A MECHANIZED HARVESTER FOR MARIGOLD FLOWERS

By

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FLOWERS

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PREFACE

This thesis is the culmination of four years of research conducted to develop a machine capable of harvesting marigold flowers such that the plants suffer minimal damage to allow them to be harvested multiple times. The intent of this research was to help develop an alternative crop for Oklahoma farmers. The design proved to be capable of removing the flowers from the plants and separating the flowers from the trash that was also collected by the machine. The low overall efficiency of the design was disappointing, but with changing from a plot type system to a full-fledged system, some of contributing factors to the low efficiency can be reduced or eliminated. Also, improved horticultural practices and climate conditions could also drastically effect the performance of the current system or any future refinements.

I would like to thank my major advisor, Dr. John Solie, for his time, guidance, and support given throughout this project. I would also like to thank my committee members, Dr. Marvin Stone and Dr. Niels Maness, for their assistance and support during this project.

Additionally, I would like to acknowledge the Oklahoma State University Biosystems and Agricultural Engineering staff and student employees for their advice, their part in building the components of the harvesters, and for their help in collecting the field data for this project. Of the staff, I would especially like to thank Robert Harrington, Research Equipment Specialist, for his extreme patience, understanding, and expertise shared during the construction of the harvesters. I would also like to thank

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CHAPTER I

INTRODUCTION

As the demand for organic and natural foods increases, farmers must meet the demand in new and innovative ways. The agriculture industry as a whole must produce safe, high-quality foods and food by-products on an ever-increasing scale. One of the expanding new areas is natural food colorings. One of the many new food colorings derived from naturally occurring plant pigments is xanthophyll. Xanthophyll pigments, primarily lutein, are being used in a wide variety of products including multi-vitamins, dairy foods, and poultry products. Xanthopyhyll pigments are yellow-orange in color, and are found in varying concentrations in many different plants, typically in young growth. Broccoli, spinach, and alfalfa have relatively high concentrations of lutein in comparison to many other sources. However, the petals of some varieties of marigolds, the concentration can be 100-1000 times the concentration found in other sources (Scott et al, 1968). This makes marigolds an extremely valuable crop for farmers, if the pigments can be produced economically.

Marigolds are harvested primarily by hand. This effectively limits production to areas where manual labor is cheap and plentiful, as it is in Mexico and several Third World countries. After laborers harvest the flowers, they are transported to processing centers where they are stored in large, uncovered piles for several weeks until they are processed. Due to the nature of the pigments, this often results in significant loss of pigments and a poor quality product.

Machine harvesting has been done on a limited basis in Mexico and California. These efforts have been focused on high-speed impact removal of the flowers and plant material. The harvested material consists of a combination of flowers, petals, leaves and stem material are then processed for pigment extraction. However, this process is also inefficient due to the large amount of material that must be processed.

The most efficient way of producing lutein pigments from marigold petals would be to only harvest the flowers from the plant. If harvesting can be done without excessive damage to the plant, the plant will survive to re-bloom and produce another crop. Also by removing only the flowers from the plant, the amount of material processed to produce a given amount of pigment is less, thus making the process more efficient. The research described in this thesis details the development of a mechanized harvester for marigold flowers.

The objectives of this project were to 1) Design a harvester to gently remove the flower from the plant with a minimum of damage to the plant. 2) Employ an on-the-go separation system that will remove most of the trash from the flowers as they are harvested. Secondary goals are to combine the flower removal and separation systems into a complete harvesting system. Also, the final design must be done in a manner that scaling the design up to a commercial-scale machine is possible.

By harvesting the flowers in a manner in which the plants can continue to grow and produce blooms, the profitability of the crop is greatly increased. Removing the unwanted material from the intact blooms on the machine will reduce the amount of material that will have to be processed for drying. It will also effectively remove the immature buds and the flowers that have already wilted. By removing all of the material to leave the blooms, the material can be dried quickly to separate the petals from the receptacles for extraction of the pigments (Armstrong, 1999). The separation system must effectively handle the rigors of separating the harvested material at a plot scale and on commercial-scale machines at ground speeds comparable with that used in grain harvesting and other crops.

CHAPTER II

LITERATURE REVIEW

Marigolds are annual broadleaf plants that have a taproot system. Plants grow on a main stem that branches to form a bush. Each of the branches has many leaves that help form a dense plant canopy. When the plant reaches the proper growth stage under normal climatic conditions, it begins to bloom and will continue to do so until late fall. The blooms grow up from all of the branches on hollow peduncles (Figure 1.)

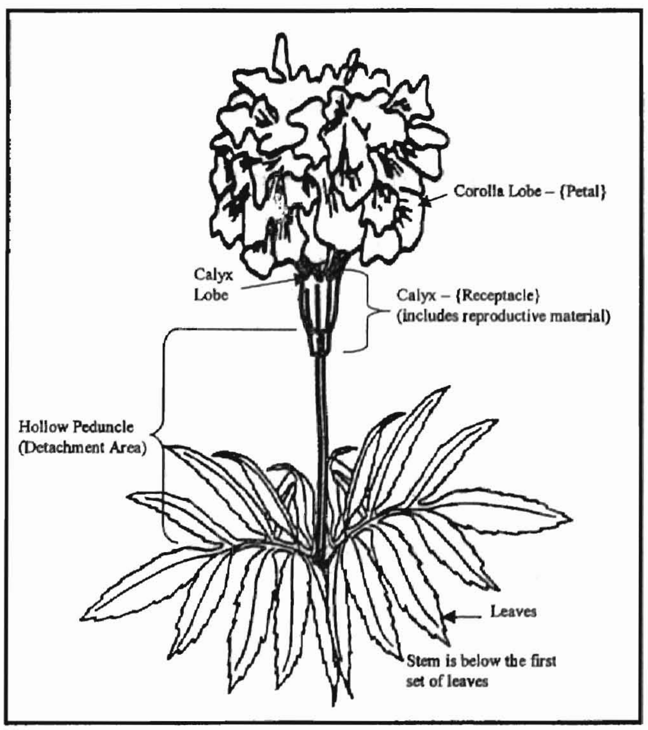

Figure 1. Diagram of marigold morphology.

The hollow peduncle typically reaches a height of 3 to 6 in. (76-153 mm) above the first set of leaves and the rest of the plant canopy. If the plant has adequate space available around it, the side branches will have peduncles that form along the sides of the plant. Flowers are distributed around the surface of the plant canopy, with the largest concentration at the top. The calyx of the flower is significantly larger than the peduncles. Varieties of flowers for machine harvesting typically have a diameter of 2 to 3 in. (51-76 mm) when in full bloom, depending upon the time of the harvest and water availability. With the large calyx attached to the peduncle, a natural weak point is formed at the junction of the two parts. When the flower is pulled away from the plant, it will snap the peduncle at the bottom of the calyx or slightly below that point. When detaching the flower by hand, 7 to 10 pounds (31-45 N) of force is required to rupture the peduncle (Buser, 1997).

Several vegetable crops have been planted at high density in an attempt to alter the plant architecture to make it easier to harvest the crop mechanically. Okra is just one example of this strategy. In normal plantings, okra has a main stem with many axils along the stem that support the flower and later the seed pods. When the planting density is increased to a high enough degree, the number of axils on the lower portion of the plant decreases. The result is that the flowers are set higher on the plant, making mechanical harvesting easier (Wu, 1995). Our attempt at high density marigold planting is aimed towards increasing top canopy flowers at the expense of flowers on the side of the canopy.

Harvesting a crop by mechanical means is a well-established practice. However, most of the methods pertain to grain, forage, and vegetables in which the plant is at the end of its life cycle, so any damage done to the plant itself does not matter. In the case of many fruits and vegetables that are harvested multiple times in a growing season, damage to the plant is undesirable. In numerous cases, this fact has limited multiple harvest crops to manual labor. With manual labor, the plants can be protected during the harvest, but as a result, the labor cost is prohibitively high. Some of these crops have been bred so that they set fruit only one time, resulting in the need for only one harvest. Chemicals have been used in some cases to make the plant release the ripe fruit from the plant so that it can be harvested mechanically through the use of a rake or windrower and a pick-up machine. In other instances machines have been developed to manipulate the plant so the fruit is removed without damaging the plant.

The mechanisms used in harvesting fruits and vegetables are nearly as varied and numerous as the harvested crops. Using motions that mimic hand harvesting is one common trait for some machines that harvest plants that are upright (non-vining) and that produce their fruit somewhere in the plant canopy. This action is typically some sort of stripping action that mimics how a person would move their hand through the plant canopy to grasp the fruit and pull it from the plant. This action has been successfully used on cranberry (Norton, 1975) and blueberry harvesters (Cargill, Kirk, 1983), as well as in other applications.

As the fruits are separated from the plants, typically leaves, stems, and other materials are gathered as well. Since this material is of no commercial value, it is best to separate it from the fruit as soon as possible, to reduce the necessity of transporting it to the processing or storage center. Often, the physical characteristics of the unwanted "trash" and the fruit are different enough that the separation is an easy process. One example of this is used in onion harvesters that use the elasticity of the onions to "bounce" them off of a rotating drum into a collection bin. They are separated from the dirt clods, because the clods will break up and not bounce nearly as far as the onions, allowing the dirt to be dropped back to the ground (Coble, 1983). Some strawberry harvesters use high velocity air to blow the stems and leaves from the berries as a means of separation (Hansen, et al., 1983). However, in some crops, the elasticity or weight of the trash materials cannot be used as a separating mechanism. In some cases, physical size is used as a separation tool, while in others the "rolling ability" of the fruit can be used to separate it from trash material. Some pepper harvesters use differentially speeded belts with fingered combs to separate peppers from pepper branches. These belts also act as a thresher to remove the peppers that are still attached to the branch (Marshall, 1983). From these few examples, it is easy to understand the complex relationships of the different components of a harvesting system.

CHAPTER III

EXPERIMENTAL HARVESTERS

In 1996, experiments were performed to determine the method of picking the flowers. The obvious method of harvesting was to remove the flowers from the plant in a stripping action similar to the dry cranberry harvester developed by J. S. Norton. (Norton, 1975). To investigate this method, a series of hand-held rakes with different finger and slot arrangements were tested to determine the best configuration to pluck the bloom from the plant. The experiments showed that a spacing of at least 0.5 in. (13 mm) was needed to allow for the hollow peduncle to slide between the fingers. A larger gap was ineffective in keeping the flowers from pulling through the gap. These early experiments also determined that in order to remove all of the flowers from the bed of plants, the fingers would need to extend into the top edge of the plant canopy. With a continuous series of equally spaced fingers, some of the plant branches and leaves were caught in the mechanism, resulting in the plant being pulled up from the ground. In order to harvest the flowers without the plants being uprooted, a gap greater than 0.5 in. (13mm) was needed between the finger pairs. Through trial and error it was determined that the finger pairs needed to be spaced approximately 3.5 in. (89 mm) apart.

