EFFECTS OF IRRIGATION SCHEDULING AND AMOUNTS ON FLUE-CURED TOBACCO IN ONTARIO

TOBACCO SCIENCE

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The effects of two start irrigation times (250 and 1100 corn heat units (CHU) accumulated after transplanting), two end irrigation times (1700 and 2500 CHU accumulated after transplanting) and two minimum soil moisture conditions (9% and 5% volumetric soil moisture) on flue-cured tobacco (*Nicotiana tabacum* L. cv. Delgold) grown in southwestern Ontario were investigated over five years in a field study. Early season irrigation, at 9% minimum soil moisture content, starting when 250 CHU had been accumulated after transplanting (9 to 15 days) increased leaf number and yield in one year, quality in two years, and reducing sugars concentration in three years and decreased alkaloid concentration in three years. Irrigation during harvest continuing until 2500 CHU had been accumulated after transplanting (102 to 116 days) did not produce any consistent response. Irrigation at a minimum of 9% vs. 5% volumetric soil moisture consistently increased tobacco growth, yield, quality, and reducing sugar concentration and reduced total alkaloid concentration. The reduction in total alkaloid concentration was attributed to dilution by increased yield rather than a change in the amount of alkaloids produced.

Additional key words: *Nicotiana tabacum* L., soil moisture, alkaloids, reducing sugars.

INTRODUCTION

In Ontario, flue-cured tobacco, *Nicotiana tabacum* L., is grown on coarse textured sandy soils with inherently low moisture holding capacity. The tobacco irrigation recommendations pertaining to irrigation scheduling and amount of water to apply are based, primarily, on work done at the Delhi Research Station from 1953 to 1956. Growers typically apply 40 to 100 mm of irrigation water during the rapid vegetative growth stage of crop development (mid-July to early August) to supplement inadequate or poorly distributed natural rainfall (D.L. VanHooren, Tobacco Specialist, Ontario Ministry of Agriculture, Food and Rural Affairs, personal communication). Moderate moisture stress between the time the tobacco crop is established (late May) and early July is not considered harmful. Irrigation during harvest is thought to be only occasionally necessary to promote the development of the tip leaves and to hasten the maturity of the crop (2).

It has been reported that irrigation can improve yields in dry years when applied in appropriate amounts depending on the stage of crop growth (4,5,10,18). Collins & Hawks (4) reported that moderate moisture stress between the time that the stand is established and the crop is knee-high may improve yield and quality. However, during the rapid vegetative growth stage, from about knee-high to early bloom, moisture stress will significantly reduce yield and quality. A number of other studies have shown that moderate moisture stress for about 30 days after transplanting will increase crop yields and improve quality (5,7,12,15). Ligon & Benoit (8) reported that after relief from moisture stress, the rate of growth of burley tobacco increased but did not exceed that of nonstressed plants, and therefore moderate moisture stress did not improve crop yield or quality.

Parups et al. (11) reported that a soil temperature of 22°C and 75% available soil moisture produced the best overall growth of tobacco and that moisture stress decreased yield and increased the nicotine content of the leaf. A number of other studies also showed that moisture stress increases the concentration of alkaloids in the leaf and generally reduces the concentration of sugars (4,7,12,19). Early moisture stress was shown by Hopkinson (7) to reduce the rate of leaf initiation and delay flowering.

Although considerable work on irrigation has been done, little research information is available on the effects of irrigation at different stages of crop growth and in different amounts under southwestern Ontario climatic conditions, and no information is available pertaining to the cultivars and production practices currently recommended in Ontario.

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Contribution received December 22, 1994. Tob. Sci. 39: 83-91, 1995.

The objective of this work was to examine the effects of variations in irrigation scheduling and soil moisture level on the yield and quality of flue-cured tobacco grown in southwestern Ontario.

