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ABSTRACT

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

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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.

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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). 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.________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 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, 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): $Kw = \frac{m^3/\text{min} \times \text{pressure (mm of } H_2O)}{2514}$. 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 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.

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	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		Fan Input Power	Box Costs	Fan and Motor Costs	Total Initial Barn Costs
	Duct Loss	Total for Barn				
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

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 as the cured capacity of a 20 box barn or 6638 Kg 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 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 and the longer column of tobacco to be dried. The most efficient air flow was .0312 m^3/min-Kg (.5 cfm/min).

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 diagnoal 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%

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*Barn capacity = 16 elements.

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

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

$$C = 26.21 \text{ Kg/hr}, \; 26.21 \text{ Kg/hr}/7.9 \text{ Kg/hr/barn} = 3.3 \text{ barns}$$

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

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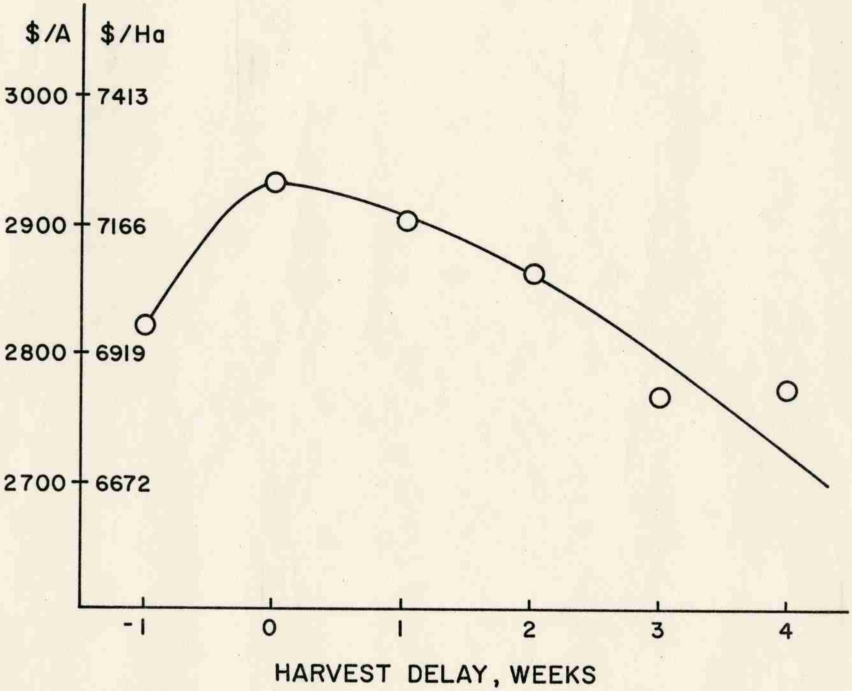
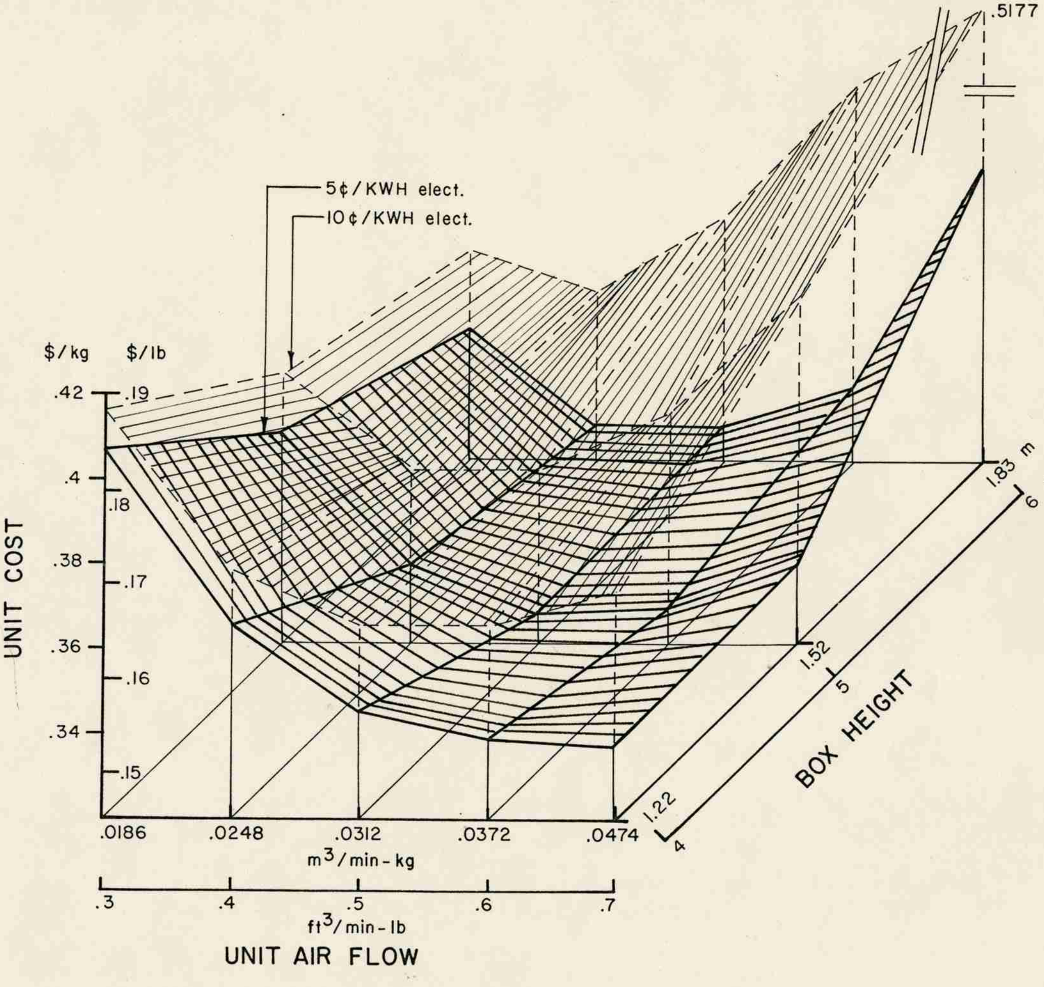
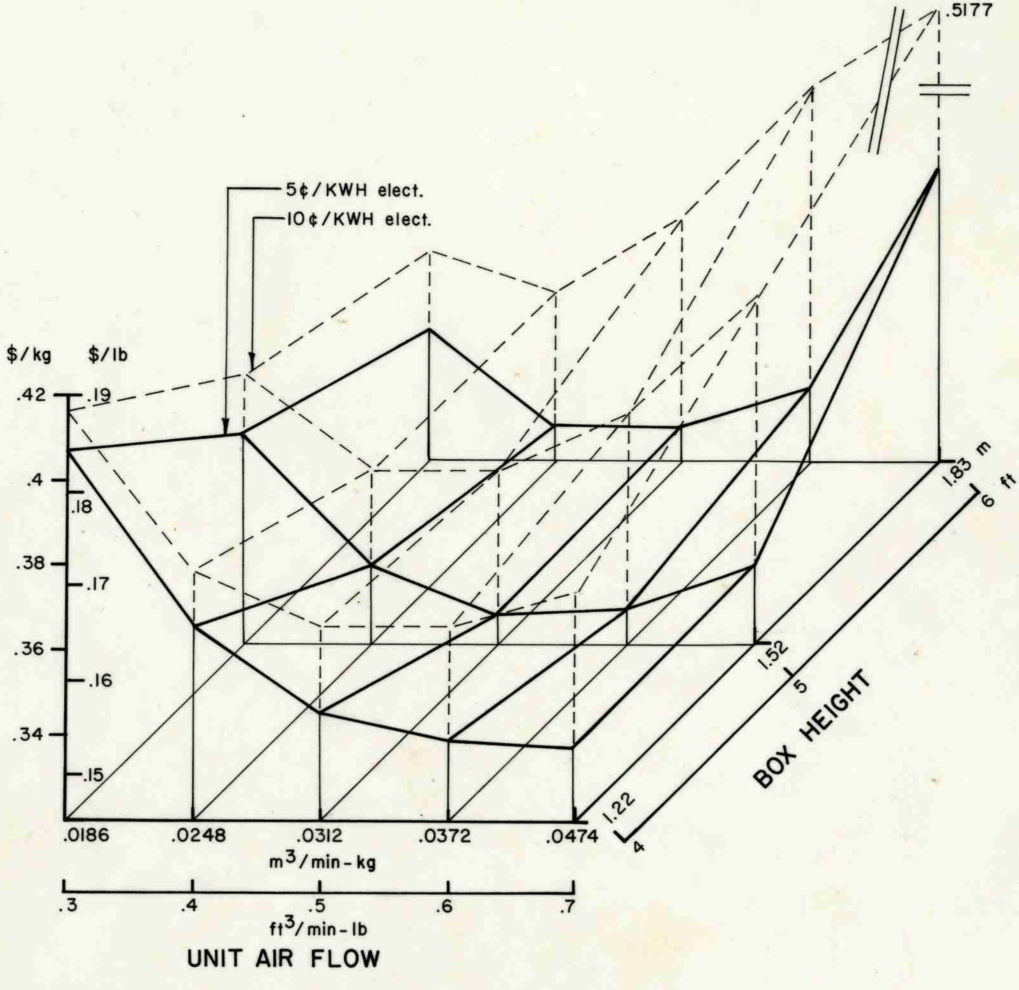


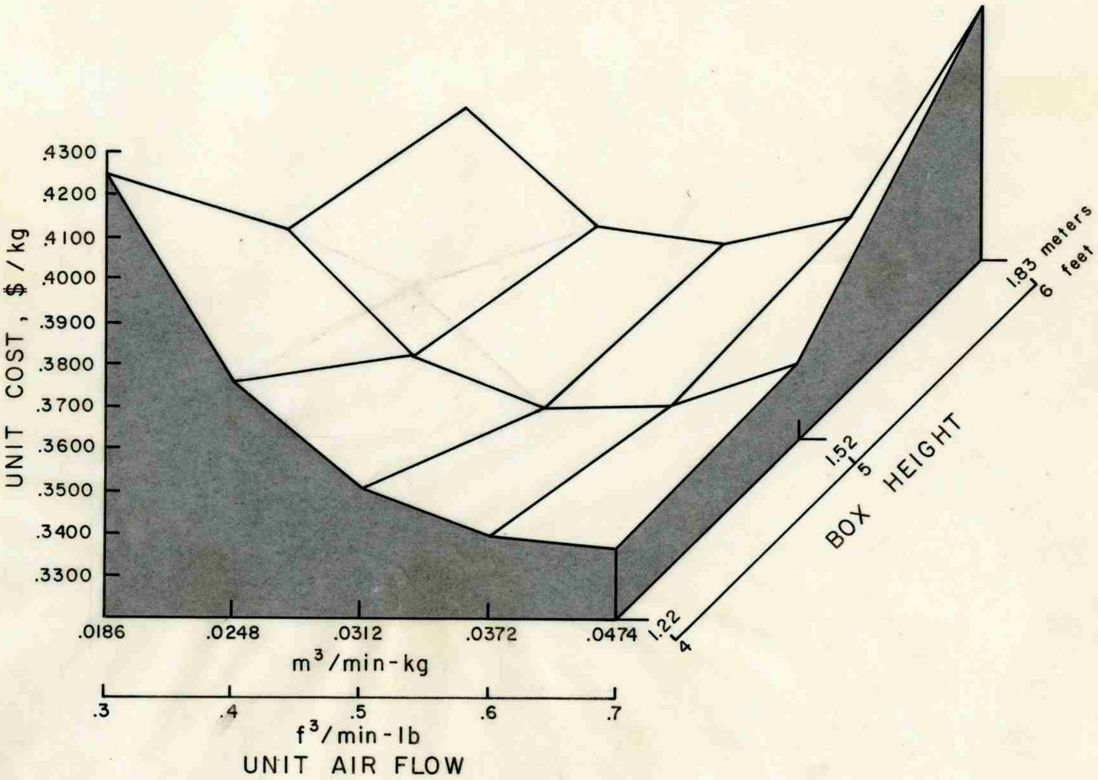
FIG. 2. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.


