Non-Computer Version of BOLLMAN

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INTRODUCTION

A non-computerized version of BOLLMAN has been requested by several individuals who are not prepared to make the investment in the computer-based COTMAN system. The major advantage of a simplified version is that the user will be able to try BOLLMAN on a small scale and should then gain confidence in it. Also, the user should gain an appreciation of the power of the computer-based version. However, this simplified "paper" version should not be considered as a complete substitute for the computer-based system. Due to voluminous data manipulations, it is not practical to attempt the SQUAREMAN portion of COTMAN without a computer. Similarly, as BOLLMAN is conducted on an increasing number of fields, the need for a computer to handle the data greatly increases.

Oosterhuis et al. (1996a) provide an overview of COTMAN concepts and glossary of terminology that can help users to better understand and use BOLLMAN. The logic of BOLLMAN is to identify cutout date, i.e., the flowering date of last population of bolls that are expected to make a profitable contribution to yield, then adjust end-of-season management on the maturation of these bolls. True cutout date either coincides with crop maturation (physiological cutout) or is dictated by end-of-season weather (seasonal cutout). At present, BOLLMAN assists with timing of insecticide termination and application of defoliants, as well as the sequencing of fields by their relative maturity.

BOLLMAN utilizes four steps:

1. Sequentially monitor nodes-above-white-flower (NAWF) to determine date of physiological cutout,
2. Estimate latest possible cutout date to determine date of seasonal cutout,
3. Establish last effective flowering date to determine true cutout date and
4. Calculate and accumulate heat units after true cutout date for each field.

STEP 1. NAWF

Initiate NAWF

Each field should be monitored for the appearance of first flowers. Start collecting NAWF data at first flower and collect once or twice per week until NAWF is less than five or until the latest possible cutout date occurs.

NAWF should be initiated at first flower because this early NAWF is an important crop indicator (Robertson et al., 1996). Sequential monitoring of NAWF once or twice a week gives information on the progressive maturity of the crop. Timely, early initiation of NAWF counts prevents the user from incorrectly associating cutout with second growth or late-flowering plants. Cutout in such cases is then deemed to be much later than true cutout, and the value of BOLLMAN is nullified.

NAWF Measurement

Users should make copies of the attached blank NAWF data collection sheet (Attachment 1). Select at least four sample sites within a field or management unit. For fields larger than approximately 40 acres, add a sample site for each additional 10 acres. It is essential to choose a representative site within each sample site. Find a plant having a first-position white flower, and count the number of main-stem nodes above the branch bearing a first-position white flower. The uppermost node counted is the highest one having an unfurled, i.e. edges not touching, leaf (Fig. 1). Find a second plant having a first-position white flower, and count NAWF. Repeat this procedure for 10 plants in each sample site. Do not sample all 10 plants from the same row. Go to the next sample site and repeat the procedure. Determine the mean NAWF for each site (round to nearest 0.1). Average the site means to determine a field mean NAWF value (round to nearest 0.1). For each field, NAWF should be determined once or twice per week from first flower until cutout (see "Physiological Cutout" below).

NAWF Variation

Considerable plant-to-plant variation in NAWF within a field normally occurs. However, the amount of variation in these values within and across sites can be meaningful. Variation within a site reflects plant-to-plant variation in growth and development. Major contributors to such variation are 1) differences in stand density, 2) sporadic insect injury, causing loss of fruit or vigor, 3) random physical injury, e.g., hail damage, 4) incidence of non-lethal plant disease and 5) spot-replanting within an area. Variation between sites is often related to differences in soil types or water status (excess or deficiency). If sites vary greatly, be sure that the sites properly represent the field. In some cases, you may want to substitute a sample site that more represents the area of the field upon which you wish to base your decisions. Generally, as variation increases, sample sizes and number of samples should be increased to reduce sampling errors.

Chart NAWF

Prior to initiating NAWF counts, make a NAWF chart (blank form, Attachment 2) for each field and fill in information relative to field name, planting date, soil type and variety. The NAWF chart plots "days after planting" (DAP) on the horizonal axis against the NAWF value on the vertical axis. Calendar dates associated with the various DAP's should be determined and entered below each 10-day increment. For example, with a May 1 planting, 50, 60, 70, 80, 90, 100 and 110 DAP would be June 20, 30, July 10, 20, 30, August 9 and 19, respectively. Designating the calendar dates associated with DAP's will greatly facilitate subsequent plotting of data and other information on the chart.