The first header constructed used retractable fingers mounted within a cylindrical drum. This arrangement closely matched that used on combine headers to push material into the feeder housing. The action of the fingers retracting inside the drum provided two benefits. First, it allowed the fingers to retract inside of the drum instead of passing through the portion of the plant that had already been harvested. As the flowers were pulled from the plant, they were usually wedged tightly between the fingers. By mounting a bar to the surface of the drum between the fingers, the flower could be pulled from the fingers, allowing for collection.

The retractable finger drum used fingers that were constructed from 1/2 in. (13 mm) diameter steel rods 9.0 in. (0.230 mm) long. One end of each finger was bent 30° on a radius of 3.25 in. (83 mm) and tapered on the end. A clamp which fit over a 1.0 in. (25 mm) diameter tube which was used to secure the fingers and set a 0.5 in. (13 mm) space between them (Figure 2).

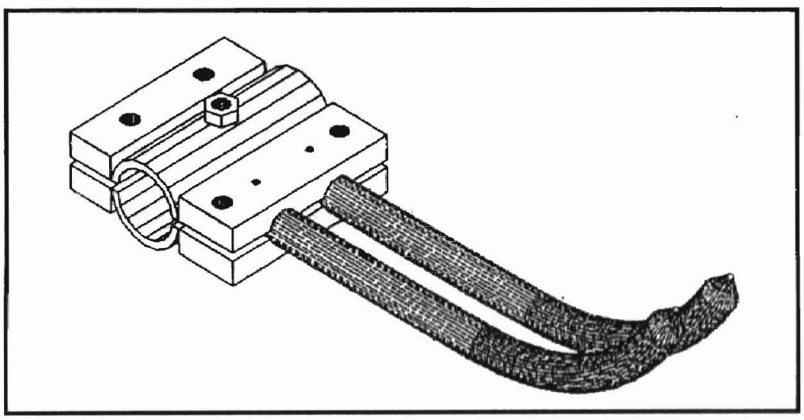

Figure 2. Finger and clamp assembly.

Eighteen of the paired finger and clamp assemblies were mounted on the 1.0 in. (25 mm) pipe with a 2.0 in. (51mm) spacing between each of the finger pairs. Four sets of these assemblies, each offset 0.875 in. (22 mm) were mounted in a circular pattern (See Figure 3).

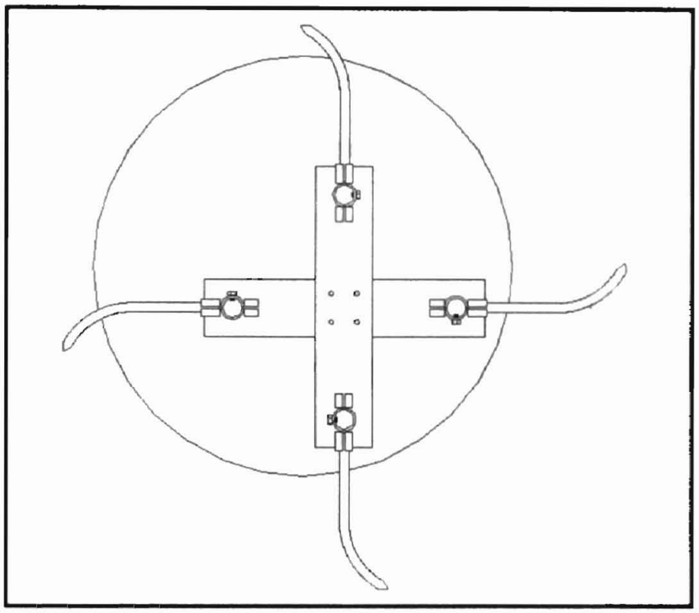

Figure 3. Circular arrangement of finger clamp assemblies within the drum.

The complete set produced a harvest width of approximately 5 feet (1.5 m). The finger and clamp assemblies were mounted in a 22.0 in. (0.56 m) diameter cylinder with slots to allow in and out movement of the fingers. The slots were fitted with 1/4 in. (6.35 mm) bars mounted along the length of the slot, and positioned between the finger pairs. As the finger pairs moved in and out of the cylinder, the bars acted as cleaners to remove the flowers that are wedged in between them. The finger and clamp assemblies were mounted on a gear set that offset the center of its axis 3 in. (76 mm) from that of the cylinder. Both the finger sets and the cylinder rotated in the same direction, which allowed the fingers to extend and retract as the entire assembly was rotated. By changing the position of the support shaft, the point of maximum finger extension could be changed in order to vary the picking geometry.

The cylinder was mounted in a framework that attached as a header to an Allis Chalmers cotton stripper. The header also had a doffer brush and a cross auger mounted within it to convey the harvested material into the feeder housing of the cotton stripper. The entire system was driven through a chain and sprocket drive using the existing cotton stripper. The header also had a doffer brush and a cross auger mounted within it to convey the harvested material into the feeder housing of the cotton stripper. The entire system was driven through a chain and sprocket drive using the existing cotton stripper header drive. A close fitting hood was mounted on the header to prevent the plucked flowers that were not wedged between the fingers from flying out of the machine. Once the harvested material entered the feeder housing, it was carried back to a blower where all of the material was conveyed upward through a ductwork where it could be captured in a bin or in a bag.

Figure 4. Retractable Finger Header on Allis Cotton Stripper.

The following season, 1998, three different harvesting methods were evaluated to examine their relative performance and damage to the plant. The finger drum harvester was compared to a direct cut header and to a flail (impact) harvester.

Figure 5. Direct cut header on Allis Chalmers cotton stripper.

The third harvester type tested, the impact harvester, used a high-speed plucking action to strip the material from the plant stem. A Chisholm-Ryder green bean stripper was used to remove the flowers from the plants. The header consisted of a series of rubber mounted rake teeth mounted on a rotating bar. Twelve bars, with teeth mounted on 3.0 in. (76 mm) centers, were staggered such that they effectively covered the entire width of the header at an effective spacing of 1.0 in. (25 mm). The rotating bar operated at a speed of 150 revolutions per minute, giving a tooth tip speed of 251 ft/s (76 m/s). Once the material was removed from the plant, it was conveyed from the header to the body of the machine by a combination of kicker wheels and a conveyor belt. After the material entered the body of the machine, it was conveyed into a storage bin through a series of elevating belts.

The retractable finger drum harvester was based on the previously described design. The finger drum was re-designed to make it smaller in diameter in in attempt to change the trajectory of the flowers as they were detached from the plant. Also, the new design reduced the weight and thus the power required to drive the unit. The header driveline of the cotton stripper was modified from a mechanical system to a hydraulic system to allow for the system speed to be varied independently from the ground and engine speed.

The direct-cut header was a modified plot combine header. The header consisted of a standard sickle bar and a cam action reel that was also mounted to the Allis cotton stripper. This header mowed off the flowers at the top of the plant canopy. The reel was lowered from its standard position to gather material extending just above the cutter bar. Once the flowers and plant material were cut, the reel pushed the material back into a cross auger which conveyed the material into the feeder housing. The material was then conveyed back into a collection bin on the harvester (Figure 5).

Figure 6. Chisholm Ryder green bean harvester.

In 1999, based on the results of the previous season's harvests, two harvesting systems were tested. The first harvesting system was the retractable finger drum header. The header was changed from the previous year by lengthening the drum by 12.0 in. (305 mm). This was done in order to more effectively harvest the entire width of the plot. As the harvesting season progressed past the first harvest, the flowers spread out into the skip rows that were left for the passage of the machine tires, leaving a significant number of flowers remaining on the plants located next to the skip rows. The increase in harvesting width decreased this effect as well as allowing the header to be increased in width to a size that would be used in a typical field-scale harvester. The scale up also allowed us to examine the dynamics of a larger machine. An improved doffer brush was also installed. Instead of using four flat brushes mounted on a shaft at 90° increments, a spiral brush was installed so that a portion of the brush was constantly in contact with the drum surface. This was done for two reasons. First, by having the brush in constant contact, the load on the hydraulic driveline would be more constant, thus reducing the pulsation in the system. Second, with the spiral brush, the open gap between the drum and the conveying portion of the header has smaller gaps to allow less material to fall through (see Figure 7.)

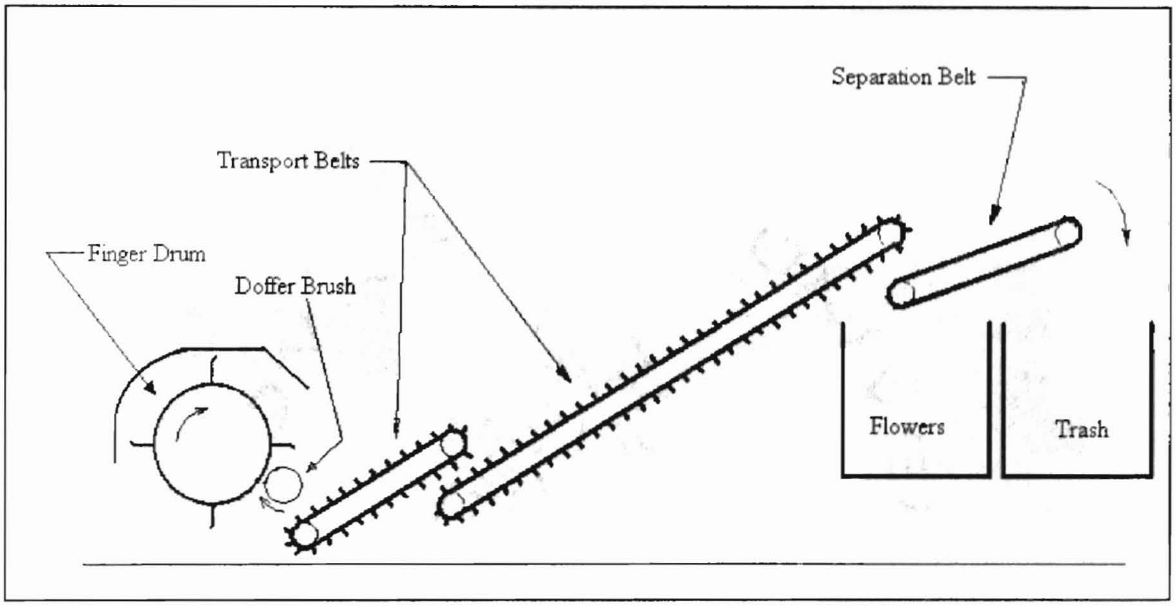

Figure 7. Side view of the header and separator system.

