Use of Affordable Sensors to Investigate Aeration and Resistance to Plant Root Penetration for Soil Assessment

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- Introduction -

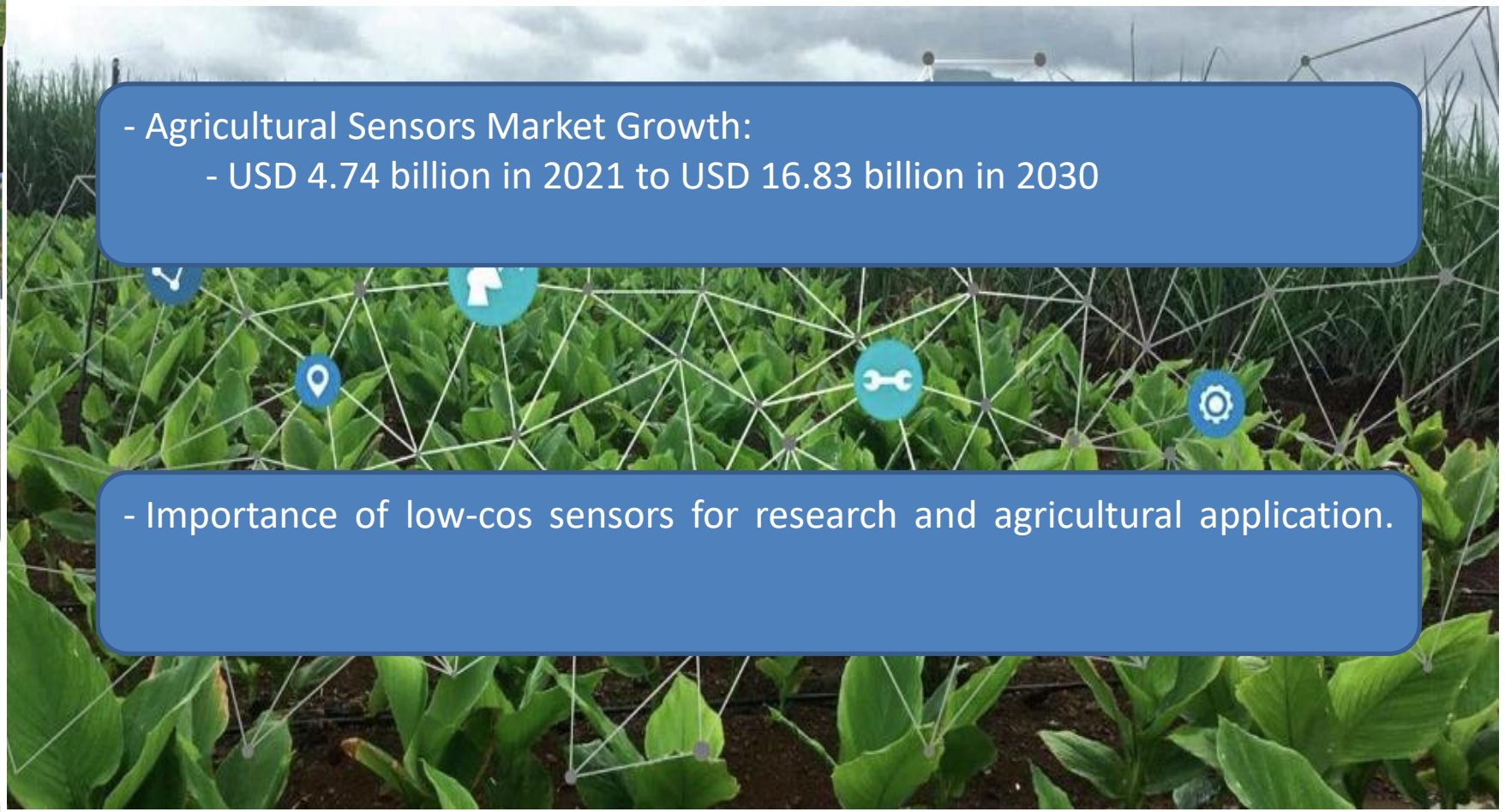
Importance of instrumentation to measure factors affecting plant root growth.

