LASER BASED DENSITY DETECTION
OF STANDING WHEAT STUBBLE

By

RANDAL K. TAYLOR

Bachelor of Science
in Agricultural Engineering
Oklahoma State University
Stillwater, Oklahoma
1985

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1989

LASER BASED DENSITY DETECTION
OF STANDING WHEAT STUBBLE

Thesis Approved:

Marvin L. Stone

Thesis Adviser

Bobby L. Clary

Willard Downs

Norman N. Durham

Dean of the Graduate College

PREFACE

Penetration of a laser beam through wheat stubble was used as a measure of stubble density. A low power, helium-neon laser was positioned perpendicular to travel direction. A photo detector was used to determine penetration duty cycle after the beam passed through the stubble.

Penetration duty cycle measured on a simulated wheat crop gave a good indication of crop density. The laser beam appeared to penetrate the simulated crop at densities where direct transmission was blocked. Some reflection of the laser beam occurred through simulated wheat stalks and off the filter on the sensor.

Tests in standing wheat stubble offered little indication that the detector could accurately indicate crop density. Correlation coefficients between stalk density and detector readings ranged between 0.60 and 0.07. A statistical model was developed to describe the system and eliminate the affect of hidden stalks. The model demonstrated the insensitivity experienced at higher stubble densities.

I wish to express my sincere gratitude to the individuals who assisted me in this project and during my coursework at Oklahoma State University. In particular, I wish to thank my major adviser, Dr. Marvin Stone for his intelligent guidance, insight, and extreme patience. I am also grateful to my other committee members, Dr. H. Willard Downs and Dr. Bobby Clary for their time and willingness to discuss any problems I may have encountered.

Special thanks are due to the staff at the Agricultural Engineering Laboratory, who provided the manpower for construction of any equipment I may have needed. The help of Mark Appleman, Van Swift, and Bruce Lambert is especially appreciated, without their help this study would not have been possible. I would also like to express deep appreciation to my family for their support of my continuing education.

TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Oklahoma has approximately 5.3 million acres of wheatland that produces over 185 million bushels of wheat yearly. Even at $2.00 per bushel, wheat yields over 370 million dollars in gross revenue for the state annually. In recent years, when wheat prices were higher, this revenue totaled an even greater amount. During this time farmers were trying to increase their harvest yields so that their profits would increase. With falling prices farmers cannot afford to invest money to increase yields, they must try to get higher yields without monetary investments. One area that should receive attention is the farm owned combine. Downs et al. (1985) reported that wheat harvest losses in Oklahoma averaged 3.2 bushels per acre and combine losses averaged 2.1 bushels per acre. At $2.00 per bushel Oklahoma farmers are leaving 22.3 million dollars worth of wheat in the field each year.

Many farmers neglect to invest time into properly adjusting their combines to achieve maximum efficiency. Newton et al. (1986) estimates only 10% of Oklahoma farmers spend time to accurately determine their combine's losses. However, a small amount of time spent adjusting a combine can yield significant increases in efficiency, thus increasing the amount of grain in the bin without increasing yields. Minimizing combine losses can also save money by reducing summer tillage and chemical costs (Downs et al. 1985). Summer tillage and chemical use on wheatland are related to the amount of grain left in the field at harvest and reducing combine losses will reduce this amount of grain.

Ideally a combine operator wants to harvest every bit of his crop, but unfortunately this is not possible. Although no combine is 100% efficient, it may be possible to approach this figure with an experienced operator. However, because the combine is easily the most complex machine on most farms, operators with the necessary experience to run one efficiently during the long hours of harvest are uncommon. The operator is responsible for continuously controlling the following combine functions.

(1) ground speed
(2) steering
(3) header height
(4) reel height
(5) reel speed

Occasionally the operator may need to make all of these adjustments simultaneously and is seldom ever controlling less than three at one time. In addition to these functions an operator also monitors.

(1) changing crop and field conditions
(2) chaffer returns
(3) grain flowing into the bin
(4) loss monitor

Based on his observations of these items an operator may make changes in any one or more of the five functions previously discussed. He may also make changes in fan setting or cylinder speed without leaving the operator's position. The operator's main objective is to operate at some optimum combine efficiency, which can be defined as harvesting at maximum capacity with the least loss. Because feedrate effects loss more than any other factor, the operator's primary desire is to keep feedrate constant.

Mailander and Krutz (1984) reported that losses increase strongly with increased feedrate. The operator controls feedrate by visually detecting crop density while listening to the cylinder for overloading. He adjusts ground speed to keep the feedrate constant as crop density and height change. As crop height changes the operator adjusts header height to make sure he is getting all of the grain without cutting an excess of material-other-than-grain (MOG). Decreasing the MOG to grain ratio increases the combine's grain capacity without significantly increasing combine losses (Hill and Frehlich 1985).

Given all of the elements a combine operator must monitor or control and the general lack of concern for losses, the idea of automatically controlling some combine functions is certainly appealing. Controlling the feedrate of material through the combine would probably benefit the operator more than controlling any other element. However, for an automatic control system to control feedrate, it must accurately measure the feedrate early enough so that adjustments can be made.

Objectives

The objectives of this thesis research were:

1) To develop and evaluate a laser based crop density detector. The sensor would have the potential to measure crop feedrate before material enters the combine.

2) Test the detector using simulated wheat stubble constructed with wooden wheels and dowel rods.

3) Investigate the effects of ground speed and crop density on performance. The performance of the detector was determined by its ability to indicate stalk density for a range of ground speeds similar to those used in actual harvest conditions.

4) Repeat the test procedure on standing wheat stubble in the field.

CHAPTER II

LITERATURE REVIEW

Introduction

Improving combine sensors has been the topic of several research programs. Sensors can give an indication of how efficiently a machine is operating. Sensors can also be used as an input to some type of control system that reduces the operator's responsibilities and may improve machine performance. Because grain loss and feedrate are the two items that have the greatest impact on efficiency, they are usually the inputs to the control system. Grain loss is measured at the cleaning shoe and straw walkers. Attempts to measure feedrate have been made at various points on the combine.

Grain Loss as an Input to the Control System

Loss monitors are standard equipment on most new combines and are available for retrofit on older models. Loss monitors provide the operator with a reading in the cab and the operator attempts to drive at a speed which keeps the reading between two limits. However a time delay exists in the fact that the monitor is sensing loss as material leaves the combine and the operator is adjusting speed to control material entering the combine. The time required for the monitor pads to record a loss and send it to the operator is larger than the time required for the operator to adjust ground speed. The operator must be aware of this fluctuation and make adjustments in small steps while allowing the monitor to stabilize before he makes further adjustments in the combine's speed. An automatic control system using the loss monitor signal as the input could control combine operation to minimize grain losses. Huisman (1983) and McGechan et al. (1982) studied control systems that used grain loss readings as the primary input. Both studies were designed to keep grain loss constant at some desired level. Huisman (1983) tested four combine control systems that used the signal from the loss monitor as part of the input. The first was a system that controlled ground speed with a signal consisting of measured walker loss and measured ground speed. The second system measured walker loss, material feedrate, and ground speed to output the momentary optimum ground speed. A third system tested used walker loss, material feedrate, threshing speed, and ground speed to control the optimum ground speed. The final system measured walker loss, material feedrate, and threshing speed to optimize the feedrate/threshing speed relationship. These systems were compared on their ability to reduce combine harvesting costs. A slight reduction in costs was obtained under the specified operating conditions. Savings in costs are not attributed to controlling to meet rapidly varying crop conditions, but by controlling to meet slowly varying crop properties and density levels (Huisman, 1983). Slowly varying crop density can easily go unnoticed by the combine operator for extended periods of time and makes the idea of a crop density detector appealing. McGechan (1982) found that the benefits of a control system which maintains a constant optimum threshing loss compared to one which maintains constant ground speed were very small. Reed (1970) and Hill and Frehlich (1985) agree that yield of MOG is the most important factor influencing threshing loss. The optimum threshing loss system measured crop variability in terms of its effect on threshing loss variability by an acoustic grain loss monitor. The constant ground speed system tested did not account for changing crop density; therefore, unless crop density in the test field was constant the feedrate through the combine was constantly changing. McGechan assumed a mean yield of 5 t/ha while Oklahoma yields are closer to 2 t/ha. The higher yields assumed by McGechan probably have less variation from the mean, so constant speed control may be more feasible.

Realizing the time required to adjust ground speed is much less than the time required to measure and inform the operator of a loss level, it is evident that measuring loss as the primary input to a control system is not feasible. The response time of the signals would be to high; therefore, increasing the time before adjustments in speed can be made. However, correlation between grain loss and crop feedrate can eliminate any time delays in the system (leFlufy and Stone, 1983). The system could then be responsive to both short- and long-term variations in crop conditions.

Feedrate as an Input to the Control System

Since loss is highly correlated with feedrate, one method for reducing loss could be to control feedrate. Controlling feedrate in a combine first requires the ability to accurately measure feedrate. Schueller et al. (1985) discusses six types of feedrate sensors. The sensors were placed in various parts of the combine and measured different parameters. An attempt was made to relate sensor outputs to feedrate. A feeder torque sensor was mounted on the hydraulic feeder drive motor and measured the differential pressure across the ports. An engine speed sensor was installed to measure engine load as feedrate changed. A sensor was mounted to measure the torque in the header auger and another was mounted to measure the torque in the clean grain auger. Air pressure under the sieves was also monitored as a potential indication of feedrate. A grain flowmeter was mounted in the grain tank to measure the rate of grain flow into the tank.

Of the six sensors, the only two that gave any indication of feedrate were the feeder torque sensor and the engine speed sensor. Data from the feeder torque sensor was scattered but did show a trend. The feeder torque sensor predicted feedrate on a particular day better than it did over the three seasons tested. The engine speed sensor performed similar to the feeder torque sensor.

Estimating Feedrate from the Density of Standing Wheat Stubble

Feedrate can be calculated from geometry of the combine system and other factors. The factors that determine feedrate are cutting width and height, ground speed, and crop density. Cutting width is approximately equal to header width and can be considered constant. Cutting height depends on the particular crop and the difference in height of the lowest and highest head being cut at any time. Ground speed is changed as crop and field conditions change, but the operator usually tries to keep it as high as possible. Crop density is the only parameter that is not constant or cannot be controlled by the operator; therefore, to keep feedrate constant it must be the primary input. The operator visually detects crop density and makes adjustments in ground speed to keep feedrate constant, but this is just one of the operator's responsibilities and occasionally is not his highest priority.

Simulation of the operator in controlling ground speed requires the detection of crop density. To measure crop density a beam of light passes through the crop perpendicular to the line of motion. The fraction of light penetrating the crop is inversely proportional to the crop density. The basic flow rate equation shows that volumetric flowrate (Q) is the product of velocity (v), and cross-sectional area (A). Velocity in this case would be ground speed, while the equation for cross-sectional area is,

$$A = (\text{crop height} - \text{header height}) * \text{header width} \quad (1)$$

The flow rate equation does not allow for the fact that the crop is not tightly packed. The volume of crop entering the combine is partially occupied by air. Hence, mass feedrate would be a more acceptable method for describing the flow of material into the combine. Mass feedrate (m) is the product of crop density and volumetric feedrate. If crop density is a function of the detector reading (DR) the mass feedrate equation is,

$$m = f(DR) * v * A \qquad (2)$$

With this equation, mass feedrate can be predicted using the known header width, constant cutting height, measured ground speed, and measured crop density.

CHAPTER III

EQUIPMENT

Sensing crop density required construction of a detector. It was hypothisized that a beam of light penetrating the crop and could sense crop density. Crop density would be a function of the amount of light penetrating the crop. A laser was chosen as the light source because the beam has a high degree of integrity.

The crop density detector consisted of a Uniphase Novette helium-neon laser (Model 1508) and a United Detector Technology photo sensor (PIN 220DP). The laser has a minimum output of 0.5 mW and a beam diameter of 0.48 cm. The rectangular 1 cm by 2 cm sensor was mounted vertically inside a tube and covered with a band pass interference filter (632.8 nm) of the same size to minimize the effect of ambient light. The filter was mounted about 0.75 cm in front of the sensor with the same orientation (Figure 3.1).

