LABORATORY THRESHING TESTS ON PEA BEANS USING LILLISTON CONVERTED PEANUT COMBINE

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LABORATORY THRESHING TESTS ON PEA BEANS USING LILLISTON CONVERTED PEANUT COMBINE

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ABSTRACT

LABORATORY THRESHING TESTS ON PEA BEANS USING LILLISTON CONVERTED PEANUT COMBINE

By Mohammad Asrar

The previous studies indicated that Michigan farmers suffered large losses in the harvesting of navy (pea) beans because of adverse weather conditions and inadequate harvesting equipment.

The primary objective of this investigation was to study the feasibility in general and threshing efficiency in particular of the Lilliston Peanut combine for navy (pea) beans. The investigation was limited to laboratory studies.

The work was carried out as follows:

1. Step by step changes in the machine accompanied by threshing tests.
2. Tests and analysis of data when the machine was ready for threshing tests.

From this study the conclusions drawn were:

1. The laboratory studies offer a good preliminary solution for studies like this one.
2. The present machine can successfully be converted for navy (pea) beans, probably with reasonable investment cost.

3. The navy bean plants can be stored, even though not ideally, without apparent weather deterioration for laboratory threshing tests.
4. More threshing tests are needed to study in detail the variables involved in the threshing of pea beans.
5. Changes in the cleaning screen, seed lift delivery tube, concave under cylinder number three and putting a new type of conveyor to replace the first two cylinders are to be considered first in this machine before releasing for field combining.
6. From the present threshing tests it can be said that efficient threshing by this machine will be at about the following conditions:
   a. Cylinder three speed 150 RPM.
   b. Cleaning fan air door 1/2 open.
   c. Tailboard three-fourths open.

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INTRODUCTION

Michigan contributed about one-third of the total edible dry bean production in the United States during the period 1954-63. The $37,957,000 annual return to Michigan farmers from this crop ranks third in value of field crops (8). Tables I and II show the importance of beans as a crop in the United States and the leading producer states (26). As it is clear from Table II Michigan is the top producing state of beans, therefore, related studies to beans is of great significance.

Navy (pea) bean, or white pea bean, as it is called sometimes, is the most important class of dry edible beans in Michigan. Michigan farmers in recent years, have produced more than 98 percent of navy (pea) beans grown in the United States (8). The production of dry edible beans by classes in the United States is given in the Table III (26). Navy beans have a wide market across the country and, in recent years, up to 25 percent of the Michigan navy beans have been exported (8). The canning industry uses most of the Michigan grown navy and red kidney beans. More than 90 percent of the navy beans consumed in the United States are canned. Canners like the navy (pea) beans because they remain whole and retain their form in the can after processing.

The production of dry edible beans is not only limited to the United States; many other countries contribute their share to the total world production. Table IV shows the acreage, yield and production, in specified continents, of this crop (26).

TABLE I

DRY EDIBLE BEANS

U.S. ACREAGE HARVESTED AND YIELD

YEAR	ACREAGE HARVESTED	AVERAGE[1] YIELD
	1,000 acres	pounds
1930	2,160	663.9
1940	1,903	890.0
1950	1,511	1,001.0
1960	1,434	1,249.0
1964	1,452	1,225.0
1965[2]	1,533	1,076.0

Source: U.S.D.A. Agricultural Statistics 1951 and 1966.

[1]Clean basis

[2]Preliminary

TABLE II

DRY EDIBLE BEANS

ACREAGE, YIELD AND PRODUCTION by STATES

	ACREAGE[1]		YIELD		TOTAL PRODUCTION[2]	
STATES	1964	1965[3]	1964	1965[3]	1964	1965[3]
California	216	222	1,375	1,421	2,970	3,155
Colorado	217	228	740	860	1,547	1,883
Idaho	124	146	1,570	1,500	1,821	2,100
Kansas	8	13	1,100	1,100	77	110
Michigan	616	665	1,260	880	7,585	5,562
Minnesota	15	9	650	700	39	28
Montana	13	14	1,620	1,610	194	209
Nebraska	76	85	1,550	1,500	1,116	1,200
New York	107	111	1,100	850	1,166	910
New Mexico	7	7	700	560	42	39
North Dakota	27	25	610	900	110	198
Utah	10	8	300	500	30	40
Washington	22	22	1,850	1,750	407	385
Wyoming	51	51	1,370	1,450	685	682

Source: U.S.D.A., Agricultural Statistics 1966.

[1] 1,000 acres

[2] 1,000 cwt.

[3] Preliminary

TABLE III

BEANS, DRY EDIBLE (Cleaned basis) PRODUCTION

By Classes, Average 1959-63, Annual 1964 and 1965[1]

CLASS	AVERAGE 1953-63	1964	1965[2]
		1,000 cwt	1,000 cwt
White Pea (Navy)	6,601	6,785	4,887
Pinto	4,613	3,609	4,551
Great Northern	1,846	1,711	1,477
Red Kidneys[3]	1,457	1,636	1,366
Large Lima	835	678	755
Black Eye, Calif.	759	787	668
Small red	585	372	385
Small white	568	455	504
Baby Lima	479	275	211
Pink	339	354	406
Black Turtle Soup	168	265	239
Cranberry	126	100	96
Yellow Eye	80	26	30
Flat small white	62	59	72
Garbanzo	49	42	87
White marrow	39	22	26
Other	666	613	741

Source: U.S.D.A. Agricultural Statistics 1966.

[1]Soybeans and mung means not included

[2]Preliminary

[3]Include dark red kidney

TABLE IV

BEANS, DRY EDIBLE

ACREAGE, YIELD, AND PRODUCTION IN SPECIFIED CONTINENTS 1955-59, ANNUAL 1964 and 1965

CONTINENTS	ACREAGE[1] AVERAGE 1955-59	ACREAGE[1] 1964	ACREAGE[1] 1965	YIELD PER ACRE[2] AVERAGE 1955-59	YIELD PER ACRE[2] 1964	YIELD PER ACRE[2] 1965	PRODUCTION[3] AVERAGE 1955-59	PRODUCTION[3] 1964	PRODUCTION[3] 1965
No. America	5359	7484	7660	579	568	545	31045	42509	41785
So. America	6429	7505	7542	589	643	616	38474	48283	46492
Europe	3130	2810	2661	473	580	455	14808	16300	12109
Asia	521	496	520	1051	986	1174	5474	4890	6103
Africa	603	618	626	452	519	532	2726	3207	3333
Total World	16042	18913	19006	577	609	578	92527	115189	109822

Source: U.S.D.A. Agricultural Statistics 1966

[1] 1,000 acres
[2] lbs.
[3] 1,000 cwt.

The losses during threshing of different crops are known to all those who are familiar with farming operations. In the United States almost all the crops are harvested and threshed with combines. Most of the threshing losses are attributed to the design and improper use of a combine itself. A considerable amount of work has been done in this direction but there is much more to be done. The introduction of spring-tooth cylinder and concaves is an example of the recent developments (14). The Department of Agricultural Engineering, Michigan State University, in cooperation with the Department of Farm Crops, started work on bean harvesting and the losses involved in harvesting and threshing in 1947.

The present study covers the possibilities of converting the Peanut Combine (1500 series), manufactured by Lilliston Implement Company, Albany, Georgia, to navy (pea) beans, particularly the threshing efficiency. The study is conducted in the research shop rather than in the field. The machine mentioned above and the pea beans for storage are provided by the Lilliston Implement Company and the Department of Farm Crops respectively. The study involves step-by-step changes in the machine and subsequent threshing efficiency tests.

