On-site measurement of soil moisture content using an acoustic system

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Abstract: Precision agriculture is a farming management concept based on observing and responding to intra-field variations. One of the most important soil properties in farming is soil moisture content and it is necessary to develop new technique for measuring this property in a precision farming system. This study investigates the measurement of moisture content in soil using an on-site, easy to use and real-time acoustic wave system. The system consists of the propagation of acoustic waves such as sweep frequency sound wave (10-300 Hz) and multiple tone sound waves (120 Hz) through the soil. Some properties of these acoustic waves enable estimation of soil water content such as peak amplitude (A), total power (TP), total harmonic distortion (THD) and signal to noise ratio (SNR). The results showed that the best model for estimating the soil moisture content was the model that expressed relationship between A and soil moisture content with R^2 = 0.999 (using sweep frequency) and relationship between TP and soil moisture content with R^2 = 0.999 (using multiple tone). It is argued that the change in the sound characteristics related to the soil moisture content can be used for a continuous monitoring and control of irrigation of crops.

Keywords: acoustic waves, soil moisture content, sound properties

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1 Introduction

Nowadays, the precision agriculture may be regarded as the best technique for crop growth because it produces the maximum economic return with low environmental impact (Tyronese et al., 2008). However this type of agriculture requires a detailed and accurate knowledge of the soil microclimate and, consequently, the application of innovative measurement technologies. In real, the analysis of both soil properties and characteristics are difficult and costly to perform and frequently require a very long time. With this aim, the measurement of water content in soil is an important task which may be fundamental information for suitable cultivations choice.

A number of techniques have been used for detection and measurement of soil water content. Some of the non-electronic techniques are gravimetric soil sampling, tensiometry, porous block and neutron scattering methods. Generally it is very difficult to obtain accurate, low cost and user-friendly real-time systems (Curtis, 2001; Kondratov and Skripnik, 1996; Curtis and Narayanan, 1998; Thomas et al., 1994).

The electronic methods used are based on the measurement of the effect of soil water content on the resistance/dielectric constant of soil, the latter being more reliable. For the determination of the water content of the soil, the large sensitivity of the dielectric constant of the soil to its water content has been utilized in time domain reflectometry (TDR) and frequency domain

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reflectometry (FDR). For a technique to be useful for soil water content monitoring in agricultural fields, it must be low-cost, quick, capable of in situ measurement of water content of the soil in the top layer and the effect of the presence of chemicals on the measurement results, should be negligible. None of the above techniques satisfy all of these requirements (Sharma and Gupta, 2010).

It is well established theoretically (Brutsaert, 1964) and experimentally (Brutsaert, 1964; Oelze et al., 2002; Flammer et al., 2001) that some characteristics of sound in soil depends significantly on its water content. The dependence of one of the sound properties (speed of sound) in soil–air–water mixture has also been theoretically analyzed by Tuncay and Corapcioglu (1996) and Lo et al. (2005; 2007). The results of their analyses show contradictory results predicting that speed of sound in soil–air–water mixture increases with water content of the soil.

In the present study, the effect of soil water content on peak amplitude (A), total power (TP), total harmonic distortion (THD) and signal to noise ratio (SNR) of sound in an agricultural soil was investigated. The experimental studies reported by Brutsaert (1964) and Oelze et al. (2002) have used ultrasound/sound pulses of frequencies of 30 kHz and 2–10 kHz, respectively, to determine the effect of water content in compact soil blocks on the speed of sound. Therefore the measured data in these experiments cannot be used for determination of water content of agricultural soil, which is kept intentionally loose to facilitate crop growth. Recently a very interesting and useful method for determination of soil moisture content has been reported by Tyronese et al. (2008). The method uses MEMs sensor to sense the moisture content of the soil. This method essentially determines the moisture content in a very small volume around the sensor.