The detector was designed to measure crop density perpendicular to the line of motion with the laser directed onto the photo sensor. Light on the sensor produced a signal which was amplified, limited (Figure 3.2), and recorded on eight inch floppy drives with a Creative Micro Systems Exorbus based computer. The computer used hardware timers to measure the proportion of time that the sensor was not responding to light (Figure 3.3).

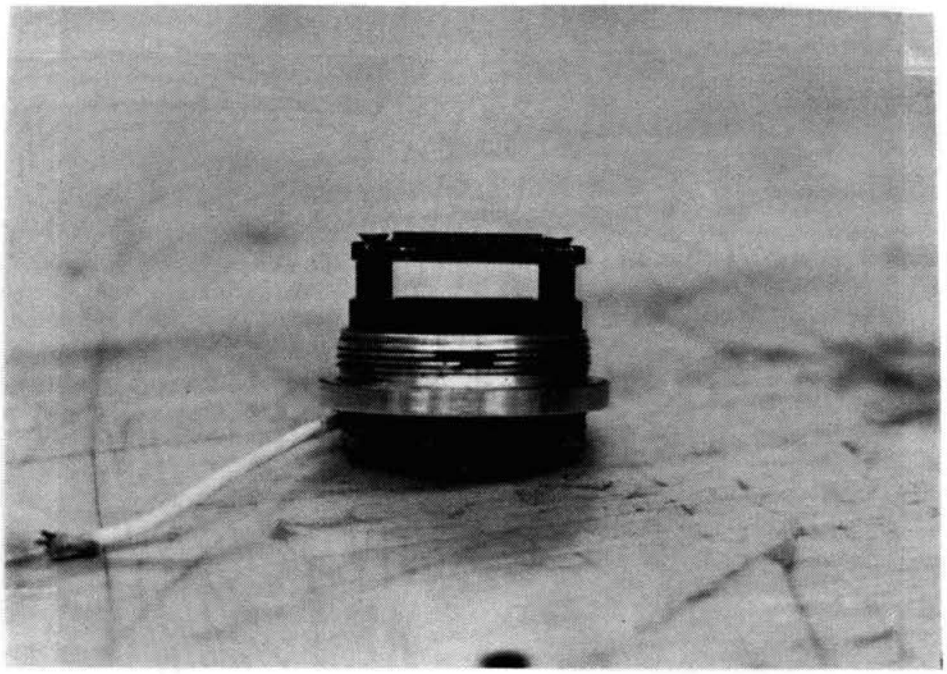

Figure 3.1. Mounting Arrangement for Sensor and Filter.

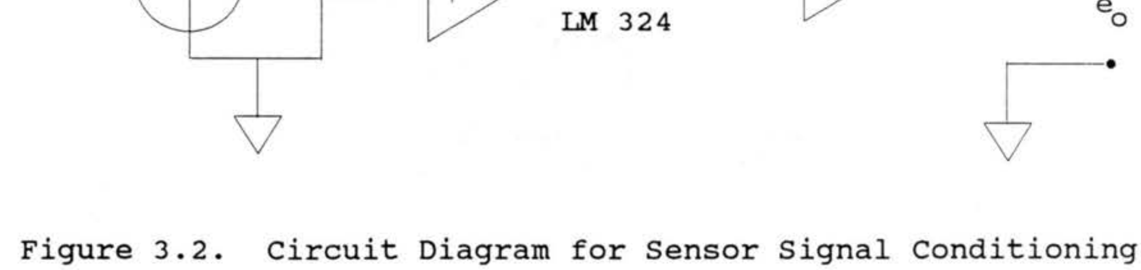

Figure 3.2. Circuit Diagram for Sensor Signal Conditioning.

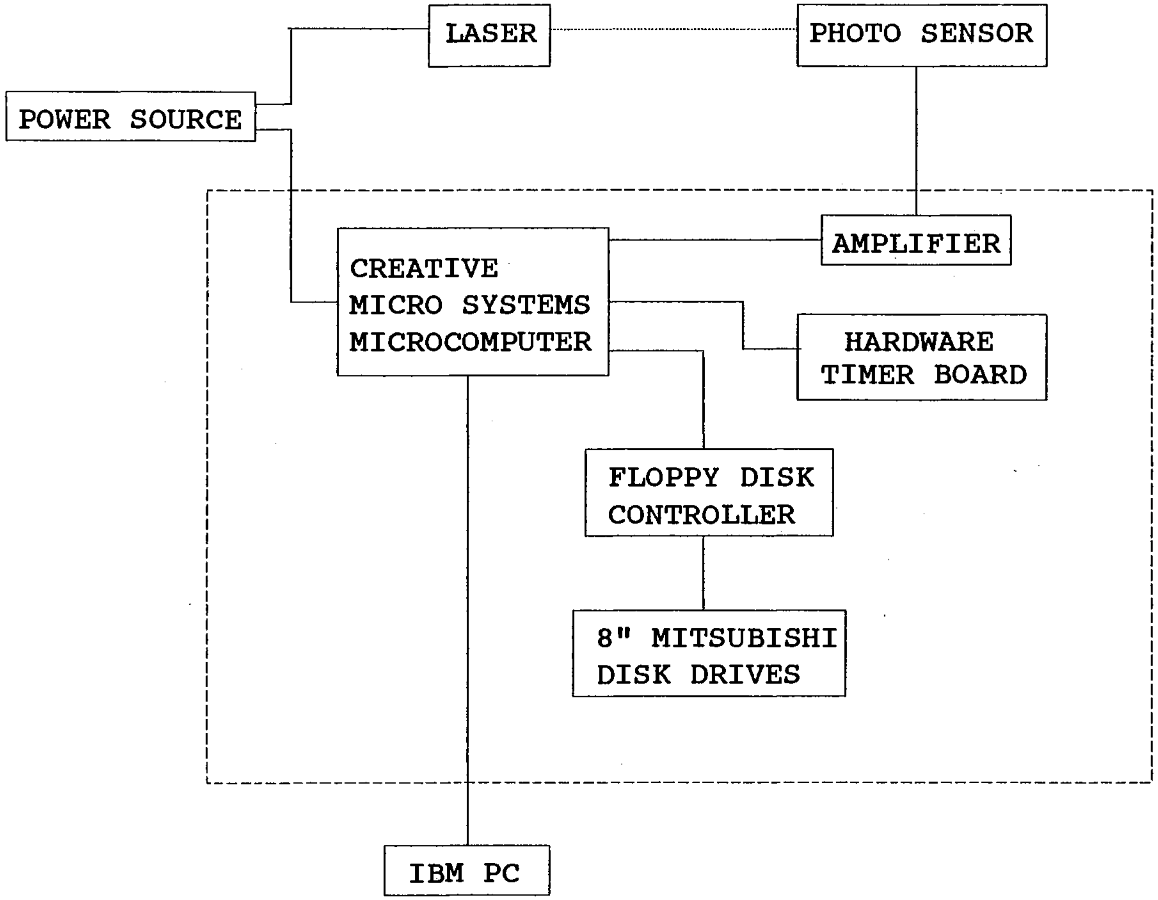

Figure 3.3. Block Diagram of the Feedrate Detection System.

The detector was tested on a simulated wheat crop and again in wheat stubble. The simulated wheat crop was constructed of wooden wheels with eight evenly spaced 0.3175 cm diameter wooden dowels per wheel. The wheels had a radius of 5.08 cm and width of 1.905 cm. The unfinished dowels were 17.78 cm long and mounted on the wheels to provide a tip radius of approximately 20.3 cm (Figure 3.4). Twenty-seven wheels were mounted on a shaft with the dowels evenly staggered approximately 0.6 degrees from dowels on adjacent wheels. The wheels were taped together to maintain the integrity of their placement. The wheels were spaced 0.63 cm apart resulting in an overall assembled length of 68.6 cm (Figure 3.5). The wheels were driven by an electric variable speed drive, to allow appropriate variation in speed. Density of the dowels was proportional to the radius of penetration of the laser beam. For example, the chance of the laser beam penetrating the dowels would be easier as the beam was moved further from the center of the axle on which the wheels rotate. Therefore, the radius at which the beam was directed through the dowels was varied to obtain a desired density.

For the field tests the laser, sensor, and computer were mounted on a platform that connected to the three point hitch of a Massey Fergeson MF 245 tractor. Speed was held constant by putting the tractor in gear and setting the throttle in a stationary position. Actual speed was determined from the length of the stubble plot and the time required to take the samples. The laser and sensor were suspended from the platform and spaced 1.2 meters apart (Figure 3.6).

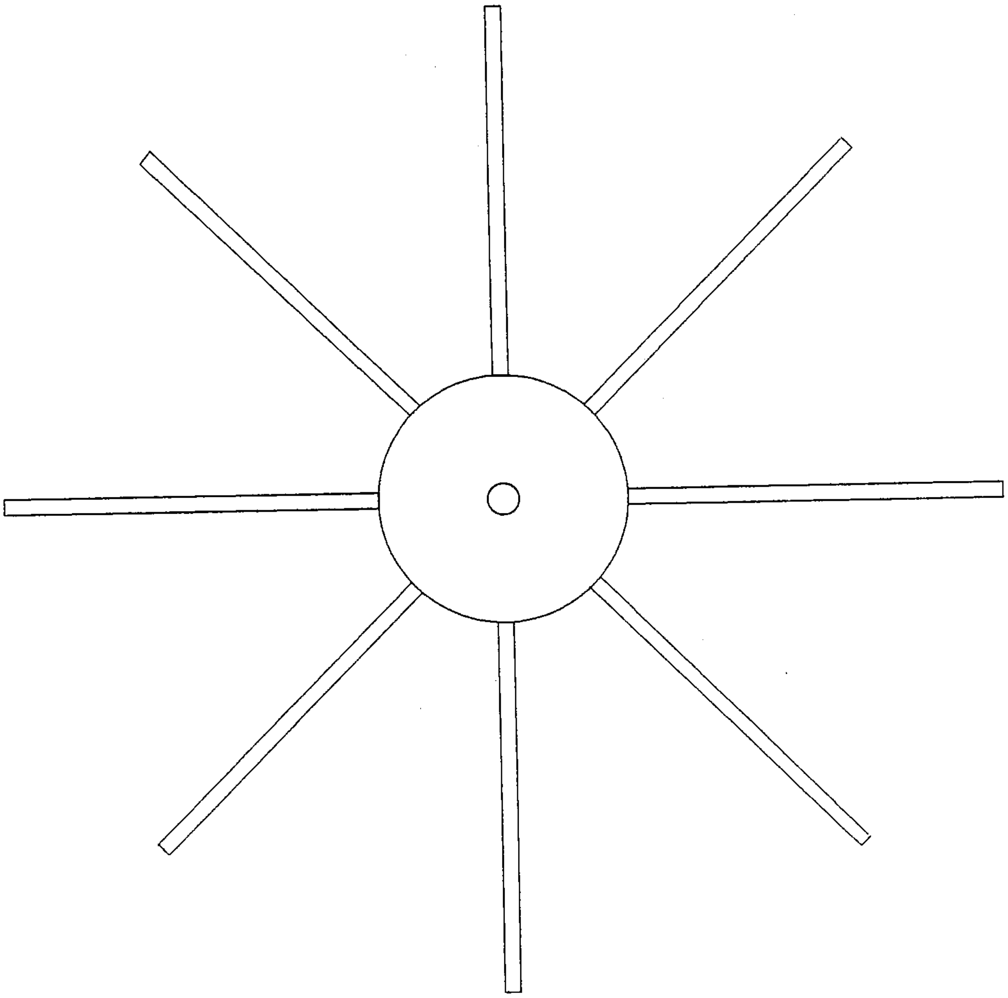

Figure 3.4. Drawing of Dowels and Wheels Used for Simulated Wheat Crop

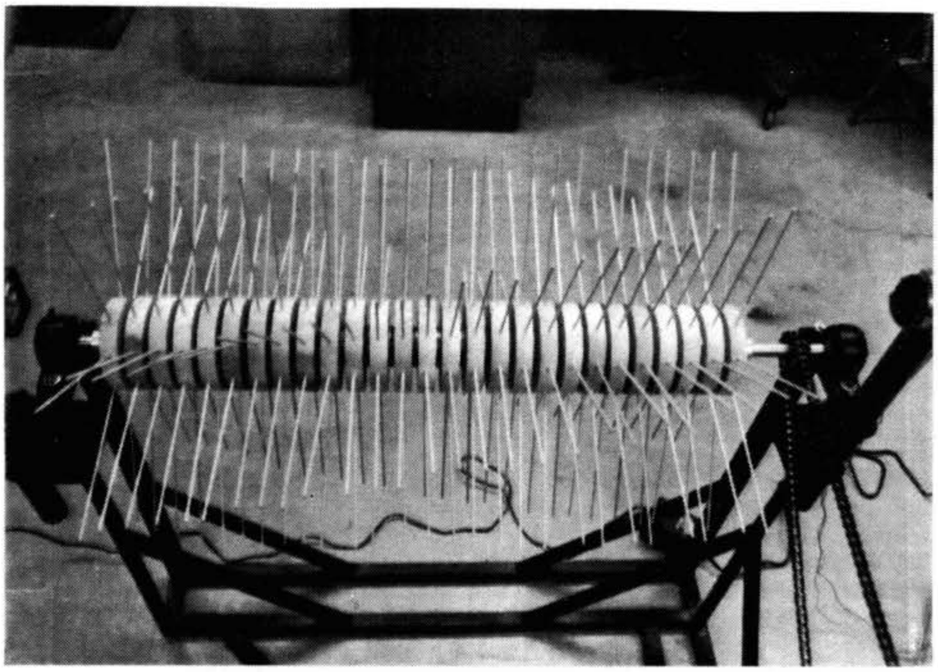

Figure 3.5. Simulated Crop Used in Laboratory Tests.

