Reducing Combine Gathering Losses in Soybeans

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THE soybean (Glycine Max, Merrill) was first harvested by combine in 1924 in Illinois. This crop was, in fact, the reason for first introducing the combine East of the Mississippi (Baker 1961).

The engineers who had advanced the use of the combine in soybeans also conducted field loss surveys subsequent to those first successful trials. A review of soybean losses published in the U.S. since 1925 showed that harvesting loss has averaged 9 percent of total yield and has declined very little (Quick 1972). About 85 percent of this combine loss was found to be at the header, primarily due to the action of the reciprocating cutterbar. Cutterbar-induced losses accounted for around 80 percent of gathering, or header loss (Quick 1970 and Dunn 1972).

The results of five seasons of field testing and header research at Iowa State University 1967-1972 are summarized in this paper in four divisions:

1 Crop management.
2 Combine operation.
3 Header attachments and modifications.
4 Pertinent crop characteristics.

Field test procedures used are outlined in the appendix. Header loss categories are defined under Fig. 1.

The primary response variable in the combine tests was defined as

HEADER LOSS (HL) PERCENT

$$= \frac{\text{Total header loss x 100}}{\text{Net potential yield}}$$

$$= \frac{\text{Sum of individual header losses}}{\text{YLDNP}}$$

where Net potential yield

= Weight of all seed potentially available to the machine, lb/acre.

= (Bin yield + Header Loss + Through-Combine Losses), lb/acre.

i. e. YLDNP

= BINPA + THLPA + TRUCOL

A computer program that enabled raw field data to be transformed into a form useful in statistical analyses is appended.

CROP MANAGEMENT PRACTICES AFFECTING HEADER LOSS

Planter

To reduce header loss in soybeans, *start with the planter.* Row spacing and planting rate influence soybean plant morphology and both were found to have significant effects on header loss. In Fig. 2 the physiology of a typical soybean plant is illustrated and, alongside, the seed distribution. The enlargement shows the predicted effect of various cutting heights on harvest loss.

Narrow-row planting in the Northern States, where indeterminate varieties are grown, has been a proven way to increase yields where weeds are effectively controlled. Yield responses in 10-in. rows, for example, were as high as 35 percent above 40-in. rows. In addition, narrow-row spacing exerted a highly significant effect on reducing header loss.

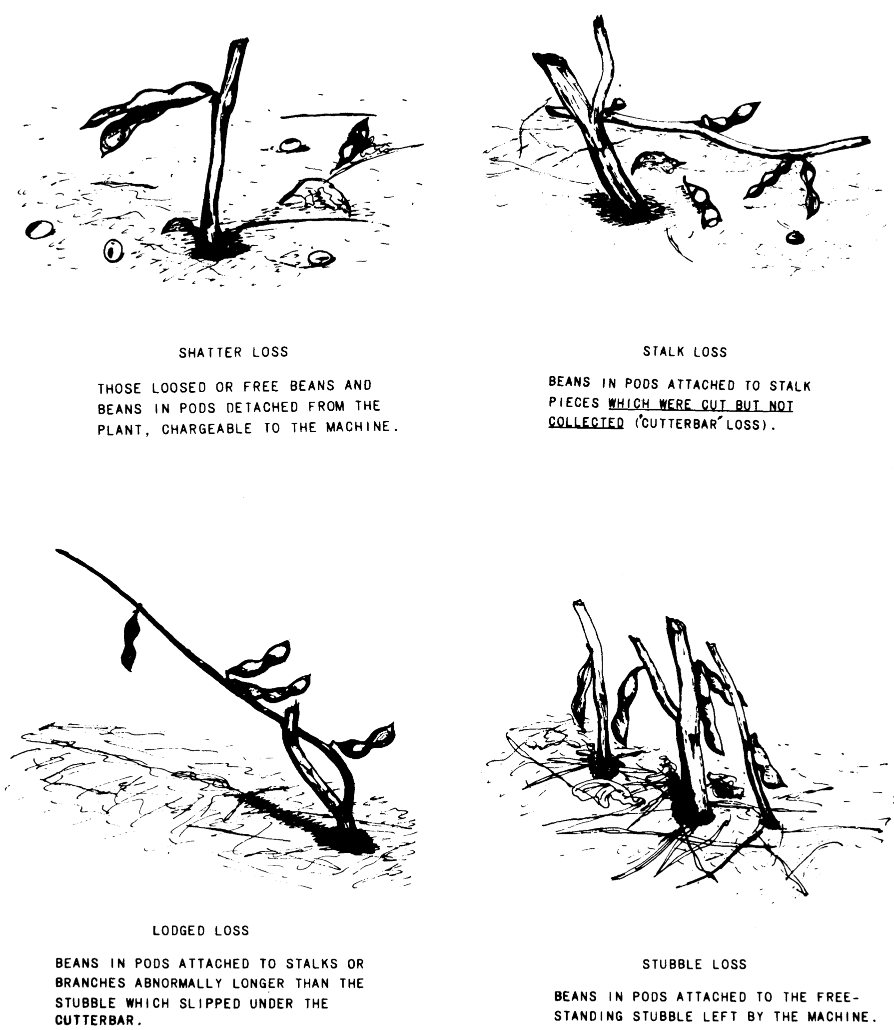

FIG. 1 Definitions of combine gathering losses in soybeans.