In this study, the dependency of peak amplitude (A), total power (TP), total harmonic distortion (THD) and signal to noise ratio (SNR) of sound in a loam soil on the water content of soil using sweep frequency (10-300 Hz) and multiple tone (120 Hz) sound waves, was investigated. These sounds and frequencies have been chosen for the experiments because of two reasons. (i) In sweep frequency sound, the range of frequency between 10 to 300 Hz were selected, because at above that frequency, the decay time of sound frequency reduced and in multiple tone sound, frequency of 120 Hz has been chosen because in this state, the frequency amplitude response has the maximum value. (ii) At these frequencies the received signals were observed to be undistorted replica of the transmitted signal making it possible to determine the characteristic of sound wave more accurately. This method allows the determination of soil water content in a larger volume of soil as compared to other methods reported.

2 Material and methods

2.1 Sound properties

Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing. Sound waves are often simplified to a description in terms of sinusoidal plane waves, which are characterized by these properties: frequency, amplitude, signal to noise ratio (SNR), total power, sound pressure, sound intensity, speed of sound, signal to noise and distortion (SINAD), total harmonic distortion (THD), etc. In this research, the dependence of some sound properties such as amplitude (A), total power (TP), total harmonic distortion (THD) and signal to noise ratio (SNR) on the water content of soil have been investigated. These sound properties are described as follows:

The peak amplitude will display the amplitude of the strongest spectral component in the entire span and expressed in percent of full scale (maximum level) (Anonymous, 2012). The total sound energy radiated by a source per unit time, generally expressed in ergs per second or watts. Also known as total sound power that is given by following Equation 1 (Anonymous, 2012):

$$L_{wt} = 10\log(n\,N/N_0) = 10\log(N/N_0) + 10\log(n) = L_{ws} + 10\log(n) \quad (1)$$

where, L_{wt}= the total sound power level (dB); L_{ws}= sound power level from each single source (dB); N = sound power (W); N_0=10^{-12}(reference sound power (W)); n = number of sources.

The total harmonic distortion (THD) of a signal is a measurement of the harmonicdistortion present and is defined as the ratio of the sum of powers of all harmonic components to the power of the fundamental frequency and expressed in percent that can be described as Equation (2) (Anonymous, 2012):

$$THD = \frac{P_2 + P_3 + P_4 + ...P_\infty}{P_1} = \frac{\sum_{i=2}^{\infty} P_i}{P_1} \quad (2)$$

This can equivalently be written as Equation (3):

$$THD = \frac{P_{total} - P_1}{P_1} \quad (3)$$

where, P_1 = the power at the first harmonic or fundamental, frequency; P_2, P_3, … = the powers of all higher harmonic frequencies.

THD is used to characterize the linearity of audio systems and the power quality of electric power systems. In audio systems, lower THD means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction by reducing harmonics added by electronics and audio media.

The SNR is computed by searching the entire spectrum to find the peak frequency and then calculating the total noise power in the remaining spectrum. The SNR is then computed as the ratio of the signal peak power level to the total noise level and expressed in decibels (dB) and defined as Equation (4) (Anonymous, 2012):

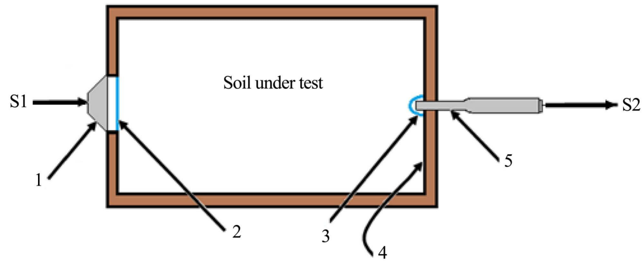
$$SNR = \frac{P_{signal}}{P_{noise}} = (\frac{A_{signal}}{A_{noise}})^2 \quad (4)$$

where, P_{signal}, P_{noise} = the average power level of signal and noise; A_{signal} , A_{noise} = the root mean square (RMS) amplitude of signal and noise.

2.2 Experimental work

2.2.1 Experimental setup

The experimental setup used for measurement of sound characteristics in soil is shown in Figure 1. The soil container is a wooden box and its size is 19×19× 33 cm^3. Two walls of cabin have been allocated for transmitter and receiver transducers and a cabin for the soil under test. A midrange loudspeaker has been used as a transmitter while the microphone (model ECM-8000, Germany Behringer Ltd.) was used as receiver. This omnidirectional microphone has ultra-linear Frequency response (20Hz-20 KHz).