- Oxygen diffusion rate:
  - fundamental for respiration and root growth;
  - Root growth.

- Soil Redox potential:
  - reflects the availability of oxygen in the soil environment.

- Resistence to root penetration:
  - influenced by factors such as soil compaction; rocks; debris and even root hairs from others plants;
    -rocks; debris and even root hairs from others plants.

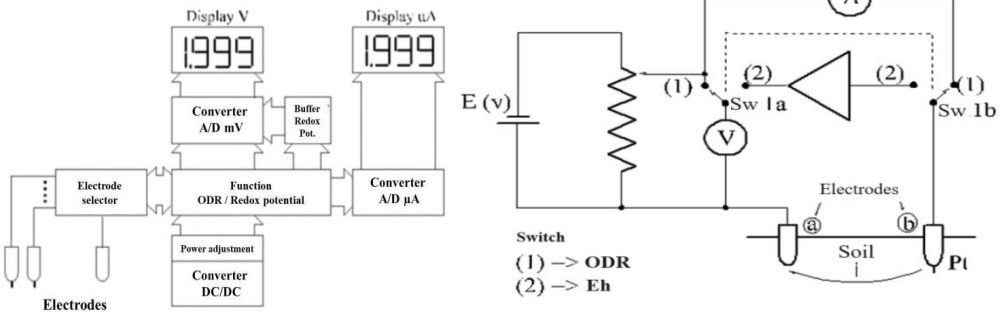
Agricultural Sensors Market

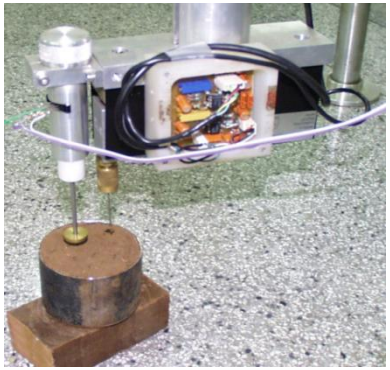


- Agricultural Sensors Market Growth:
  - USD 4.74 billion in 2021 to USD 16.83 billion in 2030

- Importance of low-cos sensors for research and agricultural application.

Purpose of the study





Sensor for soil oxygen diffusion rate

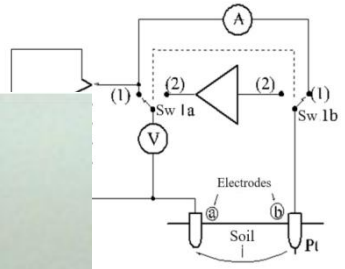
Sensor for soil redox potential

Sensor for soil resistance to root penetration

Analog to Digital Converter and Digital Signal Processing

Dashboard

Oxygen Diffusion rate sensor (ODR)



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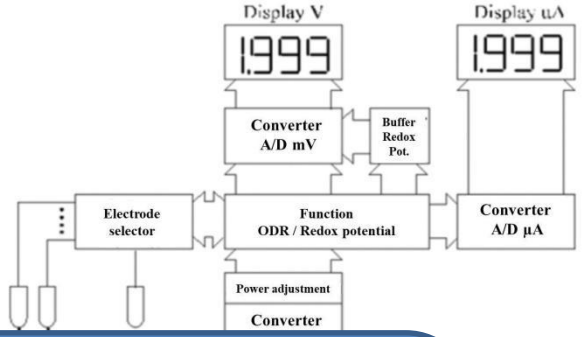
- Redox Potential Sensor Eh -

- Uses platinum electrodes and a voltmeter



-Measurement of the tendency of the soil environment to gain or lose electrons

- Eh positive: it indicates a more oxidizing environment, favorable for root growth;
- Eh negative: suggest a reducing environment with limited availability of oxygen and CO2.

-

$$Eh = Eh^0 - \frac{R * T}{n * F} * ln \frac{(Red)}{(O_x) * (H^+)}$$

- Root Penetration Resistance Sensor (SSRPM)

-The Root Penetration Resistance Sensor (SSRPM) is a device used to measure the resistance that plant roots encounter when penetrating the soil.
-This sensor is crucial for understanding the physical soil conditions that affect plant root growth and development.
-It operates through the use of a micro-penetrometer, which is inserted into the soil to measure the force required to penetrate the soil layers.