REVIEW OF LITERATURE

Beans in Michigan

It is reported that farmers in the French settlement of Detroit had supplied dry beans to Commodore Perry on Lake Erie in 1812. The Indian tribes in Chippewa and Saginaw were growing beans in Michigan in 1819 (24). The name navy bean for white pea beans is believed to be because of its naval and military importance.

Michigan produced more than 42 percent of all the edible dry beans in the United States in 1964 (26). The bean crop is an important crop for Michigan. Table V shows the acreage, yield, and production of dry edible beans in Michigan.

TABLE V

DRY EDIBLE BEANS, ACREAGE, YIELD, AND PRODUCTION MICHIGAN 1947-1965[1]

YEAR	ACREAGE HARVESTED	YIELD PER HARVESTED ACRE	PRODUCTION
	1000 acres	pounds (cleaned basis)	1000 cwt.
1947	467	670	2,847
1950	420	950	3,312
1955	504	900	4,536
1960	525	1,190	6,248
1964	602	1,260	7,585
1965	632	880	5,562

Source: U.S.D.A Agricultural Statistics 1949-1966

[1]Preliminary

In Michigan the two general types of beans are the vine type and the bush type. The bush type, the Michlite, stands fairly well and produces runners. The vine type called the Robust, grows profusely on the top of the soil and presents a difficult problem in harvesting.

Seeds of five navy bean varieties have been released to farmers during the period between 1957 and 1965 by the Michigan Agricultural Experiment Station and the United States Department of Agriculture cooperating. The bush varieties hold their pods off the ground better than the vine type beans; therefore, are less susceptible to weather damage after maturity, and usually have a lower pick. The vine type varieties can continue to blossom and set pods under hot and dry weather, whereas the bush type will suffer a substantial reduction of pod setting under such weather conditions. The bush type varieties give good production on fine-textured soils while the vine types grow better on sandier soils. Saginaw, the Thumb, and West-Central Michigan have the main concentration of navy beans (8).

Bean Harvesting Methods

In Michigan windrowing, stacking for curing, and then threshing with a stationary thresher was practiced for a long time (21). Direct combining was considered not practical until 1944, although combining from windrow was recommended under certain conditions (24). The beater harvester was one of the first machines for harvesting beans in North Carolina and Virginia. Losses involved in this machine gave a variation from 20 to 60 percent of the gross yield. The mower was very popular in harvesting different types of beans before 1922. The mowing loss, excluding threshing losses, generally amounted to 24.7 percent of the total yield. Beans were also harvested with a binder and threshed with a pea or bean separator, or grain thresher (26).

A series of tests was conducted by Bainer and Winter in California, with a combine using two rubber rollers. They succeeded in threshing very fragile beans without damage but the cost of the machine was higher (3). The use of rubber rollers or rubber bars in combines has not been widely accepted in Michigan.

The study of the different harvesting methods in Michigan has been started in the late 1940's. The various known harvesting methods as classified by McColly are pulling by a blade-type cutter usually in the form of a cultivator attachment; cutting with a rotary crop cutter; windrowing with a side delivery rake or with a bean harvester; stacking by hand or by machine; bunching by moving segments of windrows into bunches or by using a buncher attachment on a puller; hauling to a thresher or also into barn storage for winter threshing; stationary threshing; threshing machine converted to a combined harvester-thresher by the addition of a chassis and pneumatic tires, auxiliary motor, and special pick-up feeder; use of special bean combine; and small grain combine fitted with bean "attachment" equipment (14).

Field beans harvesting operations usually includpulling, windrowing, and combining from the windrow (8). In navy beans the operations involving bunching, stacking, baling, and stationary threshing have declined because of the harvester-threshers or the special bean combines. A number of both pull-type and self-propelled type combined harvester-threshers, fitted with a special pick-up device and feeder, came into use by converting threshing machines (14).

Pulling and windrowing of field beans can be done in two separate operations or as a single operation. The number of rows placed in one windrow depends upon the density of crop and the size of the combine used. The lower stem and attached root parts should be dried in windrows before combining (8).

Combine pick-up is the most common method employed in harvesting navy beans in Michigan. Some of these machines are used for both bean and other grain crops which reduces the overall harvesting cost per acre. Grain combines equipped with bean attachments are frequently used, although special bean combines are also used by farmers of larger bean acreages. Table VI shows the results of combining navy beans, utilizing a grain combine with bean attachment (8) (14).

TABLE VI

RESULTS OF COMBINING NAVY BEANS, 1955-56

	Good Operation Conditions			Beans Too Dry		
	Yield	Losses		Yield	Losses	
Harvesting Method	Bu/Ac	Bu/Ac	Percent	Bu/Ac	Bu/Ac	Percent
Direct combining	26.3	2.47	9.40	30.1	7.14	23.69
Cutter bar		2.37	9.03		7.00	23.22
Threshing		0.10	0.37		0.14	0.47
Combine pickup from rotary crop cutter						
windrow	26.3	0.47	1.80	30.1	3.50	11.62
After pickup		0.39	1.50		3.40	11.29
Threshing		0.08	0.30		0.10	0.33

Source: McColly, H.F., Harvesting Edible Beans in Michigan, ASAE Trans., 1958.

As it is evident from the above table the cutter-bar loss exceeds 9 percent and 23 percent under good and too dry operating condition respectively. The rotary crop cutter windrow, on the other hand, had a total loss of cutting and threshing of 1.8 percent and 11.62 percent under good and too dry conditions respectively. The rotary crop cutter windrows showed a pick up loss 11.29 percent, under too dry conditions, which means a saving of 11.93 percent.

Bean attachments for grain combines usually include kits for cylinder speed reduction, seed and dirt screens, and other parts which depends on the different makes and models. Some manufacturers have special cylinders, rubber covered bars and bean grates. The spike-tooth cylinder is quite popular. Bean combines usually have two cylinders specially designed for bean threshing and special separating and threshing units (8) (14).

The torsion spring-tooth cylinder and concave is a recent development in threshing edible beans, being very effective in threshing; causing minimum mechanical damage of seed; and results in less delay waiting for the heavy bean root and lower stem to dry out enough to go through conventional close fitting cylinder parts. But this equipment is not as effective in threshing small grains as other types of cylinders and concaves (14).

For the combine pickup the bean plants should be placed in fluffy windrows, free of clods, stones, and dirt. This prompted the development of bean windrowers. In case of heavy rains the bean windrower is also a useful tool for relocating the windrow. A blade-type harvesting cultivator attachment fitted with vine turners, row dividers and windrowing rods is a commonly used machine but suffers from the drawback that it pushes dirt and stones to the windrow with the beans and does not crush the root and lower stem to aid in rapid drying. The side deliver rake, equipped with bean teeth, is used to some extent with the idea to move the pulled beans onto clean ground and to lift them from clods and stones (14).

A rotary crop cutter has been under constant development in Michigan. It has given successful results in harvesting beans (15). Recent developments have included a six-row hydraulic motor driven mechanism mounted on a farm tractor.

Field beans should be harvested and handled at 17 to 18 percent moisture level in order to hold splitting and seed coat damage to a minimum. To minimize the shattering losses and to reduce the splitting losses, it may be necessary to harvest only in the morning and evening when the pods are tough. Spraying bean windrows with water to prolong or induce seed coat toughening protects the beans from cracking during combining without appreciably increasing their percentage of moisture content. Excessive percentage of split beans and checked seed coats occurs when harvesting is done at lower moisture levels (7) (8).

