Effect of water stress at different growth stages on quantity and quality traits of Virginia (flue-cured) tobacco type

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ABSTRACT

A field research was carried out in the years of 2005, 2006 and 2007 in order to determine the effect of irrigation and water stress imposed at different growth stages on quantity and quality traits of Virginia tobacco plants. A randomized complete block design with four treatments and three replications was applied at the Rasht tobacco research station. Treatments were: no irrigation (dryland farming) as the complete water stress (WS_0), water stress till the end of flower bud forming stage (WS_1), water stress till the end of flowering stage (WS_2) and full irrigation (WS_3) as control in each cropping season. The combined analysis of variance showed that the effect of water stress on all the traits related to yield, quality traits and all the traits related to yield components except number of leaves, was significant ($P < 0.01$). The interaction between year and water stress showed that the treatment of WS_0 in all three experimental years significantly ($P < 0.05$) affected the fresh and dry leaf yield, plant height and sugar and nicotine percentage. The comparison of means of three years (average of three years) also revealed that the treatment of WS_0 significantly ($P < 0.05$) affected all of the traits which were related to tobacco quantity and quality except for the number of leaves. Moreover, the level of water productivity in recognition of each water volume unit for three experimental years for the treatments of WS_1, WS_2 and WS_3 were 1.223, 0.873 and 0.594 kg/m^3, respectively, in the case of average dry leaf yield. Consequently, the results indicate that with optimizing irrigation application we can reach the higher level of productivity.

Keywords: tobacco; water stress; quantity and quality traits

As energy costs and the demand of water by industry and home usage go up, timely irrigation before the occurrence of crop injury by water stress becomes an important issue for cultivated lands where water resources are limiting (Misra et al. 2002). Water stress is perceived as water deficit and can occur with different severity (Ramanjulu and Bartels 2002). It is less clear, yet important, with respect to quantitative relationship of water stress level and yield as well as quality characteristics of tobacco and the effect of stress timing. However, for good yield and quality, tobacco should not be subjected to severe drought conditions; yet, between the time a stand is established and when plants are about knee-high a little moisture stress is not considered harmful. A shortage of moisture at this stage may improve yield and quality (Collins and Hawks 1993). Singh (1998) reported that moderate precipitations along with cloudy sky at the first development stage, moderate precipitations along with adequate sunshine at the rapid growth stage, and lack of precipitations at the harvesting time are the most favorable conditions for producing tobacco having high quantity and quality.

Irrigation is suggested only during extended drought after a stand is established until the tobacco is knee-high (Collins and Hawks 1993). Also, Reed et al. (1994) do not suggest the irrigation immediately after transplanting except in drought conditions or high temperatures. When tobacco is making its most rapid leaf growth, usually the second month after transplanting, in the knee-high to early-bloom stages moisture is extremely important (Collins and Hawks 1993). McNee et al. (1978) found that the tobacco plant was the most sensitive to soil moisture during the period of rapid growth following field establishment, and frequent irrigating was required to develop maximum leaf area and high yield. They also reported that water stress at budding stage reduced the harvested leaf area and cured leaf yields, whereas water stress during the flowering period resulted in an off-type and immature cured leaf of reduced commercial value. Doorenbos and Kassam (1979) believed that water shortage in the soil profile at the middle stage of tobacco development leads to reduction of growth and leaf expansion. Also, they reported that severe water deficit in the soil profile at the flowering and ripening stages of tobacco causes delay in harvesting time and consequently lead to reduction of leaf yield and other chemical components. Whitty and Chambliss (2005) suggested that the most tobacco sensitivity to water deficit occurs at 2–3 weeks before the flowering stage (50–65 day after transplanting). The results of a 3-year study done by Cakir and Cebi (2006) on Virginia tobacco in Turkey showed that all vegetative parameters as well as dry matter accumulation processes were significantly affected by water shortage in the soil profile during the early growth stages. They also reported that water stress of various severity occurring during rapid vegetative growth and yield formation periods reduced plant height and it influenced leaf number and leaf area development. Similarly, Wilkinson et al. (2002) demonstrated that water stress occurring at various growth stages of tobacco plant leads to yield decrease, leaf expansion and dry matter accumulation, because of decreased vegetative growth.

