INFLUENCE OF NITROGEN APPLICATION RATE AND METHOD ON YIELD AND LEAF CHEMISTRY OF TOBACCO GROWN WITH DRIP IRRIGATION AND PLASTIC MULCH

TOBACCO SCIENCE

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Due to more intensive management, higher yield potential, and possible changes in root morphology, flue-cured tobacco grown with drip irrigation and plastic mulch may require higher N rates than conventionally grown tobacco to obtain optimum yield and quality. In a plastic mulch/drip irrigation production system, nutrients can be applied pre-plant or injected directly into the drip irrigation system as a water-soluble fertilizer. Field experiments were conducted in South Carolina during 1994 and 1995 to determine the optimum rate and application method for a drip irrigation/plastic mulch system. Nitrogen fertilizer treatments consisted of 84, 100, 118, and 134 kg ha^{-1} N in various combinations of pre-plant and injected into the drip system. Cured-leaf yields, grade index, and leaf N concentration increased with increasing N rate. Reducing sugars decreased with increasing N application, while total alkaloid levels increased slightly. Cured leaf sugar to alkaloid ratio improved as N rate increased. Pre-plant fertilization was as effective as injection into the drip irrigation (fertigation) with respect to yield, quality, and cured leaf chemistry.

Additional key words: fertigation, nitrogen management.

INTRODUCTION

In recent years, there has been increased interest by producers in using drip irrigation for row crops such as corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean [*Glycine max* (L.) Merrill] (6). Plastic mulch and drip irrigation have been used in vegetable production worldwide. Benefits of a drip irrigation/plastic mulch system include enhanced irrigation efficiency, easier weed control, increased control of mineral nutrition, faster growth, and greater yield and quality (4). In vegetable production, drip irrigation is often done with fertilizer dissolved in the irrigation water (fertigation) (2). Multiple application of low rates of fertilizer in irrigation water is of particular advantage on sandy soils where leaching of N may be a problem (2).

Tobacco (*Nicotiana tabacum* L.) production using drip irrigation (without plastic mulch) was researched in South Carolina in the 1970s (14). In those experiments, yield and quality were improved as compared to dryland production (14). There has also been interest in using plastic mulch, drip irrigation, and fertigation in tobacco (1). Rathier and Frink (19) reported increased N fertilizer efficiency with timed applications to shade tobacco. However, they stated that care must be taken that the fertilization scheme does not have detrimental effects on the quality of the cured leaf. Raper and McCants (18) reported that changes in N availability can affect cured leaf N, nicotine, and reducing sugars. However, excess N application can be detrimental to leaf quality (8).

If plastic mulch, drip irrigation, and fertigation are to be used with tobacco, care must be taken to maintain physical and chemical quality of the leaf. Preliminary experiments (J. W. Rideout and D. T. Gooden, unpublished data) indicated that flue-cured tobacco grown with drip irrigation and plastic mulch require N rates in excess of those required by conventionally-grown tobacco on a given soil. Thus, this study was conducted to determine the optimal N rate for tobacco grown with plastic mulch and drip irrigation, and to investigate the effects of supplying the N either as a pre-plant application or as a combination of pre-plant and drip application.

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Table 1. Nitrogen treatments and dates of application, 1994 and 1995. Injected N was split evenly over indicated injection dates. All plots received 50 kg N ha^{-1} from 6-6-18. All additional N is from 16-0-0 ($NaNO_3$).

Total N Applied	Preplant Application	Total Injected	Injection Dates							
----------kg/ha ----------			1994							
			11 May	18 May	25 May	1 June	8 June	15 June	22 June	29 June
84	50	34	X	X	X	X				
100	50	50	X	X	X	X	X	X		
100	100	0								
118	50	68	X	X	X	X	X	X	X	X
118	118	0								
134	100	34	X	X	X	X				
134	118	16	X	X						
			1995							
			10 May	17 May	24 May	31 May	7 June	14 June	21 June	28 June
84	50	34	X	X	X	X				
100	50	50	X	X	X	X	X	X		
100	100	0								
118	50	68	X	X	X	X	X	X	X	X
118	118	0								
134	100	34	X	X	X	X				
134	118	16	X	X						

MATERIALS AND METHODS

Field experiments were conducted at the Clemson University Pee Dee Research and Education Center, located near Florence, South Carolina, in 1994 and 1995 on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult). Nitrogen fertilizer treatments consisted of 84, 100, 118, and 134 kg ha^{-1} N in various combinations of pre-plant and injected into the drip system **(Table 1)**. The 84 kg N ha^{-1} treatment was based on current South Carolina recommendations for flue-cured tobacco (9). Even though this treatment included plastic mulch and drip irrigation, it can be considered the control treatment. Treatments were replicated four times in a randomized complete block design. An experimental unit consisted of a single row of 20 plants. Other than fertilization and modifications required by the plastic mulch, recommended cultural practices (9) were followed. The plastic mulch prevented any cultivation.

