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Development of an electronic moisture meter for abaca fiber

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ABSTRACT

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An electronic, portable, cheap and easy-to-operate moisture meter was developed and fabricated using the resistivity–conductivity principle of operation which states that the presence of moisture in the fiber conducts electrical current from one terminal end to the other. Its circuitry followed that of the modified wheatstone bridge and used an LM 324 Op Am Integrated circuit.

Results of the calibration studies showed highly significant relationships between the meter reading and the oven drying method even at the fiber pressure of only 100 g/cm^2 (estimated at 4 kg pressure at the test probe handle). Further studies using fiber samples of zero and 14-blade serrations revealed highly significant relationships between the moisture reading and the oven drying method with an R-value of 0.986 and 0.976 and trendline equations of $y = 2.34 + 1.07x$ and $y = 0.8376x$, respectively. This means that the meter is still capable of reading moisture content of abaca fiber at different classifications with greater accuracy and reliability.

Potential end-users' acceptability evaluation of the meter revealed higher acceptability rating from the farmers than the traders.

Keywords: moisture meter, abaca moisture, fiber moisture, moisture content

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INTRODUCTION

Abaca fiber, commonly known in the international market as Manila Hemp, is indigenous to the Philippines. It is a principal export commodity that generates significant amount of foreign exchange. It is used for making specialty paper products such as tea bags, document papers, paper exchange bills, and the like; for cottage industry such as manufacture of bags, wall décor, etc; and for cordage. The demand for abaca fiber and fiber-based products is increasing both domestically and internationally (FIDA, 1999).

Marketing of abaca fiber is beset with problems some of which are poor fiber quality, unsorted fiber, lack of marketing association and effective price information, and too rigid fiber classification. Buyers especially the middlemen generally complain about poor fiber quality. This is due to factors like harvesting overmatured plants, poor color due to delayed stripping and low stripping quality due to poor method of stripping. Some sellers adulterate the dry fiber with wet fiber to increase weight and supposedly the selling price. Such unscrupulous practice of mixing the dry with wet fiber leads to discoloration (browning) and lowering of tensile strength of the fiber when stored. Color and tensile strength of the fibers mainly dictate the price.

Several methods of moisture determination that had been developed include instruments that employ electrical conductivity (either DC or AC), absorption of electromagnetic energy (radio-frequency regions), electrical capacitance (dielectric constant change), and infrared energy radiations. These methods are more easily adapted to continuous measurements in as much as the response of these instruments to changes in moisture is very fast.

Other methods such as oven drying, chemical tritrations, equilibrium hygrometric, and distillation are usually of the intermittent or periodic type.

The textile industry uses the regain moisture content method and implies the use of oven drying. Electrical conductivity is another method based on the relationship between direct current resistance and moisture content. However, the variation of the results this method ranges approximately from 12 to 25% moisture content. Another method is the electrical capacitance. This method is based on the principle of the change in dielectric constant between dry and moist conditions of a material. The equilibrium hygrometric method is based on the principle that the equilibrium moisture content of the air at the surface of a material is a representative of the moisture within the material. The chemical method is based on the reaction of moisture to a certain chemical. Distillation method is done by allowing the moisture of a given sample to be evaporated. The water that will be collected from the evaporation is the moisture content of the sample (Mcgraw Hill Encyclopedia of Science and Technology, 1987).

Until now, no moisture meter has yet been developed for abaca fiber, hence this study was conducted to design an electronic circuit responsive to changes in moisture content of abaca fiber. It also aimed to construct and evaluate a moisture meter for abaca fiber that is made of cheap and locally available materials, accurate and precise, simple and easy to operate. The use of the moisture meter will ensure that the abaca fiber that will be sold is properly dried.

MATERIALS AND METHODS

Review of existing methods

A review of available information was done on existing methods used to determine the moisture content of fibrous materials and textile products. Result of the activity was used to evaluate the potential methods that were adapted to the development of a portable, cheap, accurate and precise, simple and easy to operate moisture meter.

Design of electronic circuitry

After deciding on the specific methods that fit the desired moisture meter for abaca fiber, electronic circuitry was designed. Electronic technicians, with experience in a similar research were tapped to draw the circuit and fabricate the meter.

Consideration of the factors affecting design circuitry

The surface area of the terminal ends which is a function of the distance between terminal ends, length of the probe terminals, and size of the probe terminals was considered as the main factor affecting the designed circuitry.

- Distance between the terminal ends. The closer the distance of the two terminal ends, the stronger is the conductivity of the electrons from one terminal end to the other. This increases the sensitivity of the moisture tester circuitry. The distance of the probe terminals was kept constant at 1.5 cm (c-c) apart.
- Length of the probe terminals. The longer is the exposed end of the probe terminals, the bigger is the surface area for current transmission. This results to an increase in passage of the electrons from one terminal end to the other. The length of the exposed ends of the terminal was also kept constant at 2 cm.
- Size of the probe terminals. The bigger is the size of the probe terminals, the bigger is the potential surface area for the electrons to pass through from one terminal end to the other. The size of the terminal probe was kept at 5 mm.

Design and fabrication of the test probe

The test probe was designed to penetrate into the middle of the fiber bundle during testing. Moreover, consideration was made so that it also automatically provides pressure and compresses the fiber during moisture determinations to obtain more reliable results.

Compactness of the sample fiber

To obtain consistent and more reliable results, the fiber to be tested needs to be compressed to establish continuity of the moisture present in the surface of the fiber. The continuity of the moisture in the fiber served as bridge for the electrons to travel from one terminal end to the other.

