Determination of Soil Moisture for Sandy Soils Using Gas and Microwave Ovens

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Abstract

Since there are several methods used to determine soil moisture, the objective was to compare the moisture values obtained with the use of a gas oven and a microwave to the values obtained with the standard oven method. Having been carried out at the Hydraulics Laboratory of the State University of Maringá, Umuarama Regional Campus, the performance of the methods was evaluated in the determination of five levels of moisture (10, 15, 20, 25, and 30%), with dry masses obtained at 15, 20, 25 and 30 minutes for the gas oven and at 2, 4, 6 and 8 minutes for the microwave. The best drying times were selected using the Taylor Diagram. Linear regression was performed between the methods, in order to obtain the correlation coefficient (r), the Willmott agreement index (d), the performance index (c), absolute error (EA), absolute mean error (ERA), and root mean square error (RQME). By analyzing the results obtained, it can be stated that the gas oven method and the microwave method presented excellent performance when compared to the standard method. It was also concluded that the time of 25 minutes for the gas oven method was efficient and, for the microwave method, the drying time of 8 minutes was sufficient, meaning a reduction in the time for moisture determination.

Keywords: water management, irrigation, soil water content

1. Introduction

Although soil moisture is a physical concept, there are difficulties in its determination, in order to obtain a representative value of its spatial and temporal variability. Getting close to the true water consumption of a particular agricultural crop is essential for a rigorous irrigation schedule and, within this scenario, the determination of soil water content is essential to correctly manage irrigation (Toumi et al., 2016).

There are several methods to estimate soil water content, with the greenhouse method being considered the standard and used to calibrate the other methods (Nogueira et al., 2005), however, it presents the limitation of the knowledge of soil moisture be obtained at least 24 hours after collection, so the application of water via irrigation has this lag period.

Several indirect methods of moisture determination that allows obtaining an instantaneous value of the water content in the soil have emerged over the years, but most of them are limited to teaching and research institutions, being difficult to access by rural producers. Soils with sandy characteristics have lower water retention, which may allow alternative methods of moisture determination to have satisfactory performance when compared to the standard greenhouse method for moisture determination. For soils with sandy texture characteristics, with sand contents reaching values of 70% to 90%, it is believed that the determination of water content with alternative methods can provide rural producers with obtaining a moisture content more quickly. and need. In view of the above, the present work aimed to compare the moisture values of sandy soil using the gas oven and microwave methods and compare them with the standard oven method.

2. Method

The study was carried out at the Laboratory of Irrigation and Hydraulics at the Regional

Campus of Umuarama – Fazenda CAU/CCA, of the State University of Maringá, in the municipality of Umuarama – PR, located at the geographic coordinates of 23º45' south latitude and 53º19' west longitude. , at an altitude of 401 m.

2.1 Soil Description and Sample Preparation

Soil samples were collected at a depth of 0-20 cm and their physical and water properties (Table 1) were determined by granulometric analysis, determined by the methodology proposed by (Bouyoucos, 1951); particle density using the pycnometer method and soil density obtained by the beaker method, which is recommended and described in (Embrapa, 1997). Total porosity was calculated by the volumetric moisture value at a tension of 0.1 kPa. The microporosity was considered equal to the water content retained in the tension of 4.0 kPa and the macroporosity was obtained by the difference between the total porosity and the microporosity.

Table 1. Physico-hydric characterization of the soil used in the analyzes

··· Granulometry (%)···			Density (g cm^{-3})		···· Porosity (%)····			Ucc*	U_{PMP}**
Sand	Silt	Clay	Global	Particles	Micro	Macro	Total	(g g^{-1})	(g g^{-1})
13,35	2,7	83,25	1,26	2,65	26,98	25,48	52,45	0,181	0,081

* Moisture at field capacity (Ucc); **Moisture Permanent wilting point (U_{PMP}).

The samples were air-dried and passed through a sieve with a mesh size of 2.0 mm. Subsequently, 50 g subsamples were placed in an oven at 105ºC for 24 hours. After the drying period, the subsamples were moistened with distilled water, raising their gravimetric moisture level to 10, 15, 20, 25, and 35%. Water was added using a trigger sprayer with a capacity of 350 mL and homogenization was carried out with a gardening spoon. After wetting, the moisture of the subsamples was obtained using a gas oven and microwave oven and later compared with the standard method.