1. Speaker 2, 3. Thin latex film 4. Sound protective layers 5. Microphone
S1. Signal to be transmitted, S2. Received signal

Figure 1 Experimental set up (soil box)

The microphone was sealed by using rubber layer between box wall and microphone body to further shield the effect of sound waves arriving from other directions and the speaker was sealed also, using rubbery multilayer between box wall and speaker body. The partitions between the transmitter and soil cabin and that between receiver and soil cabin have circular holes of appropriate size covered by a thin latex film.

The inner walls of the soil cabin were covered respectively with polystyrene spray, nylon layer with air vacuum cells, one layer of carpet and finally a thin layer of polypropylene that helps in absorbing the sound incident upon it. This is to ensure that inner walls do not reflect sound.

The block diagram of on-site acoustic system is shown in Figure 2. The signal generator, as shown in this figure, generates various types of signals. The produced signals are sent to the sound card. The sound card (Focusrite Scarlett 8i6 is included of pre-amplifier and sound card together) has the flat frequency response of 20 Hz-20 kHz. The signals are sent from sound card to the power amplifier and then, forwarded to the speaker. The acoustic signals diffuse to the soil and after interaction between soil and sound waves; this acoustic signals are received by microphone. The output of the microphone is leaded to the pre-amplifier for amplifying and then sent to the sound card and the output of the sound card is sent to the computer for sound saving. The power supply provides the requirement power of acoustic system devices.

After sound wave recording with Audio Edit Magic software, the waves must be analyzed. So FFT Spectral Analysis System software (version 4.32.20) was chosen for sound analysis.

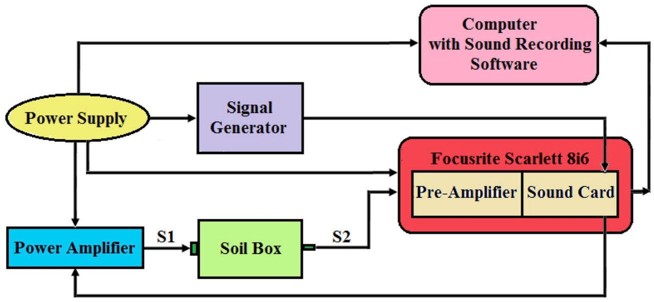


Figure 2 The block diagram of on-site acoustic system

2.3 Soil under test

Soil is a porous medium, composed of particles of different sizes, which are classified in three categories of 'sand' (large particles), 'silt' (average size particles), and 'clay' (small particles) (Hillel, 1980). The percentage of these particles in the soil determines its texture. The space between these particles (interstices) is occupied by air in dry soil, air and water in wet soil and water in saturated soil.

To study the dependence of soil moisture content on the sound characteristics, the soil samples of loam were prepared. The composition of the loam soil used for the purpose, as shown in Table 1, were determined in the Soil Testing Laboratory of the Soil and Water Research Institute of Iran. The moisture content of soil samples was determined using the oven at 105°C for 24 h and calculated as Equation (5):

$$\theta_m(\%) = \frac{m_w}{m_s} \times 100 \tag{5}$$

where, m_w is water mass and m_S is dried soil mass.

Table 1 Composition of soil samples

Soil Type	Sand/%	Silt/%	Clay/%	Texture	PL/%
1	38	33	29	loam	22.3

For this study, four soil samples of different moisture content were prepared, as given in Table 2 These moistures were chosen according to the soil plastic limit (PL) percentage (The plastic limit defines the boundary between non-plastic and plastic states. It is determined simply by rolling a thread of soil and adjusting the moisture content until it breaks at 1/8 inch diameter (Holtz and Kovaks, 1981)). The plastic limit of soil samples was determined in the Soil Testing Laboratory, as shown in Table 1. For preparing these samples with defined moistures, the suitable volume of water was calculated and sprayed in to the soil and plated the samples in the cool place for 24 h.