A pressure table was fabricated which was used to contain and provide pressure on the fiber sample to be tested. Three counter weights were used which correspond to three different pressures on the sample fibers, namely: 100 g/cm^2, 150 g/cm^2 and 200 g/cm^2.

Moisture content reading of the sample using the designed moisture meter at three different fiber pressures were taken to determine what fiber pressure would yield significant relationship between the actual moisture content and the moisture content reading of the designed meter.

Coarseness and fineness of the abaca fiber

Fineness of the fiber affects the continuity of the moisture in the surface of the fiber. Fine fiber is easier to compact than coarse fiber. To determine the effect of using different fiber texture (fineness), the meter was evaluated using two different fiber samples: zero serration and 14 blade serrations.

Evaluation

The circuitry of the designed moisture meter was subjected to a stability test using electronic oscilloscope at the Physics Section, Department of Agricultural Engineering, Leyte State University. Stability of the circuit was observed in the monitor of the instrument when there was no fluctuation in the current passing through the circuit.

Repeatability test was also conducted by subjecting the meter to testing in the same spot of the fiber bundle for 10 times. After each reading was taken, the meter was put off and then put on again for another reading. The pointer was set to zero position using the zero control knob and the reading was taken by pushing the probe terminals to the fiber bundle. Repeatability was computed using equation 1:

$$R = \frac{n}{N} \times 100 \qquad (1)$$

Where:

R = repeatability in percent
n = number of observation which gave the same reading at an allowable variation of ± 1 %
N = total number of observation

Calibration of the designed moisture meter

Calibration of the moisture meter was conducted based on the oven drying method (ASAE, 1997). Saturated abaca fiber was weighed and placed inside an oven at 70°C. Data on the moisture loss of the fiber was taken every 30 minutes. As the fibers became drier, the time interval in taking the reading was reduced to 10 minutes to determine the drying behavior of the fiber. In determining the amount of moisture loss at its time interval, equation 2 was used:

$$MCLoss = \frac{W_1 - W_2}{W_{d.b.}} \times 100 \qquad (2)$$

Where:

$MCLoss$ = moisture content loss, percent (d.b.)
W_1 = mass of the fiber at the previous weighing, grams
W_2 = mass of the fiber at the current weighing, grams
$W_{d.b}$ = bone dry mass of the fiber, grams

After the samples were weighed in an electronic weighing balance with an accuracy of $\pm$ 0.001 g, the moisture content reading of the fiber was taken using the designed moisture meter. To observe the drying behavior of the drying fiber, a drying curve was drawn by plotting the moisture content of the fiber at the ordinate axis against time at the abscissa. A scattered X-Y chart was also made by plotting the moisture reading against oven drying to establish the relationship between the moisture meter reading and the actual moisture content of the fiber. An R-value was also computed using Microsoft Excel to determine the degree of the relationship of the moisture reading and actual moisture content of the fiber.

Prospective end-users acceptability evaluation

About seventeen guide questions were developed for end-users assessment of the portability, usability, workability and general acceptability rating of the portable moisture meter. These were also made in order to introduce the instrument to prospective end-users in the locality. The guide questions were pre-tested to 10 prospective farmer-users and 10 small traders in the towns of Sogod in Southern Leyte and Mahaplag and Baybay in Leyte. Each question required the farmer and trader to give their individual score based on the scale ranging from 1 to 5 with 5 as the highest score and 1 as the lowest. Before the questions were asked, the farmers/traders were first requested to test the moisture meter to have a feel of how the instrument works and functions.

RESULTS AND DISCUSSION

The methods chosen that met the requirements of a cheap, precise and portable abaca fiber moisture meter are the electrical conductivity and electrical capacitance (dielectric constant).