Measuring resistance to root penetration is essential for evaluating soil compaction, the presence of obstacles such as stones or debris, and even the density of the roots of other plants. This helps researchers and farmers understand conditions that can limit plant root growth and, consequently, crop productivity.

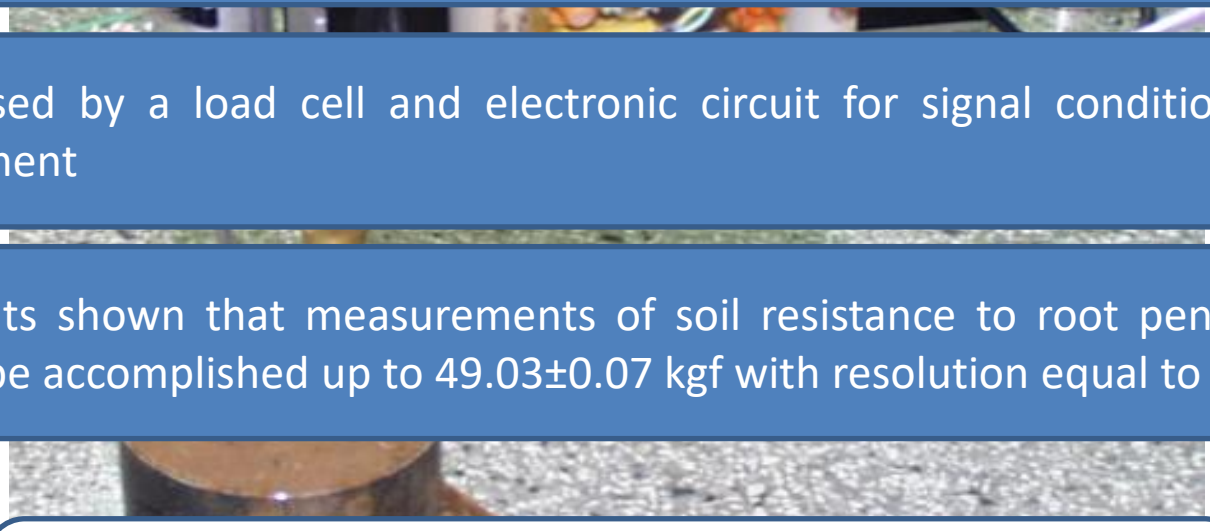
- Sensor de Resistência à Penetração das Raízes (SSRPM)

-Developed based o the ASAE R 313.3 standard for penetrometers.

-Cone angle of 30º

- base diameter of 1.6 mm

- total length of 130 mm



- Sensed by a load cell and electronic circuit for signal conditioning and treatment

- Results shown that measurements of soil resistance to root penetratiion could be accomplished up to 49.03±0.07 kgf with resolution equal to 1.57 kgf

$$RSP = g(\sigma_n, \mu, c_3, RP, \rho, \theta)$$

$$RSP = 6.98 * \rho^2 + A + B + C - D - 10.44 * 10^{-2}$$

- Sensor de Resistência à Penetração das Raízes (SSRPM)

