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EFFICIENCY OF HARVESTING NAVY BEANS WITH A COMBINE

Thesis for the Degree of M. S.

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Amir Ullah Khan

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THESIS

This is to certify that the

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"Efficiency of Harvesting Navy Beans with a Combine"

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Amir U. Khan

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H. F. McColly
Major professor

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EFFICIENCY OF HARVESTING NAVY BEANS
WITH A COMBINE

By

Amir Ullah Khan

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Approved
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INTRODUCTION

It has been frequently reported by those connected with agriculture, that large losses occur in the process of harvesting of different crops. Most small grain and other crops like beans, legumes and grasses are generally harvested with a combine in the United States. Most of these losses are, as such, attributed to a combine. Although, a considerable amount of work has been done to adapt a combine for the different crops and conditions and reduce the harvesting losses, the problem is still far from complete.

Practically every state agricultural experiment station and most of the combine manufacturing research departments, realize the importance of the problem and are constantly endeavouring to improve combine harvesting efficiency (13). For a number of years Michigan has also been working on the problem of reducing this tremendous loss of crops. The Agricultural Engineering department of Michigan State College, in cooperation with the department of Farm Crops, has been working on the combine harvesting of beans for the last five years.

In Michigan, which is the top bean producing state in the nation, a study of this sort is vitally important. Tables I and II show the importance of beans as a crop in the United States and the leading producer states (18).

TABLE I

DRY EDIBLE BEANS
U. S. ACREAGE HARVESTED AND YIELD

Year	Acreage Harvested*	Average Yield
1930	2160	663.9
1935	1865	768.6
1940	1903	890.0
1945	1485	881.0
1949	1852	1164.0

* 1,000 acres.

TABLE II

DRY EDIBLE BEANS
ACREAGE, YIELD AND PRODUCTION

States	Acreage*		Yield		Total Prod.*	
	1948	1949	1948	1949	1948	1949
California	368	363	1473#	1417#	5421	5143
Colorado	324	295	720#	860#	2333	2537
Idaho	149	149	1780#	1750#	2652	2608
Michigan	504	519	880#	1150#	4435	5968
N. Mexico	157	135	274#	410#	430	554
New York	170	156	1280#	1050#	2176	1638

* 1,000 acres
" 1,000 bags of 100#

Michigan produces about a third of the total United States production of beans. The most important class of this dry edible bean is the white pea bean, generally known as the Navy bean. Michigan produced 85 to 90% of this navy bean (15). Table III shows the average U. S. production by classes, of dry edible beans and their leading producer states in 1949.

TABLE III

DRY EDIBLE BEANS
AVERAGE PRODUCTION AND LEADING STATES

Class	1,000 bag*	Leading Producer
White Pea (Navy)	5,464	Mich; N. Y.
Pinto	4,199	Colo; N. Mex; Cal.
Great Northern	3,500	Idaho; Mo; Wy.
Lima	1,504	Cal.
Baby Lima	1,390	Cal.
Red Kidney	1,538	N.Y.; Mich; Cal.
Blackeye	346	Cal.
Pink	705	Cal.
Small White	679	Cal.
Small Red	604	Idaho; Cal.
Cranberry	458	Mich; Cal.
White Marrow	74	N. Y.
Yelloweye	159	Mich; N. Y.
White Kidney	10	N. Y.
Others	742	----
Total	21,554	----

*100 pound bags.

This study covers the efficiency of harvesting navy beans with a combine as affected by some variables. The variables involved are direct and windrow method of harvesting, use of standard and Hume reel, wet and dry crop and presence and absence of weeds. The trends of bean harvesting methods in the state of Michigan are also studied.

SURVEY OF PUBLISHED LITERATURE

History of Combine.

In the early days, most farming operations were done by hand. At first the little grain that was raised was shelled by hand but as the quantity increased, the kernels were whipped from the heads across sticks or pounded out by a staff or flail. Different crops were threshed differently, and the cleaning was done by winnowing. Small grain in the Asiatic and some of the European countries was treaded by animals to remove the kernels from the heads.

The first tool for threshing was the flail. By whom, and just when, it was invented is unknown. The Japanese people are believed to be the first users of the flail. This flail was the universal thresher till the introduction of a threshing machine. Flail was very popular with the Romans, English and most of the European people. Even in the United States it was common as late as 1912 (2).

The first person to produce a threshing machine was Jethro Tull of Shelborne, England. His machine did not prove to be very successful. Micheal Menzies produced a successful machine in 1732 which was powered by water. Later a number of English inventors worked on horse and water powered stationary threshers.

In the United States the first threshing machine was patented in 1791. During the nineteenth century a large number of people worked on threshing machines, producing a number of steam, water and horse powered machines. Most of these were stationary threshers although the later part of the nineteenth century produced some portable models. The portable models were nothing but stationary threshers on wheels. These wheels merely served the purpose of transporting the machine from one place to another and helped to thresh the grain right in the field. The crop was cut and mechanically brought to be fed into the thresher like any other stationary thresher.

The stationary and portable threshers were universally used for nearly two centuries but the invention of the present day combine has reduced their use tremendously. Table IV shows the annual production of stationary threshers and combines in the United States (18).

