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Seedlings Emergence in Compacted Soil as Measured by a Pressure Transducer

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Authors' contributions

This work was carried out in collaboration between all authors. Author KMB designed the study, managed the literature searches, analyses of the study, performed the spectroscopy analysis and wrote the first draft of the manuscript. Author DJO wrote the protocol and supervised the experimental process. Author MFA designed and fabricated the data logger and author KAS identified the species of plant. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Research was conducted to obtain an instrument for a more precise method of measuring seedlings emergence, also to indicate the amount of pressure exerted by seedlings before emerging to the surface, hence the design and fabrication of a data logger capable of measuring and logging the pressure exerted by seedlings of maize (hypogeal) and okra (epigeal) in emergence study on compacted Egbeda soil series (Ultisol). The PIC18F4550 Microchip microcontroller unit serves as the heart of the data-logging system, while seedling emergence pressure was determined using MPX5050DP pressure sensor (0-5000 milibar). The date and time were monitored with DS1307 RTC (Real Time Clock) timer, 24LC512 a 512 kbit EEPROM was used as the storage unit and LCD LM016L was used as the display unit. The circuit was designed with Proteus ISIS. The software that interfaced the design with computer was designed with Microsoft Visual Studio using Visual Basic.NET. The experiment was conducted at the departments

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of Physics, Civil Engineering and Soil Science and Land Resources Management of Obafemi Awolowo University, Ile-Ife, Nigeria, between August, 2013 and June, 2014. The emergence experiment was conducted with soil treatments consisting of four levels of soil compaction (0, 5, 15, and 25 blows of a standard proctor rammer of 2.5 kg; light BS 1377, equivalent to 0, 39, 116 and 193 kJm^{-3} respectively), at 0.12 g/g moisture content, and replicated three times in a completely randomized design. The results showed that soil strength had significant (p = 0.05) effect on percent seedlings emergence and pressure exerted by seedlings, percent seedlings emergence was negatively correlated ($p \le 0.05$) with pressure exerted by seedlings. Positive correlation ($p \le 0.05$) was also observed between soil strength and pressure exerted by seedlings at emergence as measured by the pressure transducer. Therefore the pressure transducer provides an alternative method of measuring seedling emergence as against indirect method being used.

Keywords: Ultisol; data logger; epigeal; hypogeal; sensors.

1. INTRODUCTION

Sowing seeds and their subsequent germination, and seedling establishment, are annual event in crop production. The soil acts as a physical barrier to seedling emergence and may decrease or even prevent seedling establishment especially under conditions of soil crusting or soil compaction. Seedlings must therefore exert adequate force to emerge through the soil [1].

Seedling emergence probably is the single most important phenological event that influences the success of an annual plant. Emergence represents the point in time when a seedling is weaned from dependence upon nonrenewable seed reserves originally produced by its parent, and when photosynthetic autotrophism begins. To a large extent, plant scientists have been content with enumerating, estimating, or predicting the initiation of seedling emergence (Ei) or the point in time at which 50% emergence (E50) is reached. Such imprecise indices may be appropriate for some purposes, but are prone to error in many other applications [2]. Different measurements have not expressed pressure seedlings exert in emerging to the surface, some of the measurements are:

> The standard germination test [3], 100-seed weight and seed density (gcc^{-1}) [4]. Emergence percentage was calculated by dividing the number of emerged seedlings by the total seeds sown. Mathematical expressions which include germinability, germination time, coefficient of uniformity of germination (*CUG*), coefficient of variation of the germination time (CV_t), germination rate (mean rate, weighted mean rate, coefficient of velocity, germination rate of George, Timson's index, *GV* or Czabator's index; Throneberry and Smith's method and its adaptations, including Maguire's rate; *ERI* or emergence rate index, germination index, and its modifications [5].