$$A = [-1.62 * 10^{-1} + 1.36 * 10^{-3}(A_1)] * \rho$$

$$A_1 = h_a + R_c\left(\frac{RP - \sigma_n}{(\mu * \sigma_n) + c_a}\right)$$

$$B = [1.98 * 10^{-1} - 9.20 * 10^{-3}(B_1)] * (\theta * \rho)$$

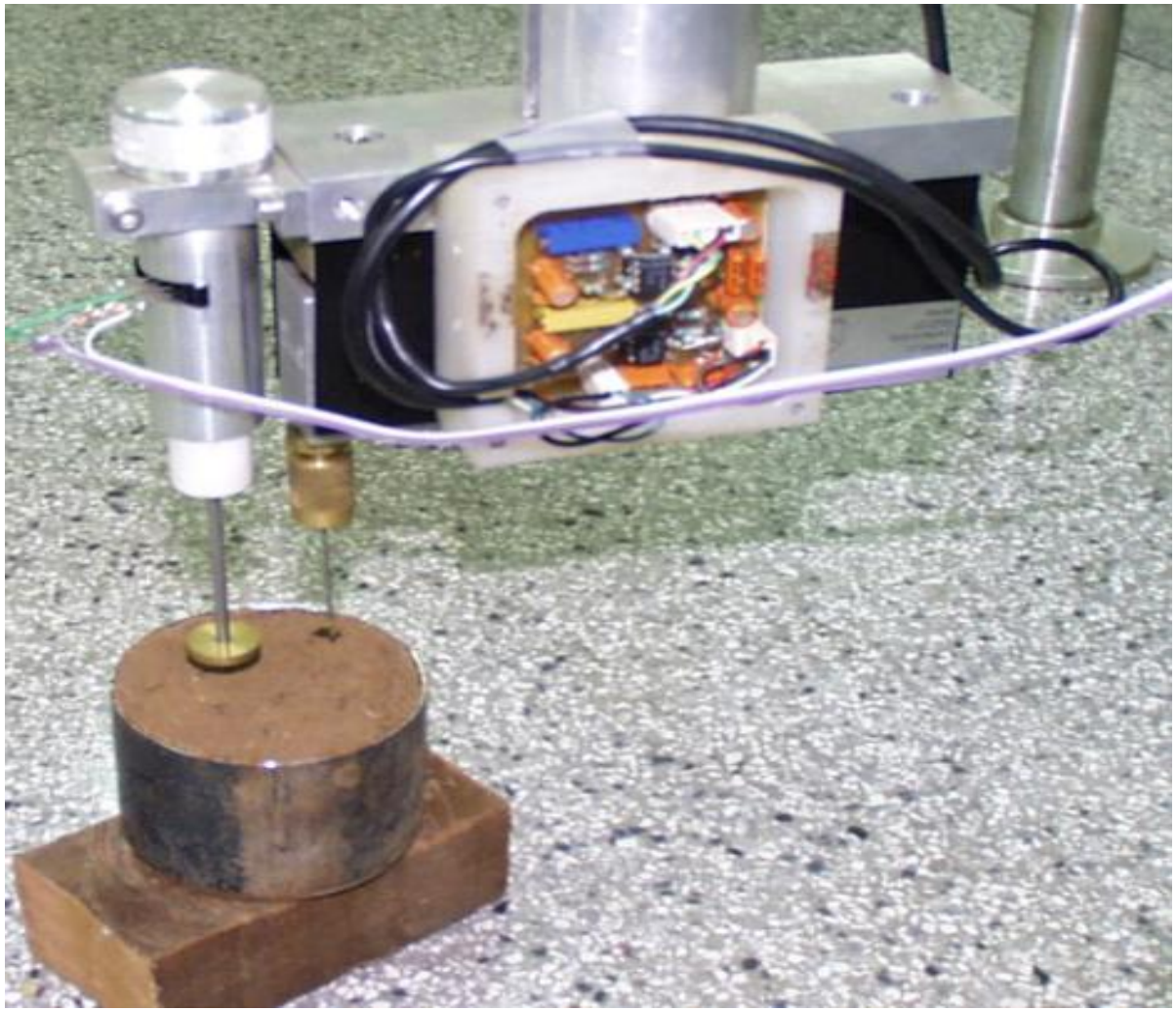
$$B_1 = h_a + R_c\left(\frac{RP - \sigma_n}{(\mu * \sigma_n) + c_a}\right)$$

$$C = 9.80 * 10^{-2}\left[h_a + R_c\left(\frac{RP - \sigma_n}{(\mu * \sigma_n) + c_a}\right)\right]$$

$$D = 2.0 * 10^{-3}\left[h_a + R_c\left(\frac{RP - \sigma_n}{(\mu * \sigma_n) + c_a}\right)\right]$$

ha – is the height of the microprobe within the soil
Rc – is the cone radius of the microprobe tip, equal to 0.08 cm

