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STUDIES OF ELECTRONIC MOISTURE METER PERFORMANCE ON FRESHLY HARVESTED GRAINS IN KANSAS

by

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CHAPTER I

INTRODUCTION

The purpose of this research was to undertake a study of electronic moisture meters used at country elevators in Kansas with special attention paid to their performance in reporting moisture content of newly harvested wheat and grain sorghum. A survey would be used to identify the different brands of electronic moisture meters used at elevators in Kansas, their numbers and their approximate ages. Since moisture content plays an important part in determining the price offered or received for grain, it would benefit both buyer and seller to know that the machine used to determine moisture is as accurate as possible, or at the very least, be aware of its variability.

It should be noted that in a State that prides itself on being the nation's largest producer of wheat, there is no official body to oversee the calibration and accuracy of electronic moisture meters used at elevators that are not involved in interstate transport of grain. The vast majority of elevators in Kansas are the local or country type and as such, the electronic moisture meters used do not have to be inspected or licensed by the State. It is the individual elevator manager's responsibility to have the moisture meters serviced, checked for accuracy or recalibrated. Fortunately, the majority recognize the importance of this piece of equipment in the successful operation of a country elevator and thus most moisture meters are well taken care of and the majority are serviced on a regular basis.

Interest in the accuracy of electronic moisture meters increased dramatically after publication of a study conducted by C. R. Hurburgh

(1980) that indicated the meters used at country elevators in Iowa during the 1979 harvest were subject to wide variation in reported moisture content when compared to oven methods for freshly harvested corn. The work by Hurburgh and others resulted in the recalibration of all electronic moisture meters in Iowa and Illinois. Testing of the 1980 and 1981 corn crops showed that further recalibration and adjustment for crop variability was needed (Hurburgh et al., 1981 and Paulsen et al., 1982). Testing is continuing on a statewide scale in both Iowa and Illinois to make sure that electronic moisture meters used at country elevators in these States are as accurate and precise as they can be. This author does not advocate the total recalibration of electronic moisture meters used in the State of Kansas, but rather is attempting to bring to the attention of concerned individuals problems that may exist with these instruments. Future studies may be needed to bring about an increase of knowledge that will allow for correction or adjustment of the existing situation.

CHAPTER II

LITERATURE REVIEW

Moisture is perhaps the most important quality in terms of economic worth and storability when dealing with grain. If the grain trade is to function in an equitable manner, the amount of moisture in a lot of grain must be accurately determined and reported. Moisture has no nutritive value. The presence of moisture in excessive amounts displaces the amount of dry matter in a bushel of grain resulting in a reduction of the amount of usable material and moisture receives the same price as grain (Christensen et al., 1982). Competition in a free market sets the base price for a commodity such as grain, while the value of a finished product such as breakfast cereal is to some degree determined by the amount of raw material it takes to make. Breakfast cereal cannot be manufactured from moisture, so any excess moisture in a bushel of whole grain subtracts from the amount of finished product (Hill, 1982). The determination of the moisture content of grain should be of utmost importance and if all parties are to receive what they are entitled to, the accuracy of that determination should be very reliable.

In an ideal situation, it is standard procedure for country elevators to test all incoming grain for moisture content with an electronic moisture meter and to charge a dockage fee if the moisture content exceeds a predetermined level. The practice of blending grains of high and low moisture has enabled elevators to gain a distinct advantage in the market place. Elevators are entitled to do this, however, if the moisture meter they use is subject to error, inequity may result (Hill and Shove, 1982). The inequity may favor either seller or buyer and result in the gain or loss of money. It may also lead to unsound storage practices resulting in economic loss due to fungal or insect damage to grain that was stored too wet (Hukill, 1963 and Bailey, 1982).

The farmer, as grain seller has learned to live with the presence of the electronic moisture meter, but perhaps not to accept it for it is very common for a farmer to take a sample of his grain to several nearby elevators and deliver to the one whose meter reads to his advantage (Hunt, 1963 and Hurburgh, 1981). This practice can lead to tension and mistrust, especially when the moisture of the delivered grain tests higher than the original sample. This points up what may be a problem in the grain trade; the variability of electronic moisture meters and the variability of samples.

The primary reason electronic moisture meters were so long in gaining acceptance by official government agencies was that when tested against approved methods, they failed to show good reliability and reproducibility of results (U.S.D.A., 1963; Hlynka et al., 1949). The Canadian Board of Grain Commissioners accepted an electronic moisture meter for official use in 1959 and the U.S.D.A. followed in 1963 (Martens and Hlynka, 1965; U.S.D.A., 1963). Recent studies have indicated that electronic moisture meters, in use at country elevators in Iowa and Illinois, have exhibited unacceptable variations from actual moisture content, and that efforts to correct the situation have not been totally successful (Hurburgh, 1981; Paulsen et al., 1982; Hurburgh et al., 1981). To understand errors that might occur in making moisture determinations with electronic equipment, it may help to review the historical background of electronic moisture meter development.

Prior to 1916, the terms "tough," "damp" and "dirty" were used to describe grain lots in trade (Hurburgh, 1981). The procedure for arriving at one of these descriptions was physical, relying on the feel, odor and hardness of the grain (Martens et al., 1963). Quantitative measures were used by some grain trading companies, but the information so gained was not shared with others and was used to advantage in the market (Hurburgh, 1981). As production of grain increased, competition between grain traders increased. With the development of export markets, it became clear that to assure uniform quality of grain, a standardized quality system was needed, whereby, all grain of a specific rank would be of equal quality. In 1916, the United States Grades and Standards for grain were established by an act of Congress (Hurburgh, 1981). Under this system grain in trade was described in specific terms. Numerical classifications or grades were developed based upon limits with respect to moisture content, test weight, broken kernel, foreign material and damaged kernels (heat damaged, total damage). The grades that were established in 1916 have, with some modification, survived to the present almost in defiance of modern commerce, processing and production (Hurburgh, 1981). There is some evidence to suggest that the U.S. Grades and Standards were based not on scientific research, but trade practices of the time (Hoffman, 1976). If this is the case, perhaps they need to be revised, but as so often is the case in traditions, they are hard to change even if wrong or outdated. Surveys have shown that farmers do not like the grading system, yet balk at the idea of changing (Hill and Rehtmeyer, 1982).

The advent of modern harvesting techniques allows corn to be harvested at high moisture content. Under the present grading system, farmers are at a disadvantage in the market place when they harvest at high moisture levels. If they sell corn without drying it, they are subject to price discounts to adjust for less dry matter content. If grain is to be bought and sold in bushels, some authors feel that it is time to devise a marketing system that would work on a standard dry weight bushel with moisture content used only to adjust for weight. A bushel would be described as a set dry weight regardless of moisture content (Hill, 1982).

The creation of the U.S. Grades meant that grain now had to be tested at official inspection points in order for a grade to be assigned. This was not difficult for test weight, B.C.F.M. or damage. Moisture content determination was difficult and time consuming. The most common way to determine moisture content is to place weighed samples into an oven and heat until all moisture is driven off. This method is fine for inorganic materials, but with organics such as grain, other volitiles in addition to moisture may be removed. There are a number of procedures describing how to determine oven moisture, but all are different with regard to temperature and time. Ovens will vary in heat distribution so different results may be obtained for the same sample at different locations within an oven and between different ovens (Hurburgh, 1981). In response to this difficulty, official agencies in Canada and the U.S. adopted the Brown-Duvel method of moisture determination in 1912 and 1916 respectively and it was the approved method until 1959 in Canada and 1962 in the U.S. (Martens and Hlynka, 1965; Hurburgh, 1981). The Brown-Duvel method of moisture determination, developed in 1907, involves the heating of a portion of grain in oil at a high temperature. Water distilled from the sample is collected in a graduated cylinder and reported as moisture (Martens and Hlynka, 1965). It was not a method that could be used at country elevators very successfully. This meant that although there was official grading and moisture determination at the interstate level of trade, the country elevator was still basically using traditional means of determining (ranking) grain quality. If the country elevator was going to operate effectively within the grain trade under the new grading system, a means had to be found that would allow rapid moisture content determination.

The possibility of using the electrical property of resistance to determine moisture content was first demonstrated in 1908. The machine worked by measuring the resistance of wheat to the flow of an electric current. This measurement gave linear relationship between the moisture content of wheat and the logarithm of its resistance for the moisture range of 11-16%. In 1909, a similar machine was built that worked on the same principle for corn (Hunt and Pixton, 1974). These machines did not receive widespread publicity or use, but served in stimulating futher research in the use of electrical properties of grain for determining moisture content.

By the mid-1930's there were a variety of machines that were available which employed the electrical properties of grain to test for moisture content. The two most common methods of detecting moisture by electrical means were measuring the conductance or capacitance of the grain (Hlynka, 1949).

All electronic moisture meters that use conductance to measure moisture content operate under the same principle as the machine built in 1908. The grain was pressed between two electrodes connected in series and conductance was measured as resistance when an electrical current was passed between the electrodes (U.S.D.A., 1963; Hunt and Pixton, 1974). These meters offered a rapid way to determine moisture and they received very thorough study. The Tag-Heppenstall Mfg.[R] manufactured by the C. J. Tagliabue Company was one of the most successful of the conductance meters. It operated by compressing a portion of grain, either weighed or unweighed,through two corrugated steel rolls that served as the electrodes, one kernel at a time. A galvanometer was used to indicate current flow and a chart was then used to convert the reading into a percent moisture content. The rolls could be hand operated or motor driven, with the motor driven machine giving a moisture determination in 10-20 seconds. The meter was fairly easy to operate and maintain. The one critical aspect of its operation was maintaining an exact distance between the rolls. This meter was accurate enough that beginning in 1934 it was used at official testing stations in Canada to give a preliminary indication of moisture content. The U.S.D.A. also allowed it to be used in a preliminary test of moisture content. It was not used in an official capacity in either the U.S. or Canada and by 1949 other meters had replaced it (Hlynka et al., 1949; Hurburgh, 1981; Zeleny, 1960). The Tag-Heppenstall Mfg.[R] meter was an improvement in terms of time when compared to the Brown-Duvel method, but it was not as accurate and it was subject to other problems. It was possible to calibrate this meter to read moisture contents from 10-24%, however, it was most reliable at moisture contents of 11-16% where its standard error when compared against a vacuum oven was ±.23% (Hlynka et al., 1949).

All meters that work by using conductance, including the Tag-Heppenstall Mfg.[R] are subject to errors when reporting moisture content because they use electrical properties of grain which are functions of moisture contents, but they are functions of other properties and conditions as well (Hlynka et al., 1949). The accuracy of a conductance meter is dependent upon the even distribution of moisture in the kernels tested (Zeleny, 1960). When there is an uneven distribution of moisture, as is the case with freshly harvested, recently wetted, or rapidly dried grain, the conductance meter yields inaccurate and unreliable moisture determinations. This is thought to be caused by conductance meters reading surface moisture on the grain kernel. At moisture contents below 7% there is not enough moisture to carry the current and at 23% there is too much (Hlynka et al., 1949; Matthew, 1963; Zeleny, 1960). Because of this, the conductance meter was of little use to country elevators where most all grain received is freshly harvested and may have been subjected to wetting by rain or dew.

Moisture meters that use capacitance as a means of determining moisture content rely on the dielectric properties of grain which are closely related to moisture content (Nelson and Stetson, 1980). These meters work by using the capacity of a condenser in which grain is the dielectric material and measuring the change in capacitance as impedance changes. The dielectric properties of a grain change with changing moisture content allowing a relationship between moisture content, capacitance and impedance to be developed. Impedance decreases as moisture content increases (Zeleny, 1960; Hunt and Pixton, 1974; Nelson and Stetson, 1980). This type of meter has been available for about 50 years. During that span of time various models have been regularly tested to prove accuracy and reliability. One such test was conducted in Canada in 1949. Results showed that one model of meter demonstrated promise with regard to being accepted by the government (Hlynka et al., 1949). In 1959, the Canadian Board of Grain Commissioners approved a capacitance meter for use in official moisture content determinations (Martens and Hlynka, 1965). The U.S.D.A. followed this lead in 1963 by approving the use of a similar meter at all federal grain inspection sites (U.S.D.A., 1963). Today the electronic moisture meters that are used at country elevators are predominately of the capacitance (dielectric) type.

Capacitance meters have several advantages over conductance meters. They are much less subject to errors from uneven moisture distribution within or among kernels. Also greater range of moisture can be measured by the capacitance system (Zeleny, 1960; Hunt and Pixton, 1974).

There are disadvantages to using a capacitance type meter. Grain sample temperature will affect dielectric properties. The use of a temperature correction factor will adjust for this. Bulk density of grain also affects dielectric properties so capacitance meters use preweighed samples. Evidence in the literature suggests that kernel damage incurred during harvesting and genetic variety of grain will also affect dielectric properties. The greatest disadvantage of capacitance meters is their inability to accurately measure moisture levels above 20%. This is most noticeable in corn at moisture levels in excess of 23-25%. This problem can be partially overcome by using a two part calibration curve. Conductance type meters require a good maintenance program and need to be checked for calibration errors frequently to assure reliable moisture determination (Zeleny, 1960; Hunt and Pixton, 1974; Hurburgh, 1981; Christensen et al., 1982).

Recent studies have shown that electronic moisture meters exhibit errors when determining moisture content of corn. The errors can be traced to calibration bias or random variability within the crop. Errors of any kind cannot and should not be tolerated, but errors that display bias cause the most harm since they will create non-random inequities. Bias errors are always in one direction, causing the meter to read consistently high or low, while random errors can be in either direction. Bias errors are easy to correct by mathematical manipulation of the calibration curve (Hurburgh, 1981). Studies in Iowa and Illinois during the 1979, 1980 and 1981 crop years show that electronic moisture meters used at country elevators were not giving accurate or reliable results. Calibration changes were enacted and results suggest that the problem has diminished, but is not solved. Year to year variability of the dielectric properties of grain may be the major contributor to the problem. Variability within a crop for any year may be the result of regional differences of soil composition and/or weather. Genetic differences between varieties also appear to contribute to variability (Hurburgh, 1981; Paulsen et al., 1982). Meters calibrated to Iowa and Illinois standards do not give good results when testing corn from Kansas (Hurburgh and Sauerwein, 1982). The literature suggests that damage to grain kernels from improper combine settings will cause meters to read low when compared to air-oven determinations (Hemeda et al., 1982). Further testing is needed, but the possibility exists that electrical properties of grain are not uniform enough to allow accurate calibration on a national or even statewide basis. This would increase the difficulty of obtaining accurate moisture determinations. This problem may have its origin in the manner in which meters are calibrated. Normally good quality, clean samples of grain are used in this process and grain that comes from the field during harvest will not display the same electrical properties (Christensen et al., 1982).

LITERATURE CITED

ASAE. 1980. Moisture Measurement - Grains and Seeds. Agricultural Engineers Yearbook. Am. Soc. Agric. Eng. St. Joseph, MI.

Bailey, J. E. 1982. Whole Grain Storage. In Storage of Cereal Grains and Their Products. Third Edition. AACC. St. Paul, MN. page 90.

Christensen, Clyde M., Byron S. Miller and John A. Johnston. 1982. Moisture and Its Measurement. In Storage of Cereal Grains and Their Products. Third Edition. AACC. St. Paul, MN. page 37.

Hemeda, Medhat A., Charles R. Hurburgh and Carl J. Bern. 1982. Effects of Corn Variety, Mechanical Damage and Drying Temperature On Electronic Moisture Meters. Proceedings ASAE Winter Meeting. ASAE. St. Joseph, MI.

Hill, Lowell D. 1982. Price and Value Relationships for High Moisture Grain. In Evaluation of the Issues in Grain Grades and Optimum Moistures. Dept. Agric. Econ., Agric. Exp. Sta., College of Agriculture, University of Illinois at Urbana-Champaign. page 3.

Hill, Lowell D. and Gene Shove. 1982. What are the Farmers Alternatives. In Evaluation of the Issues in Grain Grades and Optimum Moistures. Dept. Agric. Econ., Agric. Exp. Sta., College of Agriculture, University of Urbana-Champaign. pages 19-24.

Hill, Lowell D. and Clint Rehtmeyer. 1982. Farmer's Attitudes Towards Changing the Grade Standards for Corn. In Evaluation of the Issues in Grain Grades and Optimum Moistures. Dept. Agric. Econ., Agric. Exp. Sta., College of Agriculture, University of Urbana-Champaign. pages 31-36.

Hlynka, I., V. Martens and J. A. Anderson. 1949. A Comparative Study of Ten Electrical Meters for Determining Moisture Content of Wheat. Can. J. Res. Vol. 27:382.

Hoffman, K. J. and L. D. Hill. 1976. Historical Review of the U.S. Grades and Standards for Grain. Ill. Ag. Econ. 16(1):1-9.