MATERIALS AND METHODS

Flue-cured tobacco (cv. Delgold) was grown in fields located at the Pest Management Research Centre, Delhi, Ontario, on a Fox loamy sand soil (85% sand, 7.5% silt, 7.5% clay, 1% organic matter, pH 6.4, bulk density of 1.4 g/cc). The volumetric moisture holding capacity of the upper 45 cm of soil was determined by the pressure plate technique to be about 40% at saturation, 16% at field capacity, and 4% at permanent wilting point with 12% (54 mm/45 cm) available soil moisture. The volumetric soil moisture of individual field plots was determined by the use of the Time Domain Reflectometry (TDR) technique (16,17). The scheduling of start and end times for irrigation were based on the accumulation of Corn Heat Units (CHU) after transplanting, an adaptation of a method devised by Brown & Bootsma (3). A randomized complete block factorial design with 4 replications was used to investigate the effects of two irrigation start times (250 and 1100 CHU accumulated after transplanting), two irrigation end times (1700 and 2500 CHU accumulated after transplanting), and two minimum soil moisture conditions (9% and 5%). A nonirrigated check also was included for a total of 9 treatments (**Table 1**).

Table 1. Irrigation start schedule, end schedule, and minimum soil moisture level for the period of time during which irrigation was applied in 1989, 1990, 1991, and 1993.

Treatment	Start time	End time	Minimum soil moisture
	------------- CHU[a]	------------	----- % -----
1	250[b]	1700	9
2	250	1700	5
3	250	2500	9
4	250	2500	5
5	1100	1700	9
6	1100	1700	5
7	1100	2500	9
8	1100	2500	5
9 (Nonirrigated check)	-----	-----	–

[a]Corn Heat Units (3) accumulated after transplanting.
[b]For 1989, 1990, 1991, and 1993, respectively, the days after transplanting for each start and end irrigation schedules were: 250 CHU - 9, 15, 19, and 17 days; 1100 CHU - 46,51, 45, and 50 days; 1700 CHU - 67, 76, 69, and 76 days; 2500 CHU - 102, 109, 102, and 116 days.

Cultural Practices

Tobacco transplants produced in an unheated greenhouse were transplanted into field plots on May 29, 29, 24, 31, and 25 (Julian Days 149, 149, 144, 152, & 145) in 1989, 1990, 1991, 1992, and 1993, respectively. Field plots consisted of 4 rows 1.07 m x 23 m with a spacing of 0.61 m between plants in a row. All data were collected from the middle two rows of each plot. One of the two center rows of each plot was used for plant growth measurements and the other center row was used for the determination of plot yield and quality. Rye was grown on the field plots the previous year. Normal cultural practices for this production region were followed including 800 kg/ha of 3-6-18 fertilizer applied at transplanting plus a side-dress application of 180 kg/ha of 9-0-27 applied in late June.

After transplanting, a pair of 3.0 mm diameter x 1.0 m long stainless steel TDR probes were inserted 3.0 m from the end of the harvest row in each field plot, at a 27° angle to the soil surface, parallel to each other, and spaced 6 cm apart. This resulted in the upper ends of the probes being at the soil surface and the lower ends of the probes being 45 cm below the soil surface. To minimize soil compaction and/or possible plant injury resulting from the frequent collection of soil moisture data, the two probes were connected to a 3.5 m long, shielded twin conductor cable leading out to the end of the row. The 36 pairs of cable leads (9 treatments x 4 reps) were connected to a Tektronix 1502B Metallic TDR Cable Tester used to determine the average volumetric soil moisture in the upper 45 cm of soil (16,17).

After transplanting, trickle irrigation tubing with Netafim brand emitters spaced 32 cm apart was placed immediately adjacent to each row of tobacco, except for the nonirrigated check rows. The average water delivery rate of each emitter was about 3.0 L/hr. Different levels of moisture stress were created in each plot, independent of other plots, by allowing the volumetric soil moisture to drop to the predetermined level of 9% or 5% before adding water by trickle irrigation. Irrigation water was applied for 1.7 hr in a plot at 9% soil moisture and for 2.5 hr in a plot at 5% soil moisture. This resulted in a zone of soil about 24 cm on either side of the row and 45 cm deep being

Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

Table 2. Effects of irrigation on soil moisture and on tobacco yield, quality, and related chemical and physical characteristics in 1989.