Defoliation of Beans

The weather hazards at navy bean harvest time necessitated defoliation tests. The two chemicals, dinitro-ortho-secondary-butyl and penta-chlorophenol, are satisfactory. Analysis showed that defoliating chemicals absorbed by the bean seed through the pods was negligible and not harmful to people (18).

The three conditions in bean fields where chemical defoliation is needed are green areas due to low wet spots which cause the plants to have a slower start in growing, or more moist areas during summer dry days, which keeps the beans green; the pods are dry but the plant stems and leaves are green; and the plants have a new growth of leaves while the pods are ripe. The chemicals which do not discolor beans cause more even ripening and mature the crop earlier (18).

Both air and ground spray of defoliants may be applied. The main problem in the ground spraying is that of developing suitable vine lifters. An adaptation of the vine lifters from the rotary crop cutter was applicable. The loss of weather hazard decreases by the use of rotary crop cutter after defoliation, followed by the combine pickup (14) (18).

Harvest Losses

Harvest losses vary from field to field and from farmer to farmer. According to a survey in the North Platte Valley, Nebraska, the range of these losses was from 44 to 559 pounds per acre. It was estimated that 12 percent of the beans were left in the field after harvest. It shows that at present prices and acreage such losses would be in millions of dollars for the country (19) (22).

The factors responsible for these losses may be improper operation of machinery; mechanical limitation of machinery; poor cultural practices with regard to weeds and field surface uniformity; climatic conditions; and plant characteristics with regard to pod shattering, proximity of pods to soil surface, and uneven ripening. Improper adjustment of machinery is often the major source of these losses (19) (22).

The machinery now available for harvesting field beans can be improved. Better use of the available machinery needs to be made until new improvements are forthcoming. It has been demonstrated by some farmers that harvest losses can be held to a minimum if machinery is used at the correct time and proper adjustments are made (23).

Grain or seed losses generally include: shatter loss of overripe grain prior to harvest, cutter-bar loss consisting of missed and dropped heads or pods and grain or seedshattered on the ground in cutting, cylinder loss of unthreshed heads or pods passing out in the straw, rack loss of loose grain or seed passing over the rack with straw, and shoe loss of loose grain or seed blown or carried out with chaff.

Shattering loss in beans may be attributed to the overripeness of the crop before harvesting operations, or to the pulling and windrowing operations, or both. Every four or five beans left in the field per square foot of land means a loss of one bushel per acre. Windrow pick losses can be kept to minimum by careful handling, and by harvesting when the pods are tough (8).

Cutter-bar loss is determined by picking up the grain or seed on sample areas, after knowing the shattering losses. Cutter-bar loss amounts to 75 percent of the total grain lost (12). In a very dry crop, cutter-bar loss increases but threshing loss decreases. The bean pods have a tendency to hang close to the soil surface which causes increase cutter-bar loss. The uneveness of the ground and presence of stones makes it very difficult to get low enough to pick up all the pods (13).

Careful coordination of rate of ground travel with reel rotation, when a power operated reel is used in direct harvesting of dry beans, is necessary. If the ground speed is too low compared to reel speed, the reel speed tremendously shatters beans from the pods. In finger-type reels the tines can be adjusted to incline slightly upward as they lift the bean plant toward the cutter bar and thus decrease cutter-bar and shatter losses by 50 percent. For this reason the finger-type reel is more efficient than the standard bat-type reel (15).

The seeds are shattered out of the heads or pods by the impact of blows from the cylinder and the concaves. With field beans, cylinder losses are usually very low but split beans and cracked seedcoats from over threshing is a more serious problem (8). But this source of loss is the most important one because of the effect of the action of the cylinder upon the other loss sources (13).

Determination of the cylinder loss can accurately be done by catching the straw coming off the rack over a measured area and threshing the grains or seeds from the unthreshed heads or pods. This loss can be minimized by more threshing action without cracking seeds. It is often better to accept a small cylinder loss by lowering rack and shoe losses (6). Cylinder-concave clearance, uniform feeding, moisture content of the crop, presence of weeds, cylinder speed, number of concaves, and efficiency of the operator are the various factors which effect this loss. The cylinder-concave clearance from 1/2 to 3/4 inch, cylinder speed of about 1/3 to 1/2 of that required for threshing wheat, uniform feeding, no weeds, moisture content of 18 percent, enough concaves, and an efficient operator who is well acquainted with the mechanism and operation of the machine keep this loss to the minimum. Too narrow or too high cylinder concave clearance, unparallel cylinder and concaves, and improper functioning of separating mechanism which causes rethreshing some of the grain increases the percentage of mechanical damage (13).

Threshing conditions change appreciably from season to season, from day to day, and even the same harvesting day. The operator should make appropriate adjustments in the machine according to the threshing conditions if good results are to be obtained. Improvements in design which can make possible threshing without being too sensitive to moderate changes in conditions need due considerations. Spring-tooth cylinders and concaves is the new development of design in bean harvesting (13) (14).

Rack loss is the loose grain shaken out with straw over a measured area. Straw rack loss is generally quite low but may become heaviest by a too-high or a too-low speed, overthreshed straw and green weeds, or plain overloading due to cutting too low or traveling too fast. The loss due to rack and shoe which is also called the separating loss, is the main loss and considered to be a standard of the other sources of loss in harvesting small grains. A very high rack speed keeps the straw up and does not allow it to settle down enough to be fully caught by the next upward movement. A too-low speed does not pitch the straw sufficiently to allow for thorough separation. The speed of the rack needs adjustment according to the different loads passed over it (6) (18) (17).

Shoe loss is determined by collecting the material coming from the shoe over a measured area. Sources of this loss are primarily overloading, excessive air, and too little sieve opening. High shoe loss is associated with high rack loss, usually. Sometimes fine straw falls over the sieves and to blow it away the air speed should be increased. This straw often carries some seed along with it. Beans separate easily from straw because of their heavy weight and large size as compared to other grain. Separating losses in beans are generally low. To reduce returning of the threshed beans to cylinder and consequently to reduce splitting loss, manufacturers recommend a special sieve with 3/8 inch round holes for bean harvesting. Excellent cleaning will result by replacing the coarse adjustable chaffer with a lower adjustable sieve (11).

Mechanical Damage of Pea Beans

The mechanical properties of a material are those which describe its behavior under applied forces. Strength, elasticity, stiffness, ductility, plasticity, and brittleness are the fundamental mechanical properties (20).

Pea beans are fragile and are often damaged during normal handling operations. Beans with over five percent checked seed coats are difficult to market (8). The grade regulations on split beans and restrictions imposed by canners on checked seed coats show the undesirability of mechanical damage (9). Baldhead or other abnormalities in bean seedlings often results from roughly treated seeds (25).

The two types of mechanical damage are the visible injury and the internal injury. Beans without apparent seed coat damage may have internal injury which can not be detected before germination. The amount of visible and internal injury of seed is a function of the variety used, the level of maturity, and the violence of the mechanical handling (8) (25).

Brown (5) was the first to initiate work on the forces required to damage pea beans. Variations in forces, from 12 to 42 pounds were found to crack the seeds, when applied by flat surfaces to sides of the beans, for beans of from 6.9 to 9.2 percent moisture. Forces required for beans of similar moisture content, in edge position, were from two to over 45 pounds.

Harter (10) found "baldhead" from 0-30 percent and 10-20 percent in dry bean and snap bean seedlings respectively. He also concluded that "baldhead" results from three distinct causes--mechanical injury, damage by bacteria, and damage by insects. Associated Seed Growers, Inc., (1) studied the variety Tendergreen and reported that mechanical damage varied from 1-30 percent.