.5177
5¢/KWH elect.
10¢/KWH elect.
$/kg
$/lb
.42
.19
.4
.18
.38
.17
.36
.16
.34
.15
UNIT COST
.0186
.0248
.0312
.0372
.0474
m^3/min-kg
.3
.4
.5
.6
.7
ft^3/min-lb
UNIT AIR FLOW
1.83 m
6 ft
1.52
5
1.22
4
BOX HEIGHT

		Using 5¢/KWH elect			Using 10¢/KWH elect		
	Air Flow	Box Height			Box Height		
		4	5	6	4	5	6
.0186	.3	.4071	.3690	.3501	.4161	.3826	.3695
.0248	.4	.3656	.3389	.3279	.3792	.3806	.3592
.0312	.5	.3454	.3269	.3272	.3659	.3600	.3771
.0372	.6	.3351	.3276	.3366	.3663	.3744	.4080
.0436	.7	.3371	.3373	.3575	.3746	.4022	.5177



5¢/KWH elect.
10¢/KWH elect.
.5177
$/kg
$/lb
.42
.19
.4
.18
.38
.17
.36
.16
.34
.15
UNIT COST
.0186
.0248
.0312
.0372
.0474
m³/min-kg
.3
.4
.5
.6
.7
ft³/min-lb
UNIT AIR FLOW
1.83 m
6 ft
1.52
5
1.22
4
BOX HEIGHT



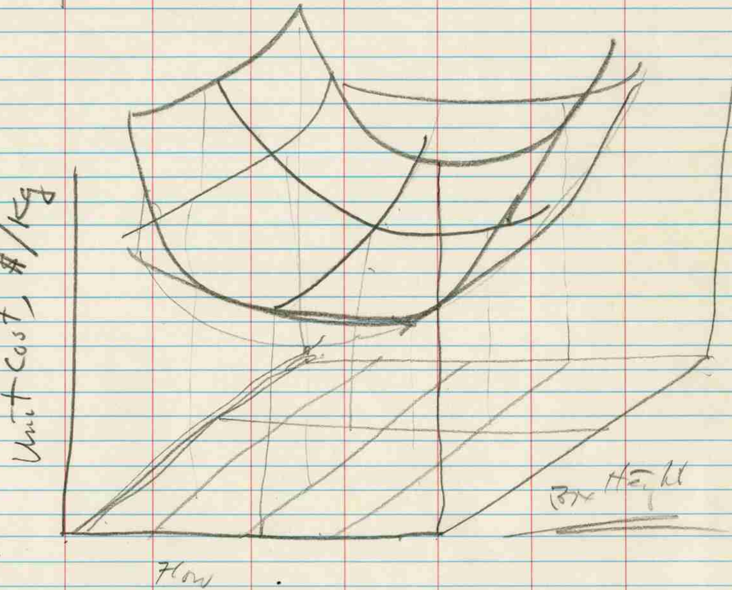
UNIT COST, $ / kg
.4300
.4200
.4100
.4000
.3900
.3800
.3700
.3600
.3500
.3400
.3300
.0186
.0248
.0312
.0372
.0474
m^3/min-kg
.3
.4
.5
.6
.7
f^3/min-lb
UNIT AIR FLOW
1.83 meters
6 feet
1.52
5
1.22
4
BOX HEIGHT

Unit Air Flow		Box Height			
m³/min-Kg	ft³/min-lb	1.22	1.52	1.83	Meters
		4	5	6	ft
.0186	.3	.4248	.3690	.3555	
.0248	.4	.3756	.3389	.3274	
.0312	.5	.3506	.3249	.3231	
.0372	.6	.3394	.3276	.3300	
.0434	.7	.3365	.3373	.3793	

#/Kg

32

.43



DEPARTMENT OF BIOLOGICAL AND AGRICULTURAL ENGINEERING

March 9, 1979

MEMORANDUM TO: ✓R.W. Watkins, Chairman
J. W. Glover
F.J. Hassler

FROM: F.J. Hassler FJHassler

SUBJECT: Manuscript Review

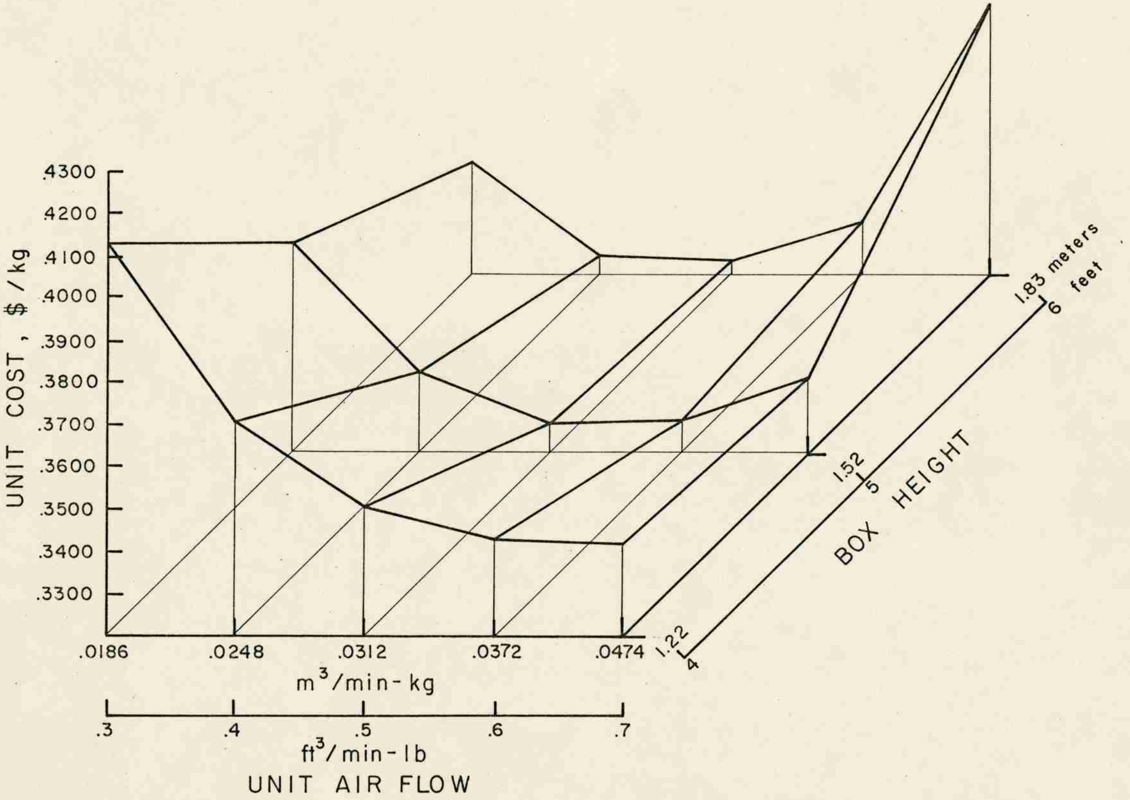
Please accept my request for you to serve as a review committee for the attached copy of manuscript, "Mechanical Harvesting of Flue-Cured Tobacco: Part 10. Optimization of Curing Capacity and Bulk Barm Parameters" by C. W. Suggs.

The manuscript has been prepared for publication in Tobacco Science.

You should work directly with the author(s) in your review process if needed; I would like a response from the Chairman about the suitability of the manuscript for publication.

encl.

cc: C. W. Suggs


.4300
.4200
.4100
.4000
.3900
.3800
.3700
.3600
.3500
.3400
.3300
UNIT COST, $/kg
.0186
.0248
.0312
.0372
.0474
m^3/min-kg
.3
.4
.5
.6
.7
ft^3/min-lb
UNIT AIR FLOW
1.22
4
1.52
5
1.83 meters
6 feet
BOX HEIGHT

~~before~~ about March 15

Air Flow

m3/min-kg	ft3/min-lb	Box Height 1.22 m 4 ft	1.52 m 5 ft	1.83 m 6 ft
~~.0186~~	~~.3~~	~~.4122~~	~~.3690~~	~~.3462~~
~~.0248~~	~~.4~~	~~.3707~~	~~.3389~~	~~.3240~~
~~.0312~~	~~.5~~	~~.3503~~	~~.3269~~	~~.3231~~
~~.0372~~	~~.6~~	~~.3431~~	~~.3276~~	~~.3327~~
~~.0434~~	~~.7~~	~~.3419~~	~~.3373~~	~~.3836~~

with 5¢/KWH elect. with 10¢/KWH elect

March 30

Air Flow		Box Height 4 1.22	5 1.52	6 1.83	4'	5'	6'
.0186	.3	.4071	.3690	.3501	.4161	.3826	.3695
.248	.4	.3656	.3389	.3279	.3792	.3808	.3592
.0312	.5	.3454	.3269	.3272	.3659	.3600	.3771
.0372	.6	.3381	.3276	.3366	.3663	.3744	.4080
.0434	.7	.3371	.3373	.3875	.3746	.4022	.5177

About March 15

	Unit Flow m³/min Kg	Box Flow m³/min	Box Pressure mm	Duct Loss mm	Total Fan Press mm	Bypass & Seepage %	20 Box Barn Flow m³/min	Fan Power KW	Drying Time Hr.	Total Curing time Hr	
4' box 1.22 m.	.0186	5.9	3.6	8.5	12.1	40	197	.95	140	200	316 Kg/box
	.0248	7.8	6.8	10.6	16.9	40	260	1.75	105	165	
	.0312	9.9	10.2	12.7	22.9	40	330	3.01	84	144	
	.0372	11.8	14.5	14.9	29.4	40	393	4.60	70	130	
	.0434	13.7	19.5	17.0	36.5	40	457	6.63	60	120	
6' box 1.83 m	.0186	8.8	12.1	11.9	24.0	45	320	3.05	140	200	
	.0248	11.6	21.0	14.9	35.9	45	422	6.03	105	165	
	.0312	14.8	34.2	17.8	52.1	45	538	11.15	84	144	
	.0372	17.6	48.4	20.8	68.8	45	640	17.51	70	130	
	.0434	20.6	92.2	23.8	116.0	45	749	34.56	60	120	

	Unit Flow m³/min Kg	Initial Barn Costs $	Annual Barn Costs $	Barn Costs/Cure $/Cure	Elect Costs @5¢/KWH $/Cure	Fuel cost @104 P M.T. $/Cure	Total Cost $/Cure	Unit Cost $/Kg.		
4' box – 1.22 m				317		105	437.49	.4122		1061.4 Kg/cure
	.0186	7938	1191	~~331~~	9.50	110.39	450.59	.4248		316 Kg/box
	.0248	7962	1194	~~274~~ 264	14.44	110.39	~~398.83~~ 393.58	.3756	.3707	
	.0312	8000	1200	240	21.67	110.39	372.06	.3503	.3454	720 hr
	.0372	8138	1221	~~220~~ 224	29.90	110.39	360.29 364.14	~~.3394~~	3431	
	.0434	8271	1241	~~207~~	39.78	110.39	~~357.17~~	~~.3365~~		
				212.74			362.91	3419		
6' box 1.83 m.				353.2			551.29	.3462		
	.0186	8875	1332	~~370~~	30.50	165.59	~~566.09~~	~~.3555~~		
				300.6						
	.0248	8901	1336	~~306~~	49.75	165.59	~~521.34~~ 515.94	~~.3274~~	.3240	1592.2 Kg/cure
	.0312	8944	1342	268	80.28	165.59	513.87	.3231	.3272	474 Kg/box
	.0372	9698	1365	~~246~~ 250.25	~~113.82~~	165.59	~~525.41~~ 529.66	.3300	3327	
	.0434	9247	1387	~~231~~	207.36	165.59	~~603.95~~	~~.3793~~	3836	
				237.77		172	610.72			
					21.50	105	366.6			
					80.50	171.8	521			1327.5

The ~~simultaneous~~ effects of box height and air flow are shown graphically by ~~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 ~~[illegible]~~ determined in a similar manner to these in the tables. A second surface, ~~is~~ shown in lighter lines above the main surface, is based on an increase in electrical costs from 5¢/KWH 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, ~~[illegible]~~, the taller box becomes more costly when electricity prices rise to 10¢/KWH. The most efficient air flow ~~[illegible]~~ was .0312 m³/min-kg (.5 cfm/min)

Some addition caution should be exercised with respect to the taller boxes ~~because~~ of the higher static air pressures required and the longer column of tobacco to be dried.

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 smallest container. For the two larger containers fuel costs were prorated on the basis of barn air flow. Cured weight was determined from the author's data as 16.7% of the input green weight of 208 Kg/m^3 (13 lb/ft^3). Costs for boxes not commercially available were determined by ~~dividing~~ alloc. the \$125 cost of a 1.22 m (4') box into \$30 for the bottom section, \$20 for the top and ~~\$0.74~~ .615/cm. /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:

$$Kw = \frac{m^3\text{/min x pressure (mm) of } H_2O}{4571.5 \text{ x fan eff.}}.$$

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. For the shorter box (\$.3454/Kg) the decrease in capital and operating costs did not compensate for the decrease in capacity. For the higher box (\$.3272/Kg) the increase in curing capacity did not compensate for the rapid increase in electrical requirements of the larger fan.

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

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 ~~volume~~ 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.

Disc

~~February 27, 1~~979

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 ~~about~~ 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). 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 ~~1000~~ 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 ~~them~~ the curing containers

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[1] Paper No.________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 size~~d~~ 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 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/~~min~~ 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 ~~higher~~ 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 ~~smallest~~ mid sized container. For the ~~two larger~~ 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 ~~dividing~~ allocating the \$125 cost of a 1.22 m (4') box into \$30 for the bottom section, \$20 for the top and \$0.~~74~~.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 = $\frac{m^3/\text{min x pressure (mm of } H_2O)}{\cancel{4571.5 \text{ x fan eff.}}\ 2514 \quad \cancel{6095.3 \times .75 \times .55}}$

~~Ref. Glover~~

~~Put 75% motor effic~~

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 ~~higher~~ taller box (\$.3272/Kg) (\$.1484) the increase in curing capacity did not quite compensate for the ~~rapid~~ increase in electrical requirements of the larger fan. It will be seen later in the paper that taller boxes and high air flows ~~rate~~ ~~and higher electric~~ ~~rates dramatically~~ 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 m³/min-kg (.5cfm/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 - box capacity
m	ft	m^3	Kg	m^3/min	m^3/min	mm of H2O	mm of H2O
1.22	4	1.52	~~316~~ ok	9.9	331 40% loss	10.2	0
1.52	5	1.~~89~~ 90	39~~3~~5	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

~~Glover~~

Table 1. Cont'd:

Box Height	Air Pressure Duct~~s~~ Loss	Air Pressure Total for Barn	Input Fan Power	Box Costs	Fan and Motor Costs	Total Initial Barn Costs
m	mm of H2O	mm of H2O	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 ha 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	2650 ~~2605~~	7961	.3272	.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 ~~it~~ 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 39~~8~~5 Kg (871 lb) of green tobacco, is analyzed. An average cured weight yield, from the author's data, of 16.~~67%~~ .8% gives 1327 Kg as the cured capacity of a 20 box barn or 6638 Kg 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 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), as they did for lower flow rates, $.3690/Kg ($.1673), giving another indication that barn ownership costs are the largest single item in curing costs.

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~~,~~ ~~and~~ 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 ~~falls~~ moves next to the highest flow rate.

~~check this~~ B

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, ~~when~~ 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) ~~Annual~~ 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 ~~Observations.~~ 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

~~Table 4.~~

~~Hrs~~

Costs

~~Stem take time today.~~

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 diagnoal 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 = 10 elements

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 ~~barn~~ cost of $1262 for a barn with 1.52 m (5ft) 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 for three-week delays, the crop loss is greater than the barn costs. The table seems to indicate that while ~~2~~ a two-week~~s~~ ~~of~~ 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 Values are for~~

the harvest before the optimum time. ~~Figure 1 shows how crop value varies with harvest schedule both before as well as after the optimum harvest time.~~ Preoptimum harvesting was not considered in the analysis tabulated in Table 5 because of the rapid decrease in value. ~~However, it was found in the course of the experimental work that the maximum crop value shown in Figure 1 occurred about one week before the "optimum" visual or subjective ripeness.~~ 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.

