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Abstract

Moisture content (MC) of poultry manure or litter affects its ammonia (NH_3) emissions. Relating MC to ammonia emission of manure or litter is thus of importance to modeling and/or managing ammonia emissions from the manure sources. Development of such relationships would require the knowledge of ammonia emission and the concomitant MC of the manure or litter. This work was carried out to characterize the operational performance of a commercially available soil MC sensor for measuring MC of meat-bird (broiler and turkey) litters and laying-hen manure. Laboratory and field calibration tests of the sensor output vs. MC of the source were conducted for the meat-bird litters and layer manure, respectively. Moisture content varied from 27.1% to 55.5 % for the broiler litter, 22.8% to 56.1 % for the turkey litter, and 11.0% to 75.0 % for layer manure. Bulk density (BD) varied from 318 to 468 kg · m^{-3} for the meat-bird litters. Sensitivity of the sensor to source temperature was also evaluated. Multivariate linear regression models were developed to relate the sensor EMF output to the litter or manure MC and BD (R^2=0.95 – 0.98). The impact of litter temperature on MC measurement by the sensor was found to be rather small, 0.31% of the measured mV per ^{o}C deviation from the mean operating temperature over the range of 4 ^{o}C to 24 ^{o}C. Results of the study indicate that when properly calibrated, the soil MC measurement sensor offers a reasonable means to quantify MC of poultry litter or manure on a real-time basis.

Keywords

Poultry manure, ammonia emission, real-time moisture content measurement

Disciplines

Bioresource and Agricultural Engineering

Comments

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Evaluation and Calibration of a Soil Moisture Sensor for Measuring Poultry Manure or Litter Moisture Content

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Abstract. *Moisture content (MC) of poultry manure or litter affects its ammonia (NH_3) emissions. Relating MC to ammonia emission of manure or litter is thus of importance to modeling and/or managing ammonia emissions from the manure sources. Development of such relationships would require the knowledge of ammonia emission and the concomitant MC of the manure or litter. This work was carried out to characterize the operational performance of a commercially available soil MC sensor for measuring MC of meat-bird (broiler and turkey) litters and laying-hen manure. Laboratory and field calibration tests of the sensor output vs. MC of the source were conducted for the meat-bird litters and layer manure, respectively. Moisture content varied from 27.1% to 55.5 % for the broiler litter, 22.8% to 56.1 % for the turkey litter, and 11.0% to 75.0 % for layer manure. Bulk density (BD) varied from 318 to 468 $kg{\cdot}m^{-3}$ for the meat-bird litters. Sensitivity of the sensor to source temperature was also evaluated. Multivariate linear regression models were developed to relate the sensor EMF output to the litter or manure MC and BD (R^2=0.95 – 0.98). The impact of litter temperature on MC measurement by the sensor was found to be rather small, 0.31% of the measured mV per ^oC deviation from the mean operating temperature over the range of 4^oC to 24^oC. Results of the study indicate that when properly calibrated, the soil MC measurement sensor offers a reasonable means to quantify MC of poultry litter or manure on a real-time basis.*

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INTRODUCTION

In 2006, worldwide chicken meat production was approximately 60.1 million tons. The United States led the world production with 16.2 million tons, followed by China (10.3 million tons) and Brazil (9.0 million tons) (USDA, 2006). Along with the increasing poultry meat and egg production come the increasing public attention and concerns over the environmental issues, including air and water quality. A major pollutant from poultry operations is the atmospheric ammonia (NH_3). It has been reported that 90% of the total NH_3 emission in Western Europe is caused by agricultural activities (Stevens et al., 1997; Kirchmann et al., 1998; Bussik and Oenema, 1998; Meissinger and Jokela, 2000). The NH_3 emitted from animal production systems contributes to eutrophication in aquatic and low-N input ecosystems (Asman et al., 1994; Asman et al., 1998; Sharpley et al. 1998; Meissinger and Jokela, 2000).

