504/gal for gas

ABSTRACT FOR TOBACCO SCIENCE

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Please type abstract double spaced below. Be brief and concise (the space below should suffice); use complete sentences.

Curing container height and air flow rate through the tobacco can be controlled by the selection of equipment and certain operational choices. These choices affect barn investment and operational costs, curing time and barn throughput. A curing system with boxes 1.22 m (4') high was found to be more expensive in terms of investment and operating costs per kilogram of tobacco cured than systems using 1.52 m (5') or 1.83 m (6') boxes. An intermediate air flow of .0312 m^3/min-Kg (.5 cfm/lb) of green tobacco was optimum as higher air flows used excessive amounts of electric power to drive the fan and lower air flows reduced barn throughput. One of the important findings was that barn ownership costs were $30 to $36 per day of the curing season and represent one of the largest costs of tobacco production.

An analysis was run to determine the most economical trade-off between barn costs and loss in crop value with delayed harvest and curing. The effect of harvest delay on crop value was evaluated over a period of several years. The results of both an intuitive and a formal analysis indicated that harvest delays of 1 to 2 weeks, instead of a normal 5 week curing season, maximized crop income by reducing curing barn requirements more than they reduced crop value.

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Mechanical Harvesting of Flue-Cured Tobacco:
Part 10. Optimization of Curing Capacity and Bulk Barn Parameters[1/]

C.W. Suggs

Bulk curing of flue-cured tobacco was introduced in 1960 and has shown a steady, but not uniform, growth in farmer adoption since its introduction. At the present time (1978) approximately 58% of the North Carolina flue-cured crop is bulk cured (Watkins, 1978). The percentage is higher in Georgia and Florida but lower in Virginia so the U.S. average is probably close to the North Carolina value.

There has been considerable interaction between bulk curing and mechanical harvesting as bulk curing is a necessary companion to successful mechanical harvesting. About two thirds of the bulk cured leaf is also mechanically harvested. Because of the labor required to fill bulk curing racks the author and his associates developed a system (Suggs, 1977) which allows machine filling of containers in which the leaf can be cured. Those containers hold approximately 300 Kg to 900 Kg (about 700 lb to 2000 lb) depending on the size of the different manufacturers' models.

Because of limited experience with bulk container curing, growers and manufacturers may not have the information needed to optimize curing system parameters and capacity and properly interface the curing containers

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[1/] Paper No. 6007 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, N.C. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

with a harvesting system. The purpose of this paper is to present data and analyses from which parameter optimization decisions can be made and to present and demonstrate a procedure for determining optimum curing capacity or number of barns for a given sized crop.

Curing Container Height

The curing capacity of a bulk barn depends,among other things, on the height of the container. In the following analysis it is assumed that no barn structural changes are required to accommodate higher containers. The analysis considers the larger fan and motor required, the extra heat and electricity requirements and the cost to make containers taller. Container sizes analyzed were .91 m x 1.37 m x 1.22 m, 1.52 m or 1.83 m high (3' x 4½' x 4, 5 or 6'). Loading density was 208 Kg/m^3 (13 lb/ft^3) and air flow was constant with respect to initial weight at .031 $m^3/min\text{-}Kg$ (.5 cfm/lb). Air leakage around the container and seepage out of the barn was taken at 40% for the lowest container height (pressure) (Cundiff and Sumner, 1977) and calculated for the other two heights on the basis that there was no change in the leakage area. Reference air pressures were taken from experience and dependent air pressures were calculated. An increase in pressure was needed to force the air through the taller boxes. Additional pressure was also required to provide the higher flow rates needed by the extra tobacco in the taller boxes.

Barn costs, including 1.22 m (4 ft) containers, were calculated on the basis of $8000 initial cost, 10% interest, 20 year life for a cost recovery factor

of .1175, 20% salvage value and 3.6% of initial costs for repairs, taxes and insurance. Curing fuel costs used in the analyses were \$104 per metric ton[1/] (\$94/ton) for the mid sized container. For the other two sizes of containers fuel costs were prorated on the basis of barn air flow. Cured weight was determined from the author's data as 16.8% of the input green weight of 208 Kg/m^3 ($13\ lb/ft^3$). Costs for boxes not commercially available were determined by allocating the \$125 cost of a 1.22 m (4') box into \$30 for the bottom section, \$20 for the top and \$0.615/cm (\$18.75 per foot) of height. Thus the 1.52 m (5') box cost \$18.75 more than the 1.22 m (4') box. Larger boxes increase the total barn cost above the \$8000 value given above. The barn holds 20 boxes and five cures can be completed in a normal season. A fan efficiency of 55% and a motor efficiency of 75% were used in calculating fan power requirements (Glover 1977): $Kw = \dfrac{m^3/\text{min} \times \text{pressure (mm of } H_2O)}{2514}$.
An electrical power cost of 5¢/Kwh was used in the analyses and cure length was 6 days (144 hrs). Fan and motor initial costs were estimated from manufacturers' catalogs.

Results

Unit costs, Table 1, reflecting farm costs, electrical costs and fuel costs, were highest for the 1.22 m box, \$.3454/Kg (\$.1566/lb). Costs for the 1.52 m and 1.83 m boxes were essentially equal at \$.327/Kg (\$.148/lb). For these two box sizes the increase in curing capacity more than compensated for the increase in investment costs and the higher electrical requirements of the larger fan. The data indicates that under the assumptions used here the optimum height lies between 1.52 m and 1.83 m and that additional increases in height past the 1.83 m container will result in increased costs. It will be seen later in the paper that taller boxes and higher air flows increase curing costs more than they increase barn throughput

[1/] Watkins, R.W. Private communication.

Table 1. Effect of Curing Box Height on Capacity, Air Flow and Pressure Requirements, Barn Costs, Fan Power, and Total Cost Per Kilogram of Tobacco Cured. Flow = .0312 m^3/min Kg (.5 cfm/lb). Duct Loss from Glover, 1977.

	Box Height		
	m 1.22 / ft 4	m 1.52 / ft 5	m 1.83 / ft 6
Capacity, m^3	1.52	1.90	2.28
Weight @ 208 Kg/m^3, Kg	316	395	474
Flow Per Box, m^3/min	9.9	12.4	14.9
Flow for 20 Box Barn With Losses m^3/min	331 40% loss	435 42.7% loss	542 45% loss
Air Pressure, mm of H_2O			
For Height	10.2	12.7	15.2
For Extra Flow, Prop. Box Capacity	0	7.1	19.0
Duct Loss	12.7	15.2	17.8
Total for Barn	22.9	35.1	52.1
Fan Input Power, KW	3.01	6.05	11.23
Box Costs, $	2500	2875	3250
Fan and Motor Costs, $	250	290	444
Total Initial Barn Costs, $	8000	8415	8944
Annual Barn Costs, $	1200	1262	1342
Annual Electrical Cost, 5-144 hr Cures, $	108	218	404
Annual Fuel Costs-5 Cures, $	525	690	859
Total Annual Expense, $	1833	2170	2605
Annual Cured Weight, Kg	5307	6638	7961
Unit Costs			
$/Kg	.3454	.3269	.3272
$/lb	.1566	.1483	.1484

Because air pressure decreases as the tobacco wilts and dries during the cure there may be some small error in calculating electrical costs on the basis of the initial air flow and pressure. However, this decrease in pressure (and increase in flow) would affect all container heights similarly so that the final comparative results would change very little. There is some increase in leakage with the higher boxes because flow resistance of the box increases with height and forces more air through the leakage openings.

Curing time was assumed equal for all box heights on the basis of the fact that box air flow was constant with respect to green weight. This means that for the taller containers the air velocity is greater. Higher air velocities often tend to dry the tobacco before yellowing is complete where the air first contacts the tobacco. This problem is more prevalent with dry weather crops or in barns which are not properly sealed. Slow drying and poor quality cures in the mid to upper part of taller boxes have also been experienced.

Air Flow

Insufficient air flow is one of the most critical problems in container bulk curing. While adequate air flow is essential to good cured leaf quality, excess air flow wastes fan power, increases exfiltration and is likely to prematurely dry the leaf.

In Table 2 the effects of air flow from .0186 to .0434 m^3/min-Kg of green leaf (.3 to .7 cfm/lb) through 1.52 m (5') high containers loaded to a density of 208 Kg/m^3, (13 lb/ft^3) holding 395 Kg (871 lb) of green tobacco, is analyzed. An average cured weight yield, from the author's data, of 16.8% gives 1327 Kg (2926 lb) as the cured capacity of a 20 box barn or 6638 Kg (14637 lb) per 5-cure season. The 1.52 m box of Table 1 is taken as a reference for Table 2 and appears as the middle line of that table.

The author's experience indicates that yellowing can be accomplished with low air flow but that drying is delayed if flow is not adequate. Yellowing time averages about 60 hours and drying time for the intermediate or reference air flow was 84 hrs for a total curing time of 144 hours (6 days). For higher or lower air flows the drying time was proportionally shorter or longer, respectively so that drying air volume for the total cure was constant for all flow rates. Barn costs were almost constant, reflecting only the costs of larger fans and motors for the higher air flows. Annual barn costs were calculated as in the previous example based on container height. Barn costs per cure were prorated on the basis of a normal curing season of 5 cures times 7 days per cure (6 days curing plus 1 day reloading) times 24 hours per day or 840 hours. Thus a barn load which cures out in 144 hours is charged with $\frac{144 + 24}{840}$ x barn annual costs.

Unit costs were lowest, \$.3269/Kg (\$.1483/lb), for the middle flow rate, Table 2. Costs did not increase as rapidly with higher flow rates, \$.3373/Kg (\$.1530/lb), as they did for lower flow rates, \$.3690//Kg (\$.1673/lb), giving another indication that barn ownership costs are the largest single item in curing costs.

The simultaneous effects of box height and air flow are shown graphically in Figure 1 as a surface whose height above the base plane represents curing costs. The box height data from Table 1 defines the middle front to rear line on the main surface, while the air flow data from Table 2 defines the middle side to side line. Other values to complete the surface were determined in a similar manner to those in the tables. Figure 1a was based on electricity costs of 5¢/Kwh while Figure 1b shows the effect of increasing electricity costs to 10¢/Kwh.

While there is little difference in the cost of curing in the 1.52 m (5 ft) box versus the 1.83 m (6 ft) box when electricity costs are 5¢/Kwh, the taller box becomes more costly when electricity prices rise to 10¢/Kwh. Some additional caution should be exercised with respect to the tallest box because the higher static air pressures required are expensive to produce and difficult to contain. Also, the longer column of tobacco may increase drying time so that some loss of quality may occur before the drying front reaches the top of the container. The most efficient air flow was .0312 m^3/min-Kg (.5 cfm/min-lb).

In Table 2 the fuel cost was considered to be constant at $104 per metric ton because the same amount of water had to be removed regardless of flow rate. Electricity costs were based on the curing times shown. However, because of heat loss through the structure and exfiltration of heated air, fuel consumption tends to increase with curing time. Cundiff and Sumner (1977) reported that 39% of the heat energy escaped from the barn during normal length cures.

The author's data from 1977 and 1978 relating flow to curing time and fuel consumption are used in Table 3 to provide a better basis for calculating unit costs. Although other conditions are the same as in Table 2, barn and electricity costs are different because curing time has changed. This table shows a significant increase in fuel costs with decreased air flow. With this refinement in the analysis the lowest per unit cost moves to the next highest flow rate.

Crop Size - Barn Space Optimization

Intuitive Analysis

Historically, priming intervals have been one week each. Also,the curing cycle has been one week so that successive primings from a field can be placed as successive cures in a single barn. When priming intervals are not equal to curing cycle time and, in fact, priming intervals may vary significantly during the season,the analysis of curing barn requirements is complicated.

Table 2. Effect of Flow Rate on Pressure, Fan Power, Curing Time, Fuel, Electricity, Barn and Unit Costs, 1.52 m (5') Curing Box.

	Unit Flow m3/min-Kg (cfm/lb)				
	(.3) .0186	(.4) .0248	(.5) .0312	(.6) .0372	(.7) .0434
Box Flow, m^3/min	7.4	9.9	12.4	14.9	17.4
Box Pressure, mm of H_2O	7.1	12.7	19.8	28.4	38.9
Duct Loss, mm of H_2O	10.2	12.7	15.2	17.8	20.3
Total Fan Pressure, mm of H_2O	17.3	25.4	35.0	46.2	59.2
Bypass and Seepage, %	43	43	43	43	43
20 Box Barn Flow, m^3/min	261	349	435	523	611
Fan Input Power, KW	1.8	3.5	6.1	9.6	14.4
Drying Time, Hr	140	105	84	70	60
Total Curing Time, Hr	200	165	144	130	120
Initial Barn Costs, $	8350	8375	8415	8560	8700
Annual Barn Costs (a), $	1252	1256	1262	1284	1305
Barn Costs Per Cure (a), $/Cure	334	283	252	235	224
Elect. Cost @ 5¢/Kwh (a), $/Cure	18	29	44	62	86
Fuel Costs @ $104 Per Metric Ton (b), $/Cure	138	138	138	138	138
Total Cost, $/Cure	490	450	434	435	448
Unit Cost					
$/Kg	.3690	.3389	.3269	.3276	.3373
$/lb	.1673	.1537	.1483	.1486	.1530

(a) Assumes that 5 standard cures (6 days curing + 1 day reloading) can be made during the year and that barn is not otherwise used. Add 24 hours to total curing time to get hours per curing cycle.
(b) Cured weight of 1328 Kg/cure taken from Table 1.

Attached paper giving values for Powell eq gives a figure of $.~~3386~~/Kg but this includes labor of $.0300/Kg.
.2443

Elect. 44×5=220

	Barn costs	Fuel (Gas & elect)	Total
Suggs	$ ~~.15~~ .19/Kg	.13	$.32/Kg
Powell	$.1157/Kg	$.0985/Kg	$.2142/Kg

Table 3. Effect of Flow Rate on Curing Time, Fuel, Electricity, Barn and Total Costs. Fuel Consumption and Curing Time from Field Experience.