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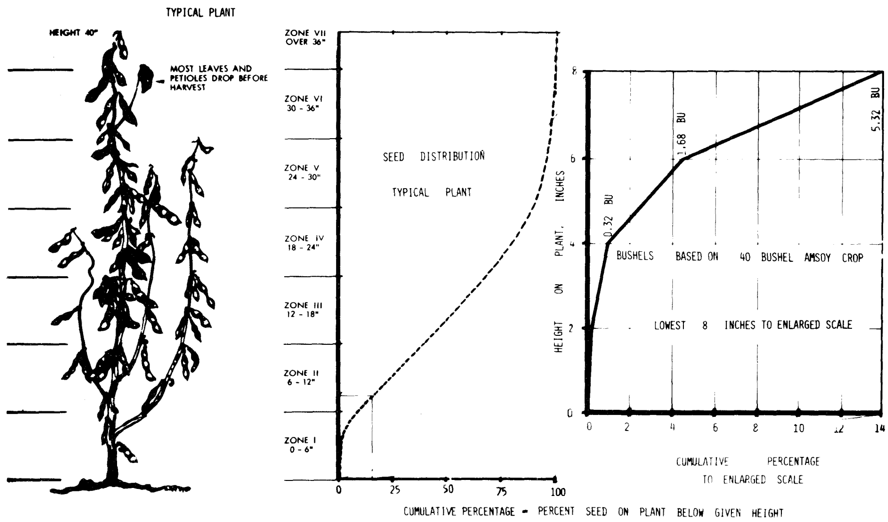

FIG. 2 Typical plant and seed distribution on plants. Amount of seed lost by cutting at given height.

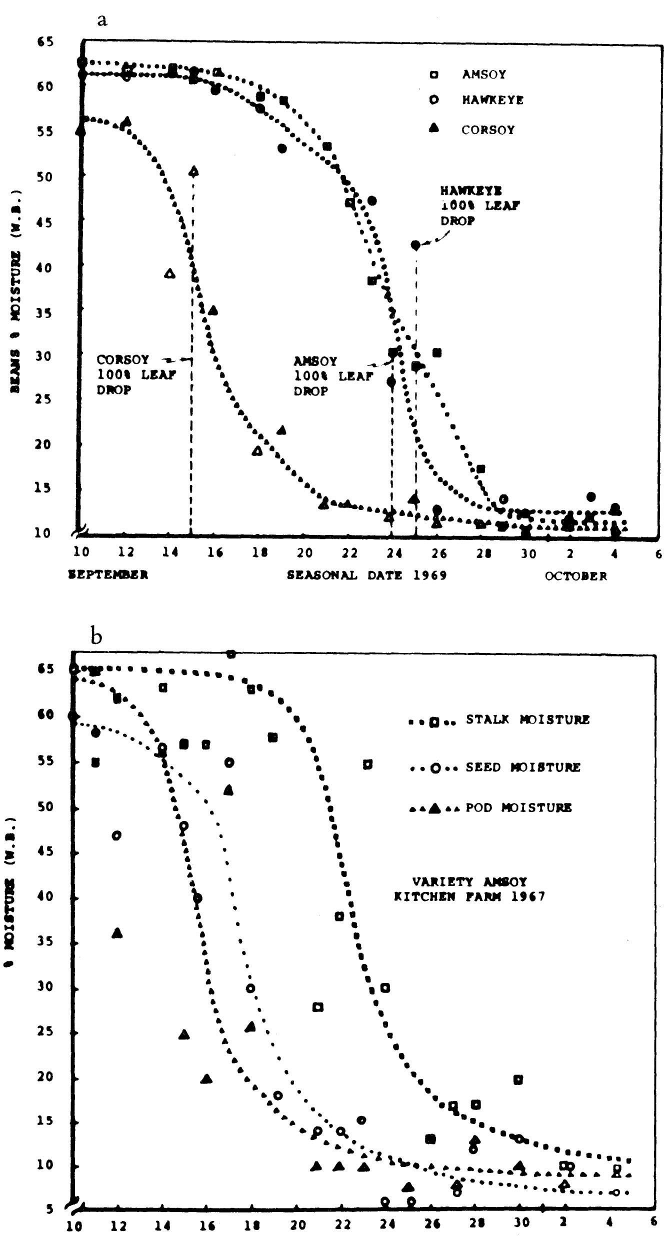

FIG. 3 Natural drying rates for (a) seeds of three varieties and (b) for seeds, pods and stems of variety Amsoy.

Yield was 19.9 percent higher and header loss 22.7 percent lower in 10-in. rows than in the 30-in. rows in the 1970 trials with variety Hark (differences significant at the 1 percent level). 20-in. rows were intermediate in both respects.

Weeds

Heavy weed infestations (predominantly Foxtail) lowered header loss by 62.9 percent in variety Amsoy field plots. But yields were 22.2 percent lower in the weedy plots (differences significant at the 1 percent level). Even *controlled* weed growth did not commend itself as a desirable means of reducing header loss.

Cultivation Practices

Header loss was found to be 14.2 percent lower on flat ground trials compared with ridged. But weed control treatment on the untilled flat ground was not fully effective and confounded the results – yield was 15 percent lower.

Plant

Plant height, podding height and number of branches per plant exerted an important effect on header losses. Each was effected by planting rate. Higher planting densities generally resulted in more spindly plants with less branches and higher pods, i.e. *less pods in the cutting zone.* Header losses were accordingly lower. The same plants were, however, less lodging-resistant. In hail-struck seasons (two out of five here) hail-lodging was seriously detrimental to harvesting.

COMBINE OPERATION

Timeliness

The soybean crop matures rapidly in a normal season – the onset of leaf-drop warning that harvest time is imminent.