Variation	Average soil moisture	Yield and quality: Plant yield	Yield and quality: Returns	Yield and quality: Grade index	Chemical characteristics: Total alkaloids	Chemical characteristics: Reducing sugars	Physical Characteristics: Number of[a] leaves	Physical Characteristics: Number of leaves after topping	Physical Characteristics: Area of 3 tip leaves
	-- % --	--kg/ha--	--$/ha--	--¢/kg--	-- % --	-- % --			-- cm^2 --
Irrigation treatment									
1	10.2 ab[b]	2930 bc	12820 b	438	3.5 f	15.5 a	31.2	17.6	945 abc
2	7.4 de	2760 cd	11870 bc	431	4.8 bcd	11.8 bcd	29.5	17.1	914 bc
3	10.8 a	3210 a	14040 a	437	3.8 ef	14.6 ab	31.0	18.2	1034 ab
4	7.7 de	2600 de	11130 cd	428	4.7 cd	12.9 abc	30.0	16.7	839 c
5	9.2 c	2920 bc	12560 b	430	4.8 bcd	11.1 cde	31.0	18.4	1122 a
6	8.1 d	2480 ef	10130 de	409	5.2 ab	8.7 ef	29.9	16.3	885 bc
7	9.5 bc	3020 ab	12870 b	427	4.2 dc	13.2 abc	30.7	18.6	973 abc
8	7.2 ef	2680 de	11160 cd	415	5.0 abc	9.7 def	29.4	17.1	1004 abc
9 (Non-irrigated check)	6.4 f	2310 f	9190 e	398	5.4 a	6.9 f	28.2	16.0	837 c
Start Time for Treatments at 9% Minimum Soil Moisture									
250 CHU (9)[c]	10.5	3070	13430	438	3.6	15.0	31.1	17.9	989
1100 CHU (46)	9.4	2970	12720	428	4.5	12.1	30.9	18.5	1047
LSD (0.05)	0.6	N.S.	630	8	0.5	2.9	N.S.	N.S.	N.S.
End Time for Treatments at 9% Minimum Soil Moisture									
1700 CHU (67)	9.7	2920	12690	434	4.1	13.3	31.1	18.0	1033
2500 CHU (102)	10.2	3120	13460	432	4.0	13.9	30.9	18.4	1003
LSD (0.05)	N.S.	190	630	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Minimum Soil Moisture									
9 %	9.9	3020	13070	433	4.1	13.6	31.0	18.2	1018
5 %	7.6	2630	11070	421	4.9	10.8	29.7	16.8	911
LSD (0.05)	0.4	120	600	9	0.3	1.6	1.2	0.6	N.S.

[a] Number of leaves >10 cm in length on July 24.
[b] Values in the same column followed by the same letter are not significantly different at the 0.05 probability, N.S. = nonsignificant.
[c] Numbers in parentheses indicate days after transplanting.

brought to near field capacity (about 16%). About 45% of the soil surface in each row was effectively covered by a single trickle line. Irrigating for longer than 1.7 or 2.5 hr did not improve the lateral distribution of water, and it would have caused significant leaching of nutrients. Rainfall amounts and the daily maximum and minimum temperatures used to calculate the accumulation of CHU after transplanting were monitored at the weather site.

Measurements and Analyses

Tobacco was harvested in five primings and cured in a downdraft stick kiln. The tobacco was sorted into grades according to the Ontario Farm Products and Sales Act, and yield, financial return, and grade index were calculated for each plot (1). Chemical analyses of cured lamina were conducted to determine total alkaloids and reducing sugars (6). Total leaf number, area of 3 tip leaves (14), and leaf number after topping were determined at the time of topping.

Analysis of variance was conducted on each of the measured and calculated variables using the General Linear Models (GLM) procedure of SAS Institute (13). The comparison of treatment effects and main effects were tested at the 0.05% probability level by Least Significant Difference (LSD). Analysis of variance indicated significant interactions between minimum soil moisture and both start and end time schedules. The 5% minimum soil moisture treatments did not produce any significant differences relating to either start time or end time. Therefore, the main-effects means for start and end times shown on **Tables 2-5** are from treatments irrigated at 9% minimum soil moisture level only.

Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

Table 3. **Effects of irrigation on soil moisture and on tobacco yield, quality, and related chemical and physical characteristics in 1990.**

