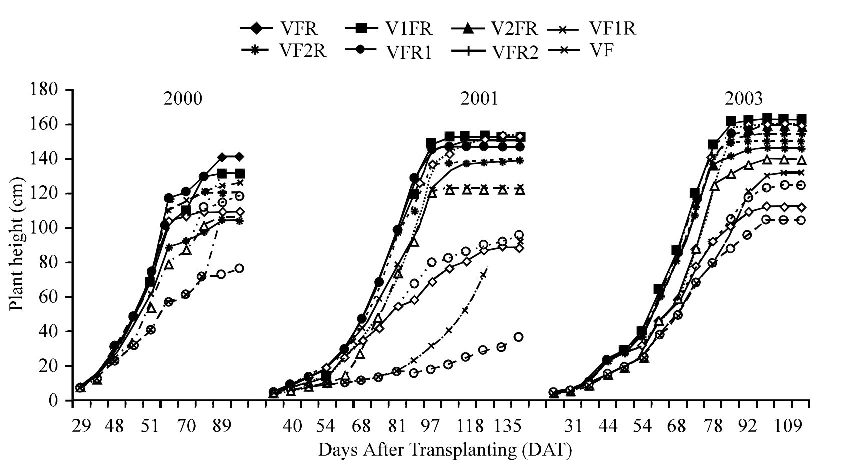

Fig. 2: Plant height growth pattern under water stress conditions at different stages. ** at p<0.01 level

reduction in irrigation water amounts (VF_2R) applied during the period of yield formation.

The final height values obtained for the treatments with favourable moisture conditions in this study are higher than those reported for NC 2326 grown in the conditions of Georgia, USA (Maw *et al*., 1997). The differences in growth characteristics of the tobacco cultivars, growing conditions and topping levels and date, all could be reasons for this disagreement. Though our results related to significant effect of even moderate moisture stress during the yield formation period confirm those obtained by Maw *et al*. (1997) showing the crucial effect of water deficits in soil profile during that period on pant growth processes.

Leaf formation and expansion dynamics under conditions of water stress: Unlike of other crops flue-cured tobacco is grown for the leaves and the extent of leaf mass developed on a given plant and/or on an unit of land directly determines the yield quantity. Due to the fact pointed out, the effect of water shortage on number of developed leaves and leaf area size, a function of leaf length and leaf width, could be considered as the effect on crop yield.

Results obtained from the 3-year study showed the significant effect ($p<0.01$) of irrigation application or exposition to water stress at earlier stages on leaf number, leaf length and width and leaf area development of the plant (Table 5).

As in the case of plant height, leaf number and size development was very slow in the period of firs 4 weeks following the transplantation and rapidly increased during the period of rapid growth and yield formation until weeks 10 and 11 in 2000 and 2003 and until weeks 11 and 12 in the second experimental year. Even a single irrigation application done during the period of rapid growth lead to statistically significant ($p<0.05$) increase in number of leaves with length ≥ 15 cm in 2001 and 2003 experimental years. Statistical evaluation of data obtained from observations done at 47 and 54 DAT, respectively in 2001

Table 5: Leaf formation dynamics under conditions of water stress, number leaves per a plant