Figure 3.6. Mounting Arrangement for Field Tests.

CHAPTER IV

METHODS AND PROCEDURE

The detector described was evaluated for its ability to indicate the crop density of wheat stubble. The detector was first tested by Taylor et al (1986) by mounting it on a combine header and correlating the readings to the measured material feedrate. Research described here addresses testing the detector on a simulated crop under controlled conditions and then on wheat stubble left standing in the field.

Laboratory Tests

The simulated crop previously described was rotated via the varialble speed drive by an electric motor. Crop density was varied by the radius of penetration of the laser beam. Angular velocity of the crop Was adjusted to produce a desired ground speed at the radius of penetration of the laser beam.

The laser and photo sensor were placed at opposite ends of the simulated crop. Both were set up with adjustable height. The laser was turned ON and height was adjusted to a predetermined radius from the center of the axle on which the crop rotated. The sensor height was then adjusted so the laser beam would strike the center of the sensor. Crop density was defined as the ratio of space occupied by the dowels at a given radius to the total space at that radius. The diameter of the dowel rods times the total number of dowel rods gives the amount space occupied by the simulated crop, while the circumference of the circle at a given radius gives the total amount of space. Therefore, crop density for the laboratory tests is a dimensionless ratio.

After the laser was adjusted to penetrate the simulated crop at a known density, the angular velocity of the crop was adjusted with the variable speed drive to a predetermined value for a specific simulated ground speed. Ground speed was determined from the peripheral velocity of the dowels at the radius at which the laser penetrated the simulated crop.

Tests were run for fixed levels of ground speeds and crop densities. Tests were run for speeds ranging from 3.22 to 9.66 km/h with 1.61 km/h intervals and crop densities ratios from 0.54 to 0.95. Five data samples were taken at each speed/density setting. Each sample consisted of 60 readings taken on 0.5 second intervals. The detector readings were averaged and normalized so that they ranged from 0.00 to 1.00 where 0.00 represents an unblocked condition and 1.00 is a completely blocked condition. The result was plotted against the known crop density and the entire data set was modeled to obtain a regression line for each speed with detector reading as a function of crop density.

Since detector readings were not exceeding 0.90, tests were run at radii less than 10.87 cm, the radius at which complete blockage should occur. The detector was set at four "impenetrable" densities (1.07, 1.23, 1.43 and 1.72) and detector readings were taken at three speeds (6.44, 8.05 and 9.66 km/h). The data were plotted in the same fashion as the data taken previously.

Field Tests

A level area with uniform stubble height was chosen and a plot measuring 0.91 meters wide by 6.10 meters long was marked. The wheat stubble was approximately 46 cm high. After marking the plot, stubble on all surrounding edges was clipped at ground level so it would not interfere with the laser or sensor.

The crop density detector was mounted on the back of a platform connected to the three point hitch of a tractor along with the computer to record the detector signal. The laser was placed slightly over one meter from the sensor to make sure that neither would touch the stubble at any point during the tests. The mounting arrangement allowed the tractor to straddle the plot while the detector was taking samples (Figure 4.1).

Tests were run at speeds of 3.14, 4.39, and 5.49 km/h with five repetitions per speed. Measurements were manually started when ground speed stabilized and before the plot was reached. Samples were taken on 0.5 second intervals. After leaving the plot the detector was manually turned OFF. Since the areas before and after the plot were cleared, density data were "sandwiched" by 0.00 readings at the beginning and end of the data file.

After all samples were taken, the stubble was cut from the plot in 15.3 cm lineal increments (Figure 4.2). The samples were bagged and weighed to determine the stubble density in the plot. Densities were averaged over the distance for which the detector readings were made. For example, if the data set recorded by the computer had 14 observations, the plot was divided into 14 sections and average densities were obtained for the sections. Appendix A contains the program which computed the average crop density for a specified number of sections. In addition, the average weight per stalk was measured and the number of stalks per section was determined. The data were plotted with detector reading as a function of stalk density.

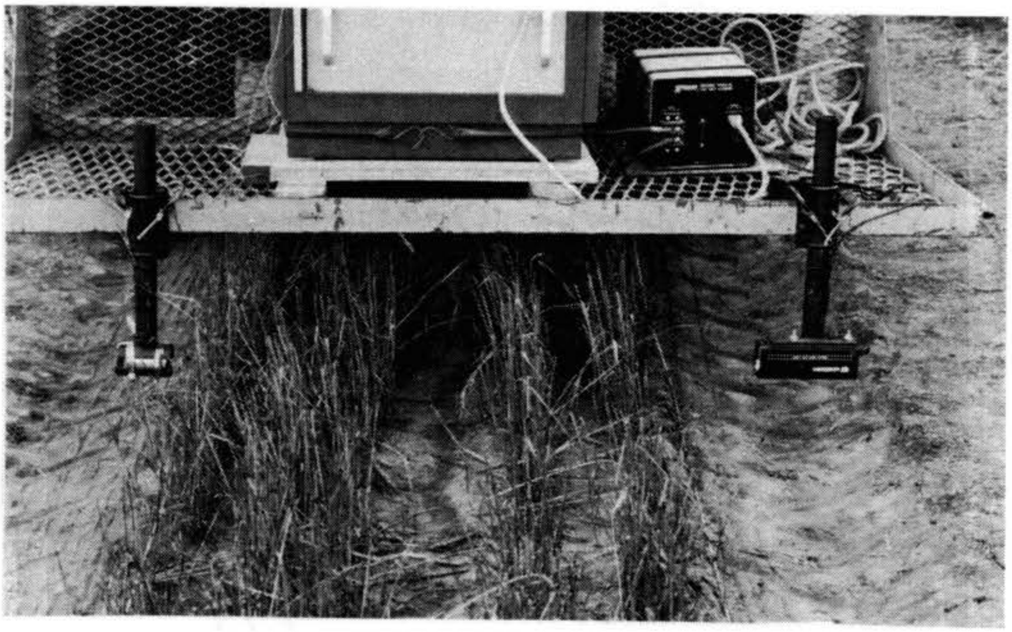

Figure 4.1. Detector During Field Tests.

Figure 4.2. Removal of Stubble After Field Tests.

CHAPTER V

RESULTS

Laboratory Tests

The normalized detector reading was plotted versus measured crop density for the simulated crop. The data taken at crop densities less than 1.00 can accurately be described by linear regression. Figure 5.1 shows the data in this range and the linear regression curve (Equation 3). The correlation coefficient for the curve is 0.96.

$$DR = 0.17 + 0.61 * CD \qquad (3)$$

where detector reading, DR, ranges from 0.00 to 1.00 and crop density, CD, ranges from 0.00 to 1.00. The detector reading is a unitless, normalized number where 0.00 is open space and 1.00 is a completely blocked condition. Crop density is the percentage of area occupied by dowels expressed as a decimal.

Tests run in the "impenetrable" zone, crop densities greater than 1.00, show that the detector is still functioning, even though the beam should have been blocked. Figure 5.1 shows the plot for the five ground speeds,

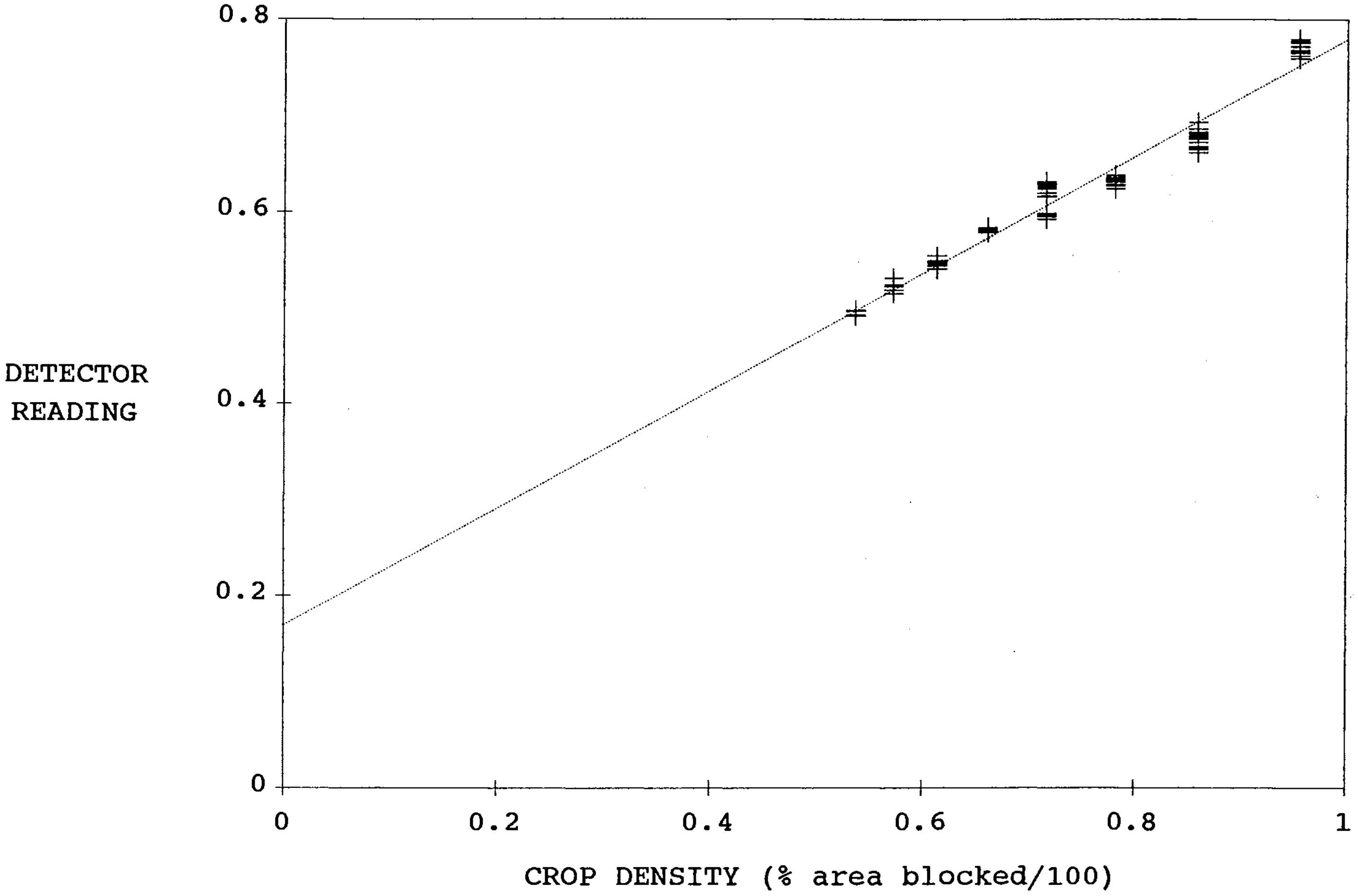

Figure 5.1. Simulated Crop Density vs Detector Reading for Crop Densities Less Than 1.00 With Linear Regression.

including data taken in the "impenetrable" zone. Appendix B contains the data from the simulated crop tests.