Hukill, W. V. 1965. Moisture in Grain. In Humidity and Moisture Measurements and Control in Science and Industry. Vol. 2. Van Nostrand. New York, NY. pages 116-122.

Hunt, W. Haward. 1963. Problems Associated with Moisture Determination in Grain and Related Crops. In Humidity and Moisture Measurement and Control in Science and Industry. Vol. 2. Van Nostrand. New York, NY. pages 123-125.

Hunt, W. Haward and S. W. Pixton. 1974. Moisture - Its Significance, Behavior and Measurement. In Storage of Cereal Grains and Their Products. Second Edition. AACC. St. Paul, MN. pages 1-55.

Hurburgh, Charles R. 1981. Improving Moisture Measurement in the Corn Market. Ph.D. Thesis. Iowa State University, Ames, IA.

Hurburgh, Charles R., C. J. Bern and S. N. Grama. 1981. Improvements in the Accuracy of Corn Moisture Measurement in Iowa. Proceedings ASAE Winter Meeting. ASAE. St. Joseph, MI.

Hurburgh, Charles R. and Charles Sauerwein. 1982. Measuring the Moisture Content of Western Kansas Corn. Summary Report. ASAE. St. Joseph, MN.

Martens, V. and I. Hlynka. 1963. Determination of Moisture in Canadian Grain by Electric Moisture Meter. In Moisture Measurement and Control in Science and Industry. Vol. 4. Van Nostrand. New York, NY.

Matthews, J. 1963. The Design of an Electrical Capacitance - type Moisture Meter for Agricultural Use. Journal of Agricultural Engineering Research. Vol. 8. pages 17-29.

Nelson, S. O. 1977. Use of Electrical Properties for Grain - Moisture Measurement. Journal of Microwave Power. 12(1):68.

Nelson, S. O. and LaVerne E. Stetson. 1980. Electrical Properties: Factors in Grain Moisture Measurement. Quarterly Farm Ranch and Home. Inst. of Ag. and Natural Resources. University of Nebraska.

Paulsen, M. R., L. D. Hill, B. L. Dixon. 1982. Moisture Meter-To-Oven Comparisons for Corn. 1982 Grain Conditioning Conference Proceedings. University of Illinois at Urbana-Champaign. pages 2-11.

U.S.D.A 1963. Comparisons of Various Moisture Meters with the Oven Method in Determining Moisture Content of Grain Agricultural Marketing Service. Grain Division.

Zeleny, Lawrence. 1960. Moisture Measurement in the Grain Industry. Cereal Science Today. Vol. 5. No. 5:130.

CHAPTER III

PROCEDURES AND METHODS

Introduction

One accepted method for determining the accuracy of an electronic moisture meter is to run a series of determinations using a grain sample of a known moisture content and comparing the results of the determinations with the known moisture. Another is to introduce a series of samples of unknown moisture content into the moisture meter and record the results of the determinations. Each sample that is tested is coded and kept stable until laboratory air-oven testing can be conducted. Results obtained when the samples are oven dried are compared with the results given by the respective moisture meters. The seond method was employed for this study since it seemed to present the fewest number of problems.

Regardless of technique used, contact must be made with contributing elevators to solicit their cooperation and assistance. To accomplish this, a letter of introduction and explanation was mailed several months in advance of the anticipated visit for sample collection. In addition to the letter, a returnable card was included which if received would indicate willingness to participate in the study by that elevator. Elevators which did not return the card were assumed to be uninterested in participating in the study and their privacy was honored.

Determination of Sampling Locations - Wheat

In order to establish a base from which to work a questionnaire and letter of explanation was sent to 292 country elevators in the State of Kansas (Appendix A). The letter was a means of introduction and briefly described the type of study that was under consideration, how the study would be conducted, and why it would be of importance to the grain trade in Kansas. The accompanying questionnaire was designed to supply the following basic information: type of electronic moisture meter used, approximate age of the meter, last service date, if known, and whether or not the performance of the meter was acceptable. A postcard form was used for the questionnaire which was preaddressed and stamped. Criteria used for selecting the elevators were: a bulk storage capacity of at least 100,000 bushels and membership in the Kansas Grain and Feed Dealers Association (K.G.F.D.A.). It was hoped membership in the K.G.F.D.A. would perhaps make the elevators more cooperative and that a lower limit of 100,000 bushels bulk storage would generate a workable number of elevators.

A total of 153 positive responses were received out of the 292 questionnaires sent. This was a return rate of 52.3% which was much greater than anticipated. The 153 responses represented 76 of 105 counties in Kansas and 71.4% of the State by area. Figures 1 through 4 are used to give the reader a visual reference of counties participating in the study. Figure 1 shows the counties that had at least one elevator responding. Table 1 is an alphabetical listing of responding and nonresponding counties.

Prior to the start of the 1982 wheat harvest, it was thought that all responding elevators would be visited for sample collection. As the

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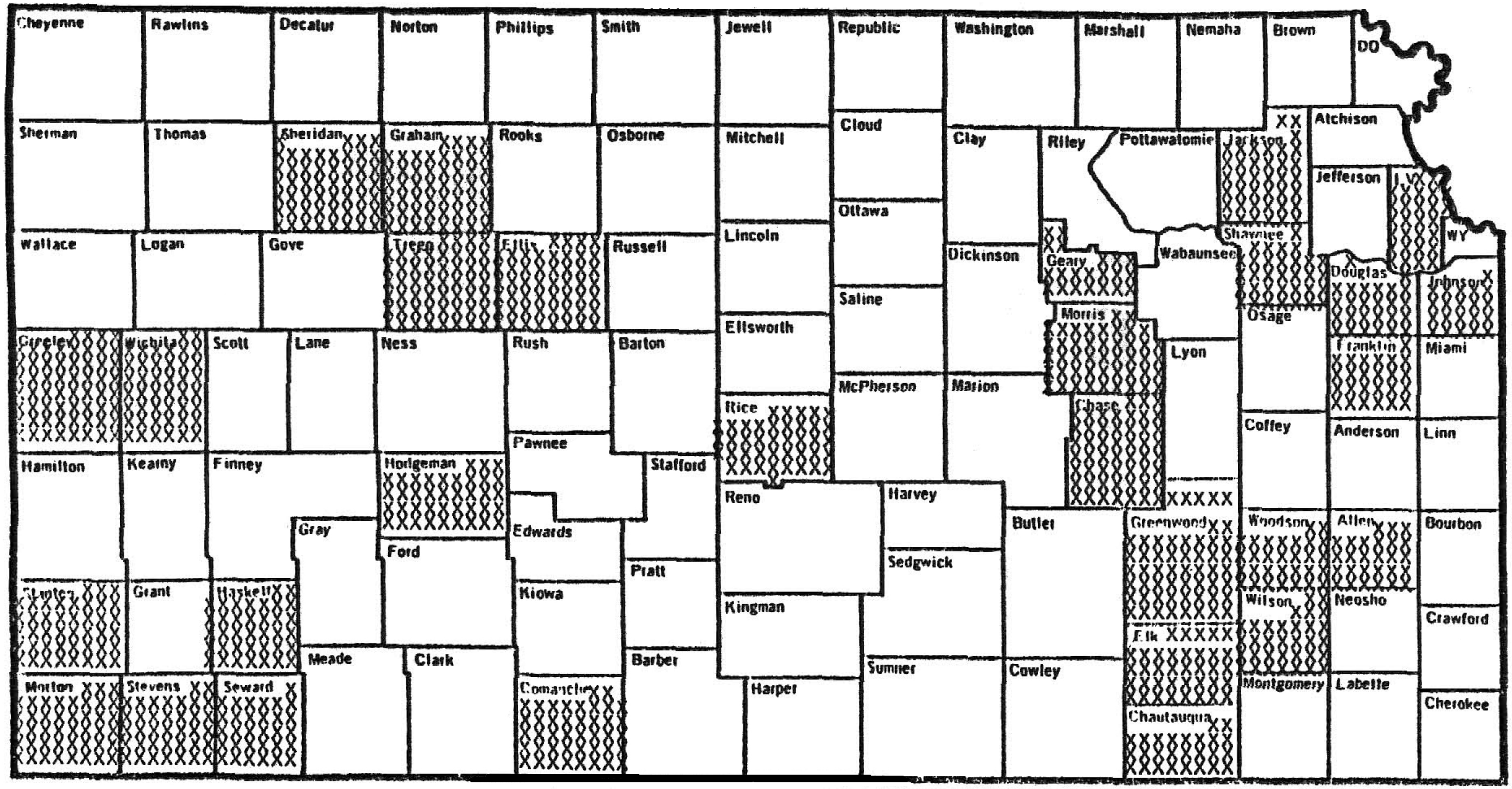


Figure 1. Responce to Written Survey

Counties having at least one elevator responding in the positive

Counties which had no responding elevators

Table 1. RESPONSE TO WRITTEN SURVEY

Positive (County)		Negative (County)
1. Anderson	41. Meade	1. Allen
2. Atchison	42. Miami	2. Chase
3. Barber	43. Mitchell	3. Chautauqua
4. Barton	44. Montgomery	4. Comanche
5. Brown	45. Morris	5. Douglas
6. Butler	46. Nemaha	6. Ellis
7. Cherokee	47. Neosho	7. Elk
8. Cheyenne	48. Ness	8. Franklin
9. Clark	49. Norton	9. Geary
10. Clay	50. Osage	10. Graham
11. Cloud	51. Osborne	11. Greeley
12. Coffey	52. Ottawa	12. Greenwood
13. Cowley	53. Pawnee	13. Haskell
14. Crawford	54. Phillips	14. Hodgeman
15. Decatur	55. Pottawatomie	15. Jackson
16. Dickinson	56. Pratt	16. Johnson
17. Doniphan	57. Rawlins	17. Kearny
18. Edwards	58. Reno	18. Leavenworth
19. Ellsworth	59. Republic	19. Morris
20. Finney	60. Riley	20. Morton
21. Ford	61. Rooks	21. Rice
22. Gove	62. Rush	22. Seward
23. Grant	63. Russell	23. Shawnee
24. Gray	64. Saline	24. Sheridan
25. Hamilton	65. Scott	25. Stanton
26. Harper	66. Sedgwick	26. Stevens
27. Harvey	67. Sherman	27. Trego
28. Jefferson	68. Smith	28. Wichita
29. Jewell	69. Stafford	29. Wilson
30. Kingman	70. Sumner	30. Woodson
31. Kiowa	71. Thomas	
32. Labetts	72. Wabaunsee	
33. Lane	73. Wallace	
34. Lincoln	74. Washington	
35. Linn	75. Wyandotte	
36. Logan		
37. Lyon		
38. Marion		
39. Marshall		
40. McPherson		

harvest got underway, weather conditions developed that did not allow normal progress. As a result of the delays, due to weather, a change in collection procedure was necessary. It was decided that as many elevators in a given area would be visited as time or weather permitted. Every effort was made to insure that most large wheat producing areas of the State were visited. This resulted in a reduction in the total number of samples collected, but allowed sample collection in representative wheat producing areas of the State. Figure 2 shows the counties from which wheat samples were collected. Table 2 alphabetically lists the counties and the number of elevators visited in each. Of 76 responding counties, samples were collected in 28. Of 152 elevators, samples were collected at 50. Comparing the counties visited, (figure 2), to wheat production by county, (figure 3), it can be seen that most areas of high production were visited if a responding elevator was present.

Grain Sorghum

To investigate the possibility of grain type affecting the performance of electronic moisture meters, grain sorghum samples were collected during the 1982 Fall harvest in Kansas. In an effort to compare electronic moisture meter performance on grain sorghum to wheat, the majority of the grain sorghum samples came from elevators where wheat samples had been collected. Because grain sorghum production is less than wheat production, some elevators that supplied wheat samples did not supply grain sorghum samples. Some of the counties with the highest grain sorghum production did not have elevators that responded to the questionnaire and thus were not included. The combination of these factors limited the size of the sampling population. Grain sorghum samples were collected in 17 of the

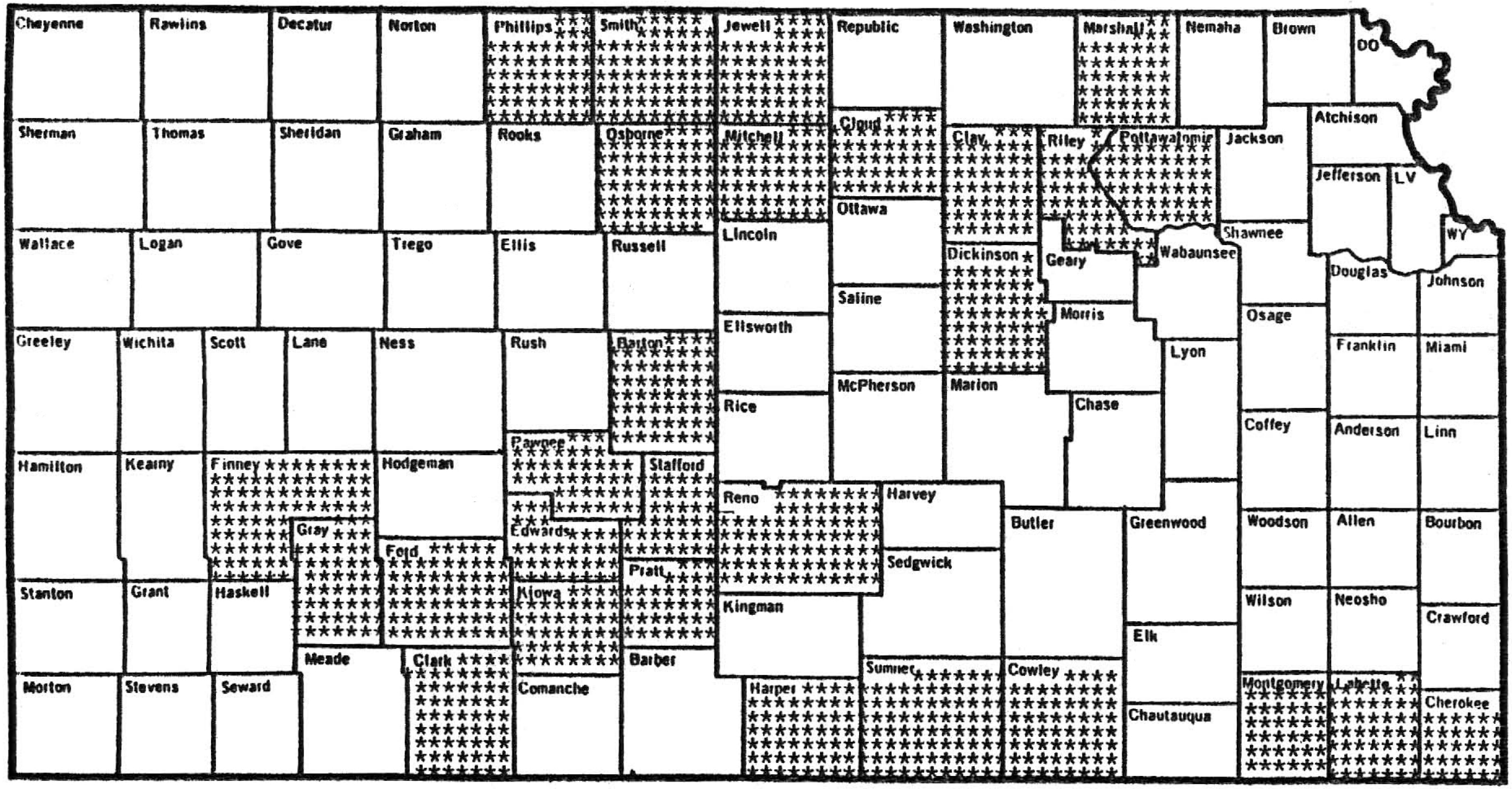
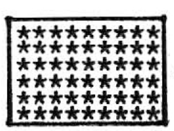
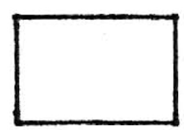


Figure 2. Wheat Harvest Sample Collection



— Counties having at least one elevator from which wheat was collected



— Counties where no samples were collected

Table 2. COUNTIES WHERE SAMPLES COLLECTED (WHEAT)

County	Number of Elevators
1. Barton	1
2. Cherokee	1
3. Clark	1
4. Clay	3
5. Cloud	1
6. Cowley	1
7. Dickinson	2
8. Edwards	3
9. Finney	3
10. Ford	1
11. Gray	2
12. Harper	4
13. Jewell	1
14. Kiowa	2
15. Labette	2
16. Marshall	1
17. Mitchell	1
18. Montgomery	1
19. Osborne	1
20. Pawnee	2
21. Phillips	1
22. Pottawatomie	2
23. Pratt	1
24. Reno	1
25. Riley	3
26. Smith	3
27. Stafford	2
28. Sumner	3
TOTAL	50