Percent emergences 15 DAP. Final seedling emergence percentage (15 days after planting) was measured by counting the seedlings. SERI (Seedling Emergence Rate Index) by [6].This index measures the maximum emergence percentage within the shortest time. The percentage of seedlings emerged (E) [7]. Emerged rate index (ERI) and percentage of emerged seedlings (PE [8]. Soil seedling emergence using a hydrothermal time model [9].

1.1 Pressure Sensor/Transducer

A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed, such a signal is electrical. Pressure sensors are used for control and monitoring in thousands of everyday applications. Pressure sensors can also be used to indirectly measure other variables such as fluid/gas flow, speed, water level and altitude. Pressure sensors can alternatively be called pressure transducers, pressure transmitters, pressure senders, pressure indicators and piezometers, manometers, among other names.

The objective of this study was to design and fabricate a data logger capable of measuring pressure exerted by seedlings in emerging to the surface.

2. MATERIALS AND METHODS

2.1 Collection of Soil Samples

Egbeda soil series (Ultisol) samples were taken from 0 – 15 cm depth under secondary bush – regrowth and continuous long term cultivation at

Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Osun State, Nigeria, air dried and gently crushed to pass through 2 mm sieve to separate the fine earth (≤ 2 mm diameter) from other soil components. Emergence studies were conducted on the soil.

2.2 Compaction and Seed Emergence Process

The process of compaction started by packing the established 0.12 g/g moisture content soil sample in 16 cm deep and 8.8 cm diameter plastic pots, each pot containing 1.5 kg soil. The treatments consisted of four levels of soil compaction (0, 5, 15 and 25 blows of 2.5 kg rammer-light BS 1377, equivalent to 0, 39, 116 and 193 kJm^{-3} respectively), a soil type (Egbeda series) and two crop types (Maize and Okra) and replicated three times in completely randomised design. Compaction was achieved by utilizing a proctor device [10]. After compaction, the samples were taken to laboratory for seed planting. Viable seeds of maize and okra were selected for the experiment. Two- 5 mm deep holes was carefully made in the soil ring and two seeds (pre-germinated by imbibition) and a pressure sensor probe was gently pressed between the holes and the soil removed was returned to cover the seeds and probe and connected to a designed and fabricated pressure transducer to measure pressure to be exerted by seedlings in emergence. Hand cone penetrometer to determine soil strength.

2.3 The Design of Pressure Data Logger

The data logger circuit is composed of a host of active components and handful passive components. The passive components are the resistors, capacitor and diodes in the circuit that are used mainly for filtering, voltage and current stability, while the active components are the real components playing a key role in the circuit. They are as follows.

2.3.1 Processor

The PIC18F4550 (Plate 1) serves as the heart of the data-logging device, it is a computer in a chip. It contains the same elements as does a computer system: Processor, Input/output and Memory/Storage. The PIC18F4550 is an embedded system manufactured by Microchip and it is a 40-pin high performance, enhanced flash USB Microcontroller with nanoWatt technology. PIC18F4550 has 32 Kb flash memory, 256 bytes EEPROM, 13 analog to digital channels (ADC), 35 IO ports, four timer modules. It can be connected to other components or devices through various communication channels such as, I^2C, SPI, USART and USB [11].

Plate 1. PIC18F4550
http://www.futurlec.com/Microchip/PIC18F4550.shtml/ 20/07/2013

2.3.2 Storage

The basic storage for the data logger is the 24LC512 EEPROM (Electronically Erasable Programmable Read Only Memory) (Plate 2). This Microchip Technology Inc. 24LC512 is a 64K x 8 (512 Kbit) Serial Electrically Erasable PROM (EEPROM), capable of operation across a broad voltage range (1.8V to 5.5V). This device is capable of both random and sequential reads up to the 512K boundary [12]. For this design the standard 8-pin plastic DIP was used.