It is well known that NH_3 emission rate from animal production can be greatly influenced by the animal manure properties and its handling practices. For instance, laying-hen houses with manure belt had been shown to emit less than 10% of NH_3 compared to high-rise houses (Liang et al., 2005). The NH_3 emission rate from poultry manure/litter depends on factors such as nitrogen (N) content and moisture content (MC) of the manure/litter, stacking configuration, pH, temperature and oxygen (O_2) availability (Li, 2006). The NH_3 emission from laying-hen manure stack with 50% MC was 59% of that from laying-hen manure stack with 77% MC during 40-d storage (Li, 2006). Drying poultry manure to more than 40% dry matter content reduced NH_3 emission from manure on belt (Groot Koerkamp, et al., 1995). Hence, manure/litter MC plays an important role in NH_3 volatilization and thus emission from the manure/litter. The standard, traditional method to determine MC of manure/litter is through oven-drying of samples, which takes 1-2 days and yields time-delayed results. However, instantaneous knowledge of MC is more desirable in modeling and controlling the gas emissions. The challenge has been, however, to find a suitable sensor that will be able to provide reasonable MC measurement on a real-time basis. The closest candidate for such applications is soil moisture sensor. However, soil and poultry manure/litter can differ greatly in properties and characteristics.

The objective of this study was to assess the suitability of a commercially available electronic soil moisture sensor for real-time MC measurement of broiler litter, turkey litter, and laying hen manure, leading to calibration equations, if possible.

MATERIALS AND METHODS

MOISTURE CONTENT (MC) SENSOR

The soil MC sensor tested in the study was made by ECH_2O (model EC-5, Decagon Devices, Pullman, WA, USA[1]). The sensor measures the dielectric constant of a medium (soil, manure, or litter) by outputting voltage signal that varies with the media MC and property (e.g., density) (Eq. 1). The medium MC can then be determined from Equation 2, with the exact relationship depending on the type and properties of the manure or liter.

$$mV = f\ (\psi, \rho) \qquad [1]$$
$$\psi = g\ (mV, \rho) \qquad [2]$$

where mV = sensor voltage output, mV
ψ = moisture content (MC), % by weight
ρ = bulk density (BD), kg/m^3

[1] Mention of product or company names is for presentation clarity and does not imply endorsement by the authors or their affiliations nor exclusion of other suitable products.

Four EC-5 sensors were selected for the calibration evaluation. During the calibration tests, the sensors were immersed into poultry litter/manure–laden plastic vessels. A CR10 measurement and control module along with an AM416 multiplexer (Campbell Scientific, Inc., Logan, Utah, USA) was used to collect the signal output of the EC-5 sensors (fig. 1) at 10-s intervals. A PC was connected to CR10 for programming and data retrieving.

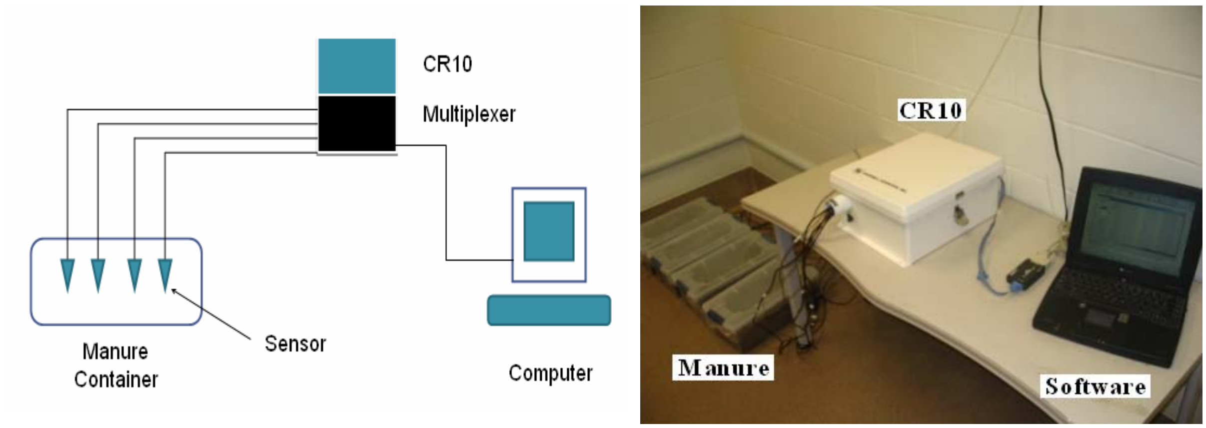

Figure 1. Schematic of the calibration system (left) and a photo of system setup in the lab (right).