Table 2 Some physical properties of soil samples

Sample Number	θ_m/%	*PL*/%	ρ_t/g cm^{-3}
1	6.56	0.3 PL	1.28
2	11.15	0.5 PL	1.21
3	15.61	0.7 PL	1.18
4	20.1	0.9 PL	1.1

3 Results and discussion

The values of acoustic properties for different moisture content were analyzed for three times recording and mean and standard deviation (sd) of data were calculated. The results of sound analysis for sweep frequency and multiple tone sound waves are shown in Table 3.

Table 3 The mean values of some acoustic properties

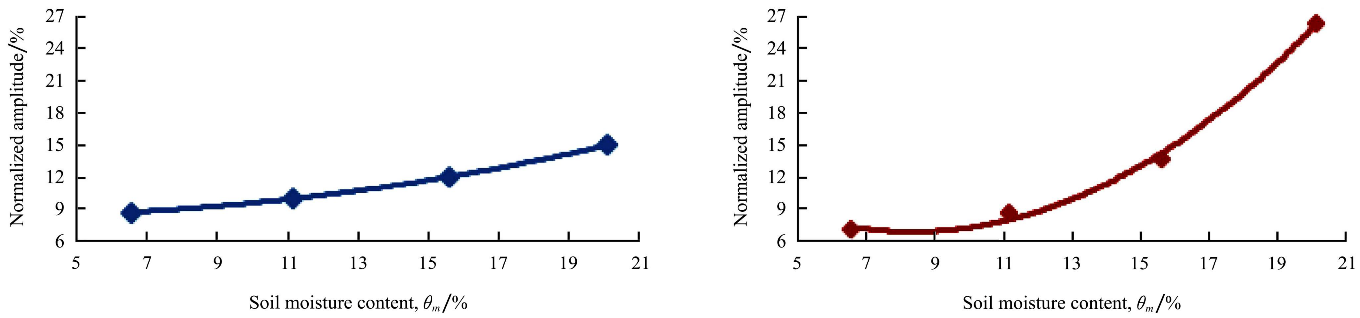
Acoustic properties	Statistical parameters	Sweep frequency				Multiple tone			
		0.3PL	0.5PL	0.7PL	0.9PL	0.3PL	0.5PL	0.7PL	0.9PL
A/%	Mean	8.69	10	12	15	7.12	8.61	13.63	26.38
	sd	0.05	0.55	0.88	0.25	0.09	0.08	0.25	0.43
TP/%	Mean	19.1	22	25	34.32	10.64	10.83	18.44	34.86
	sd	0.02	0.81	0.43	0.78	0.11	0.11	0.58	0.64
THD/%	Mean	34.5	20	22	42.9	0.42	0.82	1.52	4.18
	sd	0.34	0.21	1	0.93	0.04	0.26	0.04	0.02
SNR/dB	Mean	7.18	15	11	2.84	-0.62	4	2.87	3.48
	sd	0.09	0.26	0.86	0.11	0.05	0.21	0.34	0.06

3.1 Effect of soil water content on the peak amplitude (A)

The received sound waves were recorded for 3 repetitions and average of data is shown in Figure 3. The peak amplitude of sound is observed to increase as the moisture content of soil increases (Figure 3, a, b). The value of A increases from 8.7% to 15% using sweep frequency sound and increases from 7.2% to 26.4% using multiple tone sound for increasing soil moisture content from 0.3 PL (6.56%) to 0.9 PL (20.1%). Derived models for expressing the relationship between peak amplitude and soil moisture content, are shown in Table 4. It was observed that the model of using sweep frequency waves (R^2=0.999), is more accurate than multiple tone sound model. So, it is clear that the soil moisture content can be estimated using measurement of peak amplitude of receiving sound after passing through the soil.

3.2 Effect of soil water content on total power (TP)

The total power of sound is observed to increase against increasing the soil moisture content. The results for using sweep frequency and multiple tone sounds are shown in Figure 4(a, b). It was observed that the value of TP increases from 19% to 34.3% using sweep frequency sound and increases from 10.7% to 34.9% using multiple tone sound for increasing soil moisture content from 0.3 PL (6.56%) to 0.9 PL (20.1%). The models for expressing the relationship between total power and soil moisture content are shown in Table 5. It is clear that the model of using multiple tone waves (R^2=0.999), is preferred.