As data are collected, plot the average NAWF by DAP associated with the sampling date. The chart can also be used to maintain other field management records. For example, it would be useful to indicate inputs such as fertilizer, irrigation (and rainfall) and insecticide applications. Those inputs occurring after 50 DAP can be indicated on the chart by their respective dates of application. Earlier inputs and observations regarding other factors that might influence the plants (damage from disease, hail, herbicide, etc.) may be noted in the margins. At the end of the season, the user may wish to include information regarding yield and quality. Such charts can be maintained as a permanent record and provide valuable insight on both the productivity of the field and the influence of various management inputs on plant growth, yield and quality.

Average NAWF values can be compared to the “target development curve” (TDC, Fig. 2). The TDC assumes first flower at 60 DAP, vertical squaring interval of 2.7 days, 25 days from first square to first flower and NAWF=5 at 80 DAP. Based on these assumptions, NAWF at 60 DAP is 9.25, i.e., 25 days from square to flower divided by 2.7-day interval between new main-stem node formation.

Charted NAWF values may be near, below or above the TDC. Visual observation of the charted line against the TDC provides immediate information on the potential yield and maturity development of the crop. Fields having NAWF that are plotted *near the TDC* are developing at an optimum pace to provide the best combination of high yield and early maturation. Stressed growing conditions, e.g., lack of water, are indicated by NAWF values *below the TDC* (i.e., slope does not parallel and is more steep than TDC). Such conditions can often incite shedding of fruit. If the stressed conditions are alleviated, the plants may initiate second growth and have delayed maturity. Otherwise, plants in these stressed fields reach cutout earlier than desired. Typically, cotton plants are unable to fully recover from severe stress that occurs after flowering. A major reason for using SQUAREMAN is to help detect stress early enough that remedial action may be effective.

NAWF *above the TDC* can be caused by slow early-season growth, which delays plant development and maturity (such a situation could be detected by SQUAREMAN). Of much greater concern is a situation in which NAWF values are not declining over sampling dates. Relatively flat NAWF slopes indicate that plants are not progressing toward maturity in a timely fashion. A high (relative to TDC) and flat-sloped NAWF curve is usually due to lack of fruit development (poor retention/small bolls) in relation to vegetative growth of the plants. Such fields will likely have low yields and mature late. In contrast, relatively flat slopes that have low (relative to TDC) NAWF indicate that vegetative growth is barely sufficient to maintain additional reproductive development. Increased stress on these plants will likely cause premature cutout and low yields. However, if such fields can maintain this precarious vegetative to reproductive balance and have good late-season conditions, acceptable yields are possible. In these cases, yields will tend to increase as maturity is delayed, with corresponding increases in production costs and risks.

Physiological Cutout

Monitoring of NAWF should be stopped when a field has reached cutout, with cutout defined as the flowering date of the last effective boll population (Oosterhuis et al., 1996b). Based on crop development, an average NAWF of 5.0 typically indicates *physiological cutout*, so monitoring of NAWF should be continued until average NAWF<5.0. Fields that have experienced prolonged stress (particularly water stress) usually have plants that are relatively short with a low NAWF (5-6) at first flower. Some research data suggest that in these stressed conditions, NAWF=4.0 may more accurately define cutout. Users should only use NAWF=4.0 as the indicator in these severe cases.

Do not attempt to identify cutout with one observation of NAWF late in the season! Doing so will result in a false, late indication of cutout if true cutout has previously occurred. In these cases, either plants with second growth (flush of vegetative growth after cutout) or atypically late-maturing plants (where best plants have already ceased flowering) make it impossible to detect true cutout.

The date of physiological cutout in a field can be determined from the NAWF chart by interpolating between sample dates to determine the approximate date that physiological cutout (NAWF=5.0) is attained.

STEP 2. LATEST POSSIBLE CUTOUT DATE

Determination

In northern regions of the Cotton Belt, a cotton crop may not have sufficient heat units to mature the last effective boll population. Tests have indicated that 850 heats units (DD60's) are needed for development of the last population of flowers to develop into mature bolls. When physiological cutout occurs too late for 850 heat units to be accumulated, *weather* rather than *plant development* determines cutout. When *weather restraints* rather that *plant development* dictate cutout, flowers that occur very late in the season are not likely to have adequate time to develop into bolls. The latest possible cutout date is then determined as a function of probable weather estimated from long-term weather patterns.

