

THE APPLICATION OF HYDRAULICS TO THE DIRECT
HARVESTING OF EDIBLE BEANS

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ABSTRACT

THE APPLICATION OF HYDRAULICS TO THE DIRECT HARVESTING OF EDIBLE BEANS

by John Stevens Bolen

This study was undertaken to investigate (1) certain operations to which rotary hydraulic power would readily adapt, and (2) possible methods of harvesting edible beans directly.

The solution of problems experienced with harvesting of edible beans appears to be very dependent upon the ability to develop a direct-harvesting mechanism which can satisfactorily reduce field losses and decrease weathering losses.

Previous direct-harvesting experiments utilizing a rotary cutting disk prompted a further investigation of a mechanism utilizing the rotary disk principle.

The investigation included the development of a double-disk cutting unit which utilized a lightweight, flexible hydraulic drive system.

Included in the investigation were the determination of (1) gathering losses as affected by operating height, (2) plant movement as affected by disk speed and ground speed, and (3) the power required as affected primarily by operating height.

The basic one-row mechanism consisted of two hydraulically-driven, virtually horizontal, overlapping 13 1/2-inch disks, rotating in opposite directions at speeds ranging from 400 to 700 RPM and 500 to 1000 RPM.

Initial tests indicated that best cutting results were obtained with the slower rotating disk containing eight, evenly spaced notches, with each notch about one-half-inch long and one-fourth-inch deep.

The mechanism, as designed, was intended to be mounted on the front edge of a grain combine table to facilitate the harvesting of edible beans in one trip over the field.

The grain losses experienced with the cutting mechanism were at least comparable to losses experienced with conventional harvesting methods in the same test area.

With operating heights at which the cutting disks were at or below the surface of the soil about 65 per cent of the time, gathering losses experienced were about 2.5 per cent of the pre-harvest yield. This compared with gathering losses of about 8.8 per cent of the pre-harvest yield for conventional methods in the same area.

Shattering losses were minimal. Most of the gathering losses were a result of the pods being cut open.

The measurement of rearward plant movement indicated that rearward plant movement was directly

proportional to the ratio of peripheral disk speed to ground speed and as this ratio increased, plant movement in a rearward direction increased.

At operating heights where the cutting disks were at or below the surface of the soil about 65 per cent of the time, rearward plant movement of about two to four inches was experienced with the peripheral disk speed about eleven to twenty times as fast as the forward travel speed of the cutting machine.

The total power required to operate the cutting disks was about 1.52 HP, with about .95 HP required by the left-hand disk and about .57 HP required by the right-hand disk at operating heights and operating speeds listed above.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENT	ii
LIST OF TABLES	vii
LIST OF FIGURES.	viii
 INTRODUCTION.	 1
OBJECTIVES	4
BACKGROUND INFORMATION AND TERMINOLOGY	5
Agricultural Hydraulics	5
Components.	10
Systems.	13
Edible Bean Production.	17
Status	17
Harvest.	18
JUSTIFICATION FOR CONTINUED RESEARCH OF DIRECT- HARVESTING METHODS	27
STATEMENT OF THE PROBLEM.	29
PREVIOUS INVESTIGATIONS	31
Literature Review	31
Analysis	35
PRELIMINARY INVESTIGATION OF A ROTARY DISK CUTTING MECHANISM	38
Requirements of the Mechanism	38
Analysis of the Functions to be Performed .	40
Separation.	40
Conveyance.	41

	Page
Selection of the Basic Design	42
Pertinent Data on the Single-Disk Cutting Unit	44
DESIGN AND CONSTRUCTION OF THE FIELD TEST MECHANISM.	46
Basic Design.	46
Construction.	53
Frame Construction.	53
Disk Construction	54
Preliminary Laboratory Testing.	55
Hydraulic Drive System	56
PRELIMINARY FIELD LOSSES OF CONVENTIONAL METHODS	59
Types of Losses.	59
Procedure.	60
Results	62
CONSIDERATIONS OF AND TEST PROCEDURE FOR THE FIELD TESTS CONDUCTED.	64
Considerations of Test Procedure	64
Test Procedure	65
Preliminary Testing	66
Gathering Losses	67
Direction and Amount of Plant Movement	68
Power Requirements.	69
RESULTS AND DISCUSSION	71
Gathering Losses	71
Plant Movement	77
Effect of Operating Height	79
Effect of Peripheral Speed/Ground Speed Ratio	79
Characteristics of Plant Movement.	80
Power Requirements.	81
Operational Characteristics.	86
Plant and Stalk Condition	86
Cleanliness of Severed Plant Material	86

	Page
Ability to Save Low-Hanging Pods . . .	87
Effect of Soil and Stones on the Cutting Disks	87
Effect of Lateral Movement of the Cutting Disks on Cutting Ability . .	88
SUMMARY AND CONCLUSIONS.	90
SUGGESTIONS FOR FURTHER STUDY.	93
REFERENCES	96
APPENDIX.	99

LIST OF TABLES

Table	Page
1. Hydraulic System Types for Various Tractor PTO Horsepower Groupings.	14
2. Edible Beans--Acreage Harvested, Yield and Production--Top Six States, 1959-1964 .	19
3. United States and Michigan Edible Bean Production by Commercial Classes, Clean Basis, 1959-1964	20
4. Direct-Harvesting Tests, 1955-56	34
5. Maximum Effective Cutting Angle with a Single-disk Cutter for Various Operating Widths.	45
6. Maximum Effective Cutting Widths for Various Disk Sizes and Maximum Cutting Angles.	47
7. Disk Clearance for Multi-row Units with Various Row Widths, Disk Sizes and Disk Overlaps	52
8. Field Losses Encountered with Conventional Harvesting Mechanisms.	63
9. A Comparison of the Speed and HP Require- ments of the Cutting Disks	81
10. Additional HP Required as Operational Time at or Below the Surface is Increased.	86

LIST OF FIGURES

Figure	Page
1. Diagrammatic Relationship of Cutting Disk Dimensions	48
2. Maximum Effective Cutting Angle and Effective Cutting Width for a Double-Disk Unit	49
3. Rear View of Cutting Mechanism and Throat Clearance Above Cutting Disks.	49
4. Left-Side View of Cutting Unit	50
5. Right-Side View of Cutting Unit	50
6. Front View Illustrating Notched Disk	51
7. Hydraulic Drive System	58
8. Gathering Losses Versus Operating Height	72
9. Gathering Losses Versus Stubble Height.	74
10. Stubble Height Versus Operating Height.	75
11. Plant Movement Versus Operating Height.	78
12. Output HP, Right Motor Versus Operating Height	82
13. Output HP, Left Motor Versus Operating Height	83
14. Output HP, Total Versus Operating Height	84
15. Proposed Multi-Row Mounting on Combine Table.	95

INTRODUCTION

When one reviews the history of agricultural tractors in the United States, it is noted that hydraulics made its first notable impact in the form of a hydraulic lift in the mid-1930's. This advancement in tractor design increased the production of the operator and the operating ease of the tractor.

In the 1940's remote hydraulic power was introduced to the farm tractor. Hydraulic cylinders operated off the tractor hydraulic system were used to assist in raising pull-type implements. This innovation was the first transfer of power from the tractor to the machine hydraulically.

When comparing the main mechanical and hydraulic classes of power transmission devices used with agricultural machines, it appears that the capabilities of the former have been utilized to the fullest extent and that very few major breakthroughs in mechanical power transmission will occur. Hydraulic power, on the other hand, is seemingly on the verge of a major breakthrough in agricultural usage.

Zimmerman (1966) has shown that the range of tractor hydraulic power, as a percentage of tractor PTO-power, has increased from 10-20 per cent in 1955 to 30-48 per cent in 1964. This tractor trend indicates the availability of even larger percentages of hydraulic power and provides possibilities for the use of hydraulic motors on agricultural implements to provide mobile rotary power just as the hydraulic remote cylinder provides mobile linear power.

There are numerous applications of hydraulic power to agricultural machines at present. Much of this power, however, is used to provide linear motion.

The provision of rotary hydraulic power, in many instances, is limited by the operating characteristics of tractor hydraulic systems. For this reason, rotary hydraulic power has not been used to any great extent on agricultural machines.

When one analyzes the advantages of hydraulic motors and the possible operations or functions which might be performed by hydraulic motors in the future, one notes that the process of direct combining of edible beans is one of many processes that might accept the adaptability of hydraulic power.

It appears that the desire of bean growers to remove beans from the field as rapidly and efficiently as possible to reduce weathering losses, harvesting

losses, and operating costs can best be satisfied by a method of direct harvesting which does not require drying time and eliminates one or two trips over the field.

To facilitate a direct-harvesting mechanism to be mounted in front of the combine, a compact, lightweight and flexible drive unit in the form of a hydraulic motor appears to be most desirable.

OBJECTIVES

In view of this, the objectives of this investigation are twofold. The first set of objectives is:

1. To investigate the advantages and disadvantages of hydraulics as an additional source of rotary power for agricultural implements.
2. To analyze the different types of hydraulic systems available on tractors presently being used and investigate how well the different types of systems adapt themselves to providing a continuous source of power for remote hydraulic motors.

The second set of objectives is:

1. To investigate the methods that have been used or might be used in the direct harvest of edible beans.
2. To develop a direct-harvesting mechanism to facilitate edible bean harvesting.

BACKGROUND INFORMATION AND TERMINOLOGY

Agricultural Hydraulics

After the development of the simple hydraulic lift and remote cylinder, more advanced technology produced power steering and power brakes for the convenience of the tractor operator. Automatic lift control systems and draft sensing systems were introduced to provide weight transfer, more constant depth operation, and more efficient use of tractor drawbar HP. This again increased production and allowed the operator to perform the job easier and better than before.

Hydraulically actuated transmissions which accomplish the changing of speed ratios in tractor transmissions without declutching have been available for about ten years. Within the last five years, dynamic hydraulic transmissions, better known as torque converters, have made an impression on the tractor market. And within the past year, hydrostatic transmissions have made an impression on the tractor and implement market.

Recently, draft-sensing remote hydraulic power has become available to maximize tractor drawbar horsepower with trailing implements.

With the exception of remote cylinder usage, agricultural implements have not experienced as extensive a change from mechanical power transmission to hydraulic power transmission as the agricultural tractor has.

But upon examining the advantages of hydraulic power transmission, it appears that hydraulics may soon become a prime form of power transmission device for powering more types of agricultural implements.

Listed below are numerous reasons why proponents of hydraulics have so strongly endorsed the usage of hydraulic drive mechanisms (7).

1. Hydraulic power can be transmitted to distant or inaccessible points which would otherwise require an extensive system of belting and shafting to reach. Thus, those applications in which the power supply is far removed from where the power is to be applied readily adapt to various forms of hydraulic power transmission.
2. The ability of the operator to control large forces accurately through a conveniently located, easily operated control lever lends hydraulic power transmission to those implements which may encounter varying operating conditions and which may require constant

readjustment to maintain maximum operating efficiency.

3. The flexibility of hydraulic power transmission devices is almost unlimited. Hydraulic components such as pumps, valves, lines, and actuators, are compact devices which can easily be designed into any machine. Thus, hydraulic power adapts quite readily to the smooth, streamlined appearance which manufacturers try to acquire and which is necessary for the performance of certain operations.

Also, the flexibility of hydraulic power actuators is quite evident when considering the ease with which actuators can be moved from machine to machine or to different areas on the same machine where power may only occasionally be required. The use of a single remote hydraulic cylinder on several implements represents a versatile, low-cost source of power.

4. Hydraulic systems are self-lubricating. The only maintenance required is a regular oil filter change and an occasional oil change as recommended by the manufacturer. Because hydraulic systems are self-contained units, completely sealed from the atmosphere, their

operation in extremely dusty conditions, often experienced with farm equipment, is extremely reliable and requires minimal extra maintenance.

5. Due to advancements in hydraulic control valves, control of actuator speed, direction, and hydraulic force applied is very precise. Acceleration and deceleration of the actuators can be readily controlled with the proper valving thus eliminating any unnecessary wear or shock loading which might result from uncontrolled movement.
6. Most present day hydraulic systems have protective overload devices such as pressure relief valves which protect the hydraulic system, source of power, or machine from either overloading the machine or encountering foreign objects not normal to the operation. This feature eliminates the necessity for slip clutches, safety clutch adjustments, shear bolts and shear bolt replacement.
7. Hydraulic power transmission is a truly safe method of transmitting power. Developments in material construction have enabled hydraulic systems to satisfactorily retain oil pressures far above the 1500-2500 psi normally found on tractors at present. Flexible hoses and

breakaway couplings permit greater ranges of movement between the tractor and the implement as compared to mechanical transmission devices such as PTO Shafts, for instance, which have limited safe operating angles. With hydraulic breakaway connections, power transmission is automatically and safely shut off in the event of an accidental separation of the tractor and implement. This is not the case with mechanical transmission methods presently being used.

Of course, there are also problems which do occasionally exist with hydraulic power transmission devices. The two main problems are dust, dirt, rust and corrosion in the system and heating of the hydraulic oil to temperatures high enough to cause damage to the pressure sealing components.

Dust, dirt, rust and corrosion can usually be remedied most easily by observing the manufacturer's periodic maintenance suggestions. The availability of a fully-pressurized system including reservoir is also of assistance in eliminating these problems.

Excessive oil temperatures, 100 degrees F. or more above ambient air temperatures, are generally the result of (1) improper design of the system, or (2) improper analysis of the load requirement and consequent

mismatching between available hydraulic horsepower and horsepower required to operate the implement at continuous, full capacity.

Components

The main hydraulic components in a hydraulic system are the pump, valve and actuator.

The hydraulic pump, which is the heart of the system, converts mechanical motion into fluid flow.

The control valve functions to direct oil from the pump to the reservoir or actuator.

The hydraulic actuator, found opposite the hydraulic pump in the hydraulic system, is that mechanism which converts fluid flow into mechanical motion.

The hydraulic cylinder and piston, either single-acting or double-acting, is the most common type of actuator found on agricultural implements at present. Major tractor manufacturers have options available which allow the purchaser to connect remote cylinders designed for that tractor into quick-connect couplings at the rear of the tractor. The most common type of cylinder application is that of lifting, lowering and holding or regulating the depth of an implement in the ground.