2.2 Determination of Moisture Using the Standard Method

In the standard oven method, samples of 50 g of each moisture level (wet mass, MU) were dried at a temperature of 105ºC until a constant mass was reached, which, for soil conditions, occurred in 24 hours. The constant soil dry mass (DM), was used to obtain gravimetric moisture (U), according to equation 1:

$$U = \frac{Mu - Ms}{Ms} \quad (1)$$

where: U = ravimetric moisture, in g g^{-1}; Mu = wet mass, in g; Ms = dry mass in g.

2.3 Determination of Moisture by Means of the Gas Oven

In the oven method, a gas oven, which allowed a temperature of approximately 250 C. After temperature adjustment, 50 g samples of each pre-established moisture level were placed in the oven and the mass was measured (Ms) after 15, 20, 25, and 30 minutes. It is worth mentioning that the oven was preheated for 10 minutes before inserting the samples inside and the gravimetric moisture was obtained through equation 1.

2.4 Determination of Moisture by Means of a Microwave Oven

To obtain soil moisture through the microwave oven, equipment with a supply voltage of 120 V and a microwave frequency of 2450 MHz was used, adjusted to the maximum power (100%), which gave the equipment power of 900 W J s^{-1}.

The microwave oven was calibrated according to the methodology described in Silva & Souza (2000), using a beaker with 1000 mL of water at a temperature of 23±2ºC, measured with a thermometer with an accuracy of 0.05ºC. The beaker was placed in the microwave where it remained for two minutes with the equipment turned on at powers of 80, 60, 40, and 20%. After this time, the beaker with the water was removed from the microwave and, after 30 seconds of stirring the water with a glass rod, the final temperature was measured. With the initial (Ti) and final (Tf) temperatures, the real potential of the device was obtained using equation 2:

$$Pot = \frac{K \cdot Cp \cdot m \cdot (Tf - Ti)}{t} \quad (2)$$

where: *Pot* = apparent power absorbed by the sample, in W J s^{-1}; *K* = conversion factor, 4.184 W s cal^{-1}; *Cp* = specific heat of water, 1 cal $(g\ °C)^{-1}$; *m* – mass of the water sample, in g; *Tf* – final temperature, in °C; *Ti* = initial temperature, in °C; *t* = time, in s.

Initially, 50 g soil samples were placed in porcelain crucibles subjected to drying times of 2, 4, 6, and 8 minutes in the microwave oven. Then, the crucibles were removed, allowed to cool in a desiccator, and weighed on an electronic scale with a precision of 0.01g. Gravimetric moisture was obtained using equation 1.

2.5 Statistical Analysis

Data analysis was performed using linear regression between moisture levels (10, 15, 20, 25, and 35%). The best drying time for each alternative method was obtained using the Taylor diagram (Taylor, 2001). The regression analyzes had the moisture levels tested as the dependent variable and the gravimetric moisture obtained by the alternative methods as an independent.

For the evaluation and statistical validation of the performance of the alternative methods of determination of soil moisture, the values of gravimetric moisture, selected in the times of best fit, were correlated with the values of moisture obtained with the standard method of the oven. The coefficients of Person (r) and determination (R2) correlation between the moisture values of the standard method (Ŷi) and the moisture values were obtained in the alternative methods (Yi), the absolute error (EA), the mean absolute error (ERA), the root mean square

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error (RQME) and statistical indicators proposed by Camargo & Sentelhas (1997), defined as follows: precision - correlation coefficient "r"; accuracy - Willmott index "d" and reliability or performance "c".

The absolute error (EA) was calculated using equation 3:

$$EA = \left(\frac{\widehat{Yi} - Yi}{Yi}\right) \times 100 \quad (3)$$

where: $\hat{Yi}$ is the moisture values obtained by the standard method and *Yi* are the values obtained by the alternative methods (gas oven and microwave oven).

The absolute mean error (ERA) was calculated using equation 4:

$$ERA = \frac{\sum_{i=1}^{n} |\widehat{Yi} - Yi|}{n} \quad (4)$$

where: *n* is the number of plants sampled.