	2000 Year					2001 Year							
Treatments	29 days	48 days	61 days	70 days	75 days	27 days	47 days	54 days	61 days	68 days	75 days	81 days	88 days
VFR	4	8.00	18.00^{a}	25.00^{a}	25.00^{a}	3	5.33^{a}	6.33^{a}	9.00^{a}	12.67^{a}	15.67^{a}	21.00^{a}	23.67^{a}
VF	4	8.00	18.00^{a}	25.00^{a}	25.00^{a}	3	5.33^{a}	6.33^{a}	9.00^{a}	12.67^{a}	15.67^{a}	21.00^{a}	23.67^{a}
VR	4	8.00	14.67^{cd}	19.00^{c}	20.67^{c}	3	5.33^{a}	6.33^{a}	7.00^{bc}	8.67^{c}	10.00^{c}	11.67^{bc}	16.67^{c}
FR	4	7.00	14.00^{d}	19.33^{c}	21.33^{bc}	3	4.67^{b}	4.67^{b}	6.67^{bc}	9.00^{c}	12.67^{b}	16.00^{ab}	20.67^{b}
V	4	8.00	14.67^{cd}	19.00^{c}	19.33^{d}	3	5.33^{a}	6.33^{a}	7.00^{bc}	8.67^{c}	10.00^{c}	11.67^{bc}	16.67^{c}
F	4	7.00	14.00^{d}	19.33^{c}	20.33^{c}	3	4.67^{b}	4.67^{b}	6.67^{bc}	9.00^{c}	12.67^{b}	16.00^{ab}	20.67^{b}
R	4	7.00	10.00^{e}	12.00^{d}	15.67^{d}	3	4.67^{b}	5.33^{ab}	5.33^{c}	6.33^{d}	7.00^{d}	8.00^{c}	10.00^{d}
V_1FR	4	8.00	17.67^{a}	24.33^{a}	24.67^{a}	3	5.0^{ab}	6.00^{ab}	8.33^{ab}	12.33^{ab}	15.00^{a}	19.33^{ab}	23.33^{a}
V_2FR	4	8.00	17.33^{ab}	24.33^{a}	24.67^{a}	3	5.0^{ab}	5.67^{ab}	7.33^{bc}	12.00^{ab}	14.33^{a}	19.00^{ab}	22.00^{ab}
VF_1R	4	8.00	17.00^{ab}	22.00^{b}	23.00^{ab}	3	5.33^{a}	6.33^{a}	9.00^{a}	12.00^{ab}	14.67^{a}	18.67^{ab}	21.33^{ab}
VF_2R	4	8.00	16.00^{bc}	19.33^{c}	20.33^{c}	3	5.33^{a}	6.33^{a}	8.33^{ab}	11.00^{b}	12.33^{b}	18.00^{ab}	20.33^{b}
VFR_1	4	8.00	18.00^{a}	25.00^{a}	25.00^{a}	3	5.33^{a}	6.33^{a}	9.00^{a}	12.67^{a}	15.67^{a}	21.00^{a}	23.67^{a}
VFR_2	4	8.00	18.00^{a}	25.00^{a}	25.00^{a}	3	5.33^{a}	6.33^{a}	9.00^{a}	12.67^{a}	15.67^{a}	14.67^{abc}	23.67^{a}
Non	4	7.00	10.00^{e}	12.00^{d}	12.67^{e}	3	4.67^{b}	4.67^{b}	5.33^{c}	6.33^{d}	7.00^{d}	8.00^{c}	10.00^{d}
F	ns	ns	**	**	**	ns	*	**	**	**	**	**	**
Sd:			0.4542	0.5645	0.7279		0.2615	0.4378	0.6042	0.4237	0.4350	0.5044	0.8029

Table 5: Continued

	2003 Year						
Treatments	31 days	39 days	44 days	54 days	64 days	71 days	78 days
VFR	4	5.67^{a}	7.00^{a}	13.00^{a}	17.67^{a}	23.67^{a}	26.67^{a}
VF	4	5.67^{a}	7.00^{a}	13.00^{a}	17.67^{a}	23.67^{a}	25.67^{ab}
VR	4	5.67^{a}	7.00^{a}	9.00^{cd}	13.67^{bc}	16.67^{b}	23.33^{b}
FR	4	5.00^{a}	6.00^{a}	9.00^{cd}	16.33^{ab}	21.33^{a}	25.00^{ab}
V	4	5.67^{a}	7.00^{a}	9.00^{cd}	13.67^{bc}	16.67^{b}	23.33^{b}
F	4	5.00^{a}	6.00^{a}	9.00^{cd}	16.33^{a}	21.33^{a}	25.00^{ab}
R	4	5.00^{a}	6.00^{a}	7.67^{d}	12.33^{c}	15.67^{b}	20.00^{c}
V_1FR	4	5.67^{a}	6.67^{a}	13.00^{a}	17.00^{a}	22.67^{a}	25.67^{ab}
V_2FR	4	5.33^{a}	6.67^{a}	12.00^{ab}	16.33^{ab}	22.00^{a}	25.33^{ab}
VF_1R	4	5.67^{a}	7.00^{a}	11.67^{ab}	17.00^{a}	22.33^{a}	26.00^{ab}
VF_2R	4	5.67^{a}	7.00^{a}	10.67^{bc}	16.00^{ab}	22.00^{a}	23.33^{b}
VFR_1	4	5.67^{a}	7.00^{a}	13.00^{a}	17.67^{a}	23.67^{a}	26.67^{a}
VFR_2	4	5.67^{a}	7.00^{a}	13.00^{a}	17.67^{a}	23.67^{a}	26.67^{a}
Non	4	5.00^{a}	6.00^{a}	7.67^{d}	12.33^{c}	15.67^{b}	20.00^{c}
F	ns	*	*	**	**	**	**
Sd:		0.2446	0.4237	0.8060	0.8854	0.7363	0.8291