Variation	Average soil moisture	Yield and quality: Plant yield	Returns	Grade index	Chemical characteristics: Total alkaloids	Reducing sugars	Physical Characteristics: Number of[a] leaves	Number of leaves after topping	Area of 3 tip leaves
	-- % --	--kg/ha--	--$/ha--	--¢/kg--	-- % --	-- % --			-- cm² --
Irrigation treatment									
1	11.3 a[b]	3140 a	13480 b	429	2.6	17.9 a	28.6	16.3	756
2	9.8 b	2800 b	12400 b	442	3.1	12.9 b	28.4	16.2	731
3	11.4 a	3140 a	13770 a	439	2.6	17.1 a	28.5	16.3	757
4	9.6 b	2680 bc	11710 bc	437	3.1	13.3 b	28.7	16.0	717
5	10.7 a	3210 a	13950 a	435	2.6	17.0 a	28.5	16.4	814
6	9.8 b	2740 bc	11960 bc	437	3.0	12.3 b	28.3	15.9	696
7	11.3 a	3170 a	13720 a	433	2.6	16.9 a	28.2	16.8	732
8	9.6 bf	2570 c	11400 c	444	3.2	13.1 b	28.2	16.0	673
9 (Non-irrigated check)	9.3 b	2640 bc	11600 bc	440	3.4	11.8 b	28.0	16.0	750
Start Time for Treatments at 9% Minimum Soil Moisture									
250 CHU (15)[c]	11.3	3140	13620	434	2.6	17.5	28.5	16.3	756
1100 CHU (51)	11.0	3190	13840	434	2.6	16.9	28.4	16.3	773
LSD (0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
End Time for Treatments at 9% Minimum Soil Moisture									
1700 CHU (76)	11.0	3180	13710	432	2.6	17.4	28.5	16.3	785
2500 CHU (109)	11.3	3160	13750	436	2.6	17.0	28.4	16.5	745
LSD (0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Minimum Soil Moisture									
9 %	11.2	3170	13730	434	2.6	17.2	28.4	16.4	765
5 %	9.7	2700	11870	440	3.1	12.9	28.4	16.0	704
LSD (0.05)	0.3	100	450	5	0.1	0.9	N.S.	0.4	51

[a] Number of leaves >10 cm in length on July 17.
[b] Values in the same column followed by the same letter are not significantly different at the 0.05 probability, N.S. = nonsignificant.
[c] Numbers in parentheses indicate days after transplanting.

RESULTS AND DISCUSSION

Rainfall and Irrigation Treatments

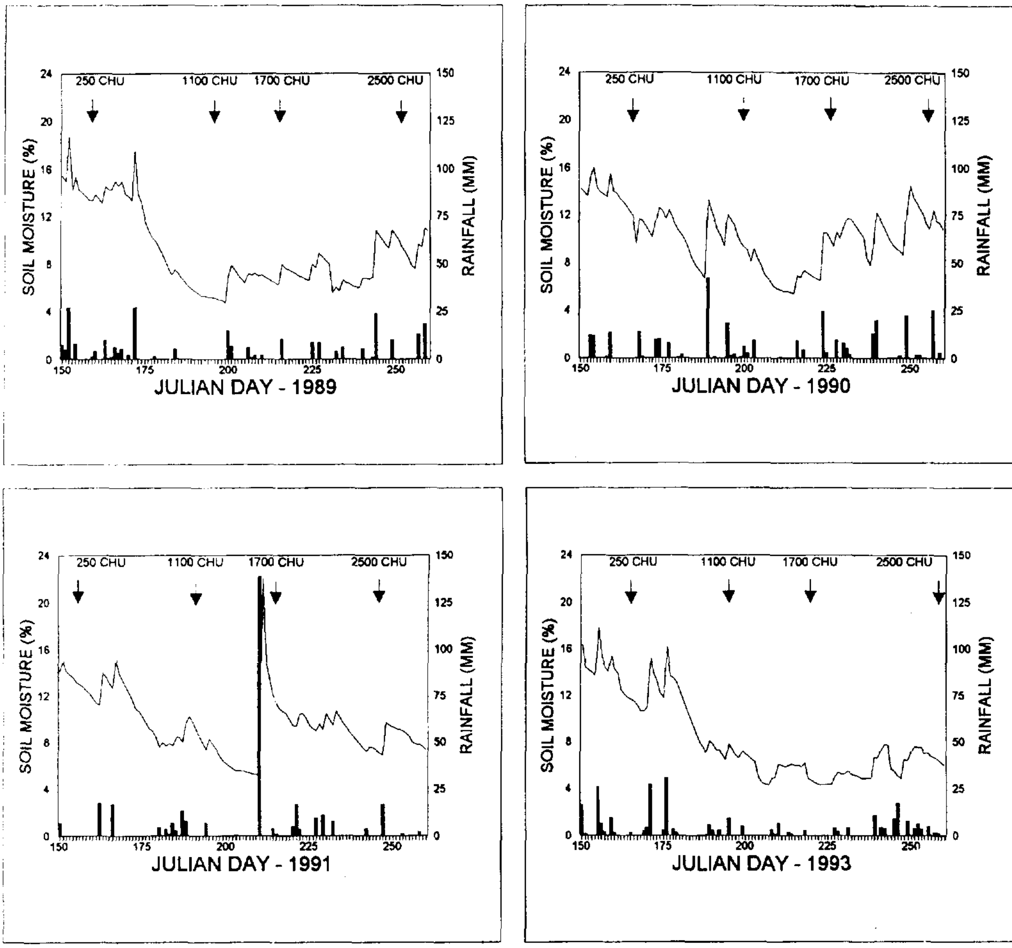
The seasonal distribution of rainfall and the resultant soil moisture levels observed in the nonirrigated tobacco check plots from Julian day 150 (May 30) to 260 (Sept. 17) are shown for years 1989, 1990, 1991, and 1993 in **Figure 1**. Irrigation was not required to maintain soil moisture in 1992 and therefore data from these field plots are not reported. **Figure 2** shows the effect of various amounts of water (rainfall + irrigation) on the average soil moisture level of the field plots from Julian day 150 to 260.