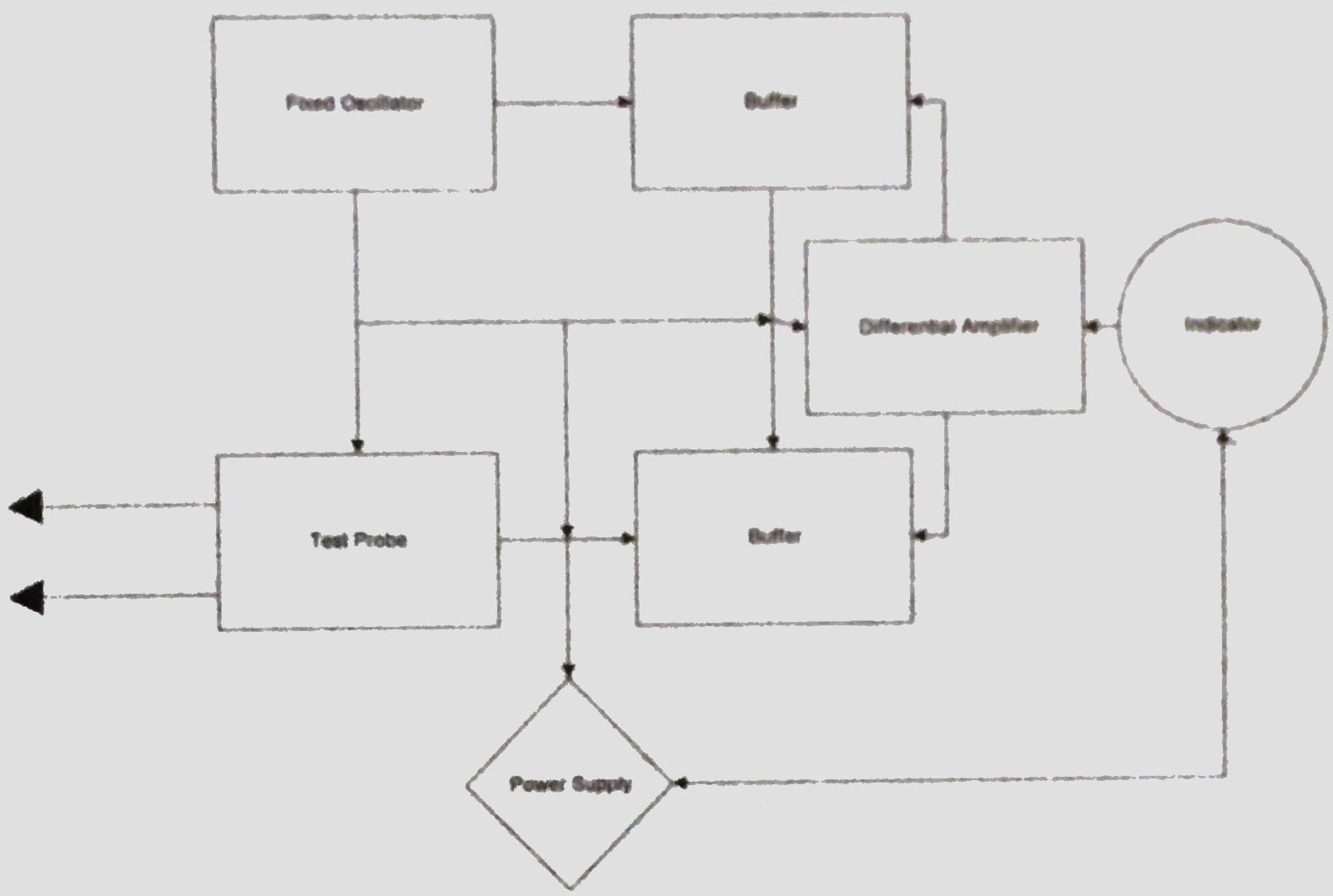
Design of electronic circuitry

An electronic circuit was designed and fabricated from electronic parts such as multi-tester indicator, LM 324 ICs, AM crystals and oscillators. Its circuitry followed the modified wheatstone bridge (Malmstadts and Enke, 1985) and operates based on the principle of conductivity which states that the presence of moisture in the fiber surfaces conducts electricity from one terminal end to the other, while the absence of it will also resist the flow of current because water is a good conductor of electricity. The test probe was made from two 3/16" Ø × 1/4 ft length stainless steel pointed at the tip to penetrate in a bundle of fiber. The different parts of the electronic circuit are shown in Figure 1.

The parts of the moisture meter are test probe, control knob, indicator, oscillator, power supply and amplifier. The flow of current starts from the power supply then to the sampling electrodes or test probe, to the oscillator then to the amplifier and finally to the indicator. The case and indiçator of the meter were adapted from that of the Sanwa multimeter tester. The indicator was modified by replacing the scale with percent moisture content. The power supply is using a single 9 volts battery.

Development of the test probe

Figure 2 shows the development of the test probe. The first test probe design consisted of two long probe terminals of 30 cm long to penetrate into the middle of the fiber bundle. However, when this was tested, it could not penetrate into the fiber bundle because the latter was hard. The next design adapted the use of a coil spring which circumscribes the two terminals. The spring was supposed to provide the necessary pressure to the fiber sample during testing. This design did not materialize due to the unavailability of the right size, diameter and spring constant of the desired compression coil spring.



Block Diagram of the designed moisture meter

Figure 1. Block diagram of the designed moisture meter showing the different parts.