The root mean square error (RQME) was calculated using equation 5:

$$RQME = \sqrt{\frac{\sum_{i=1}^{n} (|\widehat{Yi} - Yi|)^2}{n}} \quad (5)$$

The accuracy index [Iw], (Willmott, 1981) can be calculated using equation 6:

$$Iw = 1 - \left[\frac{\sum_{i=1}^{n} (\widehat{Yi} - Yi)^2}{\sum_{i=1}^{n} (|Yi - \overline{Yi}| + |Oi - \overline{Oi}|)^2}\right] \quad (6)$$

The confidence or performance coefficient "c" (Camargo & Sentelhas, 1997) was obtained by the product of the Person correlation coefficient (r) and the accuracy index (Iw), was calculated using equation 7, with interpretation criteria and respective performance classes presented in Table 2.

$$c = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \overline{y})}{\sqrt{[\sum_{i=1}^{n} (x_i - \bar{x})^2][\sum_{i=1}^{n} (y_i - \bar{y})^2]}} \quad (7)$$

Table 2. Interpreting the performance index values and their respective classes

Interpreting	Classes
0.85 < c	Excellent
0.76 < c ≤ 0.85	Very good
0.66 < c ≤ 0.76	Good
0.61 < c ≤ 0.66	Median
0.51 < c ≤ 0.61	Bad
0.41 < c ≤ 0.51	Too bad
c ≤ 0.51	Terrible

Before analysis, all experimental data were submitted to the Kolmogorov-Sminov test (P>0.01) to verify normality. Statistical analyzes were performed using the R statistical program, version 2.2.1 (R, 2021).

3. Results

3.1 Gas Oven Performance

According to Figure 1, it is possible to see that a linear equation was fitted relating the gas oven method to the moisture levels tested at different drying times. The equations obtained showed coefficients of determination (R^2) of 0.850, 0.981, 0.997, and 0.998 for the times of 15, 20, 25, and 30 minutes, respectively. It can be seen that from 20 minutes onwards, the correlation found is very strong (Hongyu, 2018), but the time of 30 minutes will be adopted for validation, with a correlation coefficient of 0.998 (Figure 1D).

Considering the drying time of 30 minutes, the highest measurement errors were verified at the moisture levels of 10 and 15% (Figure 1D), with errors of 1.36 and 1.45%, respectively.

