JEAS

JOURNAL OF ENGINEERING AND APPLIED SCIENCES

Journal of Engineering and Applied Sciences, Volume 15, Number 1, December 2019, 109-117

Least Limiting Water Range of Sandy Loam in South-Eastern Nigeria Under Different Tillage Methods

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Abstract
In this study, the Least Limiting Water Rang (LLWR) of a sandy loam soil under different tillage practices (conventional tillage, conservative tillage and no tillage) and soil depths (0-25cm, 25-50cm, 50-75cm and 75-100cm) were determined using moisture contents at field capacity, permanent wilting point, aeration and mechanical resistance. The upper limit of the LLWR for the three tillage treatments at different soil depths were determined at field capacity rather than air filled porosity, while the lower limit was determined at permanent wilting point rather than penetration resistance. On the average, for conventional tillage, conservative tillage and no tillage, least limiting water ranges of 0.066cm^3/cm^3, 0.056cm^3/cm^3 and 0.052cm^{3}cm^{3}were obtained. The least limiting water values indicate that LLWR increased as tillage intensity increased. Bulk density was also determined for the tillage practices at different depths, for conservative tillage, the lowest value of bulk density was at 75-100cm depth (1.53g/cm^3) while the highest value was obtained at 0-25 and 25-50cm depth (1.55g/cm^3). For conventional tillage, the lowest value was obtained at 75-100cm depth (1.43g/cm^3) and highest at 0-25cm depth (1.47g/cm^3). No tillage was also lowest at 75-100cm depth (1.53g/cm^3) and highest at 0-25cm depth (1.59g/cm^3). On the average, bulk densities of 1.56g/cm^3, 1.54g/cm^3 and 1.45g/cm^3 were recorded for no tillage, conservative tillage and conventional tillage respectively, this shows that bulk density decreases with intensive tillage. Also correlation coefficient for bulk density and least limiting water range at different tillage methods and soil depths gave an R^2>0.9 for all the tillage methods. Test of significance also gave p-values of 0.03, 0.05 and 0.03 for conventional tillage, conservative tillage and no tillage respectively.

Keywords: Least limiting water range; conventional tillage; conservative tillage, no tillage; sandy loam

1. Introduction

Increase in human population, scarcity of resources and environmental degradation affect the environment. Integrated evaluation of soil physical properties using the least limiting water range (LLWR) approach may allow a better knowledge of soil water availability (Fereshte et al 2017). Soil Physicist John Letey developed the Non Limiting Water Range in 1985, and this proved that there may not be equal availability of water between the field capacity and the permanent wilting point. Other physical properties like bulk density, aeration and mechanical resistance should be considered as they equally affect crop growth. The Least Limiting Water Range was introduced by da Silva et al (1994). The impact of changes in soil bulk density on plant growth is linked to water content availability and factors such as aeration or restriction to root development and growth (Safadoust et al.,2014). The least limiting water range is defined as the range in soil water within which limitations to plant growth associated with water potential, aeration and mechanical resistance to root penetration are minimal (Silva et al 1994), they also stated that response of plants to variation in water content must be considered using ranges of Field capacity, permanent wilting point, soil aeration and mechanical resistance. It is used to determine not only the physical factors that limit crop growth but also the soil quality. The critical values for crop growth are field capacity at -0.01Mpa, wilting point at -1.5MPa, air filled porosity at 110% aeration and soil resistance at 2MPa. It is used to determine not only the physical factors limiting crop growth but also the soil quality (Lapen et al., 2004; Verma and Sharma, 2008). The least limiting water range is useful as long as one realizes it depends on crop type, the growth stage and potential evapotranspiration.

2.0 Material and methods

2.1 Study Area

Field experiment was conducted at the Department of Agricultural and Bioresources Engineering Experimental Site/ Farm Workshop, Nnamdi Azikiwe University, Awka. The site lies between latitudes 6°15’11.8N to 6°15’5.3E and longitudes 7°7’118N to 7°7’183N and altitude of 142m. The soil type is sandy loam and the study was carried out in November 2017.

2.2 Soil Sampling

Soil samples were collected at three different locations with three different tillage methods (Conventional tillage, Conservative tillage and No tillage) at four different soil depths; 0-25cm, 25-50cm, 50-75cm and 75-100cm.
The particle size distribution was determined using Standard test methods for particle-size analysis of soils (ASTM D 422) .