Under the competitive field environment where dry conditions of varying duration and intensity may occur frequently during the growing season, a better picture of the quantitative relationship between tobacco yield and the level and timing of water shortage in the soil profile would be helpful in establishing of strategies for tobacco-irrigation management. Longer-term experiments were therefore made to study tobacco growth and yield subjected to a period of soil water deficit during vegetative and reproductive phases. The relative effects of water stress on quality traits associated with yield reductions were also evaluated.

MATERIAL AND METHODS

Field trials were conducted with flue-cured tobacco plant (*Nicotiana tabacum* L.) of Virginia type at the experimental farm of the Rasht Tobacco Research Station in the Guilan province of Iran (37°16' N, 49°31' E, altitude: –5 m) in the years 2005, 2006 and 2007. According to the Copen taxonomy, the region has a very humid climate. It also has warm summers with an average annual rainfall of 1250 mm (Alizadeh 2002). The amounts of precipitations along the first, second and third cropping season were approximately 240, 92 and 85.8 mm, respectively (Figure 2). Precipitation and temperature values were recorded using a weather station at the experimental site during the three experimental years, as well as long-term averages (Figure 1). Also, Figure 2 illustrates the precipitation data for the Guilan Tobacco Research Center during the growth season of tobacco as decade period in three cropping seasons. As shown in Figure 1 the first year (2005) was rainier than total yearly precipitation averages for a period of 36 years (from 1971 to 2007). The second and third years (2006 and 2007) were approximately similar to this average amount. Moreover, as shown in Figure 2 the first experimental year throughout the tobacco growth, especially in the month of August (at the end of tobacco growth), was

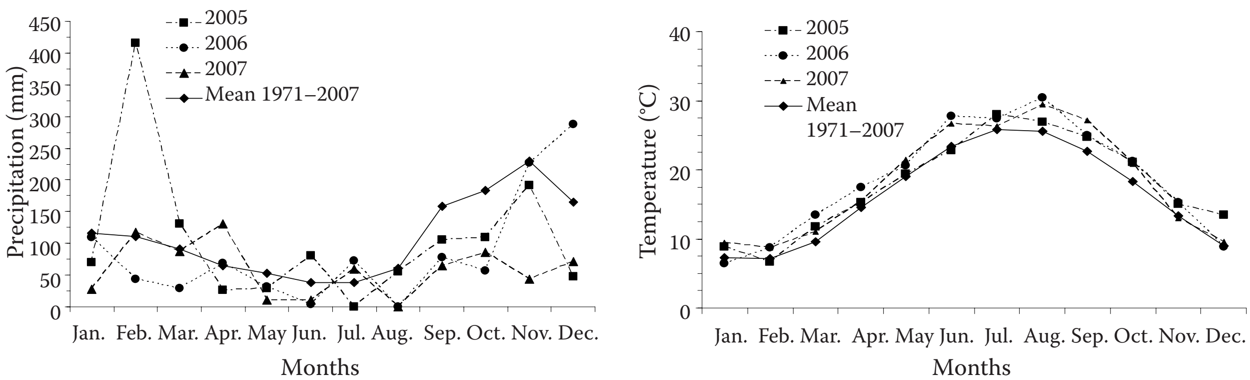

Figure 1. The amount of precipitation and temperature in 2005, 2006 and 2007 and the 36-year average 1971–2007) at the experimental site

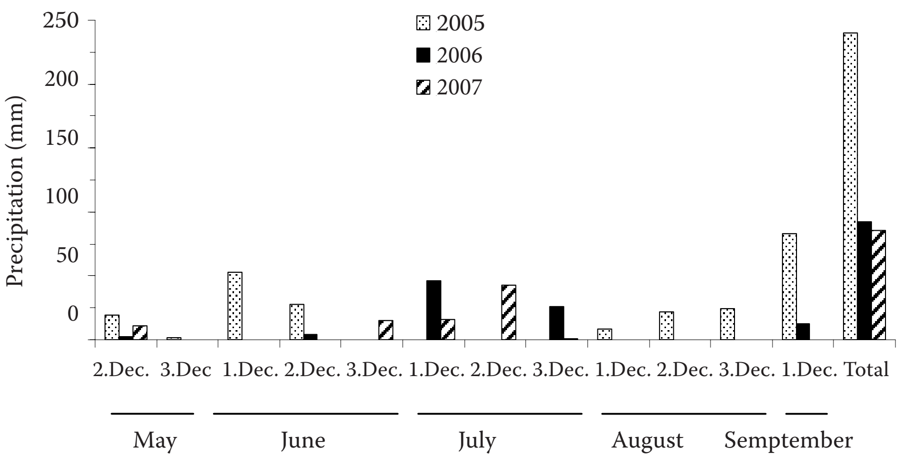

Figure 2. Precipitation data (mm) at the Guilan Tobacco Research Center during the growth season of tobacco as decade period in three years of experiments