The tests were carried out in an environmentally-controlled laboratory room for broiler/turkey litters and laying-hen manure from a belt house, but in the field (*in situ*) for laying-hen manure in a high-rise layer house.

CALIBRATION OF MC SENSOR FOR BROILER AND TURKEY LITTERS

Broiler and turkey litters were collected from commercial production houses and used in this study. Rice hulls and oat hulls were used as the bedding for broilers and turkeys, respectively. Four plastic vessel, 45 cm L x 25 cm W x 15 cm D each, were each loaded with 3.5 kg litter at 4 different MC levels, 27.1%, 36.6%, 46.1%, and 55.5%, respectively. The higher MC litter was achieved by adding water to the relatively dry litters (~ 25% MC) brought back from the field. The vessels with the respective MC litter samples were first stored in a cold room (4^{o}C) for at least 12 hr before thermally equilibrated in the study room at 21^{o}C. For each MC level, five BD levels of 318, 346, 379, 419, or 468 kg m^{-3} were achieved by pressing and thus changing the volume of the litter samples. Each vessel had the four EC-5 sensors and a type T thermocouple vertically inserted in the litter for MC and temperature monitoring, respectively. An excitation voltage of 1200 mV was applied to all the sensors. The first 2-min readings were discarded to ensure full stabilization; and 20 data points were obtained from the combination of four MC and five BD levels. At each MC level, three samples from each vessel were taken for the oven-dry MC analysis.

IN-SITU CALIBRATION OF MC SENSOR FOR LAYING HEN MANURE

To leave the manure pile undisturbed, an *in-situ* calibration of the MC sensor was conducted in a commercial high-rise layer house. Two manure piles in the house were used and 20 spots were randomly selected at the top, middle, and bottom sections of the manure piles to cover the MC spectrum. Four EC5 sensors were simultaneously inserted into the measurement area and the voltage outputs were recorded with an EM5 data logger (Decagon Devices, Pullman, WA, US). Manure samples of the measured area were taken and placed in sealed (Ziploc) plastic bags for subsequent oven-dry MC analysis.

In addition, manure samples from a manure-belt laying hen house were collected to evaluate the sensor for higher MC level. These tests were performed in the lab. For the layer manure tests, an excitation voltage of 2400 mV was applied to the sensors.

TEST OF MC SENSOR TEMPERATURE SENSITIVITY

The old version of the EC-5 sensor had been found to be sensitive to temperature. Hence, temperature sensitivity of the new sensor was evaluated. This evaluation was done by simultaneously monitoring the outputs of four EC5 sensors and temperature of the litters that had been stored in a 4°C cold room for 12 hr and allowed to warm up in the test room at 21°C ambient temperature for 25 hr.

Temperature sensitivity (TS) of the sensor was calculated as follows,

$$TS = \Delta mV/(mV_{mean} \cdot \Delta T) \times 100 \qquad [3]$$

Where TS = temperature sensitivity of the sensor, % measured mV per °C deviation from the mean temperature (14°C in this case)

ΔmV = change in sensor mV output with temperature deviation, $mV_{max} – mV_{min}$

mV_{mean} = mean mV output for the temperature range, $(mV_{max} + mV_{min})/2$

ΔT = temperature change, $T_{max} – T_{min}$ (20°C in this case)

RESULTS AND DISCUSSIONS

CALIBRATION OF MC SENSOR FOR BROILER AND TURKEY LITTERS

Figure 2 shows the voltage signals of the EC5 sensor at each MC and BD level. Due to the different litter properties, the sensor output responses were somewhat different for the broiler and turkey litters. Individual regression lines were developed for each MC and BD, all showing strong linear trend (Table 1). Therefore, a multi-linear regression model was developed for the broiler and turkey litters, of the following form,

$$mV = A * \Psi + B * \rho + C \qquad [4]$$

Table 1. Relationships of EC5 soil moisture content sensor output to moisture content (MC, Ψ) or bulk density (BD, ρ) of broiler and turkey litters.