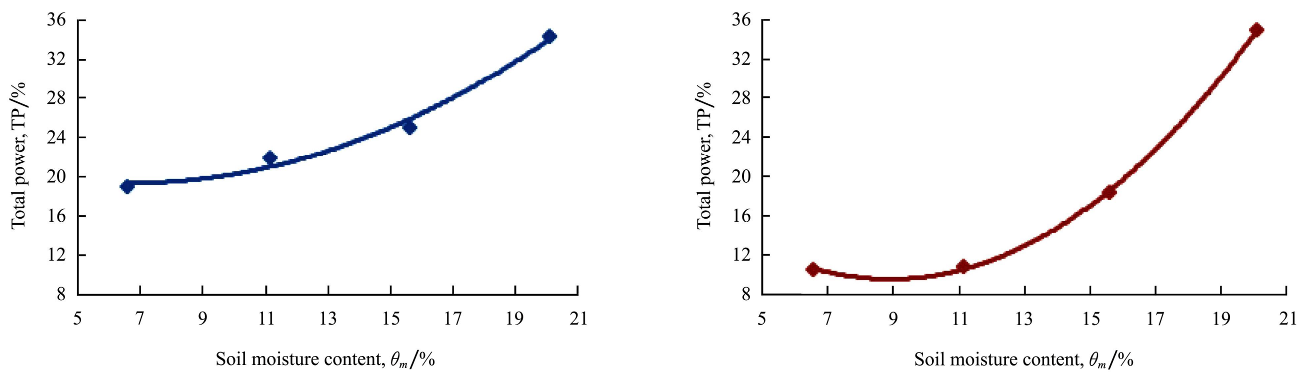
a. Using sweep frequency signal

b. Using multiple tone waves

Figure 3 Variation of peak amplitude with soil moisture content

Table 4 Derived models for expressing the relationship between peak amplitude and soil moisture content variations

Sound Property	Type of Sound Wave	Type of Model	Equation of Model	Model Constant	R^2
A_1	Sweep frequency	polynomial	$y = ax^2 + bx + c$	a=0.021, b=-0.104, c=8.468	0.999
	Multiple tone	polynomial	$y = ax^2 + bx + c$	a=0.139, b=-2.330, c=16.60	0.996



a. Sweep frequency

b. Multiple tone sound

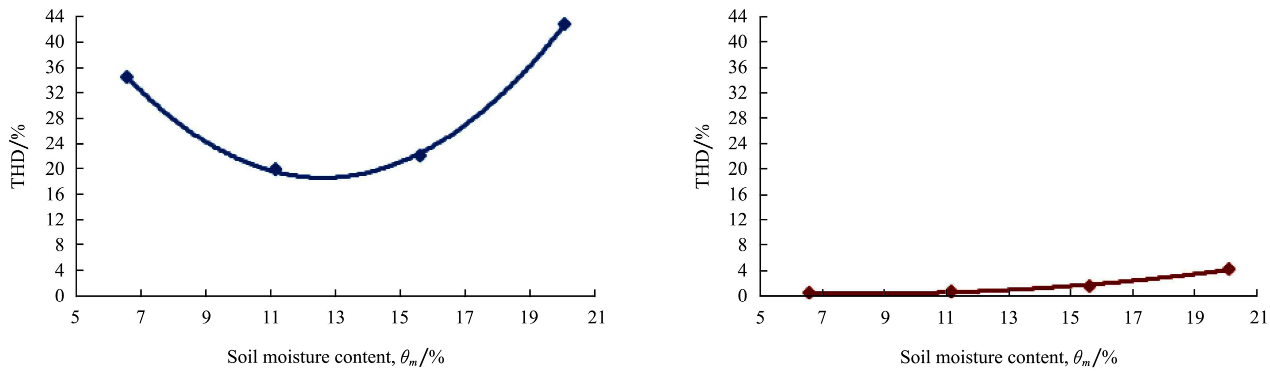
Figure 4 Variation of total power with soil moisture, using