Plate 2. 24LC512 EEPROM
http:/www.wulfden.org/downloads/datasheets/24LC512_21754E/20/07/2013

2.3.3 Timer

To keep record of date and time, the DS1307 real time clock (Plate 3) was used. The DS1307 Serial Real-Time Clock is a low-power; full binary-coded decimal (BCD) clock/calendar plus 56 bytes of NV SRAM. Address and data are transferred serially via a 2-wire, bi-directional bus (I^2C). The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power sense circuit that detects power failures and automatically switches to the battery supply.

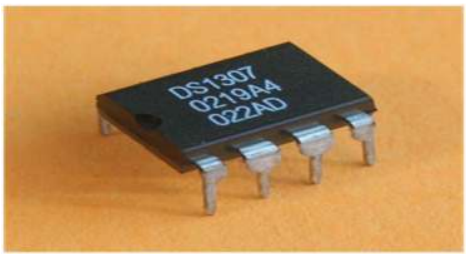


Plate 3. DS1307 RTC timer
http://www.datasheets.maximintegrated.com/en/ds/DS1307/20/07/2013

2.3.4 Display unit

The LCD (Liquid Crystal Display) LM016L (Plate 4) was used as the display unit to communicate to the outside world. The LCD Character Module Display, 2x16 characters, STN yellow/green, yellow/green LED backlight, Transflective, 6:00, Wide Temperature range, RoHS compliant, Module size 80 mm x 36 mm, English-European character. These LCDs can be controlled in two modes: 4-bit or 8-bit. The 4-bit mode requires seven I/O pins from the PIC, while the 8-bit mode requires 11 pins. For this study, the 4-bit mode was used, since it can display all the characters needed.

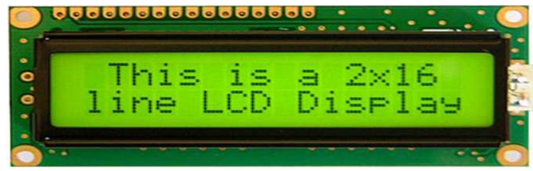


Plate 4. LM016La2X16 LCD display unit
http://www.engineersgarage.com/electronics/16x2-lcd-module datasheet/20/07/2013

2.3.5 Circuit design

The circuit diagram for the data logger was designed and simulated with Proteus ISIS professionals, while the PCB layout was designed with Proteus ARES. Proteus ISIS is a virtual laboratory and SPICE-based simulation of electronic circuits. Proteus Virtual System Modelling (VSM) combines mixed mode SPICE circuit simulation, animated components and microprocessor models to facilitate co-simulation of complete microcontroller based designs. With Proteus VSM, it is possible to develop and test a design before a physical prototype is constructed.

2.4 Construction of Data Logger

The construction was done at the Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile-Ife, Nigeria. On completion of the circuit simulation on Proteus ISIS professional software, a prototype was constructed on a breadboard (Plate 5) to test and debug the circuit.

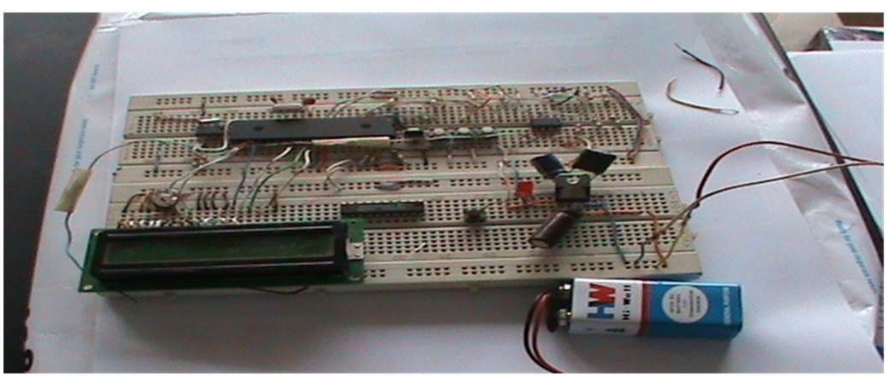


Plate 5. The breadboard layout
https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard/20/07/2013