The bulk density was determined the following equation:

$$\frac{\text{weight of dry soil (g)}}{\text{volume of soil (cm}^3)} \qquad (1)$$

The particle density was determined using the following equation:

$$\frac{\text{weight of dry soil (g)}}{\text{volume of sand particle (cm}^3)}, \qquad (2)$$

Porosity was determined using:

$$\left(1 - \frac{BD}{PD}\right) X\ 100 \qquad (3)$$

Where BD = bulk density (gcm^{-3})
PD = particle density (gcm^{-3}).

2.3 Soil water Retention Studies

The soil samples were saturated using the water bath. The saturated soil samples were placed in pressure plate apparatus to equilibrate the soil to a selected matric potential. The soils were weighed to determine the volumetric moisture content at each matric potential. 7 matric potentials were selected viz -0.01, -0.03, -0.07, -0.1, -0.2, -0.5 and -1.5MPa.

2.4 Soil strength determination

Soil strength was determined at the field using penetrometer. The penetration resistance was calculated using the following equation

$$\text{Soil resistance} = \frac{Penetrometer\ \ reading\ (N)}{base\ area\ of\ penetrometer\ \ cone\ (cm^2)} \qquad (4)$$

2.5 Determination of soil air-filled porosity

This was calculated using the equation below

$$\varepsilon_a = 1 - \left(\frac{\rho_b}{\rho_s}\right) - \theta_v \qquad (5)$$

Where θ_v = volumetric water content (cm^3/cm^3)

ρ_b = soil bulk density (g/cm^3)
ρ_s = particle density (g/cm^3)

2.6 Statistical analysis

Statistical ansalysis for least limiting water range and bulk density was performed using the Microsoft Excel to fit the relationship between least limiting water range and bulk density

3.0 Results and Discussions

3.1 Bulk Density

The value of bulk density obtained was normal, exceeding 1.0g/cm^3 unlike that obtained by Zou et al (2000) which was low. For conservative tillage, the lowest value of bulk density was at 75-100cm depth (1.53g/cm^3) while the highest value was obtained at 0-25 and 25-50cm depth (1.55g/cm^3). For conventional tillage, the lowest value was obtained at 75-100cm depth (1.43g/cm^3) and highest at 0-25cm depth (1.47g/cm^3). No tillage was also lowest at 75-100cm depth (1.53g/cm^3) and highest at 0-25cm depth (1.59g/cm^3). On the average, bulk densities of 1.56g/cm^3, 1.54g/cm^3 and 1.45g/cm^3 were recorded for no tillage, conservative tillage and conventional tillage respectively, this shows that bulk density decreases with intensive tillage. Decrease in soil bulk density with intensive tillage was also reported in Karlon and Chawla (2017), Jie et al (2013), Kurdish et al (2006).

3.2 Particle Density

From the particle density chart in fig 3.1, at 0-25cm soil depth, particle density of 2.63g/cm^3 was obtained for no tillage and conventional tillage, a lower particle density of 2.58 was obtained for conservative tillage at the same depth. For 25-50cm depth, 2.59, 2.58 and 2.54 was obtained for no tillage, conventional tillage and conservative tillage respectively, at 50-75cm depth, the particle density for no tillage was lower (2.54) than conventional tillage (2.55g/cm^3), while 2.49g/cm^3 was obtained at conservative tillage, at 75-100cm soil depth, particle densities of 2.57g/cm^3, 2.48g/cm^3 and 2.45g/cm^3 were obtained for no tillage, conventional tillage and conservative tillage respectively, particle density decreased as soil depth increased for the three tillage treatments, this is in agreement with Alam and Salahin (2013) where particle density decreased from 2.58g/cm^3 to 2.55g/cm^3 as the soil depth increased