In 1989, 264 mm of rainfall was recorded from Julian day 150 to 260 resulting in less than 9% soil moisture in the nonirrigated check plots for a total of 66 days (**Figure 1**). The distribution of rainfall was such that most of the moisture stress occurred from Julian day 181 to 243 (early and mid-season). As a result, the combination of natural rainfall and trickle irrigation produced significantly different average soil moisture due to irrigation schedule start time (250 CHU vs. 1100 CHU) and minimum soil moisture (9% vs. 5%), but not due to irrigation schedule end time (1700 CHU vs. 2500 CHU) (**Table 2**).

In 1990, 321 mm of rainfall was recorded from Julian day 150 to 260 resulting in less than 9% soil moisture in the nonirrigated check plots for only 29 days (**Figure 1**). The distribution of rainfall for 1990 was such that most of the limited moisture stress experienced that year occurred from Julian day 184 to 188 and 204 to 223 (about mid-season). As a result, the combination of rainfall and irrigation did not produce a significant difference in average soil moisture due to start or end irrigation schedules (**Table 3**).

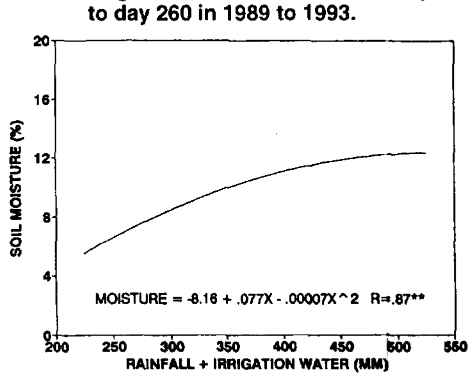
Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

Figure 1. Rainfall distribution (bars) and soil moisture level (lines) in the nonirrigated check in 1989, 1990, 1991, and 1993. The vertical arrows mark the Julian days when 250, 1100, 1700, and 2500 CHU had been accumulated after transplanting and indicate the two start followed by the two end irrigation schedules, respectively.



In 1991, 313 mm of rainfall was recorded from Julian day 150 to 260 with 139 mm recorded on day 210 alone (**Figure 1**). This extremely heavy rainfall produced the highest soil moisture observed during this study and it almost certainly caused nutrient leaching. As a result, the tobacco crop tended to produce lighter colored tobacco. Although the distribution of rainfall produced less than 9% soil moisture in the nonirrigated check plots for a total of 49 days, the major periods of moisture stress were just before the 1100 CHU start irrigation schedule and mid-season. Late in the season (day 238 to 260), lack of rainfall resulted in soil moisture stress for 20 days, however, 12 of these days occurred after the 2500 CHU end irrigation schedule. The combination of

Figure 2. Average soil moisture levels resulting from different amounts of rainfall and irrigation water received from day 150 to day 260 in 1989 to 1993.



Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

Table 4. Effects of irrigation on soil moisture and on tobacco yield, quality, and related chemical and physical characteristics in 1991.