2.5 Pressure Sensor (MPX5050DP; O-5000 Milibar)

The MPX5050DP series Piezoresistive transducer is a state-of-the art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. The pressure sensors were bought in U.S.A (United State of America) manufactured by Freescale Semiconductor Incorporated; designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

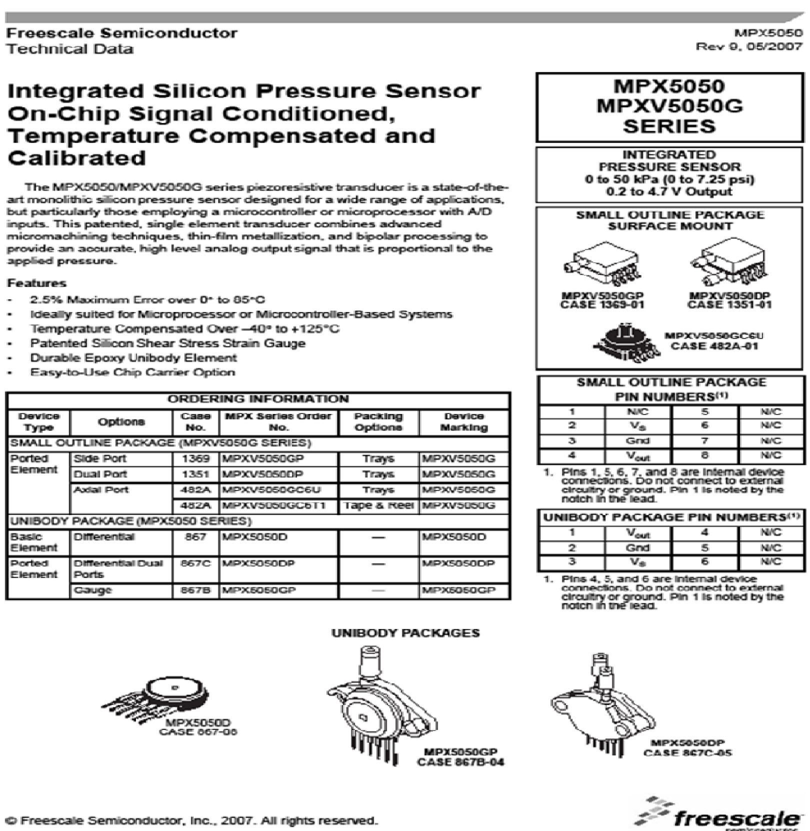
The pressure sensor was constructed with a tube in which the pressure generated as a result of emergence pressure by the seedlings will be propagated via the tube to the designed and fabricated data logger, the transducer sense this pressure electronically and transmitted to be read on display unit known as liquid crystal display (LCD).

2.6 Soil Used for the Experiment

Egbeda soil series are soil of Egbeda association, formed from fine grained biotite gneisses and schists, well-drained fine textured soils, overlying red brown, yellow brown and white mottled clay. Egbeda soils series are clay in texture by definition [13]. It occupy level and gentle sloping site at high levels in the topography, clayey and not more sandy than very clayey sand in horizon between 25.4 cm and 50.8 cm from the surface, and USDA classification as Ultisol.

2.7 Soil Strength

Hand cone penetrometer was used to determine soil strength. Penetration resistance was measured with a TE-3 penetrometer made in Nanjing.