Prior to each experiment, the experimental area was broadcast fumigated with 1,3 dichloropropene + 17% chloropicrin at 187 L ha^{-1} for disease and nematode suppression. Weed control was accomplished with a pre-plant application of napropamide (1.12 kg ha^{-1}) and pebulate (2.5 kg ha^{-1}) in 1994 and clomazone (1.12 kg ha^{-1}) and pebulate (2.5 kg ha^{-1}) in 1995. Metalaxyl (1.7 kg ha^{-1}) was also included in the herbicide mixture to provide additional disease control. After pesticide application, plots were bedded prior to fertilizer application.

All plots received 50 kg N ha^{-1} from complete (6-6-18) fertilizer. Additional pre-plant N, if required by treatment **(Table 1)**, was applied as $NaNO_3$ (16-0-0). All fertilizer materials were applied to the center of each row at a 15 cm depth. The fertilizer was then mixed into the soil with a power-driven rotary hoe with a bed-shaper attached. Drip irrigation tubing with 30.5 cm emitter spacing (Netafim Irrigation, Fresno, CA) was positioned 20 cm deep and 15 cm to the side of the row center and black plastic mulch film (0.5 mm thick) (Sonoco Products, Hartsville, SC) was applied over the row.

Greenhouse-grown seedlings of flue-cured tobacco 'K 326' were transplanted on 7 April, 1994, and 12 April, 1995. Spacing was 122 cm between rows and 56 cm within the row. Transplant water contained 6 g L^{-1} 12-48-18 "starter" fertilizer (Miller Chemical and Fertilizer, Hanover, PA). The small amount of N provided by the starter fertilizer was not included in N rate calculations.

Six tensiometers were installed at a depth of 30 cm in the row center at different locations within the experiment. Irrigation was withheld for three weeks after transplanting to encourage a deeper root system. For the remainder of the

Table 2. Influence of nitrogen application rate and method on cured leaf yield, grade index, and harvest percentage of flue-cured tobacco.

Nitrogen Treatment[2]					Percent Harvested			
Total	Pre-Plant	Injected	Yield	GI	A	B	C	D
kg/ha			kg/ha		%			
84	50	34	3223 d[1]	62 a	22.5 a	24.5 a	27.1 ab	25.9 d
100	50	50	3359 cd	63 a	15.2 c	29.0 a	24.8 b	31.0 abc
100	100	0	3313 d	64 a	18.6 b	29.2 a	24.4 b	27.7 cd
118	50	68	3690 ab	67 a	13.4 c	27.3 a	24.5 b	34.7 a
118	118	0	3578 bc	64 a	12.1 c	29.9 a	26.0 ab	32.0 ab
134	100	34	3591 bc	64 a	12.9 c	25.5 a	27.5 ab	34.2 ab
134	118	16	3837 a	68 a	11.9 c	27.0 a	30.7 a	30.4 bc

[1] Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

[2] All plots received 50 kg N ha^{-1} from 6-6-18 applied preplant. All additional N is from 16-0-0 ($NaNO_3$).

season, irrigation was applied when soil moisture tension rose above 15 centibars. Irrigation water volume varied according to growth stage and anticipated weather conditions.

Some treatments required injected N into the drip system **(Table 1)**. Fertilizer-grade $NaNO_3$ (16-0-0) was dissolved in water and introduced into the drip system using a proportional injector set to deliver a 100:1 dilution. Treatments not receiving fertigation received irrigation on the same day in the same amount that was needed to apply $NaNO_3$. Dates of injection are given in **Table 1**. The N was split equally among injection dates.

Green leaf samples were collected on 15 June, 1994, and 23 June, 1995, for nitrogen determination. After normal plant decapitation (topping), the fourth leaf down from the top (11) was collected from five plants per plot. Tissue was immediately dried at 50°C, ground in a Wiley mill to pass a 1 mm screen, and analyzed for total N by the Kjeldahl method (15).

Plots were harvested four times as leaf ripened and cured conventionally. Cured leaf was weighed and then assigned a government grade. Grade indices on a scale of 1 to 100 (1=poorest quality; 100=highest quality) were computed from government grades (5). Lamina samples were taken from each harvest, re-dried, and ground to pass a 1 mm screen. Samples were analyzed for total alkaloids and reducing sugars, using a modification of Davis' procedure (7). Total N was determined by combustion analysis. Ratios of reducing sugars to total alkaloids and total N to total alkaloids were calculated (20). A weighted average of these parameters over stalk positions was also calculated. The total amount of N removed per hectare was calculated using yield and cured leaf total N data. No attempt was made to measure or estimate stalk and root N. Nitrogen recovery was calculated as the percent of applied N found in the harvested leaf. Tissue Na was not measured, even though fertilizer Na varied among treatments. Flue-cured tobacco is affected by Na only when K is extremely limiting (10). Since that is not the case here, it can be assumed that Na did not influence the results.