rainier compared to the precipitation amount of second and third experimental years. Therefore, the water stress throughout the second and third experimental years (2006 and 2007) was more notable than in the first experimental year. Yet, as shown in Figure 2 the rainfall distribution even at the first cropping season was not commensurate with water requirements of tobacco plants due to considerable precipitations at the beginning and the end of this period. The temperature of all three years was similar to the total yearly temperature averages for a period of 36 years (Figure 1).

The soil of experimental site has a loamy sand texture. That is poor in organic matter and the pH of its saturated paste is 5.1. In order to prepare the soil for tobacco cultivation, the experimental site was ploughed at the depth of 30 cm in the autumn preceding to the three experimental years. In the month of May in all three years, secondary plough was performed at the depth of 25 cm for soil pulverization and clogs were broken into small pieces using disk method. After application of Eradican herbicide at the rate of 5 l/ha (2:1000) a rotary ploughing was applied. During the early June of 2006 and 2007 and in the first days of second decade of June 2005, seedlings of Virginia flue-cured tobacco cultivar were transplanted in experimental plots having 30 m^2 (5 × 6 m). Hence, the transplanting in the first year (2005) had about 9 days delay; it was due to no field preparation caused by heavy snow in the past April. The transplanting was accomplished when the tobacco seedlings had the height of approximately 15 cm. A randomized block design with four treatments and three replications was applied in these plots. Each plot had 6 m in length and included 6 cultivation rows having 100 cm distance in between (Singh 1998). Also, we selected the two marginal rows as a border. Treatments in each cropping season were: no irrigation (dryland farming) as the completely water stress (WS_0), water stress till the end of flower bud forming stage (SW_1), water stress till the end of flowering stage (WS_2) and full irrigation (WS_3) as control.

Soil water retention capacity or soil available water content (AWC) was determined taking the difference between water retained at –0.33 and –15 bar (equation 1) using pressure plate apparatus and then soil moisture characteristic curve was derived (Klute 1986).

$$TAW = (\Theta_{FC} - \Theta_{PWP}) \quad (1)$$

Where: *TAW* denotes the total available water, Θ_{FC} is the water content in field capacity, and Θ_{PWP} is water content in permanent wilting point.

The time of irrigation was determined using a Tensiometer that was installed in the middle of each plot at the root development zone of tobacco plant (~ 20 cm depth) after its calibrations. When 40% of soil available water was depleted in the treatments, soil was irrigated to field capacity level. In this condition the reading numbers of Tensiometers were about 25–30 cbar (Allen and Lambert 1971, Whitty and Chambliss 2005). Also, for measuring of irrigation time in low levels of soil matric potentials, gypsum blocks that were buried in soil at the root development zone were used. Water needed for irrigation was supplied by means of a water container having capacity of 8000 l. This container was nourished from a shallow well. The amount of supplied water was measured by water gage with 0.1 l sensitivity. After transplanting tobacco plants, the soil moisture content was measured and irrigation started subsequent to its rapid growth. The following irrigation periods were determined using Tensiometer and gypsum blocks by the soil moisture characteristic curve. Also, the level of water productivity (WP)

Table 1. Combined analysis of variance for the studied traits related to yield in three years of experiments (in this table and subsequent tables Rial is the currency unit of Iran)

S.O.V.	*df*	Fresh leaf yield	Dry leaf yield	Unit price	Gross income in unit area
		(kg/ha)		(Rial/kg)	
Year (Y)	2	1526751.4^{ns}	1089656.36**	12715871.7*	265405080 × 10^{6**}
Rep/year	6	1123274.6	8422.28	3383303.9	171004140 × 10^{6}
Water stress	3	72061070.9**	1916430.11**	102005457.9**	946489510 × 10^{6**}
Y × WS	6	3229448.8^{ns}	132262.36*	2846452.3^{ns}	61706321 × 10^{6*}
Error	18	1453482.5	36991.17	2149983.0	17597317 × 10^{6}
CV (%)		8.21	9.36	15.40	20.05