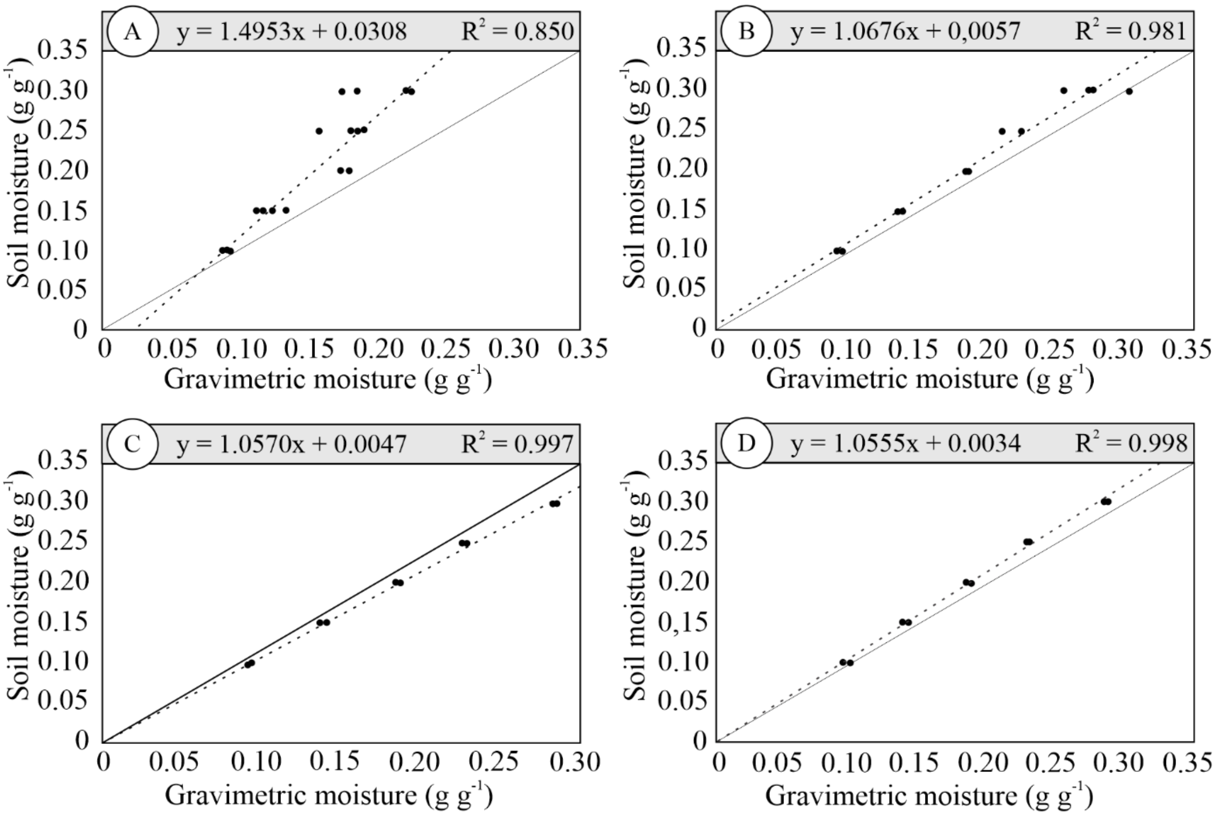

Figure 1. Gravimetric Moisture values were obtained with the gas oven method at times of 15 (A), 20 (B), 25 (C), and 30 (D) minutes compared to pre-established moisture levels

3.2 Microwave Oven Performance

According to Figure 2, it can be seen that the drying time of eight minutes resulted in the highest coefficient of determination with the value of 0.995 (Figure 2D). Error of 1.86% was verified for the moisture level of 30%, considering the time of eight minutes. It can also be seen that times of less than six minutes result in high dispersion points (Figures 2A and 2B), which will result in average measurement errors of 55.22 and 13.23% for times of 2 and 4 minutes, respectively. The mean errors for drying times of 6 and 8 minutes were less than 1.98 and 1.26%, respectively.