The data for the five speeds are best described by a logarithmic regression. The equation has a correlation coefficient of 0.98.

$$DR = 0.75 \times CD^{0.63} \qquad (4)$$

While the equation accurately describes the data, scatter does exist in the data. Sensitivity is reduced in the "impenetrable" range, but it appears that the reduction follows a trend.

Field Tests

The detector reading was plotted as a function of measured crop density for the three speeds. Figures 5.3 - 5.5 show the resulting data. Poor correlation between measured stalk density and detector reading was found. Greater scatter was found at higher speeds.

Statistical Model

The insensitive response in the field results inspired investigation of the effect of occlusion of stems in the path of the laser beam. A single stem may block the beam, preventing stems behind the first from effecting the density measurement. A simplified model was written to describe the penetration of the laser beam through the crop. The crop area between the laser and detector was divided into rows

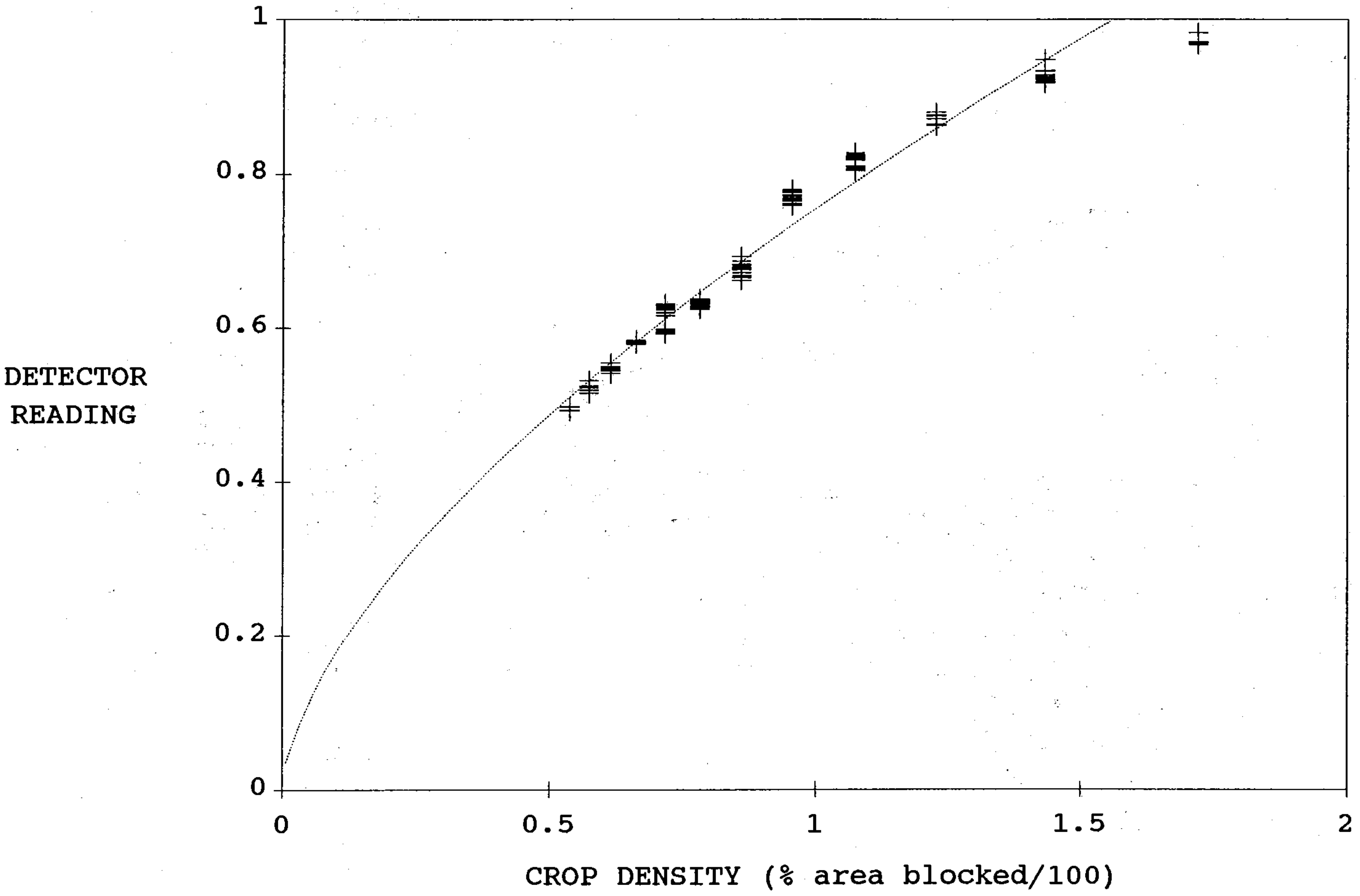

Figure 5.2. Simulated Crop Density vs Detector Reading With Logarithmic Regression.

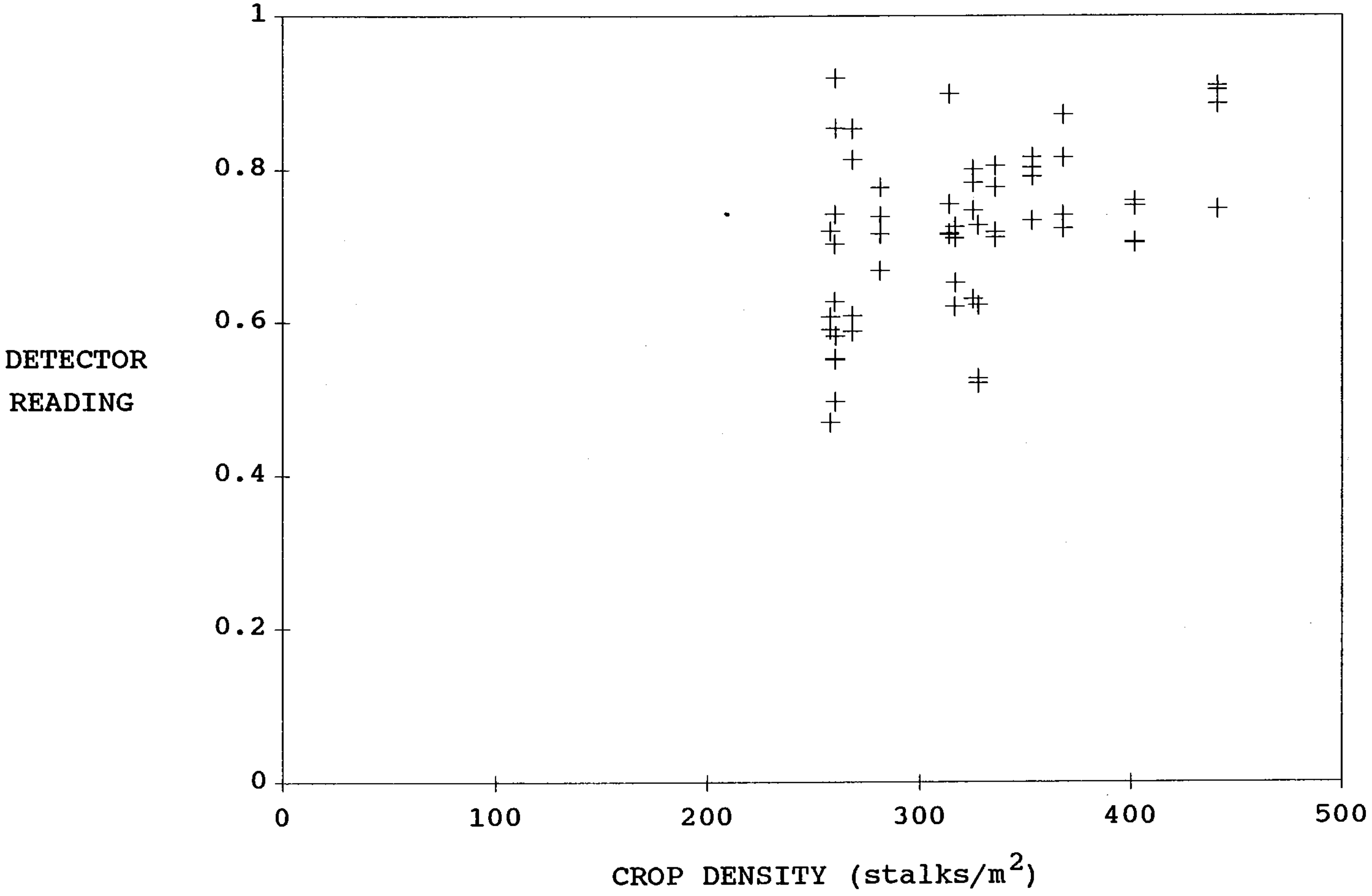

Figure 5.3. Crop Density vs Detector Reading for Field Tests at 3.14 km/h.

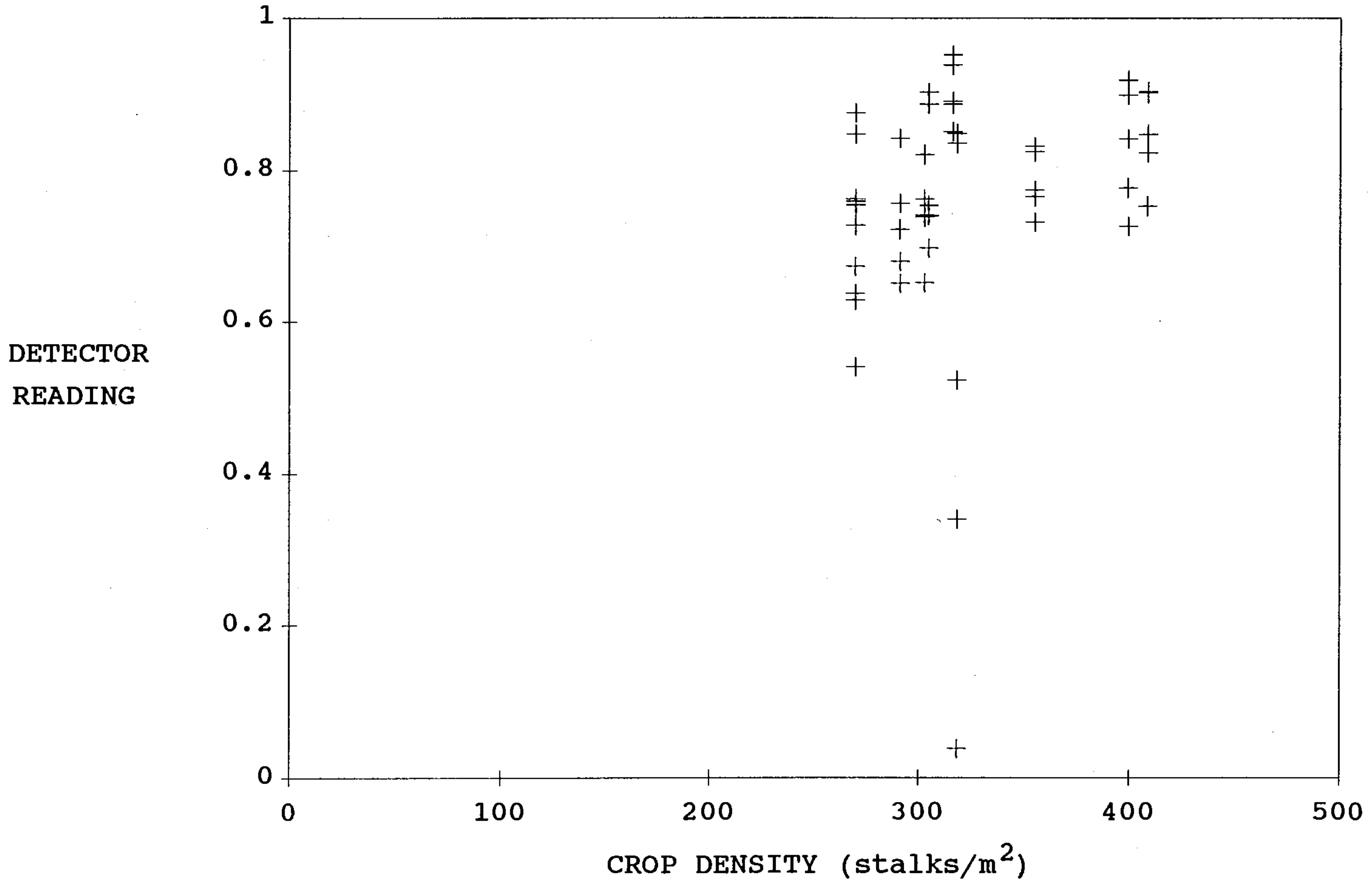

Figure 5.4. Crop Density vs Detector Reading for Field Tests at 4.39 km/h.