and 2003 experimental years indicated the negative effect of water stress induced by omission of an application or reducing the irrigation water amount by 60% (V_2FR) on leaves number with length higher than 15 cm (Table 5).

The effect of moisture status in the sol profile was even more pronounced during the period between weeks 8 and 12 of the experimental years. Field observations carried out through the period of yield formation showed the close dependence of number of developed leaves to water moisture conditions in the soil profile. Evaluation of data related to developed leaves number obtained for 61, 70 and 75 DAT (2000); 68, 75, 81 and 88 DAT(2001) and 64, 71 and 78 DAT (2003) showed that differences of high statistically significance ($p<0.01$) exists among treatments with different irrigation water amount reduction levels, indicating for high tobacco plant sensitivity to moderate and even to low water stress conditions during this period (Table 5).

The fact that the number of leaves on a plant is genetically determined is well known and widely accepted. Though results of the 3-year study indicated that the number of well developed and harvestable leaves on flue-cured tobacco is strongly dependant on soil moisture availability especially during the yield formation period and amount and distribution of precipitation during the growing period (Table 5). While, the average number of fully developed leaves under favourable moisture conditions of VFR and treatments full irrigated during the first two periods or those exposed to low moisture stress conditions at vegetative growth period was determined to vary in the ranges of 25-27 during the rainy last experimental year, the average number of the leaves during 2001 was in the ranges of 22-24. Results obtained for the treatments grown under sever water stress through the whole growing season or during the first two periods even better show the importance of climatic conditions during the growing period. Our results related to the effect of irrigation programmes and precipitation distribution through the growing season confirm results reported earlier by other authors. Maw *et al.* (1997) have studied

Table 6: The effect of water stress on leaf area of the plant, $cm^2\ plant^{-1}$

	2000 Year					2001 Year				
Treatments	29 days	48 days	54 days	61 days	70 days	27 days	47 days	54 days	68 days	81 days
VFR	961.3	6379^{a}	9737^{a}	14373^{a}	26867^{a}	341.5	2625^{a}	3360^{a}	17319^{a}	21548^{a}
VF	961.3	6379^{a}	9737^{a}	14373^{a}	26867^{a}	341.5	2625^{a}	3360^{a}	17319^{a}	21548^{a}
VR	961.3	6379^{a}	8634^{a}	9410^{ab}	11877^{d}	341.5	2625^{a}	3360^{a}	3673^{d}	4516^{f}
FR	961.3	3751^{b}	7827^{a}	9935^{ab}	25862^{a}	341.5	859^{c}	998^{d}	7409^{c}	14193^{d}
V	961.3	6379^{a}	8634^{a}	9410^{ab}	11877^{d}	341.5	2625^{a}	3360^{a}	3673^{d}	4516^{f}
F	961.3	3751^{b}	7827^{a}	9935^{ab}	25862^{a}	341.5	859^{c}	998^{d}	7409^{c}	14193^{d}
R	961.3	3751^{b}	4253^{b}	5595^{b}	6213^{e}	341.5	859^{c}	998^{d}	1364^{e}	1822^{g}
V_1FR	961.3	5877^{a}	9215^{a}	14172^{a}	26604^{a}	341.5	2054^{b}	2450^{b}	11414^{b}	17582^{b}
V_2FR	961.3	4085^{b}	8449^{a}	13659^{a}	26329^{a}	341.5	1334^{c}	1647^{c}	10572^{b}	16295^{bc}
VF_1R	961.3	6379^{a}	9065^{a}	12703^{a}	20358^{b}	341.5	2625^{a}	3360^{a}	11227^{b}	15216^{cd}
VF_2R	961.3	6379^{a}	8810^{a}	11479^{ab}	16546^{c}	341.5	2625^{a}	3360^{a}	7615^{c}	9503^{e}
VFR_1	961.3	6379^{a}	9737^{a}	14373^{a}	26868^{a}	341.5	2625^{a}	3360^{a}	17319^{a}	21542^{a}
VFR_2	961.3	6379^{a}	9737^{a}	14373^{a}	26868^{a}	341.5	2625^{a}	3181^{a}	17319^{a}	21542^{a}
Non	961.3	3751^{b}	4252^{b}	5595^{b}	6213^{e}	341.5	859^{c}	998^{d}	1364^{e}	1822^{g}
F	ns	**	**	**	**	ns	**	**	**	**
Sd:		420	1136	2252	1012		161	136	661	523