For estimating the latest possible cutout date, long-term weather data have been evaluated for several weather stations. Using these data, the latest dates from which 850 heat units were attained in 50 and 85% of historical years have been determined. To determine the latest possible cutout date for a field, choose the long-term weather station from Fig. 3 that is nearest to your farm. Choice of the percentage of years of weather data (risk factor) upon which you wish to base your decisions provides the latest possible cutout date. Indicate the latest possible cutout date on the NAWF chart with an asterisk * on the NAWF=5 line.

Choosing a Risk Factor

Obviously, the latest possible cutout date occurs later at more southern weather stations. Also, the date can be delayed by assuming higher risks, i.e., basing your decision on a lower percentage of years. Some situations in which it may be advisable to accept higher risks include: 1) locations in the more northern regions of the Cotton Belt since full maturity of the crop (850 HU past physiological cutout) is difficult to attain, 2) locations considerably south of the long-term weather station from which you are obtaining data, 3) for any portion of your fields that may have delayed maturity or 4) fields that have low late-season insect infestations.

STEP 3. LAST EFFECTIVE FLOWERING DATE

The last effective flowering date (true cutout) within a field is either the date of *physiological cutout* (i.e., when NAWF=5) or the date of *seasonal cutout*, (i.e., latest possible cutout date), whichever occurs first. If the NAWF slope intersects the NAWF=5 line prior to the latest possible cutout date (indicated by *), then the last effective flowering date is the date of *physiological cutout*. Otherwise, the *seasonal cutout* date becomes the last effective flowering date.

The last effective flowering date signals the initiation of heat unit accumulation to monitor the development of the last effective population of bolls in a field. Since all other bolls are older and more mature, end-of-season management can be based on the development of bolls arising from the last effective flowering date.

STEP 4. HEAT UNITS

Calculation

Heat units are, to a certain extent, a measure of physiological time and measure the pace of growth and development of a plant. In cotton, heat units are often measured by DD60's (degree day 60's), which indicates the amount of heat accumulation over a threshold of 60°F. Calculation and recording of DD60's must be started on the day after the *last effective flowering date* and continued daily until critical heat units associated with various management decisions have been accumulated for each field. Daily high and low temperatures should be obtained from either a maximum/ minimum thermometer located in the shade within a relatively close proximity of the field (one thermometer may service several or all your fields) or from a nearby weather station (extension office, television report, etc.). To calculate DD60's for a day, average the high and low temperatures [(high + low) / 2] then subtract 60. If the daily DD60 is a negative value, enter it as zero.

Heat Unit Chart

A simple heat unit chart can be developed (blank form, Attachment 3). The chart should have four standard columns plus a column for each field that is being monitored. The first column is for "Date." The first date should coincide with the day that the earliest maturing field reaches *last effective flowering date*. The second and third columns are for the high and low temperatures associated with that date. The fourth column is the calculated DD60's for that date.

Beginning in the fifth column, enter "field name" at the top of the column on the day that *last effective flowering date* is attained for the field. Place an asterisk * in the field column on the date it reaches cutout. DD60 accumulation commences on the day after the last effective flowering date. As fields are added, they will be arranged from earliest (fifth column) to latest (extreme right column) maturity. Add the daily DD60 to the accumulative DD60 values in each field column.

Critical Heat Units for Insecticide Termination

Since the *last effective boll population* represents the youngest bolls that should be protected, insecticide termination can be sequenced with the development of these bolls (Oosterhuis et al., 1996c). Research has indicated that developing bolls resist penetration by bollworms and boll weevils at about 350 DD60's after white flower. Therefore, when a field has accumulated 350 DD60's past the *last effective flowering date* (determined in the heat unit chart), control of these insects can be terminated. In cases in which there is considerable variation (see "NAWF variation" above), consider extending control to 450 DD60's. Fields that have reached 350 DD60's past the last effective flowering date should still be scouted for insect pests. Defoliating pests, such as loopers and armyworms, should not be allowed to prematurely defoliate the crop until it is safe to be chemically defoliated. In addition, boll weevils should not be allowed to build to extremely high levels because of their potential to injure next year's crop. When high, late-season boll weevil populations occur, their food source and overwinter sites should be eliminated by harvesting as early as possible and destroying the crop residue.