- Sensor de Resistência à Penetração das Raízes (SSRPM)



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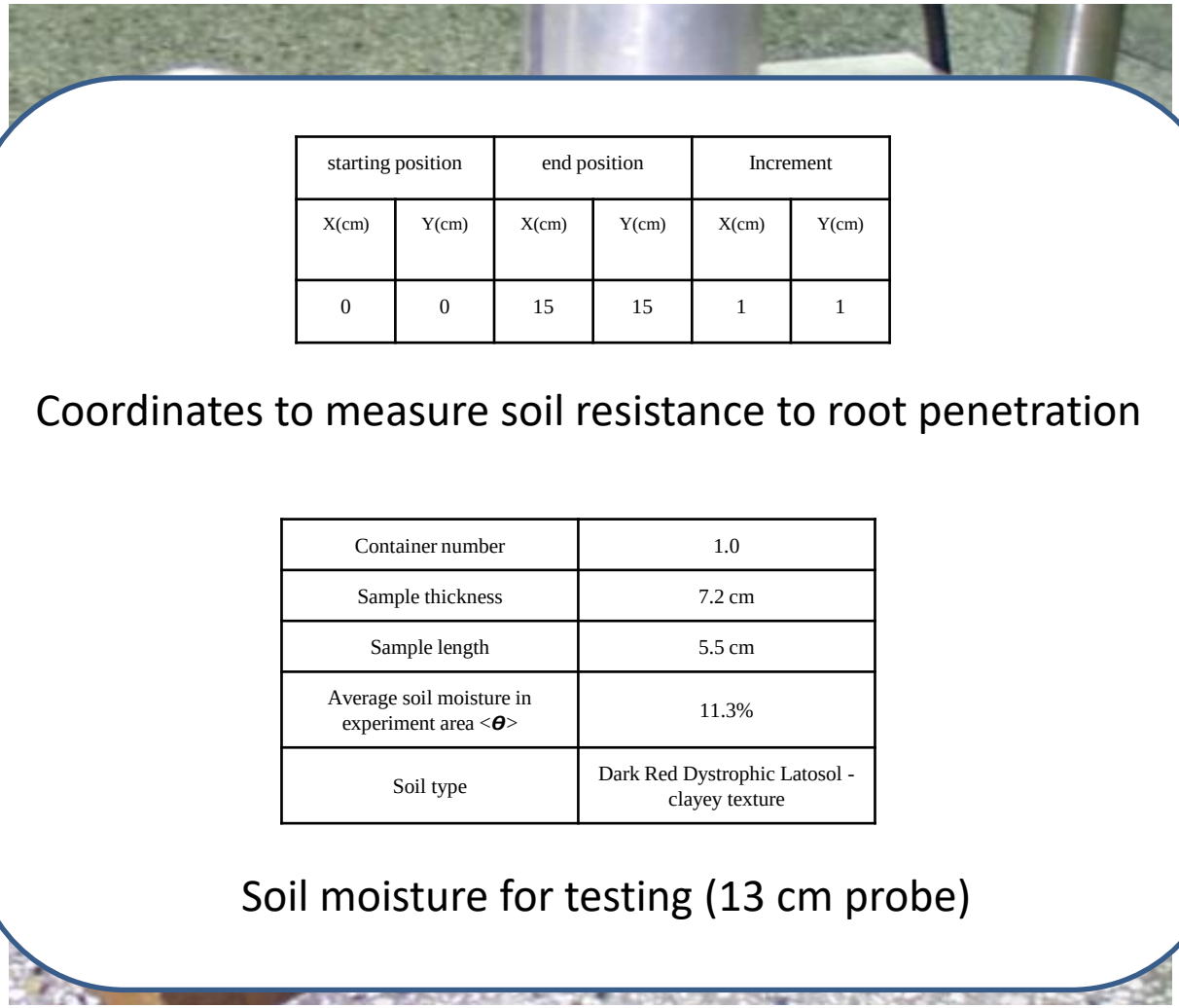