	Unit Flow m3/min-Kg (cfm/lb)				
	(.3) .0186	(.4) .0248	(.5) .0312	(.6) .0372	(.7) .0434
Curing Time, Hr	211	196	176	162	154
Fuel Costs, $/Cure	167	152	138	128	118
Electricity Cost,$/Cure	19	34	54	78	111
Barn Costs,$/Cure	350	329	300	284	277
Total,$/Cure	536	515	492	490	506
Unit Cost					
$/Kg	.4036	.3878	.3705	.3690	.3810
$/lb	.1830	.1759	.1680	.1673	.1729

If uniform harvesting is assumed then curing barn capacity times the number of curing cycles per season must be at least as large as the crop weight allocated to each barn. One common mistake in evaluating curing capacity is to over-estimate the number of curing cycles possible per curing season. When this happens part of the crop will have to remain in the field past its optimum ripeness or part will have to be harvested before optimum ripeness to prevent the harvest from "getting behind".

In order to determine how much of the crop would have to be harvested one or two weeks late for a given crop size it is convenient to break the crop up into equal elements such that barn capacity and crop size can be expressed as whole numbers. Table 4 shows a crop size of 130% of barn capacity which has been divided into 13 elements such that 10 elements will fill a barn for each of the 5 weekly primings. Element primings scheduled to the right of the first and second diagonal lines have been delayed one and two curing cycles (weeks), respectively. In the third cure, for example, the first 4 elements are from the third priming. The last 6 elements have been delayed one week and are, therefore, from the second priming as indicated by the number 2. Percentage of material harvested one curing cycle late is determined by the number of such elements as compared to the total crop. Table 5 gives the amount of harvest delay for various crop size/barn capacity ratios.

Table 4. Schedule of Crop Harvest (Priming Number) With Respect to Cure Number When the Crop Size is 130% of Barn Capacity

Crop* Element Number	Cure # 1	2	3	4	5	6	7
1	1	2	3	4		5	
2	1	2	3		4	5	
3	1	2	3		4	5	
4	1	2	3		4	5	
5	1	2		3	4	5	
6	1	2		3	4	5	
7	1	2		3	4	5	
8	1		2	3	4	5	
9	1		2	3	4		5
10	1		2	3	4		5
11		1	2	3	4		5
12		1	2	3		4	5
13		1	2	3		4	5

Harvest delayed one curing cycle

Harvest delayed two curing cycles

Amount of crop delayed 1 curing cycle = 36 elements/65 elements = 55%

Amount of crop delayed 2 curing cycles = 7 elements/65 elements = 11%

*Barn capacity = 10 elements.

A series of harvest schedule experiments (Yang, 1978, Suggs, 1977 and recent unpublished results) revealed that crop value decreased at an increasing rate as harvest is delayed, Figure 2. This suggests that some degree of barn overload could be tolerated corresponding to the period of slow decrease in crop value with respect to harvest delay. For larger delays, where crop value decreases more rapidly, the cost of additional barn space is more likely to be less than the decrease in crop value.

In order to analyze the trade off between crop size and curing system size, a barn capacity of 1328 Kg (2927 lb) per cure and an annual costs of $1262 for a barn with 1.52 m (5 ft) boxes are taken from the middle line of Table 1. The normal no-delay schedule was five primings spaced one week apart. Per cure reduction in crop value with harvest delay are taken from Fig. 2. The appropriate value for Table 5 is found by multiplying the reduction in crop value by the percentage of the crop delayed by the size of the crop affected. Annual cost for barn space to eliminate the harvest delay is found by multiplying the annual cost for a barn ($1262) by the proportion of the barn required.

For example, in order to prevent any two week harvest delay in an operation where crop size/barn capacity was 130%, one would need to add barn space until the crop size/barn capacity was 120% at which time maximum harvest delay would be only one week. This would require a total barn space of 130/120 = 1.083 or an additional 8.3% barn space. The values in Table 5 are based on one curing barn and yields of 2353 Kg/ha (2100 lb/A).

Annual barn cost, Table 5, are greater than crop value reductions for all of the one week harvest delays and for the two week delays associated with the crop size/barn capacity values of 130 and 140%. For two-week delays affecting larger parts of the crop and for all three-week delays, the crop loss is greater than the barn costs. The table seems to indicate that while a two-week harvest delay can be tolerated for a 130% or 140% crop size/barn capacity operation it can not be tolerated for the 150% or 160% barn loading factor. However, it should be pointed out that addition of enough barn space to just eliminate the 3 week harvest delay will reduce the barn loading factor to 140% so that the operation can then be considered as a 140% loading factor crop. From Table 5 it can be seen generally that additional barn space costs approach harvest delay losses at about 140% of barn capacity. In order to allow for conditions which would accelerate harvest or increase curing time it might be realistic to select a smaller loading factor.

Because barns are not available in very small sizes, it is easier to balance crop size against barn capacity when the operation involves several barns. While the author does not have data, it appears that many farmers are increasing barn utilization by extending the harvest season from one to two weeks.

Barn costs are one of the largest expenses in tobacco production. The curing season, and therefore barn usage, can be extended by selecting variety, soil type and fertility level as previously discussed. The season can also be extended by starting

the harvest before the optimum time. Preoptimum harvesting was not considered in the analysis tabulated in Table 5 because of the rapid decrease in value. If this result is dependable and not restricted to the 5 years of data summarized in Figure 2 some increase in on-farm curing barn utilization is possible.

Use of more frequent light harvest or less frequent heavy harvest has little affect on the problem as the throughput of the barn is not changed and the proportion of the crop subject to harvest delay would not be changed, provided length of harvest season is not changed.

Alternative Formal Analysis

The previous analysis approaches optimum curing capacity intuitively, making allowances for the batch operation feature of the curing barns. A more formal approach to optimization is provided by Hunt (1973) in the following equation:

$$C = \sqrt{\frac{w}{FP}\left(L + \frac{KVw}{HX}\right)} \tag{1}$$

where

C = curing capacity, Kg/hr

w = size of crop, Kg

P = curing barn costs, \$ per Kg/hr

L = labor costs, \$/hr

K = timeliness loss factor, fraction of crop value/day

F = barn fixed cost, fraction of initial cost

V = crop price, \$/Kg

H = hours of use per day

X = 4 if operation can be performed both before and after optimum, 2 if operation limited to pre or post optimum.

Tobacco curing barns, unlike grain dryers are not available in a large range of sizes. Curing capacity is increased by adding one or more of the "standard" size units. Barn capacity varies somewhat but a value of about 1328 Kg (2927 lb) per cure is a good average. Barn cost including 1.52 m (5 ft containers) is \$8415 and the curing cycle is six days plus one to unload and refill for a total of seven days. Barn curing rate is 1328 Kg/7 days x 24 hr/day = 7.9 Kg/hr-cure so that the unit cost is \$8415/7.9 Kg/hr = \$1065/Kg/hr of capacity.

Annual fixed costs, assuming 20 year life, 10% interest, 2% for taxes and insurance and a salvage value of 20% are:

$$.1175\,(.9P) + .1(.2P) + .02P = .134\,P$$

where .1175 is the cost recovery factor associated with 10% interest and a 20 year life, the second term is the interest on the salvage value of the barn and the last term is the cost of taxes and insurance.

Labor for supervising curing for a 25,000 Kg crop would amount to about two hours per day or about \$.35 per hour of barn operation. Crop value for 1978 averaged about \$2.98/Kg (\$1.35/lb) or, for a yield of 2353 Kg/ha (2100 lb/A), about \$7005/ha (\$2835/A). The timeliness factor, from the \$/ha value in Figure 2 is \$7250-\$6906/21 days = \$16.38/day-ha,

$$\frac{\$16.38/\text{day-ha}}{\$7005/\text{ha}} = .002334/\text{day}.$$

Since barn cost was calculated on the basis of a seven day use cycle the hours of operation will be 24 hours per day rather than prorating on the basis of six days of operation and one day to unload and refill. A value of X = 2 is assumed since none of the harvest was preoptimum.

Substituting these values into equation 1 for a crop size, w, of 25,000 Kg one has

$$C = \sqrt{\frac{25{,}000}{.13575 \times 1065} \left(.35 + \frac{.002334 \times 2.98 \times 25{,}000}{24 \times 2}\right)}$$

C = 26.21 Kg/hr, 26.21 Kg/hr/7.9 Kg/hr/barn = 3.3 barns

The time required to cure the crop would be 25,000 Kg/26.21 Kg/hr or 954 hr = 40 days = 5.7 weeks. This is seen to be equivalent to a crop size/barn capacity of about 115% which is smaller than shown to be optimum by the analyses in Table 5.

For tobacco harvesting, and probably for most crops, K has a larger value away from the optimum than near it. Large values of K indicate that crop value changes rapidly with time and when substituted into equation 1 yield higher optimum equipment capacities which in turn are associated with the capability of harvesting the crop rapidly. Since K is dependent on the width of the interval over which it is evaluated, the harvest duration given by the equation should be compared to the interval over which K was evaluated. If they differ appreciably, K should be reevaluated over a different interval and substituted back into the optimization equation until the harvest interval and the

evaluation interval are similar.

In the above example K was evaluated over a 3 week harvest delay while the solution gave a curing system capacity large enough to cure the crop with no more than 1 week delay. Reevaluation of K for a 1.5 week period from Figure 1 gives a value of .0016797. Substitution of this value in the optimization equation instead of the previous value gives a barn capacity of 22.6 Kg/hr for a curing season of 6.58 weeks. This is a barn loading factor of just over 130% or only slightly smaller than the 140% suggested by Table 5. Maximum harvest delay would be 1½ weeks which is the interval over which K was evaluated.

Let us now determine the response of the model to the addition of preoptimum harvesting, that is let X take on a value of 4. In order to do this it is necessary to evaluate K, the crop loss factor in the preoptimum range. A weighted average over the range - 1 week to + 1½ weeks gives a value of .06311 for K. Changing K and X in equation 1 to the above values, the optimum barn capacity becomes 21.86 Kg/hr for a harvest season of 6.81 weeks. This is only slightly larger than the 6.58 weeks found without preoptimum harvesting. Thus it is apparent that crop loss with preoptimum harvest is so large that the model essentially rejects preoptimum harvesting.

It should be mentioned that actual optimum harvest time may occur before the visual or accepted optimum time. In fact, Canadian growers because of frost hazard do successfully harvest at an earlier stage of ripeness than commonly practiced in the U.S.

Table 5. Relationships Between Crop Size, Curing Capacity, Harvest Delay-Crop Value and Curing Barn Costs.

Crop Size Kg/Barn	Crop Size / Barn Capacity %	Number of Cures or Weeks in Harvest Season	Amount of Delayed Harvest and Reduction in Crop value			Annual Costs for Barns to Eliminate Harvest Delay $		
			1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks
6640	100	5	0	0	0	0	0	0
7304	110	5.5	25% $54	0	0	126	0	0
7968	120	6	50% $116	0	0	252	0	0
8632	130	6.5	55% $140	11% $72	0	274	105	0
9296	140	7	49% $134	26% $183	0	294	210	0
9960	150	7.5	40% $117	33% $249	7% $102	316	225	90
10624	160	8	32% $100	32% $257	18% $279	336	241	180

Literature Cited

1. Agricultural Engineering Yearbook. Agricultural Machinery Management, Page 274. 1978.

2. Cundiff, J.S. and Paul Sumner. Fan Cycling and Energy Savings. Energy and Bulk Tobacco Barn Seminar. Myrtle Beach, S.C., Nov. 14-15, 1977.

3. Glover, J.W. Air Handling in Bulk Tobacco Barns. Energy and Bulk Tobacco Barn Seminar, Myrtle Beach, S.C., Nov. 14-15, 1977.

4. Hunt, Donnell. Farm Power and Machinery Management. Page 247. Iowa State University Press, Ames, Iowa, Sixth Edition. 1973.

5. Suggs, C.W. Effect of Harvest Schedule on Yield, Value, and Chemical Characteristics of Flue-Cured Tobacco. Proceedings 31st Tobacco Chemist's Research Conference, Page 4. Greensboro, N.C., Oct. 1977.

6. Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco, Part 7. Machine Filling, Handling and Curing in Large Bulk Containers. Tob. Sci. 21:51-56. 1977.

7. Watkins, R.W. Mechanization, Page 70. Section in <u>1979 Tobacco Information</u> by W.K. Collins, S.N. Hawks, F.H. Todd, W.F. Congleton, R.W. Watkins, and C.R. Pugh. N.C. Agri. Extension Service. 1978.

8. Yang, K.P. Modeling and Evaluation of Alternatives Systems for Harvesting, Handling and Curing Flue-Cured Tobacco. Unpublished Ph.D. Dissertation, North Carolina State University. 1978

Figure 1a. Effect of box height and air flow on curing costs, 5¢/Kwh for electricity.