Repeat

Omit

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/~~ha~~ 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 ~~from Table 1~~ including 1.52m (5' 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-~~barn~~ 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 = ~~.13575P~~ .134 P ~~20%~~

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 ~~machine~~ 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 1 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 ~~varies depending~~ 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.

Again, 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

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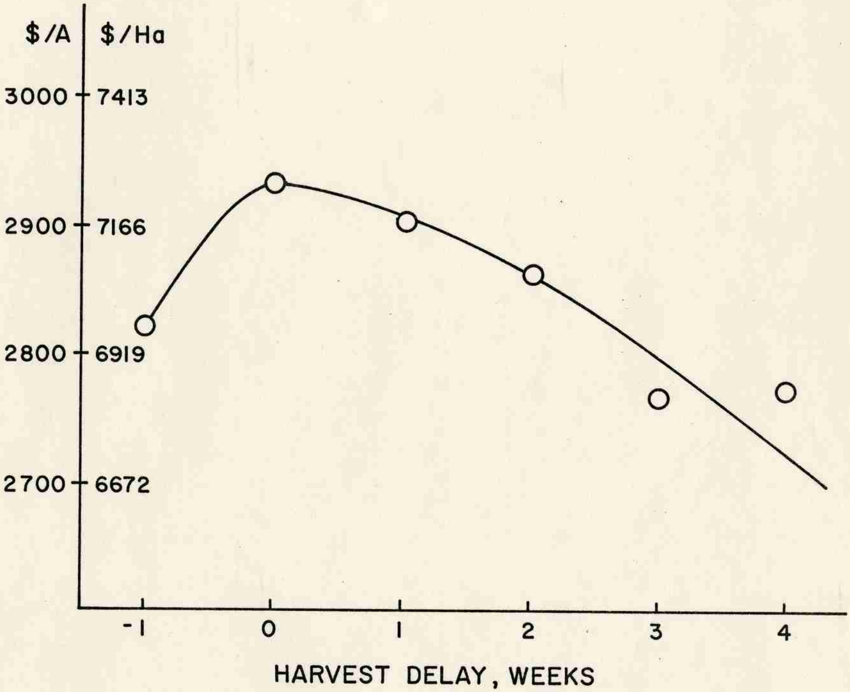

FIG. ~~1~~ 2. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.

Hassler

ABSTRACT

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

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Curing container height and air flow ~~volume~~ 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

Haske

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 ~~about~~ 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). 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 400 Kg to 1000 Kg (in english) 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 ~~them~~ The Containers (antecedent) ?

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[1] Paper No.________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 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/~~min~~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 ~~higher~~ boxes.

Barn costs including 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 smallest container. For the two larger containers fuel costs were prorated on the basis of barn air flow. Cured weight was determined from the author's data as 16.7% of the input green weight of 208 Kg/m^3 (13 lb/ft^3). Costs for boxes not commercially available were determined by ~~dividing~~ allocating the \$125 cost of a 1.22 m (4') box into \$30 for the bottom section, \$20 for the top and ? \$0.~~74~~ .615 per 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: $Kw = \frac{m^3/min \times pressure\ (mm)\ of\ H_2O}{4571.5 \times fan\ eff.}$. (mtr. eff. in coef.? why not fan eff. also?) 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. For the shorter box (\$.3454/Kg) the decrease in capital and operating costs did not compensate for the decrease in capacity. For the higher box (\$.3272/Kg) the increase in curing capacity did not compensate for the rapid increase in electrical requirements of the larger fan.

[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.

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
m	m^3	Kg	m^3/min	m^3/min	mm	mm
1.22	1.57	316	9.9	331 40% loss	10.2	0
1.52	1.89	393	12.4	435 42.7% loss	12.7	7.1
1.83	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 Power	Box Costs	Fan and Motor Costs	Total Initial Barn Costs
m	mm	mm	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 ha Cures	Annual Fuel Costs 5 Cures	Total Annual Expense	Annual Cured Weight	Unit Cost
m	$	$	$	$	Kg	$/Kg
1.22	1200	108	525	1833	5307	.3454
1.52	1262	218	690	2170	6638	.3269
1.83	1342	404	859	2605	7961	.3272

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 ~~it~~ 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 398 Kg of green tobacco, is analyzed. An average cured weight yield, from the author's data, of 16.67% gives 1327 Kg as the cured capacity of a 20 box barn or 6638 Kg 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), 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, for the middle flow rate, Table 2. Costs did not increase as rapidly with higher flow rates, $.3373/Kg, as they did for lower flow rates, $.3690/Kg, giving another indication that barn ownership costs are the largest single item in curing costs.

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, and 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 falls next to the 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, ~~when~~ 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.

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

Table 2. Cont'd:

Unit Flow	Fan 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
.0186	334	18	138	490	.3690
.0248	283	29	138	450	.3389
.0312	252	44	138	434	.3269
.0372	235	62	138	435	.3276
.0434	224	86	138	448	.3373

(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) Annual cured weight of 1328 Kg 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 Observations.

Unit Flow	Curing Time	Fuel Costs	Electricity Cost	Barn Costs	Total	Unit Costs
m^3/min-Kg	Hr	$/Cure	$/Cure	$/Cure	$/Cure	$/Kg
.0186	211	167	19	350	536	.4036
.0248	196	152	34	329	515	.3878
.0312	~~176~~ 144	138	54	300	492	.3705
.0372	162	128	78	284	490	.3690
.0434	154	118	111	277	506	.3810

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 diagnoal 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%

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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 1. 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.

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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 ~~2 weeks of~~ 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.

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repeat p. 12

The values in

the harvest before the optimum time. Figure 1 show~~s~~ how crop value varies with harvest schedule both before as well as after the optimum harvest time. Preoptimum harvesting was not considered in the analysis tabulated in Table 5 because of the rapid decrease in value. However, it was found in the course of the experimental work that the maximum crop value shown in Figure 1 occurred about one week before the "optimum" visual or subjective ripeness. If this result is dependable and not restricted to the 5 years of data summarized in Figure 1 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. 2

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/ha

L = labor costs, \$/hr

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

F =

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 from Table 1 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-~~barn~~ 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: ? used 20% on P.3.

.1175 (.8P) + .1(.2P) + .02P = .13~~575~~P .134

where .1175 is the cost recovery factor,

the second term is the interest on the salvage value of the ~~machine~~ 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. The timeliness factor, from the \$/ha value in Figure 1 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

$$C = \sqrt{\frac{25,000}{\underset{.134}{.\cancel{13575}} \times 1065}\ (.35 + \frac{.002334 \times 2.98 \times 25,000}{24 \times 2}} \qquad \cancel{(2)}$$

C = 26.~~21~~ .38 Kg/hr, 26.~~21~~ 38 Kg/hr/7.9 Kg/hr/barn = 3.3 barns

The time required to cure the crop would be 25,000 Kg/26.~~21~~ .38 Kg/hr or ~~954~~ 948 hr = ~~40~~ 39.5 days = 5.~~7~~ 6 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 ~~2~~ 1 yield higher optimum equipment capacities which in turn are associated with the capability of harvesting the crop rapidly. Since K ~~varies~~ is depend~~ing~~ent 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.

Again, 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

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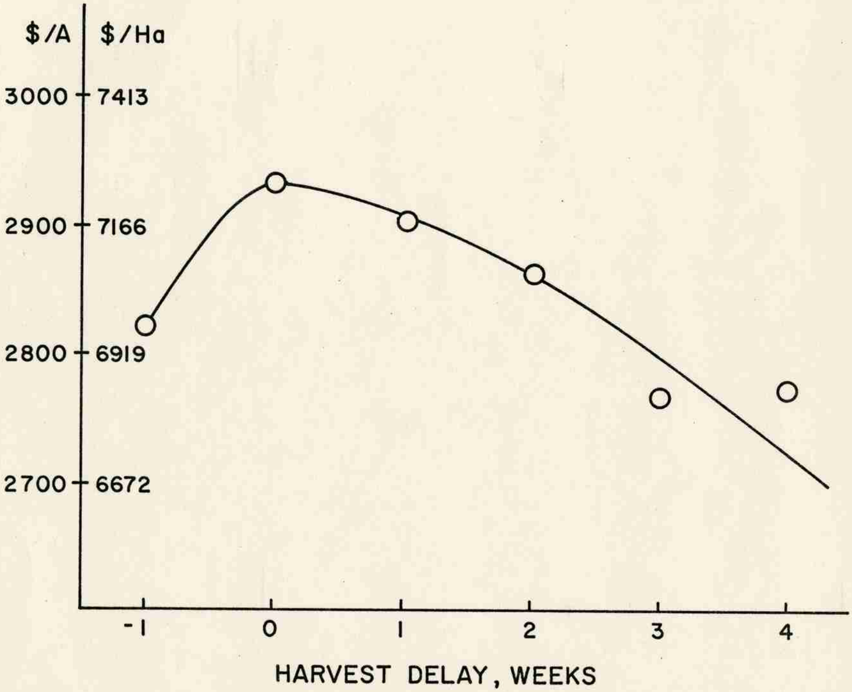

FIG. 1. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.

ABSTRACT

Glover

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 volume 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

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 about 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). 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 English 400 Kg to 1000 Kg 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 them

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[1] Paper No.________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 size 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 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/min). Air leakage around the container and seepage out of the barn was 43 in table 2 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 higher boxes.

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

? OK, but larger than normal

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 smallest container. For the two larger containers fuel costs were prorated on the basis of barn air flow. Cured weight was determined from the author's data as 16.7% of the input green weight of 208 Kg/m^3 (13 lb/ft^3). Costs for boxes not commercially available were determined by dividing the \$125 cost of a 1.22 m (4') box into \$30 for the bottom, \$20 for the top and \$0.74 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:

$$\text{Kw} = \frac{m^3/\text{min x pressure (mm)}}{4571.5 \text{ x fan eff.}}.$$

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.

Eff may also change?

High but O.K.

Results

Unit costs, Table 1, reflecting barn costs, electrical cost and fuel costs, were lowest for the 1.52 m box, \$.3269/Kg. For the shorter box (\$.3454/Kg) the decrease in capital and operating costs did not compensate for the decrease in capacity. For the higher box (\$.3272/Kg) the increase in curing capacity did not compensate for the rapid increase in electrical requirements of the larger fan.

English also

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

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 it. 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 398 Kg of green tobacco, is analyzed. An average cured weight yield, from the author's data, of 16.67% gives 1327 Kg as the cured capacity of a 20 box barn or 6638 Kg 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.

not shown in data

omit

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). 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, for the middle flow rate, Table 2. Costs did not increase as rapidly with higher flow rates, $.3373/Kg, as they did for lower flow rates, $.3690/Kg, giving another indication that barn ownership costs are the largest single item in curing costs.

BTU/lb H_2O ?

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, and 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 falls next to the 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, when priming intervals may vary significantly during the season the analysis of curing barn requirements is complicated.

For 5 ft boxes

Table 2. Effect of Flow Rate on Pressure, Fan Power, Curing Time, Fuel, Electricity, Barn and Unit Costs.

Cfm/ft² | Cfm/lb

5/lb →

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

Table 2. Cont'd:

Cfm/ft² | Cfm/lb

Unit Flow	OUTPUT Fan Power H.P.	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:

Cfm/ft² | Cfm/lb.

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
.0248	283	29	138	450	.3389
.0312	252	44	138	434	.3269
.0372	235	62	138	435	.3276
.0434	224	86	138	448	.3373

(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) Annual cured weight of 1328 Kg 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 Observations.

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

Better Table Label to reflect that this table is Field Experiment.

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 diagnoal 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 equals 10 elements

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 1. 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,barn capacity of 1328 Kg (2927 lb) per cure and an annual barn cost of $1262 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. 1. 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 all three week delays the crop loss is greater than the barn costs. The table seems to indicate that while 2 weeks of harvest 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.

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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

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

where

C = curing capacity, Kg/hr

w = size of crop, Kg

P = curing barn costs, $ per Kg/ha

L = labor costs, $/hr

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

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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 from Table 1 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-~~barn~~ 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 10% are:

$$.1175\,(.9P) + .1(.1P) + .02P = .13575P$$

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 machine 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. (\$/A) The timeliness factor, from the \$/ha value in Figure 1 is \$7250-\$6906/21 days = \$16.38/day-ha,

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

(/day-A)

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

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

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 2 yield higher optimum equipment capacities which in turn are associated with the capability of harvesting the crop rapidly. Since K varies depending 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.

Again, 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

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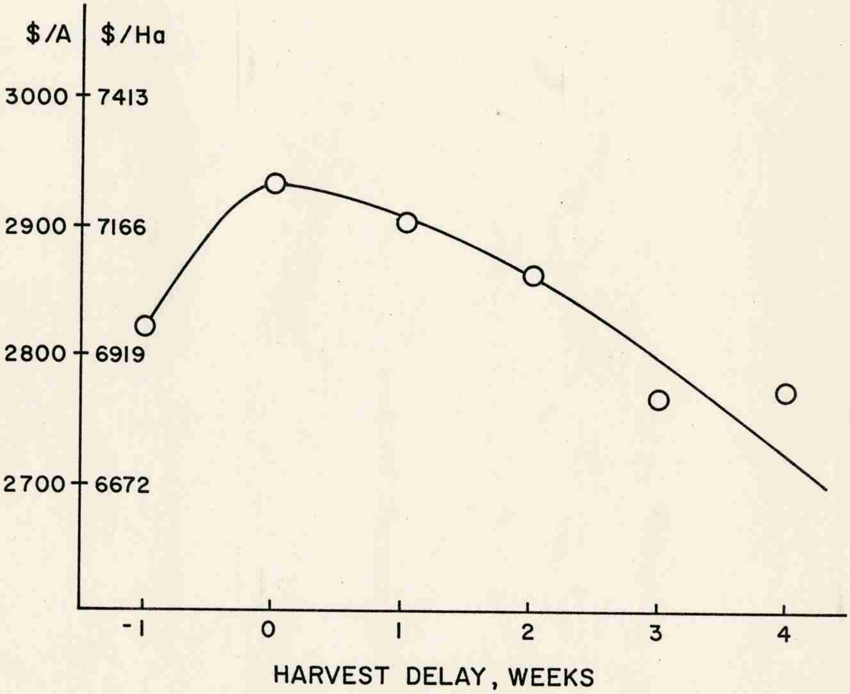


FIG. 1. EFFECT OF HARVEST DELAY ON VALUE OF FLUE-CURED TOBACCO CROP.