Critical Heat Units for Defoliation

Defoliation can also be timed by the maturity of the *last effective boll population*. To achieve near maximum yield and revenue, 850 DD60's should be accumulated after the *last effective flowering date* prior to defoliation. Some have suggested that 650 to 750 DD60's may be appropriate for defoliation when plants set fruit in a short period so that 60-70% of crop is open. Other situations in which early defoliation might be advisable include: 1) fields located in northern extreme of Cotton Belt in which full maturity may not occur, 2) fields in which picker capacity is limited and harvest should be initiated earlier in some fields, and 3) fields for which adverse weather forecasts indicate a need for early harvest.

Heat unit chart example (Fig. 4)

Median high and low temperatures (based on long-term weather data, 1950-1993) for July 28 through October 23 at Marianna, Arkansas, are charted and daily DD60's are calculated in this example chart. This provides an indication of maximum/minimum temperatures and the daily heat units that can be expected in the central Delta region of Arkansas. Obviously, actual temperatures within a specific year will fluctuate much more than these median temperatures.

In the example, six hypothetical fields that used the same weather station are listed in the order they attained cutout. Fields A1 and B2 reached physiological cutout long before the *latest possible cutout date* and were easily able to attain full maturation. Both fields C3 and D4 reached physiological cutout on August 7, the *latest possible cutout date* based on 85% of years at Marianna. Note that when multiple fields have identical cutout dates, they can use the same heat unit accumulations. Field E5 reached physiological cutout on August 14, the *latest possible cutout date* based on 50% of years. For all fields reaching cutout after the *latest possible cutout date* (August 7 or August 14, e.g., field F6), heat unit accumulation for end-of-season management would begin at the *latest possible cutout date*.

These data illustrate the importance of attaining timely cutout. Since heat unit accumulation in this example was relatively constant throughout August, variation among fields for days to cutout was similar to the variation for days to 350 heat units after cutout. However, as cutout was delayed, the time required to attain maturity (850 heat units) was greatly prolonged. The 6-day delay in cutout between fields B2 and C3 caused only a 10-day difference in time to 850 heat units, whereas the 7-day delay between fields C3 and E5 resulted in a 27-day delay to 850 heat units.

FINAL REMARKS

Hopefully, this "by hand" version of BOLLMAN will be helpful to producers or consultants in making some critical end-of-season management decisions. As experience with this paper version of BOLLMAN is gained, we encourage users to obtain information on the whole COTMAN system. The full value of plant monitoring can be achieved only when the entire growth pattern with COTMAN components SQUAREMAN and BOLLMAN is evaluated.