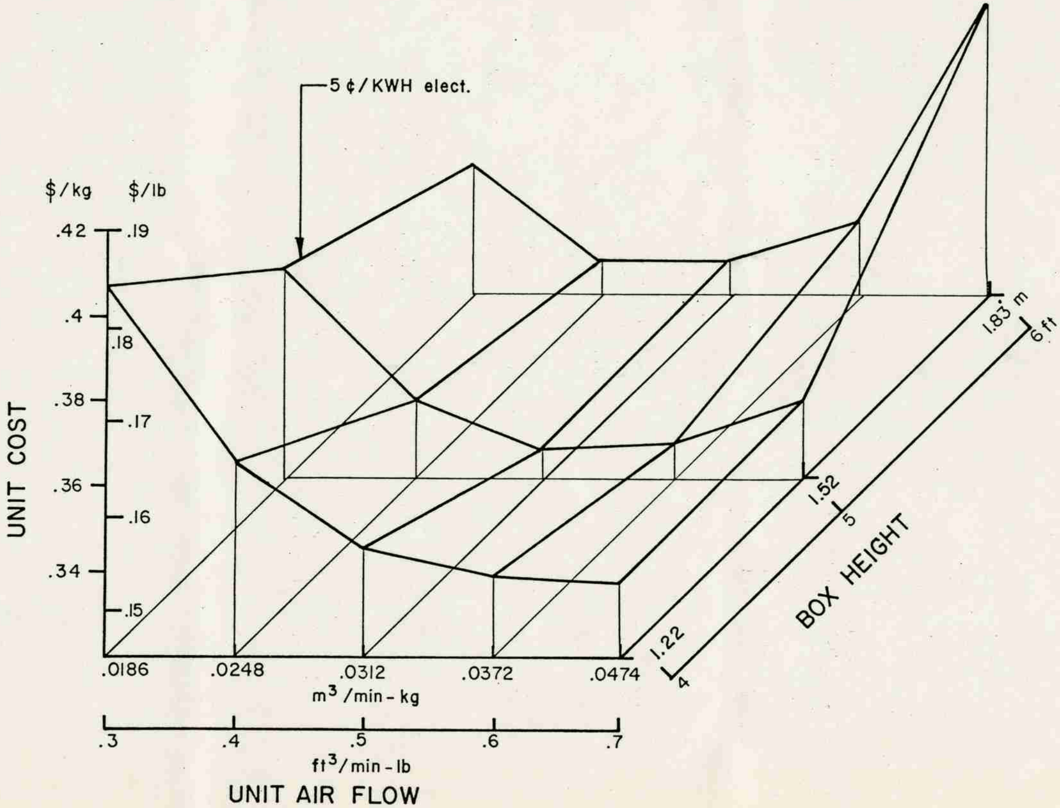
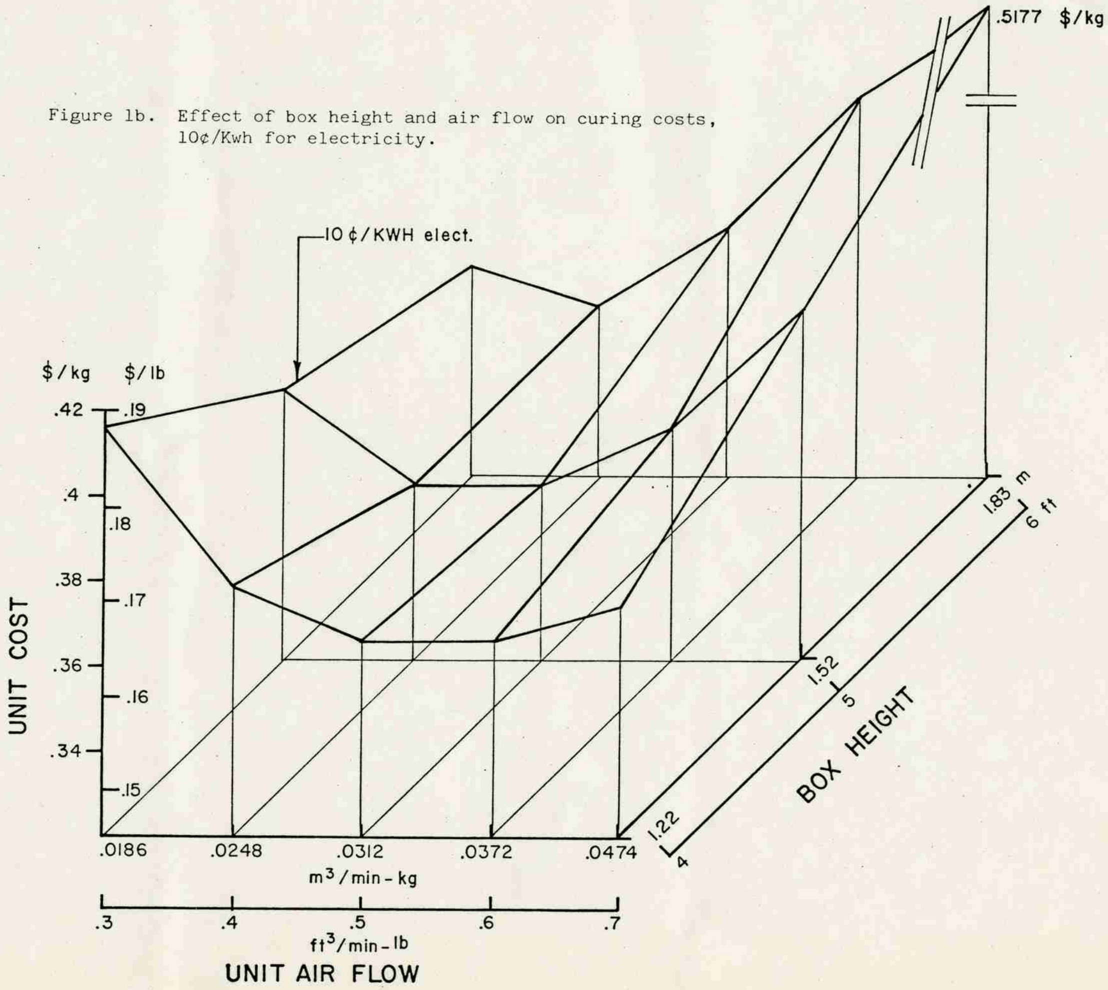


Figure 1b. Effect of box height and air flow on curing costs, 10¢/Kwh for electricity.



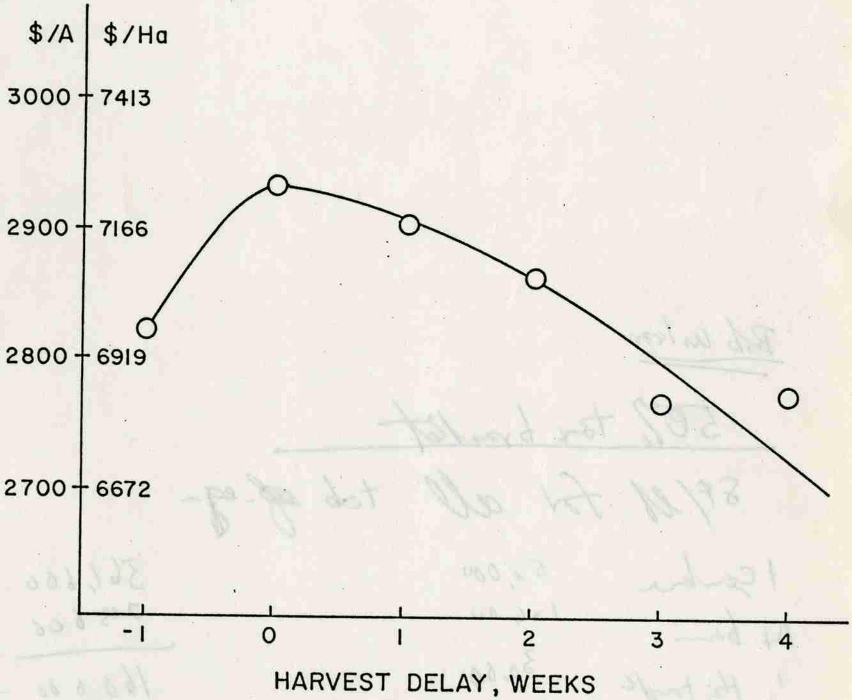


FIG. 2. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.

Bob Wilson

50% tax bracket

8¢/lb for all tob eq.

1 Combine	58,000	361,600
14 barns	1x6,00	203 606
1 Hi trailer	30,00	160,000 — 200,000 lb/hr
1 Transp.	6.000	Assume 100 A → 200,000 lb
	226	
Int 12% 10 yr	135	— 36,160/yr
	361.600	

Tax

Inv Tax credit 22600

50% tax bracket (int) 68,000

Dep 113.

203600 Tax savings

the harvest before the optimum time. Preoptimum harvesting was not considered in the analysis tabulated in Table 5 because of the rapid decrease in value. If this result is dependable and not restricted to the 5 years of data summarized in Figure 2 some increase in on-farm curing barn utilization is possible.

Use of more frequent light harvest or less frequent heavy harvest has little affect on the problem as the throughput of the barn is not changed and the proportion of the crop subject to harvest delay would not be changed, provided length of harvest season is not changed.

Alternative Formal Analysis

The previous analysis approaches optimum curing capacity intuitively, making allowances for the batch operation feature of the curing barns. A more formal approach to optimization is provided by Hunt (1973) in the following equation:

Since barn cost was calculated on the basis of a seven day use cycle the hours of operation will be 24 hours per day rather than prorating on the basis of six days of operation and one day to unload and refill. A value of X = 2 is assumed since none of the harvest was preoptimum.

Substituting these values into equation 1 for a crop size, w, of 25,000 Kg one has

$$C = \sqrt{\frac{25,000}{.13575 \times 1065} \left(.35 + \frac{.002334 \times 2.98 \times 25,000}{24 \times 2}\right.}$$

C = 26.21 Kg/hr, 26.21 Kg/hr/7.9 Kg/hr/barn = 3.3 barns

The time required to cure the crop would be 25,000 Kg/26.21 Kg/hr or 954 hr = 40 days = 5.7 weeks. This is seen to be equivalent to a crop size/barn capacity of about 115% which is smaller than shown to be optimum by the analyses in Table 5.

For tobacco harvesting, and probably for most crops, K has a larger value away from the optimum than near it. Large values of K indicate that crop value changes rapidly with time and when substituted into equation 1 yield higher optimum equipment capacities which in turn are associated with the capability of harvesting the crop rapidly. Since K is dependent on the width of the interval over which it is evaluated, the harvest duration given by the equation should be compared to the interval over which K was evaluated. If they differ appreciably, K should be reevaluated over a different interval and substituted back into the optimization equation until the harvest interval and the

evaluation interval are similar.

In the above example K was evaluated over a 3 week harvest delay while the solution gave a curing system capacity large enough to cure the crop with no more than 1 week delay. Reevaluation of K for a 1.5 week period from Figure 1 gives a value of .0016797. Substitution of this value in the optimization equation instead of the previous value gives a barn capacity of 22.6 Kg/hr for a curing season of 6.58 weeks. This is a barn loading factor of just over 130% or only slightly smaller than the 140% suggested by Table 5. Maximum harvest delay would be 1½ weeks which is the interval over which K was evaluated.

Let us now determine the response of the model to the addition of preoptimum harvesting, that is let X take on a value of 4. In order to do this it is necessary to evaluate K, the crop loss factor in the preoptimum range. A weighted average over the range - 1 week to + 1½ weeks gives a value of .06311 for K. Changing K and X in equation 1 to the above values, the optimum barn capacity becomes 21.86 Kg/hr for a harvest season of 6.81 weeks. This is only slightly larger than the 6.58 weeks found without preoptimum harvesting. Thus it is apparent that crop loss with preoptimum harvest is so large that the model essentially rejects preoptimum harvesting.

It should be mentioned that actual optimum harvest time may occur before the visual or accepted optimum time. In fact, Canadian growers because of frost hazard do successfully harvest at an earlier stage of ripeness than commonly practiced in the U.S.

COSTS OF PRODUCING BURLEY TOBACCO: 1978-79 AND PROJECTED 1980

Verner N. Grise
Agricultural Economist
Commodity Economics Division
Economics, Statistics, and Cooperatives Service

ABSTRACT: The cost of inputs used to produce burley tobacco will likely rise by about 10 percent in 1980. However, the cost per 100 pounds of tobacco will drop if yields are similar to those of 1976 and 1978. The low burley yield of 1979 increased variable costs 22 percent per 100 pounds (16 cents per pound). Sixty percent of the cost increase was due to lower yields and the remainder to higher input prices. Those estimates are based on a 1977 survey of 790 burley tobacco producers in the Bluegrass and south central areas of Kentucky and north central and eastern Tennessee, updated with 1978, 1979, and projected 1980 prices.
KEYWORDS: Burley tobacco, variable costs, total costs, yield.

INTRODUCTION

The costs of producing burley tobacco during 1978-79, with projections for 1980, are presented in this report. The major source of data for the cost estimates was a 1977 survey of 790 burley tobacco producers in five major Kentucky and Tennessee production areas (table 1). The data have been updated from the 1976 base period using indexes for individual input items.[1]

Production costs vary widely from farm to farm due to management, labor productivity, and a host of other variables. These budgets do not reflect this variability, but instead reflect the average costs of farmers in the specified production areas.

Budgets include variable costs, machinery and barn ownership, and general farm overhead costs. Variable costs include expenditures for fertilizer and lime, pesticides, sucker control chemicals, curing and heating fuel, custom operations, fuel and lubricants, repairs, tobacco crop insurance, marketing fees, and other costs such as seed and plant bed canvas. Labor costs are included for all labor used. Hired, family, and exchange labor are all charged at prevailing farm wage rates. Machinery ownership and barn ownership costs reflect the estimated age distribution of these items for the years for which costs are calculated. General farm overhead includes costs for recordkeeping, utilities, and other items that are difficult to allocate to specific enterprises.

Two additional cost components, management and land and quota (right to market tobacco without penalty) are also estimated. The management charge is computed as 7 percent of the value of the crop. Crop value was computed for 1978 using the average annual price received by farmers, and estimated 1978 yields. For the 1979 preliminary estimate, the opening day sales average of $1.42 a pound was used and $1.48 is the projected 1980 estimate. Indicated 1979 yields, as of November 1, were only 87 percent of the 1978 yield. The yield for 1980 is assumed to be 2,180 pounds per acre, the same as the 1976 base period.

[1] For a more complete discussion of concepts and procedures which underlie burley tobacco production cost estimates, refer to the article "Costs of Producing Burley Tobacco—1976," by Verner N. Grise, *TOBACCO SITUATION*, TS-163, Washington D.C., USDA, March 1978, pp. 37-42. For 1977 production cost estimates refer to the article, "Costs of Producing Burley Tobacco; 1976-78 and Projected 1979," by Verner N. Grise, *TOBACCO SITUATION*, TS-166, Washington D.C., USDA, December 1978, pp. 29-34.

DECIDING WHETHER TO LEASE TOBACCO QUOTA

The price of leased tobacco quota, especially in lease-and-transfer arrangements, is determined through the competitive bidding of growers in a county for the poundage quota of others. Therefore, each grower needs to assess whether he can afford to lease additional quota. As a general guide, the maximum amount that a grower can pay for leased quota depends upon:

(1) The expected price of tobacco and
(2) The added cost for producing leased poundage.

Therefore, each grower needs to gather information on (a) the outlook for tobacco and how his leaf usually sells in relation to the market average and (b) records of his costs of production, interpreted in light of the outlook for input prices and those costs which are subject to change, if production is increased through leased quota.

Since all farmers do not have identical costs, it follows that some cannot afford to pay as much for leased quotas as others. Generally, those growers who can compete most effectively in the leasing market have some of the following characteristics:

(1) Produce good yields of high quality which can result in lower costs of materials per pound of tobacco and above-average prices.
(2) Have surplus facilities on hand in terms of barns and machinery, so that little additional investment (or overhead) is required to expand crop size through leasing.
(3) Incur little additional labor cost, if leasing in quota.
(4) Have good cost control through careful purchasing, record-keeping and efficient production.
(5) Are financially sound, so that large margins are not required to cover risks.