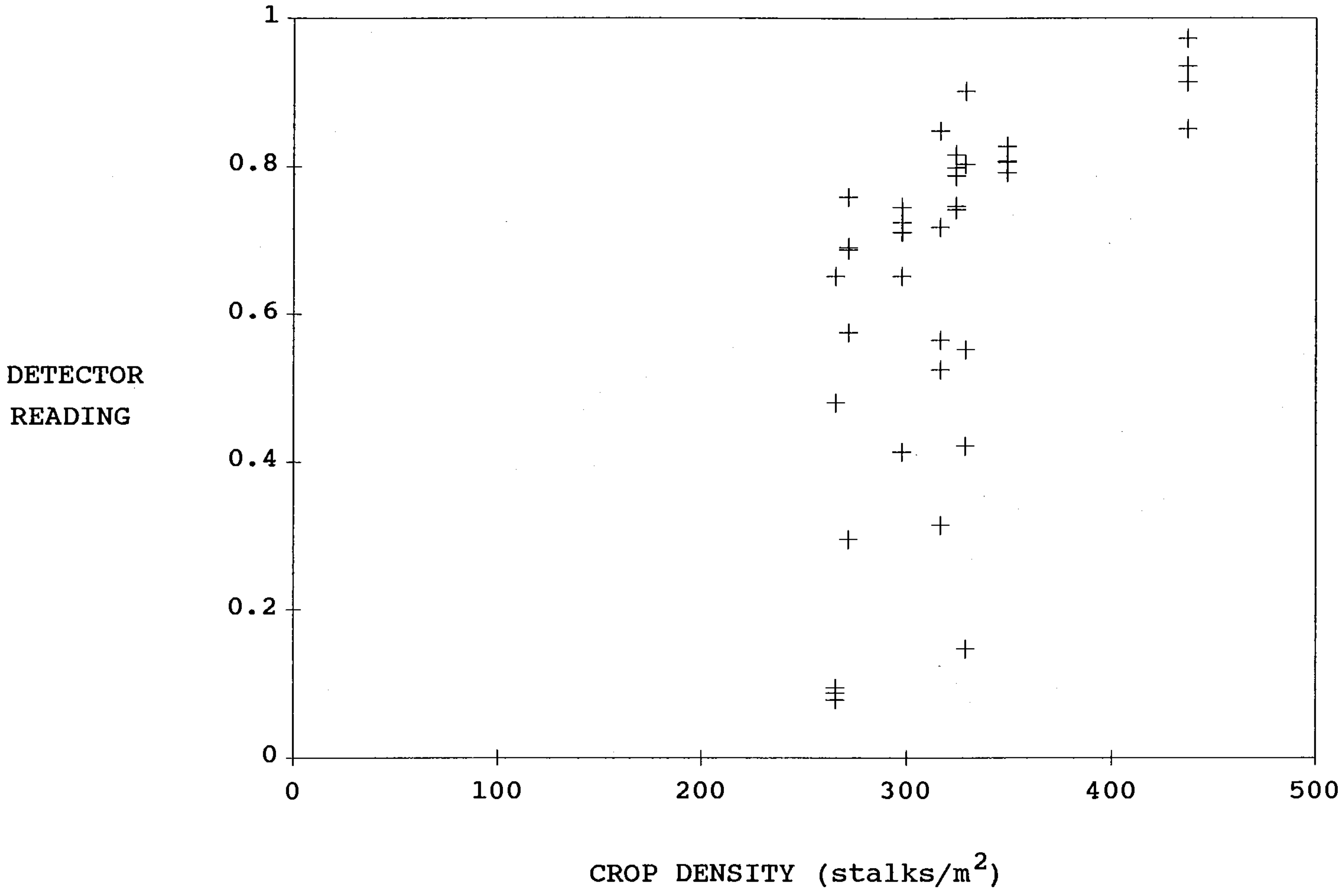

Figure 5.5. Crop Density vs Detector Reading for Field Tests at 5.49 km/h.

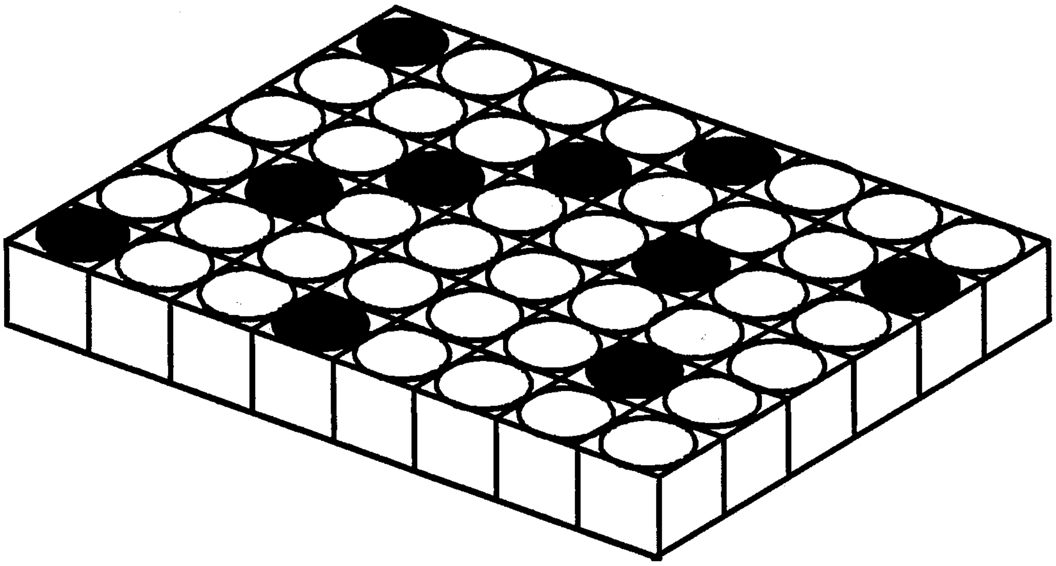

Figure 5.6. Potential Stalk Positions for Statistical Model.

perpendicular to the beam. Further, each row was divided into blocks. The blocks could be thought of as potential positions for stalks (Figure 5.6). In each row, stalks could be randomly assigned to the positions or blocks. The probability that the beam penetrates an entire row equals one minus the ratio of filled to unfilled blocks in the row (Equation 5).

$$P_{p1} = 1-R \qquad (5)$$

Further, the probability that the beam does not strike a stalk, or filled block, along a strip is the probability that a strip (parallel to the beam) of unfilled blocks occurs.

Given the above conditions, and that the rows each have the same ratio of filled to unfilled blocks, the probability of a strip of unfilled blocks occurring is shown in equation 6.

$$P_{p2} = (1-R)^n \qquad (6)$$

Where P_{p2} is the probability of an unfilled strip of blocks, R is the ratio of filled to unfilled blocks in a row, and n is the number of rows. For a given area the expression also yields the expected fraction of hits to misses along the length of a row. The probability that the beam will be blocked, P_b, is simply one minus the probability of penetration (Equation 7).

$$P_b = 1-(1-R)^n \tag{7}$$

The assumptions that the stalks are randomly assigned to the rows may be in error as the plants were seeded with an intended pattern. Further, during growth the stalks may tend to avoid each other in competing for light. A mitigating factor is that the ratio of filled to unfilled blocks will be low. For example, a grain yield of 67 kg/ha would be the equivalent of approximately 21 heads per square meter, or about 646 heads with attending stalks per square meter for a 2 t/ha yield. For 646 stalks in a square meter, where stalks measure 3.175 mm in diameter, about 0.65% of the area is filled.

Figure 5.7 shows a plot of equation 7 as R was varied from 0.0 to 0.015 (1.5% of the area filled with stalks). The value for 'n' (288) was calculated as the number of strips 3.175 mm wide in a plot 0.91 meters wide (the estimated stalk diameter and the width of the test plot respectively). The expected fraction of blockage is not linear with stalk density and in the higher density ranges, the laser system would be expected to be less sensitive.

The actual operation of the detector in the field was in a somewhat lower stalk density range. Figure 5.8 shows the probability of blockage curve overlayed on the data for all of the field tests. The expected value of the detector reading would be 1.25 times greater than the probability of blockage. The unequal scales for detector reading and probability can be justified by the ability of the detector to predict crop density when the simulated crop density is greater than 1.00.. The low sensitivity of the detector could be related to occlusion of stalks across the path of the laser beam. Another possible cause could be leaves blocking the beam. The large amount of scatter in the data renders the system ineffective in detecting stubble density.

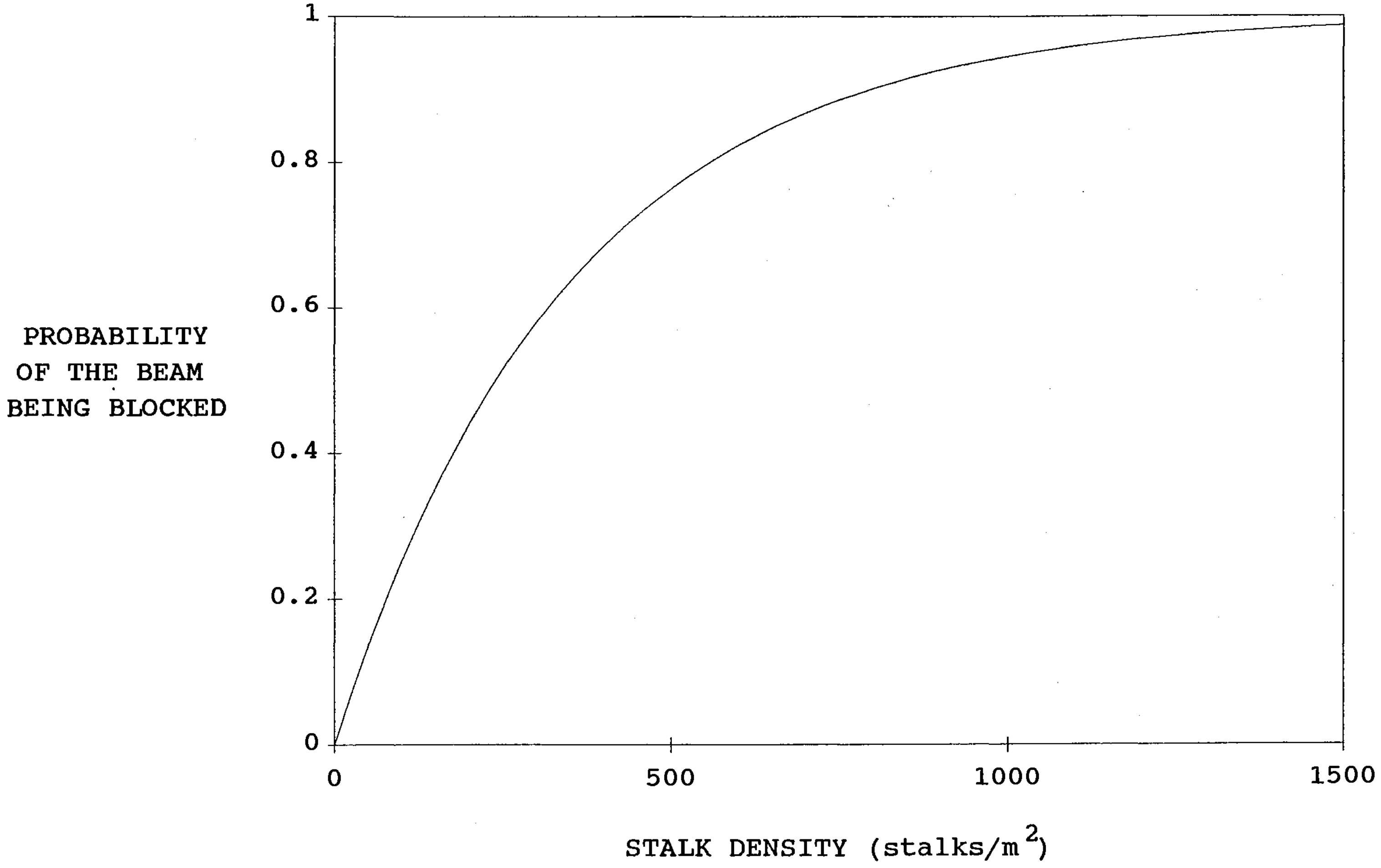

Figure 5.7. Plot of Statistical Model for 'n'=288.