Data were subjected to analysis of variance. Since analysis of variance did not indicate year by treatment interactions, 1994 and 1995 data were combined for analysis. Mean separations were accomplished using Duncan's Multiple Range Test at the 5% level of probability. Linear regression equations were developed to relate yield, grade index, leaf nitrogen, and reducing sugars to N application rate. The mean averaged across all application methods for a given N rate was used for the purposes of developing the equations.

RESULTS

Cured leaf yield was increased linearly by increasing N rate **(Figure 1)**. Significant increases in yield above the control occurred at 118 and 134 kg ha^{-1} N **(Table 2)**. There was no difference in yield caused by application method within the 118 kg ha^{-1} rate. Within the 134 kg ha^{-1} rate, higher yield was obtained when the majority of the N was applied preplant. Grade index was not affected by either rate or application method.

Percent of leaf removed in the first harvest decreased with increasing N rate **(Table 2)**. The second harvest was equal for all treatments, with a greater percentage of leaf harvested at higher N rates for the third and fourth harvests.

Mid-season leaf N concentration increased linearly with increasing N application rate (**Figure 1**). Within the 134 kg N ha^{-1} rate, N was higher when 118 kg N ha^{-1} was applied pre-plant than when 100 kg N ha^{-1} was applied pre-plant (**Table 3**). Within the 100 kg N ha^{-1} rate, tissue N was higher when N was injected (**Table 3**).

Total N concentration in cured leaf increased linearly with N application rate (**Figure 1**), with no differences within rates (**Table 3**). The total quantity of N removed in cured leaf generally increased with increasing N rate (**Table 3**). Removal was highest at 118 and 134 kg N ha^{-1}. Efficiency of applied N generally decreased with increased application rate (**Table 3**). There were no differences in efficiency due to application method within any N rate.

Total alkaloid concentration of cured leaf generally increased with N rate (**Table 3**). There were no differences within nitrogen rates. Reducing sugars declined as N rate increased (**Figure 1**), with no differences within N rates (**Table 3**). Reducing sugar to alkaloid ratio generally decreased with increasing N application, with no differences within rates. There were little differences in N to alkaloid ratios (**Table 3**).

DISCUSSION

In conventional flue-cured tobacco culture, increasing N rate often increases yield and reduces leaf quality (8). Increasing N rates applied to tobacco grown over plastic mulch with drip irrigation increased yield in these experiments. However, as opposed to conventionally grown tobacco (8), leaf physical quality (measured by grade index) did not decline with increased N application. The percentage of leaf harvested in the first harvest, and thus early leaf maturity, was greatest at low N rate. Leaf from the 84 and 100 kg N ha^{-1} rates tended to be "Lemon" in color, whereas the leaf from higher rates tended to be "Orange" in

Figure 1. Influence of N application rate on yield (A), grade index (B), leaf N concentration (C), and reducing sugar concentration (D). Each symbol represents the mean of 16 data points, with the exception of the 84 kg N ha^{-1} rate, where each represents the mean of 8 points.

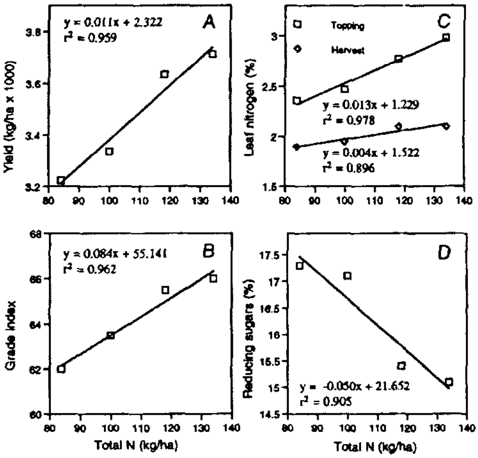

Table 3. Influence of nitrogen application rate and method on leaf nitrogen, total alkaloid, and reducing sugar concentration of flue-cured tobacco.