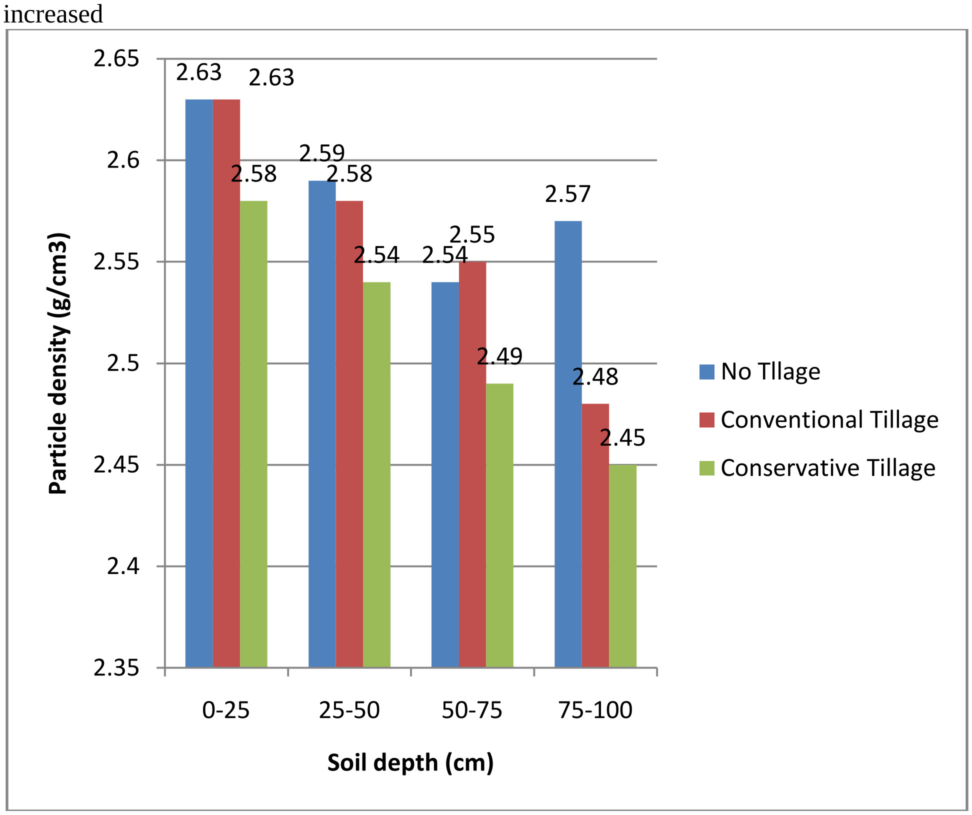

Fig 3.1 Effect of Soil Depth on Particle Density

3.3 Soil Moisture Characteristics Curve

The relationship between soil matric potential and volumetric water content for the three tillage practices at different soil depths over the range between field capacity and wilting point as shown in figs 3.2, 3.3, 3.4 and 3.5 shows that soil water content increased with decrease in soil matric potential, that is, soil moisture decreased as matric potential moved from field capacity to wilting point. This is in agreement with Zou et al., (2000) where volumetric moisture content increased from wilting point (0.09, 0.11, 0.12, 0.18, 0.21, 0.23, 0.26 0.30, 0.32, 0.22, 0.26, 0.30) to field capacity (0.28, 0.31, 0.33, 0.39, 0.43, 0.47, 0.42, 0.48, 0.51, 0.36, 0.43, 0.44) respectively

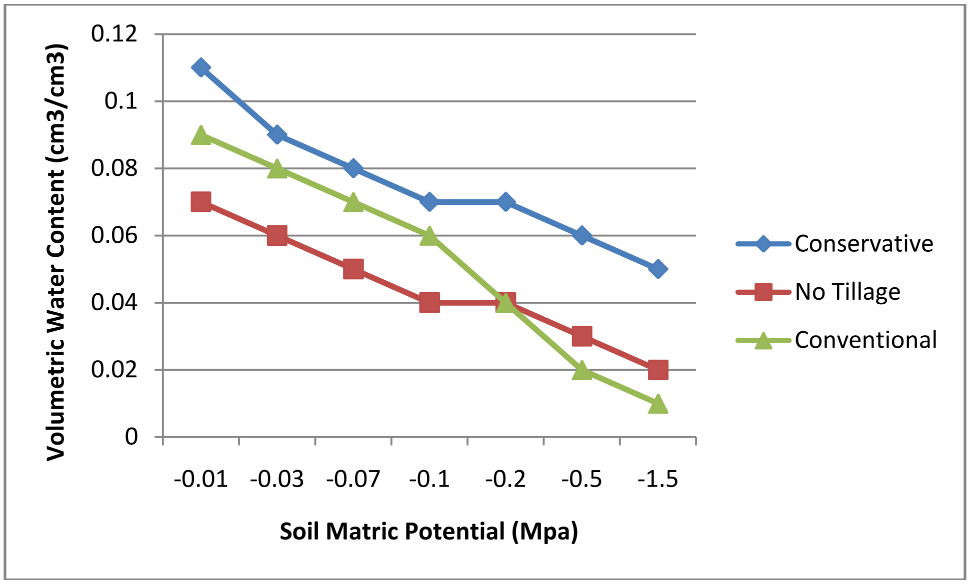

Fig 3.2 Relationship between soil matric potential(ψm) and volumetric water content for different tillage methods at 0-25cm depth