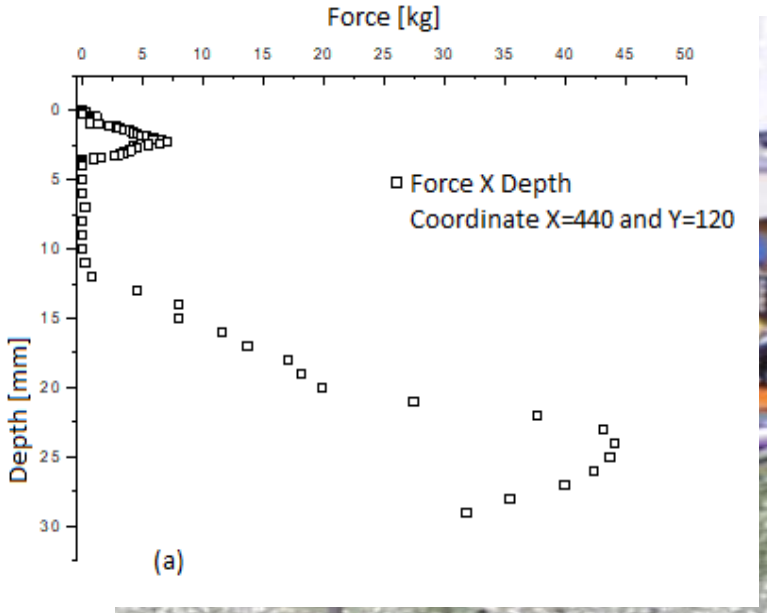
starting position		end position		Increment	
X(cm)	Y(cm)	X(cm)	Y(cm)	X(cm)	Y(cm)
0	0	15	15	1	1

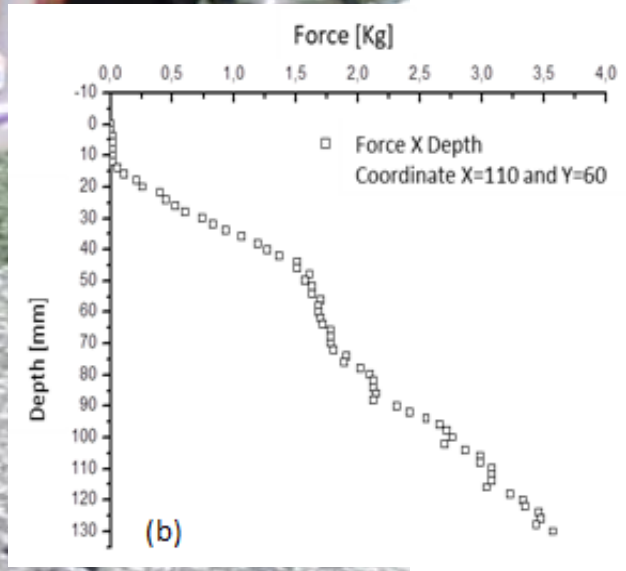
Coordinates to measure soil resistance to root penetration

Container number	1.0
Sample thickness	7.2 cm
Sample length	5.5 cm
Average soil moisture in experiment area <θ>	11.3%
Soil type	Dark Red Dystrophic Latosol - clayey texture

Soil moisture for testing (13 cm probe)