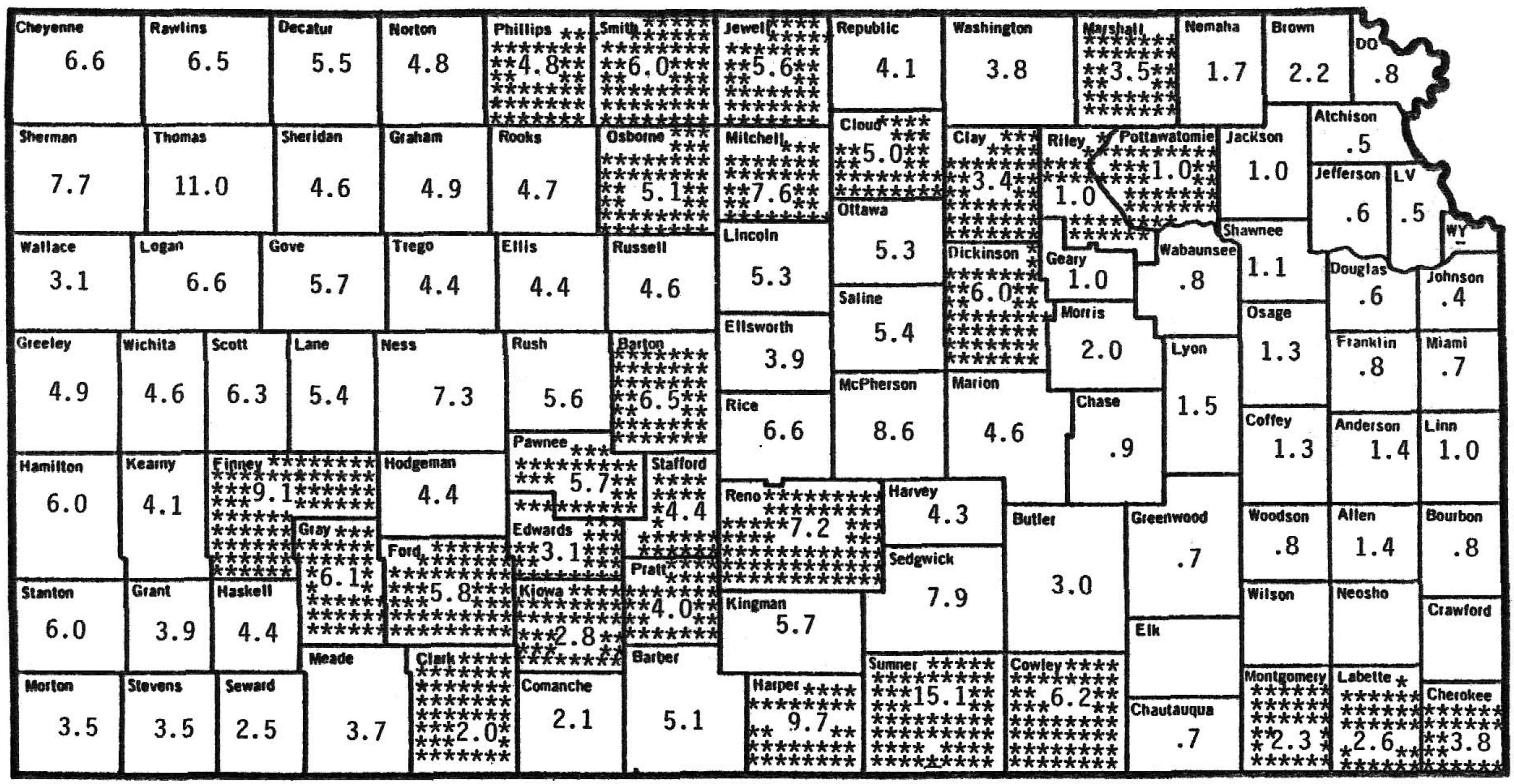


Figure 3. Wheat Production,1981
(millions of bushels)

[ ] ....Counties not visited(1982)   [***5.4***] ....Counties visited(1982)

28 counties that supplied wheat samples. A total of 26 elevators were visited for sample collection with 24 of these also contributing wheat samples. Figure 4 shows the counties from which grain sorghum samples were collected and table 4 is an alphabetical listing of these counties showing the number of elevators visited in each.

Sample Collection and Preservation

The method of sample collection was the same for both the wheat and grain sorghum. Upon arrival at a participating elevator, a data sheet was prepared that identified the elevator by a code number, the type of electronic moisture meter used, the approximate age of the meter, if known, and the last service date, if known.

As arriving grain was tested for moisture, a sample was placed in the electronic moisture meter and the measured moisture content was recorded on the data sheet. The sample was removed from the meter and placed in a numbered, air-tight polyethylene container and the moisture was recorded on it. This process was repeated to a total of 10 samples at the location. The 10 samples were placed in a large styrofoam ice chest containing dry ice that maintained an average temperature of less than OC. The air-tight polyethylene containers in combination with the cold storage were employed to safeguard the integrity of the sample during the collection and transportation process. Enough cold storage was provided so that a total of 160 samples could be accommodated. This represented 16 elevators. Normally, a total of three days was involved in the collection of this number of samples and then transportation back to the laboratory. The samples were transferred from the ice chests to a walkin freezer where they were stored until analysis.

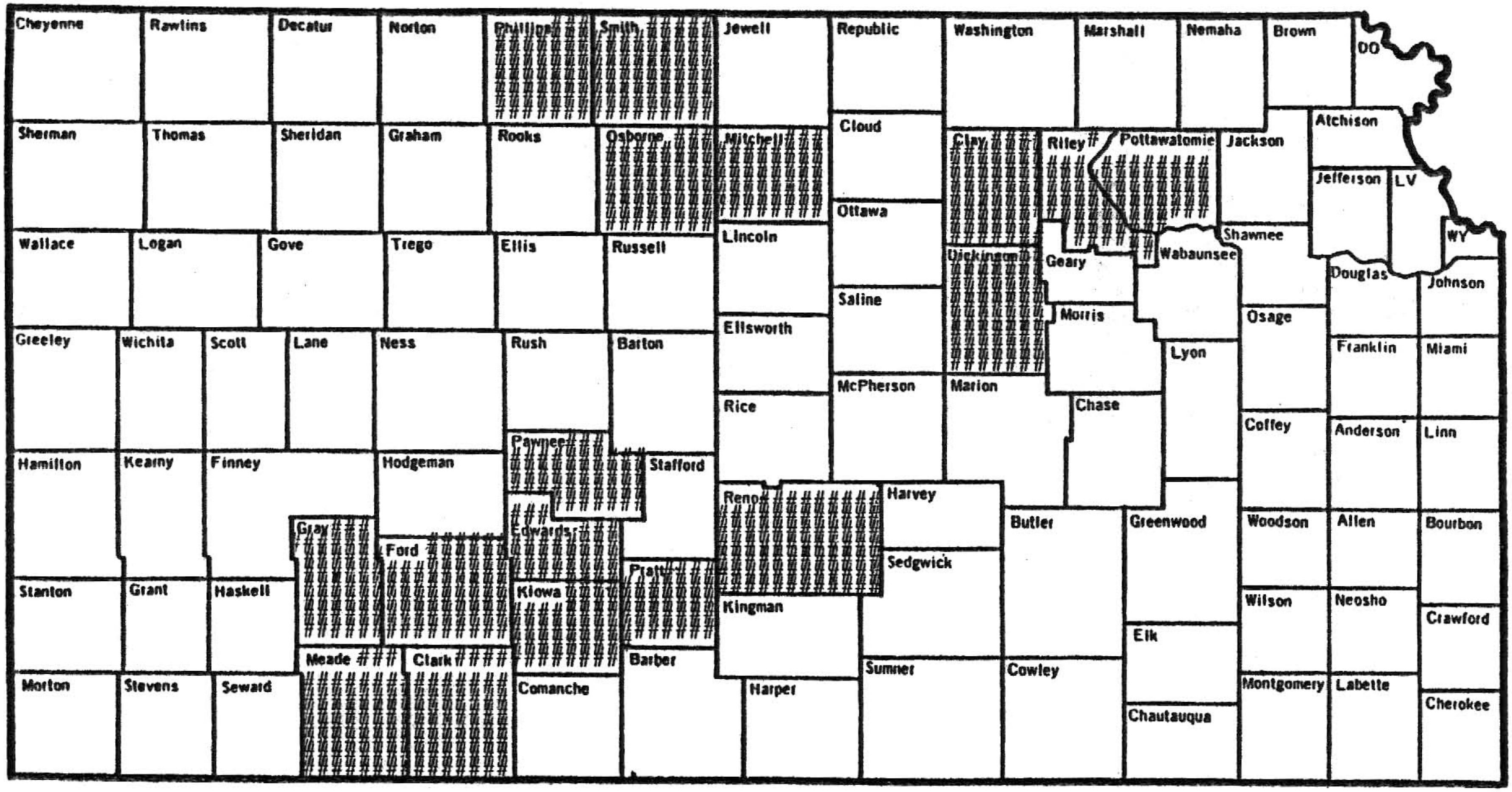


Figure 4. Grain Sorghum Harvest Sample Collection

— Counties having at least one elevator from which grain sorghum was collected

— Counties where no samples were collected

Table 3. COUNTIES WHERE SAMPLES COLLECTED (GRAIN SORGHUM)

	County	Number of Elevators
1.	Clark	1
2.	Clay	2
3.	Dickinson	1
4.	Edwards	3
5.	Ford	1
6.	Gray	2
7.	Kiowa	2
8.	Marshall	1
9.	Meade	1
10.	Osborne	1
11.	Pawnee	2
12.	Phillips	2
13.	Pottawatomie	2
14.	Pratt	1
15.	Reno	1
16.	Riley	1
17.	Smith	3
	TOTAL	27

Sample Analysis

Samples from each elevator was tested for moisture content following A.S.A.E. (1980) methods for whole grains (Appendix B). Samples were removed from the freezer on a first-in - first-out basis to assure that all samples spent approximately equal time in cold storage, and to minimize variance due to storage time. A total of 20 samples (10 from each of two elevators) were removed from the freezer and allowed to equilibrate to room temperature while sealed. The equilibration period averaged 5 hours with the room temperature at 25C. The samples were then mixed by tumbling with the lids in place. Each container was opened separately and two portions of approximately 10 g each were removed and placed in tared moisture dishes. The combined weight of sample and moisture dish was recorded to nearest milligram. Following weighing, all moisture dishes were placed on the middle rack of an air-oven. The temperature of the air-oven was 130C for the wheat and grain sorghum study. Wheat samples were dried for 19 hours and grain sorghum samples for 18 hours.

After drying, the moisture dishes were removed and lids replaced. The moisture dishes with contents were allowed to equilibrate to room temperature and were weighed to the nearest milligram. Moisture loss was determined and expressed as a percentage.

Electronic Moisture Meter Analysis

The oven moistures of the duplicate portions for each sample from an elevator were averaged and then subtracted from the reported moisture of each sample. The resulting differences indicated if the electronic moisture meter the samples were tested on was reading "high" or "low" when compared to air-oven moisture content. The mean of the differences for each elevator was derived and used to indicate average meter error. Standard deviation gave an indication of meter variability for each meter tested.

CHAPTER IV

RESULTS AND DISCUSSION

Survey Response - Wheat

Information obtained from the returned survey cards of the elevators visited for sample collection during the 1982 wheat harvest is presented in table 4. The average age of meters at elevators visited was 5 years. The oldest meter tested had been in use for 15 years while 5 of the meters tested were new. The ages of several meters were unknown because they were purchased used, no record of the purchase was kept, or personnel had changed.

Owner response to the question of satisfaction with meter performance is totally subjective. The two areas an owner of a country elevator might encounter a problem, due to inaccurate moisture meter performance, would be not charging a discount for grain that was received with a high moisture content or putting grain into storage that was of a moisture content higher than recommended as safe. Storing grain that is in excess of safe moisture content may increase the possibility of insect and/or fungal damage. Such damage may decrease the value of the grain. Therefore, accurate knowledge of moisture content may become very important with regard to the new 3 year federal storage program.

The age of a moisture meter does not seem to influence satisfaction with moisture meter performance. Almost half of the owners (48%) indicated the performance of their moisture meter was totally satisfactory, 40% of the owners were mostly satisfied with performance and 12% were somewhat satisfied with performance.

Table 4. RESULTS OF SURVEY
ELEVATORS WHERE WHEAT SAMPLES COLLECTED

Moisture Meter Type	Owner Satisfaction	Approx. Age (yrs)	Service Date
Steinlite SS250 (2)	Somewhat	4	- - -
Burrows 700	Totally	4	- - -
Burrows Auto	Mostly	?	'81
Dickey-John GAC II	Totally	New	New
Dickey-John GAC II	Totally	New	New
Steinlite RCT	Mostly	2	'81
Steinlite SS250	Totally	2	'80
Steinlite 500RC	Mostly	12	'81
Motomco 919	Mostly	4	'81
Motomco 919	Mostly	4	'81
Burrows 700	Mostly	?	?
Dickey-John GAC II	Totally	New	New
Burrows 700	Somewhat	3	'81
Burrows 700	Totally	10	'80
Dickey-John GAC II	Totally	2	'81
Steinlite DM	Totally	8	'81
Burrows Auto	Mostly	?	'81
Steinlite	Mostly	12	'82
Steinlite RCT	Totally	3	?
Burrows 700	Totally	1½	'81
Burrows 700	Totally	6	'81
Dickey-John GAC II	Totally	1	- - -
Steinlite RC500 (3)	Somewhat	8	'81
Burrows 700	Totally	9½	'72
Dickey-John GAC II	Totally	2	'81
Dickey-John GAC II	Mostly	4	'81
Dickey-John GAC II	Totally	2	'81
Motomco 919	Mostly	4	'81
Steinlite RC500	Mostly	15	'81
Dickey-John GAC II	Mostly	New	New
Dickey-John GAC II	Mostly	New	New
Dickey-John GAC II	Mostly	2	'81
Dickey-John GAC II	Mostly	3	?
Burrows 700	Totally	3	'81
Burrows 700	Mostly	8	'81
Steinlite SS250 (3)	Totally	3	'79

Table continued on next page . . .

Table 4. continued . . .

Results of Survey
Elevators Where Wheat Samples Collected

Moisture Meter Type	Owner Satisfaction	Approx. Age (yrs)	Service Date
Steinlite	Mostly	?	'79
Burrows Auto	Totally	Purchased Used	'82
Steinlite SS250	Mostly	3	'81
Burrows 700	Totally	?	?
Burrows 700	Mostly	7	'78
Burrows 700	Mostly	4	'81
Steinlite SS250	Totally	3	'82
Steinlite RCT	Totally	10	'82
Burrows 700	Totally	3	'81

Owner Satisfaction

Totally	48%
Mostly	40%
Somewhat	12%

Average Meter Age . . . . 5 yrs.

Service Record

Last Service Date	No.	%
New	4	8
'82	4	8
'81	25	50
'80	2	4
'79	4	8
'78	1	2
'72	1	2
No Record	9	18

The data regarding service date shows that a majority of the elevators had their moisture meter serviced within the past 2 years. The type of service performed will vary from simple cleaning to readjustment of calibration.

Four brands of commercially available moisture meters were encountered at elevators where samples were collected during the 1982 wheat harvest. Table 5 shows distribution by meter brand. Steinlite moisture meters have been available for the longest period of time which possibly explains their numbers. The Dickey-John GAC II is the newest and the most expensive meter available with an average cost of $3,000. Table 6 shows the production data, type of display and mode of operation of the different brands of meters encountered. The direct readout meters employ internal calibration curves, thereby, eliminating the use of "look-up" charts and increasing ease of operation. Of the 50 meters tested during the 1982 wheat harvest, 36 or 72% were of the direct readout type.

Grain Sorghum

Table 7 is a summary of survey data for elevators where grain sorghum was collected. Wheat samples were collected at all but three of these elevators. Average meter age was 2.75 years, ranging from 12 years old to new. Data shows that 79% of the meters had been serviced within the past 2 years. Table 8 shows the distribution of moisture meters by brand for grain sorghum collection.

MOISTURE DETERMINATION

Moisture Meter Vs. Oven Moisture - Wheat

All samples were run in duplicate with the average oven moisture subtrated from the reported meter moisture of that sample. Results

Table 5. DISTRIBUTION OF MOISTURE METER TYPE AMONG ELEVATORS VISITED (WHEAT)

Moisture Meter Type	Number	% of Total
Steinlite (all models)	20	40
Burrows	15	30
Dickey-John GAC II	12	24
Motomco	3	6
	50	100

Table 6. MOISTURE METERS ENCOUNTERED IN TEST

Meter Model	Approximate Date of Manufacture	Measurement Principle	Sample Weight Required	Method of Calibration and Display of Results
Steinlite SS-250	1979	Capacitance	250 g	One range, digital
Steinlite AUT	1960	Capacitance	250 g	Two range, revolving dial
Steinlite RCT	1950	Capacitance	250 g	Look-up charts, meter pointer
Burrows 700[a]	1979	Capacitance	250 g	One range digital
Motomco 919[b]	1965	Capacitance	150 g or 250 g	Look-up charts, manually rotated dial
Dickey-John GAC II	1979	Capacitance	Internal weighing	Microprocessor digital

[a]Machine manufactured for Burrows by Dickey-John Inc.