This leaflet provides a framework by which growers may develop their estimates on which to base their leasing decision. 1980 Tobacco Information, AG-187, a publication of the North Carolina Agricultural Extension Service in December 1979, provides additional information on production costs and leasing on pp. 1-10. Budgets such as reproduced on the last page of this leaflet show costs and returns estimates with efficient practices. Growers may develop their own estimates to meet individual farm conditions.

Item	Your present quota: $ per acre — Sample budget [1]	Your record or estimate [2]	¢ per lb. — Your record or estimate [3]	Leased quota — Costs per lb. if leased [4]
Fertilizer	$ 73	____	____	____
Chemicals	110	____	____	____
Curing	238	____	____	____
Other materials	30	____	____	____
Insurance, crop & bldgs.	128	____	____	____
Marketing	92	____	____	____
Equipment operation	278	____	____	____
TOTAL OPERATING	949	____	____	(A) ____
OVERHEAD	487	____	____	(B) ____
LABOR	357	____	____	(C) ____
Value of land (not shown in budget)		____	____	(D) ____
SUM of the above COSTS	xxx	____	____	(E) ____
Expected price of tobacco	xxx	xxx	xxx	(F) ____
Your margin for quota, risk & management	xxx	xxx	xxx	(G) ____
Prospective lease cost per pound	xxx	xxx	xxx	(H) ____
Returns for your risk & management [5]	xxx	xxx	xxx	(I) ____

Tips on evaluating your leasing decision

(A) Your operating costs for leased quota will probably be about the same per pound as your present operation. If not, adjust expense items, such as fertilizer and chemicals, if additional fields planted to tobacco have different fertility or disease situations.

(B) The appropriate overhead cost, if quota is leased, depends upon whether extra investment is required for the larger crop. If existing barns and machinery are not fully utilized, there may be no added overhead, up to the capacity of existing facilities. But, if new items would be needed, the relevant overhead cost depends upon how long you expect to be able to lease. e.g., if confident that you will continue leasing, the investment in new facilities might be amortized over its useful life. However, if uncertain, you might wish to charge at least annual debt repayments of principal and interest to avoid any reduced cash flow. A more conservative approach is to charge the difference between the initial investment and the estimated salvage value of equipment, in case the lease is not renewed.

(C) Is the present labor force under-utilized, or must extra labor be hired if additional quota is leased in? In the latter case, would additional workers be hired on a year-round basis or as needed?

(D) What is the annual value of land which might be occupied by leased tobacco? e.g., its rental value or net income from alternate crops.

(E) What is the total of additional production costs on a per pound basis?

(F) What is your outlook for tobacco prices?

(G) What is the difference between your expected price and your estimated additional production costs?

(H) At what rate could you lease quota in your county?

(I) Considering the difference between the margin (in G) and the lease cost (in H), are you willing to grow rented tobacco with this indicated level of net return?

---

[1] Based on summary of budget published in 1980 Tobacco Information, p. 9, AG-187.
[2] This space allows you to project your estimated costs, based on your records and expected changes in input prices.
[3] Divide your estimated per-acre costs by your expected yield of pounds per acre.
[4] Adjust your current per-pound costs if they are likely to be different for leased quota.
[5] Consider leasing if the returns appear adequate for your risk and supervision of the larger crop. If negative or too low to cover your risk, your decision may be to not lease.

TOBACCO, FLUE-CURED: Estimated revenue, operating expenses, annual overhead cost and net revenue per harvested acre, Large farm harvesting 40 or more acres with mechanical harvester and bulk-curing

Item	Units	Price	Quantity	Value	Your Estimate
Receipts	lbs.	$1.45	2100	$3045.00	
Operating inputs:					
Tobacco seed for 70 sq. yd. per acre	oz.	27.00	0.10	2.70	
Custom fumigation and p.b. cover	sq. yd.	0.25	70.00	17.50	
12-6-6, @ 67 lb. per 100 sq. yd.	cwt.	6.45	0.47	3.03	
16-0-0, @ 5 lb. per 100 sq. yd.	cwt.	6.90	0.035	0.24	
Fungicide for plant bed				0.95	
Insecticide material for plant bed				0.34	
Nematicide				43.50	
Herbicide				12.04	
8-8-24	cwt.	8.89	5.00	44.45	
15-0-14	cwt.	9.25	2.00	18.50	
16-0-0	cwt.	6.90	1.00	6.90	
Insecticide material for field				12.09	
Contact sucker control				24.20	
Systemic sucker control				16.43	
Cover crop seed				9.38	
Curing fuel for fuel-efficient barns	gal.	0.87	220.00	191.40	
Electricity				47.04	
Crop insurance				88.20	
Building insurance				40.00	
Warehouse charges	dol.	0.03	3045.00	91.35	
Marketing organization				1.05	
Leased quota	lb.				
Tractor and machinery operation				144.10	
Repair to buildings				110.00	
Interest on operating capital		0.12	200.00	24.00	
Total operating cost				949.39	
Returns to land, (quota), labor, investment and management				2095.61	
Annual overhead cost (depreciation, interest, taxes and insurance)					
Tractor, trucks and general tillage equipment				51.75	
Specialized tobacco machinery				119.92	
Bulk-barns and packhouse				315.00	
Total annual overhead cost				486.67	
Returns to land, (quota), labor, and management				1608.94	
Labor cost	hr.	3.50	102.00	357.00	
Returns to land, (quota), and management				$1251.94	

Budget prepared by Charles R. Pugh, Extension Economist, and W. K. Collins, Crop Science Extension Specialist (Tobacco) and reprinted from 1980 Tobacco Information, p. 9, AG-187.

by Charles R. Pugh, Extension Economist

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12-79-10M AG-197

Why rental rates rose so high

And what you can afford to pay this year

Johnny W. Jordan
with Barbara Antonucci

With quota rental rates in South Carolina and other flue-cured states reported as high as 60 cents a pound, many tobacco growers are beginning to wonder where it will all end. How did things get to this point?

The obvious answer is that farmers have been willing to pay more for quota in recent years because they could expect larger profits and because of the capital investment situation they found themselves in.

Leaf prices increased by approximately 25 percent from 1975 to 1977 while non-quota production costs increased only about 10 percent, providing an incentive for producers to pay higher quota prices.

The flue-cured tobacco quota had been increased by 40 percent from 1972 to 1975, making it economically feasible for many producers to mechanize their operations and lower their production costs.

But then the basic quota was reduced by 25 percent from 1975 to 1978.

Those growers who made large purchases of machinery and equipment, expecting the level of quota to remain at what it was when they purchased it, had excess machinery capacity. Many of them felt they had to bid aggressively for the available quota, and the increased demand led to the skyrocketing rental rates.

How do you know if you're paying too much for quotas? An affordable rental rate depends on the production and harvesting systems and size of the operating unit, as well as on yields, tobacco quality and, ultimately, selling price.

Changes in the tobacco farm structure in recent years have affected all of these. More mechanization has meant larger operating units, each farm unit rents a higher proportion of the tobacco quota in order to make a profit, and no longer does the quota owner produce a major portion of flue-cured tobacco.

What these changes mean is that tobacco farmers today are borrowing more money in order to meet operating expenses such as machinery, chemicals, fuel and warehousing. This makes them more sensitive to changes in farm-supply and tobacco prices.

All of this means that tobacco producers must do a better job of business management, especially when it comes to keeping production and financial records. Cash-flow projections, enterprise budgets and income statements can be important tools in making farm decisions.

The enterprise budget on the next two pages was developed by the South Carolina Extension Service as an aid to farm planning. The budget projects the various costs of production for the coming year to help the grower to analyze alternative harvesting systems, credit needs, labor requirements and affordable quota rental rates.

Included are estimates of 1980 costs of producing tobacco for four different sized operations ranging from 15 acres to 44 acres.

The enterprise budget has three major cost categories:

☐ *Variable* or out-of-pocket costs incurred in actual production and the dollars involved are listed in the first section. Variable costs are divided into preharvest and harvest because the costs prior to harvest are "sunk" once the expense is made, and many harvest decisions should be based on harvest cost only. General overhead—items such as

 Received Jan 1980

September 20, 1979

Mr. Jonathan W. Bell
Associate Editor
Tobacco International
551 Fifth Avenue
New York, New York 10017

Dear Mr. Bell:

I am returning proofs of my article entitled "Mechanical Harvesting of Flue-Cured Tobacco Part 10: Bulk Barn Parameters" with my corrections marked on the copy. There were a few places, primarily in the equations where the typesetter may want to refer back to the manuscript as my comments on the proof may not be sufficient.

Order For Reprints

I have asked our Purchasing Department to send you an order for 250 reprints without covers. You should receive this order in a week or so. In the meantime consider this letter as authorization to print and ship the reprints.

I look forward to seeing the article in Tobacco Science.

Sincerely,

C.W. Suggs
Professor

CWS/bm

Enclosure

TOBACCO INTERNATIONAL

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ESTABLISHED 1886

551 FIFTH AVENUE, NEW YORK, N.Y. 10017
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New York, N.Y.
September 17, 1979

Dr. C.W. Suggs
Dept. of Biol. & Agr. Engineering
North Carolina State University
Raleigh, N.C. 27650

Dear Dr. Suggs,

Enclosed are the proofs of the manuscript

Mechanical Harvesting of Flue cured Tobacco Part 10: . . . Bulk Barn Parameters

which you submitted to "Tobacco Science". The manuscript will be published in the "Tobacco Science" section of TOBACCO, issue of

Autumn, 1979.

It is essential that the proofs be returned to us by October 5, 1979 marked with any corrections that you may desire to be made in the manuscript prior to publication. It will be appreciated if you will make corrections only for errors of fact or typesetting, as any material changes will necessitate the return of the manuscript to the Editorial Board for further processing. If the proofs are not returned to this office by October 12, 1979 we will assume that no corrections are desired and that the manuscript in galley form meets your approval for publication.

Attached is a schedule of prices for reprints of your article. Should you desire reprints to be made by us, kindly enclose your order, specifying kind and quantity, at the time you return the proofs. A bill for reprints will follow their delivery.

Thank you for your support of "Tobacco Science".

With kindest regards,

Sincerely,

Jonathan W. Bell
~~G. Espinosa~~
~~Editor~~
Associate Editor

GE/s
Encls

Dr. C. W. Suggs
Dept. of Biol. & Agri. Eng.
186 Weaver
NCSU Campus

TOBACCO SCIENCE

August 16, 1979

Dear Dr. Suggs:

This is to advise you that your manuscript number 1209 has been approved for publication with priority number 328 and should appear about December 1979.

The publisher (TOBACCO, 551 Fifth Avenue, New York) will send you the galley proofs of your article for final proofing. At the same time, he will quote prices for reprints in lots of 250 copies. If you desire reprints, order them when you return the galley.

Sincerely yours,

E. A. Wernsman

E. A. Wernsman, Chairman
Editorial Board
N. C. State University
Raleigh, North Carolina 27607

Mechanization and Efficient Tobacco Production

Mechanization by tobacco growers throughout the world has become phenomenal. The high demand for labor for each process from transplanting to curing has been the major reason for the wide-spread change. Relative cost comparisons of mechanical equipment and bulk curing versus hand labor and conventional curing have been contributing factors. Increased hourly rates and energy costs are also important in the changes to mechanization.

The figures in this article are based on practices in the United States and Canada and have been furnished by Powell Manufacturing Company, Inc., Bennettsville, S.C. Powell is but one of several manufacturers/suppliers of tobacco production equipment and the figures represent the cost of its equipment, along with averages of fuel, electricity, and labor costs in the United States. A certain degree of extrapolation is necessary to equate these figures with those of other manufacturers.

Lower expense

Chart 1 shows operating costs at the initial stages. **Chart 2** shows that machine harvesting and curing—that is, a combine and bulk curing operation—yields a cost reduction of nearly $0.21 per pound ($0.46 per kg) from the traditional manual priming/stick barn method.

If the cost of labor were the only consideration to be made in tobacco production, that cost reduction figure by itself would make mechanization attractive.

Chart 3 outlines the operating expense of bulk curing, along with that of harvesting and barning. The cost of electricity and fuel in a bulk barn, shown in **Chart 4**, is, of course, based on use of a Powell barn.