Borthwick (4) studies on Lima bean seedlings showed that practically every part of the embryo is susceptible to some kind of threshing injury. Bainer and Borthwick (2) found that beans of low moisture content were damaged more by a threshing machine. The cylinder speeds needed to produce 15 percent of the total damage in Fordhook beans containing 15.9, 17.3, and 18.8 percent of moisture were 1,150, 1,330, and 1,600 feet per minute respectively. Associated Seed Growers, Inc., (1) dropped seed of 8, 10, and 12 percent moisture several times from different heights. The mechanical damage to beans showed to be cumulative; many low drops may cause as much loss in germination as one or two high drops. They also found that the lower the moisture level, the greater the damage. Perry (20) reported in the variety Michelite that mechanical damage varies proportionately with height of drop up to 45 feet. He also reported that damage was reduced considerably at higher temperatures and high moisture contents. Solorio (25) beat mechanically 41 strains of pea beans and found considerable difference in damage of different strains.

ORIGINAL RESEARCH

Bean Harvesting Developments

The first half of the twentieth century has seen more new technical developments in every field of science than ever before, and the rapid advancement in technology is still a continuous process.

A number of people at Michigan State University are working on the navy (pea) bean from different angles. Plant breeders and plant pathologists are doing research to find new bean varieties which are resistant to diseases, high in yield, and suitable for mechanical harvesting. Agricultural Engineers, on the other hand, are tackling the bean problems from engineering aspects.

The direct combining of the bean is still a problem, but not considered to be impracticable. To know the problems and trends in bean harvesting, a number of questionnaires have been sent to Michigan farmers since 1947. The farmers are constantly trying to find better methods by practicing newer techniques.

All the harvesting methods practiced at present suffer from disadvantages of one kind or another, but combining from the windrows is the most commonly accepted method.

Purpose of the present study

The problems encountered in harvesting and threshing of navy (pea) beans are numerous; therefore, possible studies in this connection should be made in the laboratory rather than waiting for field tests from one year to another.

The Lilliston Implement Company in Albany, Georgia became interested in bean harvesting and willingly furnished a Lilliston peanut combine (1500 series) for laboratory tests on May 18, 1966. To study the possibilities of converting this machine to a navy (pea) bean combine, some bean plants for storage were needed. Dr. Wayne M. Adams of the Crop Science Department, who was conducting field experiments on pea beans, provided about sixty bushels of bean plants at harvest time in 1966.

Description of the machine

The Lilliston Peanut combine (1500 series) is trailed and engine driven. The machine is drawn by a tractor while the picking, threshing, and separating mechanisms are driven by an engine mounted on the combine. Please refer to Figure I.

The principal parts of the machine are the pick-up assembly which lifts the windrow into the combine; the auger feeder assembly which delivers the crop to the first and the other three spring-tooth cylinders; the four spring-tooth cylinders which convey the peanut plants toward the paddles and clean the peanut plants from excessive dirt; picking cylinder screens for sifting dirt; the five adjustable stripper bars for controlling picking action; the four separating paddles which comb and carry the vines over four concave paddle screens which allow the picked nuts to fall through to the pan; the cleaning fan which provides an air blast to remove foreign material from the peanut pods; the adjustable tailboard for stopping the light but desirable peanuts from floating out with foreign material; the delivery hopper assembly conveying the peanuts into the air lift delivery system; the air lift elevator used to convey the peanuts into the tank or bag from the auger delivering to the left end side; the pan and hanger system consisting mainly of the pan floor section and the wood screen; stemmer and hanger systems below the wood screen, which includes mainly stemmer, tail board, tail gate, saw screen, and lip screen, separating fan assembly; the cylinder and

Figure I. Right side view of special combine with the chain covers removed header drives; paddle and saw drives; and the engine drive. Some of the important parts have been shown in Figure II.

The initial price of the machine is $3500.00. If successfully adapted or converted for navy (pea) bean, it could be one of the cheaper combines for this crop.

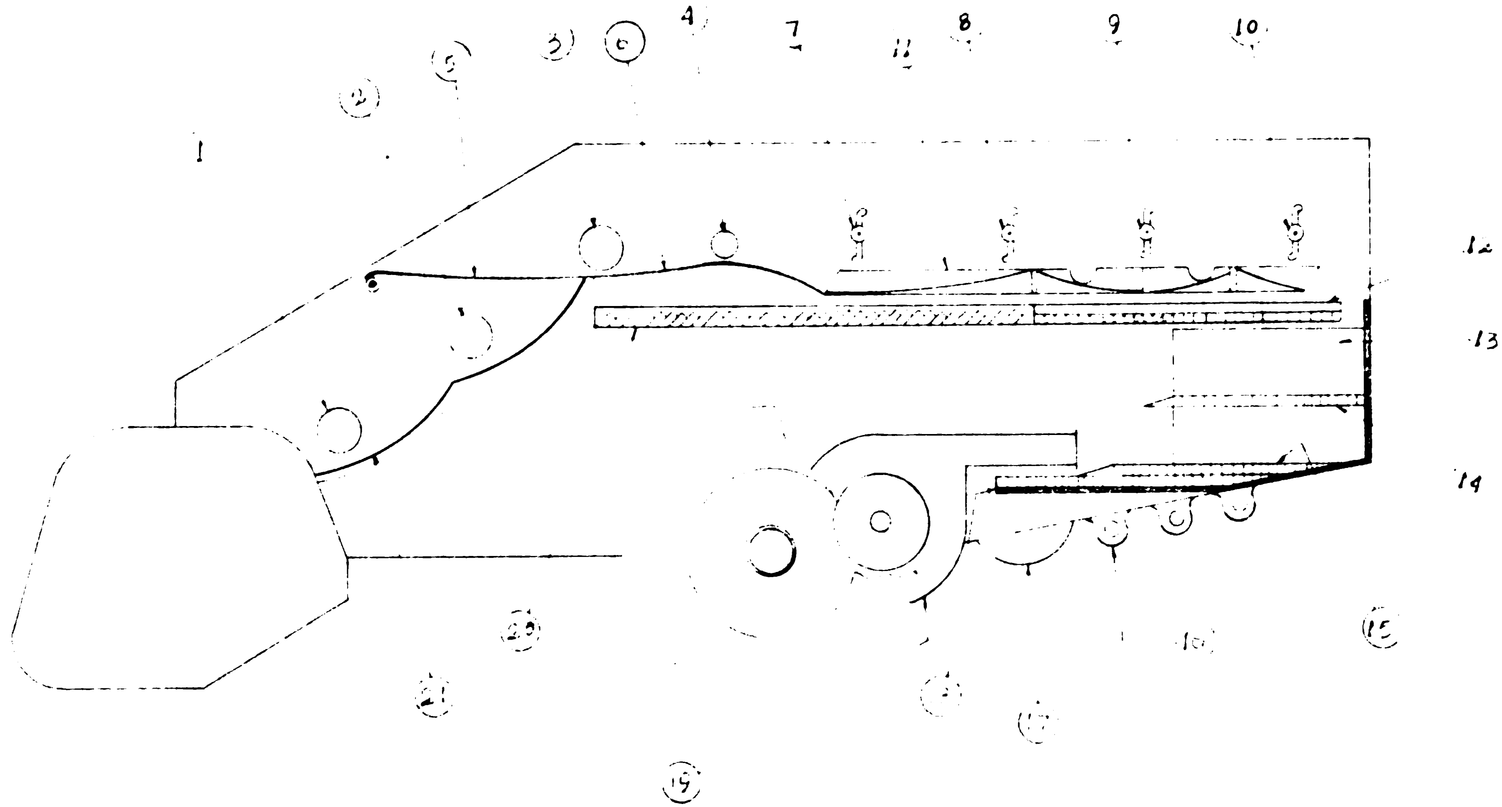
Experimental procedure

By studying the construction and operation of the machine in detail, it was determined to divide the work into separate categories--(1) the preliminary work which includes the step by step changes and rough observations of the tests, and (2) the final threshing tests which involved careful analysis of the results.