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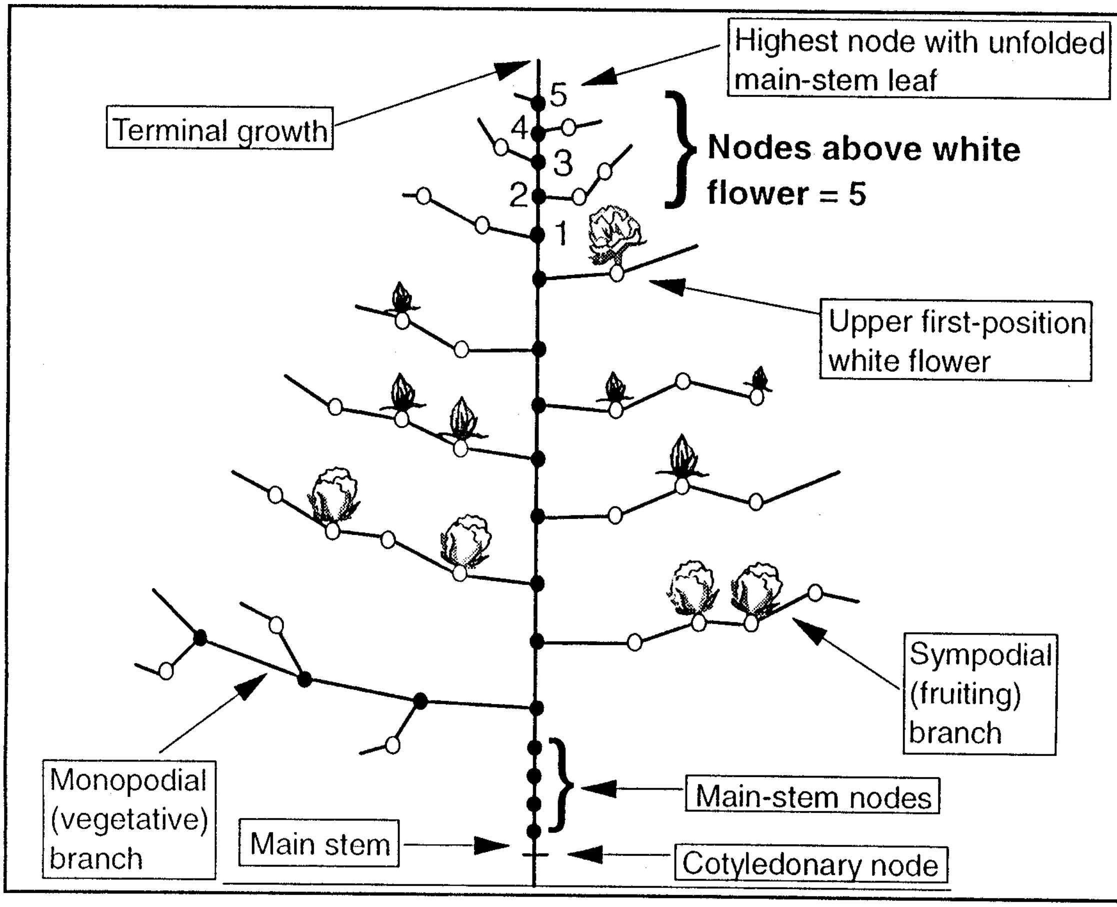


Figure 1. Plant diagram illustration of NAWF.

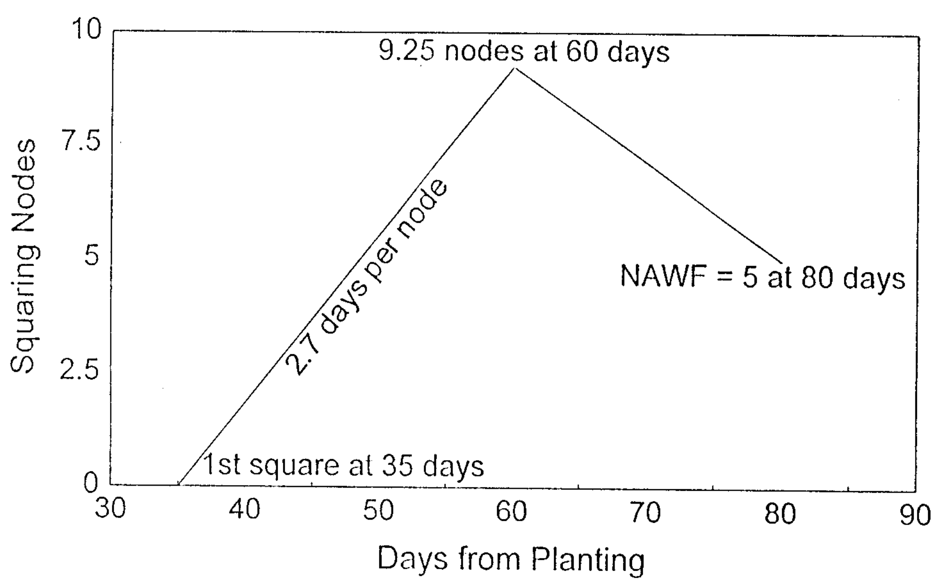


Figure 2. Target development curve.

Figure 3. Latest possible cutout dates for weather stations in several cotton production areas.