The end figure, $0.15 per pound ($0.34 per kg) of cured leaf, assumes a 100% mechanized operation. Many areas of the world are not yet suited for such an operation, nor is 100% mechan-

Chart 1. Operating costs, Transplanting through Suckering
Based on normal expected life for equipment and operating cost each year

Description	Transplanting fertilizer: Transplanter "420" F4	Spraying sucker control topping: Hi-Trac spray 4-row topping	Total, both operations
Expected life*	1,650,000 lb (747 450 kg) 750 acres (300 hectares)	6,600,000 lb (3 000 000 kg) 3,000 acres (1 200 hectares)	–
Number operators (normal)	5	1	–
Capacity	2-3 acres/hr (.8-1.2 ha/hr)	6-8 acres/hr (2.4-3.2 ha/hr)	– –
Purchase cost (over expected life)	$0.31/100 lb ($0.68/100 kg)	$0.37/100 lb ($0.82/100 kg)	$0.68/100 lb ($1.50/100 kg)
Labor cost per 100 lbs. @ $3.00 per hour rate	$0.34/100 lb ($0.75/100 kg)	$0.02/100 lb ($0.04/100 kg)	$0.36/100 lb ($0.79/100 kg)
Fuel costs**	$0.03/100 lb ($0.07/100 kg)	$0.01/100 lb ($0.02/100 kg)	$0.04/100 lb ($0.09/100 kg)
Total purchase and operating costs	$0.68/100 lb ($1.50/100 kg)	$0.40/100 lb ($0.88/100 kg)	$1.08/100 lb ($2.38/100 kg)
Total cost per pound of cured leaf			$0.01/lb ($0.02/kg)

Interest, Taxes, Repair, Ins. Housing

All values shown are based on actual results from some well-managed operations. Land costs, fertilizer, plant pulling, insecticides, etc., are extra.
**Expected life is based on 5 years at maximum capacity.*
***Fuel costs based on average of a number of farmers. Diesel fuel @ $0.55/Gallon ($0.15/1), Gas @ $0.50/Gallon ($0.13/1), and Electricity @ $0.05/kWh.*

Chart 2. Minimized Harvesting and Barning Cost

Harvesting & barning methods compared	Hrs. labor per 100 lb average	$/lb ($/kg)	Cost at $3 per hour: $/44,000lb ($/19 950kg)	$/110,000lb ($/49 900kg)	$/176,000lb ($/79,800kg)
Multi-pass priming operation (2200lb/acre) (2466kg/ha)			20 acres (8.1 ha)	50 acres (90.2 ha)	80 acres (32.4 ha)
Hand harvest-stick barn	7.75 hr*	$0.23 ($0.51)	$10,230	$25,575	$40,920
Hand harvest-bulk barn	4.76 hr*	$0.14 ($0.31)	$ 6,270	$15,708	$25,133
Combine & bulk barn**	0.57 hr	$0.2 ($.04) .02	$ 748	$ 1,870	$ 2,992
Single-pass priming operation (20% reduction)			25 acres (10.1 ha)	62.5 acres (25.3 ha)	100 acres (40.5 ha)
Hand harvest-bulk barn	3.46 hr***	$0.10 ($0.23)	$ 4,580	$11,451	$18,322
Machine harvest-bulk barn	2.44 hr***	$0.07 ($0.16)	$ 3,221	$ 8,052	$12,883

**This is average requirements reported by Clemson and N.C. State University in the fall of 1974.*
***1974 results from some efficient, well managed farms with the most modern Powell combines and Powell bulk curing equipment.*
****Average of labor requirements reported by Clemson in the fall of 1974.*

volume 181 #15

Chart 3. Operating cost—Harvesting, Barning, and Curing

	HARVESTING COMBINE GENERATION III 2 - Row	BARNING & CURING BULK CURER MAXIMISER	TOTAL
EXPECTED LIFE*	1,000,000 lb (454 000 kg) 455 acres (184 ha)	220,000 lb (99 800 kg) 100 acres (40 ha)	
NUMBER OPERATORS (Normal)	1	4	5
CAPACITY	1½-3 acres/hr (0.6-1.2 ha/hr)	8 acres(3.2 ha) (5 primings)	
PURCHASE COST (Over Expected Life)	$3.68/100 lb ($8.11/100 kg)	$5.25/100 lb ($11.57/100 kg)	$8.93/100 lb ($19.68/100 kg)
LABOR COST **	$0.34/100 lb ($0.75/100 kg)	$1.36/100 lb ($3.00/100 kg)	$1.70/100 lb ($3.75/100 kg)
FUEL COST ***	$0.26/100 lb ($0.57/100 kg)	$4.47/100 lb ($9.85/100 kg)	$4.73/100 lb ($10.43/100 kg)
TOTAL PURCHASE & OPERATING COST	$4.28/100 lb ($9.44/100 kg)	$11.08/100 lb ($24.43/100 kg)	$15.36/100 lb ($33.86/100 kg)

TOTAL COST PER POUND $0.15/lb ($0.34/kg)

ALL VALUES ARE BASED ON ACTUAL RESULTS FROM SOME WELL MANAGED OPERATIONS. LAND COSTS, FERTILIZER, PLANT PULLING, INSECTICIDES, ETC., ARE EXTRA.

* Expected life is based on 5 yrs.maximum capacity for Combine and 12 years for Bulk Curer.
** Labor based on $3.00 per hour.
*** Fuel costs based on average of a number of farmers: Diesel fuel @ $0.55/Gallon($0.15/ℓ) Gas @ $0.50/Gallon($0.13/ℓ), and Electricity @ $0.05/kWh.

ization, as outlined in **Chart 4** necessarily desirable. In some areas, cultural practices may not be suited to mechanization and the manual labor pool may be large and efficient. The quality/price ratio in a particular crop year may not be sufficient to allow growers to purchase mechanical aids. And total mechanization, it must be remembered, can initially be detrimental to tobacco quality.

Mechanization is most desirable in areas where efficient labor is scarce. Efficiency of available labor is important because, as indicated above, the quality of mechanically harvested and bulk cured tobacco sometimes suffers until the operators are familiar with its operation. In the United States, when mechanical harvesting and bulk curing in disarranged leaves were first adopted, tobacco quality declined somewhat, for at least one season, returning to the former high level when operators became more familiar with their new equipment. While the price for that lower quality tobacco did not concurrently decline, the United States' leaf reputation suffered temporarily because of increased amounts of mixed grades and disarranged leaf at auctions.

Since tobacco from every region has different characteristics and a traditional price based on its desirability in manufacturers' blends, caution is advised when mechanizing to disrupt as little as possible the quality of offerings.

In addition to fully automatic equipment, tractor drawn and high clearance aids are also available for all phases of tobacco production. Equipment suppliers and interested parties urge a systematic, gradual change to mechanization, as efficient labor becomes scarce.

For most growers in the future, it appears mechanication will be the key to making a profit.

Chart 4. Energy Cost—Fuel and Electricity

ITEM	POWELL MAXIMISER
ELECTRICITY: * KILOWATT HOURS PER 6-DAY CURE	619 kWh
KILOWATT HOURS PER SEASON: (6 CURES)	3714 kWh
COST PER SEASON AT $0.05 PER KILOWATT HOUR:	$185.70
FUEL: ** FUEL USED PER CURE: 3000 lb (1350kg) CURED LEAF	LP Gas *** 206 gal (780 ℓ)
FUEL COST PER 18,000 LB (8100 kg) CURED LEAF: BASED ON 50¢ PER GALLON ($0.13/ℓ) (6 CURES)	$618.00
TOTAL COST TO CURE 18,000 LB LEAF (8100 kg) @ 3,000 LB (1350 kg)/CURE, (6 CURES)	$803.70
TOTAL COST TO CURE 1 lb **(1kg)**	$0.05($0.11)

* All figures assume a 6-day curing schedule. Electrical data assumes 90% full load (ampere rating) at 230 volts.
** Fuel consumption figures are based on actual comparable operations. Actual costs will vary under different conditions. But Powell Bulk Barns should show a similar cost for most well-managed operations.
*** Powell oil furnaces show similar savings.

DATES

October 29-31—Tobacco Chemists, 33rd Research Conference, Hyatt Regency Hotel, Lexington, Kentucky.

April 21-25, 1980—World Tobacco Exhibition and Symposium, Palais des Expositions, Nice, France.

Novembesr 10-14, 1980—7th International Tobacco Scientific Congress and **13th CORESTA Congress,** Philippine International Convention Center, Manila.

NORTH CAROLINA STATE UNIVERSITY | AT RALEIGH

SCHOOL OF AGRICULTURE AND LIFE SCIENCES

DEPARTMENT OF CROP SCIENCE
BOX 5155 ZIP 27650

August 7, 1979

MEMORANDUM TO: Dr. Charles W. Suggs

FROM: E. A. Wernsman

We received your revised manuscript (Registration Number 1209) and are prepared to accept it for publication. I wish to ask that you have your secretary retype the tables where "white-out" has been extensively used. Tobacco Science now reproduces all tables and figures by photographing the copies provided by the author. I am concerned that many of the tables will not copy adequately.

Please return the manuscript with ribbon copies of the tables, and we will approve it for publication.

bh

Brenda - would you retype the tables that need it? -

Thanks CWS.

Table 1. Effect of Curing Box Height on Capacity, Air Flow and Pressure Requirements, Barn Costs, Fan Power, and Total Cost Per Kilogram of Tobacco Cured. Flow = .0312 m^3/min Kg (.5 cfm/lb). Duct Loss from Glover, 1977.

	Box Height		
	m ft	m ft	m ft
	1.22 4	1.52 5	1.83 6
Capacity, m^3	1.52	1.90	2.28
Weight @ 208 Kg/m^3, Kg	316	395	474
Flow Per Box, m^3/min	9.9	12.4	14.9
Flow for 20 Box Barn With Losses m^3/min	331 40% loss	435 42.7% loss	542 45% loss
Air Pressure, mm of H_2O			
For Height	10.2	12.7	15.2
For Extra Flow, Prop. Box Capacity	0	7.1	19.0
Duct Loss	12.7	15.2	17.8
Total for Barn	22.9	35.1	52.1
Fan Input Power, KW	3.01	6.05	11.23
Box Costs, $	2500	2875	3250
Fan and Motor Costs, $	250	290	444
Total Initial Barn Costs, $	8000	8415	8944
Annual Barn Costs, $	1200	1262	1342
Annual Electrical Cost, 5-144 hr Cures, $	108	218	404
Annual Fuel Costs-5 Cures, $	525	690	859
Total Annual Expense, $	1833	2170	2605
Annual Cured Weight, Kg	5307	6638	7961
Unit Costs			
$/Kg	.3454	.3269	.3272
$/lb	.1566	.1483	.1484

Table 3. Effect of Flow Rate on Curing Time, Fuel, Electricity, Barn and Total Costs. Fuel Consumption and Curing Time from Field Experience.

	Unit Flow m3/min-Kg (cfm/lb)				
	(.3) .0186	(.4) .0248	(.5) .0312	(.6) .0372	(.7) .0434
Curing Time, Hr	211	196	176	162	154
Fuel Costs, $/Cure	167	152	138	128	118
Electricity Cost,$/Cure	19	34	54	78	111
Barn Costs,$/Cure	350	329	300	284	277
Total,$/Cure	536	515	492	490	506
Unit Cost					
$/Kg	.4036	.3878	.3705	.3690	.3810
$/lb	.1830	.1759	.1680	.1673	.1729

ABSTRACT FOR TOBACCO SCIENCE

AUTHOR(s):
C.W. Suggs
AFFILIATION (first author):
N.C. State University - Biological & Agricultural Engineering Department

TITLE:
Mechanical Harvesting of Flue-Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters

TOBACCO SCIENCE, Vol. ________. Pages ____________. Year ________.

Please type abstract double spaced below. Be brief and concise (the space below should suffice); use complete sentences.

Curing container height and air flow rate through the tobacco can be controlled by the selection of equipment and certain operational choices. These choices affect barn investment and operational costs, curing time and barn throughput. A curing system with boxes 1.52 m (5') high was found to be cheaper in terms of investment and operating costs per kilogram of tobacco cured than systems using 1.22 m (4') or 1.83 m (6') boxes. An intermediate air flow of .0312 m^3/min-Kg (.5 cfm/lb) of green tobacco was optimum as higher air flows used excessive amounts of electric power to drive the fan and lower air flows reduced barn throughput. One of the important findings was that barn ownership costs were $30 to $36 per day of the curing season and represent one of the largest costs of tobacco production.

An analysis was run to determine the most economical trade-off between barn costs and loss in crop value with delayed harvest and curing. The effect of harvest delay on crop value was evaluated over a period of several years. The results of both an intuitive and a formal analysis indicated that harvest delays of 1 to 2 weeks, instead of a normal 5 week curing season, maximized crop income by reducing curing barn requirements more than they reduced crop value.

July 6, 1979

Dr. Earl Wernsman
Chairman, Editorial Board of Tobacco Science
429-A Williams Hall
N.C. State University
Raleigh, North Carolina 27650

Dear Earl:

I am enclosing two copies of Manuscript No. 1209 entitled "Mechanical Harvesting of Flue Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters," which has been revised in accordance with the suggestions of the reviewers.

The manuscripts are complete with xerox copies of the figures. In addition, I have also enclosed photographic prints of the figures for printing purposes. If there are questions please contact me.

Sincerely,

C.W. Suggs
Professor

CWS/bm

Enclosures

TOBACCO SCIENCE

EDITORIAL OFFICE
E. A. WERNSMAN, CHAIRMAN
429-A WILLIAMS HALL
N. C. STATE UNIVERSITY
RALEIGH, N. C. 27607

June 4, 1979

Registration No. 1209

Dear Dr. Suggs:

I am returning one copy of your manuscript,

Mechanical Harvesting of Flue-Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters

with the reviewers' recommendations to ( ) not approve; (x) approve after revision; ( ) approve in its present form. Copies of their critiques are enclosed. Please give careful consideration to each suggestion made by the reviewers. If you do not choose to make a particular change suggested in the review, then give a rebuttal to that comment in your letter of transmittal.

Resubmit your revised manuscript in duplicate with at least one set of figures suitable for reproduction (glossy photographs or inked drawings). Accompany this with three copies of an abstract of your paper on the enclosed forms. - Zerox

Acceptance of your revised paper will be acknowledged. At the time the printer sends you the galley-proof of your paper, he will furnish you with the prices of reprints in lots of 250 copies. Your reprint order should accompany the return of the galley.

We appreciate having had the opportunity to consider your manuscript for TOBACCO SCIENCE.

Sincerely yours,

E. A. Wernsman

E. A. Wernsman
Chairman, Editorial Board

EAW:gh

Enclosures

Manuscript Review Form

TOBACCO SCIENCE

Registration No. 1209   Date May 18, 1979

AUTHORS C. W. Suggs

TITLE Mechanical Harvesting of Flue-Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters

REVIEW COMPLETED May 18, 1979 RECOMMENDATION: ___ APPROVE IN ITS PRESENT FORM; ___ NOT APPROVE (Give reasons below); X APPROVE TENTATIVELY, SUBJECT TO THE FOLLOWING SUGGESTED REVISIONS: (itemize below):

General: This is a comprehensive review and analysis of model curing capacity and parameters. The abstract should make clear that box dimensions are being varied in height only. Harvest delays of one to two weeks extend the normal five week curing season to six or seven weeks. The manuscript is overly wordy at some points and needs rewording in a few instances.

Specific:

Page 1 - Georgia is higher, Virginia is lower, so the U.S. average is probably close to the North Carolina value.
Reword first sentence of second paragraph.

Page 2 - The paper serves in a limited way the purpose set forth. A more exact presentation might be made through computer analysis which relate the various parameters with a system of curves whereby optimization can be more clearly defined.
Middle of page "or" should be substituted for "and".
The only dimension varied was height.
The fan operated against increased pressure to force the same volume of air through the taller boxes.

Page 3 - It seems there is essentially no difference between the cost to cure for the 5' and 6' height boxes. You can't make a case for a difference of $.0001.

Page 4 - It appears that Table 1 could be rearranged with box height on the short axis of the page.

Page 5 - Although not stated, the manuscript comparison is based on use of motors and fans with the same characteristics. A more in-depth study might compare standard with high efficiency motors, and effects of fan design on air flow and energy use.