Table 6: Continued

	2003 Year				
Treatments	26 days	51 days	64 days	75 days	84 days
VFR	507.3	6352^{a}	12539^{a}	26793^{a}	30452^{a}
VF	507.3	6352^{a}	12539^{a}	26793^{a}	30452^{a}
VR	507.3	6352^{a}	6653^{b}	8203^{b}	10162^{d}
FR	507.3	4377^{b}	12177^{a}	24924^{a}	29121^{ab}
V	507.3	6352^{a}	6653^{b}	8203^{b}	10162^{d}
F	507.3	4377^{b}	12177^{a}	24924^{a}	29121^{ab}
R	507.3	4377^{b}	5499^{b}	8143^{b}	9096^{d}
V_1FR	507.3	5591^{b}	13239^{a}	25011^{a}	29389^{ab}
V_2FR	507.3	4969^{b}	12621^{a}	23475^{a}	28648^{ab}
VF_1R	507.3	6352^{a}	12796^{a}	24170^{a}	26878^{bc}
VF_2R	507.3	6352^{a}	10928^{a}	22052^{a}	25208^{c}
VFR_1	507.3	6352^{a}	12539^{a}	26793^{a}	30452^{a}
VFR_2	507.3	6352^{a}	12539^{a}	26793^{a}	30452^{a}
Non	507.3	4377^{b}	5499^{b}	8143^{b}	9096^{d}
F	ns	**	**	**	**
Sd:		477	1114	2101	935

the effect of water stress imposed at different stages of flue cured tobacco and determined averages of 25 and 20 developed leaves per a plant in the years with favourable and unfavourable precipitation distribution, respectively. On the other hand, results indicating the crucial effect of water stress at yield formation period on leaf number are in harmony with those obtained for NC 2326 tobacco plants in Georgia. Though data for average leaf numbers recorded in our experiment with K-326 plants are comparable with results given by Maw *et al.* (1997), the maximum of 24-26 leaves per a plant is higher than 19.2 published by Wilkinson *et al.* (2002). The disagreement in the number of leaves probably appears due to different topping levels applied in the discussed experiments, since high topping level above the last formed leaf was practised in our experiment while low topping at 20. leaf level is applied in the study carried out in Virginia. Moreover, Atanasov (1972) also reported an average number of 24 leaves per a plant for the growing conditions of Bulgaria.

Similar results were obtained in terms of leaf area per a plant. As in the case of plant height growth and lead number per a plant, leaf area development was very slow in the first part of the vegetative stage, followed by an intensive increase during the second half of vegetative growth (V) and yield formation (F) periods. Measurements and evaluation performed approximately 15 days after the single irrigation application done at 33, 29 and 33 DAP of the research years showed that leaf area values of the irrigated treatments is 1.7 (2000), 3.05 (2001) and 1.45 (2003) times higher than those exposed to water stress during this stage (Table 6).