TABLE IV

Year	Sta. Thre.	Combines
1929	13,558	36,957
1930	8,635	24,409
1935	4,619	3,872
1940	2,054	46,552
1945	1,185	51,418
1949	2,062	104,888

In 1828 attempts were made to combine the two operations of harvesting and threshing but were considered impractical.

Similar methods were tried in latter years, but this method of harvesting did not become commercially established until about 1880. The first successful combine was built by Mr. Hiram Moore of Kalamazoo county Michigan and was shipped to California in 1854 (16) (7). During the later part of the nineteenth century, these combined harvesters and threshers, generally called combines, were confined to the states along the Pacific coast. It was generally believed that the weather conditions and crops in other regions were not suitable for its use (16) (7).

During and immediately after the First World War, the great demand for labor saving machinery, and the high cost of grain introduced the combine in the Great Plain States. Their introduction in the Corn Belt and other states was delayed because of the general belief that a combine can only be successfully used in dry areas with large acreages. The demand for a machine for harvesting soyabeans in the Corn Belt states and the demonstration of the practicability of a combine in the Pacific and Great Plain States, gradually brought the machine into the Corn Belt and other eastern states.

As the combine was gradually moving eastwards, the manufacturers were constantly working to produce machines more adaptable to the newer regions (10). Most machines in the Pacific and Great Plain states were large, heavy and much more suited to the large scale farming of the west. Their size ranged from 10 to 20 feet of cut. Gradually smaller sized combines, ranging from 5 to 8 feet of cut were manufactured.

Farmers in the eastern states had smaller acreages and were interested in machines that cost less and save time and labor. The smaller combines were well suited for their use as they cost considerably less, save time and a large threshing crew was not necessary (9). A farmer with average acreage of small grain can buy a small combine at an investment no larger than that represented by the ownership of a grain binder and a part interest in a stationary thresher.

Combining was first practiced in Michigan in 1927. Introduction of combines in Minnesota, Wisconsin, Illinois, Indiana and Ohio occured between 1925 and 1928 (1). Their rapid spread in Michigan is evident by the number of combines in use during the first three years of their introduction. There were seven machines in 1927, thirty-three in 1928 and fifty-four in 1929 (16).

The first three years of combining in Michigan were not very successful. Michigan conditions were so different, fields and grain acreages were small, crops were more diversified, straw was required for livestock bedding and above all was the unfavorable weather conditions during the harvest season.

Present day combines range from 5 feet to as large as 24 feet of cutter bar. The most commonly used combines range from 5 to 14 feet cutter bars. The most popular widths are

5, 6, 12 and 14 feet. Combines larger than 10 feet are available in either the hill side or level type models. The hill side type has a device to level the thresher so that the grain may not accumulate at one end of the cylinder.

Small combines with cutter bars between 5 feet to 8 feet can be power take off driven or be equipped with an auxiliary engine. Larger models are all equipped with auxiliary engines. Power take off driven models are cheaper in cost but in fields where the yield is heavy and there are low sandy or wet spots, the load on the tractor reduces the engine speed, at a time when constant speed is highly desired.

A combine may be pull-type or self-propelled. The pull type combines are hitched behind a tractor and are pulled by the tractor. The threshing power can be power take-off or auxiliary engine. The self propelled combines are of quite recent development. They are usually medium and large sized combines with one engine to provide for the propelling and threshing power. These machines are highly maneuverable and are popular in the large scale farming areas. Their high initial cost has been the limiting factor for Michigan farmers. Table V shows total production of self propelled combines in the United States during 1944 - 1949.

TABLE V

Year	Units Mfg.
1944	1,100
1945	3,287
1946	3,110
1947	5,506
1948	10,198
1949	13,671

Combines may differ as to the type of cylinder. It may be a spike tooth, rasp or bar cylinder. They also differ as to the arrangement of the different component parts.

Navy Beans in Michigan.

The Chippeway and Saginaw tribes of Indians, at the time of the Treaty of Saginaw in 1819 were said to raise beans in Michigan (15). Beans were also reported to have been supplied to Commodore Perry on Lake Erie in 1812 by farmers in the French settlement of Detroit. It is believed that white pea beans were named Navy beans because they were an important naval and military food.

Navy bean is the most important class of dry edible bean and is most widely marketed throughout the United States. It is also very popular with the canning trade. Michigan produces 30% of the total U. S. production, out of which, 85 to 90% is navy beans. Navy beans, thus, are one of Michigan's most important and dependable cash field crop. Table VI shows the division, in classes, of Michigan's bean production during 1931 - 1940 (15).

TABLE VI

Class	%
White Pea (Navy)	88.9
Cranberry	4.3
Dark red kidney	3.3
Light red kidney	1.5
Others	2.0

Harvesting of beans in Michigan has not seen much progress. Methods which were practiced about a hundred years ago (1859) are often practiced at the present times (14).

Beans have been harvested with the so called McNaughton system for a long time. Briefly, it is a method in which the beans are pulled, windrowed, stacked for curing, and then threshed with a stationary thresher. Its advocates claim it to be the best method for areas with poor harvest seasons (14).

Combining of beans in Michigan, specially direct combining, is of very recent introduction. Even as late as 1944, direct combining was considered impractical, although combining from windrow was recommended under certain conditions. An extract from a 1944 publication by H. R. Rather and H. C. Pettigrove (15) goes to show how recent has been the introduction of the combine for harvesting beans.