NOTE—Execute in triplicate using additional sheets if more space is required. Retain the third copy for your file. Return the original (signed) and the first carbon (*unsigned*) along with the manuscript to this office. The unsigned copy and the manuscript will be returned to the author for his consideration.

Page 6 - Should be consistant in use of English and metric units.

Page 7 - "Some additional caution . . ." What? Management?
(0.5 cfm/min.-lb)

Page 8 - Does it really take the same amount of fuel regardless of air flow rate?

Page 9 - Table 2 - rearrange

Page 14 - Some recognition should be given to the fact that certain climatic conditions cause a speed-up in the tobacco ripening process which results in the need for a faster than normal harvesting rate.

end of ¶1
Pg 14

Summary:

The manuscript addresses an area which needs analysis and is fairly comprehensive in that it touches on most factors which influence curing capacity and barn parameters. (The author has sprinkled the text with tidbits of information based on years of research and experience in his analysis of comparative models.) There is a feeling that a potential exists for an even more in-depth study of bulk barn design, selection, operation, costs, and energy use.

Manuscript Review Form

TOBACCO SCIENCE

Registration No. 1208 9

Date May 30, 1979

AUTHORS C. W. Suggs

TITLE Mechanical Harvesting of Flue-Cured Tobacco: Part 10: Optimization of Curing Capacity and Bulk Barn Parameters

REVIEW COMPLETED May 29, 1979 RECOMMENDATION: ____ APPROVE IN ITS PRESENT FORM; ____ NOT APPROVE (Give reasons below); X APPROVE TENTATIVELY, SUBJECT TO THE FOLLOWING SUGGESTED REVISIONS: (itemize below):

✓Abstract, line 4; place dimensions before "boxes."

Page 3, under Results, 1st par. The data (last 3 lines of Table 1) indicate for ±20% change in box height, there is a 0.1% and 5.7% change in unit cost. I think the author needs to discuss the significance of a 0.1% change in unit cost under these circumstances.

✓Page 4, last line, column 5; missing "2603."

✓Page 6, par. 2, next to last line. I had trouble reading this sentence. My version is penciled on the ms.

✓Page 8, par 2, line 3; delete comma after although.

✓Page 11, par 2, line 8: .....diagonal.

✓Page 12. I had trouble understanding Table 4.

GENERAL COMMENTS: The paper is suitable for Tobacco Science. I hope that these comments will help to improve the paper.

NOTE—Execute in triplicate using additional sheets if more space is required. Retain the third copy for your file. Return the original (signed) and the first carbon (*unsigned*) along with the manuscript to this office. The unsigned copy and the manuscript will be returned to the author for his consideration.

Master

ABSTRACT

Mechanical Harvesting of Flue-Cured Tobacco Part 10:
Optimization of Curing Capacity and Bulk Barn Parameters

C.W. Suggs
N.C. State University
Raleigh, N.C.

Curing container height and air flow rate through the tobacco can be controlled by the selection of equipment and certain operational choices. These choices affect barn investment and operational costs, curing time and barn throughput. A curing system with boxes 1.52 m (5') high was found to be cheaper in terms of investment and operating costs per kilogram of tobacco cured than systems using 1.22 m (4') or 1.83 m (6') boxes. An intermediate air flow of .0312 m^3/min-Kg (.5 cfm/lb) of green tobacco was optimum as higher air flows used excessive amounts of electric power to drive the fan and lower air flows reduced barn throughput. One of the important findings was that barn ownership costs were $30 to $36 per day of the curing season and represent one of the largest costs of tobacco production.

An analysis was run to determine the most economical trade-off between barn costs and loss in crop value with delayed harvest and curing. The effect of harvest delay on crop value was evaluated over a period of several years. The results of both an intuitive and a formal analysis indicated that harvest delays of 1 to 2 weeks, instead of a normal 5 week curing season, maximized crop income by reducing curing barn requirements more than they reduced crop value.

February 27, 1979

Mechanical Harvesting of Flue-Cured Tobacco:

Part 10. Optimization of Curing Capacity and Bulk Barn Parameters[1/]

C.W. Suggs

Bulk curing of flue-cured tobacco was introduced in 1960 and has shown a steady, but not uniform, growth in farmer adoption since its introduction. At the present time (1978) approximately 58% of the North Carolina flue-cured crop is bulk cured (Watkins, 1978). The percentage is higher in Georgia and Florida but lower in Virginia ~~Other states appear to be using bulk curing on similar percentages of their crops~~ so the U.S. average is probably close to the North Carolina value.

There has been considerable interaction between bulk curing and mechanical harvesting as bulk curing is a necessary companion to successful mechanical harvesting. About two thirds of the bulk cured leaf is also mechanically harvested. Because of the labor required to fill bulk curing racks the author and his associates developed a system (Suggs, 1977) which allows machine filling of containers in which the leaf can be cured. Those containers hold approximately 300 Kg to 900 Kg (about 700 lb to 2000 lb) depending on the size of the different manufacturers' models.

Because of limited experience with bulk container curing, growers and manufacturers may not have the information needed to optimize curing system parameters and capacity and properly interface the curing containers

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1/ Paper No. 6007 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, N.C. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

with a harvesting system. The purpose of this paper is to present data and analyses from which parameter optimization decisions can be made and to present and demonstrate a procedure for determining optimum curing capacity or number of barns for a given sized crop.

Curing Container Height

The curing capacity of a bulk barn depends, among other things, on the height of the container. In the following analysis it is assumed that no barn structural changes are required to accommodate higher containers. The analysis considers the larger fan and motor required, the extra heat and electricity requirements and the cost to make containers taller. Container sizes analyzed were .91 m x 1.37 m x 1.22 m, 1.52 m ~~and~~ or 1.83 m high (3' x 4½' x 4, 5 or 6'). Loading density was 208 Kg/m^3 (13 lb/ft^3) and air flow was constant with respect to initial weight at .031 m^3/min-Kg (.5 cfm/lb). Air leakage around the container and seepage out of the barn was taken at 40% for the lowest container height (pressure) (Cundiff and Sumner, 1977) and calculated for the other two heights on the basis that there was no change in the leakage area. Reference air pressures were taken from experience and dependent air pressures were calculated. An increase in pressure was needed to force the air through the taller boxes. Additional pressure was also required to provide the higher flow rates needed by the extra tobacco in the taller boxes.

Barn costs, including 1.22 m (4 ft) containers, wêre calculated on the basis of $8000 initial cost, 10% interest, 20 year life for a cost recovery factor of .1175, 20% salvage value and 3.6% of initial costs for repairs, taxes and insurance. Curing fuel costs used in the analyses were \$104 per metric ton[1/] (\$94/ton) for the mid sized container. For the other two sizes of containers fuel costs were prorated on the basis of barn air flow. Cured weight was determined from the author's data as 16.8% of the input green weight of 208 Kg/m^3 (13 lb/ft^3). Costs for boxes not commercially available were determined by allocating the \$125 cost of a 1.22 m (4') box into \$30 for the bottom section, \$20 for the top and \$0.615/cm (\$18.75 per foot) of height. Thus the 1.52 m (5') box cost \$18.75 more than the 1.22 m (4') box. Larger boxes increase the total barn cost above the \$8000 value given above. The barn holds 20 boxes and five cures can be completed in a normal season. A fan efficiency of 55% and a motor efficiency of 75% were used in calculating fan power requirements (Glover 1977): $Kw = \frac{m^3/min \times pressure\ (mm\ of\ H_2O)}{2514}$.

An electrical power cost of 5¢/Kwh was used in the analyses and cure length was 6 days (144 hrs). Fan and motor initial costs were estimated from manufacturers' catalogs.

Results

Unit costs, Table 1, reflecting barn costs, electrical cost and fuel costs, were lowest for the 1.52 m box, \$.3269/Kg (\$.1483/lb). For the shorter box (\$.3454/Kg, \$.1566/lb) the decrease in capital and operating costs did not compensate for the decrease in capacity. For the taller box (\$.3272/Kg, \$.1484) the increase in curing capacity did not quite compensate for the increase in electrical requirements of the larger fan. It will be seen later in the paper that taller boxes and high air flows increase curing costs more than they increase barn throughput.

[1/] Watkins, R.W. Private communication.

Put where material is crossed out

Unit costs, Table 1, reflecting farm costs, electrical costs and fuel costs were highest for the 1.22 m box, $.3454/kg ($.1566/lb). Costs for the 1.52 m and 1.83 m boxes were essentially equal at $.327/kg ($.148/lb). For these two box sizes the increase in curing capacity more than compensated for the increase in investment costs and the higher electrical requirements of the larger fan. The data indicates that under the assumptions used here the optimum height lies between 1.52 m and 1.83 m and that additional increases in height past the 1.83 m container will result in increased costs.

Table 1. Effect of Curing Box Height on Capacity, Air Flow and Pressure Requirements, Barn Costs, Fan Power, and Total Cost Per Kilogram of Tobacco Cured. Flow = .0312 m^3/min Kg (.5 cfm/lb). Duct Loss from Glover, 1977.

Box Height		Capacity	Weight @ 208 Kg/m^3	Flow Per Box	Flow for 20 Box Barn With Losses	Air Pressure For Height	Air Pressure For Extra Flow, Prop. Box Capacity
m	ft	m^3	Kg	m^3/min	m^3/min	mm of H_2O	mm of H_2O
1.22	4	1.52	316	9.9	331 40% loss	10.2	0
1.52	5	1.90	395	12.4	435 42.7% loss	12.7	7.1
1.83	6	2.28	474	14.9	542 45% loss	15.2	19.0

Table 1. Cont'd:

Box Height	Air Pressure Duct Loss	Air Pressure Total for Barn	Fan Input Power	Box Costs	Fan and Motor Costs	Total Initial Barn Costs
m	mm of H_2O	mm of H_2O	KW	$	$	$
1.22	12.7	22.9	3.01	2500	250	8000
1.52	15.2	35.1	6.05	2875	290	8415
1.83	17.8	52.1	11.23	3250	444	8944

Table 1. Cont'd:

Box Height	Annual Barn Costs	Annual Electrical Cost 5-144 hr Cures	Annual Fuel Costs 5 Cures	Total Annual Expense	Annual Cured Weight	Unit Cost	
m	$	$	$	$	Kg	$/Kg	$/lb
1.22	1200	108	525	1833	5307	.3454	.1566 +5.7%
1.52	1262	218	690	2170	6638	.3269	.1483
X 1.83	1342	404	859	2605	7961	.3272	.1484 .1%

Because air pressure decreases as the tobacco wilts and dries during the cure there may be some small error in calculating electrical costs on the basis of the initial air flow and pressure. However, this decrease in pressure (and increase in flow) would affect all container heights similarly so that the final comparative results would change very little. There is some increase in leakage with the higher boxes because flow resistance of the box increases with height and forces more air through the leakage openings.

Curing time was assumed equal for all box heights on the basis of the fact that box air flow was constant with respect to green weight. This means that for the taller containers the air velocity is greater. Higher air velocities often tend to dry the tobacco before yellowing is complete where the air first contacts the tobacco. This problem is more prevalent with dry weather crops or in barns which are not properly sealed. Slow drying and poor quality cures in the mid to upper part of taller boxes have also been experienced.

Air Flow

Insufficient air flow is one of the most critical problems in container bulk curing. While adequate air flow is essential to good cured leaf quality, excess air flow wastes fan power, increases exfiltration and is likely to prematurely dry the leaf.

In Table 2 the effects of air flow from .0186 to .0434 m^3/min-Kg of green leaf (.3 to .7 cfm/lb) through 1.52 m (5') high containers loaded to a density of 208 Kg/m^3, (13 lb/ft^3) holding 395 Kg (871 lb) of green tobacco, is analyzed. An average cured weight yield, from the author's data, of 16.8% gives 1327 Kg (2926 lb) as the cured capacity of a 20 box barn or 6638 Kg (14637 lb) per 5-cure season. The 1.52 m box of Table 1 is taken as a reference for Table 2 and appears as the middle line of that table.

The author's experience indicates that yellowing can be accomplished with low air flow but that drying is delayed if flow is not adequate. Yellowing time averages about 60 hours and drying time for the intermediate or reference air flow was 84 hrs for a total curing time of 144 hours (6 days). For higher or lower air flows the drying time was proportionally shorter or longer, respectively so that drying air volume for the total cure was constant for all flow rates. Barn costs were almost constant, reflecting only the costs of larger fans and motors for the higher air flows. Annual barn costs were calculated as in the previous example based on container height. Barn costs per cure were prorated on the basis of a normal curing season of 5 cures times 7 days per cure (6 days curing plus 1 day reloading) times 24 hours per day or 840 hours. Thus a barn load which cures out in 144 hours is charged with $\frac{144 + 24}{840}$ x barn annual costs.

Unit costs were lowest, \$.3269/Kg (\$.1483/lb), for the middle flow rate, Table 2. Costs did not increase as rapidly with higher flow rates, \$.3373/Kg (\$.1530/lb), as they did for lower flow rates, \$.3690//Kg (\$.1673/lb), giving another indication that barn ownership costs are the largest single item in curing costs.

The simultaneous effects of box height and air flow are shown graphically in Figure 1 as a surface whose height above the base plane represents curing costs. The box height data from Table 1 defines the middle front to rear line on the main surface, while the air flow data from Table 2 defines the middle side to side line. Other values to complete the surface were determined in a similar manner to those in the tables. Figure 1a was based on electricity costs of 5¢/Kwh while Figure 1b shows the effect of increasing electricity costs to 10¢/Kwh.

While there is little difference in the cost of curing in the 1.52 m (5 ft) box versus the 1.83 m (6 ft) box when electricity costs are 5¢/Kwh, the taller box becomes more costly when electricity prices rise to 10¢/Kwh. Some additional caution should be exercised with respect to the tallest box because of the higher static air pressures required are expensive to produce and difficult to contain. ~~and the longer column of tobacco to be dried.~~ The most efficient air flow was .0312 m^3/min-Kg (.5 cfm/min-lb).

Also, the longer column of tobacco may increase drying time so that some loss of quality may occur before the drying front reaches the top of the container

In Table 2 the fuel cost was considered to be constant at $104 per metric ton because the same amount of water had to be removed regardless of flow rate. Electricity costs were based on the curing times shown. However, because of heat loss through the structure and exfiltration of heated air, fuel consumption tends to increase with curing time. Cundiff and Sumner (1977) reported that 39% of the heat energy escaped from the barn during normal length cures.