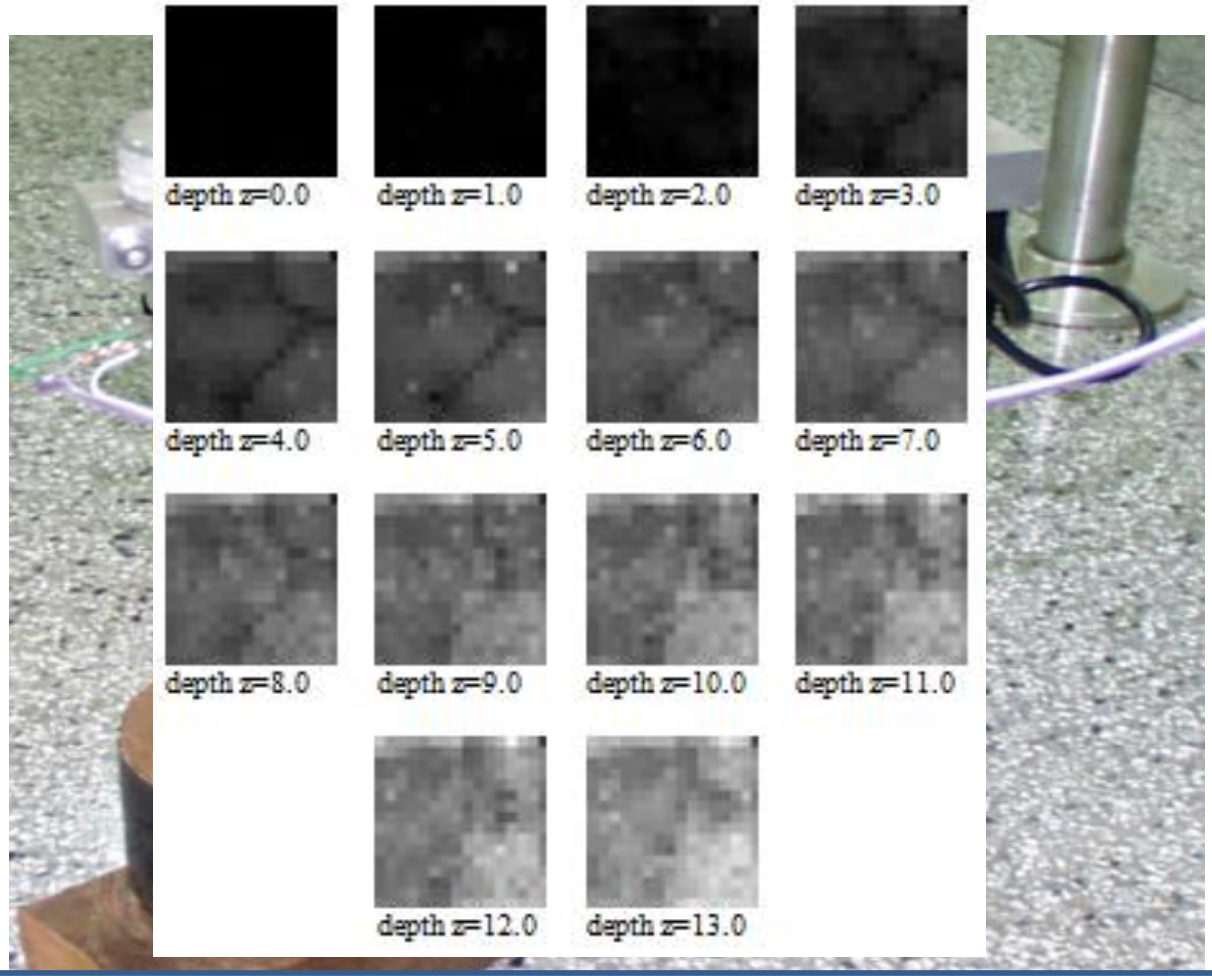
- Sensor de Resistência à Penetração das Raízes (SSRPM)





Variation in soil resistance to root penetration for the 3cm (a) and 13cm (b) probe as a function of depth Z, for coordinates (X=440, Y=120) and (X=110, Y=60) respectively