Property	Level	Broiler Litter	R^2	Turkey Litter	R^2
MC, %	Ψ1=27.1	mV = 0.367 ρ + 172.4	0.98	mV = 0.367 ρ + 193.2	0.98
	Ψ2=36.6	mV = 0.574 ρ + 127.2	0.99	mV = 0.574 ρ + 159.1	0.99
	Ψ3=46.1	mV = 0.663 ρ + 73.41	0.98	mV = 0.663 ρ + 159.8	0.99
	Ψ4=55.5	mV = 0.739 ρ + 161.6	0.99	mV = 0.570 ρ + 227.1	0.98
BD, kg m^{-3}	ρ1=318	mV = 3.557 Ψ + 208.8	0.99	mV = 2.969 Ψ + 215.1	0.97
	ρ2=346	mV = 3.554 Ψ + 227.4	0.98	mV = 3.427 Ψ + 215.3	0.98
	ρ3=379	mV = 3.859 Ψ + 229.9	0.99	mV = 4.240 Ψ + 207.1	0.99
	ρ4=419	mV = 4.012 Ψ + 244.3	0.99	mV = 4.860 Ψ + 212.8	0.99
	ρ5=468	mV = 4.619 Ψ + 249.4	0.92	mV = 4.725 Ψ + 237.9	0.99