> "In general the use of the combine to thresh standing beans is impractical. However, the combine is often used to thresh beans from the windrow. This system is very economical of labor if the weather is favorable and the windrows are free from stones. In the case of heavy and continuous rains, serious damage to the crop may occur in the windrow before the beans are dry enough to be combined."

One of the first machines to harvest beans was the beater harvester which was used in North Carolina and Virginia. The losses from this machine varied from 20 to 60% of gross yield, giving an average of 43% over a three year period. Until 1922 the mower was also very popular for harvesting different types of beans. The loss in mowing usually ran 24.7% of the total yield. This excludes any threshing losses. Occasionally beans are also harvested with a binder and threshed with a pea or bean separator, or grain thresher. (20)

The Garwood brothers were the first to show the great possibility of reducing harvesting labor and losses by combining beans. A Massey Harris combine, specially converted for bean harvesting, was tried by them in Illinois. Its success has been responsible for the acceptance of the combine as a bean harvesting machine.

Before 1924, 13 man hours, 29 horse hours and 3/4 of a tractor hour were required to grow and harvest an acre of beans. Now an acre can be grown and harvested in 3.7 man hours and 2.1 tractor hours. Table VII shows the acreage harvested by the different methods in U. S. (18).

TABLE VII

DRY EDIBLE BEANS
HARVEST METHOD, BY PRINCIPAL STATES 1943

STATES	Acreage Harvested 1943 1,000 Acre	% of acreage that was harvested with a combine		threshed with thr. & huller	
		from stand crop	from windrow or pile	from windrow	from stack
New York	113	1.6	4.4	8.2	85.8
Michigan	617	0.2	26.3	20.9	52.6
Nebraska	80	23.8	52.1	11.2	12.9
Montana	62	1.0	28.0	57.0	14.0
Idaho	168	0.6	71.4	25.2	2.8
Wyoming	112	10.0	25.2	50.0	15.0
Colorado	507	----	42.0	16.4	41.6
New Mexico	240	----	37.4	31.3	31.3
California	442	----	90.6	9.4	----
Other States	63	20.0	32.0	37.0	11.0
United States	2404	1.9	45.7	21.0	31.4

*All data except acreage harvested refer to 1944.

Discussion of Harvesting Losses.

The efficiency of operation of any machine is usually in direct proportion to the efficiency of the operator (5). The combine, like any other machine, will do a very satisfactory job if it is properly adjusted and kept in good running order for various kinds and conditions of crops (3) (4) (11). The combine is never finally set, changes must be made for damp mornings, dry afternoons, new varieties and field conditions (8).

In order that the machine be operated at its highest efficiency, the operator must be thoroughly familiar with the operation, adjustment and care of the combine. However, the efficiency of the operator is not the only factor controlling the losses.

Field tests have indicated that no combine will waste much grain if it is operated below its limit capacity (12). Experts believe that in combining beans, a 10% loss is expected and is considered normal (8). Actual tests, however, have shown losses as high as one-half of the yield. A major portion of these losses can be attributed to a combine.

There are four separate, distinct areas of the combine at which grain can be lost. The cutter bar, cylinder, rear of the straw rack, and rear of the sieves (5) (12). Losses at these areas are known as the cutter bar, cylinder, rack and shoe. Some machines have separate openings in the rear which makes it possible to collect the rack and shoe losses separately. The machines used in this study did not have that provision and so the rack and shoe losses had to be combined into one separating loss.

Efficiency of combining is dependent on the extent of these losses. Furthermore it is important that they balance each other as much as possible. It is not efficient harvesting to have one loss low and another high (12).

Cutter Bar Loss.

All grain, whether loose or in pods, left on the ground by the cutter bar or pick up, is considered to be a cutter bar loss. Losses at the cutter bar account for 75% of the total grain lost (6). This loss was the largest in the local studies, in some cases as high as 48% of the yield.

The factors affecting this loss are numerous. Height of cut (17), moisture content of the crop, the way the crop stands, efficiency of seed bed preparation, adjustment of the reel are a few (19). A very dry crop, due to excessive shattering, tends to have a higher cutter bar loss but at the same time such a crop has a lower threshing loss. This is evident from the results of the test runs.

Beans is a crop which usually does not grow very high above the ground. The bean pods, being heavy, have a tendency to hang close to the ground. This is the reason that cutter bar losses in bean harvesting usually run higher than other crops in which the grain is higher above the ground. The tests very clearly indicated the need of improving pick up methods to reduce the tremendous amount of cutter bar loss. Few runs were performed in which the grain was carefully pitched by hand, thus picking up practically all the pods from the ground. The results showed a tremendous saving, in some cases doubling the yields.

Direct combining produces the greatest harvesting problems. The unevenness of the ground and the presence of stones makes it rather impossible to get low enough and pick all the pods. Poor cultivation practices produce ridges in which the bean pods hang down and are very hard to pick up with the present day combines. Special fingers and reels have been developed to improve the situation but they have not yet been completely satisfactory.

The setting of the reel has also been a factor affecting this loss. It should be operated as high as possible with the center well back of the cutter bar so most of the beans batted out would land on the feeder. Most of the batting can be eliminated by slowing the reel until a gentle pushing action is obtained (5).

Cylinder Loss.