[b]Motomco meter is used exclusively by Federal Grain Inspection Service

Table 7. RESULTS OF SURVEY
ELEVATORS WHERE GRAIN SORGHUM
SAMPLES COLLECTED

Moisture Meter Type	Owner Satisfaction	Approx. Age (yrs)	Service Date
Dickey-John GAC II . . .	Mostly	1	'81
Dickey-John GAC II . . .	New	New	- - -
Dickey-John GAC II . . .	Mostly	3	?
Dickey-John GAC II . . .	Mostly	2	'81
Burrows 700	Totally	3	'81
Dickey-John GAC II . . .	Totally	1	?
Dickey-John GAC II . . .	Totally	2	'81
Dickey-John GAC II . . .	Mostly	4	'81
Dickey-John GAC II . . .	Totally	2	'82
Burrows 700	Totally	6	'81
Burrows 700	Totally	1½	'81
Dickey-John GAC II . . .	New	New	- - -
Dickey-John GAC II . . .	Totally	2	'81
Burrows 700	Somewhat	3	'81
Steinlite	Totally	8	'81
Steinlite	Mostly	12	'81
Steinlite	Totally	2	'80
Steinlite	Mostly	2	'81
Dickey-John GAC II . . .	Totally	New	- - -
Dickey-John GAC II . . .	Totally	New	- - -
Burrows 700	Mostly	?	'81
Steinlite	- - - -	- -	'81
Steinlite	- - - -	- -	'81
Steinlite	Somewhat	4	?
Burrows 700	Mostly	5	'80

11 owners totally satisfied with meter operation (42%)
9 owners mostly satisfied with meter operation (35%)
2 owners somewhat satisfied with meter operation (8%)
4 owners did not respond (15%)

Average Meter Age -- 2.75 years

- SERVICE RECORD -

Last Service Date	No.	%
New	4	15
'82	1	3
'81	16	61
'80	2	8
?	3	12

Table 8. DISTRIBUTION OF MOISTURE METER TYPE AMONG ELEVATORS VISITED (GRAIN SORGHUM)

Moisture Meter Type	Number	% of Total
Dickey-John GAC II	13	50
Steinlite (all models)	6	23
Burrows 700	7	27
	26	100

could then be reported as a difference. Differences were averaged for each meter and reported as average meter error. Positive error or meter bias favors the grain buyer while negative error or meter bias favors the seller.

Table 9 is a summary of the performance of all Steinlite moisture meters tested. The average error for each meter ranges from -1.35 to +.712 with an overall average error of -.515% moisture. Seventeen meters had negative average errors and three had positive average errors. It appears that some owners who have meters whose performance is questionable have recognized that fact. However, there are instances where this is not the case.

A negative overall average error does not, of itself, indicate that the Steinlite meters in the test where constantly reading in favor of the seller, only that the largest amount of error encountered was negative. Figure 5 is a scatter diagram and regression line of all observations originating from Steinlite moisture meters. The slope of the line is negative which indicates that Steinlite meters tested were more biased toward negative values at higher moisture levels. By not intersecting the zero line, the regression line shows that Steinlite meters are biased negatively. Figure 6 is the regression line with attendant 95% confidence interval based upon predicted values.

Table 10 is a summary of the performance of the Burrows 700 moisture meters tested. The Burrows 700 is a direct readout moisture meter with an internal calibration curve. The overall average meter error was -.495 with individual meter average error ranging from -1.322 to +.279. Of the meters tested, 2 showed positive average error and 11 showed negative

Table 9. RESULTS FOR STEINLITE MOISTURE METERS
(ALL MODELS)
(WHEAT)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
1	Totally	- .609	.462
2	Totally	- .297	.269
7	Mostly	-1.304	.367
9	Totally	- .518	.435
10	Totally	- .853	.150
11	Totally	- .416	.250
12	Somewhat	+ .712	1.227
19	Mostly	- .077	.915
25	Somewhat	- .134	1.024
26	Somewhat	+ .186	.687
27	Somewhat	+ .474	.230
31	Totally	- .484	.448
32	Mostly	-1.238	.268
34	Totally	- .920	.176
36	Mostly	- .776	.167
40	Mostly	- .131	.271
41	Totally	-1.288	.222
42	Mostly	- .936	.191
49	Somewhat	-1.174	.182
50	Somewhat	-1.350	.292

Average Meter Error . . -.515

8 owners totally satisfied with meter operation (40%)

6 owners mostly satisfied with meter operation (30%)

6 owners somewhat satisfied with meter operation (30%)

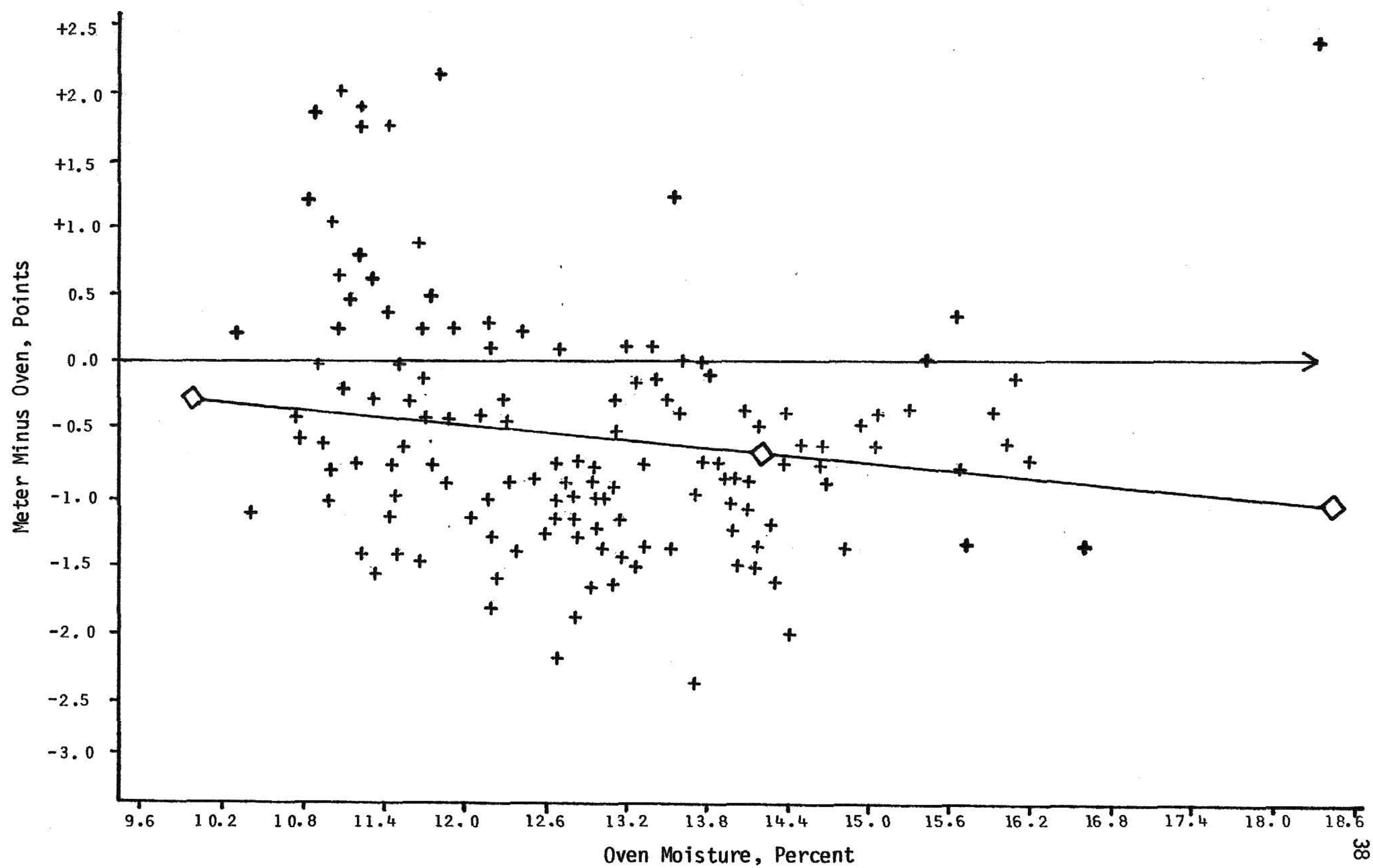


Figure 5. SCATTER PLOT AND REGRESSION LINE, STEINLITE (WHEAT)

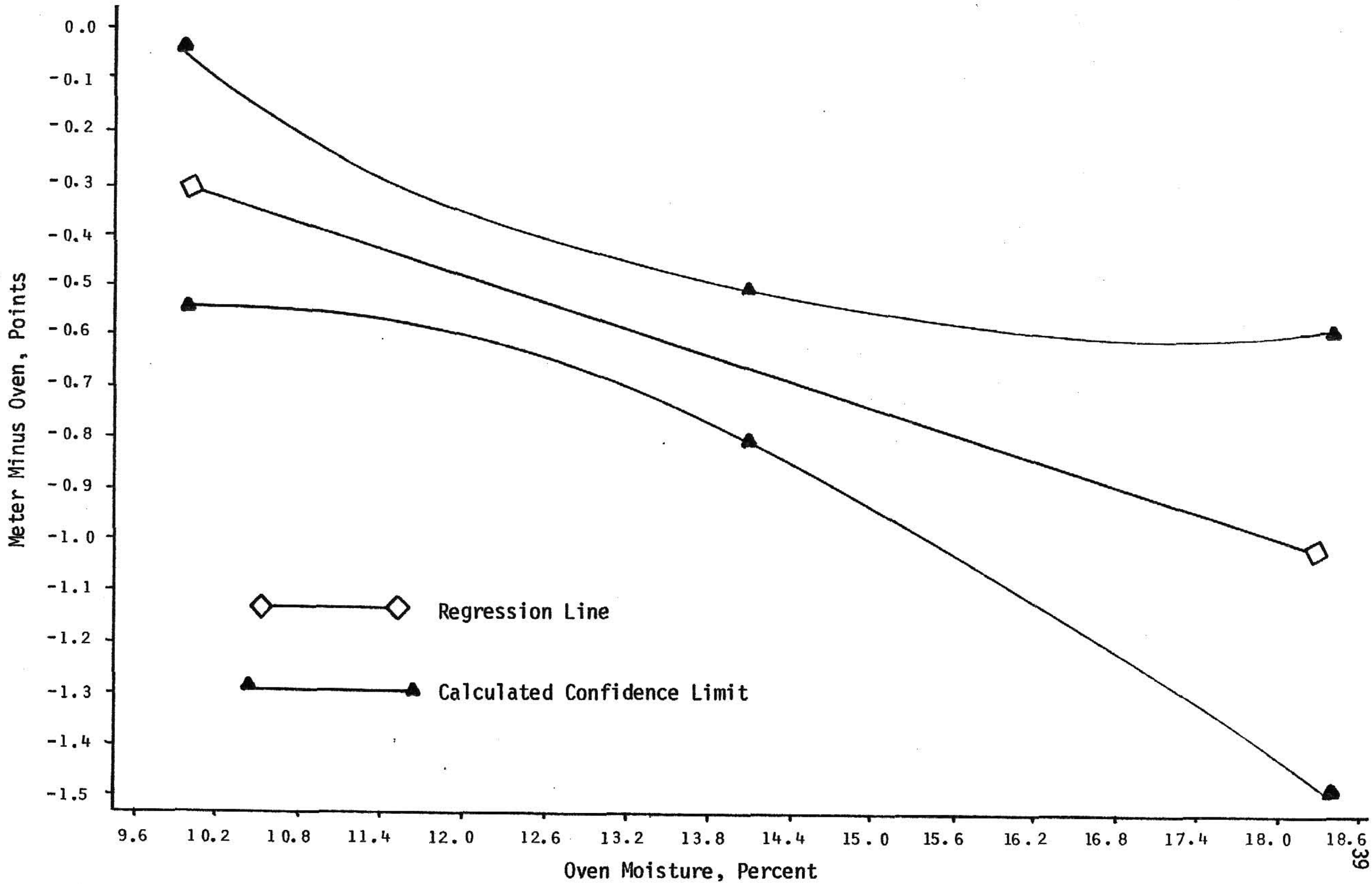


Figure 6. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS FOR STEINLITE (WHEAT)

Table 10. RESULTS FOR BURROWS 700 MOISTURE METERS (WHEAT)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
3	Totally	- .108	.228
4	Mostly	+ .040	.442
5	Totally	-1.065	.417
6	Mostly	- .761	.515
13	Mostly	- .180	.482
14	Totally	- .104	.361
29	Totally	+ .279	.158
30	Totally	- .395	.377
37	Mostly	-1.293	.359
45	Mostly	-1.050	.204
46	Somewhat	- .408	.321
47	Totally	-1.322	.259
48	Totally	-1.222	.238

Average Meter Error . . -.583

7 owners totally satisfied with meter operation (54%)

5 owners mostly satisfied with meter operation (38%)

1 owner somewhat satisfied with meter operation (8%)

Does not include Burrows Automatic Moisture Analyzer (3) average error. Figure 7 is a scatter diagram of all observations with the regression line superimposed on it. The regression line has a negative slope indicating that Burrows 700 moisture meters tested were more biased toward negative values as moisture content increased. The negative bias of the meters was indicated by the regression line not intersecting the zero line. Figure 8 is the regression line with computed 95% confidence intervals.

Table 11 is a summary of performance of the Dickey-John GAC II which is a direct readout meter having an internal microprocessor. Average meter error was -1.05 with individual meter error ranging from -1.722 to -.316. All Dickey-John GAC II meters tested had negative average error. Figure 9 shows the scatter plot and regression line. The negative slope of the regression shows that as moisture content increased the amount of negative error increased. The regression line does not intersect the zero line, thus showing negative bias for Dickey-John GAC II meters. Figure 10 shows the regression line and computed 95% confidence intervals. The confidence intervals are tighter, for the Dickey-John GAC II displayed the most negative bias when testing wheat.

Table 12 is a summary of the performance of the Motomco 919. There were only 3 such meters in the test and, thus the number of observations were severely limited. For this reason, the Motomco 919 was not included in the study of results. Average error was -.594 and individual meters ranged from -.725 to -.374.