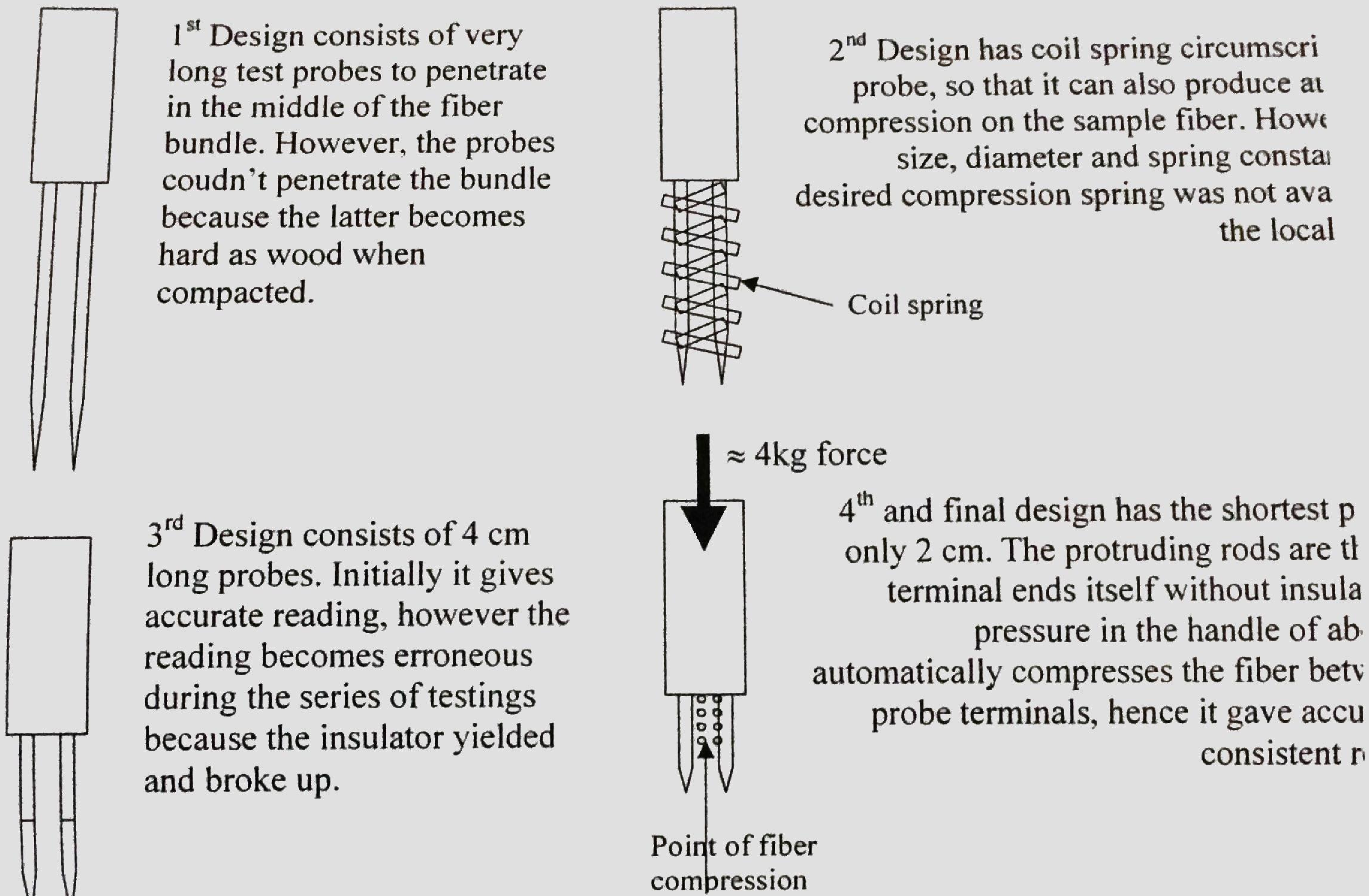


Figure 2. Development of the probe

Figure 3. Perspective view of the designed moisture meter for abaca fiber.

The next design had shorter probe terminals of only 4 cm. Half of the terminal length was covered by an insulator. However, when this was inserted into the fiber bundle during the series of trials, the reading of the meter became erroneous since the surface area of the terminal ends increased because the insulator yielded and broke up. The final design adapted the shortest probe terminals with only 2 cm long. The exposed portion of the length was the terminal ends and do not have any insulator. Since the probe terminals are short, the fiber sample becomes automatically compressed at the middle of the probe teminals.

Description of the prototype

The electronic moisture meter prototype (Figure 3) weighs only 500 g. The circuitry is using LM 324 Op Am Integrated Circuit, designed for instrumentation purposes that has a rated sensitivity of .002mV. It is accurate, reliable, low drift and operates at high range of temperature and humidity (Horowitz and Holl, 1986). The meter is provided with a Light Emitting Diode (LED) that lights at on position and off at off position. It has also a zero control knob that is used to set the pointer to zero for greater accuracy during reading.

The indicator displays the actual moisture content reading as the test probe is penetrated on to the fiber bundle.

Salient features

Read Out :	Analog
Least Count :	0.5% MC
Power supply:	single 9 volts battery
Measurement range:	8-35% MC
Total weight:	500 grams
Accuracy:	±2% of true value (oven drying method)
Reliability:	97%
Repeatability	100% at an allowable variation of 1 % MC d.b.
Sensitivity:	@ 14% MC of the fiber, resistance reading was 20MW and current reading at 1m
Cost:	P 2000.00