With the increased use of remote cylinders in the late 1940's, the necessity arose for a standard cylinder with a standard stroke and standard overall length to

mount on an implement with standard mounting points which required a given stroke to achieve its full range of operating heights.

This necessity was met in 1948 when the ASAE set forth industry guidelines which standardized remote cylinder and implement mountings for these remote cylinders thus enabling greater interchangeability between various makes and models of tractor and implement remote cylinder applications.

Remote cylinders are used in those applications where the operation is only intermittent and the cylinder is only operating or moving a small percentage of the time the entire hydraulic system is in operation. For this reason, any overloading or mismatching which may occur between the job being performed and the capabilities of the hydraulic system is minimized.

Hydraulic motors, the other main type of hydraulic actuator, can be likened to a hydraulic pump which is used in reverse to provide mechanical rotary motion derived from fluid flow. Hydraulic motors do, in fact, use many of the same parts that hydraulic pumps utilize.

The application of hydraulic motors differs from remote cylinders in two distinct ways. It is for these reasons that the use of hydraulic motors has not, as yet, been readily evident with agricultural implements (7).

First, the addition of remote cylinders to the tractor hydraulic system posed no real problem as far as matching the cylinder to the system or the cylinder to the job mainly because of the relatively low and intermittent flows encountered.

Matching hydraulic motors to the tractor hydraulic system and implement is, however, much more critical due to the continual operation which may be experienced. The hydraulic system must have both adequate pressure and flow to provide the necessary horsepower and torque output required by the implement under all conditions.

Secondly, hydraulic motors and motor mountings are as yet unstandardized, as are the implements which do not have mountings provided. The position of hydraulic motors as applied to agricultural implements at present is analogous to that of remote cylinders in the early 1940's; tremendous opportunities for the use of hydraulic motors exist once hydraulic motors and agricultural implements are studied, reviewed, grouped and standardized to utilize the benefits of rotary hydraulic power as fully as the benefits of linear hydraulic power have already been utilized.

In addition to the proper matching of the system motor and load, the hydraulic system, in order to perform properly, should provide a means for efficiently reversing the hydraulic motor with provisions made for

absorbing any overloads which may be imposed on the motor during severe operation.

Means also must be incorporated within the hydraulic system to control speed and force or torque output of the actuator with ease and also limit actuator speed to an acceptable level.

The hydraulic system and motor should efficiently provide the necessary torque to prevent any excessive heat buildup within the system.

The hydraulic system must be capable of maintaining a satisfactory hydraulic fluid temperature to prevent premature failure of the hydraulic components.

Once these features can be included in tractor hydraulic systems, the adaptability of the hydraulic system to the inclusion of remote hydraulic motors appears to be quite acceptable to agricultural applications.

Systems

Recently, Zimmerman (1966) conducted a hydraulic survey of fifty-four farm tractors with at least 23 PTO HP manufactured by eight companies. Table 1 summarizes his findings:

TABLE 1.--Hydraulic system types for various tractor PTO horsepower groupings.

System Type	No. of Tractors	20-39 PTO HP	40-59 PTO HP	60-79 PTO HP	80-99 PTO HP	100+ PTO HP
Open-center	44	11	14	8	4	7
Closed-center	10	2	2	2	2	2
Variable displacement pump	8	1	2	1	2	2
Constant displacement pump	2	1		1	0	0

Eighty-one and one-half per cent of the major tractors available on the market today are equipped with open-center hydraulic systems and constant displacement pumps.

The nomenclature, open- or closed-center, refers to the design of the control valve. A system containing a control valve which allows flow through its center in the neutral position is an open-center system. No flow through the valve when in neutral indicates a closed-center valve and a closed-center system.

The basic open-center system is relatively simple in design; but as the number of functions operated by this type of circuit increase, the complexity of the entire system also increases. In order to provide proper sequential operation and adequate pressure and

flow control to the individual functions, a close matching of the pump, valve, flow divider and actuator is required. Due to the complexity, the number of valves and actuators which can be added to the system is limited.

Since open-center systems are constant displacement systems, the trend of increasing available hydraulic horsepower through, generally increased pump output requires that additional flow capacity be built into the system to prevent excessive increases in neutral line pressures which would cause more heat generation and horsepower loss in the system.

The remaining tractors, which made up 18.5 per cent of the total number in the survey, are equipped with closed-center hydraulic systems.

There are basically two types of closed-center hydraulic systems being used.

The first type incorporates a small constant-displacement pump which is used in conjunction with an accumulator and unloading valve to provide a constant available working pressure and a storehouse of hydraulic energy in the accumulator.

This accumulator system takes advantage of the fact that less horsepower is required to operate the small pump at full capacity for a given period of time.

Also, with the low displacement, heat buildup and horsepower losses due to neutral line pressures are minimized.

The accumulator, when charged, provides flow rates in excess of pump displacement for a limited period of time.

The main disadvantage of closed-center accumulator systems is that they provide relatively high flow rates for only limited periods of time. For prolonged operation, the usable flow is only that which is provided by the hydraulic pump, which is relatively low. Also, space must be available to mount the accumulator, which is sometimes rather bulky.

This characteristic would not adapt these types of systems to those motor applications which require large volumes of oil.

The second type of closed-center system incorporates a variable displacement pump with sufficient capacity to meet the flow and pressure requirements of the functions when they are operating yet return to essentially zero flow when there is no requirement for oil. This feature, of course, provides the necessary pump flow for prolonged operation of hydraulic motors yet minimizes the heat buildup and energy loss within the system, when in neutral, due to the no flow characteristic of the pump.

Closed-center systems with variable displacement pumps take up a minimal amount of space within the

machine due to the minimum amount of valving required and the absence of a bulky accumulator. Furthermore, the variable displacement feature of these pumps, coupled with an essentially constant working pressure, allow actuator speed and force or torque output to be easily controlled and limited for protection of the machine (6).

Edible Bean Production

Status

Edible bean production in Michigan is important both to the state and nation.

United States Department of Agriculture statistics for the six-year period including 1959 and 1964 indicated that 40 per cent of the national edible bean acreage was harvested in Michigan, and 39 per cent of the national edible bean production was produced in Michigan.

It was also noted that for the six-year period previously mentioned, Michigan produced 99.4 per cent of all pea or navy beans, 58.5 per cent of all cranberry beans, and 27.8 per cent of all red kidney beans produced in the United States.

Within the state, 91 per cent of the total edible bean production was navy beans, and 6 per cent of the total production was red kidney beans.

During this same six-year period, navy beans made up 36 per cent of the total United States production followed by pinto beans with 24 per cent, great northern beans with 10 per cent, and red kidney beans with 8 per cent (14).

Further reference is made to Tables 2 and 3 listing statistics which may be of interest with regard to state and national production figures.

Present bean production is centered in the Saginaw Valley and Thumb Area. Harvesting of the crop generally takes place after the beans and pods have ripened sufficiently, generally, sometime between early September and the middle of October.

Harvest

Present operations included in the harvest are:

(1) removing the plant from the ground, (2) placing rows of plants together in windrows, and (3) threshing.

The operation of removing the plant from the ground is most often done with a blade-type-puller mounted on a tractor. The end result of this operation is removal of the plant from the ground with the tough taproot still attached. The amount of dirt and rocks included in the plant material by the blade-type puller is dependent upon how efficiently the depth of the blades can be controlled.

TABLE 2.--Edible beans--acreage harvested, yield and production--top six states, 1959-1964.

State	Acres Harvested 1000 A.	Yield/A. lbs.	Production, Clean Basis 1000 cwt.
1959			
Michigan	509	1260	6413
California	254	1442	3662
Colorado	211	780	1646
Idaho	123	1800	2214
New York	89	940	837
Nebraska	77	1650	1270
U. S. Total	1435	1290	18505
1960			
Michigan	525	1190	6248
California	221	1403	3100
Colorado	217	820	1786
Idaho	117	1680	1966
New York	96	1270	1219
Nebraska	71	1900	1065
U. S. Total	1400	1244	17411
1961			
Michigan	541	1360	7358
California	241	1353	3256
Colorado	239	940	2247
Idaho	95	2020	1923
New York	87	1530	1331
Nebraska	74	1900	1406
U. S. Total	1414	1391	19672
1962			
Michigan	573	1350	7732
California	215	1477	3184
Colorado	220	750	1650
Idaho	101	1820	1835
New York	87	1350	1242
Nebraska	77	1350	963
U. S. Total	1414	1369	17942
1963			
Michigan	584	1470	8585
California	225	1478	3325
Colorado	196	1100	2156
Idaho	98	1830	1796
New York	92	1140	968
Nebraska	73	1900	1387
U. S. Total	1370	1459	19982
1964			
Michigan	613	1240	7601
California	195	1424	2776
Colorado	186	960	1508
Idaho	94	1640	1542
New York	100	1170	1170
Nebraska	67	1600	1072
U. S. Total	1355	1252	17375
U. S. Six-year Average	1404	1318	18481
Michigan Six-year Average	558	1302	7267

TABLE 3.--United States and Michigan edible bean production by commercial classes, clean basis, 1959-1964.

	1959 1000 cwt.	1960 1000 cwt.	1961 1000 cwt.	1962 1000 cwt.	1963 1000 cwt.	1964 1000 cwt.	% of Total Production 1964	Six- Year Average	% of Total Production 1959-1964
United States									
Pea	6,069	5,845	6,755	6,725	7,599	6,801	39%	6,632	36%
Pinto	4,381	4,475	5,592	4,042	4,508	3,666	21%	4,444	24%
Red Kidney	988	1,474	1,555	1,579	1,691	1,637	9%	1,487	8%
Great Northern	2,256	1,572	1,678	1,428	2,186	1,663	10%	1,797	10%
Cranberry	204	124	116	82	104	100	1%	122	1%
Others	—	—	—	—	—	—	20%	—	21%
Total	18,505	17,411	19,672	17,942	19,982	17,375		18,481	
Michigan									
Pea	6,006	5,811	6,714	6,696	7,565	6,771	89%	6,554	91%
Cranberry	164	111	113	75	93	92	1%	108	1%
Red Kidney	125	224	393	460	700	573	8%	413	6%
Others	118	102	138	161	227	165	2%	152	2%
Total	6,413	6,248	7,358	7,392	8,585	7,601		7,267	

The next operation of windrowing may be performed in conjunction with the previous pulling operation or separately with another trip through the field. Bean windrowers are designed to gently lift the bean rows into a common windrow on clean ground. This windrowing operation assists in removing dirt and stones included with the bean plants by the bean pullers. Side-delivery rakes are sometimes used in place of windrowers, but they do not function as well as bean windrowers in cleaning up the plants and attached roots without creating excessive field losses.

After a usual one-two day drying period, the threshing operation is then performed. Many operators use regular grain combines equipped with a pick-up attachment and special bean attachments. Special bean combines with spring-tooth cylinders and concaves designed specifically for the easily threshed bean pod and easily cracked bean kernel are available and used by the larger producers. Bean special combines are also available. These machines, although much similar to the regular grain machine, utilize spike-tooth cylinders, perforated grain pans and special grain elevators to secure a clean, uncracked product in the grain tank.

Problems and peculiarities of the edible-bean harvest are as follows:

1. Unpredictable, excessive precipitation and high relative humidity existing after pulling and before threshing may increase grain loss and grain damage and consequently decrease crop value.
2. The percentage of man-hours/acre required for harvesting seems to be much greater than is required for comparable crops such as soybeans.
3. Severe plugging may be experienced in combining beans with a rasp-bar machine if the taproot is not allowed to dry sufficiently prior to combining; drying speed can also be increased if the taproot can be lacerated to some extent by the puller mechanism.
4. The incorporation of dirt and rocks with the plant material may induce unnecessary machine wear and premature failure; it may lower the value of the crop due to excessive foreign material in the grain.
5. The position of the bean pods near the bottom of the stalk and close to the soil surface requires that the stalks be severed from the ground at or near ground level to reduce field losses.

6. The ease with which the bean pods are opened requires that removal and conveyance of the stalks be as gentle as possible to reduce shattering losses (4).

An example of the problem caused by weather damage is given by McColly (1958) who reports that in 1954 40 per cent of the crop was lost by spoilage in the windrow resulting from excessive precipitation during the harvest season. He further reports that beans left standing in anticipation of direct combining had spoilage losses of the lower pods only. These losses were considerably less than losses encountered with windrowed beans. It is also interesting to note that the windrowed beans had a higher pick percentage, or percentage of undesirable material, than the standing beans. This, of course, would result in a higher market value for the standing crop, which was later combined directly.

United States Department of Agriculture Statistics for 1959 indicated that 38.5 per cent of the time required to crop edible beans in the nation was spent in harvesting, while only 24 per cent of the total time was required to harvest soybeans, a similar crop. Soybeans were harvested almost entirely by a direct-combining process in the nation.

These same statistics indicated that 37.5 per cent and 19.7 per cent of the total cropping time was spent in

harvesting edible beans and soybeans respectively in Michigan.

Three man-hours/acre were required for the harvest of edible beans in Michigan and in the United States, while only 1.2 man-hours/acre were required to harvest soybeans directly in the state and nation (5).

The large, tough taproot which generally remains attached to the plant after pulling must be allowed to dry out sufficiently to pass through the rasp-bar cylinder and concaves used in most small grain combines. Since the large taproot dries slower than the rest of the plant, the excessive dryness of the beans and pods which exists when the taproot is sufficiently dry results in unnecessary shattering losses. Drying time of the taproot and other parts of the root system can be reduced if some laceration and ripping of the root system can be accomplished when the plant is removed from the ground.

The abundance of dirt and rocky material in wind-rowed beans creates an unnecessary hazard to the harvesting machine and may lower the market value of the product. As McColly (1958), Asher (1951) and Gunkel (1962) have reported, rocks at or near the surface of the ground have created problems in previous direct-harvesting attempts.

It should be mentioned at this point that there is no reason for operating in such rocky conditions as are

found in areas of Michigan and New York, for instance, with the rock removal equipment available. Rocks are not only harmful to bean harvesting machinery but also create excessive wear on most other machines used in these rocky areas. The damage to equipment resulting from rocks can be far greater than the cost of removing the rocks over a period of years.

The low-hanging position of the bean pods on the stalk requires that a direct-harvesting mechanism be operated very close to the surface of the ground. With some crops, it is extremely difficult to operate below all pods without severing the plant below the surface of the ground due to the ridging which may exist in the row after planting and cultivating. This condition may result in ungathered pods or pods which pop open when contacted by the severing mechanism.