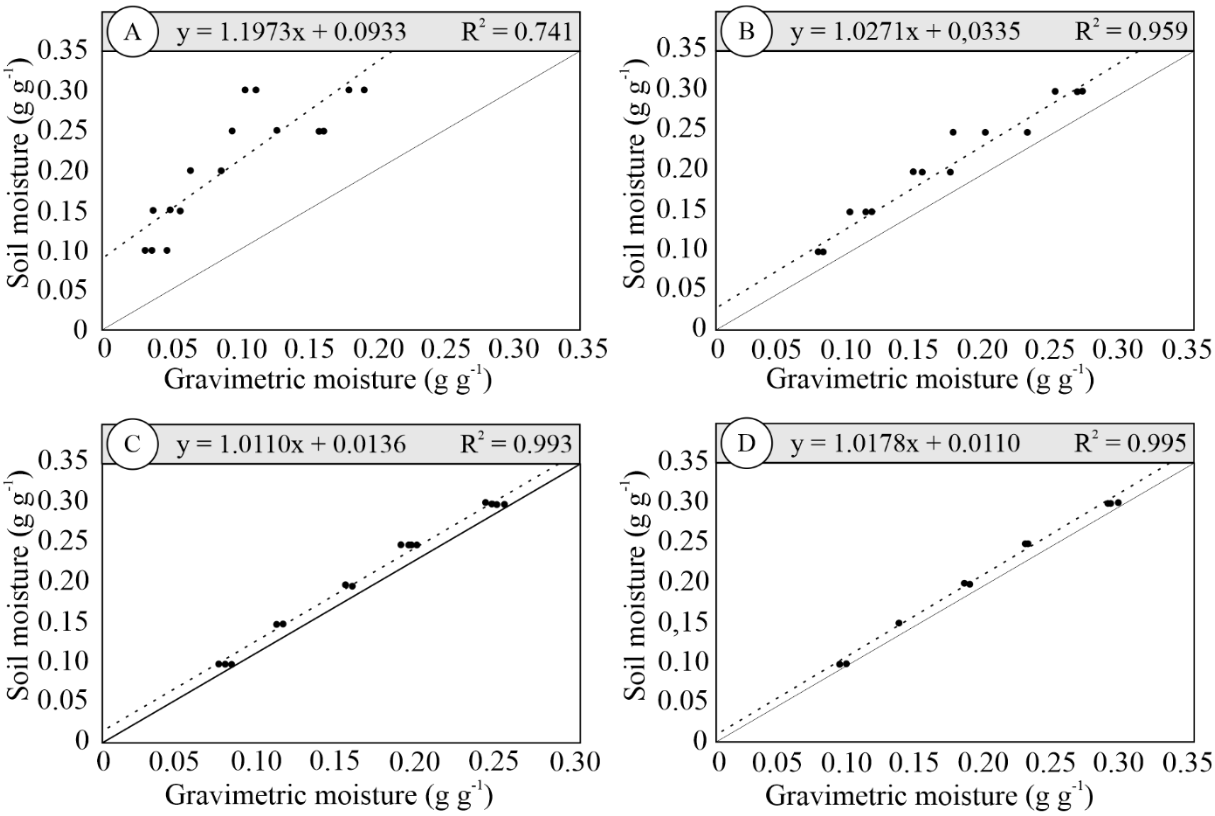

Figure 2. Gravimetric moisture values were obtained with the gas oven method at times of 2 (A), 4 (B), 6 (C), and 8 (D) minutes compared to pre-established moisture levels

3.3 Validation of Alternative Methods

The Taylor diagram provides a convenient way to compare different models between observed and estimated data, in this work moisture values were obtained by the standard method and estimated through alternative methods. The closer the point of a method to the reference (Standard Method), the more efficient it will be. Therefore, according to the Taylor diagram, the gas oven and microwave oven methods performed better at 25 and 8 minutes, respectively (Figure 3). These drying times were the ones closest to the reference.

At these times, the gas oven and microwave methods showed standard deviations of 6.85 and 7.11%, with both methods showing R2 values greater than 0.99. As shown in Figures 1 and 2, the times of 15 and 2 minutes, for the gas oven and microwave, respectively, were farther from the reference (Figure 3), showing lower validation rates than the other times tested.