The retractable finger drum header was build into a framework that mounted to the main unit of the Chisholm Ryder green bean harvester (see Figure 8). This had multiple advantages over the previous designs. The harvester had a much larger power plant and hydraulic system that allowed for the machine to be operated at a much higher speed than in previous designs. Secondly, the material handling system on the previous harvesters were inadequate to support the harvested material flowrates. The Chisholm Ryder bean harvester has a much larger conveyor system that handled the flowrates. Also, based on observations from last years harvests, one of the conveyor belts has been modified to act as a separator (Figure 7.). As the harvested material was moved up a steep incline by the cleated conveyor belt, the flowers had a tendency to roll down the incline and accumulate at the bottom of the belt while the loose petals, leaf and stem pieces, and immature buds were caught on the cleats and carried over the back of the conveyor (see Figure 7).

Figure 8. Front view of the retractable finger drum on Chisholm Ryder drive unit.

The separator belt consisted of an inclined belt with 0.5 in. (13 mm) tall cleats spaced every 8.0 in. (0.203 m) on the belt. A bin for the cleaned material was placed underneath the front portion of the belt and a second bin was placed under the rear portion to catch the trash for analysis. The separator belt pitch was controlled by a hydraulic cylinder allowing for different angles for testing purposes or to adjust for varying field conditions. The separator was driven by a hydraulic motor that was connected to a flow control valve, allowing the belt speed to be varied independent of all of the other machine functions.

A single row concept header was constructed to test the concept of using fixed finger rather than retractable fingers. This header used the same finger pairs used on the retractable finger drum header. The header utilized five pairs of fingers mounted on each side of a piece of 2.0 in. (51mm) square tubing, giving an effective harvest width of 16 in. (0.4 m). The spacing between the pairs along the length of the tubing was 2.0 in. (51 mm) and the offset of each group from one side of the tubing to another was 0.875 in. (22 mm). To remove the flowers wedged between the fingers, a second bar was mounted directly above the square tubing. Straight fingers made from 0.25 in. (6.35 mm) music wire were screwed into the bar. The fingers were mounted so that they would move through the gap between the fingers of the lower bar. A chain and sprocket drive was used to time the upper and lower bars. A spiral doffer brush was added behind the lower finger bar to help convey the flowers into the bin and to fill the gap between the flowers and the edge of the bin (Figure 9).

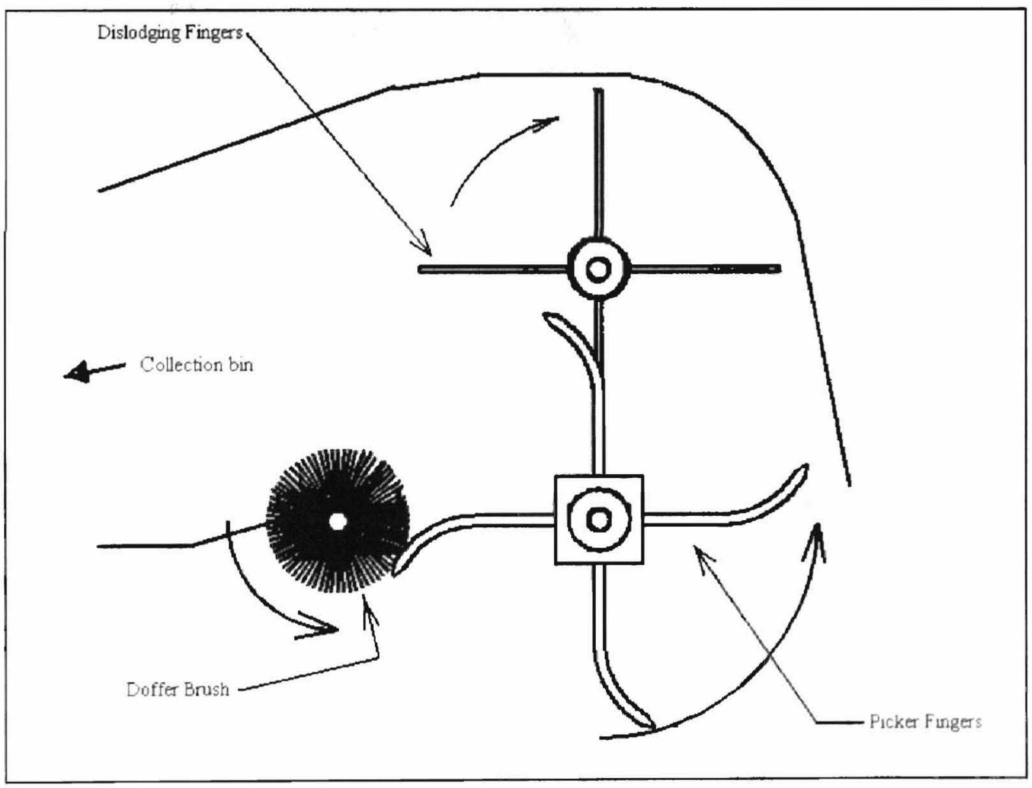

Figure 9. Diagram of the fixed finger concept header.

The upper and lower finger reels were driven with a hydraulic motor through a series of chains. These chains were configured to make the upper fingers counter-rotate against the lower finger bar. The sprockets were sized so that the upper and lower finger bars rotated at the same speed. This mechanism was built into a small frame that was mounted on the three-point hitch of a tractor (Figure 10).

Figure 10. Fixed finger header mounted on John Deere tractor.

For the 2000 harvest season, a new header, based on the experimental fixed finger header was developed and mounted on the Chisholm bean harvester. The system retained the separating mechanism from the 1999 machine. The full-scale fixed finger header had a picking width of approximately 89 in. (2.25 m). The lower paired fingers were the same as those used on both of the earlier models. The diameter to the outside edge of the finger path was the same as it was in the experimental fixed finger header. The upper fingers were changed from those tested in 1999. Instead of the steel rods, modified plastic pickup reel fingers from a Massey Ferguson plot combine were used. These fingers were longer than the originals, thus increased the velocity at which they removed the wedged flowers. The increased velocity allowed the flower to travel farther toward the rear of the header, making collection easier. Secondly, the plastic fingers which are more flexible, helped to reduce breakage from lodged weeds, or other plant material. The header was mounted with two transverse conveyor belts that fed the harvested material to another belt that conveyed the material back into the main unit of the harvester. The doffer brush was driven by a sprocket, from the lower finger bar. Both finger bars were driven by a single hydraulic motor via a series of sprockets and chains that allowed the timing of the upper and lower bar intermeshing to be adjusted to maximize the removal of the lodged flowers. The transverse conveyors were driven by hydraulic motors plumbed in parallel, and were mounted upstream from the rearward conveyor belt drive motor. The finger bar drive and the transverse conveyor motors were fitted with flow control valves so that the speed of both could be controlled. After the material has been dropped on the main conveyor, it was elevated and dropped onto the separation belt. This portion of the 2000 design needed no functional changes from its original form except the addition of a cover to prevent wind from blowing the harvested material all to one side of the separator, preventing good separation (see Figure 11).

Figure 11. Fixed finger header on Chisholm Ryder harvester.

From Figure 11, it can also be seen that tarps were added to connect the separation conveyor to the collection bins. This was done to prevent the separated material from blowing into the wrong bin or out of the machine. In a production model harvester, the trash would not be collected, thus allowing that portion of the harvested material to drop back into the plot or diverted into the space between rows. Also, in a production machine, the clean material bin would be larger and would most likely need an open or something similar to distribute the flowers within the bin. This was not required with this machine due to the size of the plots.

CHAPTER IV

METHODOLOGY FOR TESTING AND RESULTS

For the 1998 harvesting season, data were collected for the harvester system, to compare the reaction of the plants to the different harvesting methods, as well as to examine the comparative effectiveness of each of these systems in harvesting marigolds. The information collected during that year was not done in a manner to perform meaningful statistical analysis. During the second and third season, the experiments were performed in a manner in which a statistical analysis could be performed. In some cases, the plots established to provide the data did not grow consistently, so that meaningful data was impossible to collect.

However, by reducing the number of replications meaningful data was collected. To examine the performance of the headers, the harvester was run over a series of test plots to determine a range of rotational and ground speeds over which each header performed well without severely injuring the plants. From this, a reel index was determined. The reel index (RI) is calculated by:

$$RI = \frac{N \times E_L}{V \times C} \qquad (1)$$

where:

N = drum (or fixed finger bar) speed (rpm)

E_L = effective picking length of the fingers (in.)

V= ground speed of the header (mph)

C = 1056 = conversion constant

The effective picking length was observed to be approximately 6.0 in. (152 mm) for both the retractable finger drum and the fixed finger headers.

Comparison the performances of the headers required two key items. First, the picking efficiency of each of the headers needed to be examined by measuring how well the header removed the flowers from the plants. The picking efficiency (PE) was calculated:

$$PE = \left[\frac{M + D}{M + D + LOP}\right] \times 100 \qquad (2)$$

where:

M = number of flowers harvested by the machine

D = number of flowers removed by the machine but dropped

LOP = number of flowers left on the plant

How well the header conveyed the flowers into the storage area after they have been removed from the plant was another important measure of header performance. The overall efficiency (OE) was calculated:

$$OE = \left[\frac{M}{M + D + LOP}\right] \times 100 \qquad (3)$$

The performance of the separator belt was another important factor when evaluating the machine. Two critical measures of the cleaning system performance were the percent of the trash in the clean bin and the percentage of the intact flowers in the trash. The percentage of trash collected in the clean bin (not removed by the belt) was calculated:

$$TCB = \left[\frac{CBT}{THW}\right] \times 100 \qquad (4)$$

where:

TCB = percent trash in the clean bin

CBT = weight of the trash in the clean bin

THW= Total weight of material collected by the machine (flowers and trash)

Also important is the percentage of the flowers collected in the clean bin. The separator belt must remove trash from the clean bin without dumping flowers into that bin. The percentage of flowers in the bin (PFB) was calculated:

$$PFB = \left[\frac{CB.}{CB + TB}\right] \times 100 \qquad (5)$$

where:

PFB = percent flowers in the clean bin

CB = number of flowers in the clean bin

TB = number of flowers in the trash bin

1998 Harvesting Season

During the 1998 harvesting season, the three different harvesting systems were evaluated to determine the machine that did the best job of harvesting flowers from the plots and to determine the plant's reaction to each of the harvesting methods. The operating speeds, reel indexes, and other machine parameters were optimized for each machine using several test plots to determine the best setup for comparison to the other.

The plots used for the experiments were planted on ground owned by S&S Farms, Hinton, Oklahoma. The soil in which the flowers were planted was a sandy loam soil with a 5% or less slope. The soil was prepared by using a disc and culti-packer to work the soil to a depth of 6to 8 in. (.15 to .20 m) and left a very firm seedbed. The marigold seeds were prepared for planting by encapsulating them in clay for easy singulation and handling. The seeds were planted using a Monosem air planter at a depth of 0.25 to 0.50 in. (6.4 to 12.7 mm). The seed spacing within the rows was 2.0 in. (51 mm) and row spacing was 9 in. (0.229 m). Eight rows 100 ft. (30.5 m) long were planted per plot. Two varieties of hybrids were tested to determine the suitability of each for machine harvesting. Seed Dynamics varieties E1236 and I822 were chosen for their bloom size, color, and compatibility with the local climate and soil.