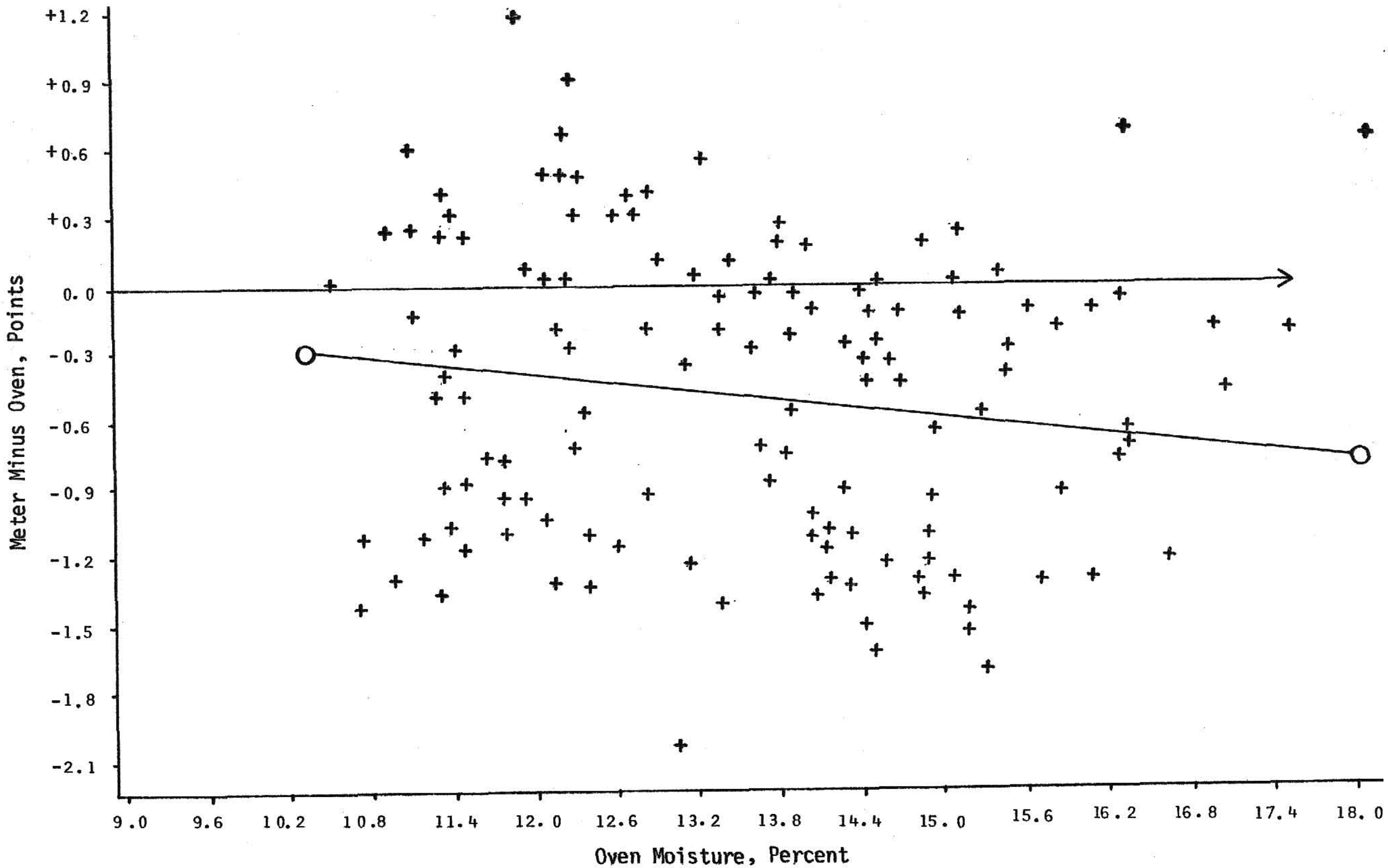


Figure 7. SCATTER PLOT AND REGRESSION LINE, BURROWS 700 (WHEAT)

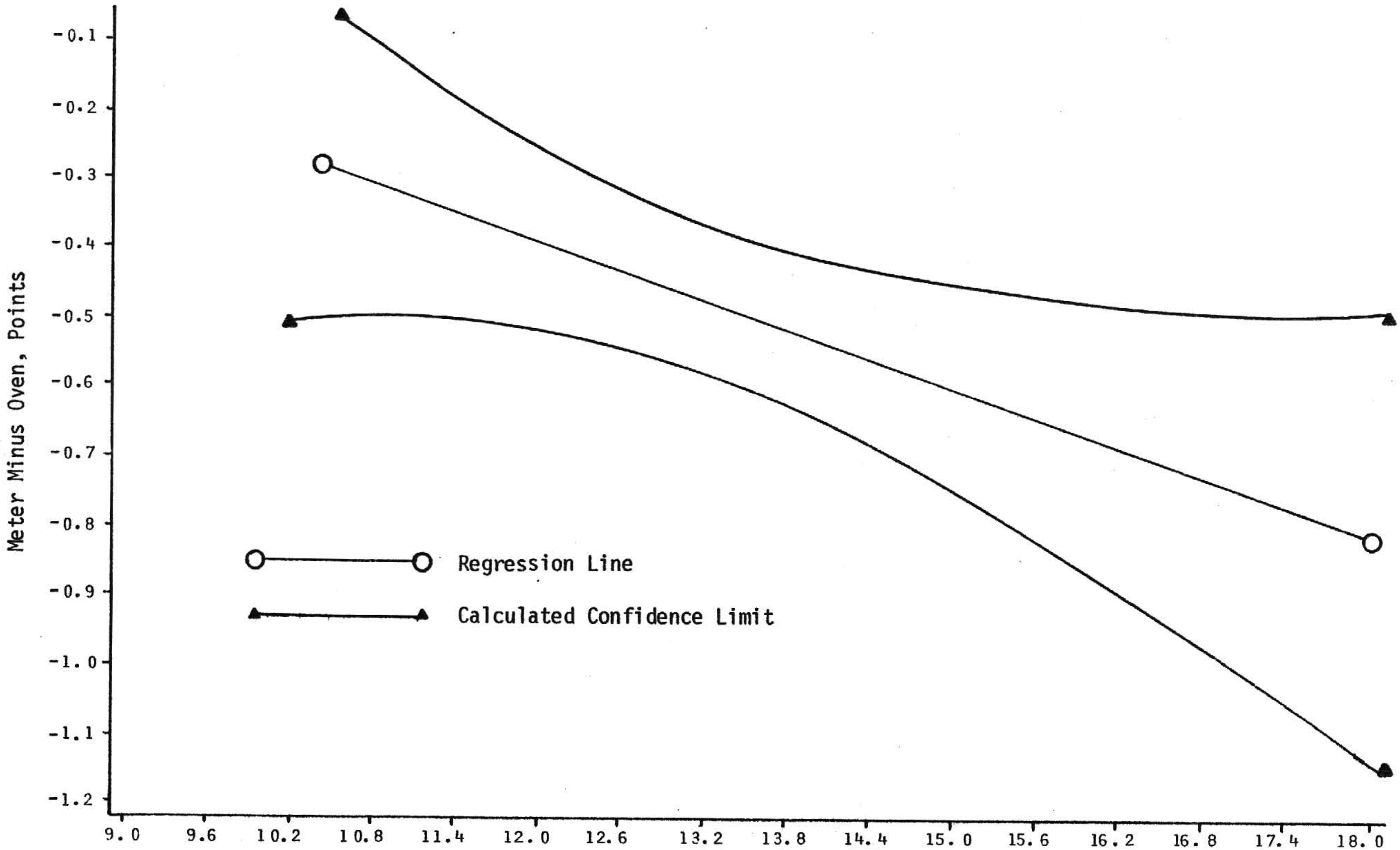


Figure 8. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS, BURROWS 700 (WHEAT)

Table 11. RESULTS FOR DICKEY-JOHN GAC II MOISTURE METERS (WHEAT)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
15	Mostly	-1.088	.181
16	Mostly	-1.039	.270
17	Mostly	-1.492	.179
18	Mostly	- .742	.343
21	Totally	-1.722	.400
22	Mostly	-1.576	.328
23	Totally	- .957	.156
24	Totally	- .316	.109
28	Totally	- .924	.208
35	Totally	-1.384	.148
43	Totally	- .367	.346
44	Totally	-1.080	.123

Average Meter Error . . -1.05

7 owners totally satisfied with meter operations (58%)

5 owners mostly satisfied with meter operation (42%)

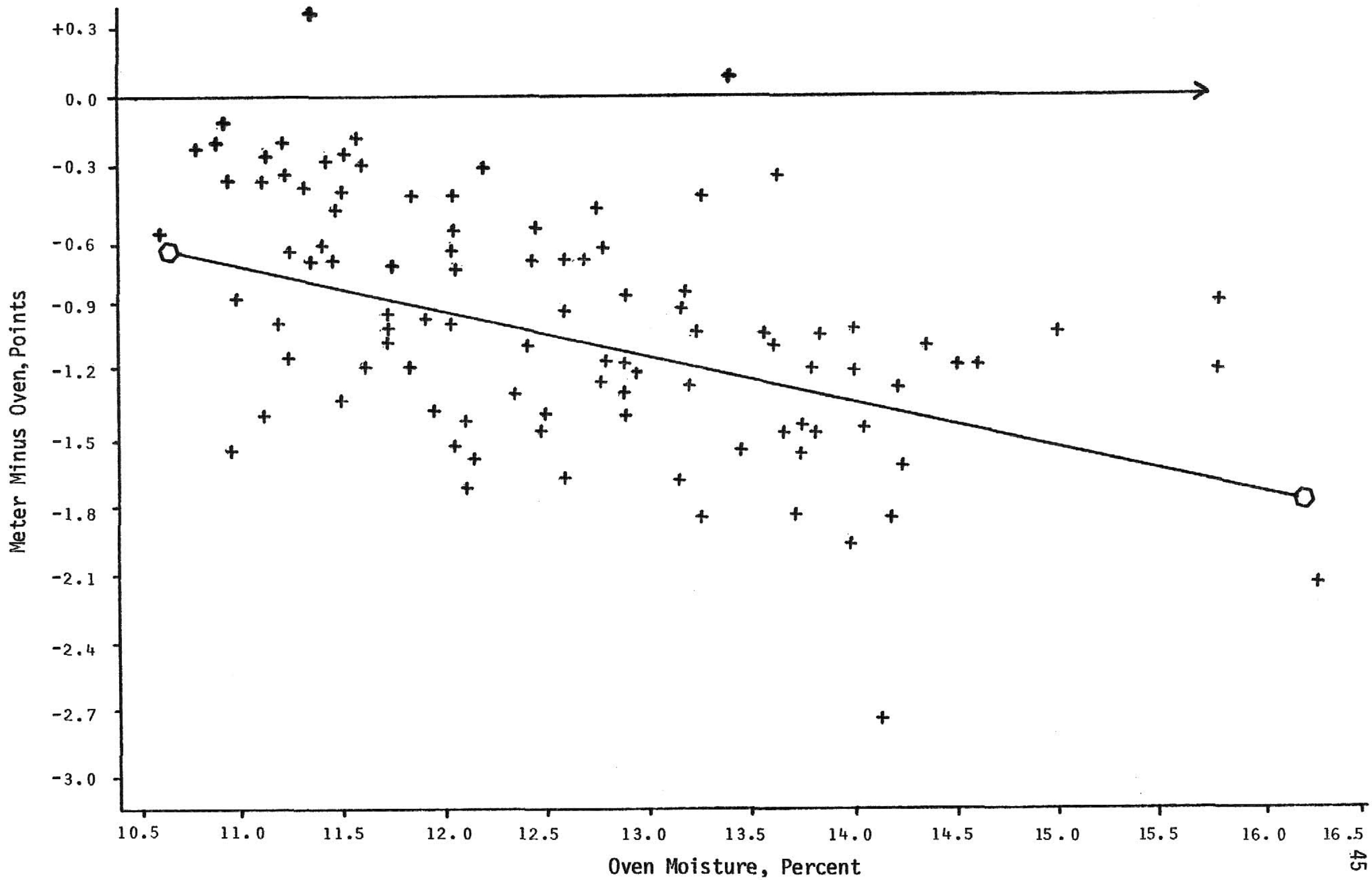


Figure 9. SCATTER PLOT AND REGRESSION LINE, DICKEY JOHN GAC II, (WHEAT)

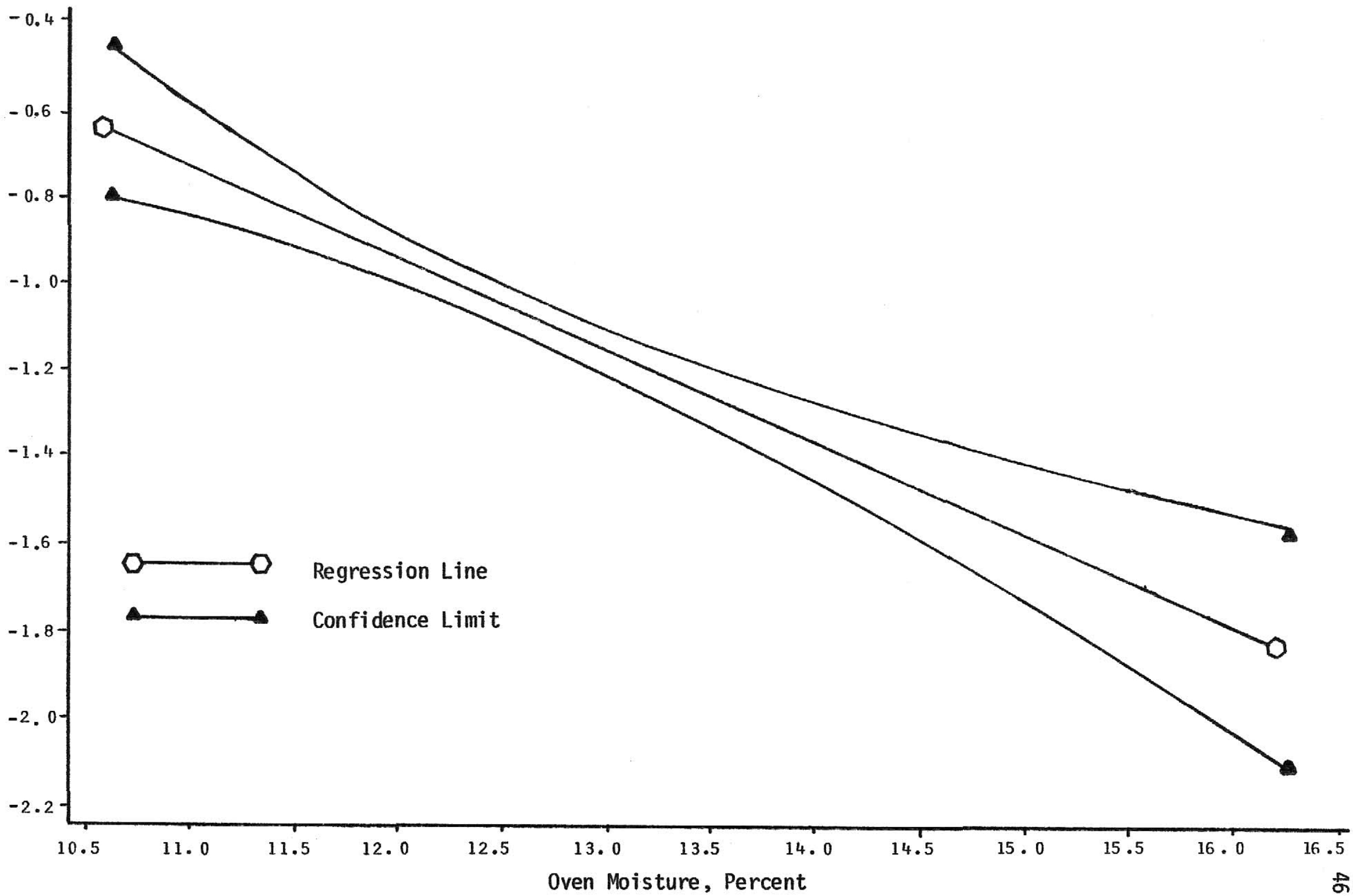


Figure 10. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS, DICKEY JOHN GAC II (WHEAT)

Table 12. RESULTS FOR MOTOMCO 919 MOISTURE METERS (WHEAT)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
20	Mostly	- .685	.398
38	Mostly	- .725	.103
39	Mostly	- .374	.139

Average Meter Error . . . -.594

Summary of Wheat Study

The study of moisture meter performance during the 1982 wheat harvest has shown that the 500 samples from the 50 meters tested yielded an overall negative result. However, a high degree of variability accompanied the negative result. This is in agreement with results reported by Paulsen et al. (1982) and Hurburgh (1981). The variability may have been caused by differences in meters, crops and to some degree by the oven used in the test. Crop differences resulting in changed dielectric properties among samples are responsible for approximately 85% of total variability (Hurburgh, 1981; Hurburgh et al., 1981 and Hemeda et al., 1982). Differences of performance among like meters is responsible for a further 10% of total variability and this amount will increase as moisture content of grain increases (Hurburgh et al., 1981). All meters exhibit this phenomena and it perhaps is beyond present manufacturing techniques to correct, because even after total statewide recalibration of meters in Iowa and Illinois, meter to meter variation was still a problem (Paulsen et al., 1982). The amount of total variation contributed by the numbers of ovens used in combination during the experimental procedure is 5% or less and any improvement here would not significantly affect total variability (Hurburgh, 1981). Only one oven used in the present study, so variability contributed by it should not be significant. Since 85% of total variability is a direct result of sample to sample variation, if progress is to be made in overall meter performance it must come about through better understanding of the dielectric properties of grains and how those properties change with respect to genetic variety of crop, weather conditions and geographical area.

Figure 11 shows the regression lines of the Steinlite, Burrows 700 and Dickey-John GAC II moisture meters tested during the 1982 wheat harvest. All 3 show a negative slope, but the Dickey-John GAC II seems to show a very pronounced negative slope. Negative slopes of the regression lines of the 3 types of moisture meters indicate that as moisture content increases, the amount of negative error increases. This would be in favor of the seller. At an average error of -.515 for Steinlite meters and -.495 for Burrows 700 meters, it is doubtful that any farmer is getting rich from not having his grain discounted or an elevator losing money in noticeable amounts. If sellers or buyers were absorbing significant erroneous discounts of encountering problems, changes would be instituted to correct the situation. Sellers would stop dealing with an elevator that did not provide equitable treatment and elevators would institute plans to see that they had reliable moisture meters.

The performance of the Dickey-John GAC II in this study indicated that a problem may exist. An average meter error -1.05 may have caused a sizable amount of revenue to be lost. Since error is all negative, randomness will not help average it out. The performance of the Dickey-John GAC II's appears to indicate that they were improperly calibrated. All meters tested displayed negative bias. The standard deviation values of the Dickey-John GAC II suggest that meter precision was quite good. By examining figure 9, the negative bias of the meters can be clearly seen. Of 120 observations, all but 2 appear below the zero line. The regression line did not intersect the zero line, so negative bias was present.