Location	Years analyzed	Harvest completion date*	Latest possible cutout date:[†] 50% years	85% years
Birmingham, AL	1948-1995	12/1	8/18	8/11
Huntsville, AL	1959-1995	12/1	8/14	8/2
Mobile, AL	1948-1995	12/1	9/2	8/26
Montgomery, AL	1948-1995	12/1	8/26	8/21
Tuscaloosa, AL	1949-1993	12/1	8/21	8/14
Hope, AR	1950-1993	11/15	8/18	8/10
Keiser, AR	1959-1993	11/1	8/9	7/31
Marianna, AR	1950-1993	11/1	8/14	8/7
Rohwer, AR	1960-1993	11/15	8/17	8/9
Stuttgart, AR	1950-1993	11/1	8/14	8/8
Tallahassee, FL	1948-1995	12/1	9/3	8/29
Columbus, GA	1948-1995	12/1	8/25	8/19
Macon, GA	1949-1995	12/1	8/24	8/18
Savannah, GA	1951-1995	12/1	8/30	8/23
Alexandria, LA	1930-1993	11/1	8/25	8/20
Amite, LA	1948-1993	11/1	8/24	8/19
Calhoun, LA	1948-1993	11/1	8/20	8/15
Houma, LA	1930-1993	11/1	8/27	8/22
Lafayette, LA	1948-1993	11/1	8/26	8/22
Lake Charles, LA	1962-1993	11/1	8/27	8/23
Natchitoches, LA	1930-1993	11/1	8/24	8/20
Shreveport, LA	1930-1993	11/1	8/23	8/19
Winnsboro, LA	1930-1993	11/1	8/22	8/16
Holly Springs, MS	1962-1993	11/30	8/10	7/30
Jackson, MS	1964-1993	11/30	8/24	8/18
Popularville, MS	1960-1993	11/30	8/30	8/25
Stoneville, MS	1950-1993	11/30	8/21	8/14
Tupelo, MS	1963-1994	11/30	8/18	8/8
Portageville, MO	1973-1996	11/1	8/5	7/29
New Bern, NC	1949-1993	11/1	8/15	8/5
Raleigh, NC	1948-1995	11/1	8/6	7/30
Charleston, SC	1946-1995	12/1	8/27	8/19
Florence City, SC	1948-1995	12/1	8/20	8/30
Covington, TN	1964-1993	11/1	8/8	7/30
Jackson, TN	1964-1993	11/1	8/8	7/30
Abilene, TX	1948-1995	10/25	8/16	8/9
Austin, TX	1948-1995	9/30	8/2	8/8
Corpus Christi, TX	1948-1993	8/15	6/27	6/26
Dallas,TX	1948-1995	9/30	8/11	8/7
Lubbock, TX	1948-1995	10/30	8/8	8/2
Midland, TX	1948-1995	10/30	8/16	8/11
Coastal Plains, VA	1933-1994	11/1	8/4	7/28

*Target dates for completion of harvest at the Arkansas and Stoneville, Mississippi, locations were based on day length and probability of dry weather. Dates for all other locations were estimated by cotton extension specialists or researchers in the respective states.

[†]The latest date from which 850 HU's were accumulated in 50 and 85% of years. Calculations assumed 14 days from defoliation of latest fields to harvest completion.

Fig. 4. Heat unit chart example (using median high:low temperatures at Marianna, Arkansas).

HEAT UNIT CHART (DD60 = [(High + Low) / 2] - 60

Date	Temperature High	Temperature Low	Daily DD60	Fields, list sequentially as cutout is reached: A1	B2	C3/D4	E5	F6
7/28	93	70	21.5	*				
7/29	93	70	21.5	21.5				
7/30	93	70	21.5	43				
7/31	92	71	21.5	64.5				
8/1	92	71	21.5	86	*			
8/2	92	69	20.5	106.5	20.5			
8/3	91	70	20.5	127	41			
8/4	91	70	20.5	147.5	61.5			
8/5	93	70	21.5	169	83			
8/6	92	70	21	190	104			
8/7	93	70	21.5	211.5	125.5	*		
8/8	92	69	20.5	232	146	20.5		
8/9	92	70	21	253	167	41.5		
8/10	91	69	20	273	187	61.5		
8/11	91	69	20	293	207	81.5		
8/12	91	69	20	313	227	101.5		
8/13	89	68	18.5	331.5	245.5	120		
8/14	90	68	19	350.5	264.5	139	*	
8/15	91	69	20	370.5	284.5	159	20	
8/16	93	69	21	391.5	305.5	180	41	
8/17	91	69	20	411.5	325.5	200	61	*
8/18	91	68	19	430.5	344.5	219	80	80
8/19	90	68	19	449.5	363.5	238	99	99
8/20	91	69	20	469.5	383.5	258	119	119
8/21	92	68	20	489.5	403.5	278	139	139
8/22	90	68	19	508.5	422.5	297	158	158
8/23	91	67	19	527.5	441.5	316	177	177
8/24	92	67	19.5	547	461	335.5	196.5	196.5
8/25	91	67	19	566	480	354.5	215.5	215.5
8/26	91	68	19.5	585.5	499.5	374	235	235
8/27	91	69	20	605.5	519.5	394	255	255
8/28	91	68	19.5	625	539	413.5	274.5	274.5
8/29	90	69	19.5	644.5	558.5	433	294	294
8/30	91	68	19.5	664	578	452.5	313.5	313.5
8/31	91	68	19.5	683.5	597.5	472.5	333	333
9/1	90	67	18.5	702	616	490.5	351.5	351.5
9/2	91	68	19.5	721.5	635.5	510	371	371
9/3	89	67	18	739.5	653.5	528	389	389
9/4	89	67	18	757.5	671.5	546	407	407
9/5	88	64	16	773.5	687.5	562	423	423
9/6	89	65	17	790.5	704.5	579	440	440
9/7	90	65	17.5	808	722	596.5	457.5	457.5
9/8	90	65	17.5	825.5	739.5	614	475	475