TOBACCO SCIENCE

May 1, 1979

Dear Dr. Suggs:

This will acknowledge receipt of your manuscript entitled,

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

This manuscript has been assigned the Registration No. ~~1208~~ 1209 which will identify it in any future correspondence.

Sincerely yours,

E. A. Wernsman, Chairman
Editorial Board
N. C. State University
Raleigh, NC 27650

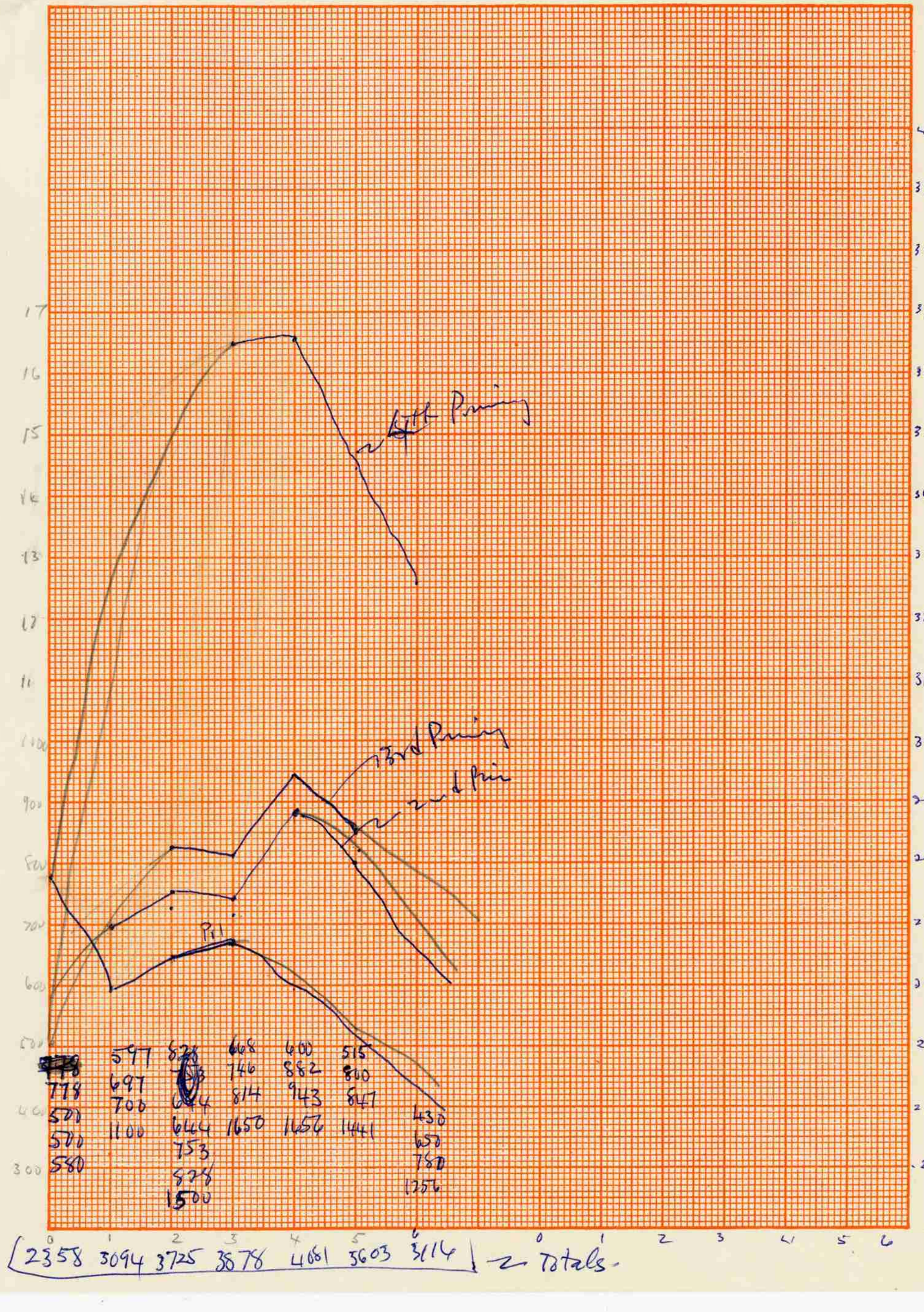
Dr. C. W. Suggs
Dept Biol. Agr. Eng.
186 Weaver Labs
NCSU Campus

Harvest schedule

Values by Primings

1978 Data

Trt #	Rep 1	2	3	4	Totals	Av.
1 1wk gr						
Pr ~~Rep~~ A	758	878	766	710	3112	778
Pr ~~Rep~~ B	776	550	728	734	2788	697
Pr ~~Rep~~ C	832	878	792	809	3311	828
Pr ~~Rep~~ D	1564	1814	1452	1771	6601	1650
2 Normal						
Pr A	559	487	503	838	2387	597
B	812	728	728	743	3011	753
C	818	778	852	809	3257	814
D	1885	1501	1985	1253	6624	1656
3 1wk aR						
Pr A	620	635	694	628	2577	644
B	784	724	787	687	2982	744
C	1097	759	959	957	3772	943
D	1590	1244	1408	1521	5763	1441
4 2wk aR						
Pr A	744	608	685	635	2672	668
B	835	702	809	1184	3530	882
C	940	674	827	948	3389	847
D	1313	1101	1365	1253	5032	1258
5 1wk gr.						
Pr A	702	766	886	838	3192	798
B	1126	744	614	1286	3770	942
C	1560	784	2250	1789	6383	1596
D		1409			1409	352



[2358 3094 3725 3878 4081 5603 3114] ← Totals.

Feb 15

				100 1	120 2	140 3
	1	2	3	1	2	3
100	0	0	0			
110	54	0	0	126		
120	116	0	0	252		
130	140	72	0	274	8.3% 105	
140	134	183	0	295	16.67 210	
150	117	249	102	316	17.86 22.5	.07.14% 9.0
160	100	257	279	336.	31.90 240	14.28% 180
170						160
	28	72	139			

~~optimum curing capacity would increase to 33.11 kg/hr for a curing season of 4.49 weeks. These values are realistic for once over harvesting but are small for the normal 4 or 5 priming multipass harvest as the crop normally ripens over a period of about 5 weeks. In fact, with enough curing capacity to handle the crop in 4 ½ to 5 ½ weeks there would likely be times when barns would be empty because ripe tobacco was not available.~~

The use of this equation and the results therefrom suffer some problems if interpreted to mean the per priming schedule. When the crop is harvested several times the first primings would be harvested nearly on schedule. Later primings would suffer progressively more delay.

The curve in figure _____ is based on the deviation of each priming from optimum harvest schedule. For example, for the point one week past optimum, each priming was removed one week after optimum ripeness. If we plot the change in crop value with harvest time for each priming and sum we should get some flattening of the value versus time curve in the vicinity of the optimum as some primings would increas~~ing~~e in

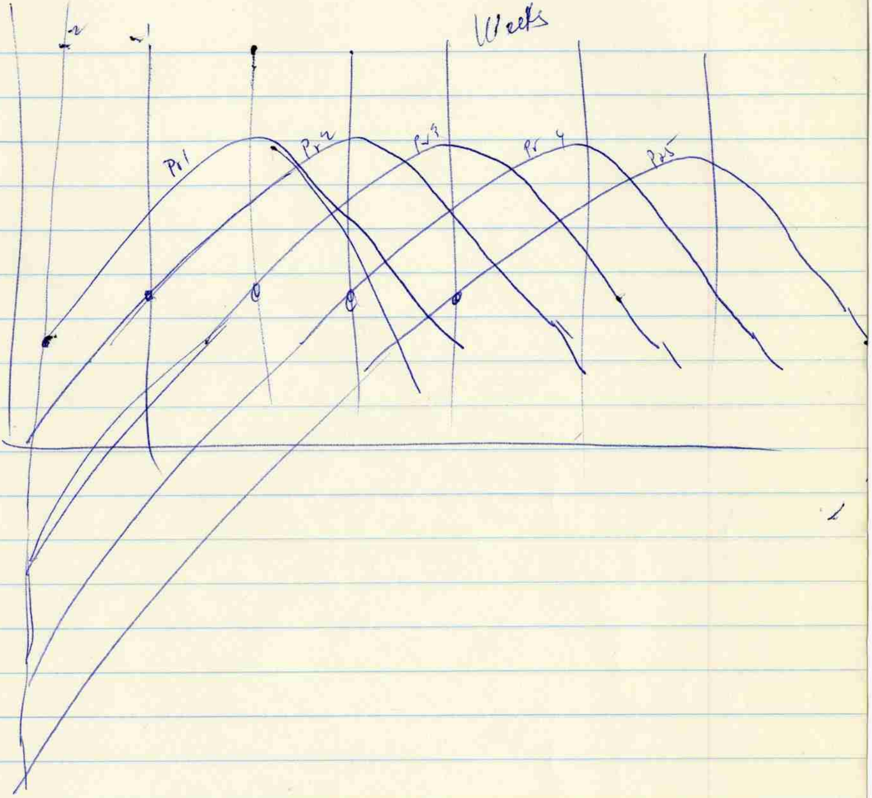
~~value whereas others would be decreasing. By this process we get a value of K = .003 from which we get a capacity of 23.48 kg/hr for a curing season of 1065 hrs or 6.34 weeks. This is in agreement with table 6.~~

If X is allowed to go to 4 indicating that the crop can be harvested both ~~equally successfully~~ pre-and post-optimum then ~~C is equal to~~ it will be necessary to evaluate the crop loss factor K over the ~~20.67 kg/hr or the harvest season is 1209 hrs = 7.20 weeks long.~~ While it is not traditional for U.S. growers to exercise very much pre-optimum harvesting, Canadian growers do successfully harvest at an earlier stage of ripeness because of frost hazards later in the season.

Although the harvest season is six to seven weeks long no primings would have to be made more than about one week from optimum ripeness because the crop normally ripens over a five week period. Because the formula restricts the harvest to near the optimum ripeness it is appropriate to evaluate K in the vicinity of the optimum.

For K = .00138 evalued over the interval one week each side of optimum, C = 16.84 Kg/hr, or the harvest season is 1484 hours or 8.83 weeks long.

1978



2650	2826	2934	2906	2862	~~2768~~ 2795	2725	2652	2576		
	265	2826	2934	2906	2862	2795	2725	2652		
		263	2826	2934	2906	2862	2795	2725		
			2650	2826	2934	2906	2862	2795	2725	
			2450	2650	2826	2934	2906	2862	2795	2725
			2753	2836	2865	2844	2788	2722		

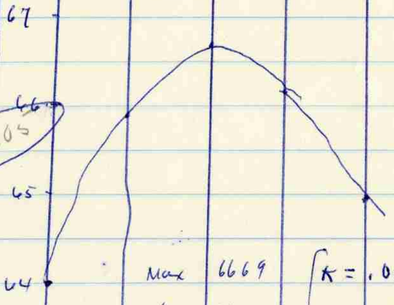
5799	6100	6402	6703	7005	6747	6489	6231	5973			
	5799	6100	6402	6703	7005	6747	6489	6231	5973		
		5799	6100	6402	6703	7005	67x7	6489	6231	5923	
			5799	6100	6402	6703	7005	6747	6489	6231	5973
				5799	6100	6402	6703	7005	6747		
				6402	6591	6669	6635	6489			

2565
2836
29

21

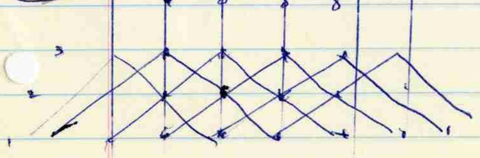
2844
2788
56
21
77

40
14



K = .0016678.05

18.1936 Kg/hr
8 to 18 weeks



Max	6669
-7 days	6591
+7 days	6635
-K	.001671
+K	.000728

K = .000728, X = 2, Capacity = 16 Kg/hr, = ~~9~~ 9.3 week harvest season

K = .001671, X = 2 Capacity = 22.54 Kg/hr, , 6.596 week harvest season

Composite ~~Yield~~ Value vs Harvest schedule

Feb 14-79

$/A - Actual
$/A - 1978 prices

	$1.17/lb 1976	$1.07/lb 75	$.98/lb 74	$.89/lb 73	78	Av.	lb/A
2 weeks gr	1935 2229	1949 2459	3349 3035 3192	2386 2356 2371	3919 3716 3881	2826 ~~2344~~	2093
1 week gr	2058 2376	2029. 2560	2455. 3378	1587 2407	3953 3953	2934	- 2173 lb.
optim.	2159 2487	1970 2486	2347 3229	1652 2506	3824 3824	2406.	2153
1 week OR	2296 -2644	1630 2057	2061 2835	1978 3000	3774 3774	2862	2120
2 weeks OR	2195 2528	1523 1922	2351 3234	1632 2475	3656 ~~3656~~ ~~3683~~ ~~3654~~	2768	not on line
3 weeks OR	1990 2292	1808 2281	2785 3144	1638 2485	3672	~~2550~~ 2775	
4 weeks OR					3662 3662		

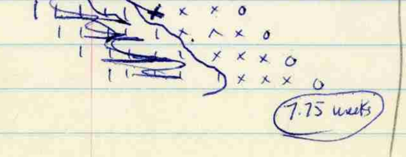
94% check

Ref $1.35/lb in 1978

K Values

	~~Yr~~ 76	75	74	73	78	
Max	2644	2660	3378	not usable	3953	
-7	2487	2459	3192		3881	
+7	2528	2486	3229		3850	
-K	.00848	.00564	.00787		.00260	.00615
+K	.00627	.00413	.00690		.00372	.00526
AvK	.00737	.00488	.00738		.00316	.00570

3710
3448
$262 for b Hoor hours



For K = .00526 & ~~X~~ = 2 Capacity is 38.37 Kg/hr or harvest time is 3.878 weeks - this is the time to harvest one priming -