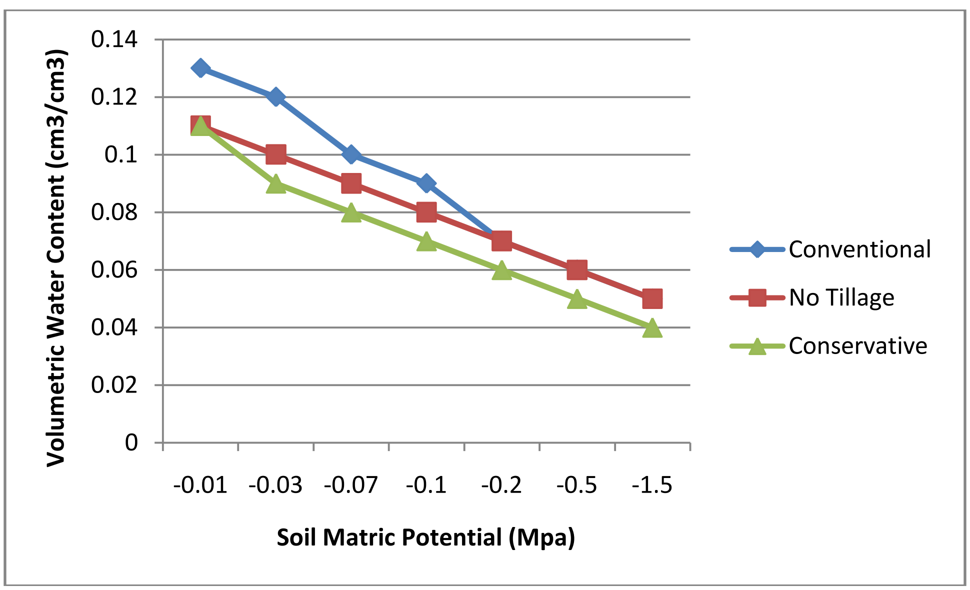

Fig 3.3 Relationship between soil matric potential(ψm) and volumetric water content for different tillage methods at 25-50cm depth

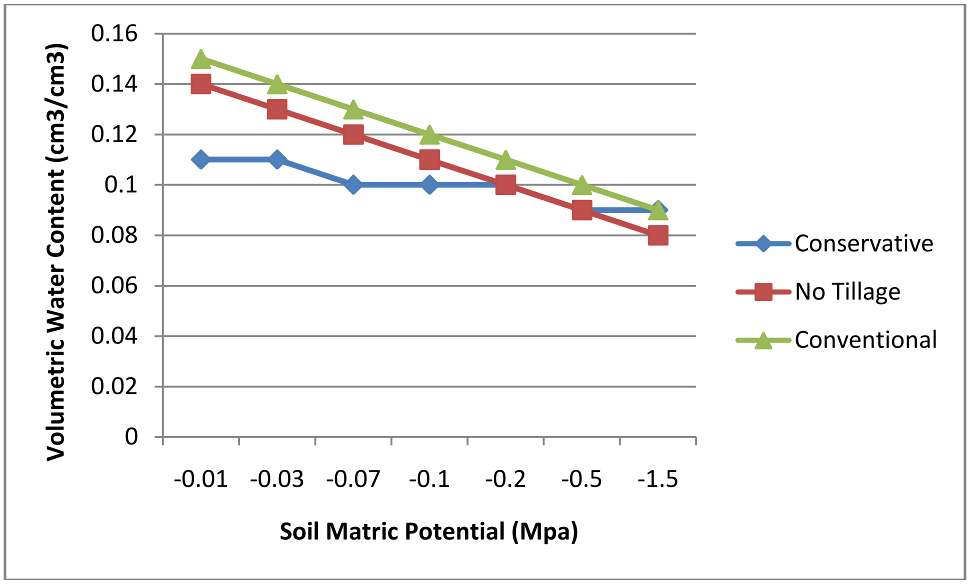

Fig 3.4 Relationship between soil matric potential(ψm) and volumetric water content for different tillage methods at 50-75cm depth