Fig. 4. continued.

Date	Temperature High	Temperature Low	Daily DD60	Fields, list sequentially as cutout is reached: A1	B2	C3/D4	E5	F6					
9/9	88	67	17.5	843	757	631.5	492.5	492.5					
9/10	88	65	16.5	859.5	77305	448	509	509					
9/11	86	63	14.5		788	662.5	523.5	523.5					
9/12	87	64	15.5		803.5	678	539	539					
9/13	86	64	15		818.5	693	554	554					
9/14	86	62	14		832.5	707	568	568					
9/15	87	62	14.5		847	721.5	582.5	582.5					
9/16	86	62	14		861	735.5	596.5	596.5					
9/17	86	62	14			749.5	610.5	610.5					
9/18	85	64	14.5			764	625	625					
9/19	87	62	14.5			778.5	639.5	639.5					
9/20	85	62	13.5			792	653	653					
9/21	87	61	14			806	667	667					
9/22	83	60	11.5			817.5	678.5	678.5					
9/23	82	58	10			827.5	688.5	688.5					
9/24	82	57	9.5			837	698	698					
9/25	82	55	8.5			845.5	706.5	706.5					
9/26	82	57	9.5			855	716	716					
9/27	81	56	8.5				724.5	724.5					
9/28	81	56	8.5				733	733					
9/29	82	56	9				742	742					
9/30	84	56	10				752	752					
10/1	82	55	8.5				760.5	760.5					
10/2	83	56	9.5				770	770					
10/3	80	55	7.5				777.5	777.5					
10/4	81	53	7				784.5	784.5					
10/5	80	52	6				790.5	790.5					
10/6	79	51	5				795.5	795.5					
10/7	78	52	5				800.5	800.5					
10/8	79	50	4.5				805	805					
10/9	78	50	4				809	809					
10/10	78	50	4				813	813					
10/11	80	50	5				818	818					
10/12	81	52	6				824	824					
10/13	80	50	5				829	829					
10/14	78	50	4				833	833					
10/15	79	50	4.5				837.5	837.5					
10/16	79	50	4.5				842	842					
10/17	76	49	2.5				844.5	844.5					
10/18	76	46	1				845.5	845.5					
10/19	75	43	0				845.5	845.5					
10/20	73	43	0				845.5	845.5					
10/21	75	48	1.5				847	847					
10/22	74	47	0.5				847.5	847.5					
10/23	75	50	2.5				850	850					