For K = .0057 X = 4 capacity is ~~28.73~~ 39.88 Kg/hr or harvest time is ~~5.18~~ 3.731 weeks -

		500	400	300 ↓	258	343	431	574	
1st	~~6000~~ 5800	6302	6703	7005	6747	6404	5973	5457	
2nd		5800	6302	6703	7005	6747	6404	5973	
3rd			5800	6302	6703	7005	6747	6404	5973
4th				5800	6302	6703	7005	6747	6404
5th					5800	6302	6703	7005	
					6511	6632	6566	6317	

$-K = .002468$

$+K_{1 week} = .001346$

$+K_{2 weeks} = .0032$

$+K_{10.5 days} = .002026$

139 209
72 139
67 70 73, 76 79

115

K = .0080~~8~~8339

65

	0	1	2	3	4	5	6	7	8	9	
1st	1660 1785	1910	2030	2030	1965	1910	1845	1780	1715		
2nd	1535 1660	1785	1910	2030	2030	1965	1910	1845	1780	1650	
3rd	1535	1660	1785	1910	2030	2030	1965	1910	1845	1715 1780	1650
4th		1535	1660	1785	1910	2030	2030	1965	1910	1845	1715 1780
5th			1535	1660	1785	1910	2030	2030	1965	1910	1845 1715 1780
		1660	1784	1883	1944	1969	1956	1906	1843	1780	1715

K = .00138

.00311978

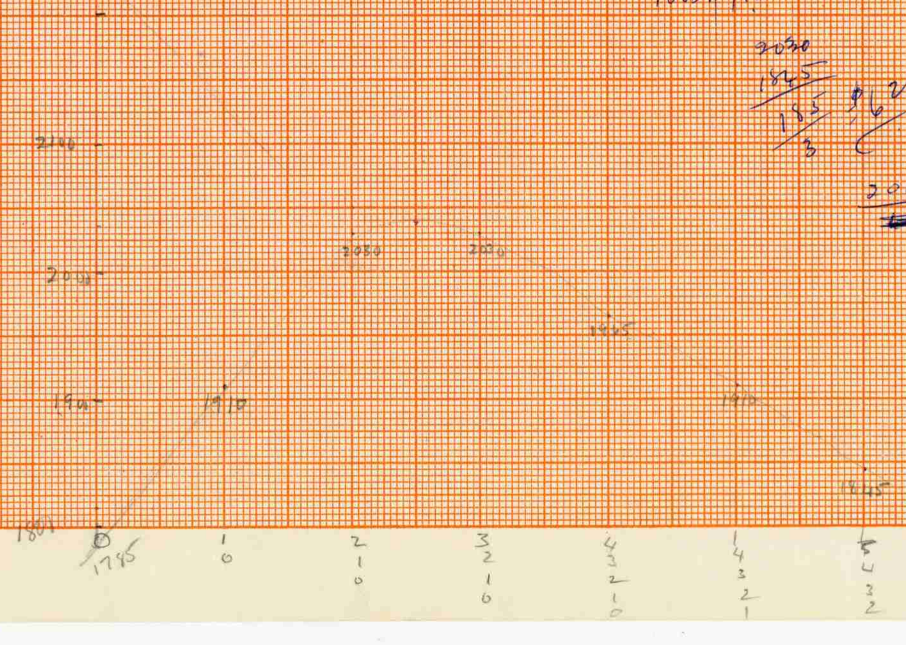
K .003047

2030
1845
185
183
3
$62/week

$\frac{2040}{[illegible]}$ = .0042

2015
1715
300
300/5 = $60/week

60/7 = $8.57/day



MECHANICAL HARVESTING OF FLUE-CURED TOBACCO. PART 5. FACTORS AFFECTING RATE OF ADOPTION[1]

By CHARLES W. SUGGS[2]

Economic analyses utilizing machine costs and labor reductions give breakeven acreages of 16 to 50 acres depending on the assumptions concerning labor wage rates, machine expenses and the amount of labor saved. Since flue-cured tobacco allotments average only three acres each, considerable redistribution of acreages will be required if mechanization is to become widespread. Ease and convenience of operation, reduction of drudgery and the possibility of expanding the tobacco acreage or adding new enterprises as labor requirements and management stress are reduced also affect the decision to mechanize. Peanut harvesting, mechanized in the ten years between 1956 and 1966, was similar to flue-cured tobacco in the ratio of breakeven acreage to acreage of the average farming operation, the machinery investment per dollar of crop value and the percent labor reduction. The investment per dollar's worth of labor saved was $11.60 for peanuts but only $7.80 for tobacco. It was concluded that mechanical harvesting and bulk curing are economically feasible. Subject to such factors as machine and barn availability and cost, capital supply, machine evolution and allotment fluidity, mechanization rates similar to those found in peanuts can be expected with as much as 20% of the crops being mechanically harvested by 1975.

One of the primary factors which determines the adoption of a new production technology is economic in nature. However, other factors, especially in the case of agricultural systems, may be as important or perhaps more important than costs and returns. For example, studies of corn pickers revealed that field losses averaged more than 10% and often ran as high as 20% or even more (11). Picker-sheller losses have been estimated by Burrough and Harbage (2) to be about 13%. At the classical Midwest hand picking rate and the prices in effect at the time corn pickers were introduced and accepted the crop could have, in many cases, been hand picked for the value of the field losses. When machine costs are added to the value of the field losses, the direct economic incentive for machine harvesting becomes very obscure and the reasons for mechanization must be sought elsewhere. For example, some factors which may have been important are labor drudgery, timeliness of operation and management stress. A more detailed discussion of these relationships by Horne (3) separates the factors which affect the financial returns of new machinery from those which influence operational ease, convenience, dependability and capacity.

The objective of this paper is to examine, analyze and discuss the factors which are expected to affect the mechanization of flue-cured tobacco harvesting.

DESCRIPTION OF SYSTEM

Machine Background

Mechanical harvesters for flue-cured tobacco were developed in the Biological and Agricultural Engineering Department at North Carolina State University during the 1950's and early 1960's. Machines based on this work first became available commercially in the 1960's but were not accepted by farmers, partially because of marginal machine reliability and performance but primarily because the random leaf (unaligned) output was not acceptable to the market. Hand alignment of the mechanically harvested leaf was not feasible because of high labor costs. In the late 1960's the University made farm-scale lots of mechanically harvested random leaf available to the tobacco trade for their examination, purchase and evaluation. Buyers found that they could accurately estimate market value and process random leaf without difficulty and dropped their earlier objection to it. Warehousemen and government graders concurred in this action. With this development, several harvesters were farmer operated in 1971. This increased to approximately 50 machines in 1972, to about 350 in 1973. For 1974, the total should increase to approximately 1400 machines.

Machine Operation and Capacity

Mechanical tobacco harvesters are high clearance, one-row-harvest, two-row-straddle machines capable of operating at field speeds up to 6 mph. Depending on ground speed and the number of leaves being removed per stalk, harvest rates may be as high as 6000 lb/hr of uncured leaf. Average season harvesting rates are somewhat lower because field speeds are slower when harvesting the lower leaves and because both upper and lower leaves are usually smaller than midstalk leaves.

Machine capacity was initially predicted to be about 5-6 acres per day or about 30-35 acres per week. Weekly capacity was also taken to be the yearly capacity as a field is reharvested at approximately weekly intervals throughout the harvest season instead of in a once-over operation. Estimates of machine capacity were conservative and examples of farmers harvesting 60 acres with one machine are now available.

Mechanical harvesters are best used with bulk barns because of the random leaf output of two of the three machine brands available. It has been demonstrated both experimentally and on-farm that random leaf can be bulk cured without degradation of quality (7).

ECONOMIC ANALYSES

Previous Economic Reports

Several analyses have been made comparing hand harvesting of flue-cured tobacco with mechanical harvesting (3,5,1,8). These reports vary somewhat in the assumption made concerning machine cost, life, oper-

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[1] Approved for publication as paper number 4046 in the journal series of the North Carolina Agricultural Experiment Station. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Experiment Station of the products mentioned nor criticism of similar ones not mentioned. [2] Professor, Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, N.C. Contribution received May 18, 1973: Tob. Sci. XVIII: 30-33, 1974.

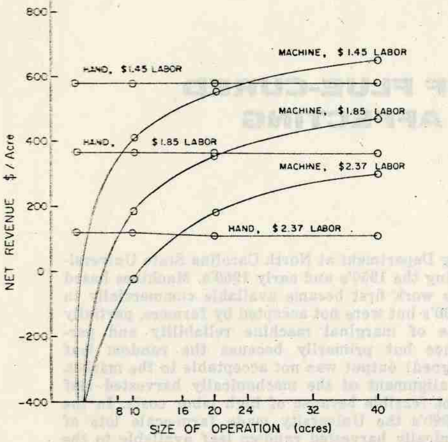

Figure 1. Effects of wage rate and size of operation on net revenue from hand and machine harvested tobacco. (Grise and Gavett)

ating speed, wage rate and labor saved. These analyses also vary with respect to the assumptions about existence of bulk barns and the condition of existing stick barns. These reports are in general agreement, however, and give breakeven acreages of 16 to 50 acres. Analyses which assumed that the farmer had serviceable conventional barns and was using a stitching machine gave high breakeven acreages. This indicates that the partial mechanization afforded by the stitcher is very efficient.

An analysis by Grise and Gavett (5), shown graphically in **Figure 1**, illustrates the effects of size of operation and wage rate on net revenue and the breakeven point of machine versus hand methods. This analysis assumed a change from conventional barns with hand looping and hand priming to mechanical priming and bulk curing.

The use of bulk barns with hand priming affords a significant amount of profitable mechanization as evidenced by the number of bulk barns sold before mechanical harvesters were adopted. However, because labor for priming is less readily available than for barning, the need for the mechanical harvester is greater than the labor savings indicate. Bulk curing and mechanical harvesting complement each other to form an efficient system. Because of this interdependency they will be considered together in much of the following discussion.

Machine Life, Costs and Capacity

While tobacco harvesters have not been commercially available long enough for them to wear out, some estimate of their useful life may be made by studying other machines. The replacement market for peanut combines in the U.S. is about 1500 machines per year[3] With a peanut combine population of about 10,000 machines the average life is 10,000/1500 or about 7 years. Grain combine life is about the same for peanut combines. These estimates plus an evaluation of the engineering design of tobacco harvesters suggests that tobacco harvesters should also have an average useful life of about 7 years.

Machines currently sell for about $15,000 and bulk barns sell for about $1000 per acre of capacity. Thus a 60 acre operation would require a capital outlay of $75,000.

Labor Distribution

A machine capacity of 60 acres has been demonstrated. This could be increased by more efficient utilization of machine time including the running of two or more shifts of operating crews. While the use of two machines rather than two shifts would reduce the hazard of crop loss due to machine breakdown the additional machine cost probably could not be justified.

Wage Rates and Labor Savings

As wage rates increase, mechanical harvesting can be justified on smaller acreages. Studies generally indicate that an increase in wage rates from $1.50 per hour to $2.50 per hour decreases the breakeven acreage by about 40%.

With mechanical harvesting, bulk curing labor requirements are about 96 hours per acre less than for hand priming-hand stringing (3). Labor requirements are only about 61 hours per acre less than for hand priming-machine tying and 32 hours less than for hand priming-bulk curing.

Size of Operation

If a harvester can be justified only on relatively large tobacco operations, considerable redistribution of tobacco acreage will be necessary if widespread mechanization is to occur. ASCS data for all flue-cured belts indicates an average allotment of about three acres. Only about 1.5% of the allotments equal or exceed the lower breakeven point of 20 acres. Thus, it is evident that allotments must be combined into larger operating units if widespread mechanical harvesting is to be realized.

A significant proportion of tobacco allotments are already being combined into single operating units. Once this was limited to cash rent, tenant and share crop arrangement. Now poundage lease and transfer accounts for most allotment combinations. In contrast to an average allotment size of approximately 3 acres, operating units average approximately 12 acres.[4] It is expected that some custom harvesting will be used as one means of aggregating efficient size units.

Tobacco production is characterized by large, unevenly distributed labor inputs. About 145 hours of the 246 hour total required per acre comes in the six-week harvest period. Most farmers, therefore, depend on hired labor for harvesting because they do not have on-farm work for such large amounts of labor the rest of the year. Sometimes laborers are hired year around in order to insure their availability during tobacco harvest. When this is done, harvesting labor cost is usually greater than the nominal rate times the number of hours worked because workers are

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[3] *John Barrows, Harrington Manufacturing Company, Lewiston, N.C., private communications.*

[4] *Charles Pugh, N.C. State University, private communications.*

employed in less productive jobs during the off-season. For this reason harvest crews often consist of housewives, children, students and individuals on vacation from other jobs. While such crews may work for less than average wage their productivity may fall below average.

Hand priming is a particularly strenuous task because of the high heat stress and the physical stress due to the stooped position. It is difficult to find workmen willing and able to work under these conditions.

A field crew to match the capacity of the barn crew must be available. A field crew under or over-sized results in lost efficiency. Farmers invest a significant amount of time in recruiting crews and keeping them working. Reduction of crew size in itself, independent of labor cost reduction, is an important factor in the mechanization of tobacco harvesting.

Machine Evolution

Economic analyses, almost of necessity, tend to freeze a machine in time and space, but often allow evolution of wage scales. This tends to underestimate the advantages of mechanization because machines usually evolve rapidly immediately after their introduction. Such evolution results in increased capacity, further labor reduction, greater dependability and often in labor saving and cost reducing breakthroughs in related operations.

Returns to Management

Returns per acre may not be a suitable criterion of the justification for mechanizing. Farm operators are interested in the total returns to management. Thus, if mechanization reduces the stress and demands on management so that the size of the operation can be increased, it may be possible to justify mechanization even when per acre returns are reduced by mechanization. This reasoning appears to be present among many farmers who are presently considering the purchase of tobacco harvesters.

Manufacturing Capacity

The capacity of industry to manufacture machines can be an important factor affecting the rate of crop mechanization. Industry is usually hesitant to install tooling and manufacturing capacity during the introduction of mechanization as machines wear out or become obsolete. Thus, field machines with a life of 10 years would need to be replaced at a yearly rate of 10% of the total number in operation. The same manufacturing rate during the initiation of mechanization would completely mechanize the crop in 10 years. If 10,000 harvesters are required to mechanize tobacco harvesting, a production rate of 1000 machines per year would mechanize harvesting in 10 years and provide for 10% yearly replacement thereafter.