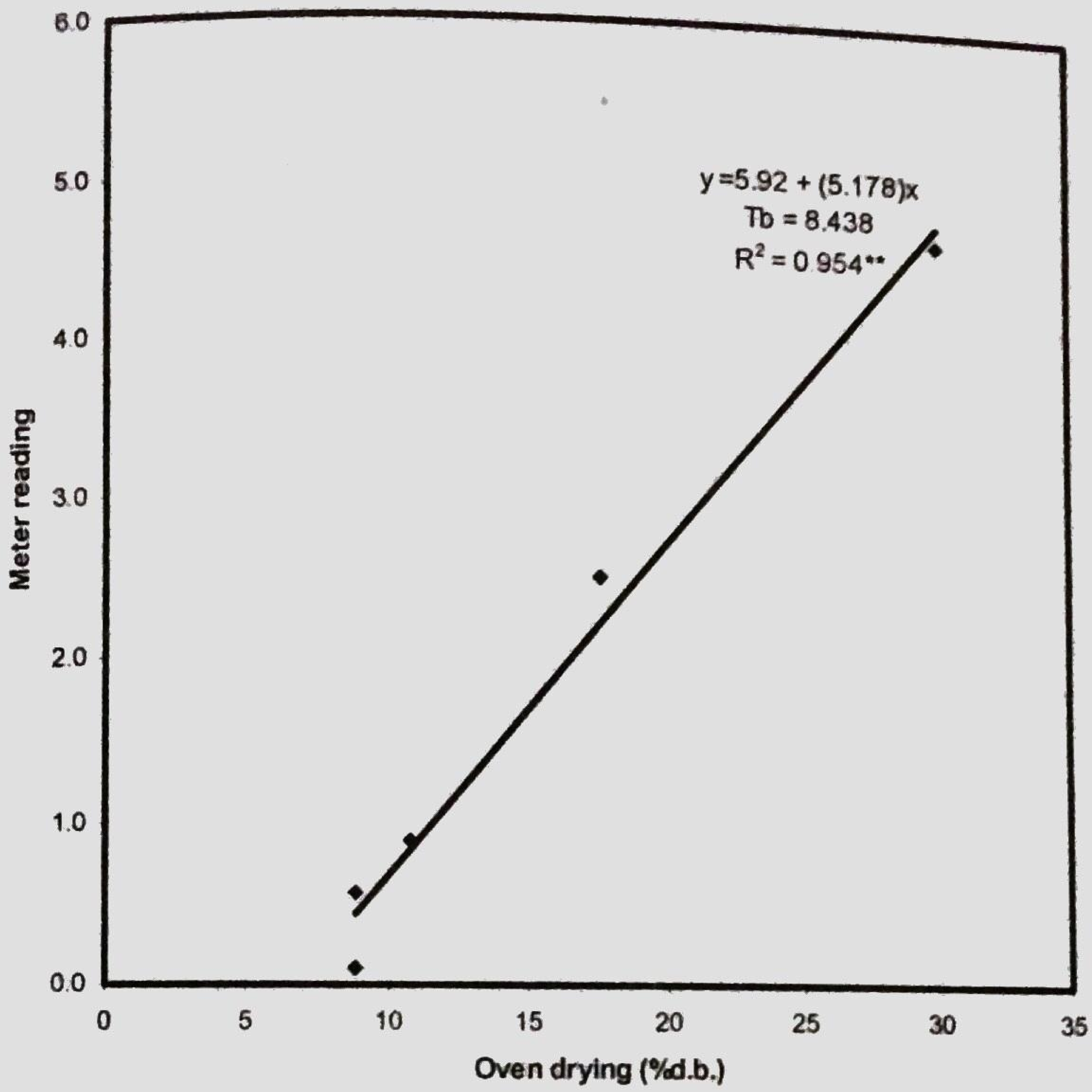


Figure 4. Linear relationship between meter reading vs oven drying method at 100 g/cm² fiber pressure

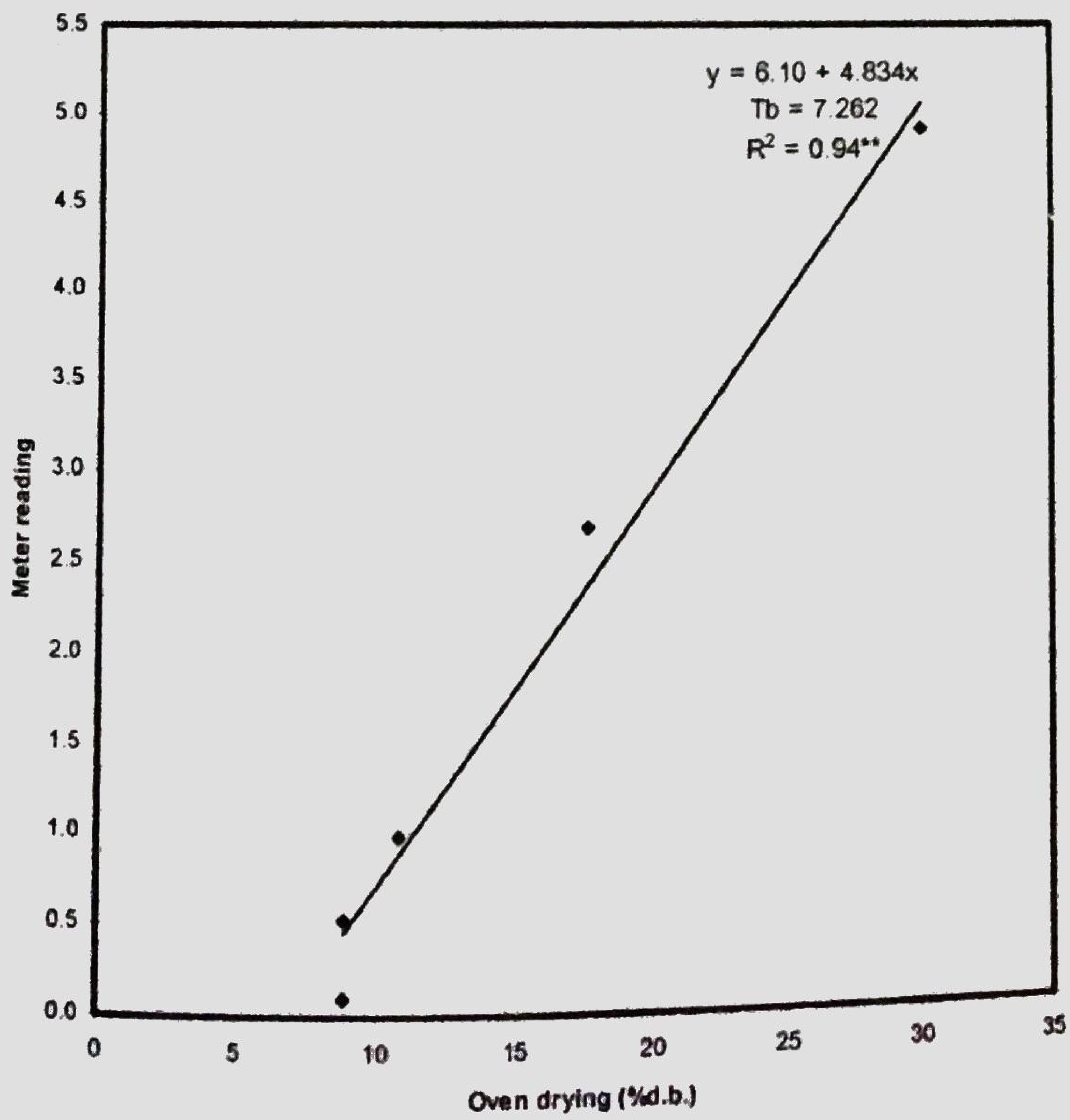


Figure 5. Linear relationship between meter reading vs oven drying method at 150 g/cm² fiber pressure