Table 5 Derived models for expressing the relationship between total power and soil moisture content variations

Sound Property	Type of Sound Wave	Type of Model	Equation of Model	Model Constant	R^2
TP	Sweep frequency	polynomial	$y = ax^2 + bx + c$	a = 0.079, b = -1.049, c = 22.84	0.985
	Multiple tone	polynomial	$y = ax^2 + bx + c$	a = 0.201, b = -3.584, c = 25.56	0.999

3.3 Effect of soil water content on total harmonic distortion (THD)

The total harmonic distortion (THD) of sound was calculated using Equation 2 and Equation 3 and variation in THD of sound with soil moisture content are shown in Figure 5(a, b). The results show that THD decreases against increasing the soil moisture content until 0.6 PL, after this, moisture leads to increase against increasing the soil moisture content in using sweep frequency (Figure 5, a) but in using multiple tone sound wave, THD is observed to decrease against increasing the soil moisture content until 0.4 PL, after that increases against increasing the soil moisture content (Figure 5, b). It can be seen that dependence of total harmonic distortion of sound on soil moisture content by using sweep frequency sound (R^2=0.998) may be described better than using multiple tone sound (Table 6).



a. Using sweep frequency

b. Using multiple tone sound

Figure 5 Variation of total harmonic distortion with soil moisture content

Table 6 Derived models for expressing the relationship between total harmonic distortion and soil moisture content variations

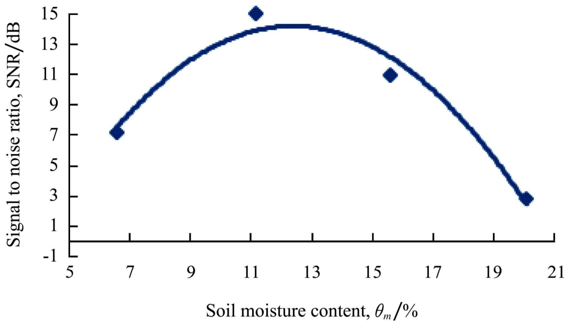
Sound Property	Type of Sound Wave	Type of Model	Equation of Model	Model Constant	R^2
THD	Sweep frequency	polynomial	$y = ax^2 + bx + c$	a = 0.434, b = -10.98, c = 87.99	0.998
	Multiple tone	polynomial	$y = ax^2 + bx + c$	a = 0.028, b = -0.48, c = 2.446	0.983

3.4 Effect of soil water content on signal to noise ratio (SNR)

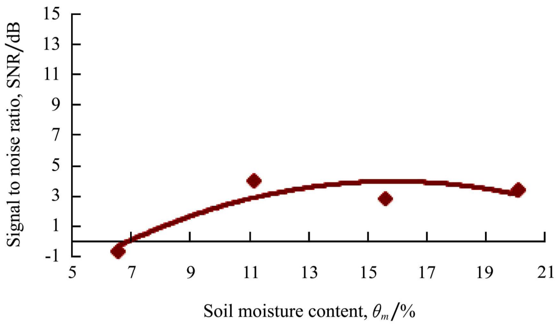
The signal to noise ratio (SNR) of sound was measured using Equation (4) and variation in SNR of sound with soil moisture content as shown in Figure 6 (a, b). The results show that SNR increases against increasing the soil moisture content until soil moisture content reaches to 0.6 PL, after this moisture, SNR leads to decrease against increasing the soil moisture content by using sweep frequency (Figure 6, a), but in using multiple tone, SNR leads to decrease after 0.7 PL against increasing the soil moisture content (Figure 6, b). According to Table 7, it was observed that using sweep frequency sound wave for estimating the behavior of SNR against soil moisture content (R^2=0.966) is more suitable than using multiple tone sound wave.