The weather played a significant factor in the growth of the plants. Roughly a week after planting, lightning struck the pump that provided the irrigation water for the plots. It was nearly another week before the well could be repaired and for the plants to receive any water. With many of the seeds germinating and some plants beginning to break through the soil surface, many of the plants perished. This resulted in a stand of 20-25% of that planted. A second planting was done in late May in order to produce a stand that was capable of producing meaningful results. This also reduced the harvesting season by nearly a month, thus reducing the opportunity to observe the long-term effects of the harvesters on the plant growth and response to harvesting stress. With the late planting, the flowers had less time to develop a good root system to cope with the hot weather. This less developed root system at the time of harvest made the plants more susceptible to uprooting and also required longer to recover from harvesting stress.

The Chisholm Ryder green bean harvester was very effective in removing the flowers from the plant. There are several characteristics that make this harvester undesirable. First, when the flowers are harvested, a considerable amount of damage is done to the upper plant canopy. This damage included the removal of a large portion of the plant leaves and nearly all of the small buds that represent the next generation of blooms. Also, many of the receptacles are split open by the impact of the finger. As the flower dried, the receptacle fell apart, complicating separation. Last, the excessive plant material that is harvested with the flowers made separation more difficult by dramatically increasing the amount of material to be cleaned. For one harvest, 80% (c.v. = 0.15) of the material harvested (by weight) was trash. In addition, the excessive plant damage required more time for the plant to recover and to begin blooming again. With increased time, the total number of harvests possible in a season were reduced.

The second harvester tested was a direct cut header. After the crop was harvested the first time, the blooms re-grew at a level that was above most of the plant leaves. The effectiveness of this method varied greatly with the plant stand. In poor stands, many blooms were located on the sides of the plant. In order to harvest these blooms, more of the plant canopy was harvested. This impaired the plant growth, which also increased the amount of time in between harvests. However, in stands that were very dense and uniform, this effect was much less of a factor. The main disadvantage with this system lay with the large amount of plant material harvested. For many of the flowers, there was a considerable section of stem and leaf material that is still attached. This made separation and processing of the blooms much more difficult, due to the long sections of plant stem that were often still attached to the bloom. This resulted in 72% (c.v =0.17) of the harvested material (by weight) was trash. Another disadvantage in poor plant stands or in younger stands was that many of the side branches sent up blooms that did not extend as high as the rest of the plant canopy. These flowers were unharvestable unless the top portion of the plant canopy was removed again, which defeated the purpose of using this type of header system.

The third harvester that was evaluated this season was a modification of the 1997 finger picker. From the 1997 design, the reduction of the drum diameter and reach of the fingers had the effect of changing the trajectory of the blossoms when they snapped from the peduncle. This trajectory change resulted in fewer of the flowers being lost from the front of the harvester. The blossoms that were picked were less damaged than those harvested by the Chisholm Ryder bean picker, because the finger picker operated at about 50 rpm less than the Chisholm Ryder unit. Drum speed could be reduced because the finger picker grasped the bloom between two fingers instead of using impact to detach it. This mode of harvesting caused the least amount of damage to the marigold plants. It was also observed that the number of immature buds that were removed from the plants was less than that of the Chisholm Ryder unit. The harvested material was composed of 75% (c.v. = 0.11) trash by weight, which lay between the direct cut and impact harvesters. However, the reduced damage enabled the plant to return to full bloom much quicker than the bean picker or the direct cut header, potentially increasing the number of harvests per season. From observations after the harvest, the impact harvester plots returned to full bloom seven to ten days after the plots harvested with the retractable finger drum unit. Although tested only at the final harvest, it as expected with multiple harvests, the plant canopy would become more uniform as it grows back from the damage inflicted by the harvester.

One problem with the current system used with the retractable finger drum was that the flow of the material plugged the elevating cleated conveyor belt that transferred the material from the header to the storage bin. When this occurred, a considerable amount of flowers and other material were ejected from the machine. Also, the inclined belt conveyor bruised the flowers and destroyed some flowers as it dragged them over the sheet metal floor of the conveyor housing.

The material harvested was collected and stored in plastic bags. These bags were then placed in a cooler until it could be analyzed. The weight of the harvested material was recorded in the field, but the weight of the components of the harvested material was not determined until after the analysis was complete. With the loss of moisture from the material and the subsequent fermentation of the material, the weights were not used in the analysis.

From the testing of the different harvesters, it was determined that the modified 1997 finger picker was able to harvest the largest number of flowers per unit area (Table 1). The results showed that the mean was statistically different than the means of the other two headers, which were not significantly different from each other. Table 1 also shows that there is a significant difference in the number of harvested flowers from the different varieties.

	Variety	
Harvester	**E1236**	**I822**
Direct Cut	125	85
Chisholm Ryder	122	86
Retractable Finger Drum	145	96

Table 1. Average Yield (flowers/m^2) of 4 Replications for Harvest 3, 1998.

The decision of which header provided the best solution to harvesting the flowers was based on the results presented in Table 1, as well as the observational information on the plant response to the damage inflicted by the machines. Using this method, it was determined that the modified 1997 retractable finger harvester was the most successful in harvesting blooms.

1999 Harvesting Season

The flowers planted for this season were planted in the same manner as in the previous years. Once again, the resulting stand was very poor. Most of the plots had germination rates of about 10-25%. From looking at the plants and digging up the rows of seeds, it was determined that the lack of uniformity of the stand was the result of little of the seed being planted at the proper depth. A second planting was made with a better-prepared seedbed in a different field. During this planting, difficulties were experienced with the clay encapsulating the seed plugging the holes in the seed plate, not allowing the proper number of seeds to be laid down in the bed. However, the plots in question were replanted to insure that at least the specified number of seeds were actually placed in the beds.

The marigolds stands were poor, large gaps of no plants were left in the planter rows, some in excess of 5 ft. (1.5m). It was determined that the poor stand was the result of poor germination. The resulting plant stand was highly irregular with some showing a dense stand, and other portions with only about 20% of the plot covered with plants. As a result, the flower distribution was highly irregular, including many flowers on the sides of the plants, therefore making mechanical harvesting more difficult. The uneven distribution made determining the proper harvesting height difficult and as a result some tall plants were damaged while nearby plants were not even touched by the harvesting fingers. The harvesting height was determined to be set so that the bottom edge of the drum was in contact with the top edge of the continuous plant canopy.

The retractable finger drum picked the flowers fairly well for variety I822, and moderately well for variety E1236, as can be seen in Figure 8. However, 30-75% of the flowers removed from the plant never made it into the machine for separation.

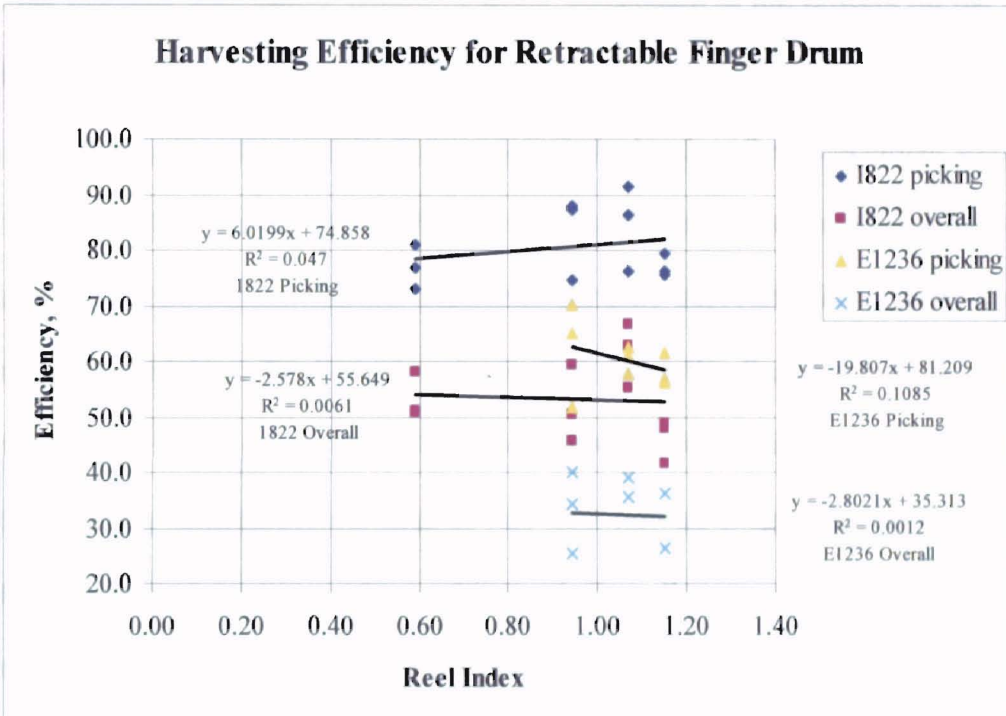

Figure 12. Picking and overall efficiencies for the retractable finger drum header. Each data point represents a 6'x 100' plot.

Also, by looking at the variability of the efficiencies within the same treatment, it can be shown that the experimental error caused by the differences in the plots made determining the general trends. This plot-to-plot variability with the small number of data points reveals little in statistical analysis, but the overall trends in performance are important to help measure the characteristics of the machine. The graph shows that there is little difference in the harvesting efficiencies over the range tested in this experiment. It can also be noted that the picking efficiency, and subsequently the overall efficiency, of variety E1236 showed a slightly negative trend while variety I822 showed a slightly positive trend. When the picking and overall efficiencies of the harvester was examined, it showed that 20 to 35% of the total number of flowers were removed from the plant but did not make it into the machine for separation and collection. Also, the graph revealed that the machine was able to remove a larger percentage of the flowers on the plants of variety I822 when compared to E1236.

The largest portion of the flowers lost at the header after detachment were thrown out in front of the machine due to the trajectory imparted by the paired fingers during the detachment of the flower. Shields were only partially successful in trapping the flower. The sheet metal bent the flowers over so that when the fingers come in contact the peduncles, the flowers were bent over even further, resulting in a detachment trajectory that was nearly horizontal, resulting in very few flowers lodging in the fingers so they could be collected by the machine. Many of these flowers would drop to the ground when the fingers of the harvester began moving through the plant canopy, allowing the blooms to drop through the openings created by the movement of the plants. The remainder of the flowers that were dropped by the retractable finger drum fell into voids in the row. These flowers were removed from the plant by the paired fingers, but were not wedged between them. If there were a continuous plant canopy, more of the flowers would have a chance to be captured by the header. There would still be a significant number of the flowers that would be lost through the plant canopy, but some type of shield could be installed to catch the blooms before they were able.

Experiments for the fixed finger header were performed on a split plot basis due to the limited availability of good plant stands. The variables for the reel index varied from 0.5 to ~2.0, while the ground speed was varied from 0.75 to 2.25 mph (0.33 – 1.0 m/s). The fixed finger header performed in a similar manner to the retractable finger drum for variety I822. Figure 13 shows the partial test results of the experiment. The figure shows the results for a ground speed of 1.5 (0.67 m/s).