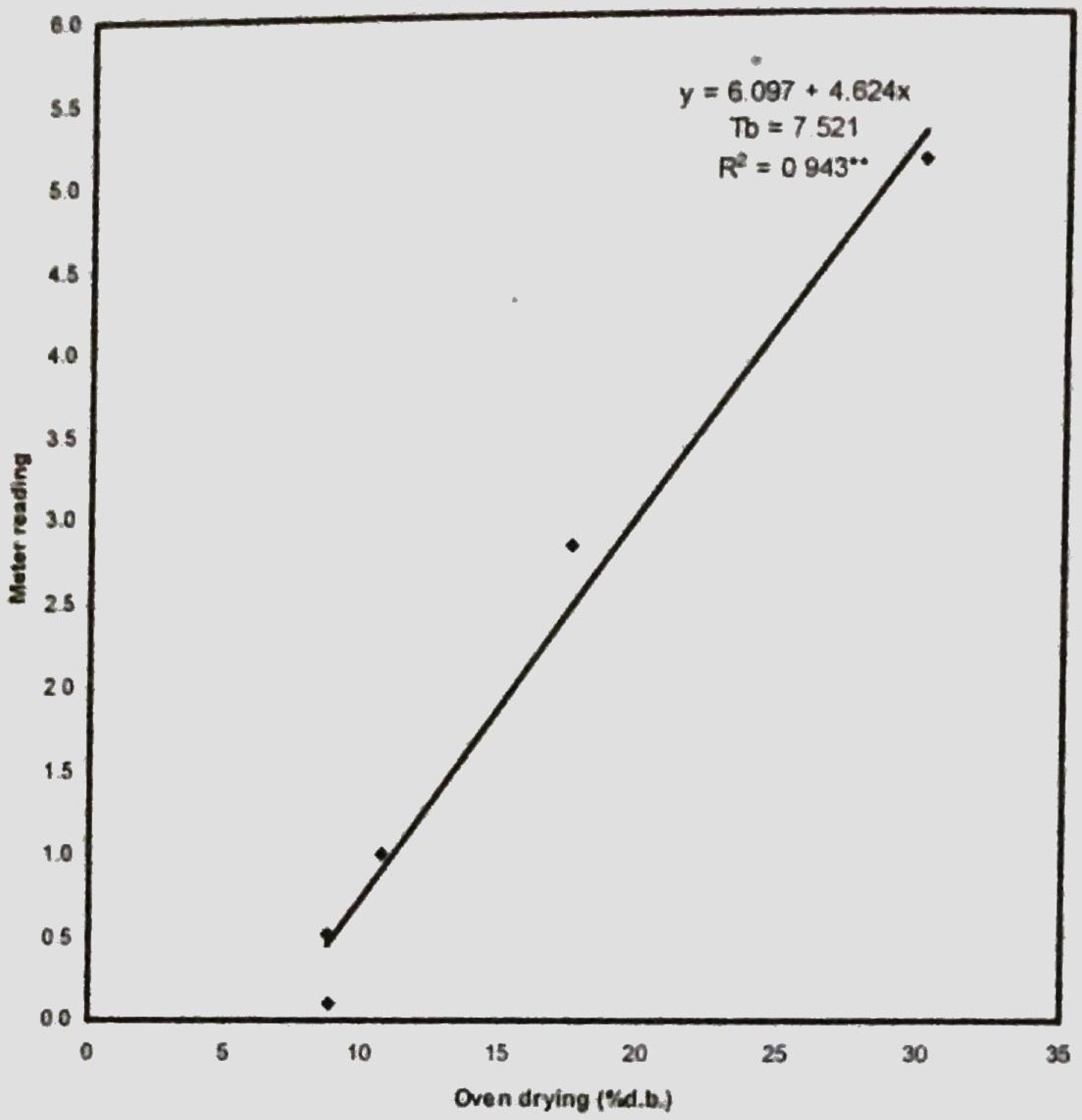


Figure 4. Linear relationship between meter reading vs oven drying method at 200 g/cm^2 fiber pressure