Asher (1951) reported that the low-hanging pods may be subjected to mold formation if excessive precipitation and relative humidity persist for any period of time after the crop matures. This condition was also cited by McColly (1958) in bean harvesting experiments conducted in 1954.

The harvestability of edible beans is also dependent upon the varieties grown.

The two main types of edible beans grown in Michigan are the bush-type and vine-type varieties.

The bush-type bean includes the Gratiot, Sanilac, Seafarer and Seaway varieties. The bush-type varieties are less subject to white mold due to their ability to hold the pods up off the ground, thus allowing better air circulation. This characteristic also results in less damage to the beans from extremely wet weather and promotes easier harvesting. This characteristic results in the bush-type varieties being planted in over 90 per cent of the fields in the prime bean growing areas of Michigan.

The vine-type bean found in the lighter textured soils, although not prominent in Michigan, seems to produce best in the hotter, drier years when pod set becomes a problem. Vine-type varieties carry their pods lower to the ground. Vine-type beans grown in Michigan include the Saginaw and Michelite varieties.

JUSTIFICATION FOR CONTINUED RESEARCH OF
DIRECT-HARVESTING METHODS

Khan (1952) reports that a survey of county extension agents in 1952 indicated a trend toward harvesting methods which would reduce labor and risk. This trend has occurred to a certain extent in the Michigan bean-producing areas of the Saginaw Valley and Thumb Area. This survey also indicated a desire for a bean variety more adaptable to direct-harvesting methods.

The work conducted by Gunkel (1962) and others at Cornell was encouraged by that state's bean commission. Gunkel's attempts at direct harvesting were successful but did not create any great changes in New York bean production methods, apparently for two reasons: (1) attempts to have the particular pulling mechanism mass produced were futile, and (2) edible beans did not play an important part in New York's agriculture and were considered to be a highly specialized crop in that area.

The Michigan Bean Commission has become interested in direct-bean harvesting methods and has requested of Michigan State University that research be resumed in this area.

Reports of previous work done in this area are, in general, quite favorable towards direct-harvesting methods.

A subjective comparison of conventional pulling methods and direct-harvesting methods indicated that direct-harvesting methods should increase profit by reducing the operating costs of the harvest and by reducing the field losses and pick percentage of the crop due to inclement weather during wet years.

STATEMENT OF THE PROBLEM

When one reviews the previously discussed problems and peculiarities of the edible bean harvest, the requirements for a direct-harvesting mechanism become more evident. These requirements are as follows:

1. It should reduce the man-hours/acre required to harvest a crop as compared to conventional pulling methods.
2. It should allow the crop to be combined with a rasp-bar type machine immediately after removal from the ground to reduce weather damage.
3. It should maintain the crop in a condition which is as dirt-free and rock-free as possible.
4. It should be able to gather all pods, especially low-hanging pods, with a minimal amount of grain loss.
5. If the mechanism is to be mounted on the front of a combine, which is most desirable when it is considered that this would reduce the number of trips required over the field, it should be light in weight so that excessive load is not

applied to the table of the machine and short in operable length so that it does not extend too far forward from the table creating visual and/or structural problems.

6. It should be relatively inexpensive and comparable in use to other attachments used with small grain combines; i.e., pick-up or corn-head attachments.
7. In addition, (a) if a mechanism is to be positioned on each row, as opposed to a full length cutter bar, it should be capable of functioning satisfactorily within a given range to either side of that row; and (b) the mechanism should be readily adjustable as needed to maintain maximum operating efficiency in various crop and soil conditions.

PREVIOUS INVESTIGATIONS

Literature Review

Asher (1951) conducted research into direct-bean harvesting methods using a combine cutter bar mechanism with various auxiliary attachments.

Best results were obtained with a parallel-bar reel attachment and pea-type guards on the cutter bar.

Asher concluded that this direct-harvesting method was superior to conventional pulling methods when used with bush-type beans under all conditions and with vine-type beans only under adverse conditions. The reasons given for superiority of the cutter bar mechanism included minimized weather risk and reduced labor costs. Field losses were approximately the same for both methods. Under the wet, adverse conditions with vine-type beans, the direct-harvesting method proved superior because the cutter bar losses incurred included those beans near the ground which were subjected to weather damage and became moldy which raised the pick percentage and lowered crop value.

It might also be noted that in Asher's report continual reference was made to the unfavorable

and unpredictable weather conditions which persisted during the harvest, sometimes delaying intended operations for two to three weeks.

Khan (1952) also conducted edible bean harvesting tests in 1950 and 1951. These tests were basically concerned with four types of losses as they were affected by certain variables. These losses, as defined, included:

Cutter bar loss: All grain, loose or in pods, left on the ground by the machine and never passing through the machine

Cylinder loss: Unthreshed grain left in the pod but carried through the machine

Separating loss: All shelled or loose grain carried over the separating and cleaning mechanism and lost out the rear of the machine

One of the four variables involved in the harvesting tests was the difference in losses resulting from direct versus windrow harvesting of the crop.

Results of these tests with other variables relatively constant indicated field losses as a per cent of preharvest yield to be 22.7 per cent for a direct-harvesting mechanism utilizing a reciprocating cutter bar.

Tests for a machine equipped with a conventional pick-up attachment yielded a loss of 17.2 per cent. Test conditions were listed as humid weather with a wet crop.

Direct combining a wet crop resulted in cutter bar losses of 48.0 per cent of the total field loss but only 23.9 per cent of the total loss when the crop was dry.

As explained by Khan, high cutter bar losses with a wet crop were the result of the pods hanging very low and being left in the field. With a dry crop, although the losses were less, the percentage of shattered grain popping out of the pods was higher.

As a comparison to what some people might consider as ideal, in one series of tests a man walked in front of the machine manually pitching windrowed beans into the conveyor. Cutter bar losses, as defined, were 1.7 per cent and 2.3 per cent of the preharvest yield for wet and dry crops respectively.

Khan concluded that of the three types of losses listed, the one loss which was predominant in almost all tests was the cutter bar loss which claimed about one-half of the preharvest yield in some instances.

McColly (1958) reported that 40 per cent of the crop was lost in the windrows due to inclement weather during the latter part of September, 1954.

Direct harvesting tests by McColly in 1955 and 1956 in which he compared direct-harvesting with a

cutter bar to direct harvesting with a single-disk rotary cutter followed by a pick-up attachment on a combine indicated increased gathering efficiency with the rotary cutting mechanism.

Reference is made to Table 4 which provides a comparison of the results obtained with a cutter bar and a rotary cutter by McColly in 1955-56.

TABLE 4.--Direct-harvesting tests, 1955-56.

Harvesting Method	Harvesting Condition					
	Yield Bu/A	Good Loss Bu/A	Loss %	Yield Bu/A	Dry Loss Bu/A	Loss %
Direct cut w/cutter bar	26.3	2.37	9.03	30.1	7.0	23.22
Cut w/ rotary cutter, pick-up	26.3	.47	1.50	30.1	3.4	11.29

It was also reported that losses with the rotary cutter were reduced to 3.0 per cent under dry conditions if the machine were operated in the morning when a dew was still present.

Gunkel and Anstee (1962) conducted direct-harvesting experiments during 1961-62 which investigated various mechanisms designed to pull the plant from the soil.

Their comparisons of experimental pulling devices to conventional pulling methods were based upon conventional method losses of 2.04 Bu/A and 2.9 Bu/A in 1959 and 1961 respectively. The conventional method which they discussed included pulling, raking, and picking up the crop.

One device utilizing a rubber fingered V Belt on each side of the plant resulted in pulling losses of 1.57 Bu/A which was considered to be significantly lower than conventional losses in 1959. Work in 1960 with this device resulted in losses of 2.62 Bu/A.

Experience in New York at this time indicated the rotary cutting device was unacceptable due to the large amount of rocks at the soil surface which rapidly dulled the cutting edges.

During 1960, a four-belt puller was also used, but losses of 2.87 Bu/A were considered excessive.

Best results were obtained with a flat-belt puller in 1961. The optimum belt speed to ground speed ratio resulted in minimal losses of 1.0 Bu/A. During this same year, the same rubber-fingered V Belt device tested in 1959 lost about 2.4 Bu/A.

Analysis

The increased cutter bar losses resulting from direct-harvesting methods are, of course, reductions in the net profit returned to the landowner, but the

labor-saving method of direct harvesting and condition of the direct-harvested product may tend to offset field losses and increase net profit returned to the landowner. Reference is made to the reports of McColly (1958) concerning the high pick percentage in windrow-harvested beans as compared to direct-harvested beans in moist weather particularly.

The effect of direct-harvesting methods becomes more complicated when the overall combine operating efficiency is evaluated as it is affected by the method of harvest. Khan indicated this in his evaluation that cylinder and separating losses increased as the volume of plant material passing through the machine increased. This volume is likely to increase with a windrow-harvested crop which has been pulled.

It must be remembered that McColly's tests concerned with the rotary cutter in 1955-56 were on a two-phase operation which included cutting and pickup. Undoubtedly, some of the losses reported were a direct result of the pickup mechanism and not the rotary cutter.

The marked difference existing between losses of the cutter bar and rotary cutter appear to significantly favor the rotary cutting mechanism under both wet and dry conditions.

Flat-belt pullers, which envelop the entire plant, investigated by Gunkel and Anstee have not been used

extensively, although they function well. Correspondence with Gunkel indicated the device could readily be mass produced and mounted but this was not done because of the relatively insignificant status of New York State edible bean production. The use of the flat-belt pullers in rows narrower than 36 inches probably limited their acceptance also.

Gunkel and Anstee's experience with a rotary cutting mechanism, unfortunate as it was, could have been more pleasant had the field been cleaned of rocks as all fields should be. Other reasons for an experience of this type, as related by the manufacturer of the rotary cutting machine, would include improper angle of operation or depth of operation of the cutting units.

PRELIMINARY INVESTIGATION OF A ROTARY

DISK CUTTING MECHANISM

Requirements of the Mechanism

Reports by McColly (1958) indicated that the rotary cutting disk principle performs satisfactorily under Michigan conditions. It was reported that combining can be accomplished directly behind rotary cutting disks with no adverse effects on the machine.

In view of these reports and in view of the fact that it does not appear that direct harvesting with a reciprocating cutter bar can be accomplished without high cutter bar losses and large amounts of foreign material passing through the machine, it was decided that the rotary cutting principle be investigated in detail with the thought in mind that a rotary cutting mechanism be developed that could be mounted on the front of a combine to facilitate direct harvesting.

The design requirements of a direct-harvesting mechanism utilizing the rotary cutting principle for this type of a crop would include those requirements as listed on pages 29 and 30 of this report.

The application of rotary cutting disks to these requirements would indicate that:

1. A rotary cutting mechanism should reduce the man-hours/acre required for harvest by including the pulling and windrowing operations with the threshing or combining operation.
2. A rotary cutting mechanism should enable the crop to be combined immediately, even with a rasp-bar type machine, since the cutting mechanism either cuts off or lacerates the taproot sufficiently to allow immediate combining.
3. A rotary cutting mechanism should leave the plant material in a condition which is as dirt-free and rock-free as is possible. In viewing the operation of a rotary cutting disk, there was no evidence of foreign material being mixed or thrown in with the plant material.
4. A rotary cutting mechanism used in conjunction with rod-type lifters, if necessary, and operated at or near the surface of the ground should be able to move under all low-hanging pods.
5. A series of rotary cutting mechanisms, hydraulically driven, in-line and close to

the front of a combine table, and short in operable length should be light in weight and close enough to the operator to eliminate any structural or visual problems.

6. A basic rotary cutting mechanism appears to be relatively simple in structure and, consequently, should be relatively easy to manufacture at a cost comparable to other front-mounted combine attachments.
7. A rotary cutting unit should be capable of functioning satisfactorily within a given range which could be easily maintained by the operator to either side of the row.

Analysis of the Functions to be Performed

Ideally, a mechanism of this type should perform two specific functions: (1) separation of the plant from the ground, and (2) conveyance of the plant to the combine.

Separation

Ideal separation would include severance of the plant stem from the root system, thus minimizing the amount of foreign material and plant material passing through the combine.

If complete severance is not accomplished, the root system should be lacerated to such an extent that it will not promote any plugging at the combine cylinder.

Any foreign material clinging to the roots should be sufficiently loosened by the cutting mechanism so it does not remain with the plant.

Ideal separation would, of course, involve a minimal amount of contact between the bean pods and the cutting mechanism and a minimal amount of vibration of the plant by the cutting mechanism as separation is accomplished to insure that the bean pods are not accidentally opened, which would cause the beans to be lost on the ground.

Conveyance

Conveyance or movement of the bean plant into the gathering mechanism of the combine after separation would ideally be short in distance with as little agitation of the plant material occurring as is possible.

Ideally, rotation of the cutting disks would impart sufficient rearward motion to the separated plant to move it rearward into the combine gathering mechanism; such as, an auger or conveyor in the combine table. This, of course, would require that the cutting mechanisms be mounted close to the base machine and would not require any additional conveying mechanism.

Selection of the Basic Design

The basic designs considered included:

1. A single cutting disk similar to the Hopkins machine.
2. A single cutting disk with a stationary shear bar below the disk to provide a cutting or shearing edge for complete severance of the plant but requiring that the shear bar be operated at or just below the surface of the soil.
3. Two cutting disks with one disk on each side of the row, rotating in opposite directions, with one disk rotating slower than the other to acquire both a holding and severing action on the stem of the plant, to reduce shattering losses.
4. Three cutting disks with two disks on one side and one disk on the other side of the row with the paired disks serving to hold the plant stem as the third disk rotates between them, severing the plant stem.

The design utilizing the two disks was chosen because it should function in severing the plant almost as well as any of the designs, should not require as much force to push through the soil as the design utilizing the stationary shear bar or the three disks, should not

require as much rotational horsepower as the three-disk design, and should provide a desirable set of controlled variable conditions in the differing speeds of the rotating disks.

With regard to the function of conveying of the plant material to the combine, the ideal situation, as previously stated, would be that the cutting disks would impart sufficient impetus to the plants which would move the plant material directly into the combine table. Viewing Hopkins' machine in operation indicated the plants were moved rearward a short distance.

If rearward movement should not be sufficient, a reel-type or walker-type feeder could be mounted directly behind and above the cutting disks to move plant material away from the cutting disks and onto the combine table. This addition would, of course, increase the complexity and cost of such a unit; and the extra handling would promote somewhat higher shattering losses.