**and *significant at 1 and 5%, respectively; ^{ns}non significant

was measured by following equation (Oweis and Hachum 2005):

WP_{irr} = yield in irrigation condition per hectare/water used in hectare (2)

In order to prevent the plants from diseases such as Rhizoctonia, Blue mold and brown spots on the leaf surfaces, treatments were irrigated in the mornings. The first period of irrigation was accomplished approximately 30 days after transplanting in every year due to simulating of root development and their better prevalence into the soil. Cultural practices including fertilization with a compound fertilizer (N:P:K), adding of soil by the side of plant stems, and spraying against pestilences and diseases such as Agrotis throughout the vegetative growth stages of flue-cured tobacco plant were performed.

Leaves were harvested six times in each of the three years. The harvesting time in the third (2007) and second (2006) experimental year was selected at the first and third decade of August, respectively. The commencement of tobacco harvesting in the first experimental year (2005) delayed about 42 days compared with the third experimental year due to the occurrence of precipitations at the final growth stages (Figure 2). Some important traits of tobacco plants at flowering stage including leaf length, leaf width, plant height, the number of leaves, fresh leaf yield, dried leaf yield, unit price, gross income per unit area, and Leaf Area Index (LAI) were measured. Equation 3 illustrates the calculation method of leaf area index for tobacco plant in this study. Quality traits such as sugar and nicotine percentage were also measured.

$$LAI = a + b\,(W \times L) \quad (3)$$

Where: *W* and *L* denote the leaf width and length (cm), respectively, and *a* and *b* are the coefficients. This coef-

Table 2. The interaction between year and water stress on the studied traits related to yield

Treatments (year × water stress)	Fresh leaf yield	Dry leaf yield	Unit price	Gross income
	(kg/ha)		(Rial/ha)	
$Y_1 \times WS_3$	17178.66^{a}	2257.66^{b}	12098.33	27107350.00^{b}
$Y_1 \times WS_2$	16703.66^{a}	1951.00^{b}	9907.00	19658300.00^{b}
$Y_1 \times WS_1$	15079.66^{a}	1897.33^{b}	7415.00	14098466.70^{b}
$Y_1 \times WS_0$	9232.00^{b}	1132.66^{d}	3899.66	4445400.00^{b}
$Y_2 \times WS_3$	14403.66^{a}	1936.00^{b}	12673.33	24676266.70^{b}
$Y_2 \times WS_2$	17279.33^{a}	2389.00^{b}	12154.33	29040583.30^{b}
$Y_2 \times WS_1$	15187.00^{a}	2050.66^{b}	10023.00	20777966.70^{b}
$Y_2 \times WS_0$	10755.33^{b}	1471.33^{c}	5689.33	8386983.30^{b}
$Y_3 \times WS_3$	15816.67^{a}	2563.33^{b}	11748.33	30123624.70^{b}
$Y_3 \times WS_2$	17269.00^{a}	2936.00^{a}	13974.00	41019663.00^{a}
$Y_3 \times WS_1$	15444.33^{a}	2520.67^{b}	9197.33	23377594.70^{b}
$Y_3 \times WS_0$	11801.33^{b}	1543.00^{c}	5440.67	8385042.30^{b}

Means in each column with the same letters are not significantly different at the 5% probability level using the Tukey's mean separation test

Table 3. Mean of three experimental years for the studied traits related to yield

Treatments	Fresh leaf yield	Dry leaf yield	Unit price	Gross income
	(kg/ha)		(Rial/kg)	
Three years	14679.22	2054.05	6818.11	20924770.00
Water stress				
WS_3	15799.67[b]	2252.33[a]	12173.33[a]	27302413.80[a]
WS_2	17084.00[a]	2425.33[a]	12011.77[a]	29906182.10[a]
WS_1	15237.00[b]	2156.22[a]	8878.44[b]	19418009.30[b]
WS_0	10596.22[c]	1382.33[b]	5009.89[c]	7072475.20[c]

Means in each column with the same letters are not significantly different at the 5% probability level using the Tukey's mean separation test

ficients for the Coker type of flue-cured tobacco plant were about $a = 0.00057$ and $b = 42.87$, respectively (Sarmadnia and Koochaki 1988). The data obtained from field measurements and laboratory observations were subjected to an analysis of variance using the SAS software and the Tukey's mean separation test procedure was applied.