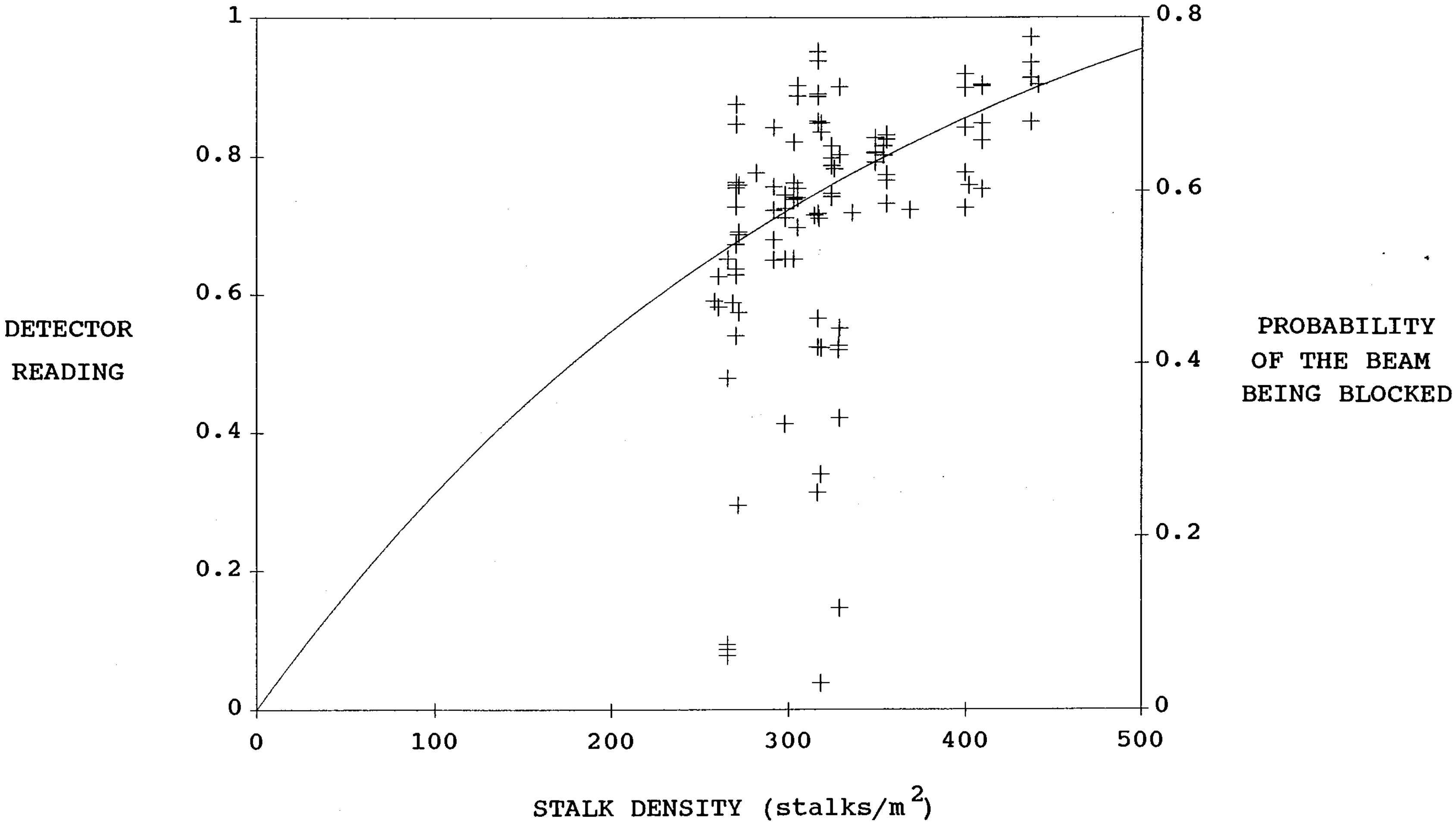

Figure 5.8. Probability of Blockage Curve Overlayed on Data From Field Tests.

CHAPTER VI

DISCUSSION

The data illustrate the detector's ability to indicate percent blocked area for the simulated crop when 'stalks' are evenly spaced and not blocking each other from the laser beam. The correlation coefficients for simulated crop density as a function of detector reading were high for the entire system within the range of the initial crop densities.

The ability of the detector to perform in the "impenetrable" zone was probably due to reflection or error in dowel alignment. Reflection was evident during the tests as the laser beam could be seen at different levels on the dowels and on the wall behind the laser. Reflection may cause the correlation of detector reading and crop density to decline logarithmically at high crop densities. The dowels were approximately the same color and diameter as wheat stalks so the reflection may also occur in wheat stubble. The surface texture of the dowels is probably more coarse than that of wheat stalks and could cause reflection. Error in dowel alignment may have allowed beam penetration in crop densities greater than one. Any slight error in alignment could have provided a gap for the beam to penetrate. Also because of small diameter, all dowels were not perfectly straight. Imperfections in the dowels caused imperfect alignment.

Speed had had no effect on the detector reading. Figures 6.1 - 6.3 show plots of the sensor and conditioned responses at 3.55, 5.96, and 7.54 km/h. The sensor response is the lower curve and the conditioned response is the square curve. Both responses are high when the laser beam is blocked and low when it is open. The conditioned response is the output of the circuit in figure 4.2. As expected, the sensor response is not a square curve. There is some variation along the horizontal portions of the curve and some slope to the vertical portions. The conditioning circuit sufficiently eliminates the variation along the horizontal portion of the curve, but does not totally eliminate the slope along the vertical portions. The slope of the vertical portions of the curve has been minimized by the conditioning circuit and is consistent regardless of penetration time.

The detector did not function as well under field conditions as in the laboratory. The data were not described accurately by regression equations. The apparent difference is the lower sensitivity due to the occlusion of stalks at higher densities or the possible interference of leaves. However, the statistical model developed for the problem offers some promise in describing detector characteristics. The curve from equation 6 with 'n' equal

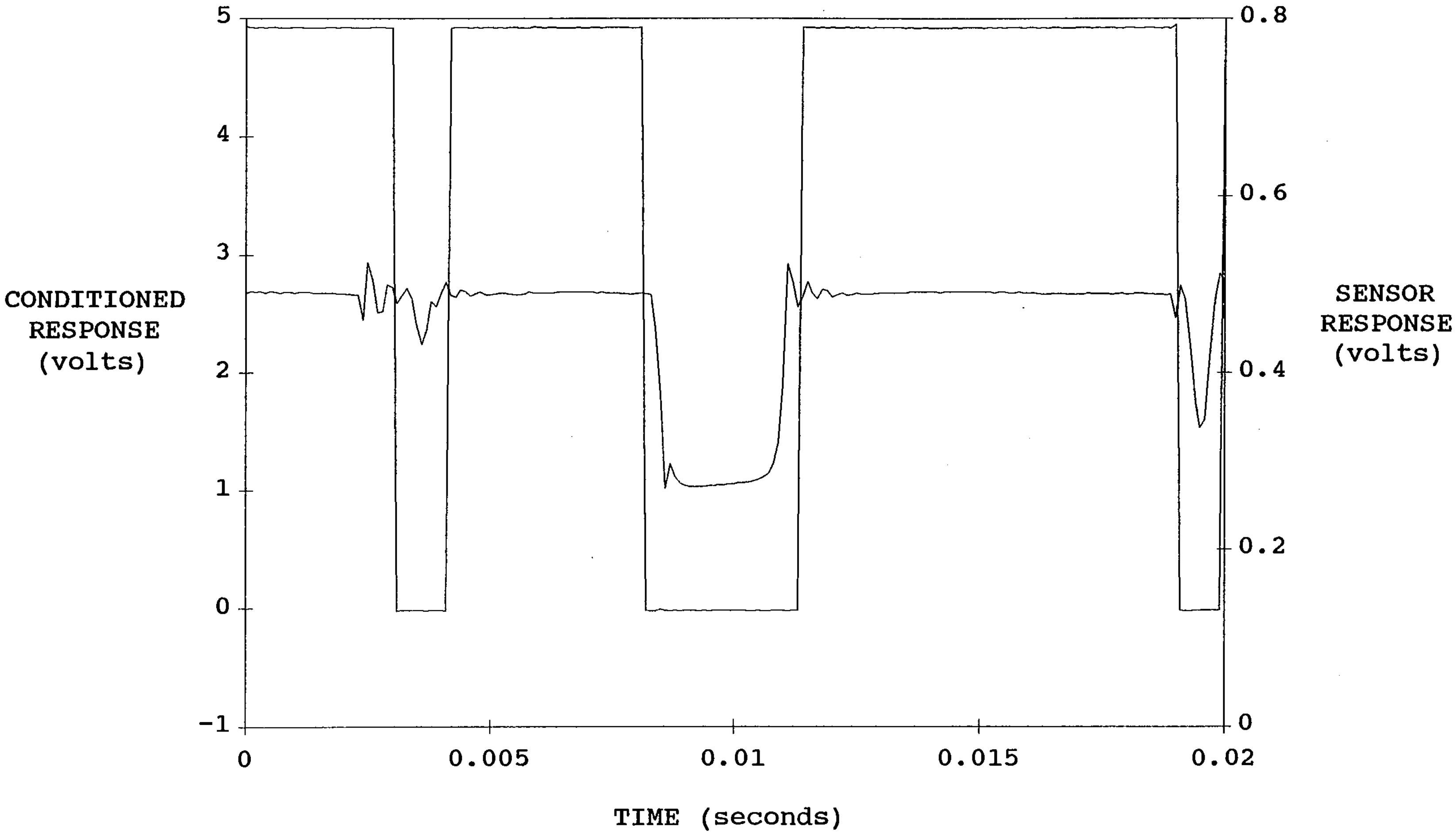

Figure 6.1. Sensor and Conditioned Responses for Simulated Crop at 3.55 km/h.