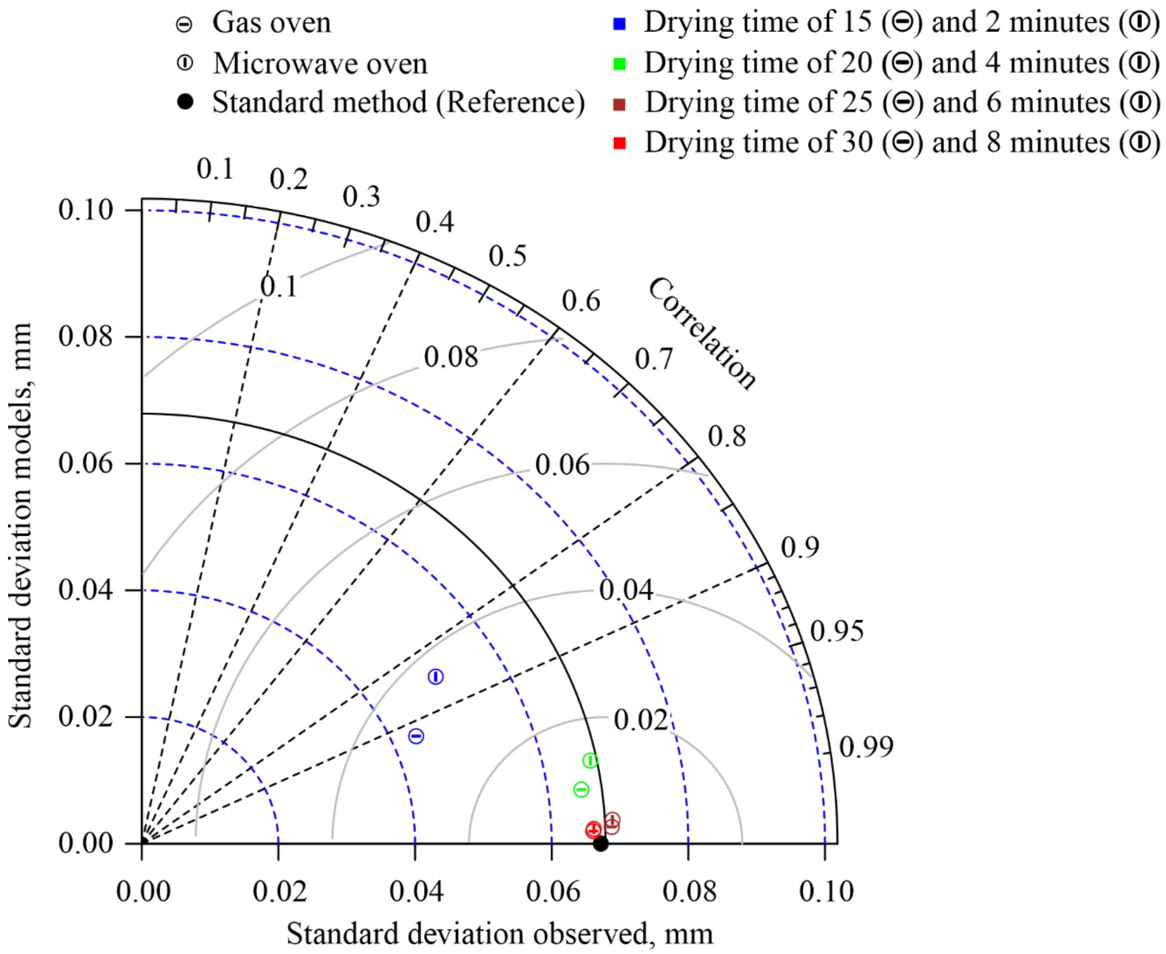

Figure 3. Application of the Taylor Diagram graphically representing the statistics and cross-tabulation, referring to the moisture values obtained by the alternative methods and the standard method

The Taylor Diagram increases the quality of the discussion about performance and the choice of a particular model, as it is possible to simultaneously analyze a series of statistics of observed and estimated data (Pereira et al., 2014). In this study, we adopted drying times of 25 and 8 minutes for the gas oven and microwave, respectively, and correlating them with the standard oven method, linear equations were adjusted for both methods (Figure 4).

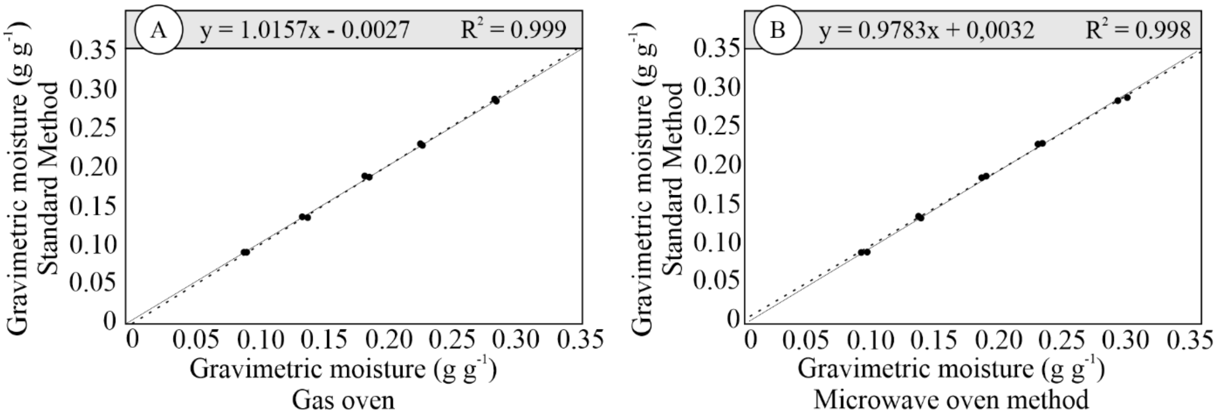

Figure 4. Comparison between gravimetric moisture values obtained using the gas oven at 25 minutes (A) and microwave at 8 minutes (B) with the standard oven method

The determination coefficients found were very strong (Hongyu, 2018), with values of 0.999 and 0.998 for the gas oven and microwave, respectively. It can be seen that the measurements at the 30% moisture level generated the highest errors for the microwave oven, with a value of 3.57%, which resulted in a dispersion of these points for this moisture (Figure 3B).

As can be seen in Table 3, the performances of both alternative methods were classified as excellent, with the correlation coefficients (r), agreement index (d), and performance index (d) showing values very close to 1, indicating a good association and almost perfect agreement between the variables involved in the analysis.

Table 3. Correlation coefficient values (r), agreement index (d), performance index (d), performance class, absolute error (EA), absolute mean error (ERA) and root mean square error (RQME) for the correlation between standard oven (E), gas oven (F) and microwave oven (M) methods

Variables	r	d	c	Classes	EA	ERA	RQME
E × F	0.9996*	0.9997	0.9993	Excellent	1.28	5.63	0.22
E × M	0.9995*	0.9995	0.9989	Excellent	1.24	5.86	0.31

* Correlation coefficient different from zero, by t test, at 5% probability level

It is noticed that the regression between the standard method and the alternative methods allowed low values of EA, ERA, and RQME. According to Janssen & Heiberger (1995) the closer these values to zero, the greater the accuracy and confidence of the fitted model. The validation indicators of the alternative methods used in this study confirmed that the gas oven and the microwave oven can be used to estimate soil moisture with the adoption of times of 25 and 8 minutes, respectively.