Variation	Average soil moisture	Yield and quality: Plant yield	Returns	Grade index	Chemical characteristics: Total alkaloids	Reducing sugars	Physical Characteristics: Number of[a] leaves	Number of leaves after topping	Area of 3 tip leaves
	-- % --	--kg/ha--	--$/ha--	--¢/kg--	-- % --	-- % --			-- cm^2 --
Irrigation treatment									
1	11.8 a[b]	3660 a	15310 a	419 a	3.4 cd	18.3	32.3 a	18.2 a	1167
2	10.3 b	2960 b	12190 b	412 ab	4.0 a	12.3	30.3 a	16.3 c	1076
3	12.1 a	3800 a	15670 a	412 ab	3.1 d	19.7	32.5 a	18.0 ab	1074
4	9.9 b	3080 b	12850 b	418 ab	3.9 ab	14.1	30.7 de	17.2 abc	1032
5	11.6 a	3580 a	15060 a	420 a	3.6 bc	17.7	32.1 ab	18.1 a	1066
6	10.1 b	3080 b	12560 b	407 ab	3.8 ab	12.0	31.3 bcd	16.8 c	1098
7	11.5 a	3510 a	14440 a	411 ab	3.6 bc	18.1	32.0 abc	18.1 ab	1138
8	10.2 b	3190 b	12700 b	399 b	4.0 a	11.5	31.1 cde	17.0 bc	1168
9 (Non-irrigated check)	9.7 b	2940 b	11940 b	406 ab	3.9 ab	12.4	30.8 de	16.7 c	1037
Start Time for Treatments at 9% Minimum Soil Moisture									
250 CHU (9)[c]	11.9	3230	15490	416	3.3	19.0	32.4	18.1	1121
1100 CHU (45)	11.6	3550	14750	416	3.6	17.8	32.0	18.1	1102
LSD (0.05)	N.S.	N.S.	N.S.	N.S.	0.3	1.1	N.S.	N.S.	N.S.
End Time for Treatments at 9% Minimum Soil Moisture									
1700 CHU (69)	11.7	3620	15190	420	3.5	18.0	32.2	18.2	1117
2500 CHU (102)	11.8	3660	15020	412	3.4	18.9	32.2	18.0	1106
LSD (0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Minimum Soil Moisture									
9 %	11.7	3640	15120	416	3.4	18.4	32.2	18.1	1111
5 %	10.2	3080	12570	409	3.9	12.5	30.8	16.8	1093
LSD (0.05)	0.3	160	670	N.S.	0.2	1.2	0.5	0.6	N.S.

[a] Number of leaves >10 cm in length on July 18.
[b] *Values in the same column followed by the same letter are not significantly different at the 0.05 probability, N.S. = nonsignificant.*
[c] Numbers in parentheses indicate days after transplanting.

rainfall and trickle irrigation did not produce a significant difference in average soil moisture due to start or end irrigation schedules (**Table 4**).

In 1993, 265 mm of rainfall was recorded resulting in less than 9% soil moisture for a total of 76 days (**Figure 1**). Rainfall was deficient from about day 185 to 260, and as a result, average soil moistures were significantly different for start and end irrigation schedules as well as for minimum soil moisture level (**Table 5**).

Effect of Irrigation Start Time

Only in 1989 and 1993 were conditions dry enough so that soil moisture content dropped below 9% early in the season and the application of irrigation water at 250 CHU vs. 1100 CHU resulted in significantly different average moisture levels. Yields were increased by early irrigation in 1993 only. Total returns and grade indices were increased by irrigation in both years. Although early irrigation produced an overall average improvement in leaf quality, as measured by grade index, it did not consistently affect any particular leaf position (sands, cutter, body, etc.) or any leaf color classification (mahogany, orange, green, etc.). These data indicate that early irrigation can improve yield and quality, and they do not support reports suggesting that moderate moisture stress between the time the tobacco crop is established and early July is not harmful (2,18).