The cylinder loss includes unshelled grain left in the heads and carried to the rear of the machine by the straw rack. This source of loss is probably the most significant, not from the standpoint of extent, but because of the effect of the action of the cylinder upon the other source of loss. A study on small grain in Ohio shows the distribution of the different losses in wet and dry years (13).

	Cylinder.	Rack.	Shoe.
Wet Year	9.8%	58.0%	32.2%
Dry Year	14.2%	43.3%	42.5%

It is evident from the above that cylinder loss is not a major loss. The higher cylinder losses during dry years are due to less attention paid in shelling in such years. Cylinder losses in navy beans are even lower than the small grain. Navy beans, being larger thresh easier and do not need a very wide cylinder-concave clearance. A close clearance often results in higher split losses.

Uniform feeding of the machine is quite important in reducing this loss. Heavy bunch of crop passing through the machine overloads the machine and a large amount of pods are cushioned through without being threshed. Other factors affecting this loss are presence of weeds, high moisture content of crop, too slow a cylinder speed, too large a cylinder-concave clearance, and not enough concaves. Split beans, on the other hand, are caused by too narrow a cylinder-concave clearance, too high a cylinder speed, unparallel cylinder and concaves and improper functioning of separating mechanism thereby rethreshing some of the grain.

The recommended cylinder speed for beans is about half of the speed used for small grain. The cylinder-concave clearance should be from 1/2" to 3/4" (5). Following of proper instructions, as to the speed and clearance, will easily control this loss to a minimum.

Separating Loss.

Separating loss (rack and shoe) include all the shelled or loose grain carried over the rear of the straw rack with the straw. This loss, although not very evident in the present study, can be one of the heaviest (13). It can be affected by the volume, condition and nature of the material passing over the rack (11). In harvesting of small grain it has been considered to be a key loss and a criterion of what is happening at the other sources of loss (12).

The speed of the rack usually affects this loss substantially. A very high speed will keep the straw up and not allow it to settle down sufficiently to be fully caught by the next upward movement. A slow speed, on the other hand, will not pitch the straw sufficiently to allow for effective and thorough separation. A straw rack is usually the first functional unit to be overloaded and so its speed must be carefully adjusted. Presence of green material and higher moisture content of the crop increases this loss.

High shoe losses are usually associated with high rack losses. Occasionally fine straw falls over the sieves. Most farmers usually increase the air blast to blow away this straw. The straw often carries some grain away. Beans, being large and heavier than other grain, separate easily from the straw. It is very hard to blow beans away by a strong blast and, therefore, separating losses in bean harvesting have not been excessive. Often times a high rate of travel increases this loss by overloading the rack. Higher moisture contents of the crop also increases the loss.

Manufacturers recommend the use of special sieves with 3/8" round holes for bean harvesting. This reduces the returning of the threshed beans to the cylinder and thus reduces the splitting loss. Still better results can be obtained by replacing the coarse adjustable chaffer with the lower adjustable sieve. This arrangement does an excellent cleaning job (5).

ORIGINAL RESEARCH

Trends in Harvesting.

Due to the two great world wars, the first half of the twentieth century has seen very rapid advances in almost all fields of engineering. Modern research has been so rapid that constant changes and improvements are being brought forth in the construction, operation and maintenance of practically every machine.

The introduction of the combine for bean harvesting in Michigan has brought about changes in harvesting techniques. Methods, which were considered practical and most economical are now losing their importance. In order to keep pace with these rapid changes, it was necessary to study the situation by actually asking the opinions of people directly connected with bean harvesting. A questionnaire was sent in the winter of 1952 to the County Agricultural Agents of the important bean producing counties. The results were compared with the results of a similar questionnaire, sent by the Agricultural Engineering Department in 1947. This comparison showed the trends of bean harvesting in Michigan during the five year period (1947-1952).

The questionnaire included a table to list, in percent, the methods practiced for harvesting beans in their county. The results from this study are shown in Table VIII. Each questionnaire also included five questions. The answers of which are discussed further in the study.

The direct method of combining has been declining in dry seasons but is increasing in wet seasons. The hand stacking and threshing from stacks method has stayed about the same during dry seasons, but it has declined sharply from 35.5% to 25.5% in wet years. Mechanical stacking and then threshing from stacks has never been a very important method and has declined in both the dry and wet seasons.

Hauling to the barn and then threshing has also declined substantially in both the dry and wet seasons. The decline is more pronounced in dry years than in wet years. Combining from windrow has been a very popular method and has been gradually increasing in popularity. It has increased in both the dry and wet years although the increase in wet years is 5% more than in dry years. The other methods have also shown a considerably large increase in both the dry and wet years. This shows that the farmers are not satisfied with the present harvesting methods. They are trying, more and more, to find better methods by practicing newer techniques.

Results of Harvesting Methods Study.

Q. What types or makes of machines seem to be most suited for harvesting beans in your area?

A. Almost everyone included the use of an all crop combine. Two included the use of special bean combines. One county also practiced the use of bean shaker and windrower. The Allis-Chalmers seem to be the most commonly used combine.