The author's data from 1977 and 1978 relating flow to curing time and fuel consumption are used in Table 3 to provide a better basis for calculating unit costs. Although other conditions are the same as in Table 2, barn and electricity costs are different because curing time has changed. This table shows a significant increase in fuel costs with decreased air flow. With this refinement in the analysis the lowest per unit cost moves to the next highest flow rate.

Crop Size - Barn Space Optimization

Intuitive Analysis

Historically, priming intervals have been one week each. Also,the curing cycle has been one week so that successive primings from a field can be placed as successive cures in a single barn. When priming intervals are not equal to curing cycle time and, in fact, priming intervals may vary significantly during the season,the analysis of curing barn requirements is complicated.

Table 2. Effect of Flow Rate on Pressure, Fan Power, Curing Time, Fuel, Electricity, Barn and Unit Costs, 1.52 m (5') Curing Box.

	Unit Flow	Box Flow	Box Pressure	Duct Loss	Total Fan Pressure	Bypass and Seepage	20 Box Barn Flow
cfm/lb	m^3/min-Kg	m^3/min	mm of H_2O	mm of H_2O	mm of H_2O	%	m^3/min
.3	.0186	7.4	7.1	10.2	17.3	43	261
.4	.0248	9.9	12.7	12.7	25.4	43	349
.5	.0312	12.4	19.8	15.2	35.0	43	435
.6	.0372	14.9	28.4	17.8	46.2	43	523
.7	.0434	17.4	38.9	20.3	59.2	43	611

Table 2. Cont'd:

Unit Flow	Fan Input Power	Drying Time	Total Curing Time	Initial Barn Costs	Annual Barn Costs (a)
m^3/min-Kg	KW	Hr	Hr	$	$
.0186	1.8	140	200	8350	1252
.0248	3.5	105	165	8375	1256
.0312	6.1	84	144	8415	1262
.0372	9.6	70	130	8560	1284
.0434	14.4	60	120	8700	1305

Table 2. Cont'd:

Unit Flow	Barn Costs Per Cure (a)	Elect. Cost @ 5¢/Kwh (a)	Fuel Costs @ $104 Per Metric Ton (b)	Total Cost	Unit Cost	
m^3/min-Kg	$/Cure	$/Cure	$/Cure	$/Cure	$/Kg	$/lb
.0186	334	18	138	490	.3690	.1673
.0248	283	29	138	450	.3389	.1537
.0312	252	44	138	434	.3269	.1483
.0372	235	62	138	435	.3276	.1486
.0434	224	86	138	448	.3373	.1530

(a) Assumes that 5 standard cures (6 days curing + 1 day reloading) can be made during the year and that barn is not otherwise used. Add 24 hours to total curing time to get hours per curing cycle.

(b) Cured weight of 1328 Kg/cure taken from Table 1.

Table 3. Effect of Flow Rate on Curing Time, Fuel, Electricity, Barn and Total Costs. Fuel Consumption and Curing Time from Field Experience.

Unit Flow		Curing Time	Fuel Costs	Electricity Cost	Barn Costs	Total	Unit Costs	
cfm/lb	m^3/min-Kg	Hr	$/Cure	$/Cure	$/Cure	$/Cure	$/Kg	$/lb
.3	.0186	211	167	19	350	536	.4036	.1830
.4	.0248	196	152	34	329	515	.3878	.1759
.5	.0312	176	138	54	300	492	.3705	.1680
.6	.0372	162	128	78	284	490	.3690	.1673
.7	.0434	154	118	111	277	506	.3810	.1729

If uniform harvesting is assumed then curing barn capacity times the number of curing cycles per season must be at least as large as the crop weight allocated to each barn. One common mistake in evaluating curing capacity is to over-estimate the number of curing cycles possible per curing season. When this happens part of the crop will have to remain in the field past its optimum ripeness or part will have to be harvested before optimum ripeness to prevent the harvest from "getting behind".

In order to determine how much of the crop would have to be harvested one or two weeks late for a given crop size it is convenient to break the crop up into equal elements such that barn capacity and crop size can be expressed as whole numbers. Table 4 shows a crop size of 130% of barn capacity which has been divided into 13 elements such that 10 elements will fill a barn for each of the 5 weekly primings. Element primings scheduled to the right of the first and second diagonal lines have been delayed one and two curing cycles (weeks), respectively. In the third cure, for example, the first 4 elements are from the third priming. The last 6 elements have been delayed one week and are, therefore, from the second priming as indicated by the number 2. Percentage of material harvested one curing cycle late is determined by the number of such elements as compared to the total crop. Table 5 gives the amount of harvest delay for various crop size/barn capacity ratios.

Table 4. Schedule of Crop Harvest (Priming Number) With Respect to Cure Number When the Crop Size is 130% of Barn Capacity for a 5 Cure Harvest Season.

Crop* Element Number	Cure #						
	1	2	3	4	5	6	7
1	1	2	3	4		5	
2	1	2	3		4	5	
3	1	2	3		4	5	
4	1	2	3		4	5	
5	1	2		3	4	5	
6	1	2		3	4	5	
7	1	2		3	4	5	
8	1		2	3	4	5	
9	1		2	3	4		5
10	1		2	3	4		5
11		1	2	3	4		5
12		1	2	3		4	5
13		1	2	3		4	5

Harvest delayed one curing cycle

Harvest delayed two curing cycles

Amount of crop delayed 1 curing cycle = 36 elements/65 elements = 55%

Amount of crop delayed 2 curing cycles = 7 elements/65 elements = 11%

*Barn capacity = 16 elements.

Yang, 1978,

A series of harvest schedule experiments (Suggs, 1977 and recent unpublished results) revealed that crop value decreased at an increasing rate as harvest is delayed, Figure 2. This suggests that some degree of barn overload could be tolerated corresponding to the period of slow decrease in crop value with respect to harvest delay. For larger delays, where crop value decreases more rapidly, the cost of additional barn space is more likely to be less than the decrease in crop value.

In order to analyze the trade off between crop size and curing system size, a barn capacity of 1328 Kg (2927 lb) per cure and an annual costs of $1262 for a barn with 1.52 m (5 ft) boxes are taken from the middle line of Table 1. The normal no-delay schedule was five primings spaced one week apart. Per cure reduction in crop value with harvest delay are taken from Fig. 2. The appropriate value for Table 5 is found by multiplying the reduction in crop value by the percentage of the crop delayed by the size of the crop affected. Annual cost for barn space to eliminate the harvest delay is found by multiplying the annual cost for a barn ($1262) by the proportion of the barn required.

For example, in order to prevent any two week harvest delay in an operation where crop size/barn capacity was 130%, one would need to add barn space until the crop size/barn capacity was 120% at which time maximum harvest delay would be only one week. This would require a total barn space of 130/120 = 1.083 or an additional 8.3% barn space. The values in Table 5 are based on one curing barn and yields of 2353 Kg/ha (2100 lb/A).

Annual barn cost, Table 5, are greater than crop value reductions for all of the one week harvest delays and for the two week delays associated with the crop size/barn capacity values of 130 and 140%. For two-week delays affecting larger parts of the crop and for all three-week delays, the crop loss is greater than the barn costs. The table seems to indicate that while a two-week harvest delay can be tolerated for a 130% or 140% crop size/barn capacity operation it can not be tolerated for the 150% or 160% barn loading factor. However, it should be pointed out that addition of enough barn space to just eliminate the 3 week harvest delay will reduce the barn loading factor to 140% so that the operation can then be considered as a 140% loading factor crop. From Table 5 it can be seen generally that additional barn space costs approach harvest delay losses at about 140% of barn capacity. In order to allow for conditions which would accelerate harvest or increase curing time it might be realistic to select a smaller loading factor.

Because barns are not available in very small sizes, it is easier to balance crop size against barn capacity when the operation involves several barns. While the author does not have data, it appears that many farmers are increasing barn utilization by extending the harvest season from one to two weeks.

Barn costs are one of the largest expenses in tobacco production. The curing season, and therefore barn usage, can be extended by selecting variety, soil type and fertility level as previously discussed. The season can also be extended by starting

the harvest before the optimum time. Preoptimum harvesting was not considered in the analysis tabulated in Table 5 because of the rapid decrease in value. If this result is dependable and not restricted to the 5 years of data summarized in Figure 2 some increase in on-farm curing barn utilization is possible.

Use of more frequent light harvest or less frequent heavy harvest has little affect on the problem as the throughput of the barn is not changed and the proportion of the crop subject to harvest delay would not be changed, provided length of harvest season is not changed.

Alternative Formal Analysis

The previous analysis approaches optimum curing capacity intuitively, making allowances for the batch operation feature of the curing barns. A more formal approach to optimization is provided by Hunt (1973) in the following equation:

$$C = \sqrt{\frac{w}{FP}\left(L + \frac{KVw}{HX}\right)} \qquad (1)$$

where

C = curing capacity, Kg/hr

w = size of crop, Kg

P = curing barn costs, \$ per Kg/hr

L = labor costs, \$/hr

K = timeliness loss factor, fraction of crop value/day

F = barn fixed cost, fraction of initial cost

V = crop price, \$/Kg

H = hours of use per day

X = 4 if operation can be performed both before and after optimum, 2 if operation limited to pre or post optimum.

Tobacco curing barns, unlike grain dryers are not available in a large range of sizes. Curing capacity is increased by adding one or more of the "standard" size units. Barn capacity varies somewhat but a value of about 1328 Kg (2927 lb) per cure is a good average. Barn cost including 1.52 m (5 ft containers) is \$8415 and the curing cycle is six days plus one to unload and refill for a total of seven days. Barn curing rate is 1328 Kg/7 days x 24 hr/day = 7.9 Kg/hr-cure so that the unit cost is \$8415/7.9 Kg/hr = \$1065/Kg/hr of capacity.

Annual fixed costs, assuming 20 year life, 10% interest, 2% for taxes and insurance and a salvage value of 20% are:

$$.1175\,(.9P) + .1(.2P) + .02P = .134\,P$$

where .1175 is the cost recovery factor associated with 10% interest and a 20 year life, the second term is the interest on the salvage value of the barn and the last term is the cost of taxes and insurance.

Labor for supervising curing for a 25,000 Kg crop would amount to about two hours per day or about \$.35 per hour of barn operation. Crop value for 1978 averaged about \$2.98/Kg (\$1.35/lb) or, for a yield of 2353 Kg/ha (2100 lb/A), about \$7005/ha (\$2835/A). The timeliness factor, from the \$/ha value in Figure 2 is \$7250-\$6906/21 days = \$16.38/day-ha,

$$\frac{\$16.38/\text{day-ha}}{\$7005/\text{ha}} = .002334/\text{day}.$$

Since barn cost was calculated on the basis of a seven day use cycle the hours of operation will be 24 hours per day rather than prorating on the basis of six days of operation and one day to unload and refill. A value of X = 2 is assumed since none of the harvest was preoptimum.

Substituting these values into equation 1 for a crop size, w, of 25,000 Kg one has

$$C = \sqrt{\frac{25{,}000}{.13575 \times 1065} \left(.35 + \frac{.002334 \times 2.98 \times 25{,}000}{24 \times 2} \right.}$$

C = 26.21 Kg/hr, 26.21 Kg/hr/7.9 Kg/hr/barn = 3.3 barns

The time required to cure the crop would be 25,000 Kg/26.21 Kg/hr or 954 hr = 40 days = 5.7 weeks. This is seen to be equivalent to a crop size/barn capacity of about 115% which is smaller than shown to be optimum by the analyses in Table 5.

For tobacco harvesting, and probably for most crops, K has a larger value away from the optimum than near it. Large values of K indicate that crop value changes rapidly with time and when substituted into equation 1 yield higher optimum equipment capacities which in turn are associated with the capability of harvesting the crop rapidly. Since K is dependent on the width of the interval over which it is evaluated, the harvest duration given by the equation should be compared to the interval over which K was evaluated. If they differ appreciably, K should be reevaluated over a different interval and substituted back into the optimization equation until the harvest interval and the

evaluation interval are similar.

In the above example K was evaluated over a 3 week harvest delay while the solution gave a curing system capacity large enough to cure the crop with no more than 1 week delay. Reevaluation of K for a 1.5 week period from Figure 1 gives a value of .0016797. Substitution of this value in the optimization equation instead of the previous value gives a barn capacity of 22.6 Kg/hr for a curing season of 6.58 weeks. This is a barn loading factor of just over 130% or only slightly smaller than the 140% suggested by Table 5. Maximum harvest delay would be 1½ weeks which is the interval over which K was evaluated.

Let us now determine the response of the model to the addition of preoptimum harvesting, that is let X take on a value of 4. In order to do this it is necessary to evaluate K,the crop loss factor in the preoptimum range. A weighted average over the range - 1 week to + 1½ weeks gives a value of .06311 for K. Changing K and X in equation 1 to the above values, the optimum barn capacity becomes 21.86 Kg/hr for a harvest season of 6.81 weeks. This is only slightly larger than the 6.58 weeks found without preoptimum harvesting. Thus it is apparent that crop loss with preoptimum harvest is so large that the model essentially rejects preoptimum harvesting.

It should be mentioned that actual optimum harvest time may occur before the visual or accepted optimum time. In fact, Canadian growers because of frost hazard do successfully harvest at an earlier stage of ripeness than commonly practiced in the U.S.

Table 5. Relationships Between Crop Size, Curing Capacity, Harvest Delay-Crop Value and Curing Barn Costs.

Crop Size Kg/Barn	Crop Size / Barn Capacity %	Number of Cures or Weeks in Harvest Season	Amount of Delayed Harvest and Reduction in Crop Value			Annual Costs for Barns to Eliminate Harvest Delay $		
			1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks
6640	100	5	0	0	0	0	0	0
7304	110	5.5	25% $54	0	0	126	0	0
7968	120	6	50% $116	0	0	252	0	0
8632	130	6.5	55% $140	11% $72	0	274	105	0
9296	140	7	49% $134	26% $183	0	294	210	0
9960	150	7.5	40% $117	33% $249	7% $102	316	225	90
10624	160	8	32% $100	32% $257	18% $279	336	241	180

Literature Cited

1 Agricultural Engineering Yearbook. Agricultural Machinery Management, Page 274. 1978

2 Cundiff, J.S. and Paul Sumner. Fan Cycling and Energy Savings. Energy and Bulk Tobacco Barn Seminar. Myrtle Beach, S.C., Nov. 14-15, 1977.