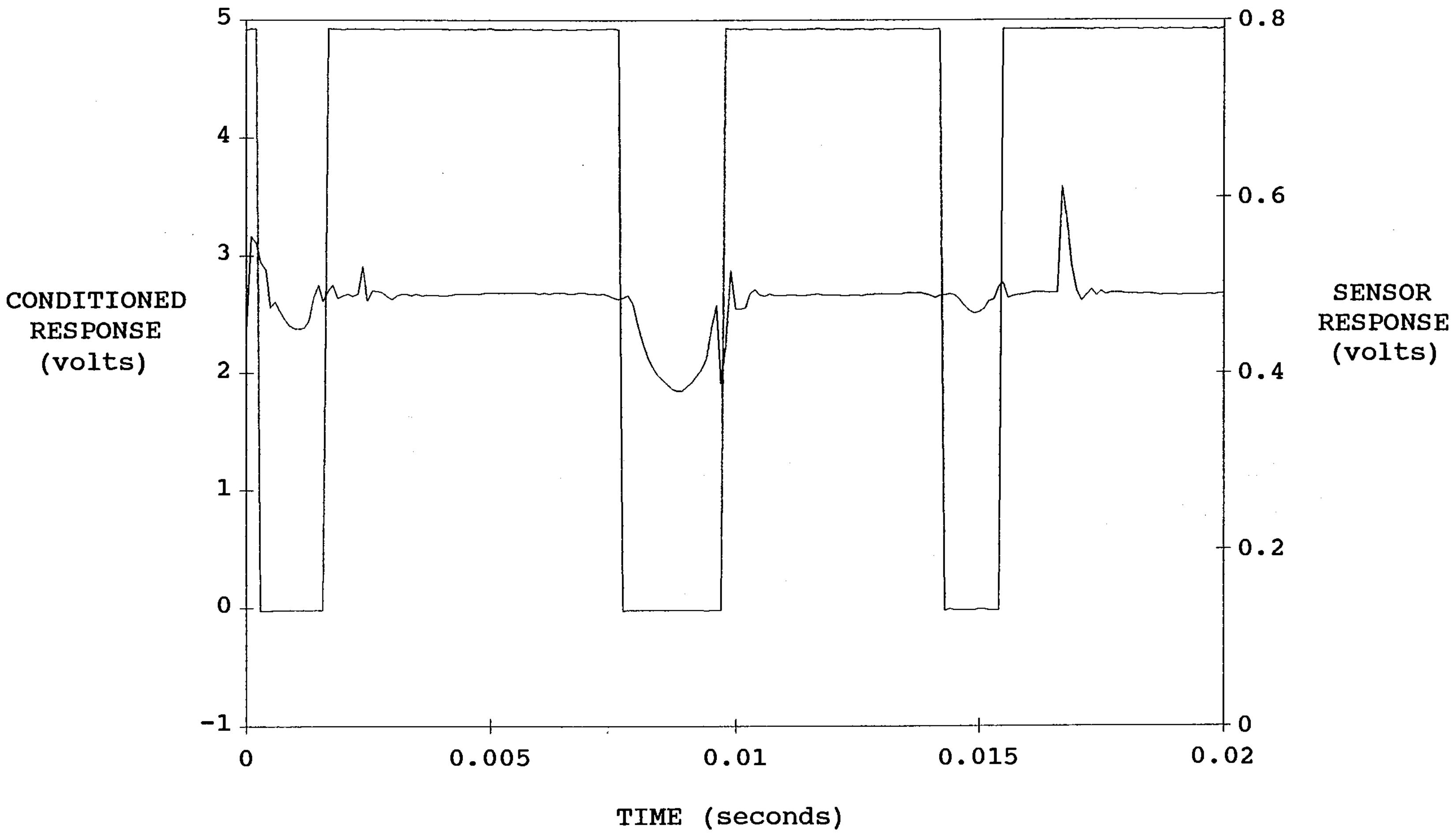

Figure 6.2. Sensor and Conditioned Responses for Simulated Crop at 5.96 km/h.

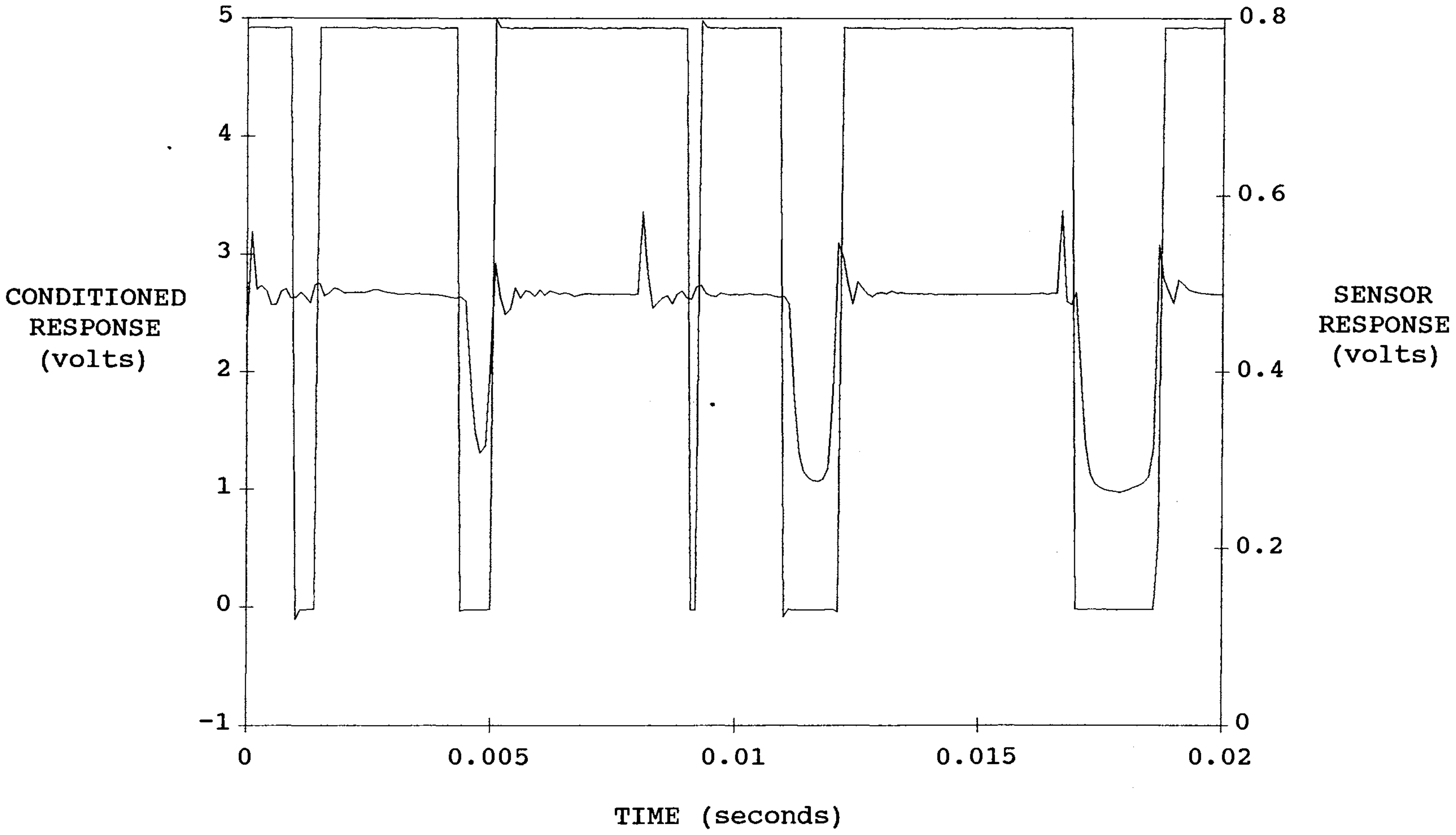

Figure 6.3. Sensor and Conditioned Responses for Simulated Crop at 7.54 km/h.

to 288 (total number of rows in a 0.91 meters wide for 3.175 mm stalk diameter) fits through the data as well as the regression line (Figure 5.8). The probability and detector reading scales are different. The probability scale was set at 80 percent of the detector reading scale because the detector was functioning in conditions where it should have been blocked during the laboratory tests and the probability curve approximated the regression curve at this point.

Any interference of leaves with the beam would tend to make the crop appear more dense than it actually is, thus forcing the detector reading onto the less sensitive portion of the probability curve. Leaves would block the beam as easily as a stalk, but would have much less impact on the density or weight per unit area of the crop.

While the readings were not at the maximum level (1.00), the detector's performance could be improved by reducing the spacing between the laser and sensor. This would reduce the occlusion of stalks and amount of leaves present, but would not eliminate either.

The ability of the detector to repeat accurate readings in the simulated crop was good. This was probably due to the fact that starting position was not a factor. The dowels were evenly spaced and samples were taken over the same pattern. For example, the dowels passed through the detector many times for one sample and since the density was the same the readings were averaged for each test. However, starting position could have caused a problem with field tests. The detector was started before it reached the crop and began taking readings on one half second intervals. There was no method for insuring that samples would begin exactly at the edge of the plot. The lower data points on the graphs (Figures 5.4 and 5.5) of field data were attributed to this problem. Samples also could have been skewed one way or the other based upon where they started. If samples were skewed very much it would cause the detector response to be plotted against an inappropriate crop density. In other words, the divisions of the stubble plot would not coincide with the detector readings recorded by the computer.

All tests conducted for this research were run with the planting rows parallel with the line of motion. The detector could have a problem if it were run perpendicular to the rows. The response would probably cycle from totally blocked to totally open. Height and row spacing would both have an impact on the degree of cycling. If the detector were run close to the ground, cycling of the response would be a greater problem. However, the further the detector is from the ground, the less impact cycling would have on the readings. This results from the plants tendency to spread out as in grows taller. The overall impact of cycling may also be reduced by lengthening the sample time. A longer sample time would allow the detector to compensate for cycling by averaging the reading over the sample period.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

In general the detector was effective under the laboratory conditions in which it was tested. The model of the system accurately estimates percentage of area blocked as a function of the detector reading and speed. Detector reading was a logarithmic function of crop density. The detector did not estimate crop density in the standing wheat stubble. While the data may show a trend, there is entirely too much scatter. The test plot may have been too wide, allowing some stalks to be hidden behind others. A narrower plot may reduce the amount of stalks that can be hidden as the detector passes.

Conclusions

The following conclusions were reached after carefully examining the data with respect to the objectives of this research:

(1) The laser based crop density detector using the simulated crop performed well. The detector successfully measured crop density (percentage of blocked area) over a range of crop densities and speeds that were estimated to be

similar to those encountered under actual harvest conditions.

(2) The detector output was not affected by the speed at which the simulated crop crossed the laser beam (i.e. ground speed).

(3) The crop density range of the detector was greater than the theoretical range. This was credited to reflection of the laser beam around the dowel. The data gathered in the crop density range greater than 1 were still accurate in the model of the system; therefore, the detector width (the distance between the laser and photo sensor) could be larger than anticipated by examining crop density.

(4) Reflection could create a problem if it were encountered in the field and was not predictable as in the simulated crop in the laboratory.

(5) The detector was not able to detect crop density of standing wheat stubble accurately. Poor performance may have been due to some stalks being hidden by others. Hidden stalks would show up when the sample was weighed, but would not be detected by the sensor.

(6) The statistical model for the system demonstrates the loss of sensitivity with the system at higher crop densities. This reinforces the logarithmic regression equations for describing crop density.

Recommendations

While the detector did not function well in the field, the laboratory tests are definately encouraging. Future field tests should be conducted with a narrower plot. Also the impact that leaves have on the readings and crop density should be quantified. The effects of dust and vibration should also be studied.

REFERENCES

Byg, D.M., and G.E. Hall. 1968. Corn Losses and Kernal Damage in Field Shelling of Corn. TRANSACTIONS of the ASAE 11(2):164-166.

Downs, H.W., M.L. Stone, K.A. Newton, and V.D. Swift. 1985. Strip Control of Volunteer Wheat and Other Weeds in Conservation Tillage. ASAE Paper No. 85-1518.

Hill, L.G., and G.E. Frehlich. 1985. Effects of Reducing MOG/G on Combine Performance. ASAE Paper No. 85-1577.

Huisman, W. 1983. Optimum cereal combine harvester operation by means of automatic machine and threshing speed control. Doctoral Thesis, Agricultural University, Wageningen.

Kruse, Jim, G.W. Krutz, and L.F. Huggins. 1982. Microprocessor Based Combine Ground Speed Controller. ASAE Paper No. 82-3040.

leFlufy, M.J., and G.T. Stone. 1983. Speed Control of a Combine Harvester to Maintain a Specific Level of Measured Threshing Grain Loss. J Agric Engng Res. (1983)28:537-543.

Mailander, Mike, and Gary Krutz. 1984. Development of a Dynamic Model of a Combine Harvester in Corn. ASAE Paper No. 84-1588.