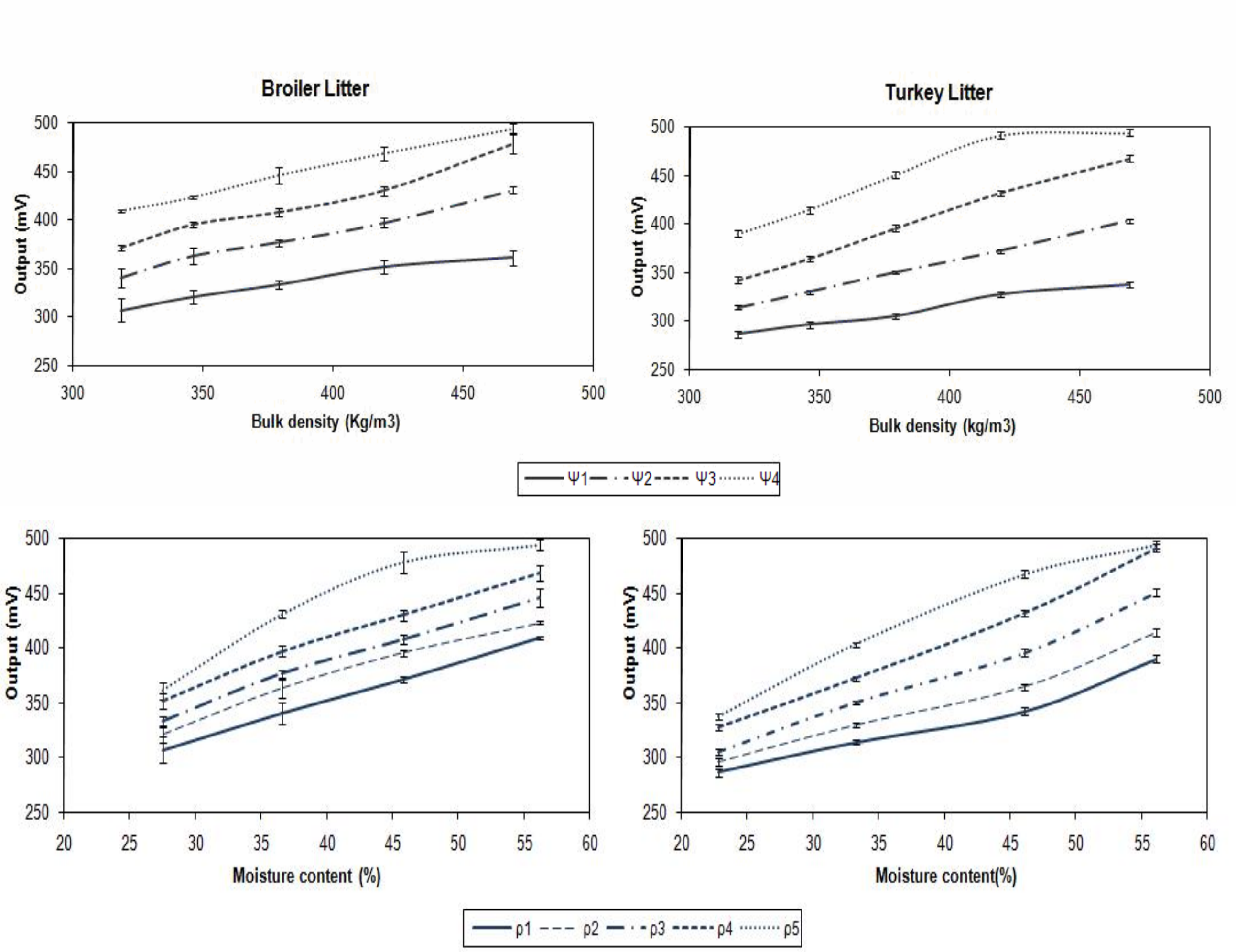

Figure 2. Voltage output of the EC5 sensor at different levels of moisture content (Ψ) and bulk density (ρ). (Ψ1 – Ψ4 were, respectively, 27.1%, 36.6%, 46.1%, and 55.5%; and ρ1–ρ5 were, respectively, 318, 346, 379, 419, and 468 kg m^{-3}.)

Table 2. Results from analysis of variance (ANOVA) for the EC5 soil moisture sensor output (mV) vs. moisture content (Ψ, %) and bulk density (ρ, kg·m^{-3}) of broiler and turkey litters, of the form mV = A * Ψ + B * ρ + C

Parameter	Broiler Litter			Turkey Litter		
	Value	Standard Error	P value	Value	Standard Error	P value
A	3.92	0.19	<0.001	4.04	0.23	<0.001
B	0.54	0.004	<0.001	0.63	0.005	<0.001
C	21.91	17.14	0.22	-26.31	32.08	0.27

Rearranging Equation 4 to solve for MC (Ψ, %) yielded the following calibration equations,

For broiler litter, $\Psi\ (\%) = 0.26\ mV - 0.14\ \rho - 5.59 \quad (R^2 = 0.98)$ [5]

For turkey litter, $\Psi\ (\%) = 0.25\ mV - 0.16\ \rho - 5.59 \quad (R^2 = 0.98)$ [6]

CALIBRATION OF MC SENSOR FOR LAYING-HEN MANURE

The linear relation of the EC5 sensor output to MC for the laying-hen manure is shown in Figure 4, incorporating data from the *in-situ* measurement of manure in high-rise house and laboratory measurement of manure from belt house (R^2=0.95). The data gap between 40% and 65% MC was due to the drastic differences in manure MC between the high-rise and belt housing systems, with the manure in the high-rise house much drier than that of the belt house.

Rearranging the regression equation yielded the following calibration equation for the laying-hen manure,