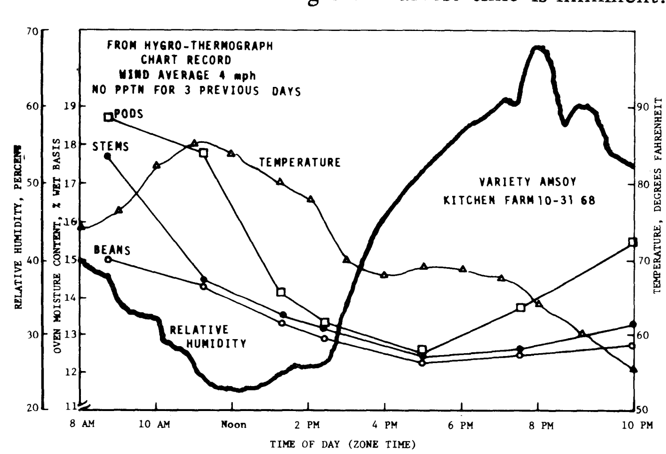

FIG. 4 Diurnal variations in weather and in seed moisture content, variety Amsoy.

Observe in Fig. 3 the rapid decline in bean moisture content after leaf-drop. Monitoring of crop moisture showed that plant moisture variations lagged normal daily weather fluctuations by 4 to 5 hr, Fig. 4. Header loss was found to increase approximately exponentially as moisture content decreased (Quick 1972).

Loss Characteristics of the Standard Header

Performance characteristics of a 10-ft standard header equipped with regular (fixed) cutting platform, automatic height controller and pickup reel are shown in Fig. 5. The curves plotted were obtained by least-squares multiple-regression data analysis. The prediction equation for total header loss was -

$$HL = 10.8316 - 4.2301 + 1.4109\,V^2 - 1.2997\,L + 0.2891\,L^2$$

with

$S_{HL/V,L}$ standard deviation = 2.0143 percent

R^2, regression coefficient = 0.9691

V = forward speed, range 1 to 4 mph

L = mean stubble length, range 3 to 7½ in.

The original regression analyses included a stubble length x combine speed interaction term but this was not found significant (at the 10 percent level).

Lowest measured header loss in the replications was 2.3 percent of net potential yield at the 1 mph and 3-in. stubble length setting. Predicted minimum header loss was 4.61 percent at 1.5 mph and 3-in. stubble.

There was a tendency for gathering loss to increase slightly at very low forward speeds (below say 1.5 mph) due to plant parts falling out of the header more readily at the lowest speeds.

Optimum machine adjustments were governed by crop conditions. Ideal reel index, or ratio of reel tip speed to ground speed, for the pickup reel was around 1.7 with the reel set 9 in. ahead and 9 in. above the tip of the cutterbar sections at a forward speed of 2.5 mph. There was some evidence that reel index should be even higher for low combine speeds and that it should be reduced as speed is increased but this effect was difficult to isolate in the field. Reel index setting did not appear to be so critical at combine speeds over 4 mph. These comments regarding reel index apply only in erect crop conditions.

High speed operation increased capacity at the expense of greater header loss and longer stubbles. At speeds above 4 to 5 mph the cutterbar was "crowded" to the point where whole plants could slip under the platform without being cut, Fig. 6.

HEADER ATTACHMENTS AND MODIFICATIONS

The reciprocating cutterbar has been isolated *a posteriori* as the prime cause of header loss and capacity-limiting header component. It was indicted by the following: (a) A process of elimination: – cutterbar loss was first isolated in the laboratory using a header simulator at 79.6 percent of total header loss (Quick 1970). This was subsequently confirmed by component loss isolation in the field, where Dunn (1972) found cutterbar-related losses averaged 81.1 percent of header loss. (b) The gathering process was studied by high-speed photo-instrumentation. The large lateral movement of stems during cutting and the tendency for the reciprocating cutterbar to thrust plants away from the platform was particularly evident. This tendency increased with forward speed and at conventional knife speeds of 450 to 500 cycles per minute the 3-in. knife was deemed to be "overcrowded" at speeds above 3.2 mph. (c) Certain header attachments were effective because they controlled plants during cutting. But the recurrent theme throughout all these tests was the imperative to *cut low for minimum header loss.*

Narrow-Pitch Cutterbar

The use of a 1½-in. pitch cutterbar with 3-in. stroke, Fig. 7, reduced header loss by as much as 26.6 percent below the standard 3 x 3 in. reciprocating cutterbar, all other factors being equal. Two seasons of testing with the narrow-pitched design on a fixed platform indicated consistently that stubble length was less at the test speed (2.5 mph) and that the difference in header loss between the two cutterbar pitches was more pronounced the lower the platform height, or at moderately faster combine speeds. Work is continuing on this development on a floating cutterbar.