Preliminary work:

Before conducting any threshing tests it was obvious that the slots of the sand screens number one and two, the three rows of slots in the pan floor, and the slots of the saws screen were big enough to allow the threshed pea bean seeds to fall through to the ground. The sand screens and the three rows of slots in the pan floor were used in this machine to remove the heavy dirt

Figure II



Sectional View of Special Combine

Legend:

1.	Cylinder number one.	11.	Paddle screen.
2.	Cylinder number two.	12.	Wood screen.
3.	Cylinder number three.	13.	Tail board.
4.	Cylinder number four.	14.	Stemmer.
5.	Feeder	15.	Saw screen.
6.	Cylinder screen and concave.	16.	Saws shaft.
7.	Separating paddle No. one.	17.	Delivery Trough.
8.	Separating paddle No. two.	18.	Lip screen.
9.	Separating paddle No. three.	19.	Separator fan assembly.
10.	Separating paddle No. four.	20.	Pan.
		21.	Sand screen.

Sectional view of special combine

from the peanut plants going through the cylinders section of the machine. The saw assembly was installed to chop down the harder stems not blown out with the straw to smaller sizes to pass through the slots. Neither of the two problems of heavy dust nor harder stems is a serious problem in pea bean combining. Galvanized metal sheet (28 guage) pieces, one 56"x39 3/4", three 36"x6 11/16", and one 25 1/2"x39" sizes were used to cover the slots in sand screens, pan floor, and saw screen respectively. To get access to the sand screens and saws screen, the pipes of cylinder number one and two and saw assembly were removed. The cylinder pipes, saws shafts and pulleys were replaced after covering the slots with sheets, so that it would not change the other working conditions of the machine.

On October 7, 1966, the machine was tested for threshing for the first time. The main problem noticed was the threshing of bean plants by the first three cylinders; therefore few other tests which followed were mostly concentrated on the possibilities of using these cylinders only as conveyors. Two possible approaches were tried. First, each alternative cylinder bar from cylinders number two and three was removed with the plan to minimize hitting action of the cylinder bar springs to the pea bean plants, but it did not help appreciably. Second, different cylinder speeds from maximum to gradually slower ones were tried by controlling the throttle speed. These tests were ended when the cylinder number one and two speeds reached sufficiently below the ground speed of three miles per hour, the speed usually used in the field, and without noticeable change in the threshing amounts of these cylinders. This clearly suggested that cylinder one and two cannot be used as conveyors. The calculations of workable revolutions per minute of the first three cylinders for field work and respective RPM of the cylinders during the last test of this kind are shown as follows:

a. PTO speed = 264 feet/min. = 3 miles per hour

   diameter of the first 3 cylinders = 26.5"

   (measured between tips of two opposite teeth)

   circumference of first 3 cyl. = 26.5"x $\frac{22}{7}$ = 83.3"

   RPM of these cyl. = 264" x $\frac{12}{83.3}$ = 38"

   (required to match the PTO speed of 3 MPH)

b. RPM Cyl. No. 2 (measured) = 24

   Number of teeth of the sprocket on right cyl. #2 shaft = 48

   Number of teeth of the sprocket on left cyl. #2 shaft = 17

Number of teeth of the sprocket on left cyl. #1 shaft = 54

$$\text{RPM cyl. \#1} = \frac{34\text{x}17}{54} = 7.6$$

Number of teeth of the sprocket on right inside cyl. #3 shaft = 42

$$\text{RPM cyl. \#3} = \frac{48\text{x}24}{42} = 27.44$$

Number of teeth of the sprocket on the right outside cyl. #3 shaft = 42

Number of teeth of the sprocket on the right outside cyl. #4 shaft = 19

$$\text{RPM cyl. \#4} = \frac{42\text{x}27.44}{19} = 60.65$$

As it is clear from these calculations that the first three cylinders must run at 38 revolutions per minute to match the forward travel speed of three miles per hour, but the speeds of the first two cylinders are 7.6 and 27.44 revolutions per minute respectively which are well below the initial speed. Therefore the first and second cylinders could not be used as conveyors. Installation of another kind of conveyor to replace the first two cylinders is necessary. The chain and pulley arrangement to drive the first and second cylinder was disconnected at this point for further tests.

The next step was to use cylinder three and four for all the threshing job. For this purpose, first of all, some kind of hand feeder was needed. Three pieces of galvanized sheet metal of the sizes 38"x28.25", 38"x7", and 38"x5 5/8" were cut. To make a hand feeder for the cylinders three and four, pieces were fitted such that it starts from beneath cylinder three and extends over the central bar of cylinder two and gives an open space from above of approximately one foot which is used for feeding the bean plants to cylinders three and four. The slope of this sheet hand feeder is such that the plants pushed by hand through the opening slip toward cylinder three. This sheet made hand feeder is represented by (5) in Figure II.

To test the threshing efficiency of the cylinders Nos. three and four, two bushels of bean plants were run through the machine and more unthreshed pods resulted at the rear and the delivery trough; very few cracks and splits at the rear and more cracks and splits in the seed bag; considerable trash in the seed bag; some whole pods dropping to the pan floor through the large holes in cylinder screen under cylinder number three. To control the dropping of unthreshed pods through cylinder screen some sort of concave was necessary to be put on this screen. A galvanized metal sheet (28 guage) 31"x40" with appropriate strip holes for the fingers of stripper bars number six and seven was fitted over the cylinder screen. The purpose of this concave was twofold; first to control the dropping of whole pods through the cylinder screen, and secondly to work as a concave and thus increase the threshing efficiency of the cylinders.

The next thing, to increase the threshing efficiency was to increase the speed of the two cylinders. The sprocket with 19 teeth on the outer right hand side of the shaft of cylinder four was replaced by a sprocket of 15 teeth. This arrangement of sprockets gave a speed of 220 and 616 revolutions per minute, at the maximum throttle opening, for the cylinder three and four respectively.

The machine was started to observe the results of the new changes. But after threshing about half a bushel of bean plants, some heavy roots were stuck in the holes of the sheet, left for strippers bars fingers. Consequently the sheet was raised from the surface of cylinder screen and resulted in breaking the flexible wire used for tying the sheet on the cylinder screen, due to the excessive friction force developed between the cylinder number three spring-teeth and the tying wires. To overcome this problem this 40"x16" concave under cylinder three Fig. I (6) was covered by expanded metal lath as shown in Fig. III and IV.