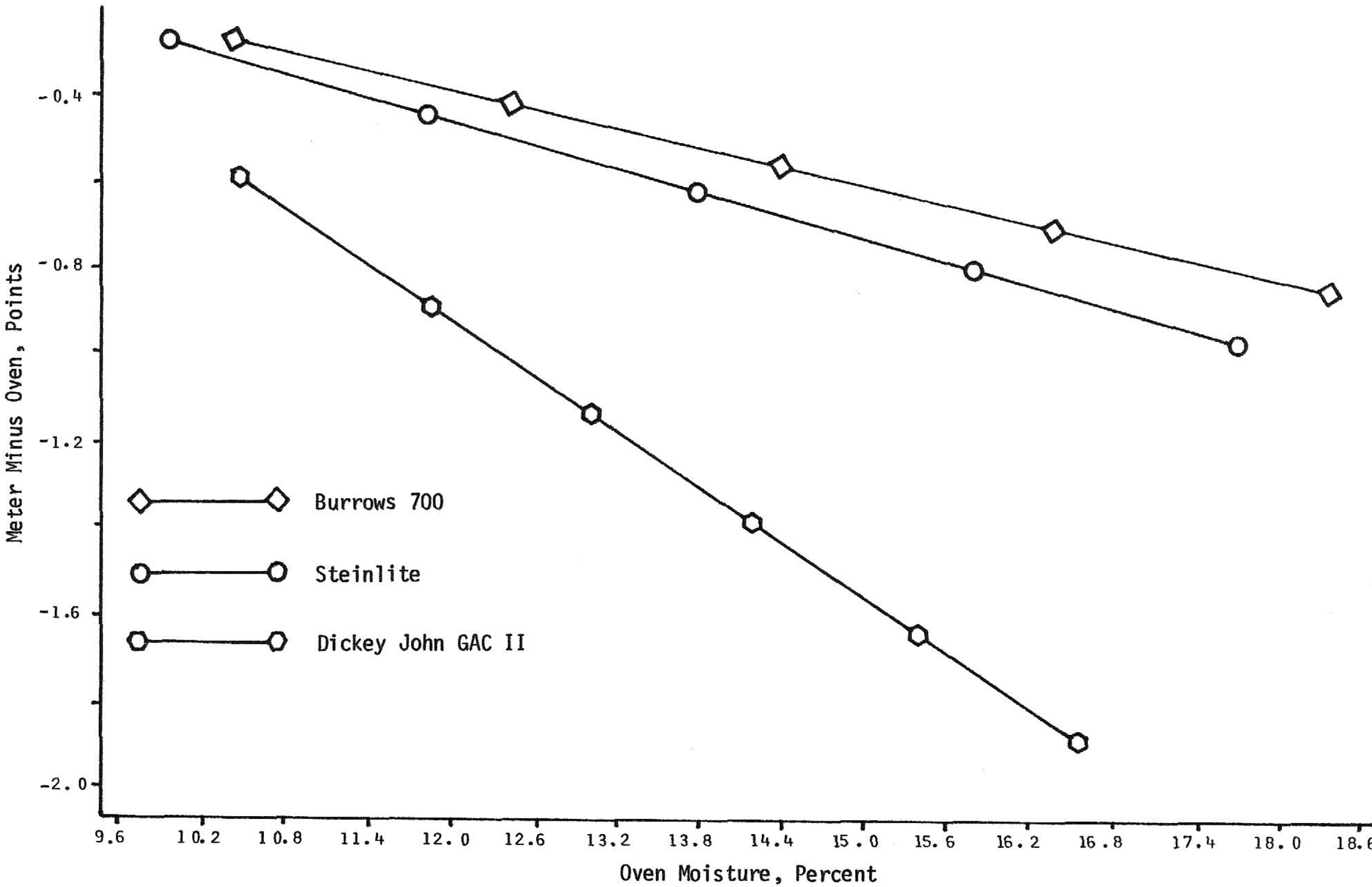


Figure 11. COMPARISON OF REGRESSION LINES (WHEAT)

Figure 5 and 7 show a significant number of observations above the zero lines. The regression lines of these meters have shown that they are negatively biased. The observations above the zero line may be a result of randomness or as is more likely, they represent observations from elevators with a meter that had a positive average error.

All meters exhibited an increased amount of error as moisture content increased. This agrees with results reported by (Hurburgh, 1981 and Paulsen et al., 1982) who say that amount of error increases with increasing moisture content, but as moisture content decreases, the amount of error decreases. The majority of observations in this study appear below the zero line, thereby, showing bias towards negative values. A meter that performed perfectly would have observations only on the zero line. The studies conducted in Iowa and Illinois during 1980 and 1981 show a majority of observations above the zero line (Hurburgh, 1981 and Paulsen et al., 1982). Regression lines generated by computer for the studies in Iowa and Illinois intersect the zero line and exhibit a negative slope due to the negative error encountered at moisture levels above 25% in freshly harvested corn (Hurburgh, 1981 and Paulsen et al., 1982). The negative slopes of the computer generated regression lines for the individual meters tested in this study are a result of the generally negative value of the individual observations. The observations generated in Iowa and Illinois respond to curvilinear regression treatment resulting in positive humped curves (Hurburgh, 1981). Such treatment worked in this study on the observations for the Burrows 700 moisture meters and yielded a negative humped curve. The Burrows 700 appeared to exhibit the most random variability among observations and this perhaps explains why it responded to curvilinear regression treatment. The corrected calibration curves used in Iowa and Illinois for the 1980 study gave a more linear response than the 1979 study (Hurburgh, 1981).

The 50 moisture meters that were tested during the 1982 wheat harvest showed an overall error of -.663% moisture. There were 44 meters that showed negative error. Overall average negative error was -.801%. Positive error was seen in 6 meters. Overall positive error was +.351%.

Statistical analysis for general linear models indicates that all three of the regression lines for wheat are significantly different from zero and have negative slopes. The regression lines were found to be not significantly different in regard to slope. At an average moisture content, one expects them to give similar results for similar moisture levels.

Grain Sorghum

Grain sorghum samples were run the same as wheat samples. Table 13 summarizes the results obtained for all Steinlite moisture meters. The overall average error was -.385 with individual meter error ranging from -.796 to -.086. Only one meter appears out of line and that is due to its standard deviation. Unexpected crop or meter variation may have occurred on the day samples were collected. Figure 12 is a scatter diagram of individual observations with the regression line superimposed on it and figure 13 is the same regression line with corresponding 95% confidence limits.

Table 14 summarizes the results obtained for the Burrows 700 meters tested. Overall average error was -1.008 with individual results ranging from -1.850 to +.133. There are 2 meters which exhibit high

Table 13. RESULTS FOR STEINLITE MOISTURE METERS
(ALL MODELS)
(GRAIN SORGHUM)

Elevator Code Number	Owner Satisfaction	Meter Performance Avg. Error	Std. Dev.
17	Totally	- .796	1.367
18	Mostly	- .088	.096
19	Mostly	- .086	.109
24	No Response	- .476	.161
25	No Response	- .652	.185
26	Somewhat	- .216	.287

Average Meter Error . . -.385

1 owner totally satisfied with meter operation (16%)

2 owners mostly satisfied with meter operation (33%)

1 owner somewhat satisfied with meter operation (16%)

2 owners gave no response (33%)

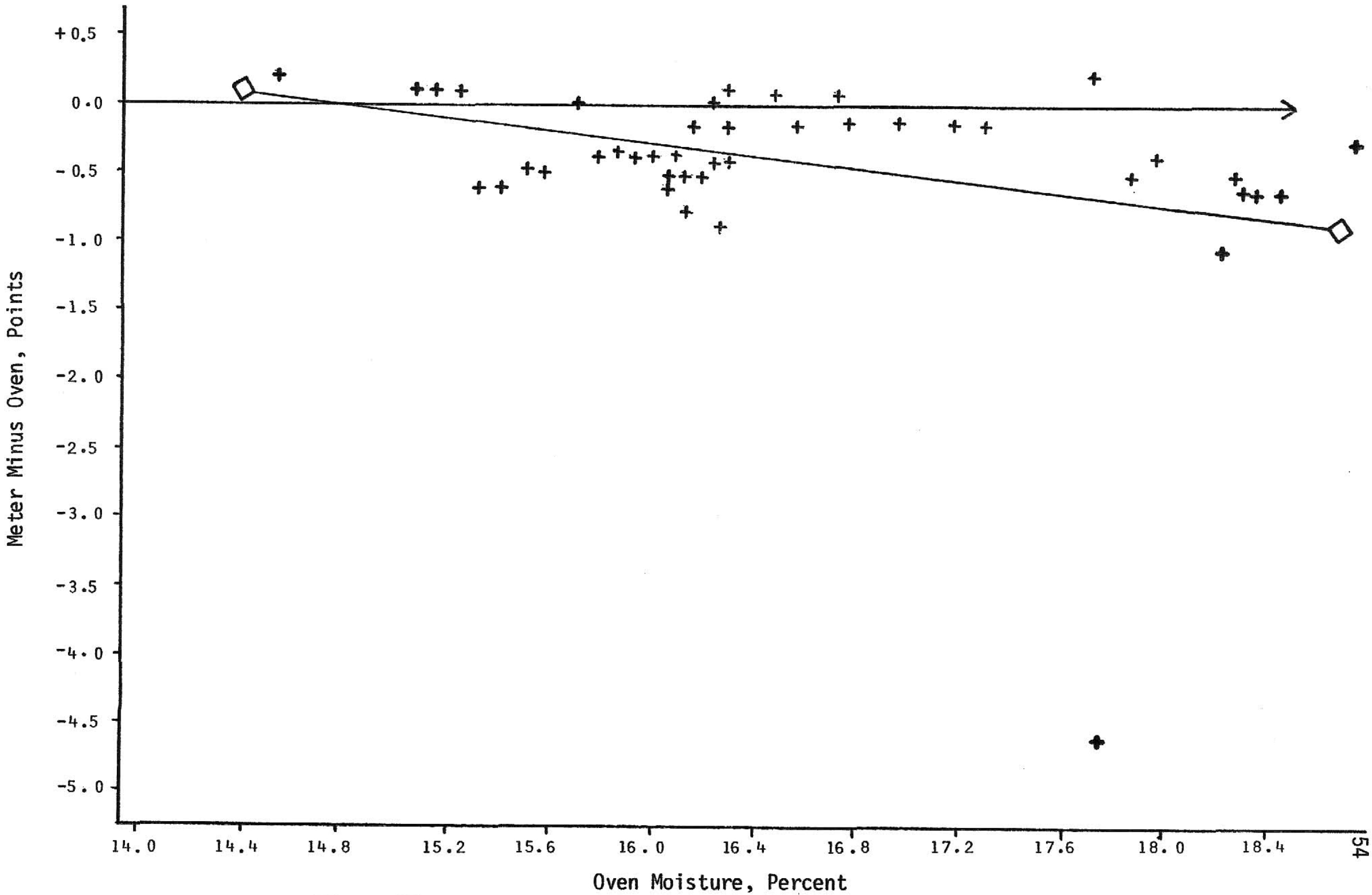


Figure 12. SCATTER PLOT AND REGRESSION LINE, STEINLITE (GRAIN SORGHUM)

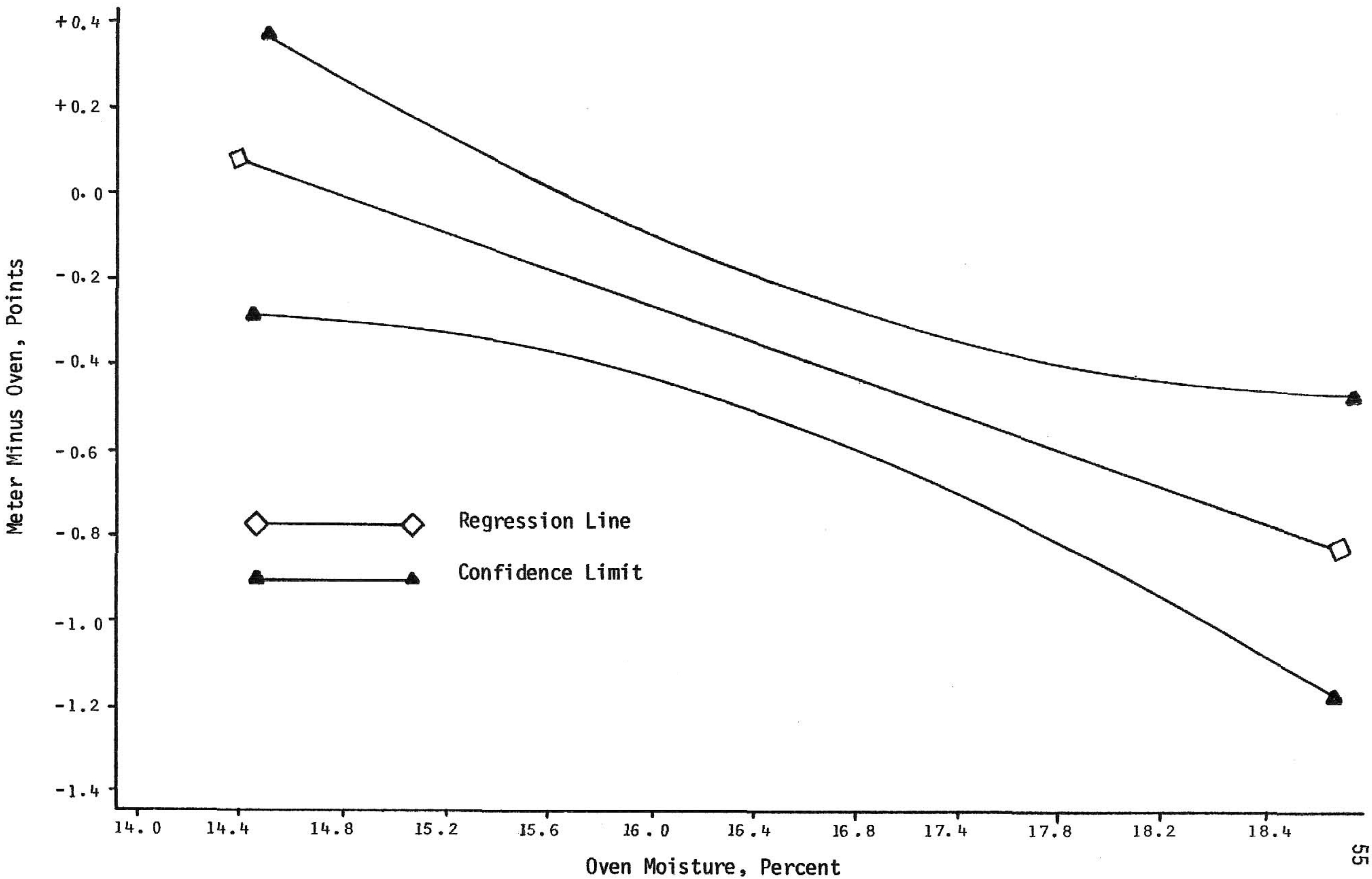


Figure 13. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS, STEINLITE (GRAIN SORGHUM)

Table 14. RESULTS FOR BURROWS 700 MOISTURE METERS (GRAIN SORGHUM)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
5	Totally	- .798	.171
6	Mostly	- .720	.309
12	Totally	+ .133	.840
13	Totally	- .728	.230
16	Somewhat	-1.670	1.650
23	Mostly	-1.423	.132
27	Mostly	-1.850	.373

Average Meter Error . . -1.008

3 owners totally satisfied with meter operation (43%)

3 owners mostly satisfied with meter operation (43%)

1 owner somewhat satisfied with meter operation (14%)

standard deviations and this is perhaps due to crop or meter variability on the day the samples were collected, or is evidence of operator error. Two of the meters that gave a large negative response have small standard deviations and it is possible they were improperly calibrated. Figure 14 is a scatter diagram of observations with the regression line superimposed on it. Figure 15 is the same regression line with 95% confidence limits shown.

Table 15 is a summary of the results obtained for the Dickey-John GAC II. Overall average error was -.519. Individual meter error ranged from -.783 to -.204. There were 4 meters (Elevators 10, 11, 15, 22) with standard deviations that were high when compared with the others. Perhaps crop or meter variability was responsible for the high standard deviations. Figure 16 is the scatter of observations with the regression line superimposed over it. Figure 17 is the regression line and 95% confidence limits.