RESULTS AND DISCUSSION

Yield. The combined analysis of variance for the traits of fresh leaf yield, dry leaf yield, unit price, and gross income in unit area are shown in Table 1. The effect of water stress on tobacco plants for all the traits related to yield was significant ($P < 0.01$). The year had a significant effect on dry leaf yield ($P < 0.01$), unit price ($P < 0.05$) and gross income in unit area ($P < 0.01$), while fresh leaf yield was not affected by year. The interaction between year and water stress in tobacco plants for the traits of dry leaf yield and gross income in unit area was significant ($P < 0.05$) whereas the interaction between year and water stress had no influence on fresh leaf yield and unit price.

The interaction between year and water stress showed that just the treatment of WS_0 in each of three experimental years significantly ($P < 0.05$) affected the fresh and dry leaf yield, while the traits of unit price and gross income in unit area were not affected by any of the water stress treatments (Table 2). The comparison of means of three years (average of three years) also revealed that the treatment of WS_0 significantly ($P < 0.05$) affected all of the traits which were related to tobacco yield. The comparison of means of three years also indicated that the treatment of WS_1 significantly ($P < 0.05$) affected the traits of unit price and gross income in unit area (Table 3). Similar results about the adverse effect of water stress on tobacco plants, such as its dry yield reduction, were reported before (Hawks 1970, McNee et al. 1978, Moor and Tyson 1999, Cakir and Cebi 2006). For example, Reed et al. (1994) found that the intense water stresses delayed the common process of leaf ripening. Also, they reported that the water stress elongated the growth stage of tobacco plant and caused burning of the leaf margins and therefore, led to unsuitable quality and quantity of the leaves. They also expressed that the harvested leaves which had insufficient moisture content did not change to the suitable yellowish color during the process of drying and hence, their cost of drying increased and the value (price) of tobacco decreased.

Yield components and quality traits. The combined analysis of variance for the traits of yield components including leaf length, leaf width, plant height, number of leaves, leaf area index, and for the quality traits such as sugar percentage and nicotine percentage were also applied (Table 4). According to Table 4, the year had a significant effect on leaf length ($P < 0.05$) and number of leaves ($P < 0.01$) and other traits related to yield components and quality traits were not affected by year. In addition, the effect of water stress on quality traits and all the traits related to yield components except number of leaves were significant ($P < 0.01$). Furthermore, the effect of interaction between year and water stress on the quality traits as well as leaf area index and leaf length was significant (Table 4).

The interaction between year and water stress showed that none of the water stress treatments could affect the traits of leaf length, leaf width, number of leaves and leaf area index, whereas the treatment of WS_0 in all three experimental years significantly ($P < 0.05$) affected the plant height and sugar %. Also, the treatment of WS_0 in the years of 2005 and 2006 significantly ($P < 0.05$) affected

Table 4. Combined analysis of variance for yield components and quality traits

S.O.V.	*df*	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Number of leaves
Year (Y)	2	106.36*	12.44ns	80.03ns	16.86**
Rep/Year	6	33.25	29.86	57.86	5.92
Water stress	3	280.48**	56.62**	3223.06**	3.43ns
Y × WS	6	105.17*	18.96ns	252.40ns	2.71ns
Error	18	26.58	10.12	110.01	1.84
CV (%)		8.85	11.01	7.11	6.16

S.O.V.	*df*	Leaf area index	Sugar percentage	Nicotine percentage
Year (Y)	2	5.02ns	1.26ns	1.29ns
Rep/Year	6	3.16	36.89	0.75
Water stress	3	11.59**	264.91**	4.70**
Y × WS	6	3.63*	17.68*	0.12**
Error	18	1.79	4.55	0.02
CV (%)		22.43	16.18	8.96