Q. What are the advantages or objections to each of the different methods of harvesting beans now in use in your county?

A. The disadvantages of using a combine were poor performance in adverse seasons and unevenly ripe crop, higher splits, large investment, high cutter bar loss, and constant danger of stones in the field. The advantages were less labor cost and timely harvest. All the rest of the methods were considered to be labor and time consuming methods. Mechanical or hand stacking and threshing from stacks were generally considered to be good methods in wet years. In general, the opinions were, that the excessive labor in stacking is more than balanced by the savings in lower losses in a poor season.

Q. What is the trend in the use of different harvesting methods used in your county? That is, is it toward more stacking and threshing from stacks or more combining?

A. The replies were almost unanimous, more combining. Few counties specified the windrow method of combining.

Q. In your opinion, what method of harvesting beans is most practical for the farmer considering all factors such as spoilage hazards, labor, losses from shattering, etc.

A. The majority of the replies considered stacking and threshing from stacks the best method. Two answers included the special bean combines to be the best method of harvesting.

Q. What can the college do that will be of greatest assistance to the bean growers?

A. Develop tall varieties which could be combined directly without excessive cutter bar loss. Also work on developing varieties with higher yield and evenly maturing crop. A few mentioned the development of mechanical handling to eliminate high labor cost.

TABLE VIII

METHODS OF HARVESTING BEANS IN PERCENT
PRACTICED DURING 1947 AND 1952
IN 14 COUNTIES OF MICHIGAN

No.	County	1				2				3				4				5				6			
		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
		47	52	47	52	47	52	47	52	47	52	47	52	47	52	47	52	47	52	47	52	47	52	47	52
1	Arenac	15		5		25		30						20		40		40		25					
2	Barry	10				10	85			10				20				35	15			15			
3	Clinton	57	50		20	40	25	50	60					10	5	35	10	40	20	10	10	5		5	
4	Eaton	2				30	10	70	25					28	15	20	25	20	60	5	10	20	15	5	40
5	Genesee						5		10	1		5		2	25	4	25	97	70	91	65				
6	Gratiot					5		10		10		10		10		15		75		65					
7	Ingham	25	5			5	5							10	1			50	85		50	10	4		
8	Ionia			5		75		80						10		10		15		5					
9	Isebella	20		15		15		50		1		1		25		15		30		15		9		4	
10	Lapeer					30	40	30	40					10	10	10	10	40	50	40	50				
11	Livingston	15				10								25				50							
12	Mescota					10	10	10	30					70	5	80	10	20	10	10	10		75		50
13	Saginaw						2		4		1		2		2		3		95		93				
14	Tuscola		8		2	10	5	25	10		2		3	10	5	25	15	50	80	25	70	30		20	
	Average*	10	7	2.5	3.1	20	21	35	25	2	.3	1.5	.7	20	8	26	14	45	54	30	44	5	11	4	13

1. Direct combining of standing beans.
2. Handstacking and threshing from stack.
3. Mechanical stacking and threshing from stacks.
4. Hauling to barn and threshing.
5. Combining from windrow.
6. Other methods.
* Based on the number of completed questionnaires returned.

Experimental Procedure.

Most of the field work was done during the harvest season of 1950 and 1951. Unfortunately, due to unusually poor weather conditions during the fall of 1950, very few test runs were possible. A major part of the study was, therefore, carried out during the fall of 1951.

The procedure for collecting the losses was the standard method usually practiced by the U. S. D. A. and other experiment stations in combine harvesting studies. A large canvas 16' x 12' was folded at the middle and its four ends were tied independently with twine, at two points on the rear of the combine. The ends were attached to the combine by knots which could be snapped open, thus facilitating the instant detaching of the canvas when desired.

Three men, besides the operator, were required to run the test. One collecting the grain from the spout and the remaining two collecting straw on the canvas. The man at the spout was also responsible to signal the two men at the canvas for the starting and stopping of the straw collection. After tieing the canvas, the combine was operated for a distance so as to fill the machine with grain and straw. After the machine had operated for a while, the man at the spout signalled the men at the canvas to snap loose and unfold the top two ends of the canvas. The two men carried a marker which they dropped on the ground to mark the start of the run.

The man at the spout started the collection of the grain simultaneously with the collection of the straw.

After a reasonable amount of grain had been collected, he again signalled and stopped collecting the grain. The two remaining attached ends of the canvas were immediately detached from the combine by snapping the knots. The straw was carefully filled in bags and labelled, taking care, not to fill any of the loose grain from the canvas. The loose grain was also collected in separate bags and labelled. The length of the run was measured from the marker to the front end of the canvas.

Grain was also picked from small precalculated areas of the strips where the straw had already been collected. Four stakes were tied with a nonelastic twine in a manner to enclose a precalculated area. This was done so as to include the same width covered by one run of the combine. In order to reduce the chances of errors, three samples were picked from each strip. Thus all the grain, loose or in pods, not picked by the combine was collected and labelled.

All the straw and grain samples were brought to the laboratory. Due to the unavailability of a suitable thresher, the straw had to be rethreshed by hand. The grain samples were cleaned and their weights recorded. All the data was later reduced to per acre and percent of preharvest basis to facilitate comparison.

The different losses were:

Cylinder loss. Grain from rethreshed straw.

Separating loss. Loose grain on canvas.

Cutter bar loss. Grain picked from pre-calculated areas.

Variables Involved.