Introduction of stationary equipment like bulk barns would be expected to progress at a slower rate because of a longer life, unless manufacturers are willing to install excess production capacity. With an assumed life of 20 years, barns would need to be replaced at a yearly rate of 5% of the total number in operation. Bulk barns were introduced in 1960 and since 1965 the yearly increase has been about 60%, compound annual rate, **Figure 2.**

Mechanical harvesting is growing at a much faster rate since its introduction in 1970, **Figure 2.** In 1972 the annual increase was about 700%. The 1973 increase is expected to be about the same rate. At the present growth rates, mechanical harvesting capacity will soon equal bulk barn capacity as can be seen by extrapolation of the lines in **Figure 2.** Mechanization would then be slowed down because bulk barns are required to handle mechanically harvested tobacco. However, if the demand for mechanical harvesting is strong enough it would tend to increase the growth rate of bulk curing.

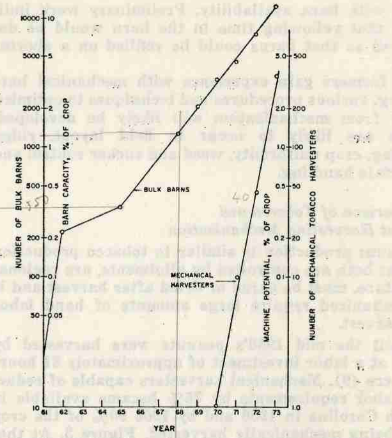

Figure 2. Growth of bulk curing and mechanical harvesting of flue-cured tobacco.

Alternative and Additional Enterprises

Perhaps the most important change afforded by mechanical harvesting is the expansion of the operator's tobacco acreage as a result of the increased acreage which can be managed by one person. This practice will absorb large acreages of lease tobacco and will be beneficial to small allotment holders who prefer other employment to tobacco farming. As off-farm job opportunities increase, mechanization of tobacco harvesting will increase the trend for small farmers to lease their crops and enter non-farm jobs.

In order to more fully utilize their management capacity, farm operators who do not expand their tobacco production as they mechanize may want to start or increase production of livestock and various crops which are compatible with tobacco. The possibility of using bulk barns as a drying, curing or storage barn for hay, grain, peanuts, potatoes, etc. is also worthy of consideration. Use of the barns for other crops would, of course, spread their costs over a wider income base and increase the profit margin.

Modifications in Tobacco Production Practices

In an effort to further increase the capacity of harvesting and curing equipment some farmers are dividing their crop between plantings designed for early and late harvesting. They expect to obtain part of the spread in harvest date from variety, part from planting date and part from cultural practices, primarily fertilizer levels. While these techniques may not completely eliminate overlap of the harvesting schedule with present varieties, plant breeders are striving to develop varieties with more widely separated harvesting dates.

There is also some interest in ripening agents. These chemicals would allow some manipulation of ripening date so that harvesting could be better correlated with barn availability. Preliminary work indicates that yellowing time in the barn would be decreased so that barns could be refilled on a shorter cycle.

As farmers gain experience with mechanical harvesting, various procedures and techniques to optimize gains from mechanization will likely be developed. These are likely to occur in field layout, ridge shaping, crop uniformity, weed and sucker control and materials handling.

Comparison of Tobacco and Peanut Harvesting Mechanization

Peanut production is similar to tobacco production in that both are controlled by allotments, are regional in nature, must be cured or dried after harvest and if unmechanized require large amounts of hand labor for harvest.

Until the mid 1950's peanuts were harvested by hand at a labor investment of approximately 31 hours per acre (9). Mechanical harvesters capable of reducing labor requirements by 75% became available in North Carolina in 1956 and by 1966 90% of the crop was being mechanically harvested, **Figure 3.** At that time approximately 169,000 acres of peanuts were grown in North Carolina.

Several factors characteristic of the crop and relating to mechanization are evaluated in **Table 1** along with comparable values for tobacco and a few values for grain. When peanut mechanization began the estimated breakeven acreage was about 2.5 times the average allotment. In tobacco the breakeven acreage is about 3.5 times the size of the average operational unit. Percent labor reductions are about the same for both crops. The equipment investment per dollar of annual crop value is slightly more for tobacco than it was for peanuts at the time they were first mechanized in North Carolina, 69¢ versus 57¢. The value for grain at 89¢ may not be applicable since it was not taken at the time grain production was being mechanized (10).

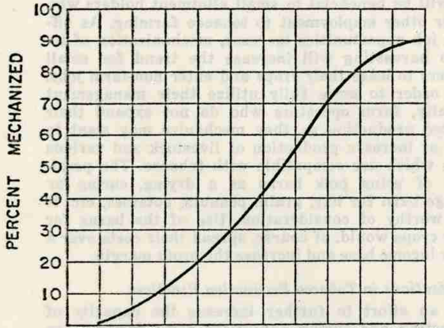

Figure 3. Mechanization of peanut harvesting in North Carolina.

Annual gross value of the crop harvested per machine was much higher for tobacco than for peanuts and higher for peanuts than for wheat. The equipment cost per dollar of labor saved was $11.60 for peanut harvesting but only $7.80 for tobacco. Since these values relate equipment costs to the cost of the labor saved they are meaningful indices of one of the forces which drive a farmer toward crop mechanization. Equipment costs for both peanuts and tobacco included harvesters plus driers or curing barns. The value for peanuts includes an annuity investment to cover the added fuel costs of drying mechanically harvested nuts. This was not necessary in the tobacco data as fuel costs are not affected by mechanization.

Table 1. Economic Factors Affecting the Mechanization of Grain, Peanut and Tobacco Production

Factor	Grain*	Peanuts** Machine & dryer	Flue-Cured Tobacco Machine & barns
Year	1970	1958	1973
System Investment, $	16,000 av.	14,700	75,000
Machine capacity, Acres	325 (Average use)	100	60
Value of crops, $/acre	55	260	1800
Value of total crop harvested	$18,000	$26,000	$108,000
Average crop allotment, A	—	8	4
Average size of operation, A		10	12 (est)
Breakeven acreage		25	40-50
Labor reduction, man hr/A		23	80
Labor saved by machine, hr.		2300	4800
Value of labor saved $		1265 (@55¢)	9600 (@2.00)
Number of average operations needed to breakeven		2.5	3.5
Investment per $ crop value	$0.89	$0.57	$0.69
Labor reduction, % of total		75%	73%
Investment per $ of saved labor		$11.60	$7.80

**Values from* New Holland Line *28(4):5-7, winter 1971. **Values for 1958 from W. T. Mills and J. W. Dickens, Harvesting and Curing Peanuts the Winrow Way, N.C. Agri Exp. Sta. Bulletin 405, April, 1958. The peanut system investment includes a $6,000 4%, 10 year annuity to cover the [illegible] annual added expense of artificially drying the mechanically harvested nuts.*

The number of average size operations required for an economic unit, equipment cost per dollar of crop value and the percent labor reduction are all strikingly similar for peanuts and tobacco. However, the equipment cost per dollar value of labor reduction for tobacco is about ⅔ as large as the value for peanuts at the time they were mechanized.

These comparisons suggest that the present impetus for the mechanization of flue-cured tobacco is greater than it was for peanuts in 1958. At that time peanut harvesting was about 5% mechanized. Eight years later, in 1966, it was 90% mechanized. Tobacco harvesting may be about 3% mechanized by the summer of 1973. If mechanization in tobacco gains acceptance as fast as it did in peanuts flue-cured tobacco could be almost completely mechanized by 1981.

DISCUSSION

Gavett (4), applying tomato and cherry harvester adoption rates to flue-cured tobacco, predicted that tobacco harvesting would be 40% mechanized by 1975. However, when he applied cotton and potato harvester adoption rates he predicted that tobacco harvesting would be only 10% mechanized by 1975. The present study, using peanut harvester adoption rates suggests that 20% mechanization by 1975 would be feasible. This would require approximately 2,000 harvesters, a number that is probably within present manufacturers' capabilities.

The growth of bulk curing may be meaningful in predicting the growth of mechanical harvesting. On-farm bulk curing started in 1960 with one barn. This was followed by a period of very rapid (percentage) growth followed by a period of slow growth which was related to poor market acceptance. Since 1964 growth rate percentage has been stable at about 60% per year, **Figure 2.** In 1973 it is expected that about 10% of the crop will be bulk cured. If the present growth rate holds, 16% of the 1974 crop and about 25% of the 1975 crop would be bulk cured.

Figure 2 indicates that at the present growth rate harvester capacity will exceed the capacity of bulk barns available for curing the random leaf by about

1974. Because of their interdependency, growth rates are then expected to increase for bulk curing and decrease for mechanical harvesting, paralleling each other, so that an equilibrium can be attained. It is predicted that about 20% of the crop will be mechanically harvested by 1975. In **Figure 2** a 10:1 scale between barns and harvesters was selected so that barn capacity and machine potential would have the same scale in terms of percent of the total crop. Although bulk barn manufacturing capacity is increasing it may not be possible to keep up with demand as approximately 10 bulk barns are required per harvester if each machine is to operate near capacity.

Traditional analyses of the economics of crop mechanization are usually limited to a consideration of labor costs, equipment investment, repairs, depreciation, taxes and insurance. Historical evidence suggests that analyses limited to these factors tend to underestimate the gains derivable from mechanization. Other important factors which add economically and otherwise to the desirability and justification of agricultural mechanization include such things as evolution, dependability and capacity, returns to management, alternative practices, availability and skill of labor, allotment fluidity and drudgery level of the labor involved.

Farmers appear to have an intuitive feel for these additional factors and are able to place value judgements on many of them. They tend to buy, and find profitable, more equipment than traditional analyses would justify. Ultimately, mechanization rate is dependent primarily on the strength of the forces supporting mechanization. One important measure of this, the equipment investment per dollar value of labor saved, was $7.80 for tobacco as contrasted to $11.60 for peanuts at the time they were being mechanized. This comparison suggests that tobacco harvesting may be mechanized at least as fast as peanut harvesting which was virtually completed in ten years.

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Reprinted from Tobacco Science XVIII, pp. 30-34; TOBACCO *Vol. 176, No. 7, pp. 29-33.*

on Feb 9. Pete Greene quoted a price of $160. for a 66" box and said that $125. would be reasonable for a 4' box. Labor would be the same. [The larger box would be heavier & harder to handle & deliver]
cws

Leakage Calculations

Container height

$$A = \frac{cfm\sqrt{S}}{1096.5(.6)\sqrt{\Delta P}} = \frac{\sqrt{S}}{1096.5(.6)}\frac{cfm}{\sqrt{\Delta P}} = .0004050\frac{cfm}{\sqrt{\Delta P}}$$

4' $A_{351} = .0004050\frac{351}{\sqrt{.4}} = .22477\ ft^2 = 32.367\ in^2$

5' $A_{439} = \text{——}\ \frac{439}{\sqrt{.78}} = .2013 = 28.99\ in^2$

6' $A_{526} = \text{——}\ \frac{526}{\sqrt{1.35}} = .183353 = 26.40\ in^2$

351 = 60%

Now Assume that 40% of the air for the 4' box bypasses the box or seeps out of the plenum, then the equivalent area for "escape" air is 21.578 in². The escape area is assumed to be constant regardless of box height.

4' A_{box} is 32.367 in² A_{escape} is 21.578 in² = 40% of total

5' A_{box} is 28.99 in², A_{escape} is 21.578 in² : = 42.7% of total

6' A_{box} is 26.40, A_{escape} is 21.578 in² = 45.0% of total

Horsepower

$$HP = \frac{Cfm \times Pressure}{6356 \times eff} = \frac{cfm \times Press}{3495.8}$$

4' $= \frac{11700 \times .9}{3495.8} = 3.01$

5' $= \frac{15323 \times 1.38}{3495.8} = 6.05$

6' = 19145 × 2.03/3495.8 =

Air Flow vs box size, density etc.

Glover has discussed the relationship between box height & fan requirements. He has assumed a constant density of packing box. He states that "As electricity becomes (more) expensive, the most economical big box container will become shorter in high

1. We have curves of static pressure across box vs flow for various depth boxes loaded to 14 lb/cu ft. or about 750 lb for a 48" box.

2. We need a better discussion of the flow through partially dry tob.

3. We need to develop flow curves for boxes of tob at lighter & heavier packing densities.

Calculations –

$$\text{Flow} = 1096.5\,(.6)\,A\sqrt{\frac{\Delta P}{\delta}}, \quad A = \frac{\text{Flow}\,\sqrt{\delta}}{1096.5\,(.6)\,\sqrt{\Delta P}}$$

$\frac{1}{A} =$ 6' $A] = .22$ sq ft $= 31.7$ sq in –

P=1, Flow=540 $\delta = .071$ height = 72"

flow = .5 cfm/lb.

my calculations suggest that 24-30 sq in is better for 52" box

$\frac{1}{A}$ 4.05 = R 5' $A] = .2469$ sq ft $= 35.55$ sq in

P=1 Flow=607. $\delta = .071$ height = 60"

$\frac{1}{A} = 3.516 = R$ 4' $A = .28436$ sq ft. $= 40.946$ in^2

P=1 Flow= $\delta = .071$ height 48"

43%

Box Height Optimization

1. Assume constant density
2. Assume constant air flow per lb of tob. net .5 cfm/green lb
3. Assume curing time constant.
4. Assume 4 ft box cost is 15% for top, 25% for bottom and remainder for sides - Cheaper to add height than more boxes. 125 for 4' box, $50. for top & bottom plus 18.75/ft of height
5. Assume ~~300 sq. ft.~~ , 55% fan eff- ~~12,500 cfm @ 1." press~~
6. Assume 20 boxes 13 lb/cuft 54 × 36 = 13.5 cross section × 4 = 54 cuft
5 = 67.5
6 = 81.

Table has be reevaluated.