The third consideration regarding the conveying mechanism would be to mount the cutting unit forward of a standard combine pick-up attachment, but again, the extra handling and cost involved resulted in this method only being thought of as an alternative.

Pertinent Data on the Single-Disk
Cutting Unit

Peripheral speed of the 26-inch diameter disk at reported rotational speeds of 500 to 600 RPM would be 3400 to 4080 FPM.

At reported operating speeds of five to six MPH, the relation of peripheral disk speed to ground speed, hereinafter referred to as Peripheral Speed/ Ground Speed Ratio, would range from 6.4/1 to 9.3/1.

The maximum effective cutting angle, which is important in the determination of the effective cutting width or operating width, will hereinafter be defined as the maximum angle at which material, as it comes in contact with the periphery of the rotating disk and is severed, is effectively moved rearward over the disk.

With no information available regarding this angle, an investigation of the desired operating width, assuming a safety margin of one-inch on the edge of the disk, allowed for an approximation of the maximum cutting angle. Table 5 lists this calculated data for a 26-inch diameter disk.

Table 5 indicates that for an operator to have a reasonably satisfactory operating range on each row, the maximum effective cutting angle must be in the area of 55-75 degrees, thus allowing a maximum effective operating range of 4.6 to 8.6 inches.

TABLE 5.--Maximum effective cutting angle with a single-disk cutter for various operating widths.

Operating Width, inches	1.4	2.0	2.8	3.6	4.6	5.5	6.5	7.5	8.6	9.7
Maximum Cutting Angle, degrees	35	40	45	50	55	60	65	70	75	80

DESIGN AND CONSTRUCTION OF THE FIELD TEST MECHANISM

Basic Design

Considerations in the design of the proposed double-disk unit included:

1. Sufficient horizontal overlap of the two disks to accomplish severance of the plant stalk.
2. Allowance for sufficient clearance between the rear edges of the disks (opposite the overlapped edges) which would operate on adjacent rows in a multi-row unit.
3. An effective cutting width comparable to the estimate for the single-disk unit presently manufactured.
4. Sufficient horizontal clearance between the driving shafts to allow rearward passage of severed plant material.

The initial assumption to be made with a unit of this type operating under these conditions was that an overlap of one to one and one-half inches should be sufficient to separate the upper plant from the root system.

Once the overlap was established, the equation listed below yielded the effective cutting width at various maximum effective cutting angles for various size disks. Table 6 illustrates these values. Figure 1 diagrammatically illustrates the disk overlap, disk clearance, maximum effective cutting angle and other pertinent information. Figure 2 illustrates the maximum effective cutting angle and the cutting width.

$$\text{Effective Cutting Width} = 2(R - \frac{1}{2}OL - R \cos \emptyset)$$

Where:

R = Radius of the cutting disks, inches

OL = Overlap of the cutting disks, inches

$\emptyset$ = Maximum effective cutting angle

TABLE 6.--Maximum effective cutting widths for various disk sizes and maximum cutting angles.

Maximum Cutting Angle, degrees	55		75	
	Disk Overlap, inches		Disk Overlap, inches	
	1.0	1.5	1.0	1.5
Disk Size, inches	Maximum Effective Cutting Width, inches			
12	4.1	3.6	7.9	7.4
12.5	4.3	3.8	8.3	7.8
13	4.6	4.1	8.6	8.1
13.5	4.7	4.2	9.0	8.5
14	5.0	4.5	9.4	8.9

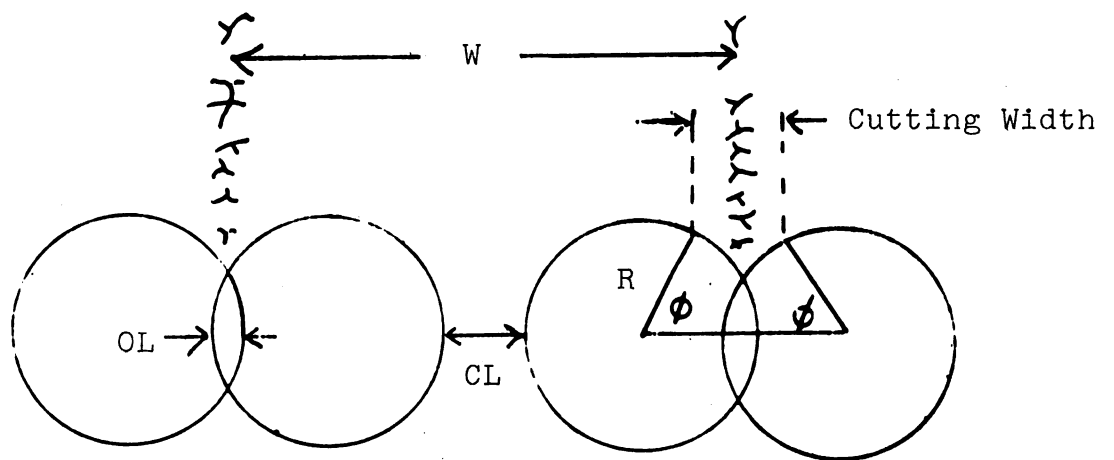
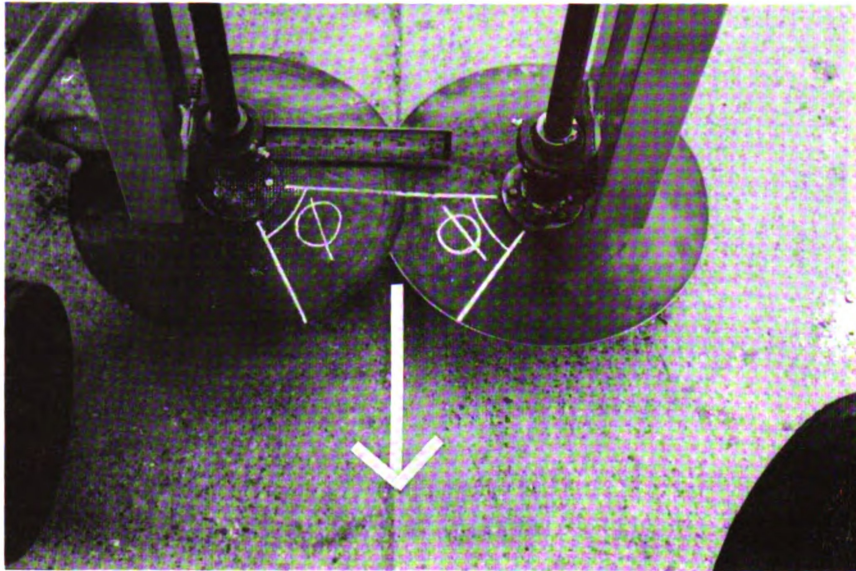
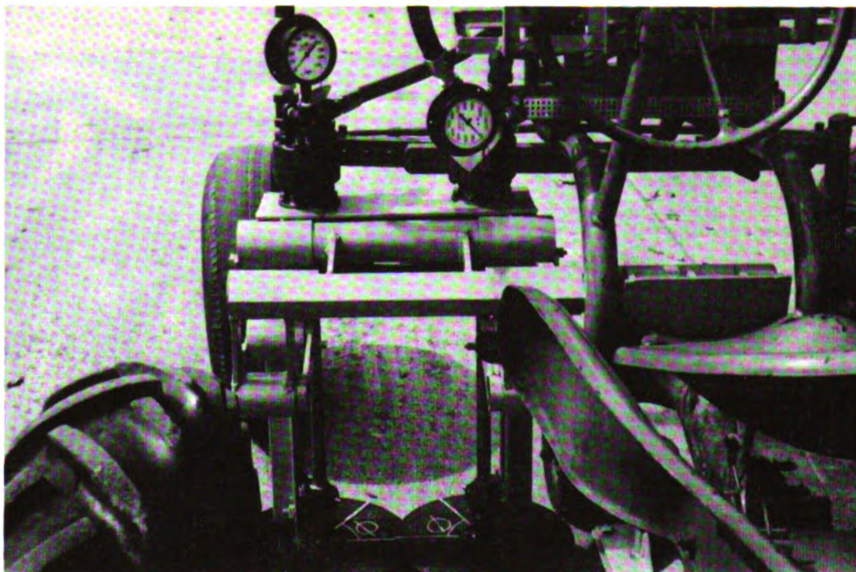


Figure 1.--Diagrammatic Relationship of Cutting Disk Dimensions



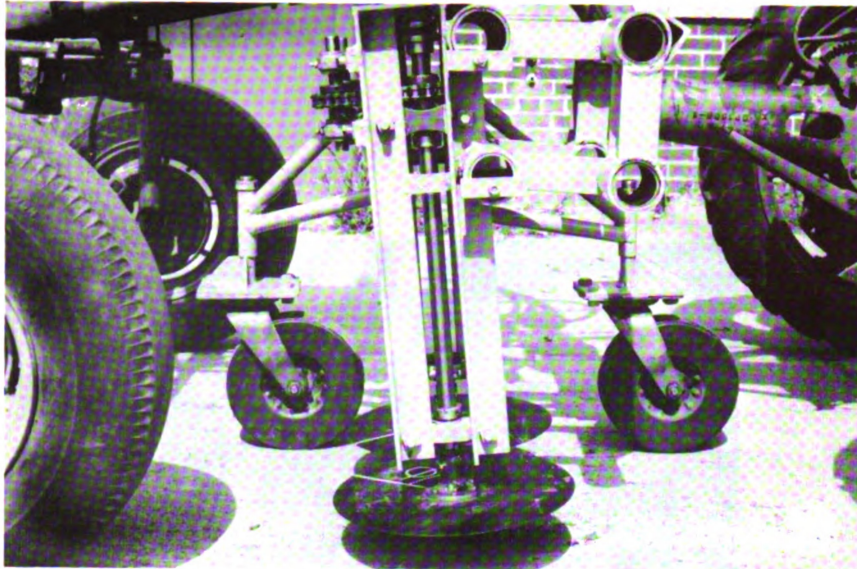
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Figure 2.--Maximum Effective Cutting Angle and Effective Cutting Width for a Double-Disk Unit



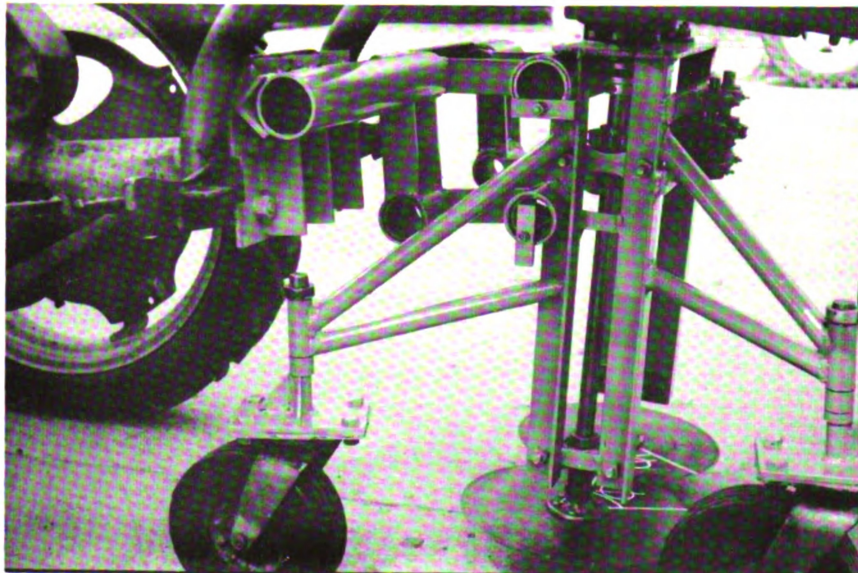
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Figure 3.--Rear View of Cutting Mechanism and Throat Clearance Above Cutting Disks



Neg. File 002

Figure 4.--Left Side View of Cutting Unit



Neg. File 002

Figure 5.--Right Side View of Cutting Unit



Neg. File 002

Figure 6.--Front View Illustrating Notched Disk

The equation expressing the clearance between the disks' edges opposite the overlap with an in-line multi-row unit would be as follows:

$$CL = W - 2D + OL$$

Where:

CL = Horizontal clearance between disks, inches

D = Diameter of disks, inches

OL = Overlap of the two disks, inches

W = Row Width, inches

TABLE 7.--Disk clearance for multi-row units with various row widths, disk sizes and disk overlaps.

Row Width, inches	26		28		30	
Disk Overlap, inches	1	1.5	1	1.5	1	1.5
Disk Size, inches						
12	3	3.5	5	5.5	7	7.5
12.5	2	2.5	4	4.5	6	6.5
13	1	1.5	3	3.5	5	5.5
13.5	0	.5	2	2.5	4	4.5
14	-	-	1	1.5	3	3.5

Final disk selection was of the 13.5-inch size. The average maximum operating width for maximum cutting angles of 55 degrees to 75 degrees was 6.625 inches with an inter-row clearance for multiple units of 2.5 inches when spaced on 28-inch rows with an overlap of 1.5

inches. This overlap will also allow operation of this unit in 26-inch rows with one-half-inch clearance still available for in-line multiple units.

This average operating width is comparable to that of the single-disk machine which had an average range of 6.6 inches for the above listed maximum cutting angles.

Construction

Frame Construction

The construction of the mechanism was such that it would be no wider than the width of one row yet wide enough to provide horizontal throat clearance above the cutting disks and between the disks' drive shafts for rearward plant movement.

The fore and aft length of the mechanism was limited as much as possible to reduce the weight of the unit and increase its compactness.

The height of the mechanism was directly related to the vertical throat clearance required above the cutting disks for rearward plant movement.

Overall dimensions of the unit frame were as follows:

Frame Width: 21 inches

Frame Length w/floating linkage: 16 inches

Frame Length w/o floating linkage: 8 inches

Frame Height: 24 inches

Cutting Disk to top frame height: 26 1/2 inches

Disk diameter: 13 1/2 inches

Disk position, center to center: 12 1/4 inches

Disk overlap: 1 1/4 inches

Disks width, overall: 25 3/4 inches

Vertical throat clearance between disks and

top frame: 19 3/4 inches

Horizontal throat clearance w/o shaft guards:

11 1/4 inches

Horizontal throat clearance w/shaft guards:

9 inches

Gauge wheels were installed on one side of the unit to maintain a specific operating height. An adjustment was provided to vary the height of the gauge wheels with respect to the cutting disks.