4. Discussion

Direct methods for soil moisture determination use a heat source to measure the water content of a soil sample (Ribeiro et al., 2018), basically by evaporation. The standard method is the oven method (Embrapa, 1997), where a temperature of 105ºC is adopted so that a given sample has a constant mass after a given time interval. This temperature is sufficient to promote only water evaporation and not soil burning (Mazur et al., 2022), so any method that promotes the removal of water content from a soil sample can be adopted as an alternative method for determining moisture. In the case of using temperatures above 105ºC, the sample must be subjected to drying for shorter times (Zambon et al., 2021), as verified in the work of Buske et al. (2014), who observed that the ideal drying time to be adopted for the electric oven would be 20 minutes, while for the microwave oven 5 minutes.

The results obtained in this work reveal that the drying time of 25 minutes in the gas oven resulted in an ERA of 5.63% and RQME of 0.22%, which can be considered low and which makes it possible to obtain results in a much shorter interval. when compared to the standard greenhouse method (Ribeiro et al., 2018). Authors such as Buske et al. (2014) and (Vinholis et al., 2008) observed the efficiency of the use of microwaves and gas and electric ovens in the determination of soil moisture, with statements that suggest a positive results on quality control and production systems. agricultural.

One of the main limitations of the standard method is a long time (24 hours) to obtain the result, which makes irrigation management with a lag of one day (Carvalho & Oliveira, 2012). In the present study, the gas oven and microwave oven methods adopted times of 25 and 8 minutes, respectively, with low measurement errors (Figure 3 and Table 3). It is important to emphasize that times longer than those analyzed here can result in the burning of soil particles and, consequently, measurement errors.

According to Table 1, the soil used in this work has sandy characteristics. Sandy soils have lower water retention when compared to clayey soils because they have a higher frequency of pore size with radii greater than 0.03 mm (Libardi, 2018; Silva et al., 2014), this means that higher energy needs to be used to remove water from these soils (Ekwue & Seepersad, 2015; Zambon et al., 2021), so it is important that in case of repetitions of this methodology for clayey soils, the same results will not be found.

Within this context, Silva et al. (2021) found that soils with clay contents greater than 365 g kg^{-1} remained wetter than soils with clay contents between 152 g kg^{-1} and 311 g kg^{-1}, regardless of the drying method being oven (24 hours) or microwave for 6 minutes. The authors also point out that in clayey soils with higher levels of iron and aluminum oxides, due to the fact that the water is strongly retained in the colloids by adsorption forces, it makes the extraction process and drying of the soil difficult. Found that the time for stabilization of moisture in sandy soils using a microwave oven was from 48 h and that the minimum mass for drying would be 40 g.

In this study, it was found that moisture determinations with levels of 30% generated the highest errors when using the microwave oven method for 8 minutes. With sandy characteristics, with this water content, the soil is saturated. It is believed that a large amount of water present in the samples did not evaporate due to the short evaluation time, which resulted in the dispersion of values at the end of the linear equation (Figure 4B). It is also believed that for a longer drying time, the tendency would be a better adjustment of this point and smaller errors involved, as verified by Cremom et al. (2014). However, for the other points, the errors were low and the same dispersion of the points was not verified (Figure 4B), indicating that the time of 8 minutes is enough to obtain humidities with values very close to the standard method.

5. Conclusion and Recommendations

According to the methodology used in this study and the results obtained, it was possible to conclude that the gas oven and microwave method can be used to replace the standard oven method for determining the gravimetric soil moisturefor sandy soil, adopting a time of 25 minutes for the gas oven and 8 minutes for the microwave.

For soil samples with moisture contents greater than 30% using the alternative microwave oven method will result in greater measurement errors. The gas oven and microwave become methods with great potential for use by producers and technicians to measure soil moisture, since it is simple, fast, and low cost of acquisition.

It can be recommend that, for repetitions of this work, different times associated with different levels of moisture for the use of the microwave oven should be evaluated.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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