Concentrations of total alkaloids were reduced and reducing sugars were increased by early irrigation in 1989, 1991, and 1993. While this response is generally consistent

Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

Table 5. **Effects of irrigation on soil moisture and on tobacco yield, quality, and related chemical and physical characteristics in 1993.**

Variation	Average soil moisture	Yield and quality: Plant yield	Returns	Grade index	Chemical characteristics: Total alkaloids	Reducing sugars	Physical Characteristics: Number of[a] leaves	Number of leaves after topping	Area of 3 tip leaves
	-- % --	--kg/ha--	--$/ha--	--¢/kg--	-- % --	-- % --			-- cm^2 --
Irrigation treatment									
1	10.9 b[b]	3080 ab	13170 ab	427 a	3.5 d	16.4 a	29.5 ab	17.1 a	930 a
2	8.4 e	2190 cd	8590 cd	392 de	4.8 ab	8.4 cd	27.8 d	14.4 cd	734 bc
3	12.2 a	3240 a	13950 a	430 a	3.6 d	16.8 a	29.8 a	16.7 a	936 a
4	9.0 de	2150 d	8790 cd	407 bc	4.8 a	7.4 de	28.3 cd	14.2 cd	660 cd
5	10.2 c	2870 b	12180 b	424 a	4.5 bc	11.5 b	28.6 bcd	15.5 b	871 ab
6	8.5 de	2220 cd	8830 cd	398 cde	4.9 a	6.7 de	29.0 abc	14.8 bc	647 cd
7	10.9 bc	2890 b	11790 b	420 ab	4.3 c	10.5 bc	28.5 bcd	15.3 b	892 a
8	9.2 d	2480 c	9940 c	400 cd	4.5 bc	6.8 de	28.9 abc	15.0 bc	922 a
9 (Non-irrigated check)	7.6 f	1960 d	7520 d	385 e	4.8 a	5.8 e	28.5 bcd	14.0 d	531 d
Start Time for Treatments at 9% Minimum Soil Moisture									
250 CHU (17)[c]	11.6	3160	13560	429	3.5	16.6	29.6	16.9	933
1100 CHU (50)	10.6	2840	11990	422	4.4	11.0	28.6	15.4	882
LSD (0.05)	0.7	190	840	6	0.2	1.5	0.6	0.6	N.S.
End Time for Treatments at 9% Minimum Soil Moisture									
1700 CHU (76)	10.6	2980	12670	425	4.0	13.9	29.0	16.3	901
2500 CHU (116)	11.5	3030	12870	425	3.9	13.6	29.2	16.0	914
LSD (0.05)	0.7	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Minimum Soil Moisture									
9 %	11.1	3000	12770	425	4.0	13.8	29.1	16.2	907
5 %	8.8	2260	9040	399	4.7	7.3	28.5	14.6	741
LSD (0.05)	0.4	170	770	8	0.2	1.1	0.5	0.4	83

[a] Number of leaves >10 cm in length on July 13.
[b] Values in the same column followed by the same letter are not significantly different at the 0.05 probability, N.S. = nonsignificant.
[c] Numbers in parentheses indicate days after transplanting.

with other reports, it was somewhat unexpected that such a moderate difference in soil moisture at this early stage of plant development had such a significant effect on leaf chemistry. Less than 25% of the final leaf weight and alkaloid yield would have been produced by the time the second irrigation schedule (1100 CHU) began (9). One possible explanation may be that the early irrigation resulted in early utilization of nitrogen and a subsequent slight deficiency of nitrogen later in the crop's growth and development. Tobacco from the early irrigation treatments was somewhat lighter in color than that from the later irrigation treatments. These results support a report by Weybrew et al. (19), which suggested that during tobacco growth, metabolic functions are directed toward the uptake and reduction of nitrate-nitrogen and only when the pool of nitrate-nitrogen is limited are significant amounts of photosynthates converted into starch which is subsequently broken down into reducing sugars during curing. The total number of leaves at flowering and the number of leaves suitable for harvest (leaf number after topping) were increased by early irrigation only in 1993. This response does not support results of Ferguson et al. (5) and Hopkinson (7), who reported that plants subjected to moisture stress early in their development produced more leaves by the time of flowering. The area of the 3 tip leaves, calculated as 0.63 x length x width (14), was not affected by irrigation start schedule in any year, which is not unexpected considering that the greatest development of these leaves occurs just prior to and after topping.

Effect of Irrigation End Time

In 1993, the combination of rainfall and irrigation was sufficient to produce a difference in average soil moisture due to irrigation end schedule (1700 CHU vs. 2500 CHU) (**Table 5**), but the extra moisture did not produce any significant plant response. In 1989, yield and returns were improved by irrigation during harvest even though the difference in soil moisture was not significant. Irrigation during harvest did not consistently affect any leaf position (sands, cutter, body, etc.) or any leaf color classification (mahogany, orange, green, etc.).