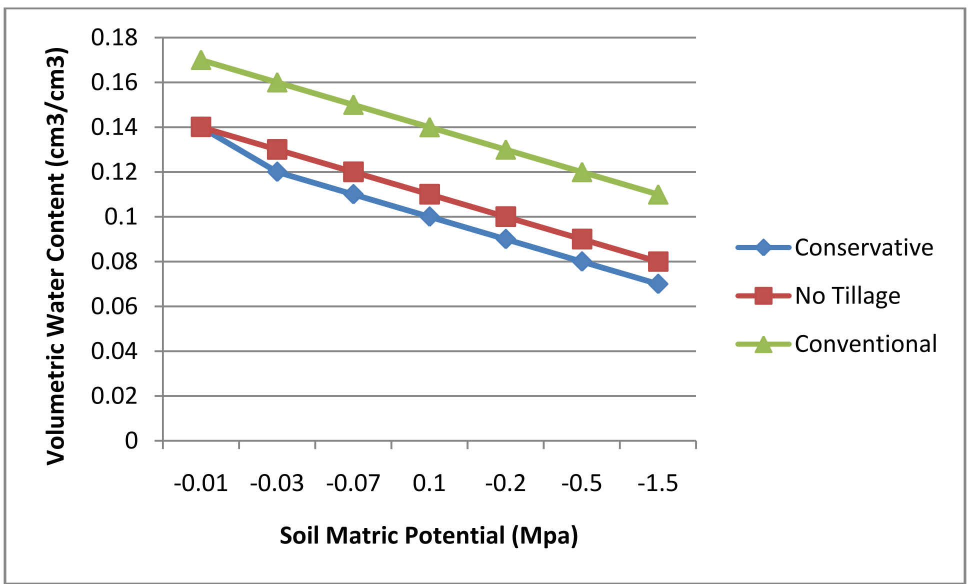

Fig 3.5 Relationship between soil matric potential(ψm) and volumetric water content for different tillage methods at 75-100cm depth

3.4 Determination of the least limiting water range

Tables 3.1 – 3.3 shows the Critical Points for Determination of Least Limiting Water (LLWR) for Root Growth for Conservative Tillage, Conventional Tillage and No Tillage. The Least Limiting Water Range (LLWR) are graphically presented in Figs. 3.6-3.8 for Conservative Tillage, Conventional Tillage and No Tillage

Table 3.1 Critical Points for Determination of Least Limiting Water Range (LLWR) for Root Growth for Conservative Tillage

Parameters	CST 0-25cm	CST 25-50cm	CST 50-75cm	CST 75-100cm
Bulk Density – ρb(g/cm^3)	1.55	1.55	1.54	1.53
FC-ψ_m = -0.001MPa(θ_{vfc})	0.1	0.11	0.11	0.14
WP- ψ_m = -1.5MPa (θ_{vwp})	0.056	0.048	0.094	0.072
PR-Q = 2MPa	0.031	0.029	0.0282	0.0274
% porosity-ε_a = 0.10 (aeration limit)	0.3	0.29	0.282	0.274
LLWR	0.044	0.062	0.068	0.051

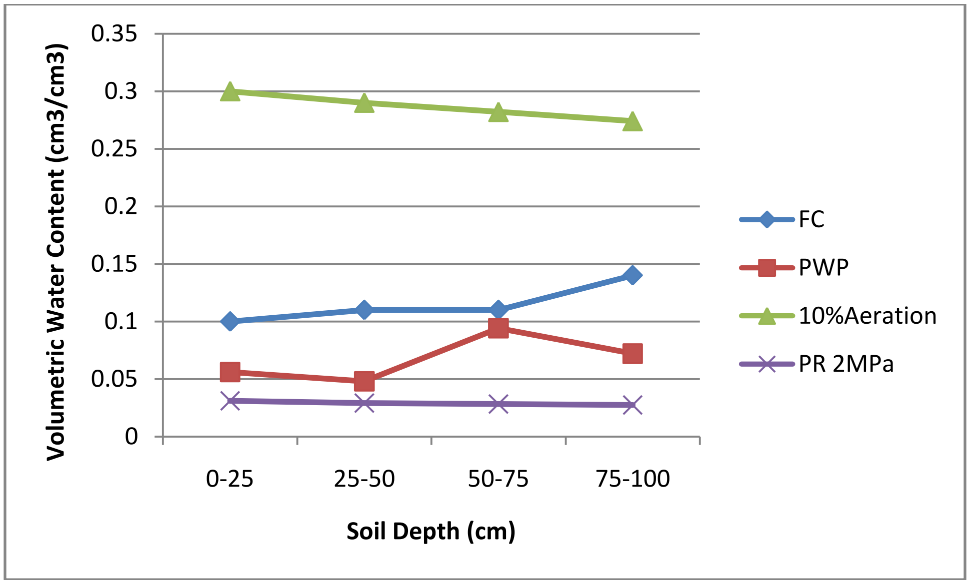

Fig 3.6 Graphical representation of least limiting water range for conservative tillage