Table 7 Derived models for expressing the relationship between signal to noise ratio and soil moisture content variations

Sound Property	Type of Sound Wave	Type of Model	Equation of Model	Model Constant	R^2
SNR	Sweep frequency	polynomial	$y = ax^2 + bx + c$	a = -0.196, b = 4.867, c = -15.92	0.966
	Multiple tone	polynomial	$y = ax^2 + bx + c$	a = -0.049, b = 1.558, c = -8.371	0.791



a. Using sweep frequency



b. Using multiple tone sound

Signal to noise ratio, SNR/dBFigure 6 Variation of signal to noise ratio with soil moisture content

4 Conclusion

Some characteristics of sound in the soil samples of loam type texture has been determined experimentally, using sweep frequency and multiple tone sound waves in a laboratory setup. It has been observed that the frequency of sound waves should be 10-300 Hz for sweep frequency sound waves and 120 Hz for multiple tone sound waves.

The dependence of peak amplitude (A), total power (TP), total harmonic distortion (THD) and signal to noise ratio (SNR) of sound on the soil moisture content has been studied experimentally. From the above results, it is clear that the sound characteristics in the soil can be calibrated in the amount of water content of the soil. Both of sound wave types (sweep frequency and multiple tone) were suitable for this purpose however according to Table 4 to Table 7, in using sweep frequency sound waves, the model of expressing the relationship between A and soil moisture content may be preferred for precise moisture estimation with R^2=0.999 and in using multiple tone waves, the model that described relationship between TP and soil moisture content with R^2=0.999 is suitable than other sound characteristics.

It has been pointed out that the some characteristics of sound in the soil can be used to determine the water content of the soil, thereby making it feasible to avoid over-irrigation and consequent disadvantages.

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References

Anonymous. 2012. Available on: http://www.spectraplus.com/DT_help/snr.htm.Accessed on 20/10/2012.

Brutsaert, W. 1964. The propagation of elastic waves in unconsolidated unsaturated granular mediums. *Journal of Geophysical Research,* 69(2): 243–257.

Curtis,J.O. 2001. Moisture effects on the dielectric properties of soil. *IEEE Transactions on Geoscience and Remote Sensing,* 39(1): 125 -128.

Curtis, J. O. and R. Narayanan. 1998. Effects of laboratory procedures on soil electrical property measurements. *IEEE Transactions on Instrumentation andMeasurement,* 47(6): 1474-1480.

Flammer, I., A. Blum, A. Leiser, and P. Germann. 2001. Acoustic assessment of flow patterns in unsaturated soil. *Journal of Applied Geophysics,* 46(2): 115–128.

Hillel, D. 1980. Fundamentals of Soils Physics. *Academic, New York.*

Kondratov, V. T. and Y. A. Skripnik. 1996. A digital device far measurement of physical and chemical parameter of materials and substances. *Proceedings of the IMTC-96 Conference,* Brussels, 2, 981 -986.

Lo, W. C., G. Sposito, and E. Majer. 2005. Wave propagation through elastic porous media containing two immiscible fluids. *Journal of Water Resources Reseach,*41, W02025.

Lo, W. C., Y. Chao-Lung, and T. Chang-Tai. 2007. Effect of soil texture on the propagation and attenuation of acoustic wave at unsaturated conditions. *Journal of Hydrology,* 338(3-4): 273–284.

Oelze, M. L., W. D. O'Brien, and R. G. Darmody. 2002. Measurement of attenuation and speed of sound in soil. *Soil Science Society of America Journal,* 66: 788–796.

Sharma, R. K. and A. K. Gupta. 2010. Continuous wave acoustic method for determination of moisture content in agricultural soil. *Journal of Computers and Electronics in Agriculture,*73(2): 105–111.

Thomas, W. L., R. G. Stevens, R. R. Topielec, and H. W. Neibling. 1994. http://cru.cahe.wsu.eduUT/CEPublication/pnw0475. Accessed on 27/11/2012.

Tuncay, K. and M. Y. Corapcioglu. 1996. Body waves in poroelastic media saturated by two immiscible fluids. Journal of Geophysical Research, 111 (B11): 25149–25159.

Tyronese, J., M. Katrina, S. Mohamed, C. Tommy, and R. Peter. 2008. Measuring soil temperature and moisture using wireless MEMS sensors. *Measurement*, 41 (4): 381–390.