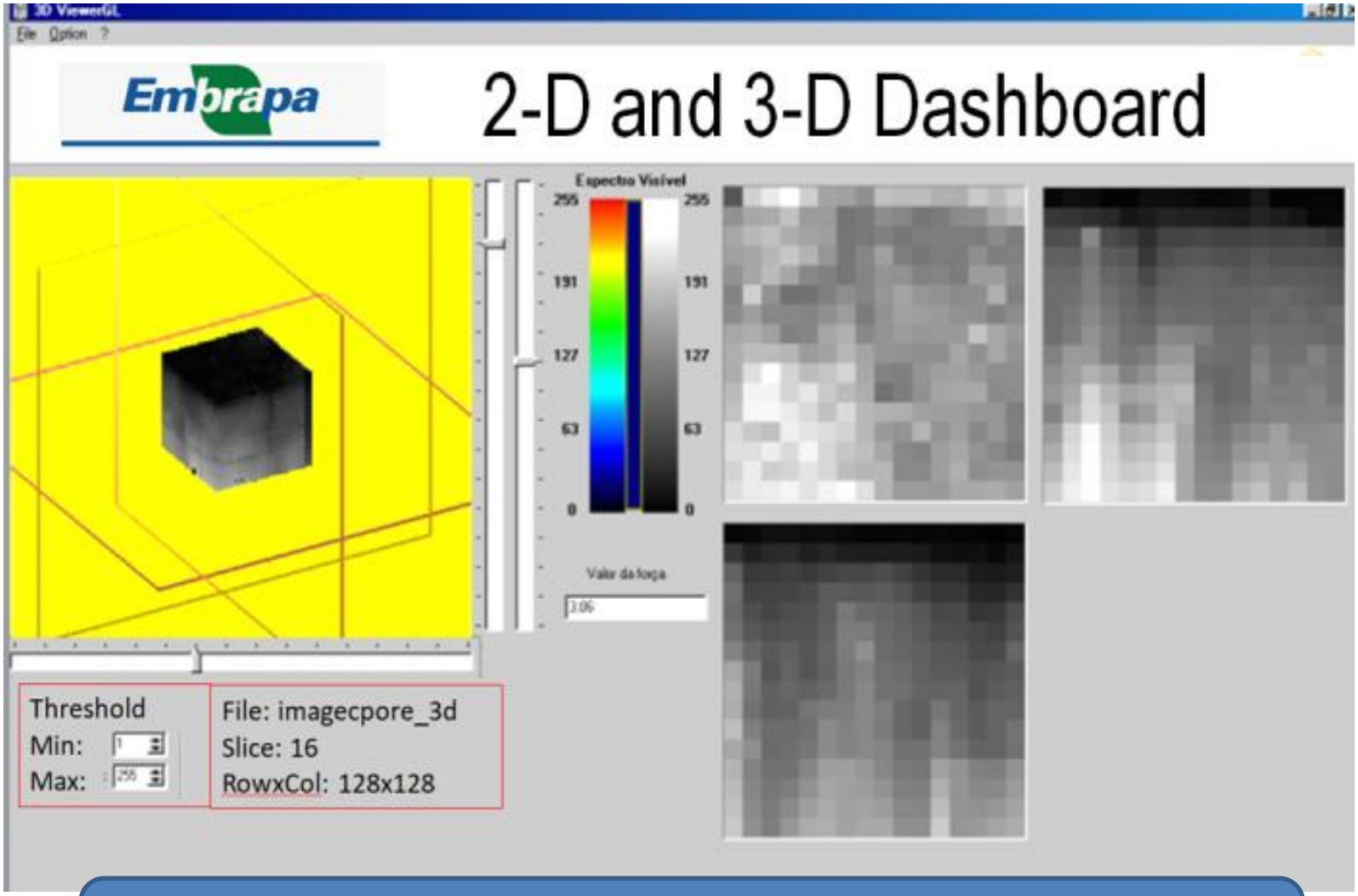
- Sensor de Resistência à Penetração das Raízes (SSRPM)



Sequence of two-dimensional maps of measures of soil resistance to root penetration for data collected in the field for the 13 cm, in the range from z=0.0 cm to z=13.0 cm, shades of gray; from black =0.0 kgf to white=50.0 kgf

: Three-dimensional map of soil resistance to root penetration, collected in an agricultural field using the 13cm probe.

- Sensor de Resistência à Penetração das Raízes (SSRPM)



Three-dimensional map of soil resistance to root penetration, collected in an agricultural field using the 13cm probe.

Conclusions and future work

- Three affordable sensors were introduced that have lproven to be quite usefull in soil science studies.
- Results have demonstrated that the sensors are capable of accurately evaluating redox potential, oxygen diffusion rate, and aeration, even in soil that is nearly saturated, as well as the soil resistance to root penetration.
-The reached level of precisions makes the final arrangement with the three sensors ideal for agricutural applications.

Future work:

- plans to integrate sensors into a ARM architecture (Acom RISC Machine) and incorporate computational intelligence to aid decision making in the agricultural setting.

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