Box Height	capacity cuft	weight lb @ 13 lb/cuft	Flow per Box	Flow for 20 Boxes	Barn Flow With bypass and seepage loss	box Press for Height + extra flow	Total	Duct pressure loss: Barn fan Press	HPower 55% eff	Green wt. per barn	Cured wt 16.7% of Green	HP Per 2500 lb barn	Barn KW	KWH per 2500 lb barn	Cost of .05/KWH	Box cost $	$	Fan and Motor cost $	Fuel	Barn cost* shell	Total Barn costs	annual Barn costs (15%)	annual barn costs plus elect for 5 cures	Barn cost per cured lb $	fuel costs $ per barn	Fuel cost per lb $ 5 cures	Total cost per lb / barn
			cfm	cfm		inches	inches	inches	HP	lb	lb	HP	KW	KWH	$	125/ea			~~Proportional to cu ft height~~	$	$						
4'	54	702	351	7020	11508 39% loss	.4+0	.4	+.4 .8	2.63	14040	2340	2.81	2.24	335	16.75	2500. 143.75 ea	~~[illegible]~~	250		5250	8000	1200	1284	.1097	110	.047	.1567
5'	67.5	878	439	8780	16566 47% loss	.5+.28	0.78	+.5 1.28	6.07	17560	2927	5.18	5.16	774	38.70	2875 162.50 ea	~~[illegible]~~	290		5250	8415	1262	1456.	.0995	158	.056	.1535
6'	81	1053	526	10530	23406 55% loss	.6+.75	1.35	+.6 1.95	13.05	21060	3510	9.29	11.09	1664	83.18	3250	~~[illegible]~~	444		5250	8944	1342	1633	.0930	224	.064	.1570

annual barn costs (includes boxes, fan & motor)
Elect costs .05/KWH
Fuel costs - allows for increased leakage (how?)

$94. per ton about 225 gal of 40¢ gas or 115 gal of 45¢ oil, per ton

Watkin's on-farm Tests averaged 225 gal of gas per ton of cured tob and 215 gal of fuel oil. gas at 40¢/gal & oil at 45¢/gal

*$8000 less cost of 20 4 ft boxes, fan & motor

Assume .850 KW per HP

* Pressure for flow of 5' box is $\frac{5}{4} \times 1 = 1.25$, now use flow eq to get pressure for increasing flow from 40 cfm/ft² to 50 cfm/ft². $cfm = 1096.5\,(.1)\,A\sqrt{\frac{\Delta P}{\delta}} = K\sqrt{\Delta P}$

$\therefore \frac{cfm_1}{cfm_2} = \frac{\sqrt{\Delta P_1}}{\sqrt{\Delta P_2}}$, $\sqrt{\Delta P_2} = cfm_2\sqrt{\Delta P_1}/cfm_1 = 50(1)/40 = 1.25$, $\Delta P_2 = (1.25)^2 = 1.56$

$$HP = \frac{cfm \times pressure\ (inches)}{6356 \times fan\ efficiency}$$

2✓

Bulk barns

$$C = \sqrt{\frac{\cancel{Q}W}{F\,P}\left(L + T + \frac{KV\cancel{Q}W}{24X}\right.}$$

let $\overset{W}{\cancel{Q}}$ = 25,000Kg. = about 25-30 A-

F = cost per Kg/hr of drying capacity $\frac{2700lb}{6\times24}$ = 18.75 lb/hr = 8.5 Kg/hr

8000/8.5 = $940.8 per Kg/hr.

L = $.25/hr supervising

T = 0

K = .004

V = $/Kg = 1.30 × 2.205 = $2.87/Kg.

$$C = \sqrt{\frac{25000}{(940.8)\times .134}\left(.25 + 0 + \frac{.004 \times 2.87 \times 25000}{24 \times 3 \times 1}\right)}$$

= 28.98 Kg/hr. one barn has rate of 8.5 Kg/hr

28.98/8.5 = 3.4 barns -

27000/2.205 = 1225 Kg/barn cure = 20.408 cures

20.408/3.4 = 6.0024 cures - not a bad answer - except that primings not considered

Acreage for bulk barn

Barn holds 2700lb. Costs. {8000 or ~~8415~~ Annual costs {1200 or 1262

Annual Recovery costs 11.75%, 20% salvage value, ~~3.6 repair~~

2.0% ins etc

1.6% repair -

Fixed costs =

(8000 + 1600) x .1175 + 1600 x d + .02 x 8000

= 13.4%

= $1072.

C is optimum barn capacity in Ha/hr = 1/263 = .0038

$C^2 = .00001446$

Labor = $4.00

Tractor = 0

b = 5 barns used 5 times/season

F = 1072 per barn = 13.4% = .134

P = Cost for system large enough to handle 1 ha/hr.

= 263 barn x 8000 = $2,167,733.

K = .004

YV = 6743

x = 3

H = 24

d = .95

2000 lb/A = 4940 lb/ha

2700 in 6 days

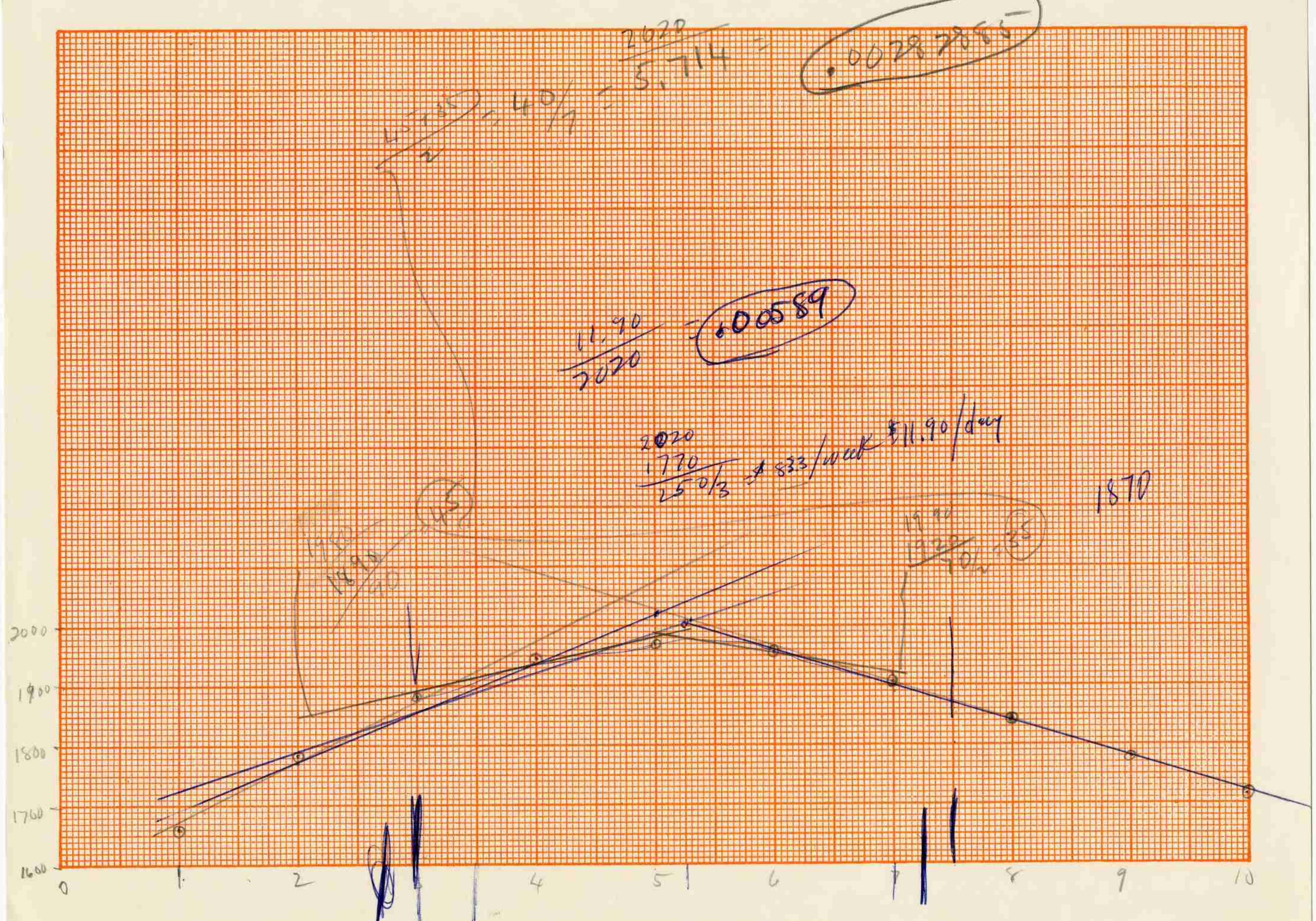
$= \frac{2700}{6 \times 24} = 18.75$ lb/hr-barn

$\frac{4940 \text{ lb/ha}}{18.75 \text{ lb/hr-barn}}$ 263 barns

26

$$A = \frac{-4 \times 5 \times 3 \times 24 \times .95 + \sqrt{(\quad)^2 + 4 \times .004 \times 6743 \times 5 \times .134 \times 2167{,}733 \times 3 \times 24 \times .95 \times .00001446}}{2(.004)(6743)(5)}$$

$$A = \frac{-1368 \pm \sqrt{1871424 + 150663.5}}{269.72} = .2002 \text{ Ha}$$



$\frac{45+35}{2} = 40/7 = \frac{2020}{5.714} = .00282885$

$\frac{11.90}{2020} = .00589$

$\frac{2020 \quad 1770}{250/3} = \$ 833/\text{week}$ $11.90/day

Bulk barns

Now consider only one priming - <u>once over</u>

$$C = \sqrt{\frac{\cancel{K}Q_g^W}{Fp}\left(L+T+\frac{KV\cancel{K}Q_g^W}{24x}\right.}$$

let $\cancel{K}Q_g^W$ = 25,000 Kilograms ~~about 125 A as this is 25,000kg/priming~~ -

P = cost per Kg/hr of drying capacity $\frac{2700\ lb}{7 \times 24}$ = 16.07/lb/hr = 7.29 Kg/hr

\$8000/7.29 = \$1097.6/Kg/hr.

F = .134

L = \$.25/hr supervision

T = 0

K = .004

V = \$/Kg = 1.30 x 2.205 = \$2.87/Kg

$$c = \sqrt{\frac{25,000}{.134(1097.6)}\left(.25+0+\frac{.004(2.87)\,25000}{24(3)}\right.}$$

Kg/\$/hr

= 26.8336 ~~barns~~ Kg/hr. = 3.681 barns -

25,000/26.8336 = 931.7 hours to cure crop. = 38.8 days ~~for one priming~~

~~- 5½ weeks!~~

~~maybe ok for once over~~

1.848 weeks before optimum +

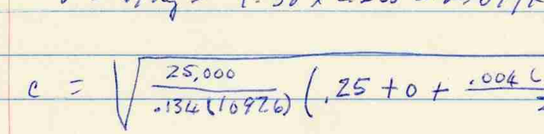
3.6969 week after

1175

1.35 × 2100

\$2835

But the delay after optimum will delay the start of second priming by 3.6969 - 1 = 2.6969 weeks and progressively more for the later primings.



931.7 hrs

5.5465 cures -

16

5 × 3.681 = 18.405 barns

For the entire crop to suffer the same average delay the curing season would be 5 weeks spread for ripening + 5.5 for delay = 10.5 weeks

$\frac{125000\ \text{Kg}}{10.5}$ = 11905 Kg/week $\frac{11905}{1225}$ = 9.722 barns.

$$C = \sqrt{\frac{25{,}000}{.134(1097.6)}\left(.25 + 0 + \frac{.004(2.87)25000}{24(2)}\right)}$$

one priming
1/5 of crop

$= 32.54$ kg/hr ⇒ 32.54 kg/hr / 7.29 kg/hr/barn $= 4.46$ 8 acres

~~32.54~~/ $\frac{25000 \text{ kg}}{32.54 \text{ kg/hr}} = 768$ hrs , 32 days = 4.57 weeks

For the entire crop to have the same average delay then the harvest season would need to be 5 weeks for ripening in normal manner plus 4.57 weeks for above delay = 9.57 weeks

$\frac{125000 \text{ kg}}{9.57} = 13062$ kg/week , $\frac{13062 \text{ kg/week}}{1225 \text{ kg/}\cancel{\text{barn}}\text{ cure}} = 10.66$ ~~barns~~ cure/week
= 10.66 barns

This analysis needs to consider the fact that the crop may not all reach its optimum at the same time. Can the timeliness factor be generalized to allow this concept - Problem becomes critical where equipment is very expensive and labor is not a significant factor. Under these conditions the existing formula gives such a small capacity that the work is not done before the next harvest (or other operation) needs to be performed —

~~$\frac{d}{dx} x^n = n x^{n-1}$~~ C^{-1}

$$\frac{dT}{dC} = \frac{-1C^{-2}}{1} \frac{KAyV}{x\,1 tpwd} = 0$$

W^{-1}

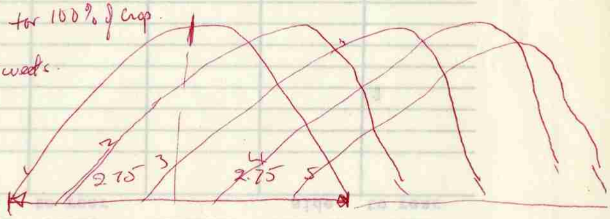
$$\frac{dAC}{dW} = FC\%p \pm \left(+1W^{-2} \frac{825A}{se} (L+T) \right) = 0$$

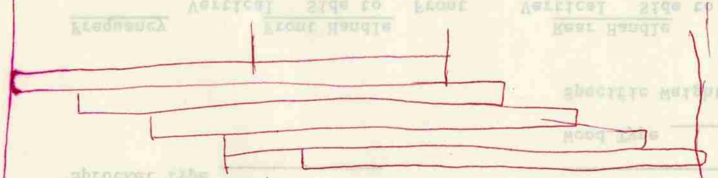
$$W^2 (FCp) = \frac{825A}{se} (L+T)$$

$$W^2 = \frac{8.25A}{Fcp\,se} L+T$$

average delay is 2.75 weeks for 100% of crop.

Some harvest with no delay some with 5.5 weeks.