4 Hunt, Donnell. Farm Power and Machinery Management. Page 247. Iowa State University Press, Ames, Iowa, Sixth Edition 1973.

5 Suggs, C.W. Effect of Harvest Schedule on Yield, Value, and Chemical Characteristics of Flue-Cured Tobacco. Proceedings 31st Tobacco Chemist's Research Conference, Page 4. Greensboro, N.C., Oct. 1977.

6 Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco, Part 7. Machine Filling, Handling and Curing in Large Bulk Containers. Tob. Sci. 21:51-56, 1977.

7 Watkins, R.W. Mechanization, Page 70. Section in 1979 Tobacco Information by Collins, W.K., S.N. Hawks, F.H. Todd, W.F. Congleton, R.W. Watkins, and C.R. Pugh. N.C. Agri. Extension Service, 1978.

3 Glover, J.W. Air Handling in Bulk Tobacco Barns. Energy and Bulk Tobacco Barn Seminar, Myrtle Beach, S.C., Nov. 14-15, 1977.

~~Please Use Numbers on References~~

8 S. Yang, K.P.

Figure 1a. Effect of box height and air flow on curing costs, 5¢/Kwh for electricity.

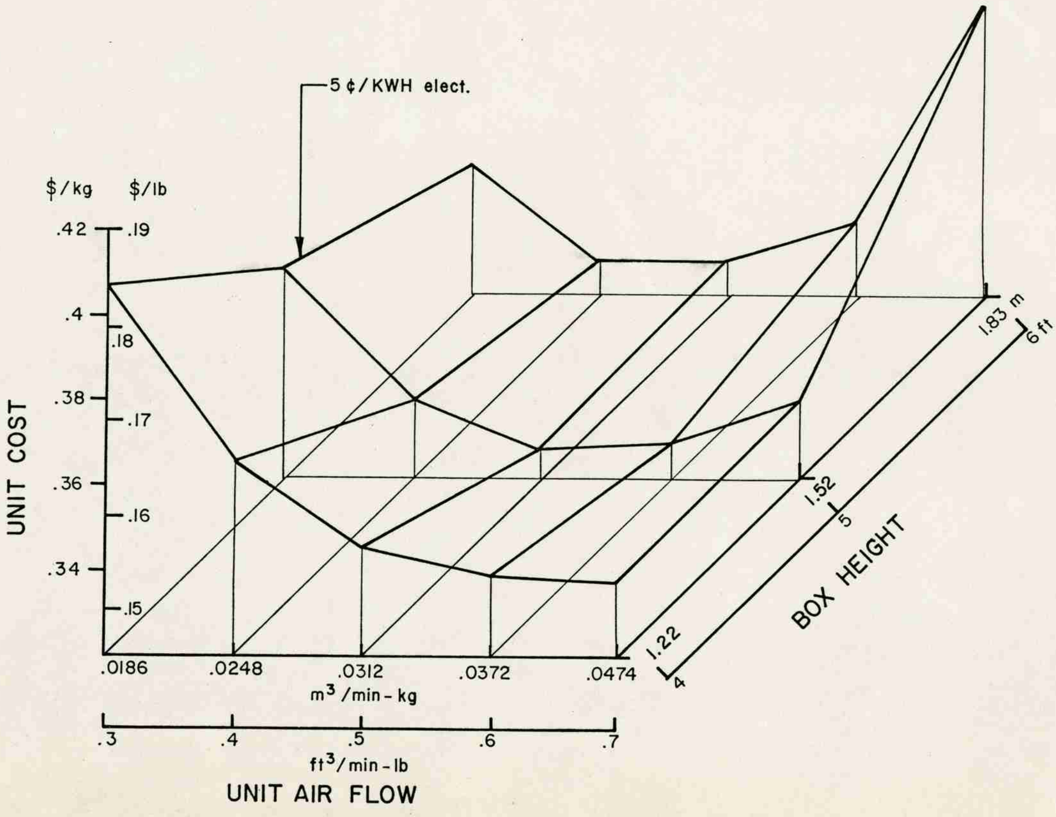
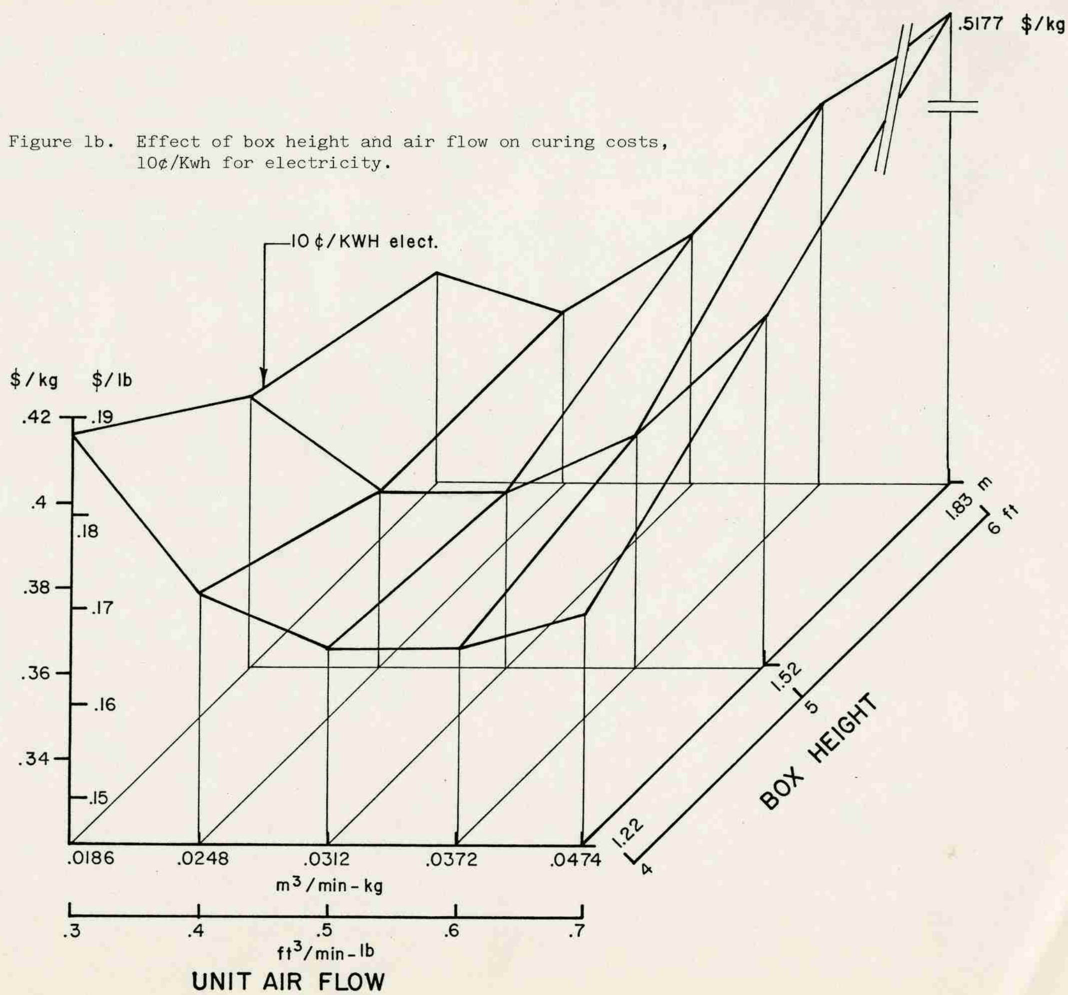


Figure 1b. Effect of box height and air flow on curing costs, 10¢/Kwh for electricity.



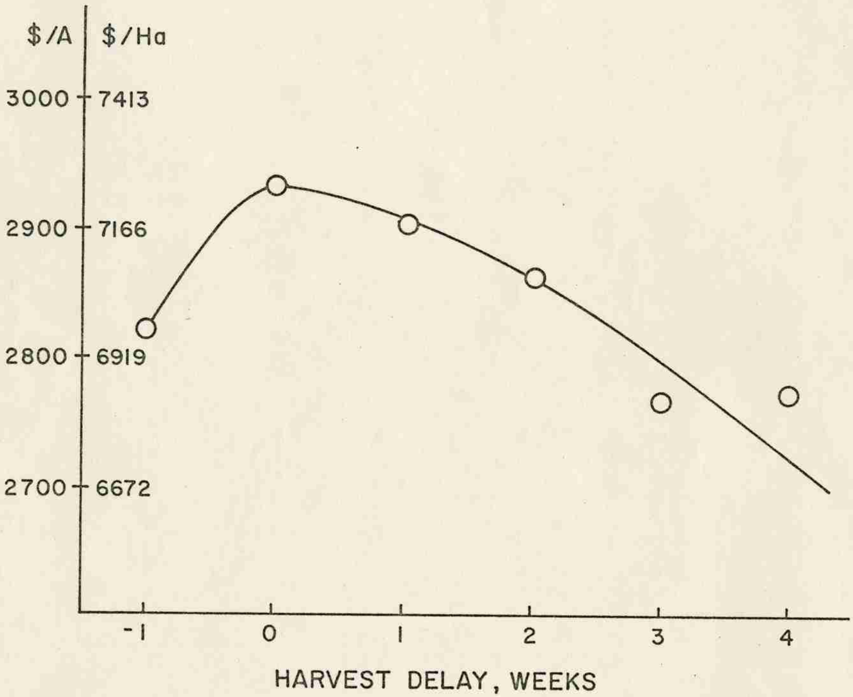


FIG. 2. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.

Table 1. Effect of Curing Box Height on Capacity, Air Flow and Pressure Requirements, Barn Costs, Fan Power, and Total Cost Per Kilogram of Tobacco Cured. Flow = .0312 m^3/min Kg (.5 cfm/lb). Duct Loss from Glover, 1977.

Box Height		Capacity	Weight @ 208 Kg/m^3	Flow Per Box	Flow for 20 Box Barn With Losses	Air Pressure For Height	Air Pressure For Extra Flow, Prop. Box Capacity
m	ft	m^3	Kg	m^3/min	m^3/min	mm of H_2O	mm of H_2O
1.22	4	1.52	316	9.9	331 40% loss	10.2	0
1.52	5	1.90	395	12.4	435 42.7% loss	12.7	7.1
1.83	6	2.28	474	14.9	542 45% loss	15.2	19.0

Table 1. Cont'd:

Box Height	Air Pressure Duct Loss	Air Pressure Total for Barn	Fan Input Power	Box Costs	Fan and Motor Costs	Total Initial Barn Costs
m	mm of H_2O	mm of H_2O	KW	$	$	$
1.22	12.7	22.9	3.01	2500	250	8000
1.52	15.2	35.1	6.05	2875	290	8415
1.83	17.8	52.1	11.23	3250	444	8944

Table 1. Cont'd:

Box Height	Annual Barn Costs	Annual Electrical Cost 5-144 hr Cures	Annual Fuel Costs 5 Cures	Total Annual Expense	Annual Cured Weight	Unit Cost	
m	$	$	$	$	Kg	$/Kg	$/lb
1.22	1200	108	525	1833	5307	.3454	.1566
1.52	1262	218	690	2170	6638	.3269	.1483
1.83	1342	404	859		7961	.3272	.1484

Brenda - Can you re organize Table 1 & 2 & 3 as below.

	Box Height					
	m	ft	m	ft	m	ft
	1.22	4	1.52	5	1.83	6
Capacity, m^3	1.52		1.90		2.28	
Weight @ 208 Kg/m^3, Kg	316		39.5		474	
Flow per Box, m^3/min	9.9		12.4		14.9	
.						
.						
.						
Air Pressure, mm of H_2O						
For Height,	10.2		12.7		15.2	
For Extra Flow, Prop Box Capacity	0		7.1		19.0	
Duct Loss	12.7		15.2		17.8	
Total for Barn	22.9		35.1		52.1	
	17.0					
.						
.						
.						
Annual Barn Costs, $	1200		1262		1342	
.						
.						
.						
Unit Costs						
$/Kg	.3454		.3269		.3276	
$/lb	.1566		.1483		.1484	

ABSTRACT

Mechanical Harvesting of Flue-Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters

C.W. Suggs
N.C. State University
Raleigh, N.C.

Curing container height and air flow rate through the tobacco can be controlled by the selection of equipment and certain operational choices. These choices affect barn investment and operational costs, curing time and barn throughput. A curing system with boxes 1.52 m (5') was found to be cheaper in terms of investment and operating costs per kilogram of tobacco cured than systems using 1.22 m (4') or 1.83 m (6') boxes. An intermediate air flow of .0312 m^3/min-Kg (.5 cfm/lb) of green tobacco was optimum as higher air flows used excessive amounts of electric power to drive the fan and lower air flows reduced barn throughput. One of the important findings was that barn ownership costs were $30 to $36 per day of the curing season and represent one of the largest costs of tobacco production.

An analysis was run to determine the most economical trade-off between barn costs and loss in crop value with delayed harvest and curing. The effect of harvest delay on crop value was evaluated over a period of several years. The results of both an intuitive and a formal analysis indicated that harvest delays of 1 to 2 weeks,instead of a normal 5 week curing season, maximized crop income by reducing curing barn requirements more than they reduced crop value.

February 27, 1979

Senior Author's Copy

MEMORANDUM

To: Director of Research Date: 5/4/79

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Manuscript: For approval X (enclose 3 copies of text; 1 copy of photos and graphs) For your information ____ (enclose 1 copy)

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Author(s) C.W. Suggs

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April 20, 1979

Dr. Earl A. Wernsman, Editor
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Raleigh, North Carolina 27650

Dear Earl:

I am enclosing three copies of a paper entitled "Mechanical Harvesting of Flue-Cured Tobacco: Part 10 Optimization of Curing Capacity and Bulk Barn Parameters" which I would like you to consider for publication in Tobacco Science. In accordance with your suggestion made during the review of a previous paper, I am submitting an abstract but no summary.

The paper is supplied with xerox copies of the figures. Photographic prints will be supplied when needed. If there are questions please contact me.

Sincerely,

C.W. Suggs
Professor

CWS/bm

Enclosure