The Floating Cutterbar

Two 10-ft combines equipped with

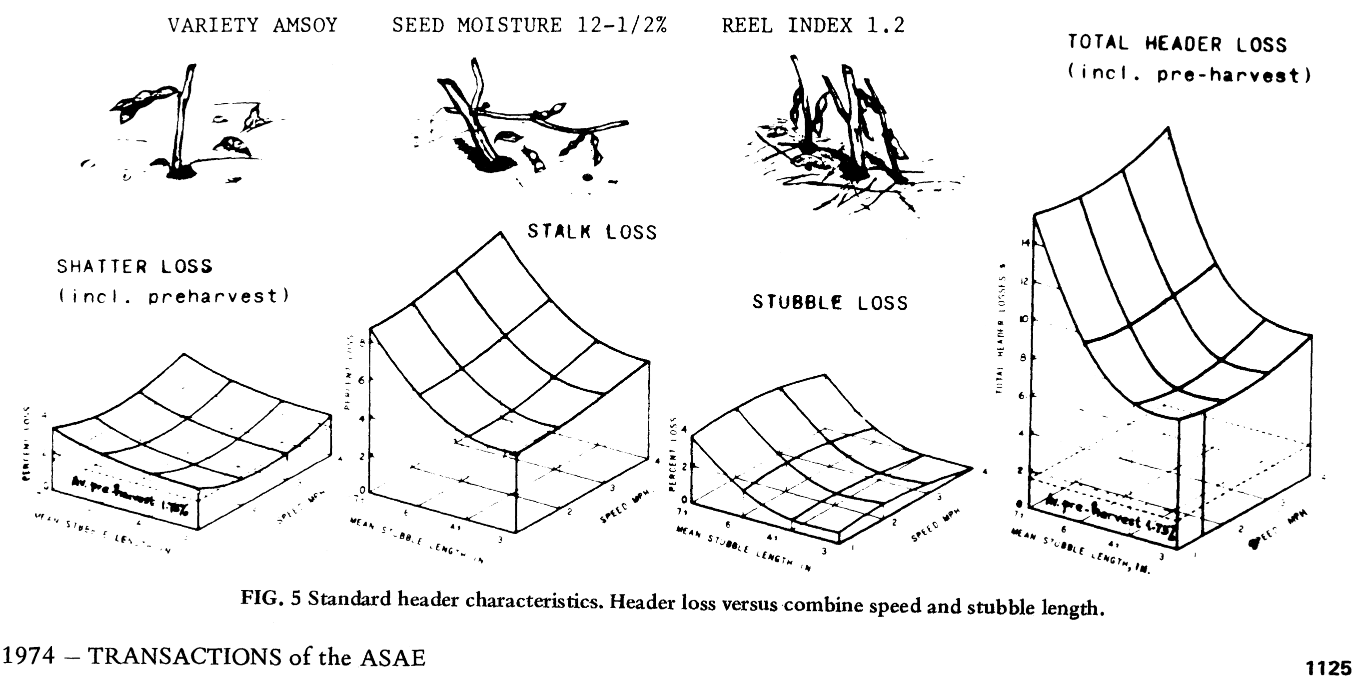

FIG. 5 Standard header characteristics. Header loss versus combine speed and stubble length.

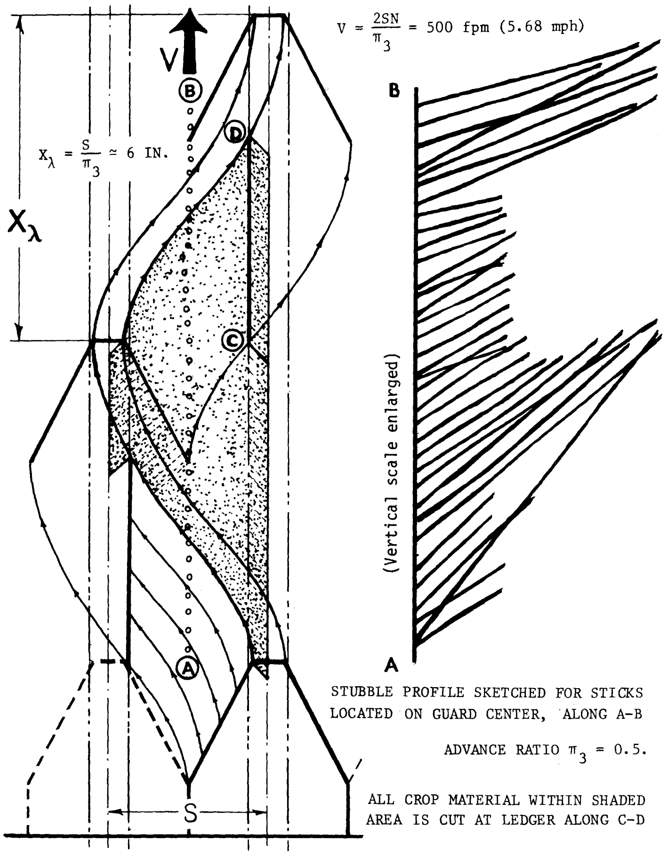

FIG. 6 Cutterbar "crowding diagram" for 0.5 advance ratio (5.68 mph). Right, laboratory simulated stubble profile.

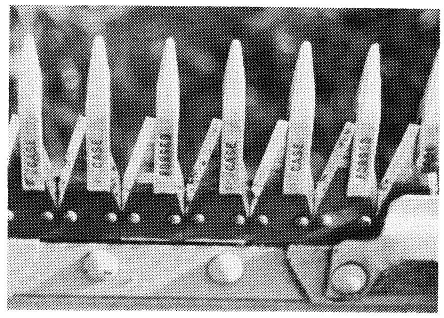

FIG. 7 Cutterbar variant with narrow-pitch guards and knife sections.

pickup reels and header height cont. were compared, one as the standard, the other equipped with a flexible floating cutterbar (Lovebar). The loss reduction obtained with this floating cutterbar was substantially dependent upon the degree of difference in stubble length obtained, see Fig. 8.

Exponential functions provided the best fit to the data by least squares regression. The average total header loss was 39.9 percent lower with the Lovebar, harvested yield was 8.2 percent higher and average stubble length 25.7 percent lower in the 10 field replications at the "standard" 2.5 mph speed of this test series.

In Fig. 9, the results of field tests on another pair of similarly equipped combines are shown, this time with a Hart-Carter floating cutterbar on the test machine. This trial was at another location and time so the two test series of Figs. 8 and 9 should not be strictly compared. Header loss was 45.5 percent lower with the floating cutterbar at 2.5 mph. The Hart-Carter equipped header could be operated at 4.3 mph for the same header loss level as the standard header at 2.5 mph.