** and *significant at 1 and 5%, respectively; nsnon significant

the nicotine %. However, the sugar percentage and nicotine percentage were significantly different in the years of 2005 and 2006 (Table 5). Moreover, the comparison of means of three years (average of three years) indicated that only the treatment of WS_0 significantly ($P < 0.05$) affected the leaf length, leaf width, plant height and leaf area index in all of the water stress treatments (Table 6). Similarly, Maw et al. (1977) observed the highest values of leaf length, leaf width, and plant height in the treatment without imposition of water stress on tobacco plants. The results of work done by Cakir and Cebi (2006) showed a significant effect of irrigation application or exposition to water stress at earlier stages on leaf length and leaf width. The similar result was also observed by Sifola and Postiglione (2002). Jerell (2001) reported that the leaf area values of tobacco plants during dry years were lower compared to the same periods of rainy years. The effect of water stress on leaf number in the present study is in contrast to the work done by Cakir and Cebi (2006). They found that water stress of different severity influenced leaf number of Virginia flue-cured tobacco plant. Also, a significant effect of water stress on leaf number was confirmed by Maw et al. (1977), Wilkinson et al. (2002) and Atannasov (1972). The differences in growth characteristics of tobacco cultivars, climatic conditions, date, and cultural practices as well as the amount of irrigation water, all could be reasons for this disagreement. This result can also be attributed to the intrinsic characteristics of Virginia tobacco plant, namely that the number of leaves of this tobacco type were not influenced by the water stress.

Furthermore, the comparison of means of three years indicated that the treatments of WS_1 as well as WS_2 significantly ($P < 0.05$) affected the sugar % (Table 6). In addition, the imposition of water stress to plants had an inverse effect on nicotine percentage compared to the sugar percentage. Hence, with an increase of irrigation level the sugar percentage increased while the nicotine percentage decreased (Table 6). However, the greatest nicotine percentage in all three experimental years was observed in no irrigation (WS_0) treatment (Table 5) and only this treatment had a significant effect ($P < 0.05$) on nicotine percentage in the first and second (2005 and 2006) experimental year. Moreover, the effect of water stress on nicotine percentage was more pronounced in the third experimental year (2007) compared with the other years (Table 5). This observation can be also explained by the dryer condition that occurred in the third year (Figure 2). In general, the lowest nicotine percentage of all treatments was observed at the second experimental year (Table 5). Nagarajan and Prasadrao (2004) and Maw et al. (1977) expressed that the optimum level of sugar percentage in the leaves of flue-cured tobacco plant is between the ranges of 10–26% and 15–25%, respectively. The imposition of drought stress in the present study within the treatment of no irrigation (WS_0) in three years reduced the

Table 5. The interaction between year and water stress with respect to yield components and quality traits

Treatments (year × water stress)	Leaf length	Leaf width	Plant height	Number of leaves
		(cm)		
$Y_1 \times WS_3$	72.66	29.66	162.33[a]	22.67
$Y_1 \times WS_2$	64.00	31.00	163.33[a]	22.67
$Y_1 \times WS_1$	65.33	30.00	161.66[a]	23.33
$Y_1 \times WS_0$	44.66	21.33	109.00[b]	21.33
$Y_2 \times WS_3$	55.33	28.33	147.66[a]	21.00
$Y_2 \times WS_2$	58.33	30.66	159.66[a]	20.00
$Y_2 \times WS_1$	59.33	30.00	161.66[a]	20.67
$Y_2 \times WS_0$	51.33	25.66	126.00[b]	21.00
$Y_3 \times WS_3$	61.00	33.67	160.00[a]	22.67
$Y_3 \times WS_2$	55.67	29.67	150.67[a]	22.67
$Y_3 \times WS_1$	57.00	28.00	145.00[a]	23.67
$Y_3 \times WS_0$	54.67	28.67	122.33[b]	21.33

Treatments (year × water stress)	Leaf area index	Sugar percentage	Nicotine percentage
$Y_1 \times WS_3$	7.30	17.40[a]	1.54[b]
$Y_1 \times WS_2$	7.07	14.37[a]	1.75[b]
$Y_1 \times WS_1$	8.02	12.68[a]	1.89[b]
$Y_1 \times WS_0$	3.30	7.15[b]	2.75[a]
$Y_2 \times WS_3$	5.15	20.65[a]	0.75[c]
$Y_2 \times WS_2$	5.61	15.83[a]	0.93[c]
$Y_2 \times WS_1$	5.77	11.78[a]	1.10[c]
$Y_2 \times WS_0$	4.34	4.22[b]	2.52[a]
$Y_3 \times WS_3$	7.89	15.47[a]	1.24[c]
$Y_3 \times WS_2$	6.22	16.89[a]	1.16[c]
$Y_3 \times WS_1$	5.62	16.85[a]	1.19[c]
$Y_3 \times WS_0$	4.35	4.95[b]	2.88[c]

Means in each column with the same letters are not significantly different at the 5% probability level using the Tukey's mean separation test

sugar percentage of tobacco plant on average to the level of 5.44% (Table 6). Therefore, this level of sugar percentage leads to a weak quality of tobacco leaves and decreases its economical value. However, the sugar percentage averaged in all the treatments in three years except the WS_0 was similar to the optimum level that was introduced by these researchers (Table 6).