Nitrogen Treatment[2] Total	Pre-Plant	Injected	Leaf Nitrogen at Topping	Leaf Nitrogen at Harvest	Leaf Nitrogen Efficiency	Total Alkaloids	Reducing Sugars	Sugar: Alkaloid Ratio	N:Alkaloid Ratio
kg/ha			%						
84	50	34	2.36 c[1]	1.90 c	72.9 a	1.88 c	17.3 a	9.24 a	1.00 ab
100	50	50	2.61 b	1.97 bc	65.6 bc	2.00 bc	16.5 ab	8.35 bc	0.99 ab
100	100	0	2.33 c	1.93 c	64.4 bc	2.02 bc	17.7 a	8.76 ab	0.95 b
118	50	68	2.77 b	2.17 a	68.3 ab	2.18 a	15.5 bc	7.17 d	0.99 ab
118	118	0	2.78 b	2.14 a	65.3 bc	2.13 ab	15.3 bc	7.22 d	1.01 ab
134	100	34	2.79 b	2.06 ab	55.6 d	2.00 bc	15.3 bc	7.68 cd	1.02 a
134	118	16	3.18 a	2.16 a	61.5 cd	2.09 ab	14.9 c	7.22 d	1.03 a

[1] Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.

[2] All plots received 50 kg N ha^{-1} from 6-6-18 applied preplant. All additional N is from 16-0-0 ($NaNO_3$).

color. Almost all leaf received "mature and ripe" (21) grades (data not shown). Quality and yield increased linearly with N application rate **(Figure 1)**. Since neither reached a maximum above which additional N did not result in additional increase or decline in yield, 134 kg N ha^{-1} does not appear to be excessive in this production system. Yield and quality declines have been reported with conventional tobacco as the result of over application of N (13).

A published tissue critical concentration for N is 3.50% to 4.25% in the uppermost fully developed leaf at bloom (11). All treatments were below this level, with only the 134 kg N ha^{-1} with 118 kg N ha^{-1} applied pre-plant being even close to the critical value. Growth is more rapid with plastic mulch when compared to conventional culture (J. W. Rideout and B.A. Fortnum, unpublished data). It is possible that rapid growth caused either a lag in N uptake or a dilution effect. Also, root system mass may have limited N uptake. Tomato root systems are often smaller when plastic mulch is used (3). Tobacco root systems with plastic have also been observed to be smaller and distributed differently than in conventional culture.

Cured leaf N concentration was not affected by N application method within N rates, even though application method may have altered root distribution. Osmond and Raper (12) reported changes in root distribution, but not final root mass, occurring from fertilizer placement in either a band or broadcast application. Whitty et al. (22) reported that total N uptake was unaffected by fertilizer placement. This seems to also be the case with plastic mulch.

Greater amounts of N were recovered in cured leaf at higher N rates. Published assumptions of dry matter and N in stem and root at given leaf concentrations may not apply since plastic mulch may change the morphology of tobacco plants. Since root and stem weights and N concentration were not measured in this experiment, it would be difficult to attempt to calculate N balance and fertilizer use efficiency. Using just leaf data, N efficiency declined with increasing N rate, with no difference within rates due to application method. This is in contrast with data obtained with shade tobacco (19). One difference between that study and these experiments is the presence of plastic mulch. The plastic protects the pre-plant fertilizer from being leached by rainfall, thus making pre-plant and injected N equally effective.

Raper and McCants (16) report that flue-cured tobacco accumulates approximately 50% of its total N by five weeks after transplanting, and over 90% by nine weeks. Final leaf area is predetermined while the leaf is still forming within the bud (17). Although it did not happen to a large degree in this study, it is also possible to alter internal quality with N stress without damaging yield and external quality (18). Therefore, it is reasonable to assume that N should be applied as rapidly as possible.

Tobacco from the 84 kg N ha^{-1} treatment was high in reducing sugars and somewhat low in total alkaloids. With a sugar to alkaloid ratio of 9.24, this tobacco would be considered to be mild in flavor (20). As the N rate increased, the tobacco became more desirable as reducing sugars declined and total alkaloids increased. There were no differences above 118 kg N ha^{-1} in the sugar to alkaloid ratio. In this study, at least 118 kg N ha^{-1} seemed to be needed for acceptable chemical characteristics. Nitrogen and total alkaloid accumulation was related, with no large differences between treatments for the N to alkaloid ratio. All were within the 0.8 to 1.1 range suggested by Tso (20) as acceptable.

CONCLUSIONS

Tobacco can be grown successfully with drip irrigation and plastic mulch. Nitrogen rate must be increased to at least 118 kg ha^{-1} to obtain acceptable yield and plant N status. Since yield and quality increased linearly throughout the range of N concentrations used in this study, a maximum N rate for this system could not be determined. Further work with higher N application rates is needed. Tobacco with desirable leaf chemistry can be obtained using this production system.

Although injected fertilizer was not detrimental, the current study did not reveal any significant advantage of injecting fertilizer into the drip tube on tobacco. From a management standpoint, pre-plant fertilization is easier to apply. Also, pre-plant fertilization is less expensive in that specialized injection equipment and water-soluble fertilizers are not required.

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