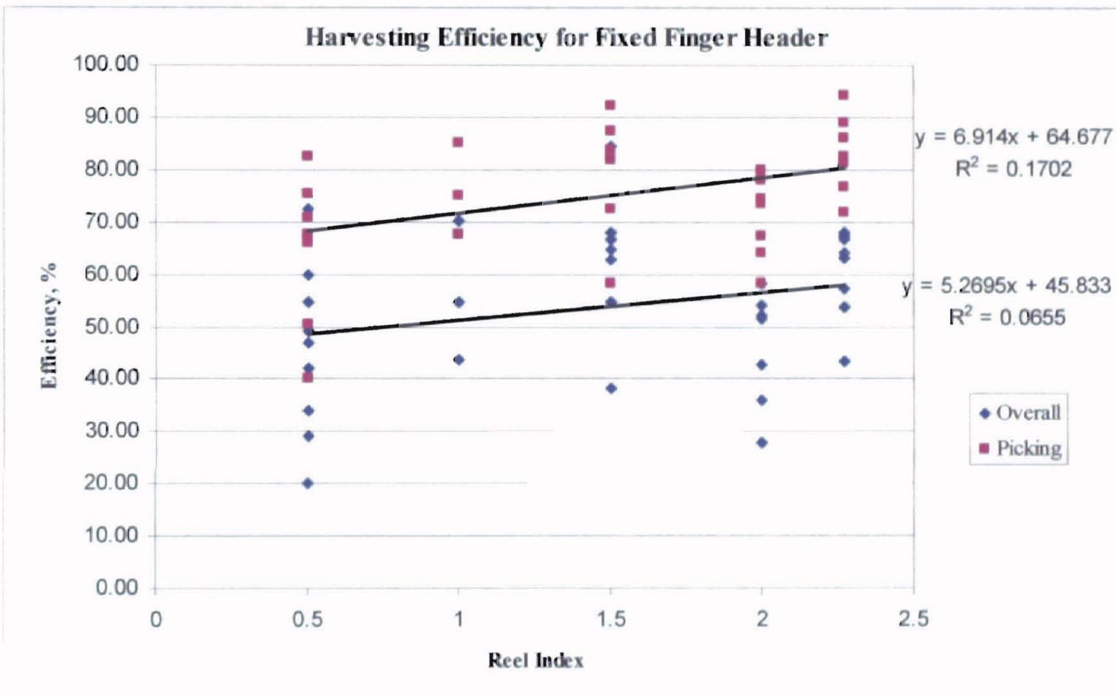

Figure 13. Picking and overall efficiencies for the fixed finger header, one 1999 harvest of I822.

The efficiencies shown in Figure 13 reflect the same trends that were seen with the retractable finger drum for the same variety and reel index. The figure also reflects the extreme variation in the efficiency within the same treatment. This was attributable to the variation in the plots themselves. The graph also indicates an increase in the overall efficiency of the header with an increase in reel index, with the exception of the efficiency at a reel index of 2.0. The plots themselves or an incorrect machine setting could be the cause of these values, but no determination as to the exact cause can be made at this time. The overall trend may not be a real indicator of the performance since the header had no handling or separation on the machine. Likewise, this harvester was tested with a 6 ft. (1.83 m) plot length in contrast to the 100 ft. (30.5 m) plots used for the other header. If the plot size was comparable, the efficiencies of the header may show more of a similar pattern, but this was not possible due to the size of the fixed finger header. The trend of increased efficiency with increased reel index needs to be weighed against the damage to the plant. Further study could show what the critical reel index that could be used without reducing plant performance. Also, from this graph, it was determined that improvement was needed in the handling of the flower in order to improve the overall efficiency. Since the fixed finger header had only a storage bin to eject the flowers into, the material would build up at the front of the storage bin until the doffer brush begin to catch it and drag it back outside of the bin as the brush rotated (see Figure 10.). From field operating observations during the data collection, the number of flowers that were thrown by the header was lower than that of the retractable finger drum header, because of the shorter distance between the center of rotation and the tip of the paired fingers. This shorter distance results in a more vertical trajectory than the retractable finger drum header. Of the remaining flowers that were dropped, the doffer brush ejected some after the harvested material accumulated to the point where it could no longer move it away from the front of the bin. Also, some flowers were dropped into the void spaces within the row like the retractable finger drum header.

When analyzing the ability of the separator to remove the clean flowers from the harvested material one of the key factors that needs to be analyzed is the cleaning efficiency as related to the total amount of material that needs to be processed (Figure 14), as well as the cleaning efficiency and the trash content in the harvested material (Figure 15).

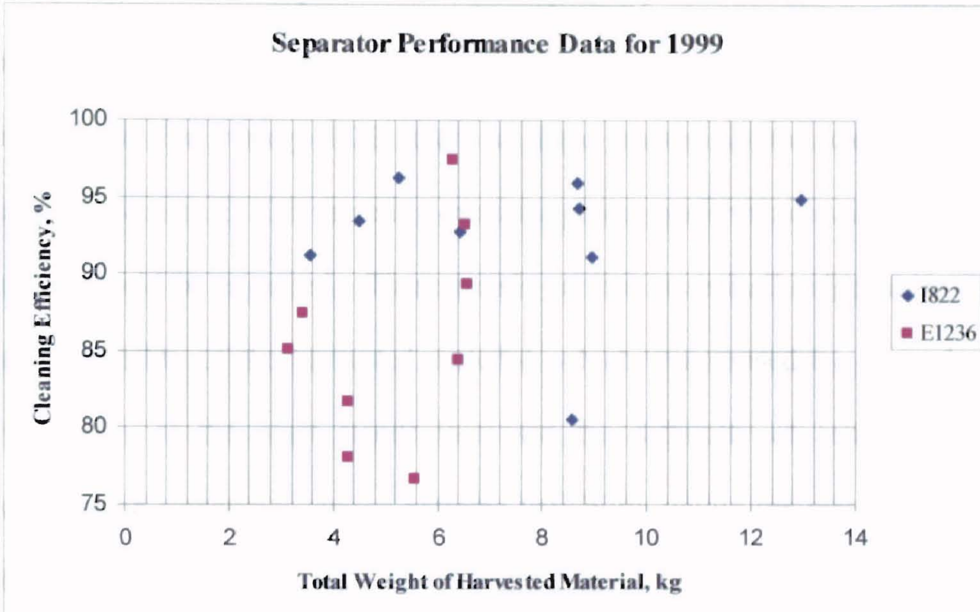

Figure 14. Performance of the separator versus amount of material processed.

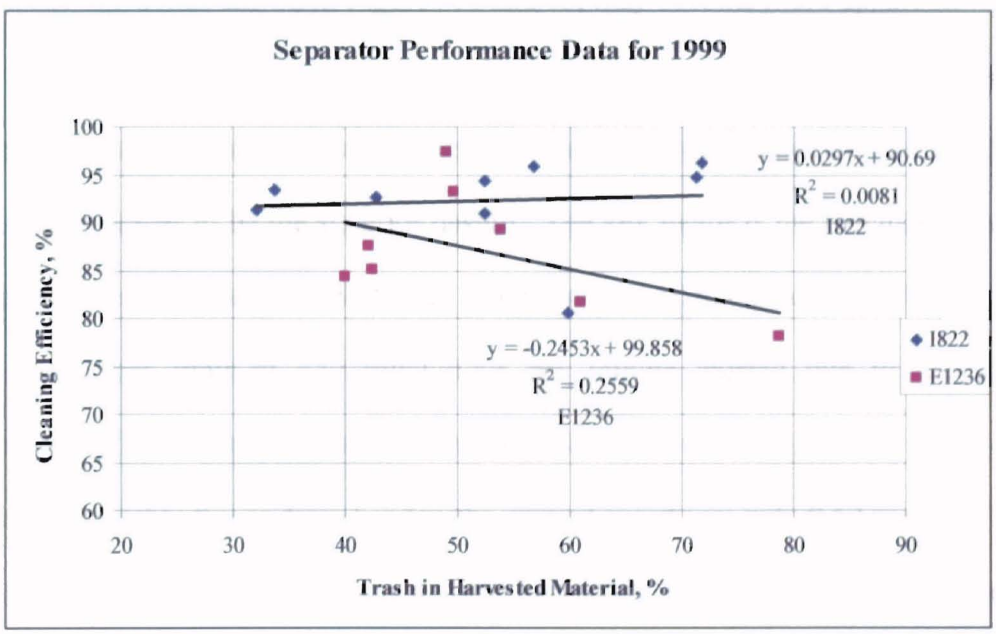

Figure 15. Performance of the separator versus harvested material composition.

Figure 14 shows that there is no pattern or trend in comparing the efficiency to the amount of harvested material for either variety. Also, there is no measurable difference in performance between the two varieties. Figure 15 reveals that when the data is examined from the standpoint of efficiency compared to the harvested material composition, some patterns start to emerge. The figure shows that for the range of trash contents found for variety 1822, there is little change in the cleaning efficiency. However, for variety E1236, there is a trend for poorer performance with increasing trash content as would be expected. These trends are not statistically significant due to the inherent variability of the harvested material, which was caused by poor plant stands. The variability of the plant stands increased the difficulty of setting the harvester correctly, which sometimes caused extreme variability within the plot. With the highly variable crop conditions, the material flow and composition varied with every few feet of harvesting distance, the performance of the separator varied greatly. With consistent crop conditions, the trends shown in Figures 14 and 15, may become more apparent.

When comparing the test results from both headers, the retractable finger drum shows a slight advantage in harvesting efficiency, however other factors result in the fixed finger header to be the superior design. The key factor is the mechanical action of the retractable finger drum. With the large amount of mass being shifted within the drum, an upper limit of 450 revolutions per minute existed due to the structural capabilities of the drum and mechanism. For the most efficient picking index attained with the retractable finger drum header, the ground speed was only 0.62 mph (0.277 m/s). This speed is too low for a practical field-harvesting unit. A profitable machine and harvesting system requires higher ground speeds, which would not be possible with the retractable finger drum.

2000 Harvesting Season

This year, experiments were designed to test the performance of the fixed finger header on the Chisholm Ryder drive unit and separator as modified from the 1999 design. The experiments were designed to test two ground speeds of 1.0 mph (0.45 m/s) and 2.5 mph (1.12 m/s), the effects of the two varieties (I822 and E1236), and reel indexes of 1.0, 1.25, and 1.5. These experiments were performed to determine the effect of the rotational speed on the harvesting capabilities of the harvester at speeds that would be in the range of those used by combines and harvesters for other crops.