Attachment 1

Data Collection Sheet: NAWF

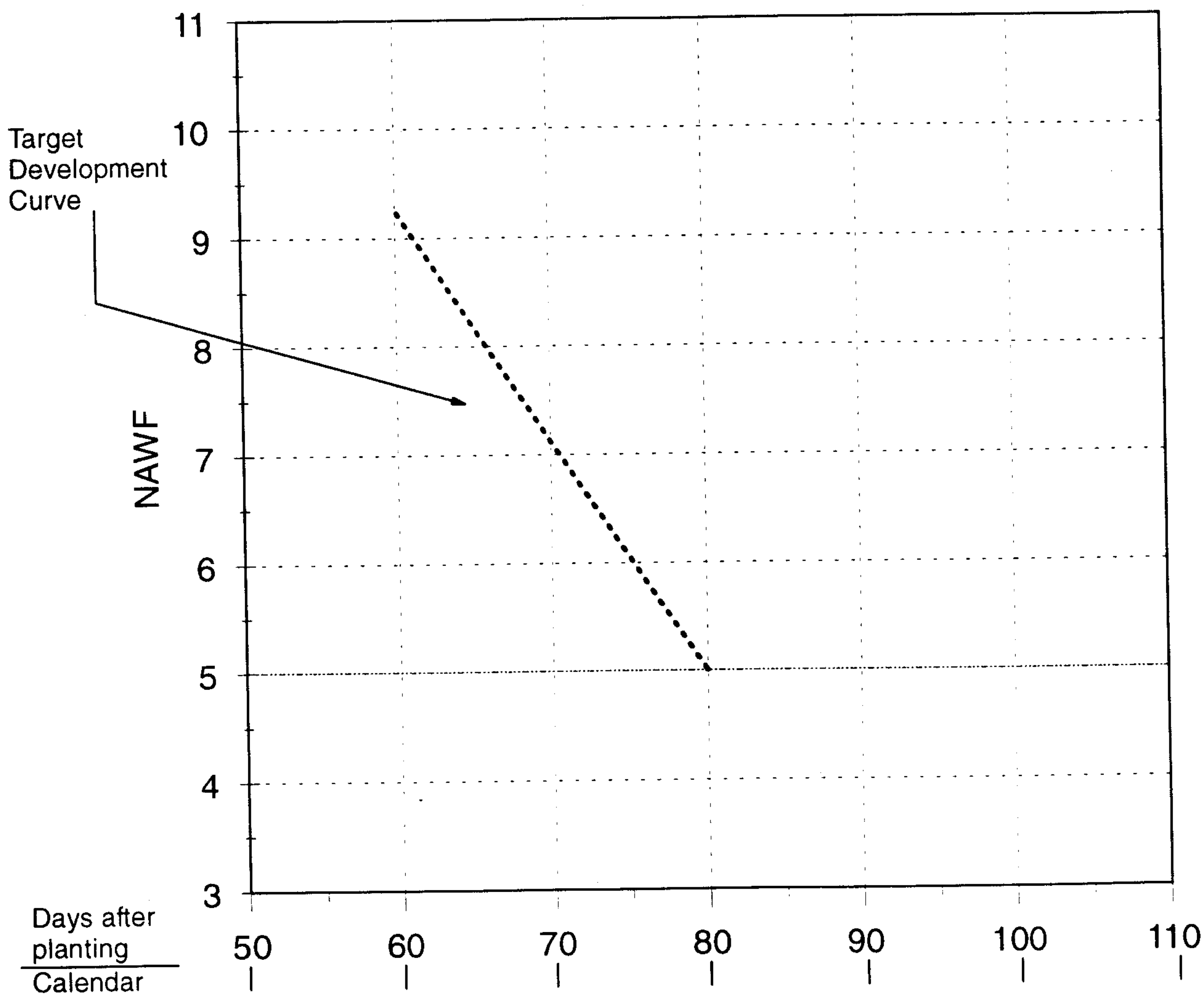
Farm Name: ______________________________ Year: ____________ Page _____ of ________

Sample Information	Site	Nodes Above White Flower (NAWF) Plant Number 1	2	3	4	5	6	7	8	9	10	Site Mean
	1											
Field name ____________	2											
	3											
Mo/day _______________	4											
	5											
Avg. of site means ______	6											
	7											
	8											
	1											
Field name ____________	2											
	3											
Mo/day _______________	4											
	5											
Avg. of site means ______	6											
	7											
	8											
	1											
Field name ____________	2											
	3											
Mo/day _______________	4											
	5											
Avg. of site means ______	6											
	7											
	8											
	1											
Field name ____________	2											
	3											
Mo/day _______________	4											
	5											
Avg. of site means ______	6											
	7											
	8											

Attachment 2. NAWF chart.

Field ____________ Year ____________ Planting date ____________

Soil type ____________ Variety ____________ Latest possible cutout date ____________
(* on NAWF 5 line)



Notes and Observations:

Attachment 3

HEAT UNIT CHART

	Temperature		Daily	Fields, list sequentially as cutout is reached									
Date	High	Low	DD60										