The principal advantages of a floating cutterbar attachment were found to be:

- a highly sugnificant reduction in header loss,
- the ability to cut uniformly lower by accommodating to ground irregularities,
- higher forward speed for the same header loss level,

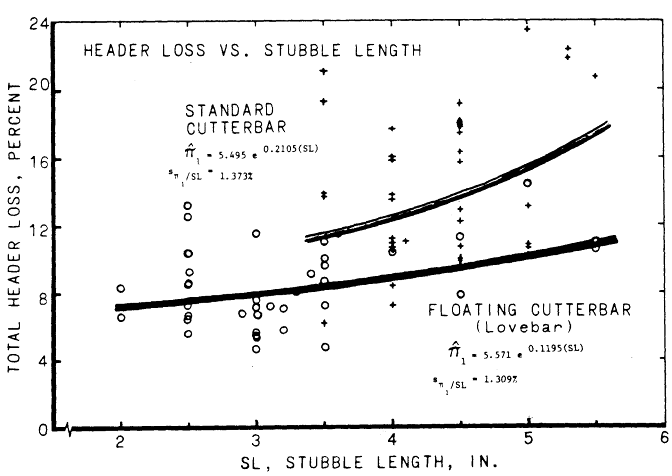

FIG. 8 Influence of stubble length on header loss, Lovebar versus standard cutterbar.

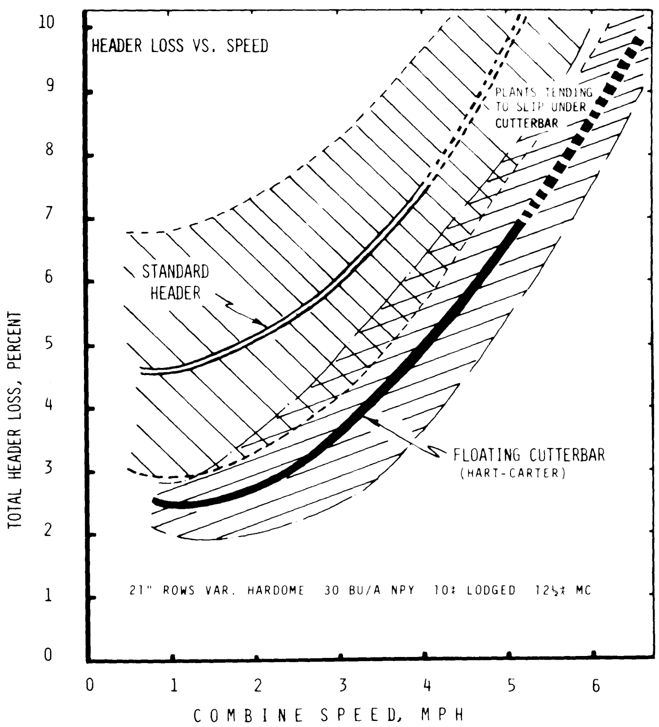

FIG. 9 Header loss/forward speed characteristics of a Hart-Carter floating cutterbar versus standard cutterbar.

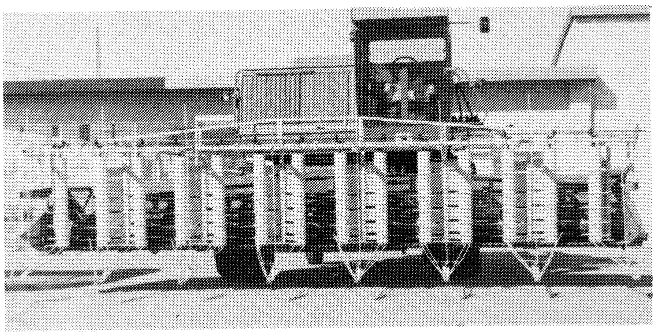

FIG. 10 Lynch row-crop vertical drum reel.

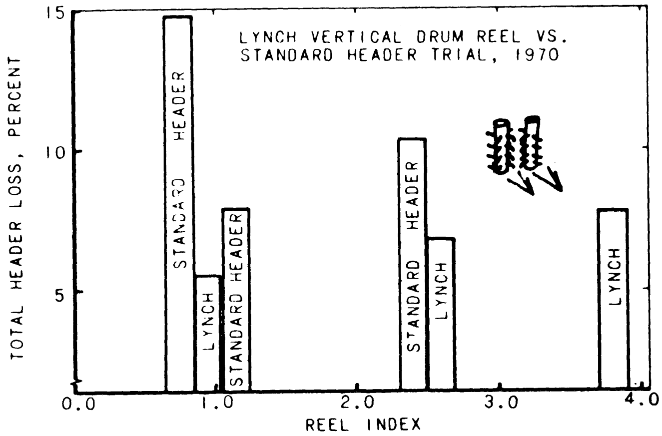

FIG. 11 Lynch reel and standard fixed platform pickup reel header compared at three reel indices.

- some degree of rock protection for the header, and
- smoother crop feeding under the platform auger.

Vertical Drum Reel

The Lynch row-crop header attachment was developed initially for sorghum as a replacement for the pickup reel, Fig. 10.

A four x 30-in. row unit was installed on the Case 10-ft header. Two seasons testing under varying crop conditions indicated a highly significant loss reduction over the standard header in all conditions and as much as 53.5 percent in lodged crop. This was primarily due to reduced stalk loss and better control over the plants during cutting, Fig. 11.

The Lynch row dividers performed very effectively as crop lifters, a major factor in the improved header performance under lodged conditions. It was necessary, on the other hand, for an operator to pay closer attention to driving the unit so that the row dividers remained near row centers, otherwise stubble length could increase. Best "reel index" for the Lynch was estimated around 1.5.