The unit was mounted on a tractor through a parallel linkage arrangement which permitted vertical movement of the unit with respect to the tractor due to variations in the soil surface. The parallel linkage also maintained the cutting disks at approximately a 5 1/2 degree forward tilt angle as the unit moved up or down.

Disk Construction

Power was transmitted from hydraulic motors through shafts to each of the cutting disks. The cutting disks were keyed to the bottom of each shaft and were also

vertically adjustable to accommodate small changes in operating height. The vertical clearance existing between the overlapping disks was approximately .054 inches for all tests.

The disks themselves were removed from a double-disk planting unit opener. A very slight concave shape of the disks required that the lower left-hand disk be mounted with the concave side up and that the upper right-hand disk be mounted with the concave side down.

The amount of concavity was found to be 1/8-inch at the center of the disk.

Preliminary Laboratory Testing

Laboratory tests were conducted to check the cutting ability of the two smooth disks. It was found that the lower bean stalks were not cut as rapidly as desired when hand-fed into the cutting unit. At disk speeds of about 600 RPM and 400 RPM on the left-hand and right-hand disks respectively, the cutting time required was about three seconds.

Consequently, it was decided to notch the cutting edge of the upper, right-hand disk. Notches were ground at eight evenly spaced points around the disk. The crescent-shaped notches were about one-half-inch long and one-fourth-inch deep. Care was exercised in grinding to insure that a sharp edge was maintained on the lower

edge of the notch. Cutting action was significantly quicker after notching.

Initial tests indicated that with right-hand disk speeds at or below 250 RPM, the stalk dropped into the individual notch and was pinched and/or sheared off by both disks. At speeds above 250 RPM, severance appeared to be the primary result of the notched edge gnawing away the stalk.

Hydraulic Drive System

The cutting disks were driven by two fixed-displacement gear-type hydraulic motors. The hydraulic motors were independent of each other to maintain maximum consistency in the test results.

Each motor was driven by a separate fixed-displacement, gear-type hydraulic pump which was, in turn, driven by a small gasoline engine.

The hydraulic motor speeds could be varied by regulating the speed of the gasoline engine. This was the manner in which the disk speed to ground speed ratio was changed.

The hydraulic motor speeds could also be varied with respect to each other by a flow control valve which could be used to divert a portion of the output flow from the pump back to the reservoir, thus reducing motor speed. As can be seen in the hydraulic system diagram,

Figure 7, this diversionary valve was in the circuit which drove the right-hand, notched disk (3, 11).

Hydraulic pump and motor selection was based on the assumption that the maximum horsepower per disk would not exceed two HP and that disk speeds within the range of 400 to 1500 RPM would be sufficient. System pressure was not to exceed 1000 psi.

With this information, the hydraulic component manufacturer's literature was used to select the necessary hydraulic pump and motor models that would satisfy the above requirements.

Two small shafts were mounted above and in front of the cutting unit. These shafts were driven from the cutting disk drive shafts at a 1:1 ratio. Two tachometers were then installed on the small shafts to provide a direct-reading mechanism for checking rotational disk speed.

A pressure gauge was installed in each hydraulic circuit to check the operating pressures developed in each circuit.

A third pressure gauge was also installed near the reservoir return line to check back pressure in the circuits.

The construction of the unit was such that disk heights and speeds could be conveniently changed and disk speeds and operating pressures could easily be determined.

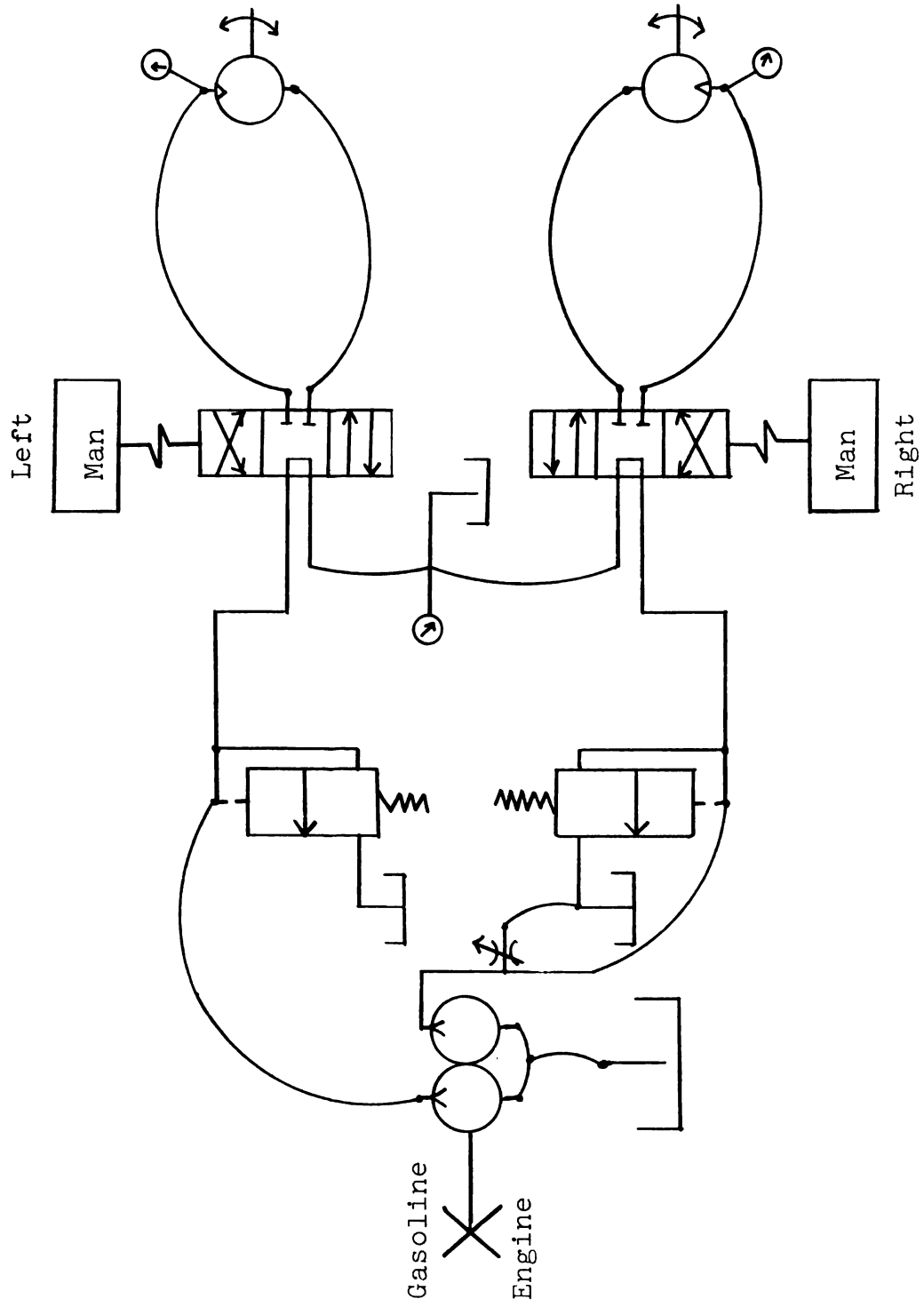


Figure 7.--Hydraulic Drive System

PRELIMINARY FIELD LOSSES OF
CONVENTIONAL METHODS

Types of Losses

During the first and second week of September, pulling, windrowing and pick-up losses were checked in various harvesting operations in the Mason, Michigan area.

Pulling losses were defined as those losses which resulted from the pulling operation in which the plant was removed from the soil. These types of losses included any beans removed from the pods as a result of the pods coming in contact with the pulling machine and any portion of the crop left in the ground by a pulling machine which was adjusted too high.

Pulling losses did not include any beans knocked from the pods by adverse weather conditions prior to pulling, sometimes referred to as pre-harvest losses. In checking, there were no pre-harvest losses resulting from weather damage.

Raking or windrowing losses included those losses resulting from raking or windrowing the crop after pulling and prior to combining. These losses were generally

the result of the crop coming in contact with the rake or windrower teeth, the soil surface and other plant material as the windrow was rolled over the ground.

In the Mason area, raking and windrowing were done in more than one operation. The reasons for this were twofold: First, leaving the pulled crop in two- or four-row multiples allowed for quicker drying before the final raking operation united row-multiples into six- or eight-row windrows for machine combining. Second, the multiple-raking operation reduced the possibility of stones being included in the windrow to be combined.

Pick-up losses included any beans or pods left on the ground as a result of the action of the combine pick-up attachment.

Procedure

Initially, pre-harvest losses were checked by a visual inspection of the test area to determine if any seeds were already on the ground. In all tests, the amount of seed on the ground prior to the harvest operation was negligible.

When checking for the pulling and raking losses, the pulling and raking losses were combined since portions of the raking operation were performed simultaneously with the pulling operation. A separation of these two types of losses was of no consequence to

later comparisons to be made with tests of the direct-harvesting mechanism.

A predetermined plot three feet long and equivalent to the width of the number of rows included in the final windrow was staked off after the windrow had been completed and was ready for combining.

All loose seeds and pods were collected from the plot. The loss per acre was then determined by correlating the number of seeds or pods found in the test plot with a given number of seeds having a known weight.

Combine pick-up losses were then checked by first placing a canvas behind and below the pick-up attachment. The combine operator then moved the combine over the test plot in a normal manner; and as the canvas dragged under the combine and passed over the specific test area, it was placed on the ground where it now covered any seeds or pods not gathered by the pick-up attachment.

After the combine had passed over the canvas, the canvas was removed and the seeds and pods left on the ground under the canvas were again collected and counted to determine the combine pick-up attachment loss.

Threshing and separating losses were not checked at the rear of the combine because they had no direct consequence to the comparison tests with the direct-harvesting mechanism.

The total of pulling, raking or windrowing and pick-up losses will hereinafter be defined as gathering losses or those losses encountered in performing all operations necessary to transfer the standing crop into or onto the combine platform or header.

In order to apply a more meaningful figure to the losses checked, it was decided that the losses should be reported as a percentage of pre-harvest yield.

Since time did not allow the checking of pre-harvest yield, an estimate of the pre-harvest yield was acquired by securing the harvested yield known by the farm operator and adding to this the loss determinations for the pulling, windrowing and pick-up operations. An estimate of one-half bushel per acre for threshing, separating and cleaning losses was also added to include all harvesting losses. The sum of harvested yield plus harvesting losses was then defined as pre-harvest yield.

Results

Table 8 numerically lists the losses resulting from conventional harvest methods.

Listed in the Appendix is pertinent data relating to each conventional field operation which would include dates of pulling, windrowing and combining, special attachments used and general field and crop conditions.

TABLE 8.--Field losses encountered with conventional harvesting mechanisms.

Operation ¹	Estimated Pre-harvest Yield		Pulling and Windrowing Losses		Pick-up Losses		Total Gathering Losses	
	Bu/A	% of Pre- harvest	Bu/A	% of Pre- harvest	Bu/A	% of Pre- harvest	Bu/A	% of Pre- harvest
A	19.56	.52	2.66	.54	2.76	1.06	5.42	
B	20.79	1.84	8.85	.61	2.93	2.45	11.80	
C	21.44	.93	4.34	1.02	4.76	1.95	9.10	
D	23.14	1.71	7.40	.93	4.02	2.64	11.41	
Average A, C, and D	21.38	1.05	4.92	.83	3.88	1.88	8.79	
Gunkel and Anstee (1959)						2.04		
Gunkel and Anstee (1961)						2.90		

¹See Appendix for information regarding the various operations.

CONSIDERATIONS OF AND TEST PROCEDURE FOR
THE FIELD TESTS CONDUCTED

Considerations of Test Procedure

The test procedure had as its main objectives:

1. The determination of grain losses resulting from the cutting operation.
2. The determination of the amount and direction of plant movement after severance.
3. The determination of the amount of power required to sever and move the plant material using a double-disk cutting mechanism.
4. The determination of the overall operating characteristics of a rotary cutting unit as related to the condition of the plant and stalk, the inclusion of soil and stones in the plant material, the ability to save low-hanging pods, the effect of soil and stones on the cutting disks, and the effect of operating the cutting disks to one side of the row.

The first three objectives were reviewed as they were affected by two main variables, which included:

1. The effect of changes in ground speed and/or rotational disk speed.
2. The effect of the operating height of the cutting disks with respect to the soil surface.

It was most desirable that all other factors be held constant which might affect the test results. This, however, was not wholly possible due to weather conditions which varied daily and soil surface irregularities which affected the operating height of the disk blades with respect to the soil surface throughout the test area.

An attempt was made during the test procedure to take note of these uncontrollable variables in order that the resultant test data would be more meaningful.

Test Procedure

The first three objectives of the testing program were to determine: (1) gathering losses resulting from cutting, (2) plant movement after cutting, and (3) the power requirements for each cutting disk.

All three determinations were made during one test run over a test plot which was one-row wide (30 inches) and usually twenty feet long. This particular area provided a sampling of fifty square feet.

Certain variables were changed and noted when moving from one twenty-foot plot to another.

Preliminary Testing

Preliminary laboratory testing included the determination of the general effect that notching of a disk had on the cutting ability of the mechanism. The overall effect is noted in the "Construction" section.

Preliminary field testing included the determination of ground speeds for various gear and throttle settings. This was done by timing the unit as it was driven over a known length of the field at different gear and throttle settings.

Also, the tachometers were calibrated to provide accurate determinations of the cutting disk drive shaft speed.

Initial operation of the unit indicated that as plant material was cut, it was moved rearward and distributed to the left over the faster rotating disk. This resulted in the plant material being deposited in front of the left rear tractor wheel. This condition was not conducive to the establishment of reliable loss tests or plant movement tests. It was also noted that plant material had a tendency to catch on or wrap around the rotating drive shaft.

Consequently, combination guard-stripper plates were installed around the disk mounting flanges and lower drive shafts to overcome the distribution and wrapping problems.

The sheet metal stripper plates were initially contoured to a shape that would lift the plant material slightly as it was propelled rearward. No appreciable lifting could be produced, however, without plugging occurring between the stripper plates. These plates are illustrated in Figure 6.

Lifting wires were installed above and in front of the edges of the cutting disks in an attempt to lift the low hanging pods over the cutting edges. These lifters did not prove to be of any benefit and were discarded.