The 2000 growing season was marked by one of the hottest Augusts on record for most of Oklahoma. This extended period of hot, dry weather had a major impact on the flowers. Despite being irrigated, the heat stress effectively slowed the flowering process to a standstill. Both varieties were harvested on August 4, 2000, for the purpose of a shakedown run for the new header with the Chisholm Ryder drive unit. From this point, the variety I822 did not set new blooms due to the heat. Some plots of the variety E1236 did set flowers, but the size of the blooms was greatly reduced. During 1999, the E1236 blooms averaged 6.30 kg/1000 blooms, but for the single harvest of 2000, the blooms weighed 1.56 kg/1000 blooms. Some of the plots had greatly varied flower size from one end of the field to the other. This reduction in size, in addition to the flowers being extremely dry by late in the day contributed to many of the flowers pulling through the picking fingers. The small flower size also influenced the effectiveness of the separator system. With the small bloom size, many of the intact flowers were caught by the cleats and did not tumble down the belt as they typically did. This helped reduce the separating efficiency to nearly half of what was seen in the harvest the previous year, using the same variety and separator system settings as the previous year.

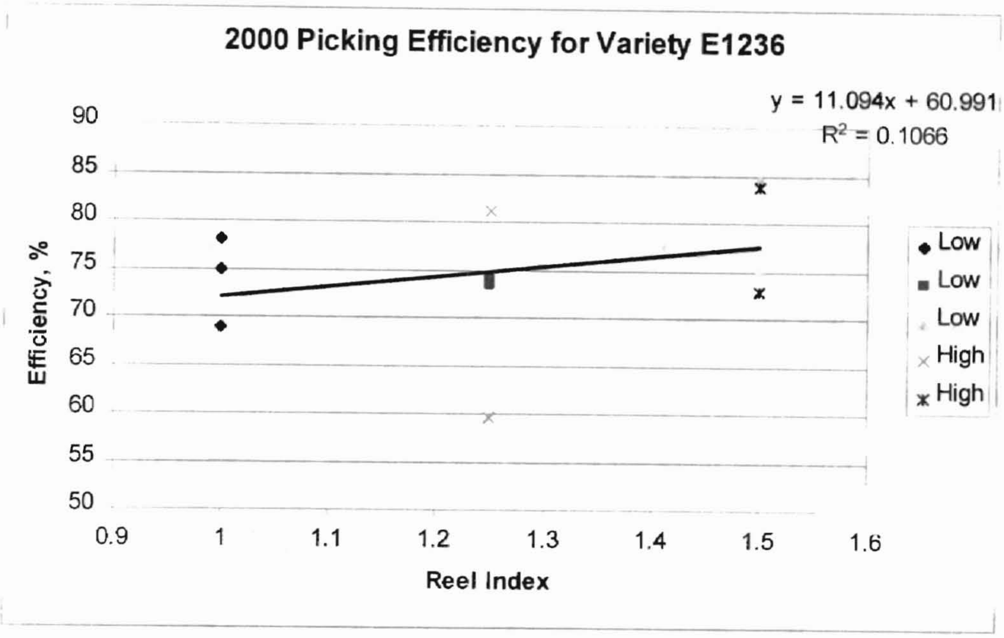

Figure 16. 2000 header performance. Low speed was 1.0 mph and high speed was 2.5 mph.

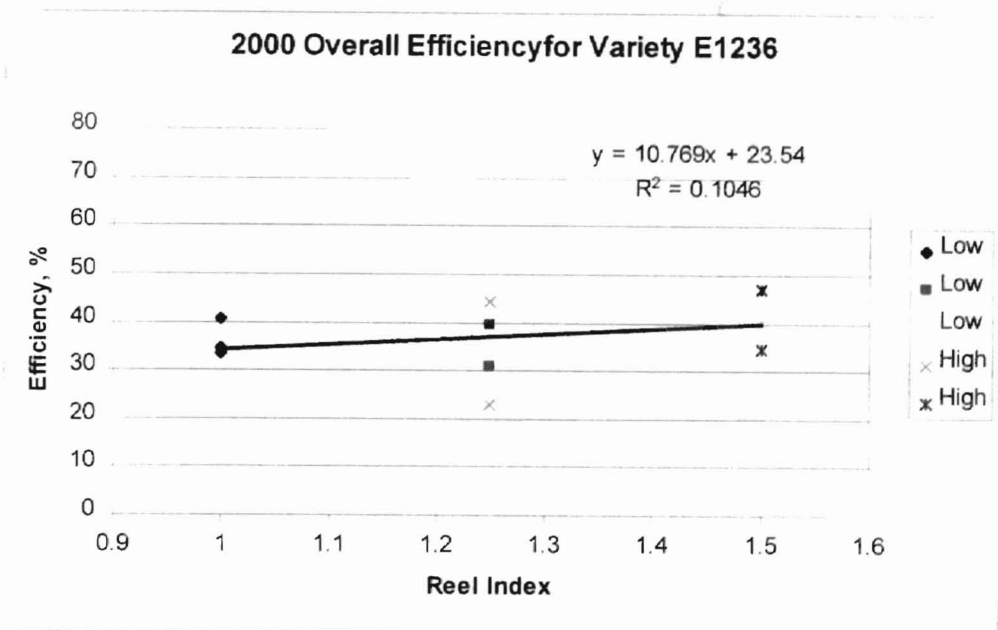

Figure 17. 2000 header performance. Low speed was 1.0 mph and high speed was 2.5 mph.

Due to the crop conditions, reduction of the number of replications and the total number of treatments available, the statistical analysis yielded little information. As can be seen in Figures 16 and 17, there is a large amount of variability between the plots at any given setting. Even with this large amount of variability, a trend for increasing efficiency with increased reel index still exists, but the relationship is not as strong as would be desired. The overall efficiency of the header is similar to that observed in previous years. The trend of increasing efficiency with increased reel index does show itself here as well, with the same weak relationship due to the high variability. Of the flowers dropped by the header, some fell into gaps in the plant stand and off the sides into the gap between plots. Many of the flowers were thrown out in front of the machine on top of the plant canopy. As the header approached and the fingers moved the plant canopy, many of them fell to the ground through the gaps created by the motion. The increase in overall efficiency almost matches that of the picking efficiency, leading to the conclusion that the increased reel index did not cause increased shattering. However, this cannot be firmly established with the limited number of replications.

CHAPTER V

DISCUSSION OF THE CONCLUSIONS AND OBSERVATIONS

Based on the experimental results of this research project, a practical harvester for marigold flowers has been developed. The machine harvested the flowers in a manner in which the large majority of the flowers were detached intact. However, the system is in need of improvement, much of which can be improved by changing the size and scale of the equipment and the plots in which the flowers are grown. The number of flowers that are lost to the edges of the header could be reduced by increasing the width of the plots and the header in order to reduce the edge effects of the system. Secondly, if the operator is placed in a location in which he can see the front of the header so adjustments to the height of the picking fingers can quickly be adjusted to match the height of the crop, the number of flowers thrown in front of the machine. Also, working on developing a more uniform plant bed to harvest the flowers from will improve the ability of any harvesting system to efficiently and effectively remove the crop from the field.

The relative efficiencies of the most recent design are consistent with the results of the previous design of finger bar system. A statistical comparison of the improvement of the system from a small 22 in (559 mm) to a 89 in (2.26 m) width can not be made due to the different methods of data collection and reel indexes that were used, however, judging by the basic trends of the header efficiency data, it appears that there has been improvement. A direct comparison between the 1999 retractable finger drum and the 2000 finger bar picker cannot be made due to the drastically different field conditions.

With improved crop conditions, the effects of the variety, ground speed, and reel index should show significant relationships. A lot of the flowers were removed from the plant and through one path or another ended up on the ground. This resulted in a very low overall harvesting efficiency, but low overall efficiencies are not uncommon in mechanical harvesting systems when compared with hand harvesting. One example of this is the rhubarb harvester developed by Marshall, showed that 5-25% more of the crop was left in the field than hand harvesting (Marshall, 1983). In order to improve the effectiveness of the machine, a shield or catcher system should be installed in front of the header to collect the flowers thrown in front of the machine. The tolerable level of the loss of flowers will need to be determined by doing an economic analysis of the final system including machinery, processing, planting, water, and labor expenses to determine the net return. The machine as it exists today is not ready for mass-market production. However, if the issue of flower loss within the plot space can be resolved with a modification to the machine, a viable harvesting system will exist.

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APPENDIX A

DRAWINGS OF CRITICAL COMPONENTS OF

THE EXPERIMENTAL HARVESTERS

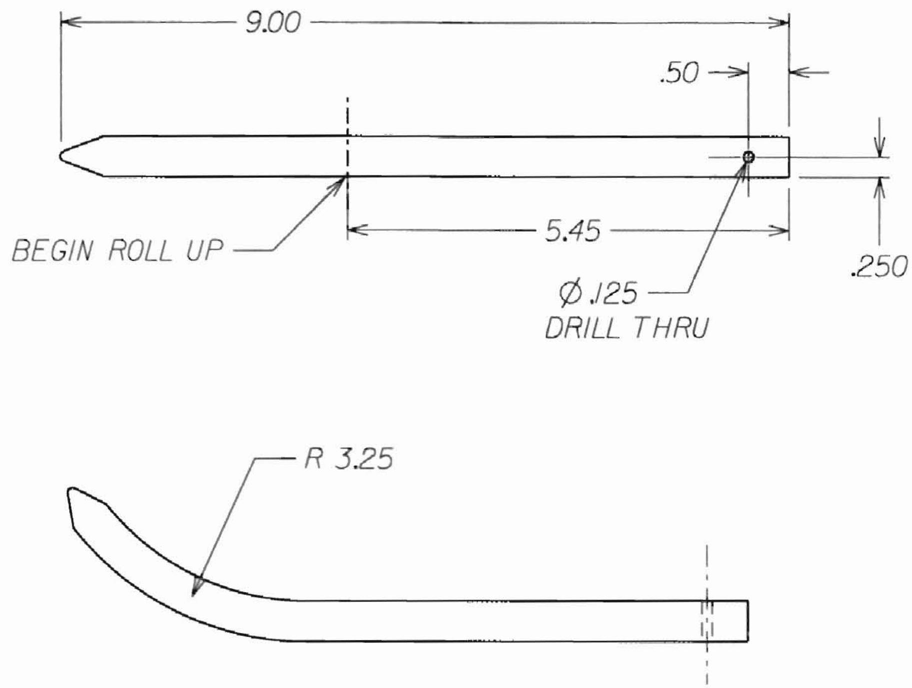


FIGURE 18. STEEL FINGER USED FOR RETRACTABLE FINGER DRUM AND FIXED FINGER HARVESTERS

MATERIAL: 1 X 1/2 IN STEEL BAR

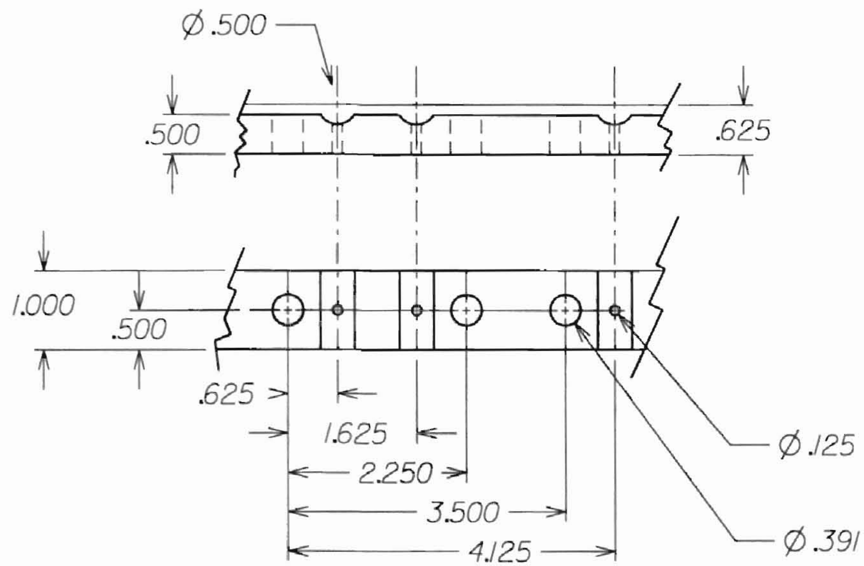


FIGURE 19. FINGER SPACING AND CLAMP CROSS-SECTION. SPACING BETWEEN PAIRS IS THE SAME FOR BOTH THE RETRACTABLE FINGER DRUM AND THE FIXED FINGER HEADER.