PERTINENT CROP CHARACTERISTICS

Pod Shatter

Pod shatter strength was investigated by several techniques: pod centrifugation, vibration, impact, tension, and compression (Quick 1974). The *agronomic* shattering index of varieties examined here did not correlate with their machine shattering propensity. A mechanical shatter index is proposed based, for example, upon the reciprocal of the pod compressive strength, Fig. 12.

The compressive shatter index was the easiest to determine of the techniques listed. Pods were mounted with suture vertical between anvils of an Instron TTBM test machine and compressed at 1 cm per sec loading rate. Fig. 13 shows a typical test result.

In spite of the limitations on the extent to which a slow speed Instron test might be used to represent a dynamic situation as at the header, it is anticipated that with further study a good correlation will be confirmed between the machine shatter loss of a soybean

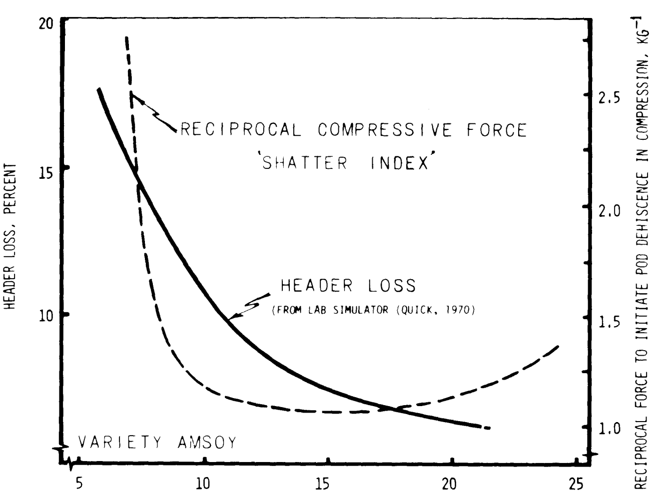

FIG. 12 Pod compressive shatter index and influence of moisture content.

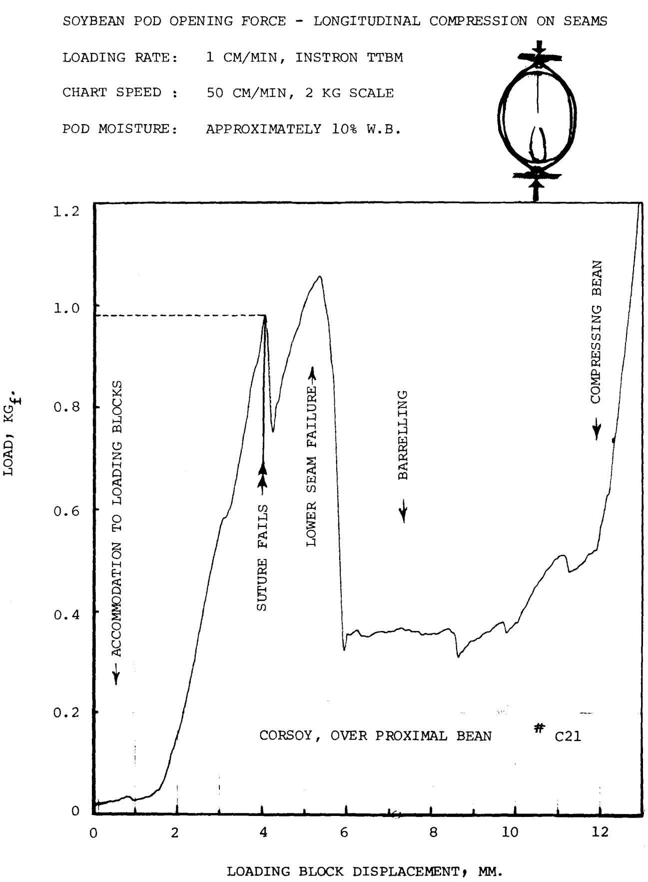

FIG. 13 Facsimile of chart from Instron pod compression test.

variety and its compressive shatter index. This may prove a useful quantitative criterion in plant breeding. The breeding of a new variety may take over a dozen years from concept to reality. Certain recent agronomic developments are tending to aggravate the engineering problems, e.g. a growth - regulant spray that lowers the plant's center of gravity and produces more branching low on the plant. Not all the combine gathering loss problem can be laid at the engineer's doorstep.

Criptic Shatter

Plants of variety Amsoy were observed to have an occasional pod partly dehisced early in one harvest season. The term "cryptic" shatter was coined for pods that had the suture partly open. Plants bearing such pods could not be handled without shattering these pods. If only one pod on each alternate plant fell into this category, the potential shatter loss would be 1 bu per acre, or 2 percent loss in a 50 bu per acre field. Such a loss level was estimated to exist in the Amsoys in 1971. This would represent the lowest practical limit of header loss attainable.

CONCLUSIONS

The cutterbar was found to be the chief constraint on combine capacity in soybeans. The most effective header attachments and modifications were those which assisted in or improved the crop cutting action and reduced header losses accordingly.

A substantial improvement in soybean harvesting efficiency could make a modest improvement in the national yield level, but a header design that substantially reduces gathering losses would make a large difference in the farmer's profit picture.

A competent operator in a good crop year could reduce header losses to one-half or even one-third the 9 percent U.S. average loss by harvesting early, operating when crop moisture is higher, and traveling slower (Byg and Johnson 1970). Narrow-row cropping is a positive aid in the Northern States.

The recent rise of the soybean crop to the fore in U.S. agriculture might be expected to hasten the widespread adoption of header attachments such as the floating cutterbar and contribute to improved management and harvesting practices. But the ultimate reduction in soybean gathering loss may depend on the plant breeder.