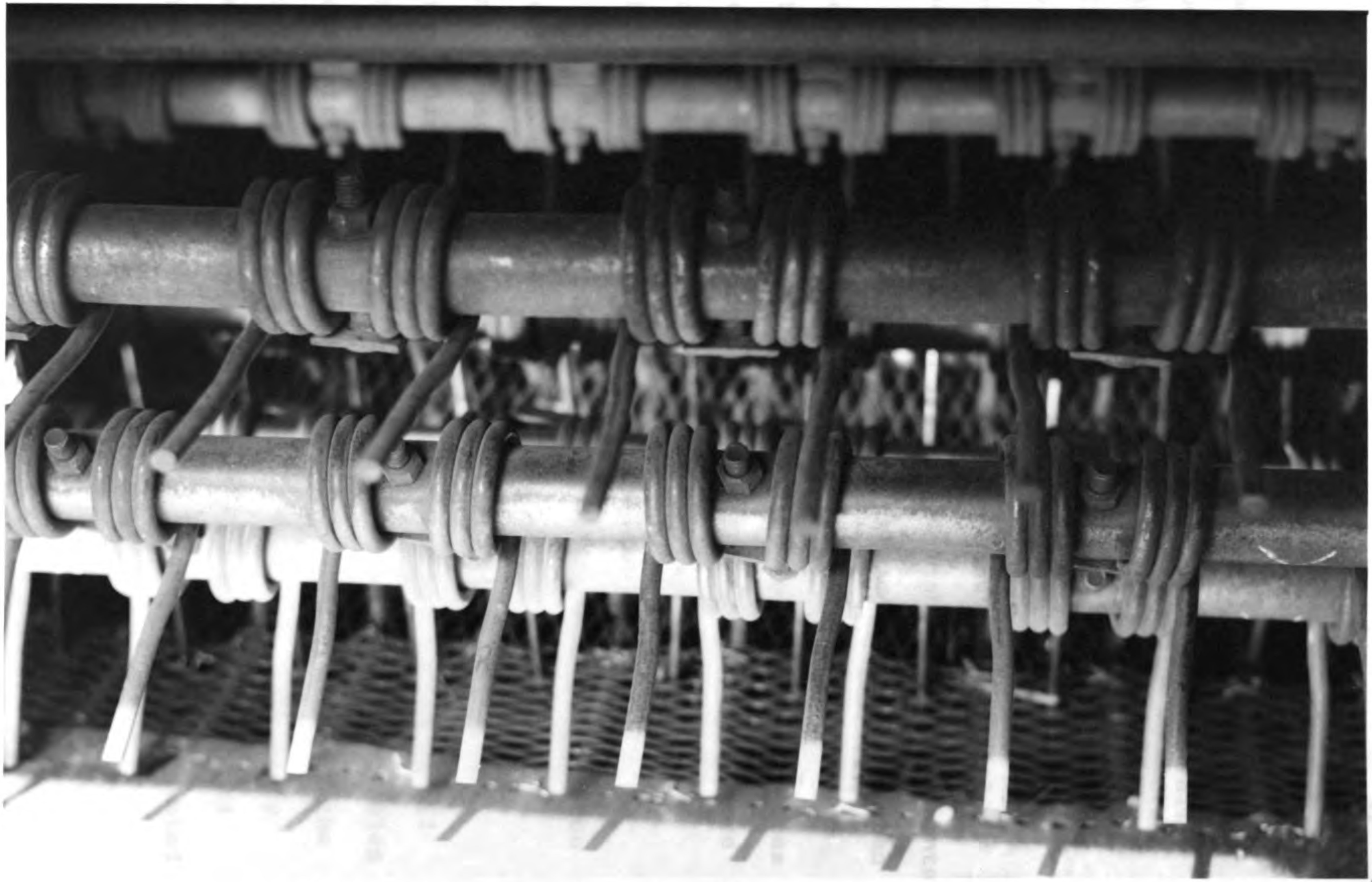


Figure IV. Front view of cylinder three and expanded metal lath concave

The expanded metal lath was fitted such that stripper bar No. 6 was permanently kept at full engagement position. The stripper bar No. 7 could be used at full- and fifty percent engagement. Three slots for full, and fifty percent, and completely out of engagement are provided under every stripper bar handle. The clearance between the tips of cylinder springs and the expanded metal concave varies from 1/4 to 1/2 inch at various points.

In the next threshing test the amount of unthreshed pods decreased tremendously but still not negligible. These unthreshed pods were attributed to the larger spaces between every two spring on the cylinder three; therefore adding some more spring teeth to the bars of cylinder three seemed to be the next appropriate step.

Holes 3/8" diameter were drilled, centered between every two cylinder springs and one in the center of the empty space at one end of the bars. Cylinder springs from cylinder one and two were removed and fitted in all the new drilled holes except four holes. These four holes were left only on four cylinder pipes, one on each of the four pipes at the long open ends. They were left empty because of no obvious need. The addition of the new 44 cylinder spring to the 48 cylinder springs already mounted on the 12 cylinder pipes gave a total of 96 cylinder springs on cylinder number three.

On June 22, 1967 the machine was tested again. About two bushels of bean plants were threshed. The speed of cylinder three during this test was kept near 220 RPM. The bean plants were drier than normal field conditions. Cleaning of an air opening was little more than one-third. The results were no unthreshed pods at the rear, little seed damage in the delivery trough, more than 50 percent seed damage in the seed bag, and some trash in the seed bag. By careful observation it was found out that mechanical damage in the seed bag was mainly due to the wire dust screen in the elevator delivery tube which hit the beans very sharply because of the high speed of the beans in the delivery tube.

Since the investigation at this point was mostly concentrated at the threshing efficiency of cylinders, it seemed advisable to detach the auger delivery hopper assembly and put a box under the lip screen for collecting the threshed seed during the future tests.

Final Threshing Tests

To get best threshing results from any combine it is important to know the proper adjustments of the various variables involved. These threshing tests were mainly centered at the cylinder losses and the relationship of the cylinder losses to the other variables. Different cylinder speeds, position of the stripper bars, cleaning fan air openings, and amount of water added were used to see the results. The quantity of bean plants stored was not enough for a detailed study; therefore, clear cut conclusions can not be drawn because of insufficient data. The data shown in the Table VII, however, give some important information related to the problem.

The 14 tests given in the Table VI were run on different dates and the data was carefully analyzed for moisture content of the threshed seeds, threshed seed in the seed box, loss of threshed seed at the rear, unthreshed pods both in the seed box and the rear, visible mechanical damage to the seed in the seed box and at the rear, and trash accumulation in the seed box. Counts were made of cracked and split seeds. All the measurements were taken in grams. The amount of bean plants used for each test was one bushel.

Different cylinder speeds ranging from 150 to 283 RPM for cylinder three were used with the idea to find out the optimum cylinder speed for good threshing. The

Table VII Laboratory Threshing Tests of Navy (Pea) Bean With Lilliston Peanut Combine (1500 Series)

1			2	3		4	5	6	7				8				
									THRESHED SEED				UNTHRESHED				
									Seed Box		Rear		Rear		Seed Box		
Test No.	RPM Cyl. No. 3	RPM Cyl. No. 4	Water sprayed per bu. in c.c.	Position Stripper Bar No. 6	Position Stripper Bar No. 7	Cleaning fan air open	Total pre-threshing seed	Seed moisture percent	Grams	% pre-thresh-ing	Grams	% pre-thresh-ing	Grams	% pre-thresh-ing	Grams	% pre-thresh-ing	% cyl. loss
				Full	Engage	Extra[1]											
1	220	616	350	Engage	1/2	Minimum	1255.7	**	1220	97.16	7.7	.61	6.0	.47	22	1.76	2.23
2	220	616	300	"	1/2	1/2	1253		1220	97.37	11.7	.94	15.3	1.21	6	.48	1.68
3	150	420	300	"	1/1	"	1271.6		1254	98.61	5.4	.42	10.2	.81	2	.16	.97
4	150	420	450	"	1/2	"	1224.4		1200	97.56	2.7	.22	21.0	1.71	5.7	.51	2.22
5	220	616	225	"	"	Full	1433.3		1233	89.36	135	9.47	54.0	.38	11.3	.79	1.17
6	220	616	0	"	1/1	"	1400.0		1280	91.42	110	7.87	7.5	.53	2.5	.18	.71
7	220	616	125	"	1/1	4/5	1323.7		1260	95.16	50	3.8	10.0	.76	3.75	.28	1.04
8	220	616	150	"	1/1	1/3	1300.4		1275	98.04	15.6	1.2	5.3	.41	4.5	.35	.76
9	283	792	225	"	1/1	1/3	1278	13.2	486	38.02	792	61.7	0	0	0	0	0
10	245	686	400	"	1/1	minimum	1333.5	11.3	1187	89.01	138.5	10.4	3.0	.22	5.0	.37	.59
11	230	644	400	"	1/1	"	1313.2	12.0	1139	86.73	169.4	12.9	2.8	.21	2.0	.15	.36
12	230	644	550	"	1/2	"	1352	11.9	1192	85.20	146.5	10.7	9.0	.66	4.5	.33	.99
13	230	644	*	"	1/2	"	1372	18.9	1268	92.41	44.0	3.5	30.0	2.18	30.0	2.18	4.36
14	230	644	*[1]	"	1/2	"	1372.4	13.9	1280	93.29	89.0	6.5	1.53	.11	1.9	0.13	.24