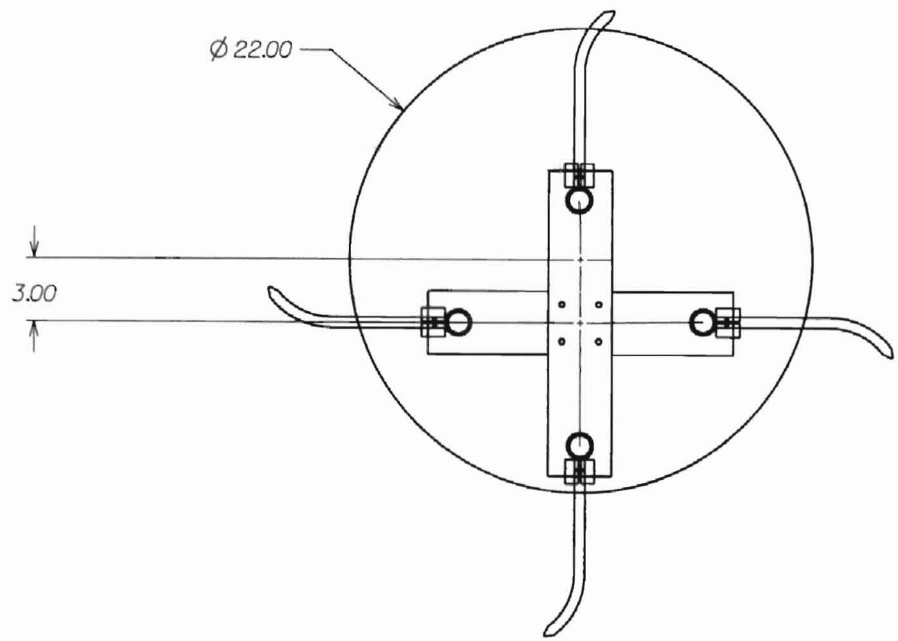


FIGURE 20. SIDE VIEW OF THE RETRACTABLE FINGER DRUM HEADER SHOWING THE ECCENTRICITY OF THE FINGERS IN RELATION TO THE CO-ROTATING DRUM.

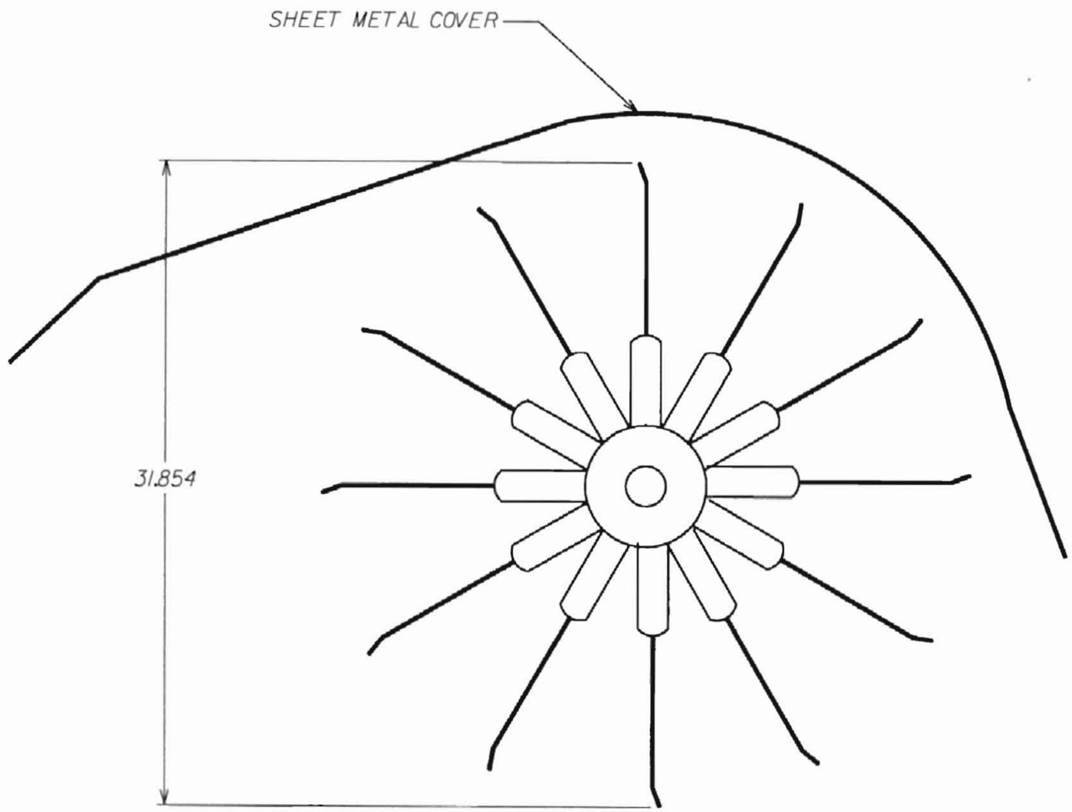
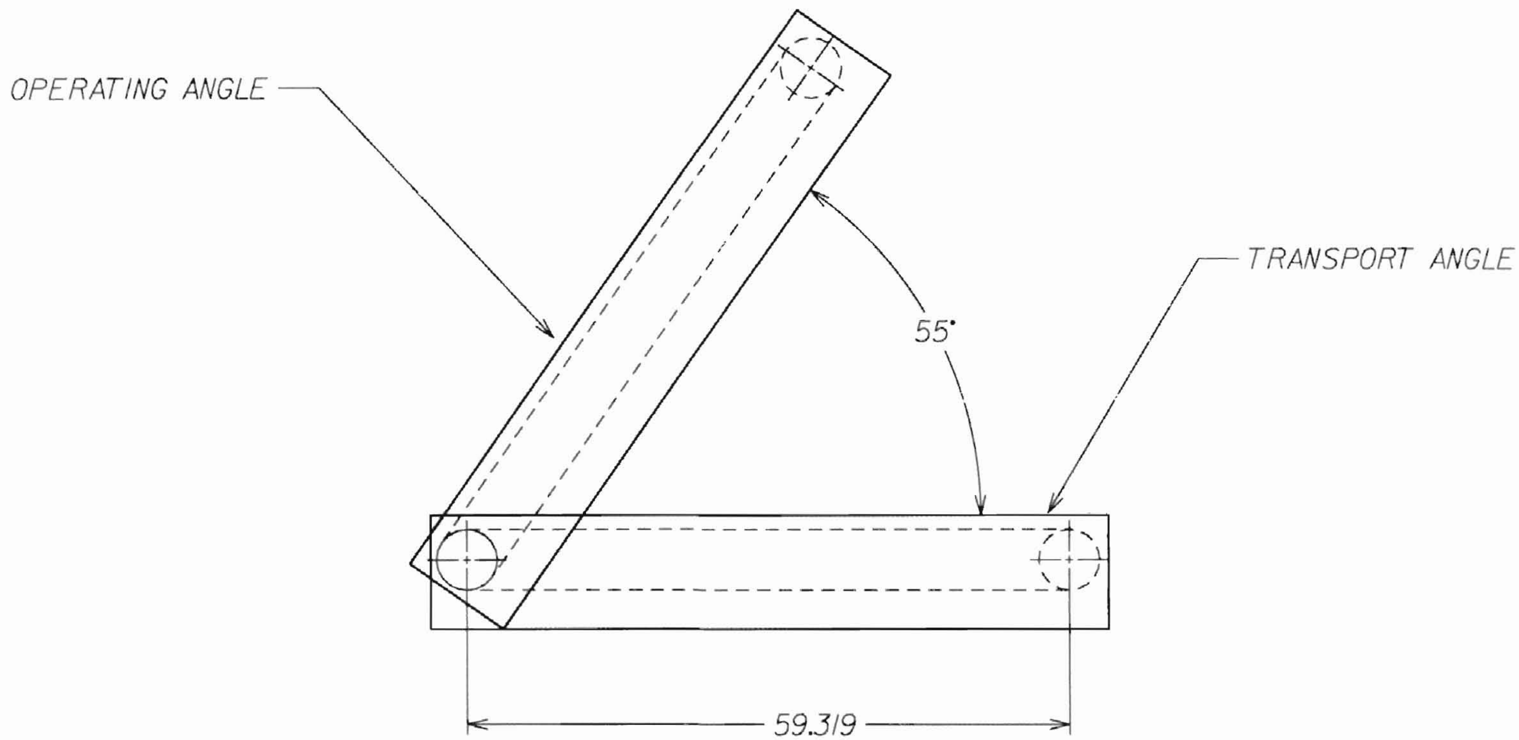


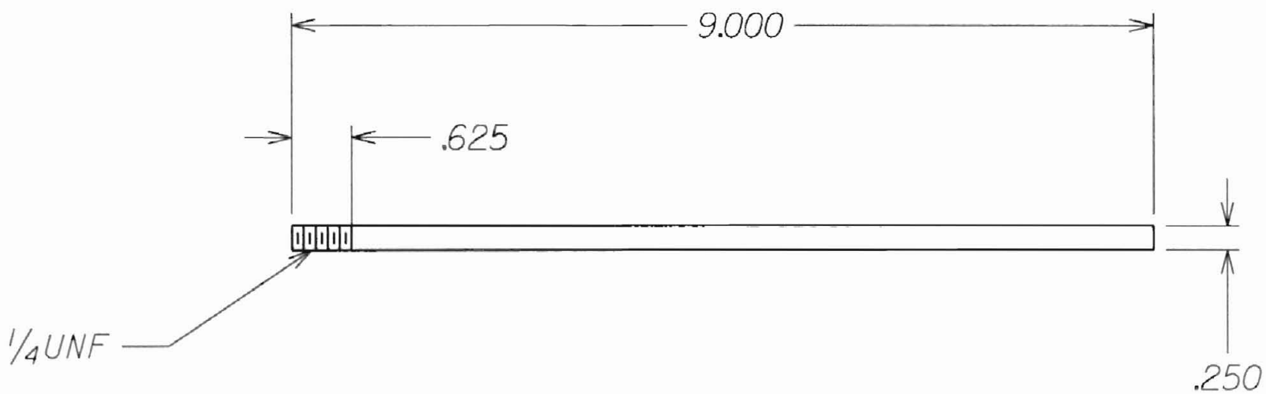
FIGURE 21. SIDE VIEW OF THE REEL PORTION OF THE CHISHOLM RYDER GREEN BEAN STRIPPER AND THE RELATIVE POSITION OF THE SHEET METAL HOOD.