Freescale Semiconductor
Technical Data

MPX5050
Rev 9, 05/2007

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX5050/MPXV5050G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV5050G SERIES)					
Ported Element	Side Port	1369	MPXV5050GP	Trays	MPXV5050G
	Dual Port	1351	MPXV5050DP	Trays	MPXV5050G
	Axial Port	482A	MPXV5050GC6U	Trays	MPXV5050G
		482A	MPXV5050GC6T1	Tape & Reel	MPXV5050G
UNIBODY PACKAGE (MPX5050 SERIES)					
Basic Element	Differential	867	MPX5050D	—	MPX5050D
Ported Element	Differential Dual Ports	867C	MPX5050DP	—	MPX5050DP
	Gauge	867B	MPX5050GP	—	MPX5050GP

MPX5050
MPXV5050G
SERIES

INTEGRATED PRESSURE SENSOR
0 to 50 kPa (0 to 7.25 psi)
0.2 to 4.7 V Output

SMALL OUTLINE PACKAGE SURFACE MOUNT

MPXV5050GP CASE 1369-01

MPXV5050DP CASE 1351-01

MPXV5050GC6U CASE 482A-01

SMALL OUTLINE PACKAGE PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS(1)

1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGES

MPX5050D CASE 867-08

MPX5050GP CASE 867B-04

MPX5050DP CASE 867C-05

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freescale semiconductor

Fig. 1. Data sheet indicating types of MPX5050 sensors from the manufacturer
http://www.datasheetcatalog.com/datasheetpdf/M/P/X/5/MPX5050.shtm/20/07/2013

The penetrometer had a drive mechanism powered by hand crank, allowing insertion at a constant rate. The cone had a 10° angle with a cone base cross-sectional area of 1 cm^2. The penetrometer was pressed into the soil at a constant rate of 0.02 ms^{-1}. The measurement range of the penetrometer was 0.2 to 8.0 MPa with a precision of 0.04 MPa.