$$\Psi\ (\%) = 0.065\ \text{mV} - 8.32 \quad (R^2 = 0.95) \qquad [7]$$

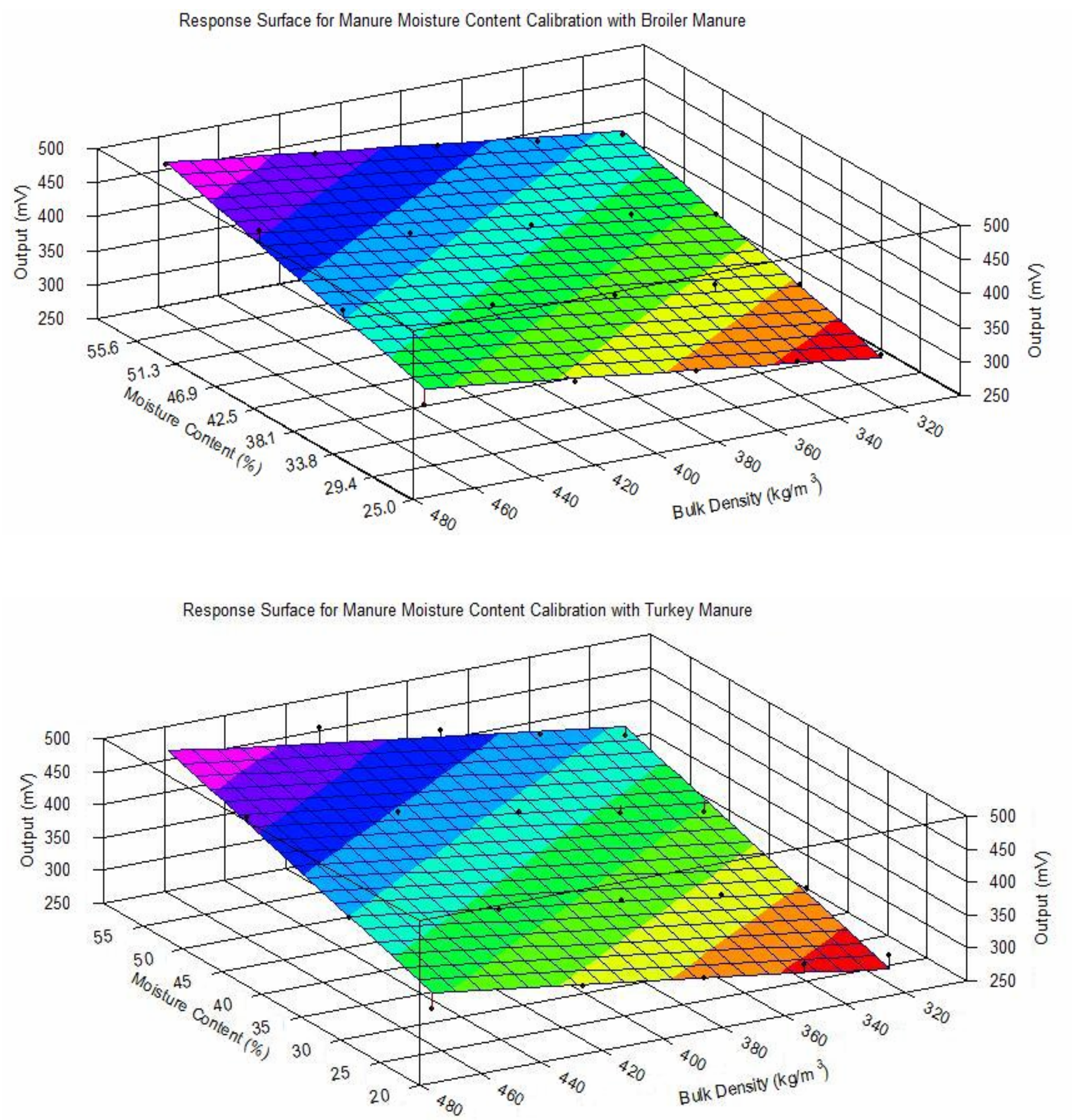

Figure 3. Response surfaces of EC5 sensor to moisture content and bulk density of broiler (top) and turkey (bottom) litters.