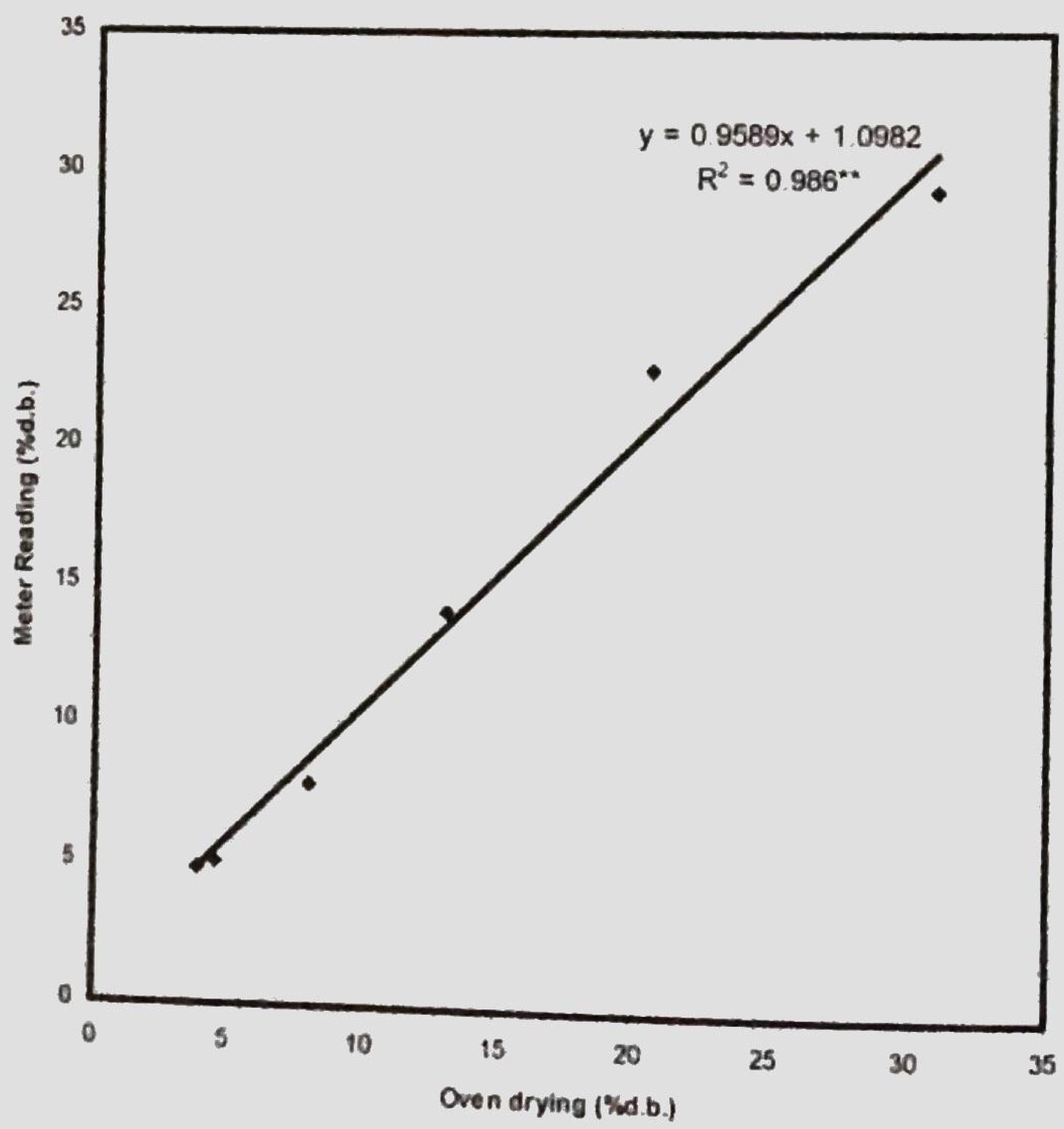


Figure 4. Linear relationship between meter reading vs oven drying using fiber from zero serration