Effect of Soil Moisture Level

The plots irrigated when soil moisture dropped to the 9% level received an average of 162, 112, 117, and 118 mm of water in 1989, 1990, 1991, and 1993, respectively, with approximately 32 mm water being applied at each irrigation. In comparison, the 5% plots received an average of 60, 15 (5 of 16 plots irrigated), 21 (7 of 16 plots irrigated), and 54 mm of water in 1989, 1990, 1991, and 1993, respectively, with approximately 48 mm of water being applied at each irrigation.

Irrigation at 9% minimum soil moisture vs. 5% produced significant differences in each year for most of the variables measured. The more frequent water applications in the 9% treatments produced an average of 391, 469, 562, and 741 kg/ha more cured leaves in 1989, 1990, 1991, and 1993, respectively, than did the 5% treatments. This yield response due to more frequent irrigation is consistent with reports made by many researchers. Total returns were greater in all years and grade indices were higher in 1989 and 1993 for the 9% treatments. The improvement in grade index due to more frequent irrigation is contrary to reports by Walker & Vickery (18) and Tonello et al. (15). Walker & Vickery (18) applied a single irrigation at the time of flowering, which is comparable in terms of amount and timing of water application to our 5% treatments, but this did not improve grade index compared with treatments receiving more frequent irrigations. One possible explanation for this difference in response from trials conducted at the same location, albeit some 35 years apart, may be related to different tobacco cultivars. The average yield of tobacco (cultivar unknown) from the best irrigation treatment in Walker's trial was 2590 kg/ha compared with 3350 kg/ha for treatment 3 in this trial. The cultivar Delgold clearly has a greater yield and quality potential than the older lines, but it may not be as tolerant of moisture stress.

The 9% minimum soil moisture treatments consistently produced leaves with a lower concentration of alkaloids and a greater concentration of reducing sugars compared with the 5% minimum soil moisture treatments. The average alkaloid production (calculated as % alkaloid x cured leaf yield) by the 9%, 5%, and nonirrigated check treatments was 113, 110, and 106 kg/ha, respectively. The reduction in alkaloid concentration observed in irrigated treatments was almost totally due to dilution from increased yields. This observation is consistent with that of Weybrew et al. (19). If metabolic priority in tobacco growth is directed toward the uptake and reduction of nitrate-nitrogen, then it would logically follow that plots receiving similar amounts of organic and inorganic nitrogen would produce similar amounts of amino acids, proteins, and alkaloids as long as they were not too severely or continuously affected by drought.

The average reducing sugars production (calculated as % reducing sugar x cured leaf yield) by the 9%, 5%, and nonirrigated check treatments were 470, 295, and 237 kg/ha, respectively. The additional availability of moisture apparently allowed a significantly increased production of photosynthates, which, given the limited pool of nitrate-nitrogen, were converted into starch and eventually reducing sugars. This observation does not support the contention by Weybrew et al. (19), however, that drought, by limiting the uptake of nitrate-nitrogen, shifts the metabolic pathway toward the production of starch. It appears more likely that drought simply reduces the amount of photosynthate produced and thereby reduces the production of starch in the uncured leaf and overall yield.

The total number of leaves produced was increased by more frequent irrigation in 1989, 1991, and 1993. The number of leaves judged to be suitable for harvest (suitable size at time of topping) was increased by more frequent irrigation in all years. The area of the 3 tip leaves was increased by more frequent irrigation in 1990 and 1993 These observations are generally consistent with reports by Orphanos & Metochis (10) and Collins & Hawks (4).

This study indicates that irrigation should start soon after transplanting and that flue-cured tobacco in Ontario does not respond

Tobacco Science, 1995, 39-14, p. 83-91, ISSN. 0082-4523.pdf

positively to moisture stress at any stage of crop growth. Tobacco was more tolerant to moisture stress late in the growing season after harvest of the lower leaves had started. Thus irrigation during harvest would have limited benefits. Although this trial did not determine an optimum response by tobacco to soil moisture availability, it clearly indicates that in most years frequent irrigations providing an additional 120 to 160 mm of water will produce a positive response in crop growth and development.

ACKNOWLEDGEMENT

We thank L. Peterson and C. Caughill for technical assistance. The financial assistance of the Ontario Tobacco Research Advisory Committee is gratefully acknowledged.

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