McGechan, M.B., and C.A. Glasbey. 1982. The Benefits of Different Speed Control Systems for Combine Harvesters. J Agric Engng Res. (1982)27:537-552.

Newton, K.A., M.L. Stone, and H.W. Downs. 1986. Reducing Grain Losses of a Combine's Cleaning Unit by an Expert System. ASAE Paper No. 86-1579.

Schueller, John K., Michael P. Mailander, and Gary W. Krutz. 1985. Combine Feedrate Sensors. TRANSACTIONS of the ASAE 27(1):2-4.

Taylor, Randal K., Marvin L. Stone, and H. Willard Downs. 1986. Laser Based Crop Density Detection. ASAE Paper No. 86-1619

APPENDIXES

APPENDIX A

CROP DENSITY AVERAGING PROGRAM

Basic Program

```
10 CLS
20 INPUT "Enter the number of samples";S
30 DEFDBL X
40 DIM X(50),WGT(50),SUM(50),A(50),DENSITY(50)
50 REM Data retrieval routine.
60 OPEN "crap.dat" FOR INPUT AS #1
70 WHILE NOT EOF(1)
80      I = I+1
90      INPUT #1,X(I),WGT(I)
100      XMAX=X(I)
110 WEND
120 CLOSE #1
130      INTERVAL=XMAX/S
140     X(0) = 0 : XINT = INTERVAL : K = 1
150     FOR J=1 TO I
160             AINT = 0
170             IF XINT <= X(J) THEN GOSUB 350
180             IF X(J)=X(J-1) THEN A(J)=0:GOTO 200
190             A(J) = WGT(J)*(X(J) - X(J-1))/6
200             SUM(K) = SUM(K) + A(J)
210     NEXT J
220 TOTAL=0
230 PRINT "type 'cont' to continue"
240 STOP
250 REM
260 REM Print results.
270 PRINT"Density in lbs/sq.ft."
280 FOR Z=1 TO K-1
290     DENSITY(Z)=SUM(Z)/(94.5833*INTERVAL)
300     PRINT DENSITY(Z)
310     TOTAL=TOTAL+DENSITY(Z)
320 NEXT Z
330 PRINT "total=";TOTAL*20/S
340 END
350 REM Subroutine to interpolate between data points.
360 WGTINT = WGT(J) - ((X(J)-XINT)*(WGT(J)-WGT(J-1))/(X(J)-
X(J-1)))
370 IF XINT=X(J-1) THEN AINT=0:GOTO 390
380 AINT = WGTINT*(XINT - X(J-1))/6
390 X(J-1) = XINT
```

```
400 SUM(K) = SUM(K) + AINT
410 PRINT SUM(K),AINT,XINT,WGTINT,J
420 XINT = INTERVAL + XINT
430 K = K + 1
440 RETURN
```

APPENDIX B

SIMULATED CROP DENSITY DATA

CROP DENSITY	DETECTOR READING	SPEED km/h
1.71887	0.97114	3.22
1.71887	0.96973	3.22
1.71887	0.96811	3.22
1.71887	0.98225	3.22
1.71887	0.96694	3.22
1.43239	0.92165	3.22
1.43239	0.92217	3.22
1.43239	0.91759	3.22
1.43239	0.92403	3.22
1.43239	0.91901	3.22
1.22776	0.87514	3.22
1.22776	0.87592	3.22
1.22776	0.87509	3.22
1.22776	0.87953	3.22
1.22776	0.87153	3.22
1.07429	0.82723	3.22
1.07429	0.82488	3.22
1.07429	0.82283	3.22
1.07429	0.82040	3.22
1.07429	0.81816	3.22
0.95493	0.76200	3.22
0.95493	0.76616	3.22
0.95493	0.75931	3.22
0.95493	0.76840	3.22
0.95493	0.75922	3.22
0.85943	0.69343	3.22
0.85943	0.67915	3.22
0.85943	0.67858	3.22
0.85943	0.68094	3.22
0.85943	0.67209	3.22
1.43239	0.92825	4.83
1.43239	0.94779	4.83
1.43239	0.93412	4.83
1.43239	0.92611	4.83
1.43239	0.93228	4.83
1.22776	0.86426	4.83
1.22776	0.86426	4.83
1.22776	0.86235	4.83

1.22776	0.86222	4.83
1.22776	0.86221	4.83
1.07429	0.82225	4.83
1.07429	0.82167	4.83
1.07429	0.81980	4.83
1.07429	0.81874	4.83
1.07429	0.81776	4.83
0.95493	0.77251	4.83
0.95493	0.76546	4.83
0.95493	0.76734	4.83
0.95493	0.76804	4.83
0.95493	0.76482	4.83
0.85943	0.68626	4.83
0.85943	0.68315	4.83
0.85943	0.68224	4.83
0.85943	0.68225	4.83
0.85943	0.68239	4.83
0.78130	0.63592	4.83
0.78130	0.63265	4.83
0.78130	0.63089	4.83
0.78130	0.62666	4.83
0.78130	0.63761	4.83
1.07429	0.81019	6.44
1.07429	0.80688	6.44
1.07429	0.80882	6.44
1.07429	0.80609	6.44
1.07429	0.80409	6.44
0.95493	0.77112	6.44
0.95493	0.77258	6.44
0.95493	0.76649	6.44
0.95493	0.77604	6.44
0.95493	0.77994	6.44
0.85943	0.67538	6.44
0.85943	0.67568	6.44
0.85943	0.67703	6.44
0.85943	0.67785	6.44
0.85943	0.67628	6.44
0.78130	0.63828	6.44
0.78130	0.63545	6.44
0.78130	0.62419	6.44
0.78130	0.62791	6.44
0.78130	0.62837	6.44
0.71620	0.59719	6.44
0.71620	0.59480	6.44
0.71620	0.59242	6.44
0.71620	0.59698	6.44
0.71620	0.59854	6.44
0.66110	0.58052	6.44
0.66110	0.58265	6.44
0.66110	0.58180	6.44
0.66110	0.58165	6.44
0.66110	0.57873	6.44
0.95493	0.77805	8.05
0.95493	0.77614	8.05

0.95493	0.77186	8.05
0.95493	0.76854	8.05
0.95493	0.76636	8.05
0.85943	0.66744	8.05
0.85943	0.66573	8.05
0.85943	0.66497	8.05
0.85943	0.66777	8.05
0.85943	0.66183	8.05
0.78130	0.63496	8.05
0.78130	0.63184	8.05
0.78130	0.63525	8.05
0.78130	0.63143	8.05
0.78130	0.63311	8.05
0.71620	0.62594	8.05
0.71620	0.63171	8.05
0.71620	0.63128	8.05
0.71620	0.62919	8.05
0.71620	0.63033	8.05
0.66110	0.58230	8.05
0.66110	0.58115	8.05
0.66110	0.58021	8.05
0.66110	0.58000	8.05
0.66110	0.57995	8.05
0.61388	0.55416	8.05
0.61388	0.54406	8.05
0.61388	0.54050	8.05
0.61388	0.54568	8.05
0.61388	0.54446	8.05
0.78130	0.63060	9.66
0.78130	0.63487	9.66
0.78130	0.63314	9.66
0.78130	0.63734	9.66
0.78130	0.63380	9.66
0.71620	0.62766	9.66
0.71620	0.62354	9.66
0.71620	0.61938	9.66
0.71620	0.61609	9.66
0.71620	0.61581	9.66
0.66110	0.58368	9.66
0.66110	0.58214	9.66
0.66110	0.58191	9.66
0.66110	0.58168	9.66
0.66110	0.58416	9.66
0.61388	0.54813	9.66
0.61388	0.54912	9.66
0.61388	0.54685	9.66
0.61388	0.54823	9.66
0.61388	0.54874	9.66
0.57296	0.51865	9.66
0.57296	0.51489	9.66
0.57296	0.52228	9.66
0.57296	0.53143	9.66
0.57296	0.52404	9.66
0.53715	0.49765	9.66

0.53715	0.49663	9.66
0.53715	0.49144	9.66
0.53715	0.49243	9.66
0.53715	0.49729	9.66

APPENDIX C

FIELD CROP DENSITY DATA

3.14 km/h		4.39 km/h		5.49 km/h	
CROP DENSITY	DETECTOR READING	CROP DENSITY	DETECTOR READING	CROP DENSITY	DETECTOR READING
328.04	0.52014	318.29	0.03822	328.7	0.55198
353.34	0.8163	316.36	0.85114	324.07	0.799
260.14	0.5824	399.3	0.72616	436.73	0.97174
368.11	0.72308	408.95	0.84812	348.77	0.80564
441.03	0.90402	354.94	0.73208	297.84	0.725
401.79	0.75914	302.86	0.65178	271.6	0.69098
325.62	0.78326	304.78	0.7539	316.36	0.71806
317.07	0.71098	270.06	0.63766	265.43	0.09406
281.31	0.7771	291.28	0.84212	328.7	0.80334
314.37	0.71544	270.06	0.54052	324.07	0.74188
268.3	0.58846	318.29	0.83586	436.73	0.9137
336.03	0.7188	316.36	0.89104	348.77	0.80726
257.83	0.59092	399.3	0.91918	297.84	0.65178
260.03	0.62682	408.95	0.8236	271.6	0.75876
328.04	0.52644	354.94	0.76568	316.36	0.52416
353.34	0.80268	302.86	0.74146	265.43	0.47948
260.14	0.49684	304.78	0.88756	328.7	0.14654
368.11	0.81638	270.06	0.84716	324.07	0.74688
441.03	0.90916	291.28	0.6504	436.73	0.9354
401.79	0.70618	270.06	0.67284	348.77	0.79214
325.62	0.74746	318.29	0.34026	297.84	0.74512
317.07	0.6206	316.36	0.88704	271.6	0.68754
281.31	0.73934	399.31	0.77754	316.36	0.84812
314.37	0.75548	408.95	0.75352	265.43	0.6515

268.3	0.60902
336.03	0.71146
257.83	0.46962
260.03	0.55242
328.04	0.62296
353.34	0.73388
260.14	0.91958
368.11	0.7412
441.03	0.88568
401.79	0.7044
325.62	0.80016
317.07	0.6518
281.31	0.66806
314.37	0.717
268.3	0.81376
336.03	0.80512
257.83	0.60688
260.03	0.74204
328.04	0.72776
353.34	0.79118
260.14	0.85424
368.11	0.87186
441.03	0.74866
401.79	0.75292
325.62	0.6307
317.07	0.72542
281.31	0.71606
314.37	0.89954
268.3	0.85372
336.03	0.7768
257.83	0.71962
260.03	0.70315
354.94	0.82502
302.86	0.73882
304.78	0.6979
270.06	0.75516
291.28	0.723
270.06	0.62876
318.29	0.84844
316.36	0.95158
399.31	0.89924
408.95	0.90178
354.94	0.77418
302.86	0.76234
304.78	0.90266
270.06	0.75916
291.28	0.67974
270.06	0.7278
318.29	0.52304
316.36	0.93854
399.31	0.84222
408.95	0.90376
354.94	0.83196
302.86	0.82092
304.78	0.74042
270.06	0.8759
291.28	0.75682
270.06	0.76306
328.7	0.90126
324.07	0.81624
436.73	0.85066
348.77	0.8276
297.84	0.41312
271.6	0.29546
316.36	0.31408
265.43	0.07808
328.7	0.42154
324.07	0.78764
436.73	0.97214
348.77	0.8068
297.84	0.71138
271.6	0.57424
316.36	0.5653
265.43	0.08726

VITA^{1}

Randal K. Taylor

Candidate for the Degree of

Master of Science

Thesis: LASER BASED DENSITY DETECTION OF STANDING WHEAT STUBBLE

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Tahlequah, Oklahoma, November 22, 1961, the son of Wayne and Karen Taylor.

Education: Graduated from Tahlequah Senior High School, Tahlequah, Oklahoma in June, 1980; received Bachelor of Science Degree in Agricultural Engineering from Oklahoma State University in May 1985; completed requirements for the Master of Science Degree at Oklahoma State University in May, 1988.

Professional Experience: Extension Assistant, Department of Agricultural Engineering, Oklahoma State University, June, 1985, to present.