*The bean plants were dipped in water for 1 1/2 hour, kept under plastic cover for 44 hours after removing from water, and left in open for next 3 hours before threshing.

*[1]Steamed for 15 minutes, kept under plastic cover for 44 hours, and left in open for 1 hour before threshing.

**Seed moisture for tests 1 to 8 was not recorded but it was probably around 12%.

Table VII (Cont.) Laboratory Threshing Tests of Navy (Pea) Bean With Lilliston Peanut Combine (1500 Series)

Test No.	VISIBLE MECHANICAL DAMAGE								
	Rear				Seed box				
				9				10	11
	Splits in total grams	Cracks in total grams	% splits & cracks	Splits/ 50 grams grams	Cracks/ 50 grams grams	% splits and cracks	% splits & cracks pre-threshing basis	Percent total prethreshing loss	Percent trash in seed box
1	0.0	0.0	0.0	1.6	6.4	16.3	15.5	18.34	22
2	5.7	4.0	83.0	0.8	0.8	3.2	3.1	5.73	.41
3	1.4	0.0	26.0	0.6	0.7	2.6	2.56	3.95	.04
4	0.0	0.0	0.0	0.1	0.3	0.8	0.78	3.22	.09
5	2.24	0.0	1.7	0.0	0.0	0.0	0.00	10.64	6.6
6	3.75	1.25	4.5	0.0	0.7	1.4	1.28	9.86	10.0
7	11.75	0.62	24.7	0.0	0.3	0.6	0.57	5.41	3.2
8	7.5	0.0	48.0	0.4	1.4	3.6	3.53	5.49	.25
9	10.0	3.6	27.2	0.0	7.5	15.0	5.7	67.4	0.0
10	120.0	8.0	75.8	2.3	2.0	8.6	7.65	18.64	0.0
11	42.0	0.0	84.0	0.5	1.9	4.8	4.16	17.42	0.0
12	41.4	1.8	86.4	1.8	3.3	10.2	8.69	20.38	0.0
13	16.3	1.3	35.2	0.0	1.4	2.8	2.58	10.46	1.19
14	30.0	2.1	64.2	1.3	1.9	6.4	5.97	12.71	0.11

*The bean plants were dipped in water for 1 1/2 hours, kept under plastic cover for 44 hours after removing from water, and left in open for next 3 hours before threshing.

*[1]Steamed for 15 minutes, kept under plastic cover for 44 hours, and left in open for 1 hour before threshing.

**Seed moisture for tests 1 to 8 was not recorded but it was probably around 12%.

cylinder speed was controlled by engine throttle during these tests because of the non-availability of extra sprockets.

The bean plants were stored in a covered shed with a height of about four feet, protected from the two open sides of the shed with wooden planks.

The plants were exposed to thawing and freezing which was inevitable under the conditions described; however, the changing weather conditions did not result in any apparent signs of deterioration except that the plants were drier than field conditions during harvest. To bring the plants to various conditions of dampness different amounts of water were added five minutes before the threshing tests. The range of the amount of water added per bushel was from 0 to 550 cc. for the first twelve tests.

Increased mechanical damage of seed, especially under higher cylinder speeds, was observed in the first 12 tests; therefore, the plants for the last two tests were treated differently to increase the moisture content of the seed and decrease the seed damage as a result. For the test number 14 the plants were heavily steamed for 15 minutes, kept for 44 hours under plastic cover so that the water absorbed by the pods could not evaporate but transfer to the seeds inside the pods. Then the plants were left to open atmosphere for one hour to evaporate the excess moisture from the pods before threshing. The principle behind this method was that the seed of bean absorb water very slowly and then release it also very slowly. On the other hand the structure of the pods is such that it both absorbs and releases water very quickly. The same principle was applied to the test number 13, but this time the plants were dipped in water for one and one-half hours, kept under plastic cover for 44 hours, and left for three hours in the open before threshing.

Two men were needed for running the tests. One for feeding the cylinders by hand and the other for holding the canvas cloth attached to the rear of the machine for collecting the straw. The straw collected was analyzed for whole threshed seed, damaged seeds and unthreshed pods, damaged seed, and trash due to inefficient cleaning. All the losses in different form were later converted into percent basis. All the percentages were calculated on prethreshing basis, which means the amount of seed present in the plants before threshing. The tailboard was 3/4

raised when the cylinder number three speed was 150 revolutions per minute and the cleaning fan air opening was half. For the tests where the speed of the cylinder three was 220 RPM or more the tailboard was full raised.

A baffle of a rubber piece was inserted as shown in Figure V between the cylinder four and first paddle so that the threshed seeds could not hit directly the metalpieces behind and consequently decrease the mechanical damage to the seeds.

Results and Discussion

For the tests where the cylinder number three speed was 220 revolutions per minute the percent of threshed seeds at the rear varied from 0.61 to 9.47. The variations were mainly attributed to changes in the cleaning air fan opening and efficiency of cleaning screens. The 0.61 and 9.47 percent threshed seeds lost at rear were for extra minimum opening and full opening of cleaning fan respectively. For the extra minimum opening a metal sheet cover, specially prepared for this purpose, was put on each side door of the cleaning fan. The cleaning air blast also affected the amount of trash accompanying the seed to the seed box. It was 22 percent