As shown in Table 6, the comparison of three year means of nicotine percentage showed that this trait was not affected by any of the treatments except the treatment of no irrigation (WS_0). Moreover, the level of nicotine percentage in this study, as the average of three years, was between the ranges of 1.17–2.72% (Table 6). The minimum level (1.17%) was obtained in the WS_3 treatment and the maximum (2.72) was obtained in the WS_0 treatment. Doorenbos and Kassam (1979) reported that the cultivation of tobacco plant in dry conditions would enhance the percentage of nicotine in the leaves. They also indicated the optimum level of nicotine percentage in the flue-cured tobacco plant in the range 1.5–2%. Also, Nagarajan and Prasadrao (2004) and Singh (1998) represented the optimum level of nicotine percentage in the flue-cured tobacco plant between 1.75–2% and 1.2–3.6%, respectively. However, the nicotine percentage in all the treatments was similar to the optimum level that was introduced by these researchers (Table 6).

In the average of three experimental years the ratio of sugar to nicotine for the treatments of WS_0, WS_1, WS_2 and WS_3 was 2.00, 9.91, 12.26 and 15.25, respectively (Table 6). Nagarajan and

Table 6. Mean of three experimental years for yield components and quality traits

Treatments	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Number of leaves
Three years	58.28	28.89	147.47	22.25
Water stress				
WS_3	63.00[a]	30.56[a]	156.67[a]	22.44
WS_2	59.33[a]	30.44[a]	158.00[a]	22.22
WS_1	60.56[a]	29.33[a]	156.11[a]	22.33
WS_0	50.22[b]	25.22[b]	119.11[b]	21.11

Treatments	Leaf area index	Sugar percentage	Nicotine percentage	Sugar to nicotine ratio
Three years	5.96	13.18	1.64	
Water stress				
WS_3	6.78[a]	17.84[a]	1.17[b]	15.25
WS_2	6.30[a]	15.69[b]	1.28[b]	12.26
WS_1	6.47[a]	13.77[b]	1.39[b]	9.91
WS_0	4.28[b]	5.44[c]	2.72[a]	2.00

Means in each column with the same letters are not significantly different at the 5% probability level using the Tukey's mean separation test

Prasadrao (2004) and Maw et al. (1977) introduced the optimum level of sugar to nicotine ratio in the leaves of flue-cured tobacco in the range of 7 to 13% and 6 to 10%, respectively. However, in the present study the treatment of no irrigation (WS_0) and full irrigation (WS_3) had the negative effect on this ratio. Hence, in the treatments of no irrigation (WS_0) and full irrigation (WS_3), lower and higher was obtained, respectively, compared to the optimum level that was introduced by these researchers. Therefore, to achieve the best tobacco quality, the irrigation is unavoidable; still, the excessive and unnecessary irrigation can have adverse effects on quality traits of nicotine.

Water productivity. Water productivity (WP) is one of the most important indexes in optimum usage of water resources; the cost of irrigation pumping and inadequate irrigation scheme capacity as well as limited water sources are among the reasons that force many farmers to reduce irrigation applications (Cakir 2004). Hence, in the present study this index was investigated from the viewpoint of water use efficiency and economical output. The level of water productivity, for three experimental years in average for the trait of dry leafyield, in the treatments of WS_1, WS_2 and WS_3 were 1.223, 0.873 and 0.594, respectively, in recognition of each water volume unit. Therefore, with optimizing irrigation application we can reach a higher level of productivity or dry leaf yield. Allen and Lambert (1971) introduced the flue-cured tobacco as a crop which produces higher yields and greater returns with supplemental irrigation in the southern United State. They revised the irrigation scheduling decisions that were based on the available soil moisture depleted to 50% of available capacity. They found that new criterion yielded less total cost plus loss and achieved a better utilization of the available water than did the 50% criterion. Hence, with regard to our results, it is obvious that the water stress can be completely mitigated using a suitable irrigation scheduling in north of Iran.

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