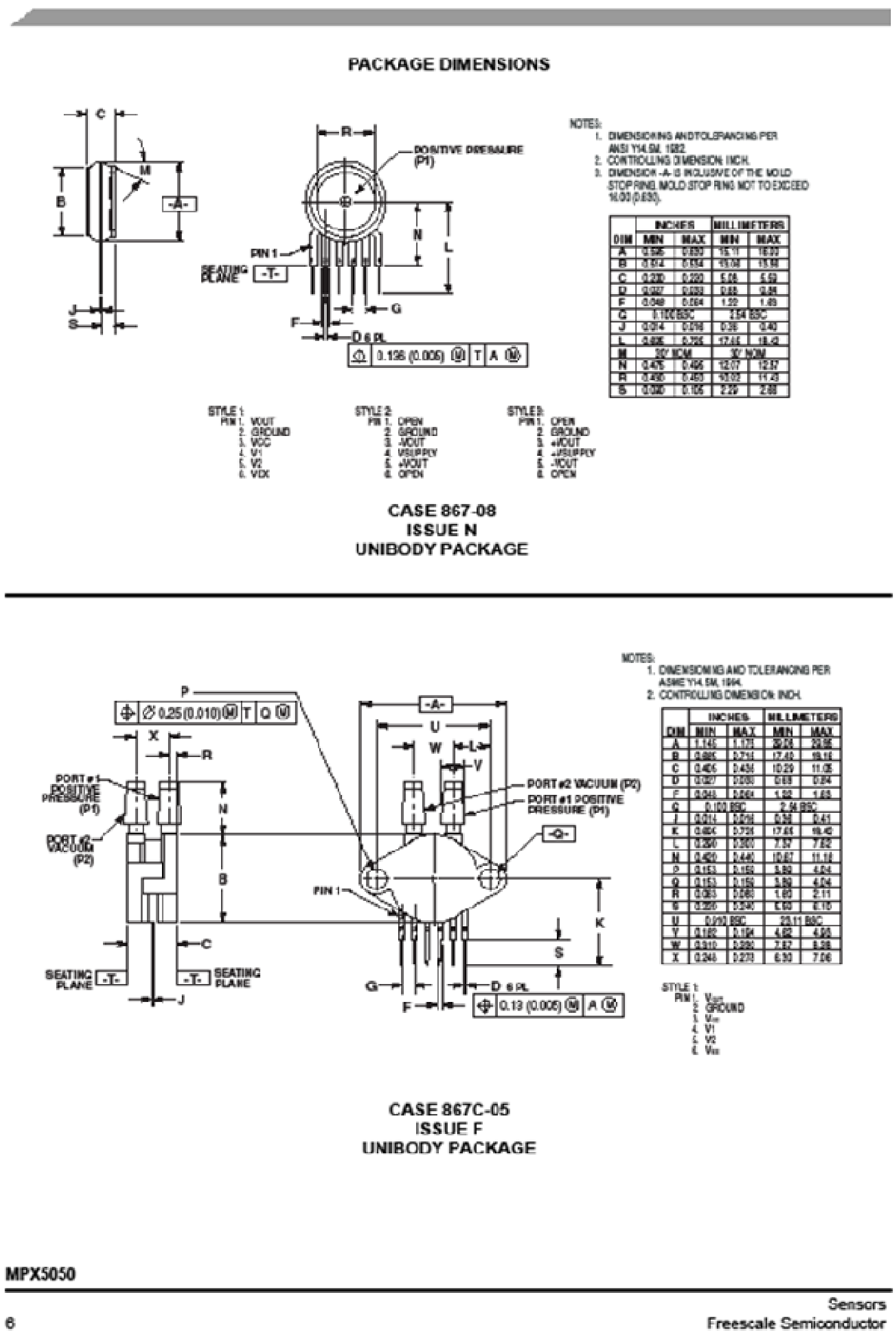

Fig. 2. Packaging dimension of two types of sensors from the data sheet
http://www.datasheetcatalog.com/datasheetpdf/M/P/X/5/MPX5050.shtm/20/07/2013

Plate 6. Data logger with sensors

Plate 7. Experimental setup with pressure sensors

2.8 Statistical Analysis

Data were analysed using SPSS statistics for descriptive statistics and correlation. A paired t-test was used to compare the means of the reading from the constructed data logger, cone penetrometer readings and percent emergence.

3. RESULTS AND DISCUSSION

Observation from the installed pressure transducer after 3 days of planting indicated that emergence (the appearance of first leaf) took place from the pre-germinated seeds the second day (48 hrs).This could not have been exactly 48 hrs but before. Thus the choice of between 43 hrs to 46 hrs, a period which fell within highest exertion of pressure, as threshold period of seedling emergence as an evidence of the seedling about to emerge.

The result (Table 1) showed that as compactive levels increased, pressure exerted by maize and okra seedlings increased, however okra exerted higher and highest pressure (7.13 milibar) than maize (1.67 milibar), this is because okra being an epigeal plant, the cotyledons would need greater pressure to elevate above the soil surface and overcame the compacted layer.

Table 1. Maize and okra seedlings emergence as measured by percent emergence and pressure transducer

Time (Hr)	Compaction level	Soil strength kg/cm^2	Pressure exerted by maize seedlings (milibar)	Pressure exerted by okra seedlings (milibar)	Maize emergence (%)	Okra emergence (%)
43	0	0.92	0.03	0.33	99	80
44	0	0.92	0.03	0.17	99	80
45	0	0.92	0.42	0.12	99	80
46	0	0.92	0.25	0.33	99	80
43	5	14.56	-0.67	4.87	82	81
44	5	14.56	-0.56	5.21	82	81
45	5	14.56	-0.61	5.35	82	81
46	5	14.56	-0.56	4.87	82	81
43	15	18.78	-0.17	4.11	62	50
44	15	18.78	-0.22	4.31	62	50
45	15	18.78	0.06	4.35	62	50
46	15	18.78	-0.11	3.85	62	50
43	25	20.50	1.67	6.82	54	38
44	25	20.50	1.50	7.12	54	38
45	25	20.50	1.25	7.13	54	38
46	25	20.50	1.25	6.28	54	38