Summary of Grain Sorghum Study

The regression lines of the Steinlite, Burrows 700 and Dickey-John GAC II meters for grain sorghum have negative slopes. This indicates that as moisture contents increased the amount of negative error increased. The regression lines for the Steinlite and Burrows 700 meters intersect the zero line. This appears to indicate that some positive bias was exhibited by these meters at lower moisture content. Figure 18 is a comparison of the three regression lines generated for the grain sorghum samples. It shows that the Dickey-John GAC II had the least negative bias at higher moisture contents. The Steinlites exhibit less error over a wider moisture range than the Burrows 700 meters. If the

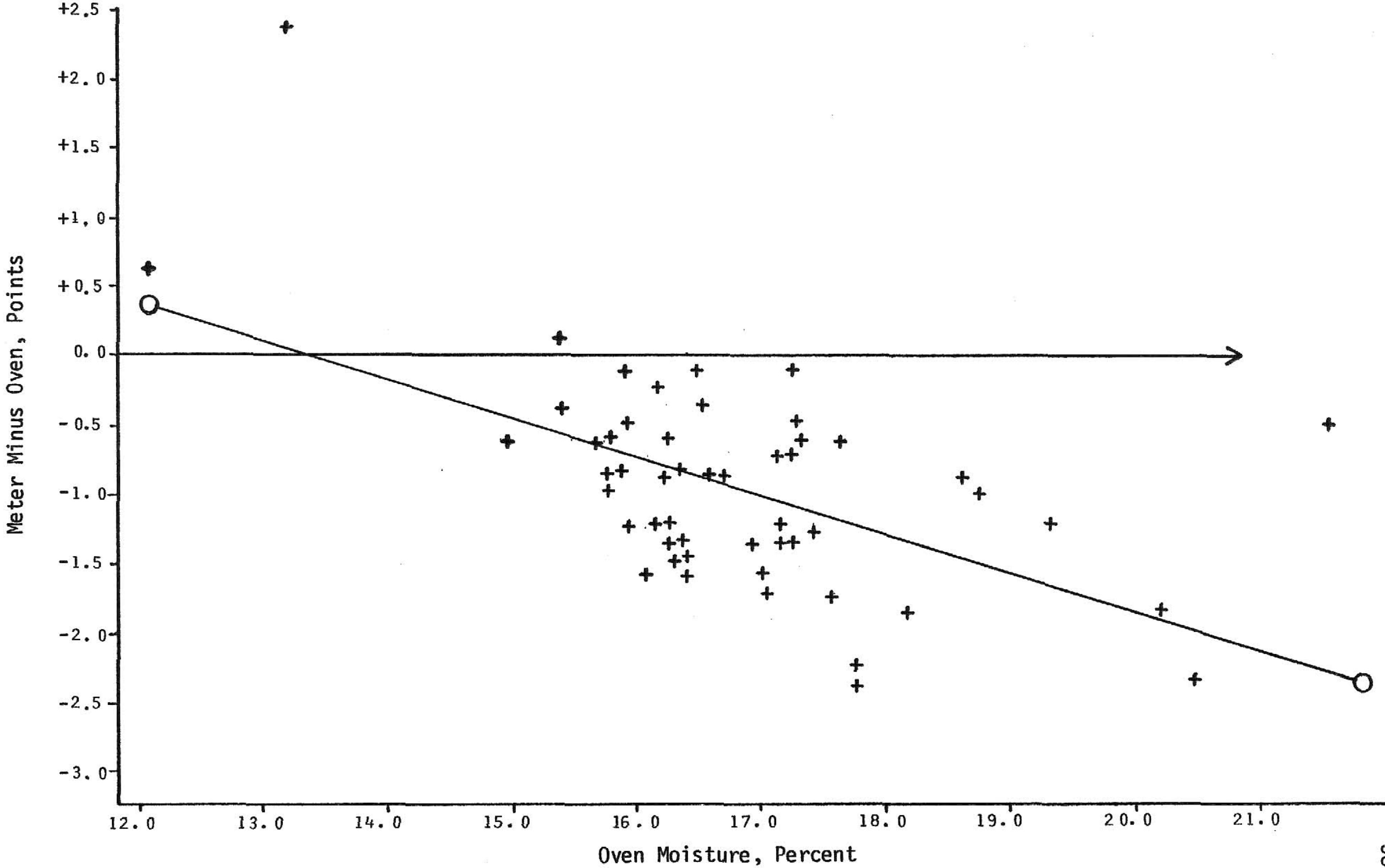


Figure 14. SCATTER PLOT AND REGRESSION LINE, BURROWS 700 (GRAIN SORGHUM)

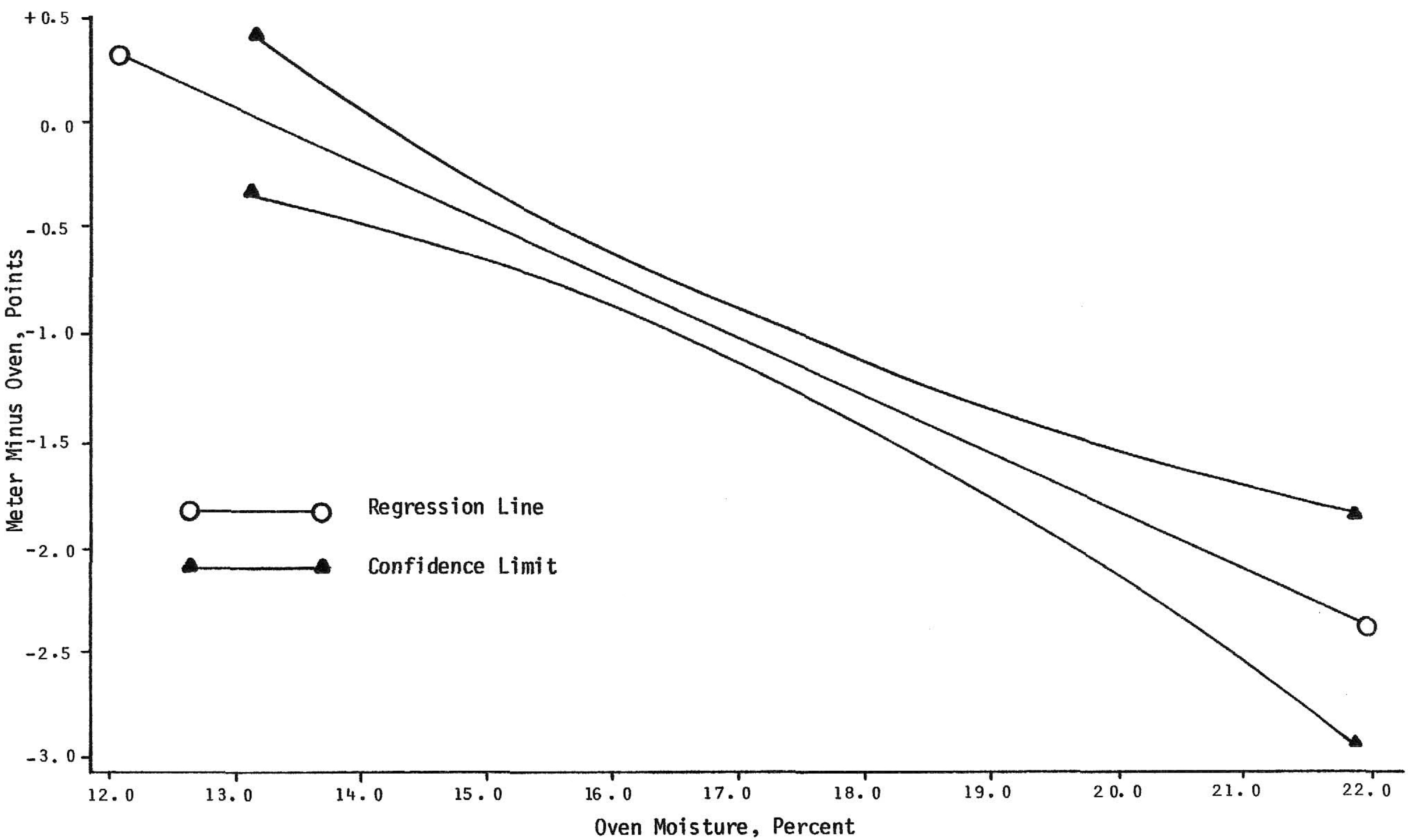


Figure 15. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS, BURROWS 700 (GRAIN SORGHUM)

Table 15. RESULTS FOR DICKEY-JOHN GAC II MOISTURE METERS (GRAIN SORGHUM)

Elevator Code Number	Owner Satisfaction	Meter Performance	
		Avg. Error	Std. Dev.
1	Mostly	-.626	.248
2	Mostly	-.406	.339
3	Mostly	-.706	.132
4	Mostly	-.603	.258
7	Totally	-.204	.099
8	Totally	-.420	.189
9	Totally	-.402	.165
10	Mostly	-.269	.470
11	Totally	-.701	.559
14	Purchased New*	-.606	.140
15	Totally	-.522	.489
21	Totally	-.504	.392
22	Totally	-.783	.469

Average Meter Error . . -.519

7 owners totally satisfied with meter operation (53%)

5 owners mostly satisfied with meter operation (38%)

*(one machine purchased new prior to harvest -- owner had not formed an opinion)

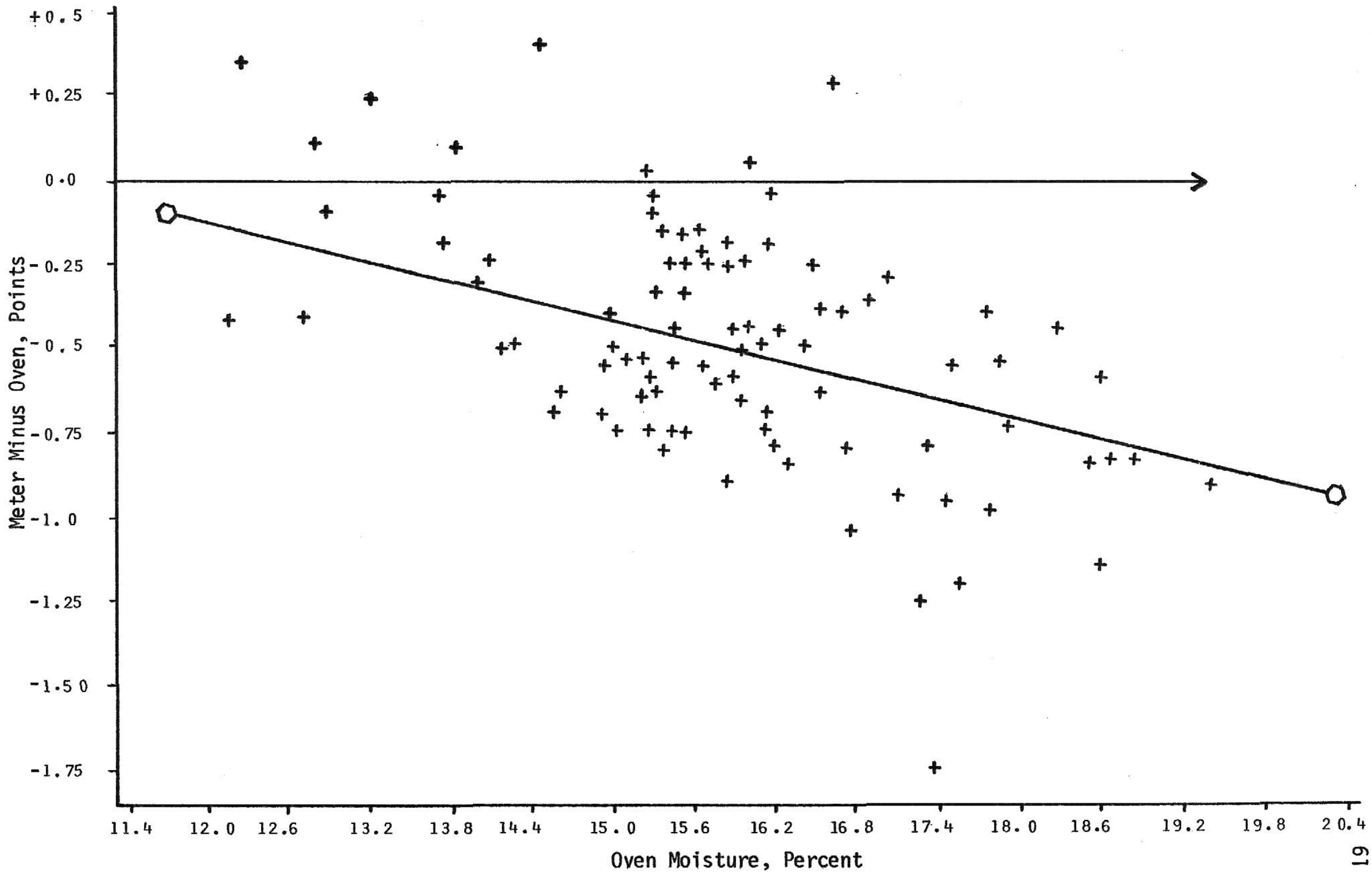


Figure 16. SCATTER PLOT AND REGRESSION LINE, DICKEY JOHN GAC II (GRAIN SORGHUM)

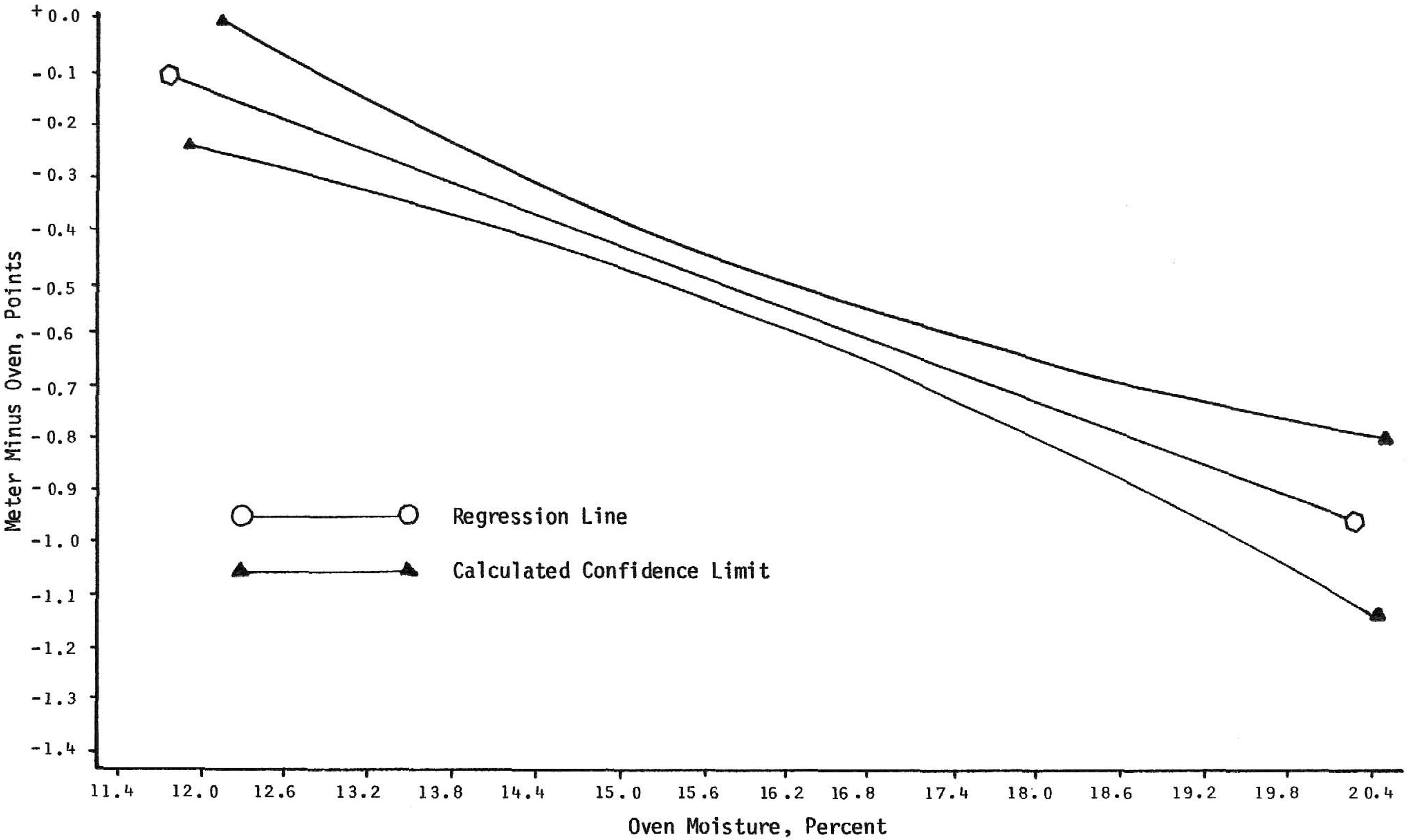


Figure 17. REGRESSION LINE AND CALCULATED 95% CONFIDENCE LIMITS, DICKEY JOHN GAC II (GRAIN SORGHUM)