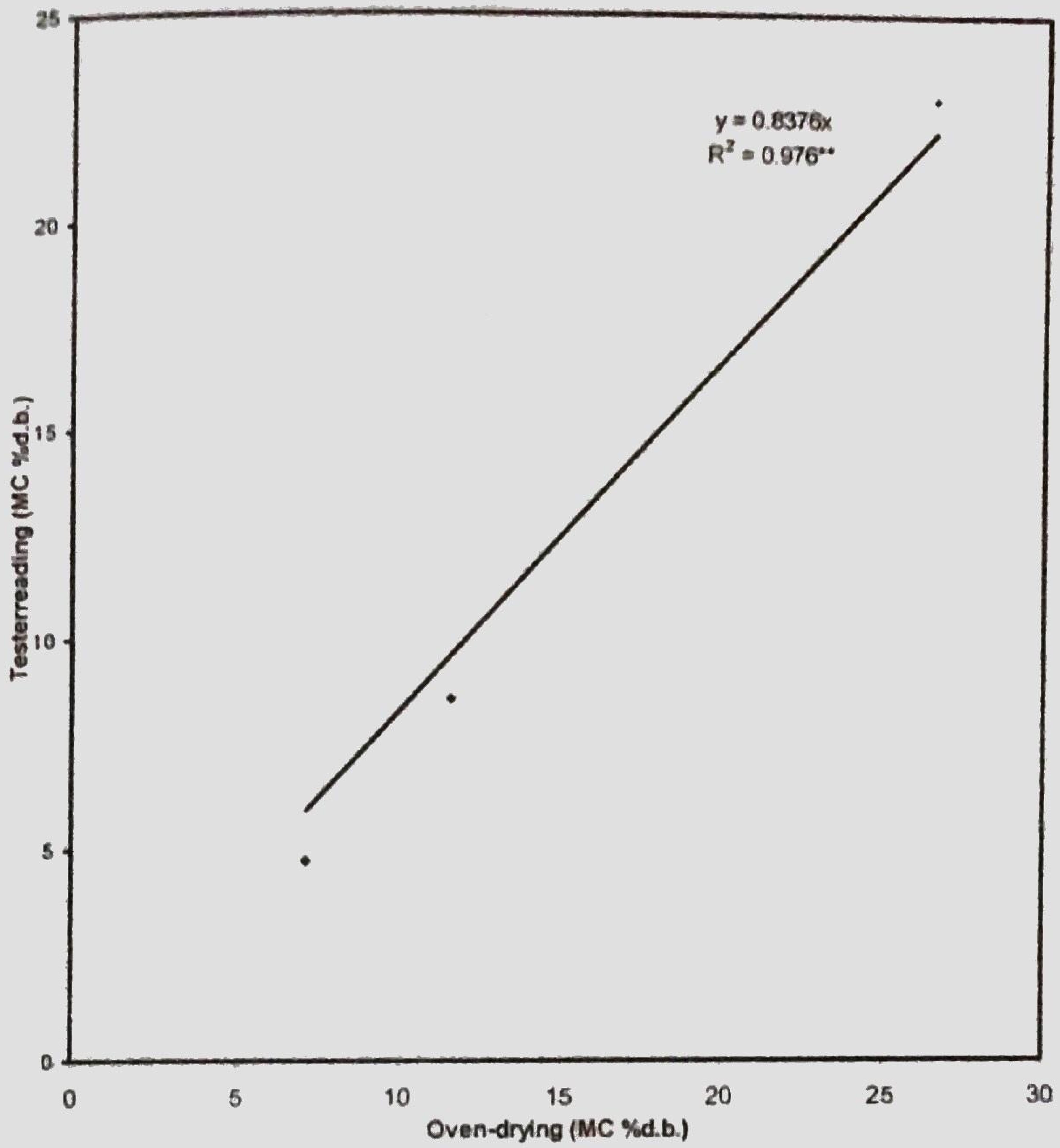


Figure 4. Moisture content reading of the tester using fiber stripped with 14 blade serrations

Evaluation Results

Figures 4, 5 and 6 show the results of the calibration studies on the meter reading based on the oven drying method at three different fiber pressures. Results showed highly significant relationships between the meter reading and the oven drying method with an R-values of 0.954, 0.94, and 0.943 for fiber pressures of 100, 150, and 200 g/cm^2. This indicates that the meter is still reliable at the lowest pressure of 100 g/cm^2.

Figure 7 shows the linear relationship between the moisture reading and the oven drying method using fiber sample from zero serration. Results revealed a highly significant relationship with an R-value of 0.986.

Figure 8 shows the plotted data of the meter reading and the moisture content of the fiber using Microsoft Excel scattered diagram. It shows an R-value of 0.976 and a trendline value of $y = 0.837x$. This signifies that the meter is accurate in giving the moisture content of the fiber even with fiber of coarser textures. It can also be noted in the diagram that the meter is only capable of reading moisture content ranging from 8% to 35%. Beyond 35% and below 8% level, the reading is expected to be erroneous.

Acceptability evaluation

Table 1 shows the users-based evaluation results of the portable moisture meter. Results showed that in terms of portability, 30% and 70% of the farmers scored 4 and 5 points, respectively, while 20% and 60% of the traders gave the score of 4 and 5, respectively. This means that the traders and the farmers were convinced that the instrument is portable. In terms of workability, 60% and 30% of the farmers gave the score of 4 and 5 points, respectively, while only 50% and 30% of the traders gave 4 and 5 points, respectively. One hundred percent of the farmers signified that the meter is useful, however, only 60% of the traders gave the highest score of 5 for usability. For general acceptability, 10%, 40% and 50% of the farmers gave the scores of 3, 4 and 5, respectively, while 20, 40 and 40% of the traders gave the scores of 3, 4 and 5, respectively. The overall results indicated that the moisture meter could be a potential instrument that would be adaptable to the end-users and maybe effective in maintaining the quality of fiber by ensuring the right moisture content during trading activity. Further, the results also showed

Table 1. Prospective farmer and trader-users evaluation results for the portable moisture meter.

Criteria	Evaluators Abaca Farmers	Abaca Traders
Portability	3 = 0%	3 = 20%
	4 = 30%	4 = 20%
	5 = 70%	5 = 60%
Workability	3 = 10%	3 = 20%
	4 = 60%	4 = 50%
	5 = 30%	5 = 30%
Usability	1 = 0	1=20%
	3 = 0	2=20%
	5 =100%	5=60%
General Acceptability	3 = 10%	3 = 20%
	4 = 40%	4 = 40%
	5 = 50%	5 = 40%

that the farmers have slightly higher acceptability rating than the traders. The reason for this has not been established yet at the moment.

During the process of acceptability evaluation, it was observed that farmers and traders do not incorporate tensile strength as one of the criteria in assessing fiber quality. They do not bother to test the fiber for strength as long as the color and moisture content are right. In terms of their decision to purchase the instrument, they do not plan to buy the instrument unless this will be required by the authority for fair trading and quality assurances.

Recommended computation for the reduction of abaca price

The recommended computation for the reduction of the price of abaca with the variation in the recommended moisture content (14%) will be based on equation 3.

$$RP = P - P\left(\frac{MC}{100} - .14\right) \tag{3}$$

Where:

RP	=	recommended price, Peso
P	=	current price of the fiber, Peso
MC	=	moisture content of the fiber, percent

Example:

What is the total selling amount of 100kg abaca fiber at 20% MC, if the current price of the fiber is P 20.00?

Solution:

1. Solving for the recommended price (RP)

$$RP = 20 - 20\left(\frac{20}{100} - .14\right) = 18.8$$

2. Solving for the total selling amount of the fiber

$$Amount = P18.8 / kg \times 100\ kg = P1{,}880$$

RECOMMENDATION

1. Further evaluation shall be conducted to ensure reliability, accuracy and usability of the developed moisture meter.

2. The Fiber Development Authority should look into the usefulness of the technology and the possibility of incorporating the meter in the buying and selling of abaca fiber.

3. The developed moisture meter maybe useful in determining the moisture content of other hard fibers such as coir, sisal, hemp, maguey, and others.

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