This study was centered around a few variables. The most important was the direct and windrow method of harvesting. Similar tests were performed in the same field or in different fields with similar conditions, to control the rest of the variables. Few runs were performed in which the crop was fed from the windrow to the canvas manually with a fork. This method resulted in a thorough pick up of all the crop and the results were very interesting.

Losses due to absence and presence of weeds were also studied. The experimental plot at East Lansing had a low spot, at the west end, where a very high weed growth was present. The east end of the same plot was free from any weed growth and thus it was possible to study the effect of weeds on losses, in the same plot. Tests were also performed to study the effect of two different types of reels. One was a standard six bat reel and the other was a Hume reel with an eccenteric mechanism, with wire fingers. These fingers protruded fruther down on their downward turn and then lifted up on the upward turn, thus lifting the lodged beans. The other variable was high and low moisture content of the crop. The results have been discussed to show the effect of these variables separately.

Massey Harris 7' self propelled Clipper Combine with Hume reel, in operation.

Standard 6 bat reel on Massey Harris Clipper combine.

Efficiency Calculation.

The efficiency of harvesting was figured on the basis of preharvest yield. Preharvest yield is the actual yield of the crop, just before the harvest. It includes all the grain on the field, unaffected by any harvesting losses.

Two different methods have been practiced in figuring the preharvest yield. Some studies have used a frame representing a precalculated area. This frame is placed in the field before the harvest, and all the plants are harvested by hand, taking care not to leave any grain or pods within the area. Usually this area is small, 1/1,000 of an acre, and so a large number of tests must be performed to get a satisfactory result. It is a very desirable method for it provides the checking of errors in efficiency studies; however, it needs extra labor.

The second method does not need any extra labor. The losses from the regular efficiency study are added to the net yield to obtain the preharvest yield. The results, are dependent on the results of the losses and net yield. The fact, that this method takes into account, the full length of the test strip, and the less labor requirements, makes it a desirable method. This second method was used in this study, as availability of labor during the harvest season was a great problem.

The efficiency of harvesting was figured as follows:

$$\% \text{ Efficiency} = \frac{\text{Net Yield X 100}}{\text{Preharvest Yield}}$$

The % losses were figured as follows:

$$\% \text{ Loss} = \frac{\text{Loss} \times 100}{\text{Preharvest Yield}}$$

Description of Equipment.

Most of the equipment used in the study was loaned to the college by the manufacturers or the dealers. A 6' Gleaner combine was used at Saginaw and East Lansing in the Fall of 1950. This machine was equipped with auxiliary engine for threshing power. A Ferguson tractor was used to pull the Gleaner combine.

During the Fall of 1951 a Massey Harris self propelled Clipper combine was acquired and used for the tests. This was a 7 feet machine loaned by the Massey Harris Company. An Oliver tractor with a bean puller was also used at Saginaw. Innes bean puller and windrower was used at East Lansing. The rotary Ferguson side delivery rake was also used at the East Lansing plots. The other equipment needed was a 16' x 12' canvas, bags, sacks, tachometer, measuring tape and scales. Two different types of reels were used. One was a standard six bat reel while the other was a Hume reel equipped with wire fingers actuated by an eccentric mechanism.

Manufacturers recommendations as to the adjustment and speed were followed. Most adjustments were done in the field under the guidance of Mr. H. F. McColly of the Agricultural Engineering Department. The machines were adjusted to operate at a cylinder speed range of 500-550 r.p.m. which was the recommended speeds for bean harvesting.

Gleaner 6' pull type combine in operation.

Ferguson rotary side delivery rake.

Oliver tractor equipped with two row bean puller.

Innes bean windrower.

Presentation of Data.

Direct and Windrow Combining.

General Information: 6' pull type Gleaner combine equipped with an auxiliary engine. Fall 1950.

Humid weather and crop.

Direct Combining.

TABLE IX

CUTTER BAR LOSSES

No.	1/1,000 acre	One acre
1.	.263#	263#
2.	.213#	213#
3.	.227#	227#
Average	.2345	234.5#
% of preharvest.		22.7%

TABLE X

OTHER LOSSES

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1	93'	8.8#	1.12#	.162#
	One acre	687.0#	87.50#	12.60#
2	90'	8.77#	.87#	.23#
	One acre	709.00#	70.00#	18.55#
3	111'	11.35#	.94#	.19#
	One acre	743.00#	61.50#	12.40#
Average/acre.		713.00#	73.00#	14.51#
% of preharvest		68.9%	7.00%	1.45%

Windrow Combining.

TABLE XI

CUTTER BAR LOSSES

No.	1/1,000 acre	One acre
1. 2. 3.	.187# .148# .193#	187# 148# 193#
Average % of preharvest.		176# 17.2%

TABLE XII

OTHER LOSSES

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1	108' One acre	11.66# 784.00#	1.9# 128.0#	.375# 25.00#
2	85' One acre	8.66# 740.00#	1.34# 115.00#	.344# 29.40#
3	88' One acre	7.72# 636.00#	.866# 71.00#	.172# 14.20#
Average/acre. % of preharvest.		720.00# 70.41%	104.60# 10.15%	22.90# 2.24%

Presence and Absence of Weeds.

General Information: 7' Self propelled Massey Harris Clipper combine equipped with a 6 bat reel. Hand pitched from windrow. Medium wet crop.