References

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APPENDIX

STANDARDIZED EXPERIMENTAL PROCEDURE FOR FIELD HEADER LOSS TESTS

Plot Size

Total yield was assessed from the sum of the bin yield (collected in a bushel basket under the outlet of the clean grain cross conveyor on the combine) plus all losses.

To minimize error in measuring bin yield to less than 1 percent (a measurement which has to be made quickly and readily on the machine in the field environment) the plot size should be sufficiently large so that bin yield is over 100 times the least scale division of the weighing scale; i.e., 10-lb minimum. In a 35-bu per acre crop and with a 10-ft wide header, this amount of yield would be produced from a 26-ft long plot (if losses were at worst 20 percent of total yield).

For convenient conversion to lb per acre units, most of the field plots were trimmed to 43.56 ft length; i.e., a 1/100-acre swath. Standard row spacing for the trials was 30 inches.

Preharvest Loss

Preharvest loss was assessed by sampling beans and pods on the ground in 3-ft x 5-ft areas in randomly selected unharvested rows adjacent to the plots.

Extension Methods of Measuring Header Losses Unacceptable

Extension Service pamphlets and some articles have advocated that header losses be measured by the following procedure (paraphrased):

"Stop combine where crop is typical of entire field, clear the header. Back up combine about 15 ft. Gathering unit losses are determined by placing the rectangular frame in the space between the parked combine and the uncut beans."

Although there is no desire to discourage farmers from conducting spot checks on their header losses, as enabled by this method, it has some drawbacks for the type of investigations involved in this study: (a) The area available for sampling is too small. (b) Combine speed over the area sampled, where the machine is decelerating to a standstill, cannot represent normal operation. (c) Less practicable at speeds over 4 mph. (d) Plants fall out of the header if machine is jerked to a stop and backed up. (e) No control over bin yield determinations. Bin yield varies considerably from place to place and should ideally be measured over the entire loss-assessing area.

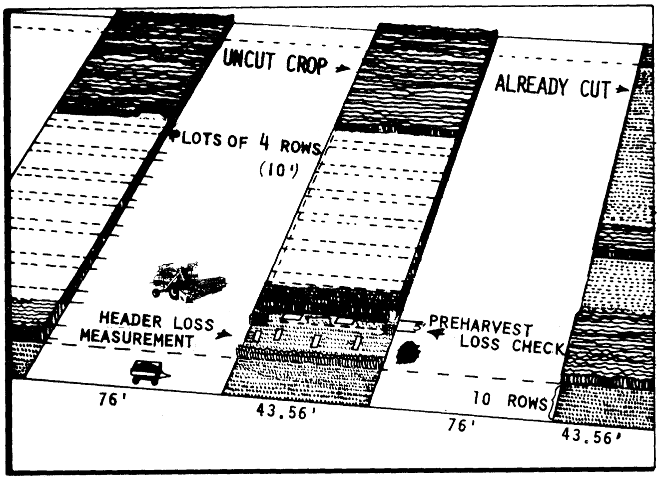
The preferred method, used here, was to run the combine completely over a predesignated and measured area, at the same time preventing the efflux from falling on the plot. This efflux material was collected in a 8-ft-wide, open-sided canvas and frame and then dumped outside the plot area. Crop remaining on the plot represented header and preharvest losses, disturbed only by the combine wheels (with the low ground pressures of the combine tires, losses were not obliterated). 40-to 80-ft wide turn alleys were left for maneuvering at each end of the plot, Fig. 14.

Loss-sampling Frame Size

A separate experiment was conducted in 1967 with USDA agricultural engineers to determine the smallest sampling frame size (FRASI) and number of subsamples needed for a given degree of experimental precision. On the basis of this experiment, the decision was made to use sampling frames 1/10,000 acre (60-in. x 10.5-in. inside dimensions), thrown down four times at random locations across two rows within the plot. Individual loss data were categorized and entered on standard data forms in beans per frame (BPF) units.

Experimental Designs

Experimental designs and layout were planned before planting in consultations with ISU Statistical Laboratory staff. Randomized, complete-block or multifactor factorial designs with replications were generally used. The size of an experiment and number of replications were chosen so that the whole operation could be conducted in one afternoon. Experiments were not normally conducted earlier than 2 p.m. so that diurnal moisture variations would be minimized. Plots were marked with



Typical Field Plot Layout. Bin yield, the combine losses, preharvest loss, combine speed, cutting height, and stubble length are measured in the field.

Personnel Required	Equipment
Driver	Combines, bin sample weigher
Supervisor/Recorder	Stopwatch
Timer	Measuring tapes
Yield Measurer	Measuring loss frames
Loss Samplers	Moisture sample bottles
Dump Supervisor	Labels, stakes

FIG. 14 Field measurement of soybean harvesting losses.

coded stakes and were separated from each other by at least two rows.

Typical Field Procedure

After the machine was serviced and warmed up, several trial runs were made in adjacent plots where operational settings were checked. Preharvest loss was assessed. The experiment then proceeded. (a) Attach bushel basket to clean grain spout of combine. (b) Attach discharge catching frame and canvas to rear of combine. (c) Run combine through plot (same driver for all tests). (d) Stop 30 to 40 ft beyond plot; leave machine running 1 min. (e) Dump efflux, or store in container for through-combine loss assessment when required. (f) Measure BINYE on scale hooked on combine. (g) Collect sample bottle from these beans, seal, and label for later moisture and beans per lb assessments. (h) Enter data; move combine to next plot according to experiment plan.