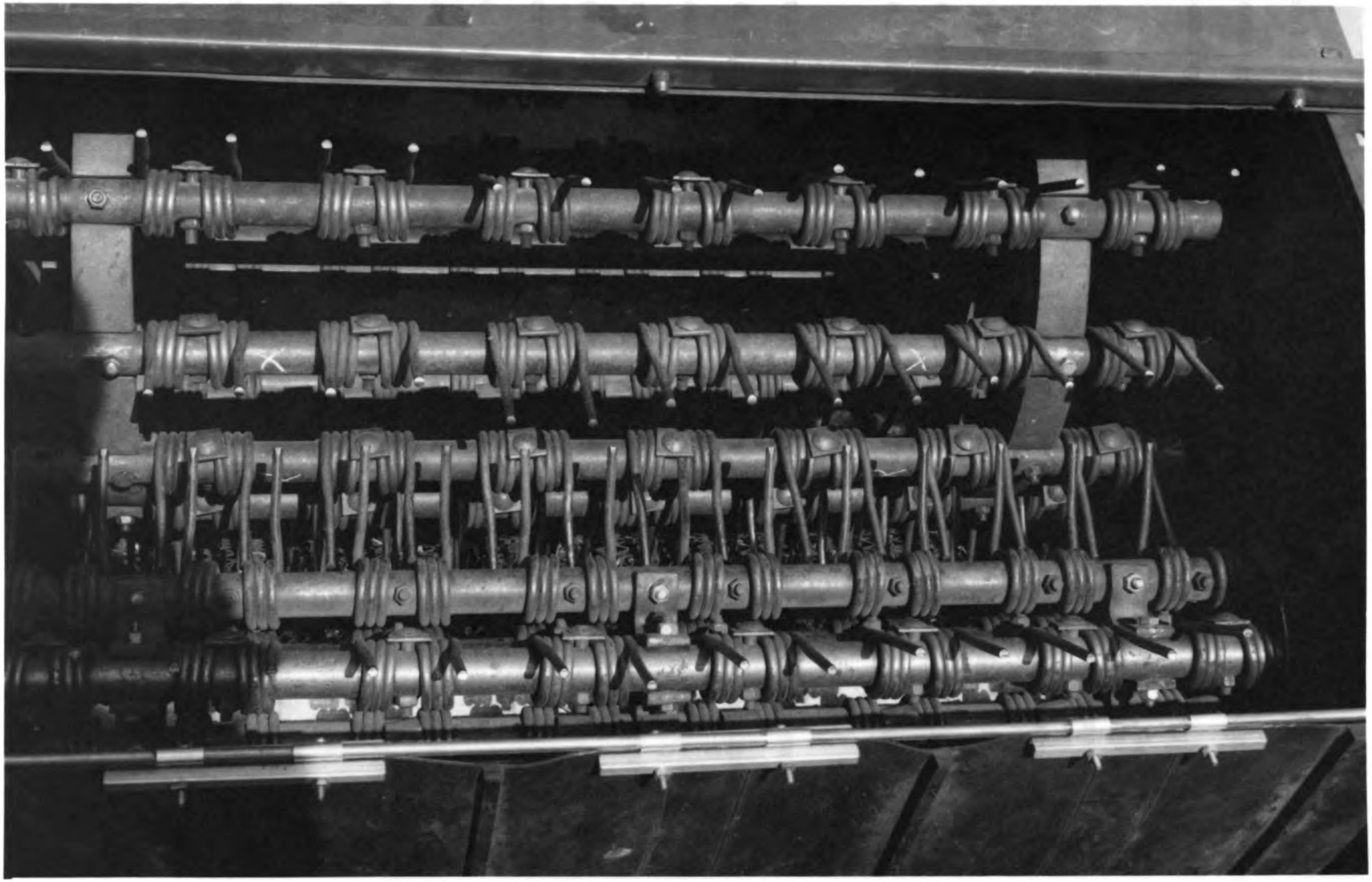


Figure V. Top view of inside machine from top center cover

seed in seed box under extra minimum cleaning air fan opening and only 0.41 percent when the cleaning air fan opening was in the halfway position.

The range of cylinder loss was from 0 to 4.36 percent depending upon the cylinder speeds and dampness of the bean plants. The 283 RPM of cylinder three gave no cylinder losses in the form of unthreshed pods but the losses at rear and mechanical damage of seed in the seed box raised to 61.7 and 15.0 percent respectively.

Visible mechanical damage in seed box varied from a minimum of 0.00 percent to a maximum of 16.3 percent. The main responsible factors for this were the cylinder speeds and moisture percent of the seed. It was 16.3 percent under a moisture level of about 11 percent when the cylinder three speed was 220 RPM. The damage was decreased to 1.4 percent when the moisture level of the seed was raised to 18.9 percent by dipping the bean plants in water, although the speed of cylinder three was 230 RPM in this test. The effect of cylinder speed difference is clear from the test numbers two and three where other conditions were the same. In these two tests the visible mechanical damage was 3.2 and 2.6 percent for the cylinder number three speed of 220 and 150 revolutions per minute respectively.

The overall losses which include unthreshed, mechanically damaged seed, and threshed seeds thrown out with straw gave a range from 3.22 to 6.74 percent. The minimum overall loss of 3.22 percent was found in the test number four where the cylinder speed was 150 revolutions per minute, cleaning fan doors were half open, tailboard was three-fourth raised, and amount of water added to the bean plants before threshing was 450 cc/bu. The different losses in these tests were 0.8 percent visible mechanical damage in seed box, 0.51 percent unthreshed in the seed box, 1.71 percent unthreshed at the rear, and 0.22 percent threshed seeds at the rear. Conditions for test number three were the same as for the test number four, except the amount of 300 cc. water added before threshing. This difference in the amount of water decreased the unthreshed pods but gave increased mechanical damage to bean seeds, resulting in overall damage of 3.95 percent. On the basis of this data the results from test numbers three and four seem quite encouraging.

The results of this study show that such investigations should be encouraged in the laboratory wherever possible.

SUGGESTIONS FOR FUTURE RESEARCH

1. The bean plants stored were not sufficient to get enough data; therefore, to find out the optimum condition of the machine, more threshing tests are needed in the future. Preferably it should be done during the coming harvesting season of beans when the plants will be in exact natural condition.
2. The continued loss of threshed seed at rear during this investigation suggests the replacement of the present cleaning screen with some kind of adjustable cleaning screen.
3. Placing and fixing finger teeth in the concave under cylinder three should be tested. This will most probably increase the cylinder threshing efficiency by not allowing the bunches of bean plants to pass through under cylinder three without taking out the seeds from the pods. This arrangement will also help in using the machine with slower cylinder speeds. This will consequently decrease the mechanical damage which results from the hitting of seeds with frame walls and other parts of the machine because of high cylinder speeds.

4. To make the machine workable for field windrowed beans a chain-type or auger-type conveyor needs to be put in the area of the first two cylinders, or to feed bean plants to the threshing cylinders.
5. Although the pickup and header assembly looks all right it still will be more desirable to test it after installing the new conveyor, and before any recommendation is made for field operation of the machine. This can be done in the laboratory if enough bean plants were stored from the harvesting season.
6. The wire dust screen in the elevator delivery tube should be replaced or covered with some sort of soft material like rubber or canvas to eliminate the mechanical damage to seed in this area. The speed of air from the air lift fan needs some investigation to find out the optimum opening of the fan door which will give efficient lifting of seed from auger delivery hopper assembly and at the same time minimum mechanical damage.
7. Proper inspection and structural analysis of bean plants in storage is suggested at different times of the storage period. This probably will help in

comparing the stored bean pod structural changes during storage to the bean pods at harvest time.

8. Some study is desirable to be done on the energy required to open the bean pods without damaging the seeds. Laboratory study on the bean pods during storage will offer a best solution to the problem.

SUMMARY

The navy (pea) bean is one of the most important field crops in Michigan. Some development in bean harvesting and threshing has been made but still it is far from the end.

The Lilliston Peanut Combine (1500 series), now under the process of conversion to pea bean windrow combining can be a successful machine for pea bean in the future. This machine gave encouraging results of threshing at the cylinder number three speed of 150 RPM, cleaning fan air door half open and tailboard three-fourth open. Modifications in the cleaning screen, lifting delivery tube and concave beneath the cylinder number three and installation of a new conveyor are the most important factors to be considered for future studies. More threshing tests need to be carried out before reaching to definite conclusions on this machine.

Laboratory studies of this kind are a success and should be continued in the future. This saves time and eliminates the long wait for harvesting season.

Laboratory studies are needed on the minimum energy required for opening the bean pods without mechanical

damage to the seeds.

The machine used for this study can be one of the cheaper and simple operated machines.

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