Gathering Losses

The initial step in determining gathering losses was to first clean a predetermined area of the field of any grain which may have been left from previous tests on adjoining rows.

After cleaning the test plot and determining the ground speed, disk speed and operating height for the given test, the test unit was then operated over the specific plot.

Grain losses were then determined by counting all the beans removed from the pods either by shattering or cutting of the pods. The number of beans lost was then

correlated with the area of the test plot to provide the number of beans lost per square foot.

To provide a more accurate estimate of the number of beans per square foot equivalent to a given loss per acre, a random sample of beans was gathered from the test plot, weighed and counted. The weight was then correlated with the number of beans to provide an estimate of the number of beans per square foot that were equivalent to one Bu/A.

For the test area, it was determined that 3.15 beans per square foot were equivalent to one Bu/A.

Direction and Amount of Plant Movement

To check the ability of the cutting mechanism to move plant material into or onto the platform or table of a grain combine, the movement of the plant material was checked by randomly selecting three individual stalks in the section of row to be harvested. These stalks were then identified with paint. Their initial standing position in the row was also identified by markers on the surface of the soil near the standing stalks.

Upon completion of the stalk identification, the subject test row was cut. The severed plant material was then inspected to locate the previously identified stalks. Upon locating the specific plants, a measurement

was taken from the initial point of stalk placement indicated on the soil surface to the final point of stalk displacement. The distance between these two points was then defined as stalk movement.

Rearward movement of the stalk was defined as movement in a direction opposite to the direction in which the cutting unit was traveling. Forward movement of the stalk was defined as movement in the same direction as the machine was traveling.

Power Requirements

To apply some realistic figures to the amount of power required for operating the disks, a pressure gauge was installed at each hydraulic motor inlet and tachometers were installed on the shafts driven by the cutting disk drive shafts.

The hydraulic motor output HP could then be calculated using the following relationship:

$$\text{Output HP} = \frac{\text{psi} \times \text{RPM} \times .229 \text{ in.-lbs./psi}}{5252 \times 12}$$

The .229 in.-lbs./psi is the manufacturer's output torque specification for operating pressures within the range of pressures experienced.

Output HP would include that power required to overcome mechanical friction of the shaft mountings, friction resulting from the disks rotating at or below

the soil surface and power required to actually perform the cutting operation.

The operating pressures for the left-hand disk and right-hand disk were found to be 70 psi and 60 psi respectively, when the machine was operating above the soil surface under no load. This pressure was relatively constant over the speed ranges encountered.

The working pressures were checked and noted during each test run. An attempt was also made to check the operating speed during each test to note whether it decreased by any significant amount from the pre-test reading. Due to the relatively low working pressures, disk speeds remained fairly constant throughout each test.

RESULTS AND DISCUSSION

Gathering Losses

Figure 8 represents the gathering losses expressed in Bu/A and in per cent of pre-harvest yield as they were affected by the operating height of the cutting disks above or below the surface of the soil.

The general shape of the curve indicates that gathering losses decreased as the operating height of the cutting disks decreased or as the operating time of the cutting disks at or below the surface of the soil increased.

Although field losses were also affected by moisture content of the seed and plant material, an attempt was made to estimate moisture content and relate its effect to gathering losses. It is interesting to note that of eighteen tests conducted with resultant gathering losses of 1 per cent of the pre-harvest yield or less, eleven of these tests were at moisture contents estimated to be at about 20 per cent.

Gathering losses with conventional methods in the Mason, Michigan area for the 1967 season averaged out to 8.79 per cent of the pre-harvest yield. This 8.79

Figure 8.--Gathering Losses vs Operating Height

per cent consisted of 4.92 per cent pulling and windrowing losses and 3.88 per cent combine pick-up losses.

A comparison of conventional gathering losses with loss tests of the two-disk cutting unit indicated that:

1. Thirty-one of thirty-two tests (97 per cent) conducted were superior to average gathering losses for conventional methods.
2. Twenty-eight of thirty-two tests (87.5 per cent) conducted were superior to average pulling and windrowing losses for conventional methods.
3. Twenty-five of thirty-two tests (78.2 per cent) conducted were superior to the smallest pulling and windrowing losses listed for conventional methods.

For the four tests with losses in excess of 4.92 per cent of pre-harvest yield, the approximate height of the stubble above the soil surface was 1.6 inches.

Figures 9 and 10, respectively, represent gathering losses as affected by the average stubble height and stubble height as affected by the operating time of the cutting disks at or below the surface of the soil.

An examination of Figure 9 indicates that gathering losses are comparable to conventional methods if the stubble height is maintained at or below one and

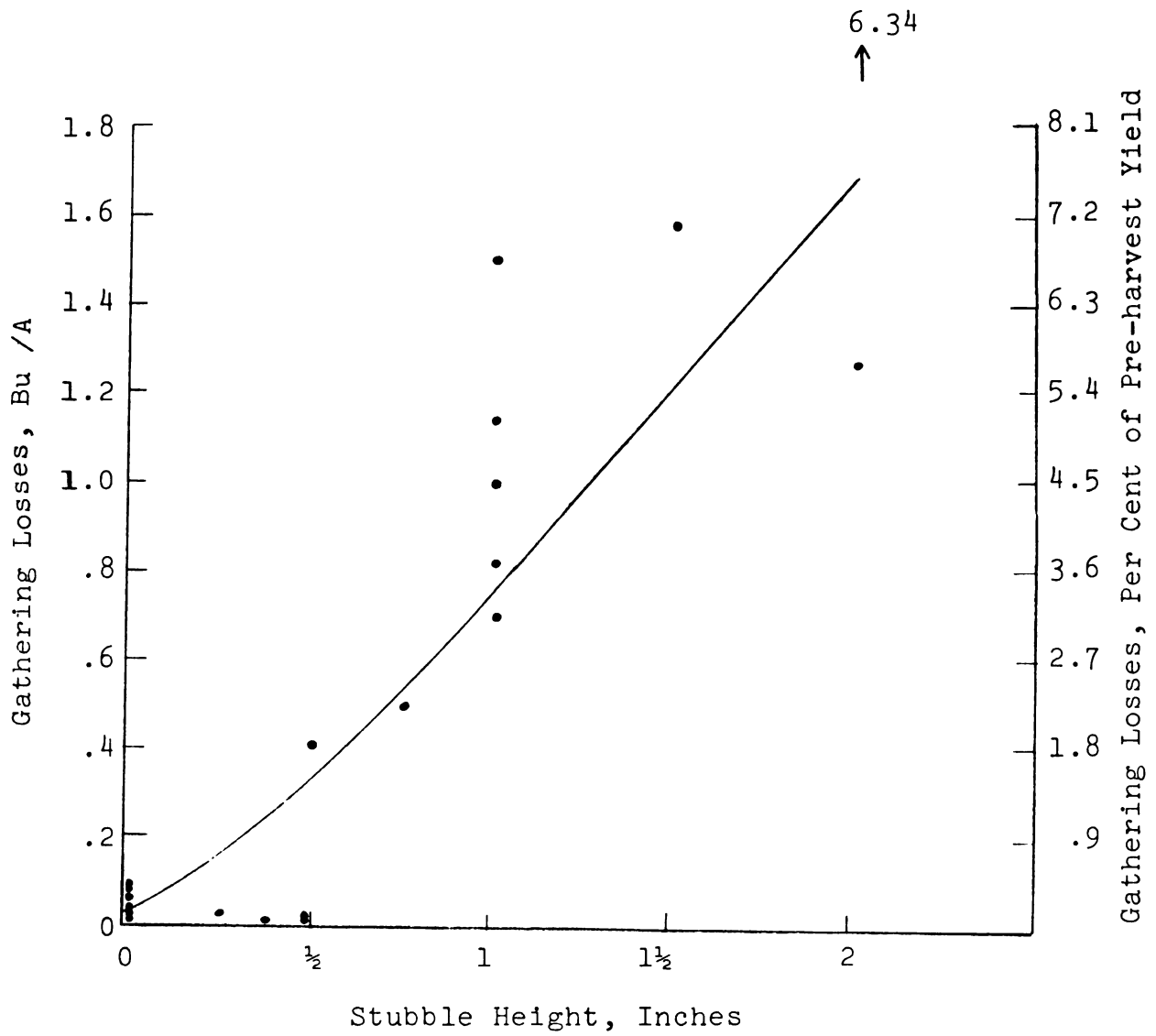


Figure 9.--Gathering Losses vs Stubble Height

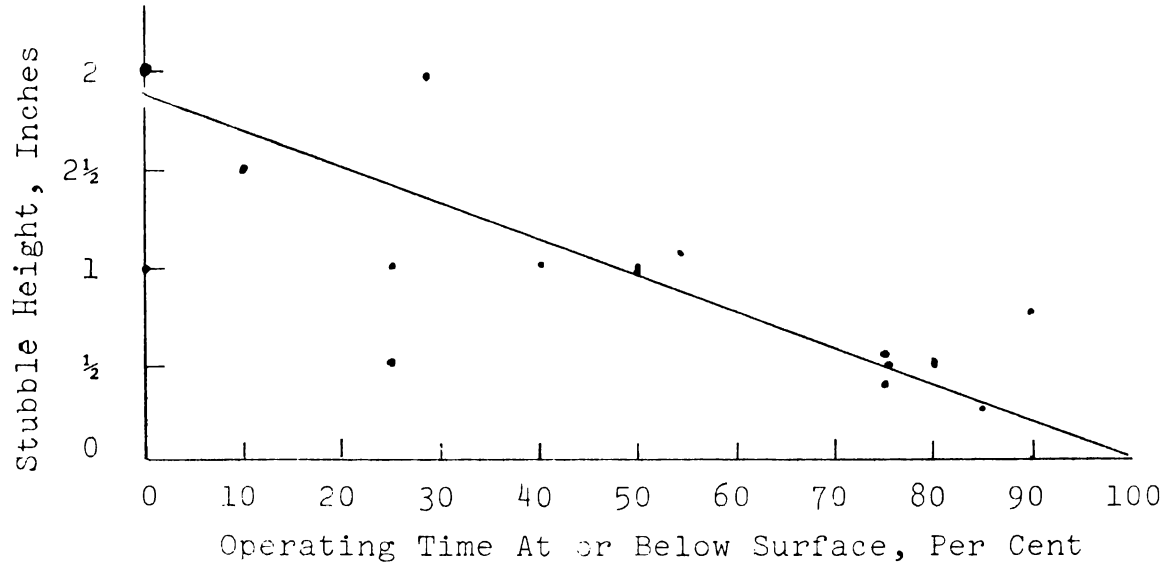


Figure 10.--Stubble Height vs Operating Height

one-half inches. It is noted that at stubble heights of one-half-inch to three-fourths inches, gathering losses can be maintained as low as 2.5 per cent of pre-harvest yield.

Following the curve represented in Figure 10, one can determine from the test data that the cutting disks should be operated at or below the surface about 65 per cent of the time with the test unit constructed.

Figure 8 indicates that at this operating height gathering losses of 2.25 per cent of pre-harvest yield could be expected. This figure would favorably compare with the 8.79 per cent average gathering losses and 4.92 per cent average pulling and windrowing losses for conventional methods.

In order to correlate the operating height of the cutting disks with the operational time at or below the soil surface, the disk height was measured vertically from the point of the "V" formed by the two disks to the bottom of the gauge wheels. For the majority of field tests conducted, the operating heights were either $2 \frac{11}{16}$ inches or $2 \frac{1}{4}$ inches. The average operating time at or below the surface was 62 per cent for an operating height of $2 \frac{11}{16}$ inches and 78 per cent for an operating height of $2 \frac{1}{4}$ inches.

It should also be mentioned that the majority of the gathering losses encountered were not shattering

losses resulting from the bean pods being popped open but were, instead, caused by the lower pods being cut open by the two disks.

It is for this reason that when the disks were just below the soil surface, the pods, although in contact with the soil, were never touched by the cutting disks.

It, thus, appears that if disk height can be maintained at or just below the soil surface, a lifting device to lift the low-hanging pods over the edges of the cutting disks is not required and may, in fact, result in more losses due to shattering.

Gathering losses may, however, be increased if it is necessary to utilize a feeding device of some type to move the severed plant material away from the cutting disks and rearward into a combine table should the cutting unit be mounted directly in front of a combine table.

Plant Movement

Since the direction and amount of plant movement was affected both by the operating height of the cutting disks and by the Peripheral Speed/Ground Speed Ratio of the cutting disks, Figure 11 represents the plant movement as it is affected by these two variables. The Peripheral Speed/Ground Speed Ratio is referred to as the P/G Ratio.