The severe drought experienced during rapid growth and yield formation periods of 2001 and favourable precipitation distribution in 2003 contributed to some differences among the experimental years. Not only were maximum leaf area values for the treatments adequately irrigated during the first two periods in the dry year much lower (21 548 cm^2/plant), than those of 26 967 and 30 452 cm^2/plant determined in the normal 2000 and rainy 2003 years, respectively, but also the consequences of water reductions and irrigation application omission during vegetative and yield formation periods varied from year to year (Table 6). While irrigation water amount reductions up to 60% at vegetative growth stage of the years with normal precipitation characteristics and rainy years were not statistically significant on the leaf area value, even 40% reduction in irrigation water amount applied with a single irrigation practice at vegetative growth period of the dry year (2001) decreased the leaf area at $p<0.01$ level of significance.

Results concerning the effect of irrigation and water stress on leaf area agree with the view that leaf elongation is among the plant processes most sensitive to water shortage (Hsiao, 1973). On the other hand, the dependence of leaf area values on seasonal precipitation amount and distribution is reported by other authors earlier. Jerell (2001) determined that leaf area values of 4-week tobacco plants varying in the ranges of 85.0-159.3 cm^2 in dry years, increase up to 641-1 367 cm^2 for the same period of the next rainy year (Table 6).

The effect of water stress on total dry matter accumulation: Dry matter accumulation dynamics and total dry matter value were also significantly affected by the soil water deficit (Fig. 3). Differences were significant at all measurement dates following the first irrigation application of the experimental years. Even under favourable moisture conditions tobacco plants increased in weight slowly early during the first four weeks after planting. Irrigation water applied at the beginning of the intensive vegetative growth stage accelerated the process

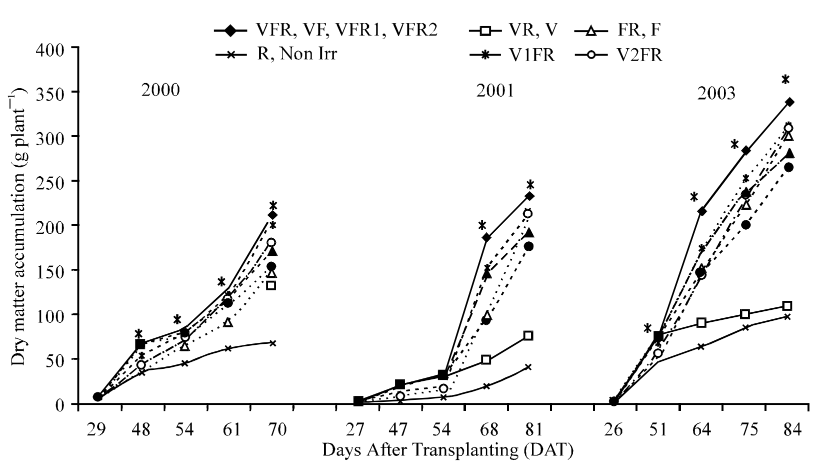

Fig. 3: Total dry matter accumulation under various water stress conditions. ** at $p<0.01$ level

of biomass accumulation. On contrary, the adverse effect of water stress on dry matter accumulation appeared to be significant under all water deficit levels. Even short-term water stress due to irrigation omission (FR) or 40 (V_1FR) and 60% (V_2FR) reduction in the irrigation water amount applied with a single irrigation practise during rapid vegetative growth, caused approximately 26, 7 and 10; 10, 8 and 9 and 11.3, 8.5 and 9% loss of final dry matter weight of the plants in 2000, 2001 and 2003 experimental years, respectively.

Serious decreases have been recorded for plants exposed to water stress during the period of yield formation imposed by irrigation omission (VR) and 40 (VF_1R) or 60 (VF_2R)% reduction of irrigation water amounts applied through multiple irrigation practises. Values of dry matter weight loss in the years of experiment were determined to vary in the ranges of 40-70, 15-17 and 22-25% under irrigation programmes including severe stress (omitted irrigation), or moderate stress conditions under 40 and 60% reduced water amount, respectively. In case of the treatments that omitted irrigation application during the earlier two (rapid growth and yield formation) periods and received first irrigation during the next period, the effect of water stress was much more pronounced. The dry matter weight loss under these treatments were determined as 71, 82 and 71% for 2000, 2001 and 2003 years, respectively.

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