Harvest is $\frac{10.5 \text{ weeks}}{5 \text{ weeks norm}}$

$$\frac{125000 \text{ Kg}}{10.5} = \text{~~2381~~ } 11905 \text{ Kg/week}, \quad \frac{\text{~~2381~~}\ 11,905}{1225} = 9.722 \text{ barns}$$

Air flow

Pg 1

Effects of Curing ~~pressure~~ airflow on Curing-Drying time.

1. Assume 5' box, 13 lb/cfm 878 lb/5' box.

2. Assume 2½ day yellowing, rest drying-

3. Evaluate ~~for~~ airflow greater than + less than .5 cfm/lb.

4. 10-15% of fuel is used in first 2½ days say average of 13% Rest during drying.

5. Cured wt of 20 box barn is 2927

6. Annual barn costs are

Flow cfm/lb	Flow Thru Box cfm	Pressure across Box in	Duct loss in	Total Fan Pressure in	Bypass and Seepage	Flow for 20 box barn.	Fan Power @55% eff HP. or KW	Electrical Requirements KW	Yellowing Time per 15 box cure @3¢/KWH	Fuel gas gal/cure
.3	263	.28	.4	.68	43%	9228 ~~9925~~	1.8	1.3	60	
.4	351 2927	.50	.5	1.00	43%	12316 ~~13245~~	3.5	2.6	60	
.5	439 2927 wt	.78	.6	1.38	43%	15403 ~~16566~~	6.5	4.3	60	329
.6	526	1.12	.7	1.92	43%	18455 ~~19849~~	10.1	7.2	60	
.7	615	1.53	.8	2.33	43%	21577 ~~23207~~	14.6	10.2	60	

Continued

Flow cfm/lb	Drying Time* To[tal] time hr.	Barn Costs	Annual ~~Barn~~ Costs	Hourly* Barn costs	Barn costs per cure	Elect costs per cure 5¢/Kwh	Fuel costs @$94./ton	Barn, Electrical and fuel cost	Cost per cured pound
			$	$	$	$/cure	$	$/cure	$
ft .3	140 200	8350	1252	1.49	298	16.00	138	454	.1551
4 .4	105 165	8375	1256	1.50	248	28.88	138	415.15	.1417
5 Ref. .5	84 144	8415	1262	1.50	216	46.8	138	401	.1369
.6	70 130	8560	1284	1.53	199	65.65	138	403	.1376
.7	60 120	8700	1305	1.55	186	86.40	138	410.40	.1402

* Assumes that barn can be used for 5 standard 7 day cures.
Assumes that 6 day cure consists of 60 hr yellowing + 84 hr drying
and that yellowing time is constant, drying time prorated on
basis of air flow. for other flow rates.

Note: Above total curing times appear to be less, for low pressure, than sometimes observed. This suggests that slow drying is more efficient but that barn losses make total efficiency less.

Pg 3

1977 Results

in	mm	Pressure		std	Time saved		(std)	fuel Saved
		High Pr2	194	200		5.91	(6.64)	
		Pr3	154	160		5.16	(6.36)	
		Pr4	163	105		5.81	(5.43)	
1.18	25 30	High Av –	150			5.63		.51
.71	18 –	Std	155		5	6.14		
.35	~~8~~9 –	Low Press	233	std (170)		9.35	(6.36)	

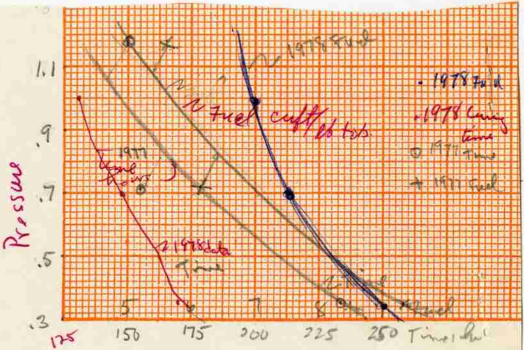
Observed

Press	Curing Time	Fuel cuft/lb tob
.35	233 hr	9.35
.71	155	6.14
1.18	150	5.63

Prorated

	Time	standardized	Fuel		
.3	242	176	9.7		163
.4	225	159	8.9		150
.5	210	$\boxed{144}$	8.2	$94/ton = $138, per 2927 lb barn	
.6	195	129	7.6	–	128
.7	180	114	7		118
.8	168	102	6.5		109

This column was developed from observed curing data by means of smoothing in the attached graph.


Pressure
1.1
.9
.7
.5
.3
125
150
175
200
225
250
Time, hrs
1978 Fuel
Fuel cuft/lb tsts.
1977 time hours
1978 data
Time
5
6
7
8
9
Time
Fuel
• 1978 Fuel
• 1978 Curing time
⊙ 1977 Time
+ 1977 Fuel

1978 Results

Observed

Pressure			Fuel	total
	MM	in	cuft/lb	time hrs
L	8.9	.35	8.97	170
M	17	.71	7.50	147
H	25.	1.0	7.09	131

Flow	Press	Fuel cuft/lb	$*	time total hrs
.3	.28 .897	9.2	172	180
.4	.5	8.25	154	168
.5	.78	7.4	138	142
.6	1.12	6.8	127	130
.7	1.53	6.4	119	127

Med pressure costs are $94./ton - others prorated on basis of fuel consumption

1978 Time & fuel data

Flow cfm/lb.	Curing Time hr 1978 data	Fuel costs 1978 data $/cure	Elect costs $/cure	Barn costs $/hr.	Barn costs $/cure	Total $/cure	Cost $/cured pound.
.3	180	172	16.20	1.49	268.20	456.4	.1559
.4	168	154	29.40	1.50	252.00	435.4	.1488
.5	142	138	46.15	1.50	213.00	397.15	.1357
.6	130	127	65.65	1.53	198.90	391.55	.1338
.7	127	119	91.44	1.55	196.85	407.29	.1391

1327 kg

1977 Time & fuel data

Flow cfm/lb	Curing Time hrs.	Fuel costs $/cure	Elect costs $/cure	Barn costs $/hr	Barn costs $/cure	total $/cure	cost $/cured lb.
.3	242	162	21.78	1.49	360.58	544.36	.1860
.4	225	150	39.38	1.50	337.50	526.88	.1800
.5	210	138	68.25	1.50	315.00	521.25	.1781
.6	195	128	98.48	1.53	298.35	524.83	.1793
.7	180	118	129.60	1.55	279.01	526.60	.1799

Effect of Fan Pressure on curing and Drying Time fuel Consumption
Grade, Price, and cured weight yield

Clayton 1978
CWS

Priming/Bay #	Pressure	Wt. in lb	Wt. out lb	water removed lb	Fuel cuft	fuel ft³/lb water removed	Curing time hrs	Drying time hrs	CWY %	Fuel eff ft³/lb of cured tob.	Grade, Price
1 1-6	Low	630	76.5	553.5 ~~[illegible]~~	1140	2.06	175	125	12.14	14.90	N1PO
1 7	Med	600	77.5	522.5	710	1.36	140	65	12.92	9.16	P4L
1 8	High	540 ~~[illegible]~~	72	468	745 ~~870~~	1.59	125	85	13.33	10.35 ~~12.08~~	P4D pilot off.
2 6	Low	650	86	564	890	1.58	145	70	13.23	10.35	X4L
1 7	Med	700	97	603	800	1.33	125	50	13.86	8.25	X3V
2 8	High	600	96½	503.5	770	1.53	100	60	16.08	7.98	P4L 2nd prim pale yellow
2 7	Low	600	110½	489.5	750	1.53	145	80	18.42	6.79	X4V
2 8	Med	600	107½	492.5	855	1.74	135	70	17.92	7.95	X4V
2 6.	High	600	110½	489.5	885	1.81	120	50	18.42	8.00	X4V
3 8	Low	750	127	623	810	1.30	165	90	16.93	6.35	C5L
3 6	Med	750	126	624	853	1.37	165	65	16.80	6.79	C4D
3 7	High	750	130	620	620	1.00	125	75	17.34	4.77	N1DL
4 6	Low	650	136½	513.5	882	1.72	220	100	21.00	6.46	B4KM
3 7	Med	650	137½	512.5	651	1.27	140	65	21.15	4.73	B4KM
4 8	High	650	139½	510.5	609	1.19	185	85	21.46	4.37	B5V
7	Low+High	750	161.5	588.5	809	1.37	170	75	21.53	5.01	B4BK
8	Med	700	158.5	541.5	851	1.57	170	65	22.64	5.37	B4F
6	Simmons Dri	750	178.5	571.5	740	1.29	210	90	23.8	4.15	

Cuft of gas / lb of water removed -

Barn	Pressure L	Pressure M	Pressure H	Total
6	1.53	1.37	1.81	4.71
7	1.53	1.33	1.00	3.86
8	1.30	1.74	1.53	4.57
Total	4.36	4.44	4.34	13.14
$\bar{x}$	1.45	1.48	1.45	

by Primings				
1	2	2	3	4
2.06	1.58	1.53	1.30	1.72
1.36	1.33	1.74	1.37	1.27
1.59	1.53	1.81	1.00	1.19
5.01	4.44	5.08	3.67	4.18

Affected by ambient Temp?

1. The center barn # 7 is most efficient followed by #6 which is under the shelter center and finally least efficient is # 8 which has one side exposed to the wind.

2. Curing time is shortest for the high pressure & longest for the low pressure. It does not seem to be affected by barn.

3. Drying time is longest for the low pressure & shortest for the medium pressure.

4. Eff in terms of amount of gas used per lb of water removed appears to be pretty much unaffected by fan pressure -

5 Eff in terms of amount of gas used per lb. of cured ~~tob~~ tobacco appears to be less for the higher fan pressure. It is likely that we are measuring a priming effect with more 1st primings in the low fan observations -

6L	8	7	6	8	7	6	
7M	6	8	7	6	8	7	
5H	7	6	8	7	6	8	

L 8 m
M 17 m
H 26 m

1978

	Barn	Pressure	Fuel eff. Cuft/lb	Drying Time	Total Curing Time	
	6	L	14.90	125	175	
	7	M	9.16	65	140	
	8	H	12.08	72	125	
2	6	L	10.35	70	145	
1	7	M	8.25	50	125	
1	8	H	7.98	60	100	
2	7	L	6.79	80	145	
2	8	M	7.95	70	135	
2	6	H	8.00	50	120	
3	8	L	6.35	90	165	
3	6	M	6.79	65	165	
3	7	H	4.77	75	125	
Pr4) 46	6	L	6.46	100	220	120
Pr3 39	7	M	4.73	65	140	110
Pr4 42	8	H	4.37	85	185	100
Pr4	8	M	5.37	65	170	

Totals

Fuel Eff	
L	44.85
M	36.88
H	37.2

Curing time

Barn	L	M	H	
6	145	165	120	430
7	145	125	125	395
8	165	135	100	400
	455	425	345	1225
	175	140	125	
	220	170	185	
5)	850	735	655	
	170	147	131	

Drying Time pressure

	L	M	H
	70	65	50
	80	50	75
	90	70	60
Σ	240	185	195
$\bar{X}$	80	62	65

Fuel $\mathrm{ft^3/lb}$ cured tob

Pressure

Barn	L	M	H	
6	(6.46) 10.35	6.79	8.00	(21.25) 25.14
7	6.79	(4.73) 8.25	4.77	(16.29) 19.81
8	6.35	7.95	(4.37) 7.98	(18.67) 22.28
	(19.60) 23.49	(19.47) 22.99	17.14 20.75	(56.21) 67.23
	14.90	9.16	10.35	
	6.46	5.37	4.37	
Total	5) 44.85	37.52	35.47	
Mean	8.97	7.50	7.09	

cured wt. yield

	Pressure				
Barn	L	M	H		
6	13.23	16.80	18.42	48.45	16.15
7	18.42	13.86	17.34	49.62	16.54
8	16.93	17.92	16.08	50.93	16.98
Total	48.58	48.58	51.84	149	
$\bar{x}$	16.19	16.19	17.28		

Variables: Cycling 15 min off - 45 on - High pressure
: Low pressure yellow - High pressure dry.

			wt				ft³/lb water		Gas	Time			
CS	Pr -	Bar	in	out	Water	Gas		Cwy	ft³/lb.	Curing	Drying	Grade	
4	1	1	600	76	524	919	1.75	12.67	12.09	165	120	N1PO	Cycle
5	1	4	600	72	528	920	1.74	12.06	12.78	140 44	96	P5D	Std air bag.
6	1	2	600	90½	509½	822	1.61	15.08	9.08	140 44	96	N1PO	L - High
9	1	4	600	79	521	735	1.41	13.17	9.30	100 50	50	X4L	air bag std
14	2	1	600	87	513	644	1.26	14.50	7.40	140 70	70	P4L	cycle
15	2	2	600	86	514	580	1.13	14.34	6.74	140 70	70	P3L	Low-High
16	2	3	600	95	505	1260	2.50	15.84	13.26	120	60	X4D	Std
17	2	4	600	94½	505.5	820	1.62	15.75	8.67	140	75	X4V	air bag
22	3	2	650	107	543	585	1.40	16.46	5.56	120	55	X4V	high press
24	3	1	650	108	542	830	1.53	16.62	7.67	145	80		Low-High

Barns 1, 2, 4 -- Cycling etc –

	Gas consumption (ft^3/lb dry tob)				Gas consumption ft^3/lb water			
Barns	cycle	L-High	std	High	cycle	L-High	std	High
1	12.09 7.40	7.67			1.75 126	1.53		
2		9.08 6.74		5.56		1.61 1.13		1.10
4			12.78 9.30 8.67				1.74 1.41 1.62	
3			~~13.26~~				~~2.50~~	
Σ	19.49	23.49	30.75	5.56	3.01	4.27	4.77	1.10
$\bar{x}$	9.74	7.83	10.25	5.56	1.50	1.42	1.59	1.10
	L 8.97	M 7.50		H 7.09				

	Curing time, hours			
Barn #	cycle	L-High	std	High Press.
1	165 140	145		
2		140 140		120
3			120	
4			140 100 140	
Σ	305	425	590	120
$\bar{x}$	152	142	125	120
		L 170	M 147	H 131

1. ~~Gas~~ Fuel consumption probably not affected.
2. Cycling extends cure by about 1 day or more.
3 Low pressure yellow, high pressure dry reduces green setting.