ANGLE CAPABILITIES OF THE SEPARATOR
FOR TRANSPORT AND OPERATING POSITIONS

FIGURE 22. CRITICAL DIMENSIONS OF THE SEPARATING CONVEYOR.

MAETERIAL: Ø1/4" COLD DRAWN ROD



FIGRUE 23. STEEL DISLODGING FINGERS.

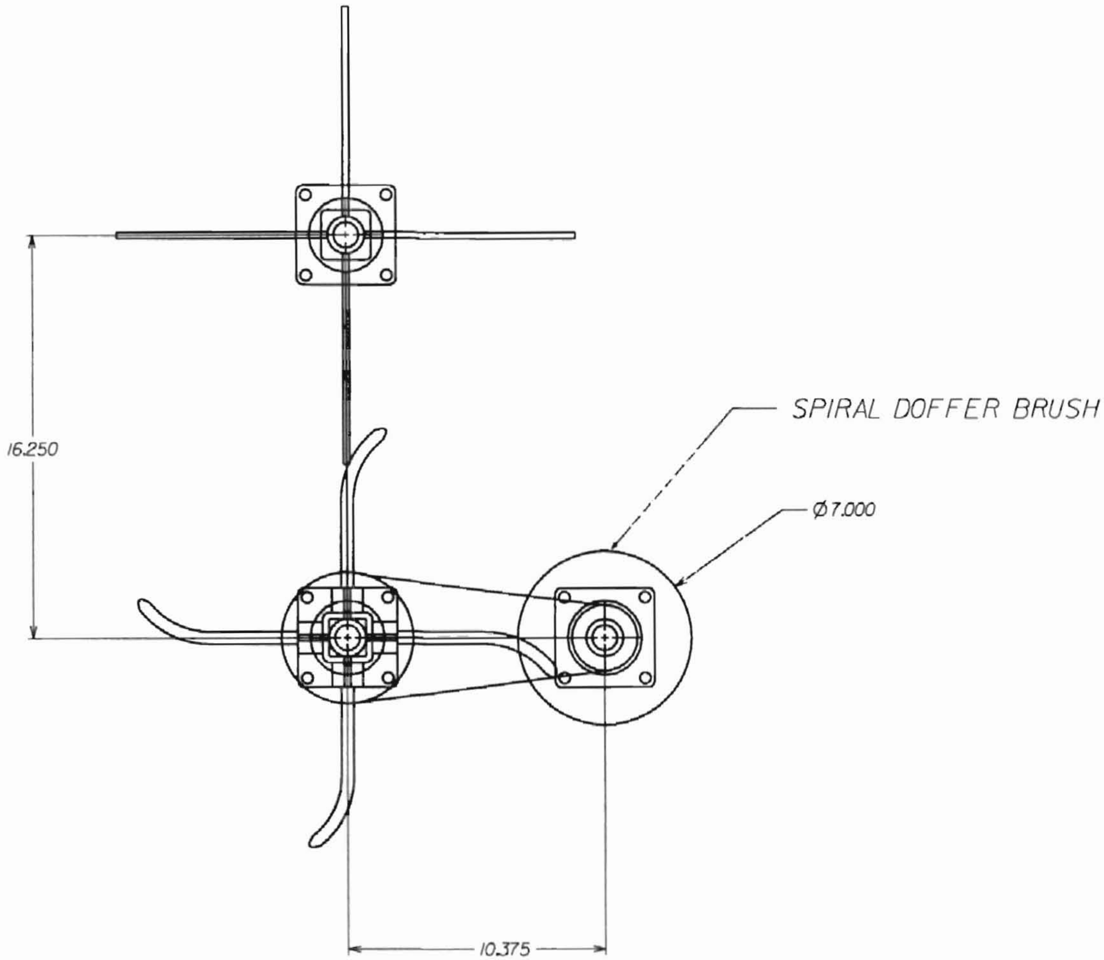


FIGURE 24. 1999 FIXED FINGER HEADER CRITICAL DIMENSIONS.

MATERIAL: MASSEY FERGUSON PART # 50633837, SPRING TINE

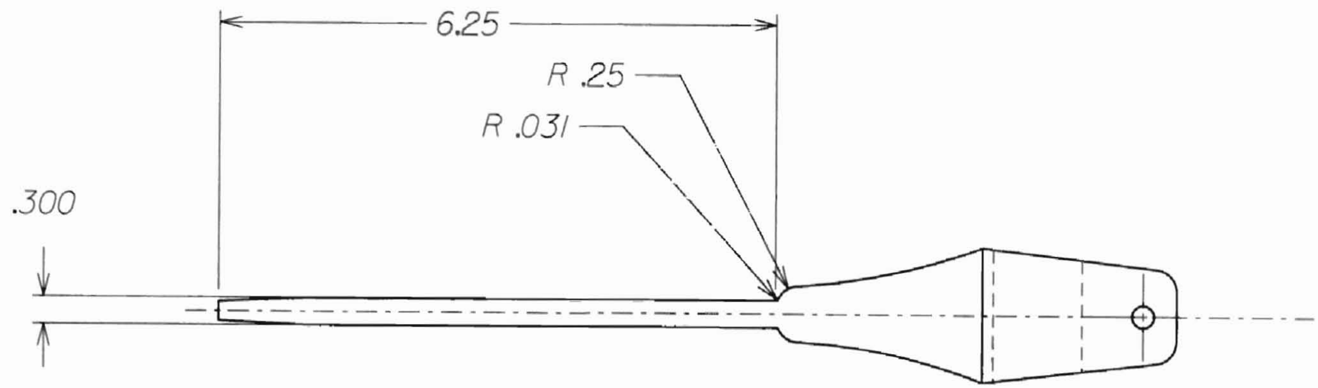


FIGURE 25. PLASTIC DISLODGING FINGERS FROM 2000 FIXED FINGER HEADER.

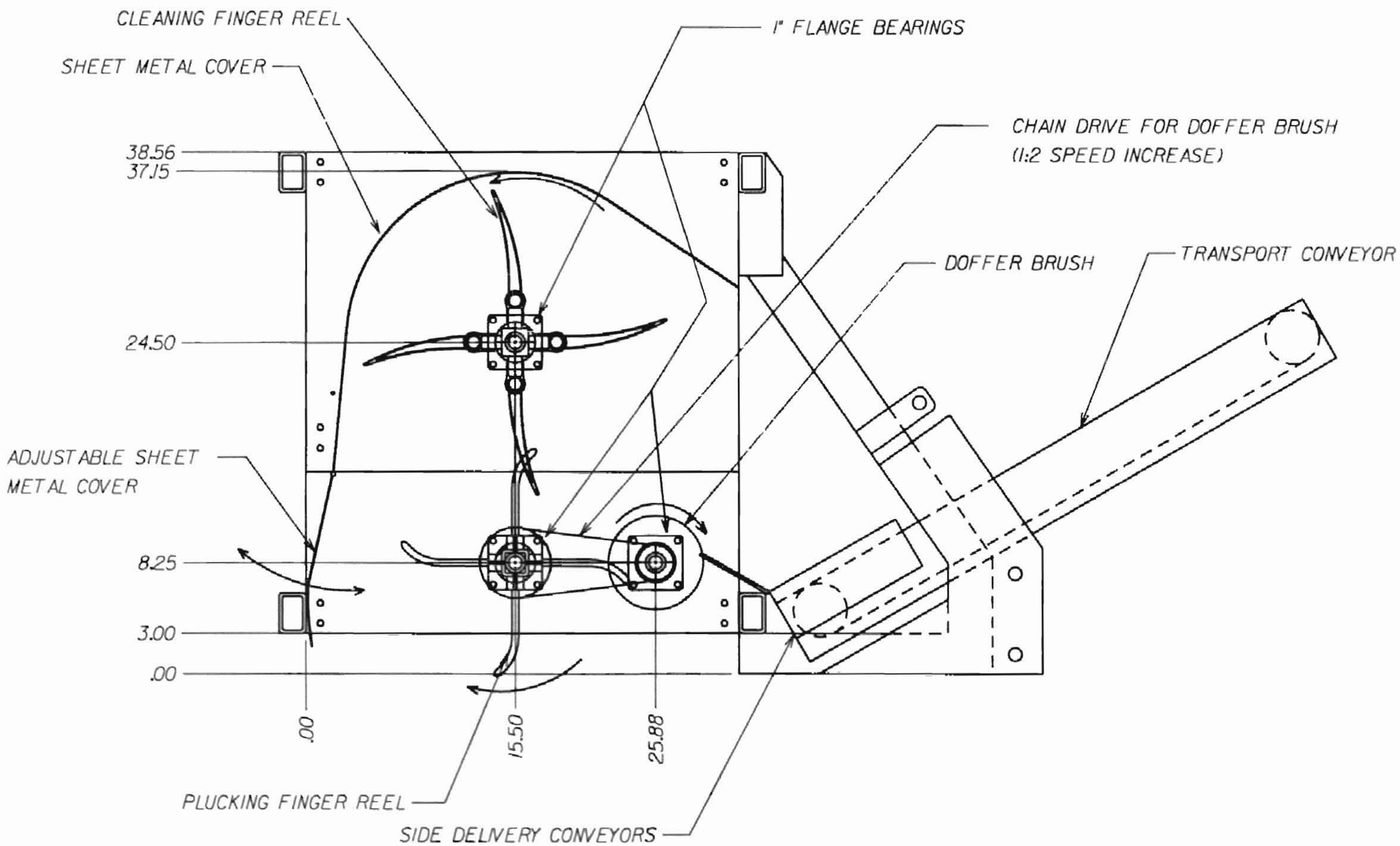


FIGURE 26. 2000 FIXED FINGER HEADER CRITICAL DIMENSIONS.

VITA

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