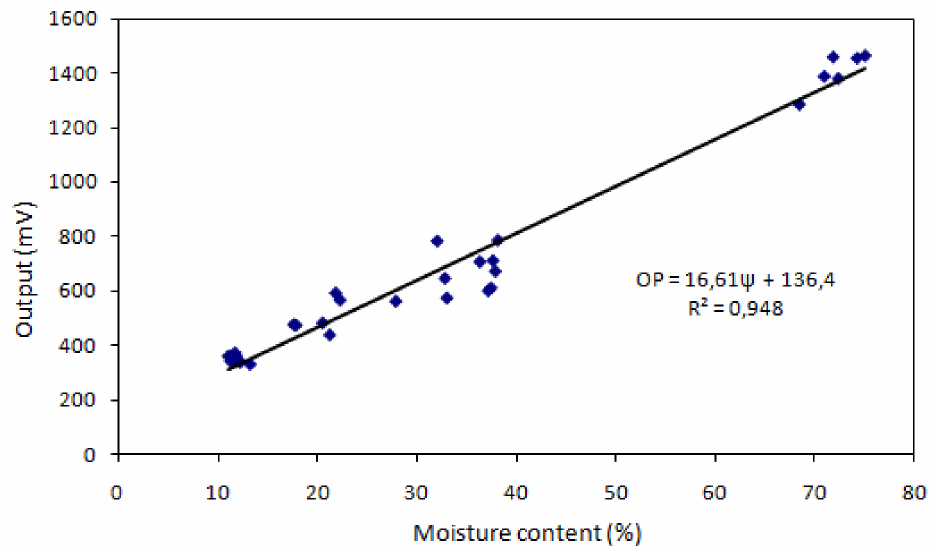

Figure 4. Linear relationship of EC5 sensor output to moisture content of laying-hen manure.

TEMPERATURE SENSITIVITY OF THE MC SENSOR

Figure 5 shows the temperature sensitivity of the EC5 sensor with broiler and turkey litters at MC of 35% or 55% over the litter temperature range of 4°C to 24°C. It can be seen that the sensitivity follows a linear pattern. Using Equation 3, the temperature sensitivity of the sensor was calculated to be 0.26% and 0.37% at MC of 35% and 55%, respectively, for broiler litter; and 0.31% at both MC levels for the turkey litter. The overall temperature sensitivity for the broiler and turkey litters was 0.31% of the measured mV per °C deviation from the mean operating temperature over the 4°C to 24°C range. In actual measurements or monitoring, it would be unlikely to have such a large temperature variation. Hence the interference on litter or manure MC measurement caused by temperature variation is expected to be even smaller.

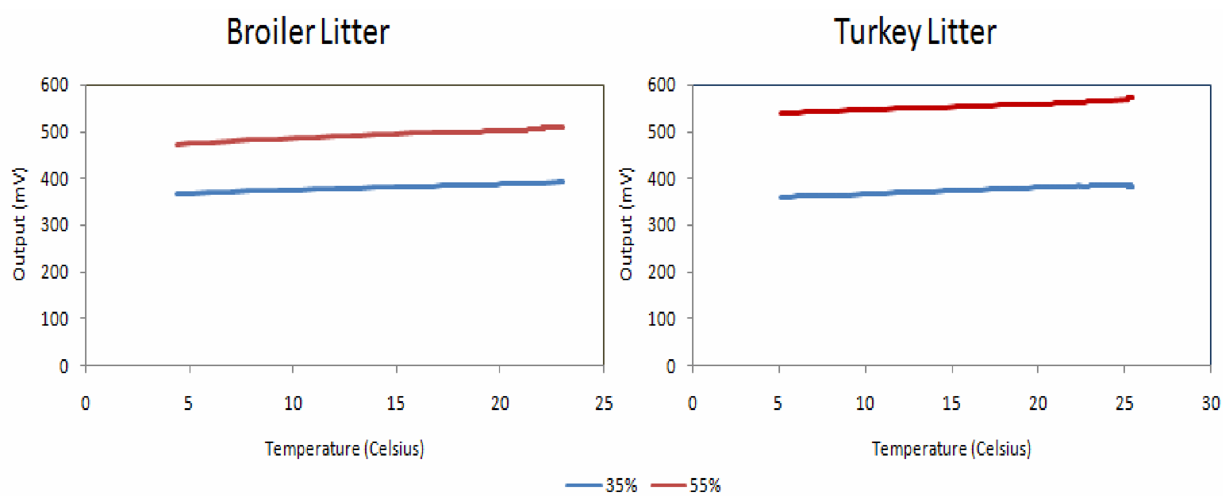

Figure 5. Response of the EC5 sensor output to temperature change in broiler and turkey litters at moisture content of 35% or 55%.

Conclusions

A commercial soil moisture content (MC) sensor was evaluated for instantaneously measuring MC of broiler and turkey litters and laying-hen manure. Calibration equations were developed that relate litter or manure MC to voltage output of the sensor (R^2 = 0.95 - 0.98). The calibration equations for broiler and turkey also include bulk density of the litter as an input variable. The MC sensor output has a small, linear dependence on the media temperature.

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