TABLE XIII

CUTTER BAR LOSSES (WEEDY)

No.	2' X 7' Loose	Pods	Total	Acre Total
1.	5 gms.	1 gm.	6 gms.	41.3#
2.	3 gms.	-----	3 gms.	20.6#
3.	3 gms.	1 gm.	4 gms.	27.6#
Average % of preharvest (Weedy)				29.83# 1.7%

TABLE XIV

OTHER LOSSES (WEEDY)

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1.	114' One acre	26.35# 1435.00#	1.27# 69.40#	.79# 43.00#
2.	134' One acre	40.00# 1860.00#	1.69# 84.80#	1.03# 47.80#
3.	96' One acre	18.40# 1192.00#	.84# 54.50#	.566# 36.70#
Average/acre. % of preharvest.		1495.00# 91.43%	69.50# 4.25%	42.50# 2.62%

TABLE XV

CUTTER BAR LOSSES
(WEED FREE)

No.	2' X 7' Loose	Pods	Total	Acre Total
1.	3 gms.	2 gms.	5 gms.	34.4#
2.	2 gms.	2 gms.	4 gms.	20.6#
3.	4 gms.	1 gm.	5 gms.	34.4#
Average				29.83#
% of preharvest				2.27%

TABLE XVI

OTHER LOSSES
(WEED FREE)

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1.	131'	24.5#	.75#	.11#
	One acre	1165.0#	35.60#	5.25#
2.	143'	28.0#	.83#	.127#
	One acre	1220.0#	36.10#	5.52#
3.	118'	21.2#	.66#	.099#
	One acre	1115.0#	34.80#	5.26#
Average/acre		1166.0#	35.50#	5.34#
% of preharvest		94.4%	2.90%	.43%

Wet and Dry Crop.

General Information: 7' Self propelled Massey Harris Clipper combine equipped with Hume reel. Direct combining of wet crop.

Wet Crop.

TABLE XVII

CUTTER BAR LOSSES

No.	2' X 7' Loose	Pods	Total	Acre Total
1.	23 gms.	25 gms.	48 gms.	330.0#
2.	37 gms.	22 gms.	59 gms.	406.0#
3.	29 gms.	32 gms.	61 gms.	420.0#
Average/acre % of preharvest				386.0# 48.0%

TABLE XVIII

OTHER LOSSES

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1.	93' One acre	4.25# 284.00#	.144# 9.62#	.051# 3.41#
2.	114' One acre	13.10# 715.00#	.139# 7.60#	.038# 2.05#
3.	95' One acre	4.76# 312.00#	.122# 8.00#	.056# 3.67#
4.	150' One acre	8.50# 352.00#	.128# 5.30#	.053# 2.20#
5.	110' One acre	7.15# 405.00#	.104# 5.87#	.044# 2.50#
Average/acre % of preharvest		413.00# 50.74%	7.27# .90%	2.77# .34%

Dry Crop.

TABLE XIX

CUTTER BAR LOSSES

No.	2' X 6'			
	Loose	Pods	Total	Total
1.	24 gms.	15 gms.	39 gms.	313.0#
2.	28 gms.	18 gms.	46 gms.	369.0#
3.	25 gms.	21 gms.	46 gms.	369.0#
4.	68 gms.	26 gms.	94 gms.	755.0#
5.	31 gms.	10 gms.	41 gms.	329.0#
6.	27 gms.	17 gms.	44 gms.	353.0#
Average/acre. % of preharvest.				414.6# 23.92%

TABLE XX

OTHER LOSSES

No.	Length of run	Grain Threshed	Unthreshed Grain	Separator Loss
1.	122' One acre	18.32# 1090.00#	.04# 2.38#	.106# 6.30#
2.	132' One acre	19.00# 1046.00#	.03# 1.65#	.087# 4.79#
3.	175' One acre	45.25# 1880.00#	.11# 4.56#	.099# 4.14#
4.	97' One acre	16.50# 1237.00#	.05# 3.75#	.181# 13.55#
Average/acre % of preharvest		1313.00# 75.60%	3.08# .17%	7.19# .41%

Standard and Hume Reel.

General Information: Massey Harris 7' Clipper self propelled combine. Direct combining. Very humid weather conditions.

Hume Reel.

TABLE XXI

CUTTER BAR LOSSES

2' X 7'			
No.	Loose	Pods	Total
1.	29.0 gms.	53.0 gms.	82.0 gms.
2.	23.0 gms.	24.0 gms.	47.0 gms.
3.	32.0 gms.	23.0 gms.	55.0 gms.
4.	35.0 gms.	28.0 gms.	63.0 gms.
5.	22.0 gms.	39.0 gms.	61.0 gms.
6.	19.0 gms.	27.0 gms.	46.0 gms.
Ave.	26.65 gms.	32.35 gms.	59.0 gms.

Standard Six Bat Reel.

TABLE XXII

CUTTER BAR LOSSES

2' X 7'			
No.	Loose	Pods	Total
1.	17.0 gms.	58.0 gms.	75.0 gms.
2.	13.0 gms.	42.0 gms.	55.0 gms.
3.	15.0 gms.	53.0 gms.	68.0 gms.
4.	17.0 gms.	49.0 gms.	66.0 gms.
5.	24.0 gms.	45.0 gms.	69.0 gms.
6.	13.0 gms.	47.0 gms.	60.0 gms.
Ave.	16.5 gms.	49.0 gms.	65.5 gms.