Table 2. Paired descriptive, correlation and t- test statistics of maize and okra seedlings emergence as measured by pressure transducer and determined by percent emergence

Variable	Mean	N	Std. deviation	Std. error mean	Correlation	Sig	t-test
Soil strength	13.69	16	7.94	1.98	-0.945	0.0001	-9.405*
Maize % emergence	74.25	16	18.13	4.53			
Soil strength	13.69	16	7.94	1.98	-0.760	0.001	-7.498*
Okra % emergence	62.25	16	19.36	4.84			
Soil strength	13.69	16	7.94	1.98	0.268	0.315	6.940*
Pressure exerted by maize	0.22	16	0.78	0.20			
Soil strength	13.69	16	7.94	1.98	0.926	0.0001	6.755*
Pressure exerted by okra	4.08	16	2.51	0.63			
Maize % emergence	74.25	16	18.13	4.53	-0.517	0.040	15.966*
Pressure exerted by maize	0.22	16	0.78	0.20			
Okra % emergence	62.25	16	19.36	4.84	-0.645	0.007	11.050*
Pressure exerted by okra	4.08	16	2.51	0.63			

N = Number of observations
Sig= Levels of probability
** Mean difference is significant at the 0.05 level*

Generally as soil strength increased, percent emergence decreased and pressure exerted by seedlings of maize and okra increased.

Compactive effort (193 kJm^{-3}) of 20.5 kg/cm^2 strength had the highest negative effect on both maize (54 %) and okra (38 %) seedlings percent emergence (Table 1), this was similar to finding of [14]. Statistical analysis of the data using descriptive, correlation and paired t- test statistics of maize and okra seedlings emergence as measured by percent emergence and pressure transducer (Table 2 above), indicated that from paired t-test, there was statistical significant (p = 0.05) between soil strength and maize and okra seedlings percent emergence, soil strength and pressure exerted by both maize and okra seedlings, maize and okra seedlings percent emergence and pressure exerted by both maize and okra seedlings. Maize seedlings exerted its highest pressure (1.67 milibar) at 193 kJm^{-3}, 20.5 kg/cm^2 and 54 % compactive effort, soil strength and percent emergence respectively, while the least pressure exerted by maize was -0.67 milibar at 39 kJm^{-3}, 14.56 kg/cm^2 and 82 % compactive effort, soil strength and percent emergence respectively. Emergence studies on okra revealed that it exerted highest pressure (7.13 milibar) at 193 kJm^{-3}, 20.5 kg/cm^2 and 38 %; while it exerted least pressure (0.12 milibar) at 0 kJm^{-3}, 0.92 kg/cm^2 and 80 % compactive effort, soil strength and percent emergence respectively, thus from the results, percent seedling emergence of maize decreased from 82 - 54 %; okra (80 - 38 %), while pressure exerted by maize seedlings increased (-0.67 - 1.67 milibar) and okra seedlings (0.12 - 7.13 milibar). A similar trend was reported by [15] when he opined that the higher the compactive effort, the higher the soil strength and dry bulk density; the lower would be the percent emergence.

4. CONCLUSION

The result indicated that soil strength had significant (p = 0.05) effect on percent seedlings emergence of both maize and okra and pressure exerted by both crops seedlings as measured by the pressure transducer, also revealed; percent seedlings emergence by both crops seedlings was negatively correlated ($p \leq 0.05$) with pressure exerted by both crops seedlings as measured by the designed and fabricated pressure transducer. Positive correlation ($p \leq 0.05$) was also observed between soil strength and pressure exerted by maize and okra seedlings at emergence as measured by the pressure transducer.

In conclusion from this study, the result of direct seedling emergence as measured by the pressure transducer was consistent and well correlated with soil strength, compactive efforts and percent emergence results. Therefore the pressure transducer provides an alternative method of measuring seedling emergence as against indirect method being used. It has also provided quantitative and qualitative information on the stress seedlings undergo before emerging to the surface.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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