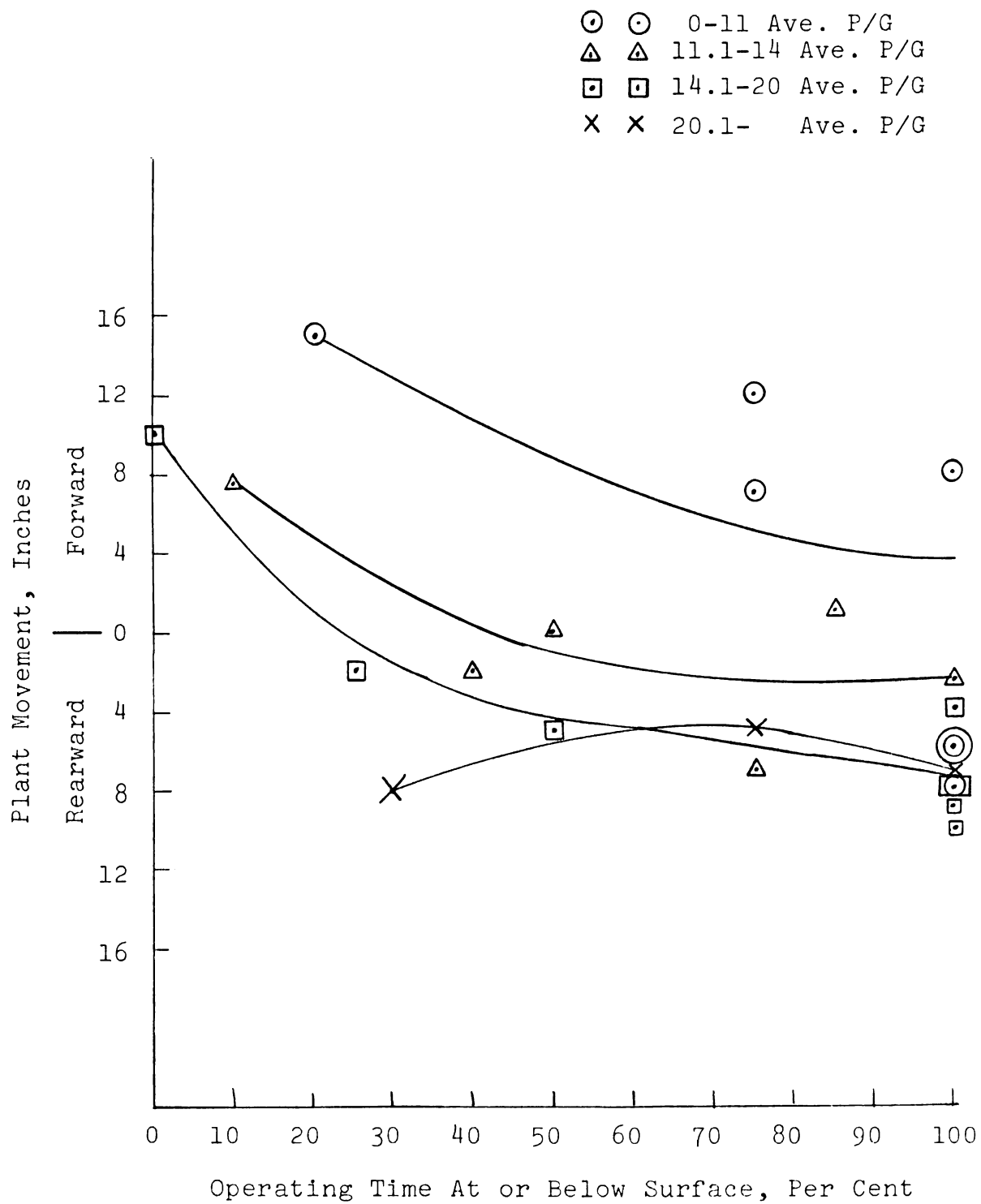


Figure 11.--Plant Movement vs. Operating Height

Effect of Operating Height

Figure 11 indicates that as the cutting disks were operated at or below the surface a greater percentage of the time, plant material was moved rearward a greater distance.

The three top curves demonstrate that rearward plant movement increased at a decreasing rate as the operating height was lowered.

For Average P/G Ratios of 11.1 - 14, the rate of change began to decrease at operating heights where the cutting disks were at or below the surface of the soil 50 - 60 per cent of the time or more.

For Average P/G Ratios of 14.1 - 20, the rate of change began to decrease at operating heights where the cutting disks were at or below the surface of the soil 40 per cent of the time or more.

At operational times of 65 per cent at or below the soil surface, plant movement was about two inches rearward for Average P/G Ratios from 11.1 - 14 and about four and one-quarter inches for Average P/G Ratios from 14.1 - 20.

Effect of Peripheral Speed/ Ground Speed Ratio

Figure 11 also represents the effect of changes in disk speeds with respect to ground speed. This figure reveals that as the Average P/G Ratio increased, plant material was moved rearward a greater distance.

Characteristics of Plant Movement

It was interesting to note that plant material, as it was severed, tended to follow the lower, faster, un-notched disk, resulting in plant deposits to the left of the center of the cutting unit. This characteristic may be acceptable if the unit were mounted on a combine table but was not desirable for straight windrowing.

Combination guard-stripper plates were installed to:

1. Distribute plant material in a straight row.
2. Prevent plant material from catching on the unit frame or wrapping around the drive shaft.

The constricting position of the guard-stripper plates tested did limit the rearward plant movement to a certain extent.

It is likely that a differently shaped stripper plate, possibly, vertically mounted above and extending parallel to a radius of the cutting disk to a point near the outer rear edges of the cutting disks, may still function to prevent wrapping, yet may allow more rearward plant movement.

As nearly as could be determined, the position of the severed plants was such that at higher P/G Ratios the main stem was pointed downward and rearward. At lower P/G Ratios the stem was pointed downward and slightly forward.

Power Requirements

Figures 12, 13, and 14 represent the hydraulic motor output HP required to drive the shaft and cutting disks individually and in total.

The figures represent HP as it is affected by two variables: (1) operating height at or below the surface of the soil, and (2) Average Peripheral Speed/Ground Speed Ratios.

Although the plotted data varied considerably, it is apparent that the horsepower required increased as the operating time at or below the soil surface increased and as the Average P/G Ratio increased.

The data shown in Table 9 lists speed and HP of the left-hand disk compared to the right-hand disk for twenty-one field tests.

TABLE 9.--A comparison of the speed and HP requirements of the cutting disks.

	Average HP Required	Average HP Required Left/Right	Speed Ratio Left/Right
Left-hand Disk	.7805	1.91/1	1.53/1
Right-hand Disk	.4085		