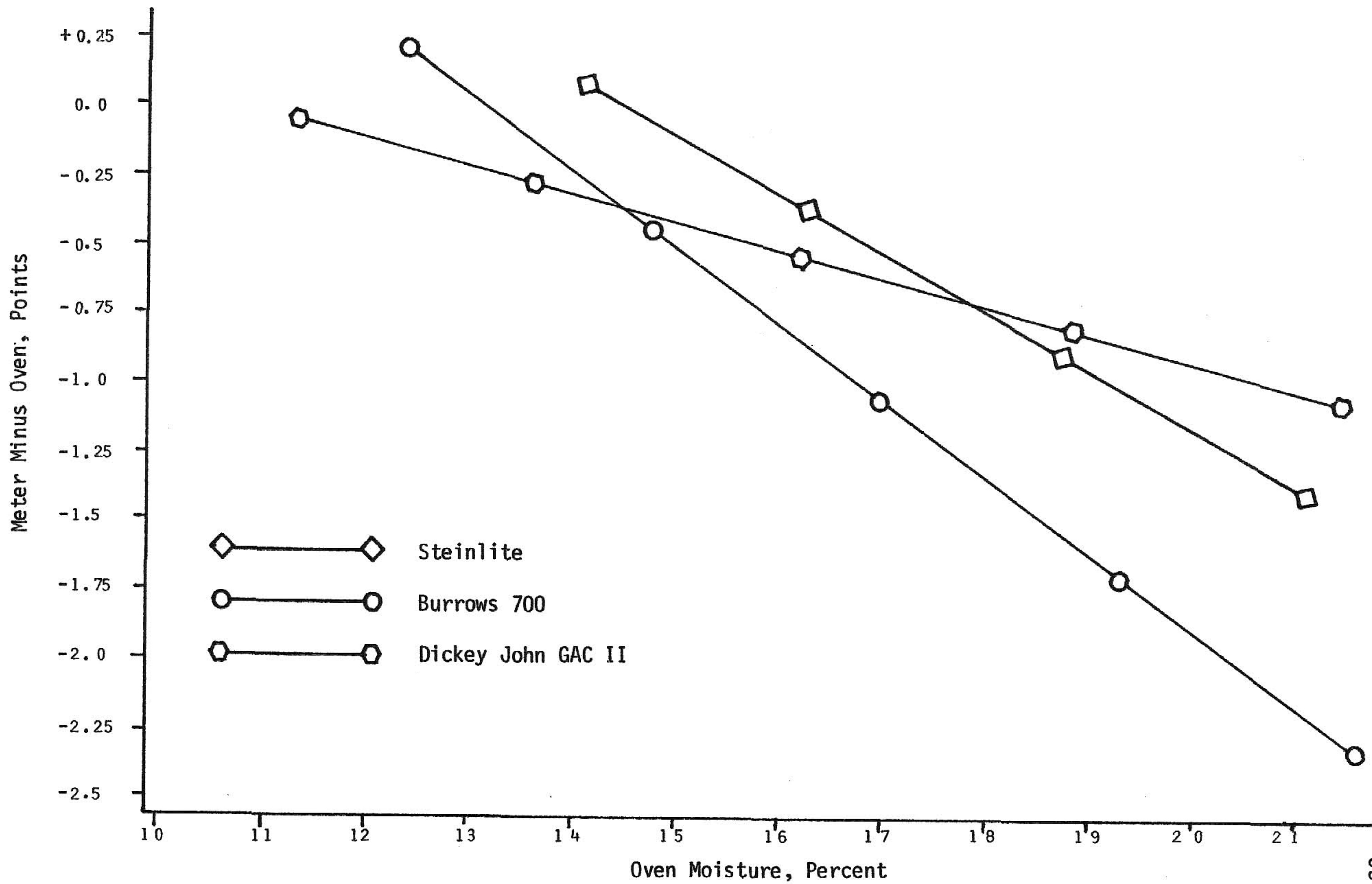


Figure 18. COMPARISON OF REGRESSION LINES (GRAIN SORGHUM)

slopes of the regressions were used to rank meter performance, this would be the order: Dickey-John GAC II, Steinlite and Burrows 700.

The majority of observations for the grain sorghum study are below the zero line as was the case with the wheat study. This is again different from results reported for corn by Hurburgh (1981) and Paulsen et al., (1982) who show a majority of observations above the zero line, especially at moisture levels of less than 25% moisture content. A study using corn reported by Hemeda et al., (1982) showed negative bias for observations below 25% moisture content and large positive bias for observations above 25% moisture content, which is contrary to the reports of Hurburgh (1981) and Paulsen et al., (1982), but supports this study's finding of negative values at moisture levels below 25%.

Statistical analysis by general linear models procedure has shown that the slopes of the regression lines from the grain sorghum study are significantly different from each other. Thus, on average, the meters are biased towards negative values, especially at higher moisture levels. Each meter responds differently to a given moisture range. The Dickey-John GAC II will cover the widest moisture range and result in the least amount of negative error at higher moisture levels.

The meters tested during the 1982 grain sorghum harvest yielded an overall meter error of -0.613% moisture. There were 2 meters that had a positive average error of +0.109% moisture and 24 meters that had a negative average error of -0.673% moisture. The amount of meter error found during the grain sorghum study is similar to that found during the wheat study.

LITERATURE CITED

Hemeda, Medhat A., Charles R. Hurburgh and Carl J. Bern. 1982. Effects of Corn Variety, Mechanical Damage and Drying Temperature on Electronic Moisture Meters. Proceedings ASAE Winter Meeting. ASAE. St. Joseph, MI.

Hurburgh, Charles R. 1981. Improving Moisture Measurement in the Corn Market. Ph.D. Thesis. Iowa State University. Ames, IA.

Hurburgh, Charles R., C. J. Bern and S. N. Grama. 1981. Improvements in the Accuracy of Corn Moisture Measurement in Iowa. Proceedings ASAE Winter Meeting. ASAE. St. Joseph, MI.

Paulsen, M. R., L. D. Hill and B. L. Dixon. 1982. Moisture Meter-To-Oven Comparisons for Corn. 1982 Grain Conditioning Conference Proceedings. University of Illinois at Urbana-Champaign. Urbana-Champaign, IL. pages 2-11.

CHAPTER V

SUMMARY

Information obtained from the returned questionnaires showed that overall average meter age was 4.6 years. The age of meters ranged from 20 years to new. Average meter age at elevators where wheat samples were collected was 5 years. The meters ranged in age from 15 years to new. Average meter age at elevators where grain sorghum samples were collected was 2.7 years. Meter age ranged from 12 years to new. The meters included in the wheat study were slightly older than the overall norm and the meters included in the grain sorghum study were newer. For all meters, the overall percent for service within the last 2 years was 67%. For the elevators supplying wheat samples it was 66% and for elevators supplying grain sorghum it was 79%.

Average age and service data of meters from elevators participating in the grain sorghum study appear to be different from the same data generated for elevators participating in the wheat study. The primary reasons for this are: some of the elevators with older meters did not contribute to samples to the grain sorghum, one elevator replaced a 5 year old meter with a new one and 2 elevators which did not participate in the wheat study contributed samples to the grain sorghum study and meter age for those two was unknown. The most popular form of moisture meter encountered during the study was the direct readout type. Meters of this kind represented 75% of the meters tested. Direct readout moisture meters provide a rapid visual report of moisture content. The Dickey-John GAC II provides a printout in combination with a visual report. Direct readout meters offer ease of operation. This may be of importance when a moisture meter is purchased. The Burrows 700 and the Steinlite SS250 are direct readout meters that require preweighing of the sample before it is placed in the meter. The Dickey-John GAC II does not require preweighing and thus offers the most ease of operation of any meter presently available. Because it contains a microprocessor, it requires a clean stable environment to insure proper operation. It is possible for the owner to periodically update the machine through a keyboard entry system using information supplied by the company. This enables calibration changes to be entered into the meter. Instead of physically altering circuits, the mathematical formula used to describe the calibration curve is changed.

Results have shown that meters tested gave a negative bias for both wheat and grain sorghum. Linear regression was used for each meter type and crop to provide a straight line model. It is believed large variability between samples resulted in poor fit of the linear models. Polynomial regression was used to check for curvilinear results. The data obtained when the Burrows 700 meters tested grain sorghum showed a curvilinear relationship for X^2. The results of regression analysis showed that the Steinlite and Burrows 700 meters performed in a similar manner when measuring moisture content of wheat or grain sorghum. The Dickey-John GAC II showed itself to be superior when measuring moisture content of grain sorghum, but had difficulty with wheat.

The coefficient of variation may be used to indicate meter performance based upon the relationship between average error and standard deviation. By using the average standard deviation and average error of a class of meters, the coefficient of variation (C.V.) can be generated. When this is done with the meters in the wheat study, it shows that although average error was low for the Steinlite and Burrows 700 meters, the precision with which that error was generated was not good. The C.V. for Steinlite meters in the wheat study was 80% and the C.V. for Burrows 700 meters was 67%. In the wheat study the average error for the Dickey-John GAC II was high, but the precision with which that error was generated was very good. In the wheat study, the C.V. for the Dickey-John GAC II's was 22%.

The causes of these different C.V.'s are varied. In the case of the Steinlite and Burrows 700 meters, the lack of precision may be caused by: improper calibration, variability of samples treated or operator error. The Dickey-John GAC II, because of the precision it exhibits is most likely improperly calibrated. Another possibility is that the 1982 wheat crop was not representative of an average crop. Inclement weather plagued the harvest throughout its duration, delaying it in many areas across the State. Conditions early in the growing season were favorable to fungal growth which may have had an effect on the wheat. Any of the conditions singularly or in combination may have altered the dielectric properties of the wheat to such an extent that normal calibration curves could not correct for. Any change of the dielectric properties would have an effect on meter performance since all the meters tested measure the dielectric properties of grain to report moisture content.

In the grain sorghum study, the use of the coefficient of variation results in the following. The average error and average standard deviation for the Steinlite meters were low, however, the C.V. is 95%. This indicates that although meter error was low, the precision with which the error was generated was practically non-existent. Even though the Burrows 700 and Dickey-John GAC II meters have different average errors, their C.V.'s are very similar and indicate that precision in error generation is not good. The Burrows 700 meters had a C.V. of 52% and the Dickey-John GAC II's had a C.V. of 58%. The conclusion that must be drawn is that none of the meters worked well when testing grain sorghum. Variability of samples most likely produced results that did not allow much precision.

Unlike Iowa and Illinois, the meters used in Kansas appear to be biased towards negative values at higher moisture levels which benefits the seller. If the meters tested are truly representative of all meters in Kansas, the error that was found to exist is not as great as the error found in Iowa and Illinois. However, it must be stressed that at moisture levels in excess of 13.5% the chance of insect and/or fungal infestation of stored grain increases. The negative error displayed by meters in Kansas increases as moisture level increases. There exists the possibility that storage problems may arise at some elevators due to the negative bias of the meter used in making moisture determinations. Negative bias causes a meter to read less than actual moisture. Therefore, grain may have been placed in storage that is not at a moisture level considered safe.

There is reason for concern about the accuracy and precision of moisture meters used in Kansas. More in-depth studies in the future may help to bring about a means of reducing moisture meter error or they may show that variability occurs to such an extent that present technology cannot compensate for it.

APPENDIX A

Letter of introduction and questionnaire sent to elevators.

Letter:

Dear Sir:

In recent years, concern has risen over the accuracy of the various electronic moisture meters used in grain elevators. Recent studies in Iowa and Ohio indicate that there are some problems with some meters used in corn at higher moistures. We are undertaking a study to determine how well the various meters are performing on grains within Kansas with some emphasis on wheat and grain sorghum. Of primary interest is the make, model, approximate age and service record of the instrument at your location. We are especially interested in the accuracy of the meters when testing higher (18-25%) moisture grains to see if there are problems in our State.

In order to begin this work, we would appreciate it if you would take a few minutes to fill out the attached card and return it at your earliest convenience.

The next phase of the study will involve collecting grain samples with meter readings on numerous locations throughout the State. These samples would then be tested for moisture using approved oven methods.

We would appreciate an indication as to whether or not you would let us collect samples and readings at your location during wheat and grain sorghum harvest. You can be assured that we wouldn't interfer with harvest activities.

We also would be more than happy to share the results of the study with you. Samples and locations would be coded so that confidentiality would be maintained. Results of data collected at your elevator would be identified to you for your benefit.

Your cooperation in this effort will be greatly appreciated. Hopefully, the study will allow us to get a feel for the performance of the meters and determine if problems do exist. If you have questions, please don't hesitate to contact me.

Sincerely,

APPENDIX A continued . . .

Questionnaire:

1. Company Name ______________________________

2. City ____________________ Zip Code __________

3. Person to Contact _______________ # __________

4. Moisture Meter Make _________________________

5. Model No. ____________ Approx. Age of Meter ______

6. Last serviced or certified (date) _______________

7. Are you satisfied with your instrument:

   ____ Totally, ____ Mostly, ____ Somewhat, ____ Not at All

8. Would you be willing to participate in the collection of samples and readings (by visit from us) at harvest?

   _____ yes, _____ no

APPENDIX B

Method for determining oven moisture of whole kernel wheat and grain sorghum.

1. 10 gms. of sample weighed into tared moisture dishes in duplicate.
2. Moisture dishes with covers beneath placed on central shelf of oven.
3. Oven was set at 130C and drying time was 19 hrs. for wheat and 18 hrs. for grain sorghum.
4. Upon termination of drying time dishes were removed and covers put in place.
5. Covered moisture dishes were allowed to equilibrate to room temperature.
6. Covered moisture dishes were weighed and results recorded.
7. Moisture was determined as loss of weight

   Moisture % = A/B x 100

   where A = moisture loss in gms.

   B = original weight of sample
8. Duplicates of same sample must check within ±.2% moisture; otherwise repeat determination.

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My parents, Dr. and Mrs. Berl Koch deserve most of the credit for what the author has accomplished. The author would like to thank and let Bill Tacker know that his friendship will not be forgotten. Shelby Kleindolph is due a hug for being my raquetball partner for three years and letting me win sometimes. For all the times she made me feel more human, I give my love and thanks to my dog, Tosha. Finally, I wish to thank God who gave me courage when I was afraid.

STUDIES OF ELECTRONIC MOISTURE METER PERFORMANCE ON FRESHLY HARVESTED GRAINS IN KANSAS

by

KIM B. KOCH

B.S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

ABSTRACT

Electronic moisture meter performance at rural or country elevators in Kansas became a matter of concern after publication of reports from Iowa and Illinois indicated electronic moisture meters used at country elevators in those States were performing in an unacceptable and unreliable manner. Electronic moisture meters in Iowa and Illinois exhibited extreme variation when compared to oven moistures for high moisture corn. The crops of concern in Kansas are wheat and grain sorghum, both of which are harvested at much lower moisture levels than corn in Iowa and Illinois. Knowledge as to how well moisture meters in Kansas perform on the two main crops was needed and also some idea of the types of meters in use at country elevators in Kansas, their ages, service dates and owner satisfaction with meter performance. Survey forms were sent to 292 country elevators and replies were received from 153 which is a return rate of 52%. The elevators responding represented 76 of the 105 counties in Kansas. Fifty elevators of the 153 responding were visited for sample collection to test electronic moisture meter performance during the 1982 wheat harvest and 23 of these elevators plus 3 others were visited for sample collection during the 1982 grain sorghum harvest.

Results of the survey responses show that the most popular brands of meters are Steinlite, Burrows 700 and Dickey-John GAC II respectively. The average overall age is 4.6 years with a range of new to 20 years of age. Service records show that 67% of responding elevators have moisture meters that were services in the last 2 years. According to the survey, the direct readout style of moisture meter is the most popular, representing 75% of total.

The results of sampling at the elevators visited during the wheat harvest show an average meter age of 5 years with 66% being serviced within the last 2 years. The overall meter error was -.66% moisture with 44 meters having negative average error of -.80% moisture and 6 meters having positive average error of +.351% moisture. Statistical analysis has shown that all meters perform the same when compared to one another.

Results obtained from samples collected during the grain sorghum harvest show an average meter age of 2.75 years with 79% of meters being serviced within the last 2 years. Overall average meter error was -.61% moisture with 24 meters showing negative average error of -.67% moisture and 2 showing positive average error of +.109%. Statistical analysis has shown that the Steinlite and Burrows 700 perform about the same in relation to each other with the Dickey-John GAC II being superior to them in regard to variation from zero line.

The testing process indicates that moisture meters in Kansas show a negative bias on average which is to the farmer's benefit. The meters in Kansas do not show quite the variation found in Iowa and Illinois, but variation does exist. Further study is needed to define what percent of total variation is caused by the sample and/or the meter.