After all the machine work has been done, then (i) Throw down the four frames in the plot; measure and record losses (two operators each measuring two frames), BPF units. (j) Measure stubble length of 20 stalks in the plot (STUBBL). (k) Punch data onto cards and send in for IBM 360/65 computer conversion into appropriate form, Fig. 15, for subsequent statistical analyses using Statistical Laboratory Computer Library Routines. Covariate analyses, as well as analyses of variance, were usually run.

APPENDIX

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$JOB            14244GROUICK    ,TIME=5,PAGES=10
C   ******* PROGRAM  TO TABULATE HEADER LOSS DATA AS PERCENTAGE OF
C           NET POTENTIAL YIELD FOR FIELD TRIALS OF COMBINE HEADERS
C           IN  SOYBEANS .     ********** GRAEME R. QUICK ********
C
C                   INDEX = DATA - END INDEXING NUMBER
C                   IDENT = PLOT IDENTIFICATION
C                   FRASI = SIZE OF MEASURING FRAME , SQ.FT.
C                   PREHAR= PRE-HARVEST  LOSS    , LBS/ACRE
C                   TRUCOL= THRU'COMBINE LOSSES , LBS/ACRE
C                   PLOTSI= SIZE OF FIELD PLOT        , SQ.FT.
C                   BINYE = BIN YIELD ,  ACTUAL PLOT YIELD
C                   BINPA = BIN YIELD ,CONV.  TO  LBS/ACRE
C                   SHABPF= SHATTER (+PREHARV)LOSS IN BEANS/FRAME
C                   STABPF= STALK ,OR CUTTERBAR,LOSS- BEANS/FRAME
C                   XLOBPF= LODGED  LOSS              BEANS/FRAME
C                   STUBPF= STUBBLE LOSS              BEANS/FRAME
C                   SHALPA , ETC = SHATTER LOSS , ETC , LB/A
C                   TSHLPA= TRUE SHATTER LOSS , LB/A ,
C                         = SHALPA - PREHAR
C                   SHABPCT , ETC  =  SHATTER LOSS , PERCENT
C                   OF NET YIELD , ETC
C
      DIMENSION   STLPA(5) , XLLPA(5) , STUPA(5) , TSHPA(5)
     $,  THLPA(5) ,  BNPA(5) , IDEN(5) , STUBL(5),
     $SHPCT(5) , STPCT(5) , STUPC(5)  , XLPCT(5) , THPCT(5)
   50 READ (5,10 ) INDEX, FRASI , BEAPP , PREHAR , TRUCOL,PLOTSI
   10 FORMAT ( I1 , F9.4 , 4F10.4  )
      IF ( INDEX .GE. 9  ) GO TO 300
      WRITE (6 , 100 ) FRASI , BEAPP , PREHAR , TRUCOL , PLOTSI
  100 FORMAT ( /5X , 'EXPT INPUT DATA',//,5X,5F10.4 )
      WRITE (6 , 150 )
  150 FORMAT ( /5X , 'HEADER LOSS DATA EXPRESSED AS PERCENTAGES',
     $//,5X, 'PLOT' ,3X,'SHATTER',2X,'STALK',3X,'LODGED',2X,
     $'STUBBLE' ,3X,'TOTAL' , 2X ,'NET POTL',' STBL'
     $, /,5X, 'IDENT' ,4X, 'LOSS' ,4X,'LOSS',
     $4X, 'LOSS',4X,'LOSS',3X, 'HDR LOSS'   ,2X,' YIELD    HT',/,
     $55X,'LB/ACRE',' INS'//)
    5 READ (5,20,END=300)IDENT , SHABPF , STABPF , XLOBPF
     $, STUBPF , BINYE , STUBLL
   20 FORMAT(1X,I4, F6.1 , 3F10.1 , F12.2 , F9.2  )
      IF(  IDENT. EQ. 0  ) GO TO 50
      SHALPA = SHABPF * 43560.0 /( FRASI * BEAPP  )
      STALPA = STABPF * 43560.0 /( FRASI * BEAPP  )
      XLOLPA = XLOBPF * 43560.0 /( FRASI * BEAPP  )
      STULPA = STUBPF * 43560.0 /( FRASI * BEAPP  )
      TSHLPA  = SHALPA - PREHAR
      IF ( TSHLPA .LT. 0.0 ) TSHLPA  = 0.0
      TOHLPA =  TSHLPA + STALPA + XLOLPA + STULPA
      BINPA  = BINYE * 43560.0 / PLOTSI
      YLDNP  = BINPA + TOHLPA + TRUCOL
      SHAPCT = TSHLPA / YLDNP * 100.0
      STAPCT = STALPA / YLDNP * 100.0
      STUPCT = STULPA / YLDNP * 100.0
      XLOPCT = XLOLPA / YLDNP * 100.0
      TOHPCT = TOHLPA / YLDNP * 100.0
      WRITE ( 6,200 ) IDENT ,SHAPCT ,STAPCT ,XLOPCT ,STUPCT
     $,TOHPCT   , YLDNP  , STUBLL
  200 FORMAT (4X,I5, 2X , 4F8.4 , F10.4 , F9.2 , F5.2  )
      GO TO 5
  300 STOP
      END


     $ENTRY

EXPT INPUT DATA
      FRASI   BEAPP          PREHAR      TRUCOL    PLOTSI
     4.3560 2270.0000       0.0000     80.0000   300.0000

HEADER LOSS DATA EXPRESSED AS PERCENTAGES
```

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE	STBL HT INS
111	1.7003	9.1392	0.0000	4.0383	14.8778	2072.69	7.30
121	2.3008	10.8766	0.0000	1.6733	14.8507	2106.14	6.20
.	.	.	.	.	.	.	.

FIG. 15 Field header loss data-reduction algorithm.