Discussion of Results.

The data from all the test runs was figured on an acre basis and the average was then taken to get the loss. This method gave every run an equal representation in the final averages, irrespective of the length of the run. The final average losses were figured in percent of preharvest yields. The two results, pounds per acre and percent of preharvest, can be compared to evaluate the efficiency variable.

The data from the direct and windrow method of harvesting showed the windrow method to be more efficient. The cylinder losses in this particular study were abnormal. This could be attributed to the high moisture content of the crop. The windrow method showed an increase of net yield by 1.51% and a decrease of the cutter bar by 5.5%. The cylinder and the separator losses increased in the windrow method by 3.15% and 1.51% respectively. This probably was due to the excessive plant matter passing through the machine in the windrow method.

The presence and absence of weeds showed that the separator loss can become very excessive in a weedy crop. The separator loss was six times the normal and the cylinder loss was doubled by the presence of weeds. The excessive weeds on the rack retarded the separating process tremendously. The net yield in a weed free field were increased by 2.97%.

This particular study also showed that a great deal of the loss can be recovered if a thorough pick up job is performed. These two sets of runs were performed by manually feeding the crop to the combine. A man walked along the combine, pitching the crop into the canvas with a fork. This method enabled us to combine most of the crop from the windrow. The cutter bar loss, which usually is the largest, was only 1.7% of the preharvest yield. The net yields from the weedy and weed free crops were 91.43% and 94.4% respectively.

The wet crop showed a very poor net yield, recovering only 50.74% of preharvest. The crop being very wet, a large amount of pods were hanging very low for the cutter bar. The cutter bar loss was 48.0% in wet and 23.92% in dry crop. The cylinder loss was 0.9% in wet and .41% in dry crop. The separator loss was .34% and .41% in wet and dry crop respectively. An analysis of the cutter bar loss disclosed higher shattering losses in dry crop but it was more then offset by the higher pod grain left on the field by the cutter bar in wet crop.

The results from the reel study showed that the Hume reel is more efficient than the standard reel. The Hume reel showed a loss of 59.0 gms. per 14 sq. ft. while the standard reel had a 65.5 gms. loss per 14 sq. ft. Further analysis of these losses disclosed that the Hume reel has a higher shatter loss but it picks up more pods to more then balance the shatter loss. This shattering is probably due to the fingers striking the pods at a high speed. Its capacity to pick the low hanging pods makes it a valuable attachment for combine harvesting of beans.

Suggestions for Further Study.

Almost all tests showed that the major loss in bean harvesting is the cutter bar loss. In some cases this loss claimed half of the crop. A detailed study of this loss is definitely needed. The first step in studying this loss would be to analyze it by breaking this loss into parts and then studying which of these parts is the most critical.

The loss can be broken down into three parts. Loss due to shattering caused by the vibration and the cutting action of the cutter bar, pods and plants missed by the cutter bar and plants already cut by the cutter bar but not delivered to canvas by the reel. With the division of the cutter bar loss into the three parts, it can be very thoroughly analyzed.

More work is also needed to improve the cultivation practices so that fields may be left level for harvesting. The ridges left due to poor cultivation practices are largely responsible for the pods missed by the cutter bar.

The Hume reel seems to be quite encouraging although it needs improvements in its operation and mounting. The shattering loss due to this reel can be reduced by properly synchronizing the speed of fingers to the ground speed. The mounting should be such that the reel could be fitted to most of the combines in a way so as to permit the necessary adjustment with greatest ease. The lowering and raising adjustment was limited when it was mounted on the Massey Harris Clipper combine, although this problem was not evident when mounted on the Gleaner combine.

Timely harvest of beans is very important to do an efficient job and so a study on the time of harvesting is needed. The cylinder and separator losses were not very excessive but they can be reduced. Almost all answers from the county agricultural agents included the necessity of an improved bean variety more adaptable to direct combining. A variety with a longer stem and harder branches to hold the pods higher will be very welcome by the growers.

If some of these problems are remedied, direct combining can be a very successful method for harvesting beans in Michigan. This would result in a tremendous saving of labor for an average bean farmer in Michigan.

Summary.

Michigan is the nation's top Navy bean producing state. Harvesting losses of the navy bean have been tremendous. Very little work has been done on harvesting efficiency, as such there is a definite need for a study on harvesting efficiency.

The growers generally use a combine for harvesting navy beans. Farmers consider combining to be an efficient method of harvesting in good harvesting seasons, but in poor seasons they prefer the stacks and threshing from stacks method. There is a trend of more combining. Most county agricultural agents consider the stacking and threshing from the stacks, the best method for harvesting. There is a definite need of a bean variety better suited to direct combining.

The windrow method of combining seems to be more efficient. The cutter bar losses are considerably lower in this method. The presence of weeds increased the separating loss by six times and doubled the cylinder loss. A particular run showed that a good pick up job can boost the net yield to 94.4%. The losses in wet crops were excessive, claiming nearly half of the crop. The Hume reel was more efficient than the standard reel. The shatter loss from the Hume reel was more, but it did a better job picking the pods thus offsetting the shatter loss.

A study is needed on the cutter bar losses, improving of cultivation practices, Hume reels operation and adjustment, time of harvest and development of a bean variety better suited for direct combining.

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