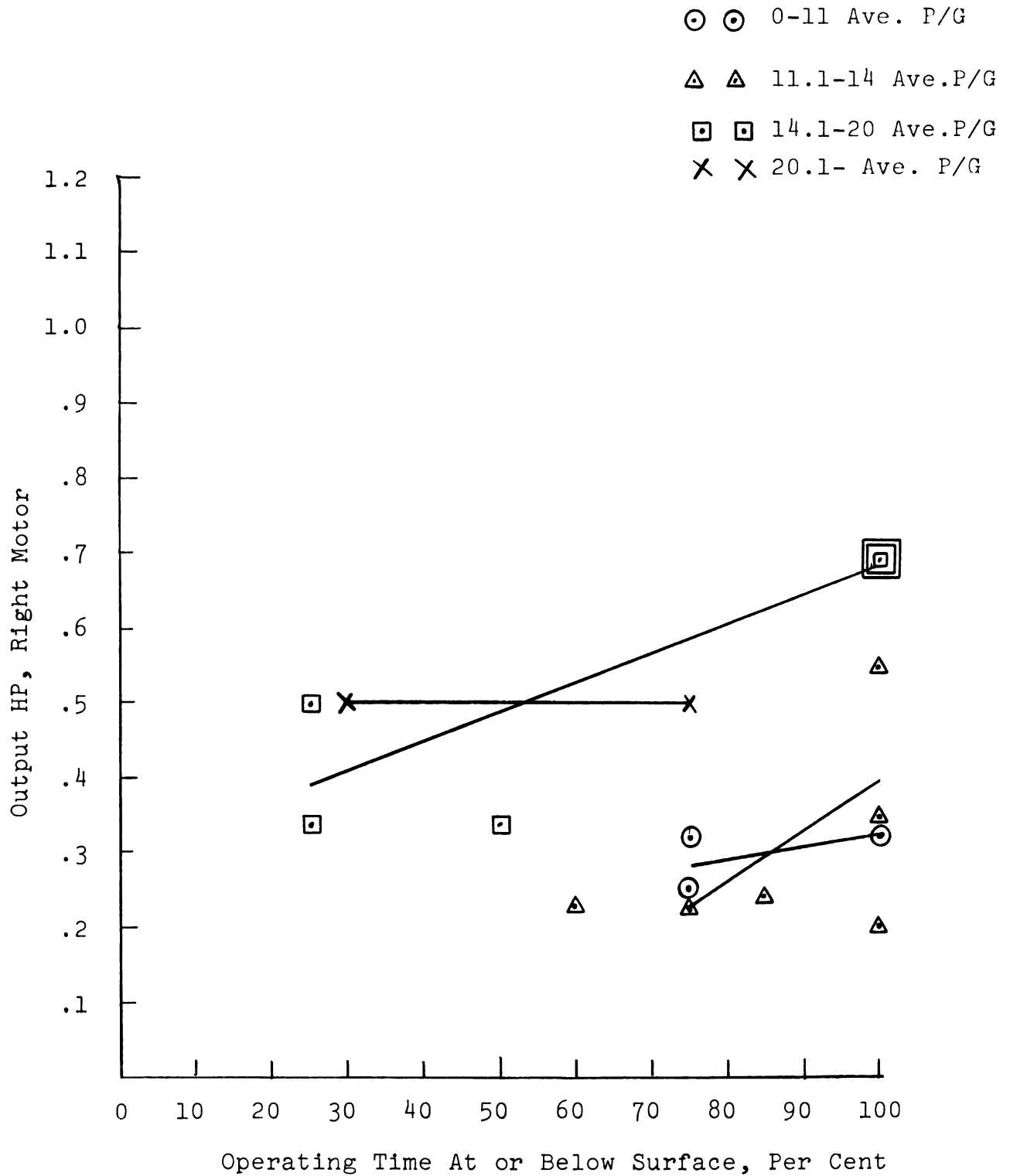


Figure 12.--Output HP, Right Motor vs Operating Height

○ ○ 0-11 Ave. P/G

△ △ 11.1-14 Ave. P/G

□ □ 14.1-20 Ave. P/G

× × 20.1- Ave. P/G

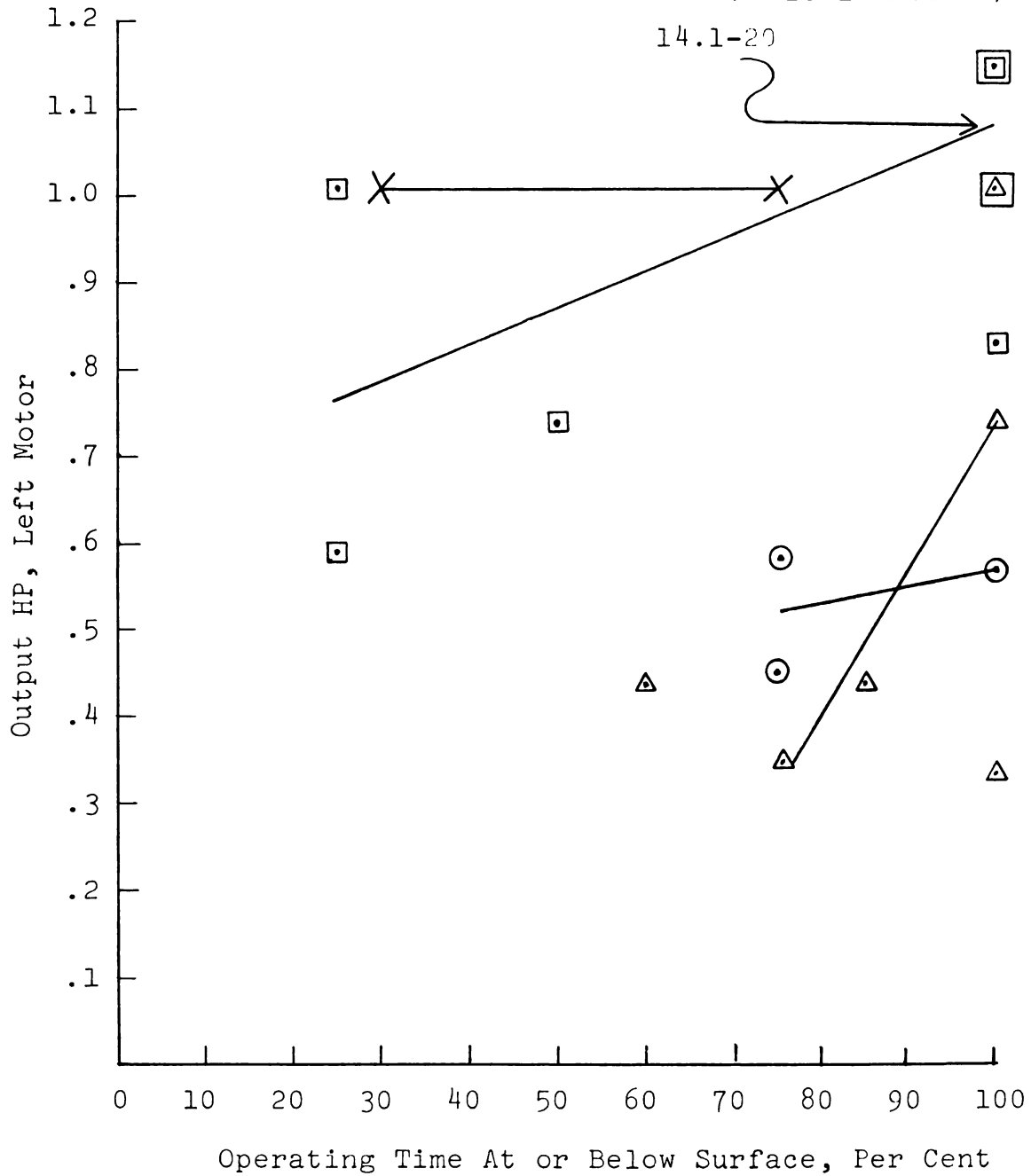


Figure 13.--Output HP, Left Motor vs Operating Height

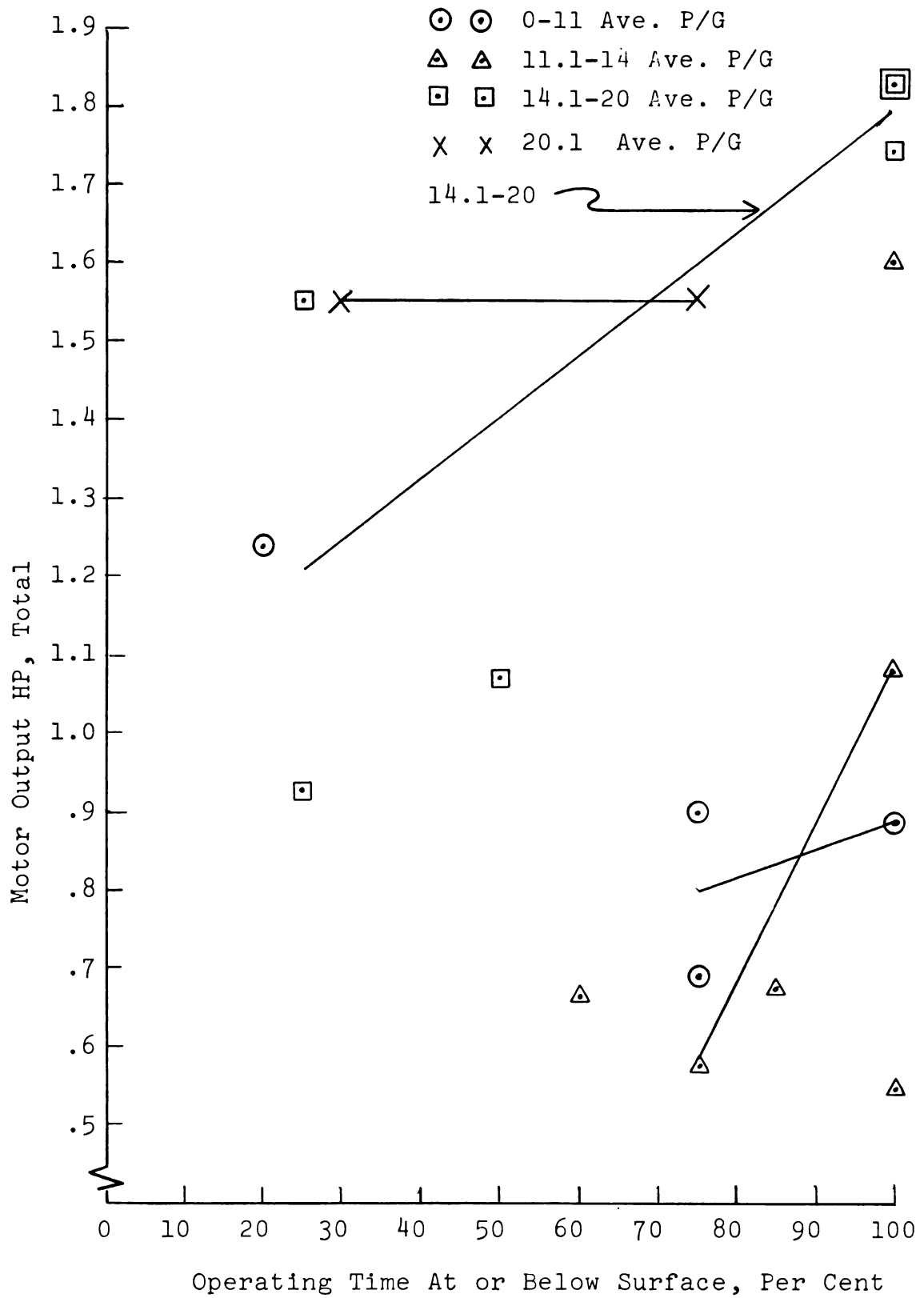


Figure 14.--Output HP, Total vs Operating Height

This data indicates that the HP required was not linearly related to disk-speed changes. For the particular test data, the differential in HP required by the two disks is approximately proportional to the speed ratio (Left/Right)^{1.5}.

The increased HP requirement at lower operating heights was a result of the increased soil friction existing between the cutting disks and soil.

In examining Figures 12, 13 and 14, the approximate HP required for operating at or below the surface of the soil at least 65 per cent of the time with a 14.1 - 20 Peripheral Speed/Ground Speed Ratio was about 1.5 HP in total with about .95 HP required by the left-hand disk and about .57 HP required by the right-hand disk.

For all tests, the maximum HP required was 1.84 in total with about 1.15 HP required by the left-hand disk and .69 HP required by the right-hand disk.

The change in the HP requirement as affected by the operating time at or below the surface of the soil is given by Table 10 which was derived from graphical data in Figures 12, 13 and 14.

TABLE 10.--Additional HP required as operational time at or below the surface is increased.

Peripheral Speed/ Ground Speed Ratio	Left-Hand Disk	Right-Hand Disk	Both Disks
	HP/10% Increase	HP/10% Increase	HP/10% Increase
11.1 - 14/1	.154	.066	.220
14.1 - 20/1	.041	.038	.079

Operational Characteristics

Plant and Stalk Condition

With the particular unit tested, there was true shear of the plant stalk with very little shredding or tearing. It was noted that at Peripheral Speed/Ground Speed Ratios of less than about 10/1 there was a tendency for the plant to be pulled forward out of the ground before complete severance occurred. This condition promoted plugging of the cutting unit.

Cleanliness of Severed Plant Material

Due to the root being left in the ground, the condition of the plant material was such that there was no soil or stones included with the plant material. This would, of course, assist in lowering the pick percentage and result in less wear on the harvesting machine.

Ability to Save Low-Hanging Pods

As previously mentioned under "Gathering Losses," the operation of the cutting disks at or below the soil surface resulted in the cutting disks moving under the bean pods, even though these pods may have been in contact with the soil surface. The majority of the losses encountered with low-hanging pods was from the pods being cut open, as opposed to being opened from contact with the flat surface of the cutting disk or unit frame.

Effect of Soil and Stones on the Cutting Disks

The field in which the unit was tested was a relatively clean field, although pebbles and stones as large as two inches in diameter were occasionally encountered. At no time during the field tests was the cutting unit damaged after contacting stones of this size.

Due to the relatively small notch size on the notched disk and the smoothness of the un-notched disk, it was felt that the stones never had the opportunity to catch on the disks and lock up the cutting unit.

The condition of the notch or trailing edge of the notch did not seem to change during the relatively short test period. In fact, operation of the cutting disks in the soil may have maintained a sharp edge on the moving parts.

If the unit should be developed for use in crops where disk height does not necessarily have to be below the surface, the possibility of damage from soil or stones would be decreased.

Effect of Lateral Movement of
the Cutting Disks on Cutting
Ability

In order to more accurately determine the effective cutting angle for a mechanism of this type, the cutting operation was observed as the machine was moved from one side of the row to the other.

It was noted that in moving down the right side of the row, poor cutting characteristics were observed as the center of the unit approached a point about four inches to the right of the row.

Poor cutting characteristics included over-running of the plant itself, inability of the disks to move the plant material rearward and plugging at the throat of the unit.

In moving down the left side of the row, these same characteristics were observed as the center of the unit approached a point about five and one-half inches to the left of the row.

A calculation of maximum effective cutting angle would indicate that the left, smooth disk has a maximum effective cutting angle of about 72 degrees while the right,

notched disk has a maximum effective cutting angle of about 85 degrees.

This indicated that the notched disk had a wider operating range and larger maximum effective cutting angle than the smooth disk.

SUMMARY AND CONCLUSIONS

A review of present edible bean harvesting methods and a comparison of these methods to the procedures used for harvesting similar crops indicated that a direct-harvesting method would increase the value of an edible bean crop by reducing the harvesting time, labor requirements and harvesting losses and by increasing crop value.

Initial work in Michigan on a single-disk rotary cutting mechanism prompted a study of the performance of a double-disk cutting unit which would completely sever the plant stalk.

Due to the requirements for a mechanism which would be light in weight and have a flexible and versatile drive system, hydraulic motors were chosen as the source of rotary power for this application. The advantages of a hydraulic drive system were readily evident for this type of application where it was desirable to increase disk speed as ground speed was increased in order to maintain a constant Peripheral Speed/Ground Speed Ratio.

The results of the field tests indicated that:

1. Gathering losses were directly proportional to operating height and decreased as operating height was lowered.
2. An operating height of 2 1/2 inches to 2 5/8 inches should provide an operating time of about 65 per cent at or below the soil surface.
3. At the above listed operating heights, gathering losses of about 2.5 per cent of the pre-harvest yield were experienced. This compared with gathering losses of about 8.8 per cent of the pre-harvest yield for conventional methods in the Mason, Michigan area.
4. Gathering losses resulting from shattering of the pods were minimal.
5. Gathering losses may be somewhat higher than the test results if it were required that a conveying device be mounted at the rear of the disks to move plant material rearward onto a combine table.
6. Rearward plant movement was proportional to the Peripheral Speed/Ground Speed Ratio and as this ratio increased, rearward plant movement increased.
7. At the above listed operating heights, rearward plant movement of about two to four inches was experienced with the unit equipped

with guard-stripper plates and operated with a Peripheral Speed/Ground Speed Ratio of about 11/1 to 20/1.

8. The horsepower required to operate the disks was directly proportional to the operating height, so that as the operating height was lowered, the required horsepower increased.
9. At the above listed operating heights and Peripheral Speed/Ground Speed Ratios of 14.1/1 - 20/1, the total power required to drive the disks' shafts was about 1.52 HP.

SUGGESTIONS FOR FURTHER STUDY

The following suggestions are provided to assist in the direction of any further studies which might relate to a double-disk cutting mechanism.

1. Laboratory research into the optimum cutting notch size, shape and speed which most effectively severs a given size stalk appears to be pertinent to the design of such a unit.
2. Laboratory research regarding the minimum disk size that will operate effectively is necessary if row widths decrease below 26 inches.
3. A more thorough investigation of the effect disk speed changes with respect to each other will have on the cutting action is important to achieve the most effective cutting action.
4. Due to the critical effect of operating height on gathering losses, the development of a mechanism to automatically control the operating height of the cutting disks appears to be especially important when operating in crops which have the grain located close to the soil surface.

5. The operational characteristics of a double-disk cutting unit mounted on the front of a combine and equipped with a conveying mechanism to move plant material rearward appears to be a necessary step in the adoption procedure for a direct-harvesting machine. A line drawing of the cutting units mounted on a combine table can be found in Figure 15.
6. A field study of the effect of various plant maturity levels, plant varieties, and plant spacings on the overall operation of the unit may provide additional information regarding the acceptability of the unit for varying plant conditions.
7. An economic study of the reduced costs and increased returns, if any, of direct-harvesting with a unit of this type compared to conventional methods will be necessary before a meaningful decision can be made regarding the acceptability of the unit.

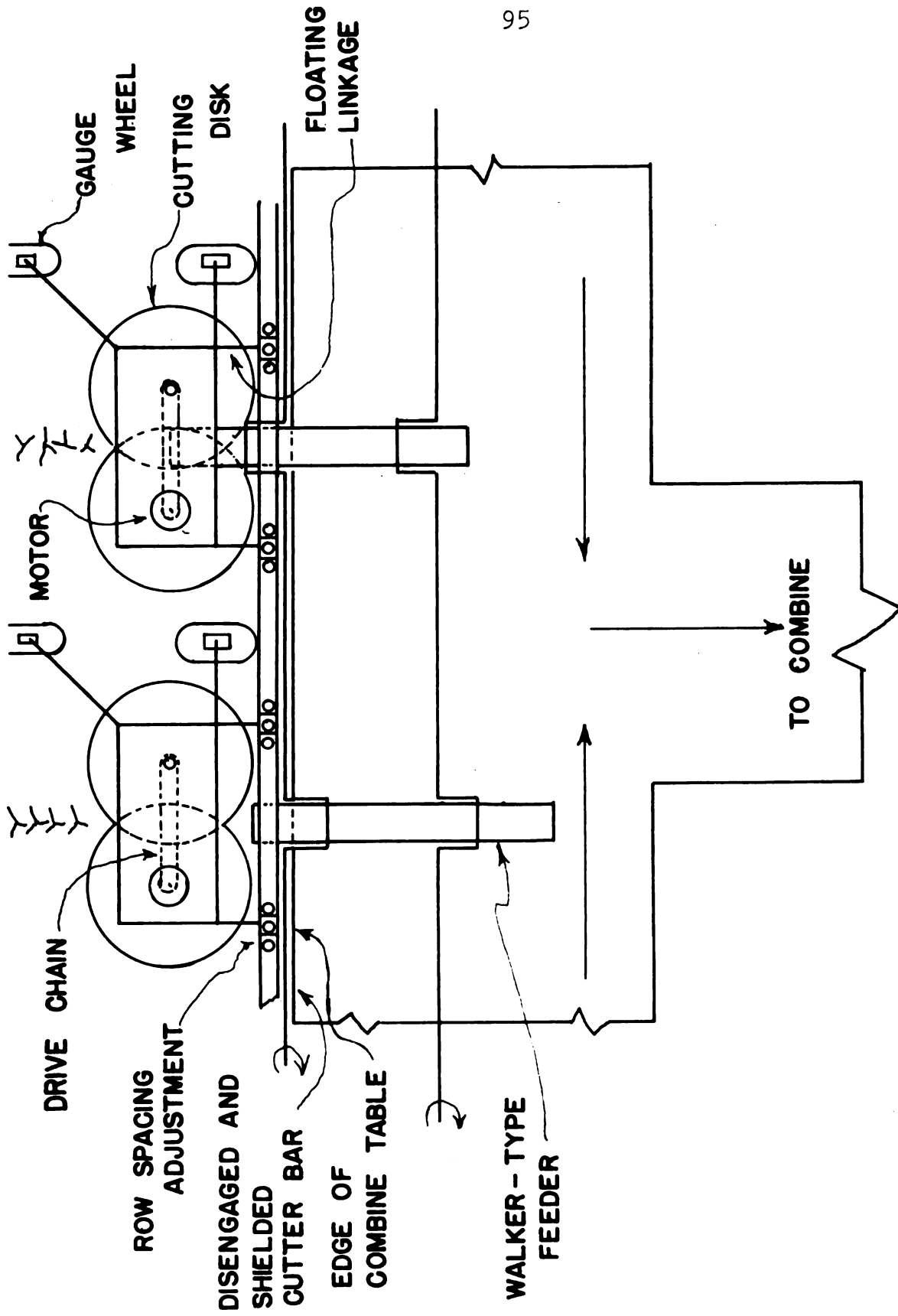


FIGURE 15: PROPOSED MULTI-ROW MOUNTING ON COMBINE TABLE

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APPENDIX

RELATIVE INFORMATION ON FIELD TESTS CONCERNED
WITH CONVENTIONAL HARVESTING METHODS

Operation A

Three field trips

1. Pull and rake, September 5
2. Rake, September 6 and 7
3. Combine, September 8

Equipment used

1. 2-Row, tractor-mounted, hydraulically-adjustable
2. Parallel-bar rake
3. Special bean combine with edible bean pick-up
attachment

Operation B

Three field trips

1. Pull and rake, September 8 and 9
2. Rake, September 10
3. Combine, September 11

Equipment used

See Operation A

This particular operation was performed in beans which had been damaged by hail and was not considered as being indicative of a normal crop.

Operation C

Three field trips

1. Pull and windrow, September 14
2. Rake, September 14
3. Combine, September 14

Equipment used

1. 4-Row, tractor-mounted, manually-adjustable
2. Edible bean windrower
3. Parallel-bar rake
4. Regular grain combine with spike-tooth cylinder
and edible bean pick-up attachment

Operation D

Three field trips

1. Pull and rake, September 18
2. Rake, September 18
3. Combine, September 18

Equipment used

See Operation A

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