As presented in Table 3.1, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The highest LLWR was 0.068cm^3/cm^3 and this was at 50-75cm soil depth, followed by 0.062cm^3/cm^3 at 25-50cm soil depth, 0.051cm^3/cm^3 at 75-100cm depth and the least was 0.044cm^3/cm^3 at 0-25cm soil depth. The portion between the field capacity and permanent wilting point in Fig 3.6 represents the least limiting water range. Increase in LLWR with sudden decrease resulted in decrease in bulk density which is in agreement with Calonego et al (2011), which reported increase in LLWR with sudden decrease with an increase in bulk density.

Table 3.2 Critical Points for Determination of Least Limiting Water Range (LLWR) for Root Growth for Conventional Tillage

	CVT 0-25	CVT 25-50	CVT 50-75	CVT 75-100
Bulk Density – ρb(g/cm^3)	1.47	1.46	1.45	1.43
FC-ψ_m = -0.001MPa(θ_{vfc})	0.09	0.13	0.15	0.17
WP- ψ_m = -1.5MPa (θ_{vwp})	0.016	0.057	0.090	0.11
PR-Q = 2MPa	0.021	0.026	0.046	0.051
% porosity-ε_a = 0.10 (aeration limit)	0.342	0.333	0.328	0.323
LLWR	0.074	0.073	0.06	0.06

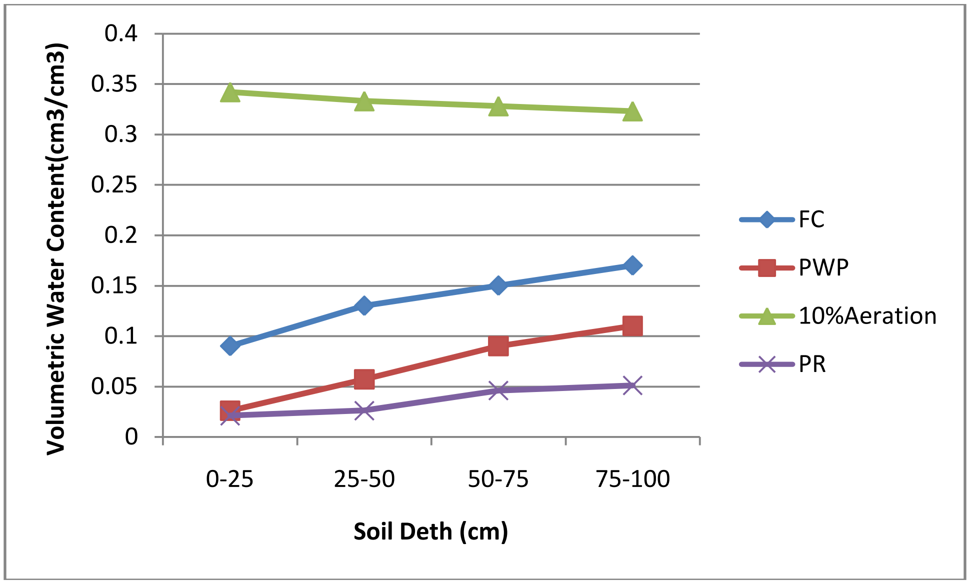

Fig 3.7 Graphical representation of least limiting water range for conventional tillage

The upper limit of LLWR is soil water content at 10% aeration porosity or soil water content at field capacity whichever is lower, while the lower limit of LLWR is soil water content at wilting point or PR 2MPa which ever is higher (Katritika 2016). As presented in table 3.2, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The LLWR is the difference between the upper limit and the lower limit. The portion between the field capacity and permanent wilting point in Fig 3.7 represents the least limiting water range. The highest LLWR was 0.074cm^3/cm^3 and this was at 0-25cm soil depth, followed by 0.073cm^3/cm^3 at 25-50cm soil depth, LLWR remained constant with a value of 0.06cm^3/cm^3 at 50-75cm and 75-100cm soil depths. Decrease in LLWR resulted in decrease in bulk density which is contrary to Calonego et al (2011), which reported increase in LLWR with sudden decrease with an increase in bulk density.

Table 3.3 Critical Points for Determination of Least Limiting Water Range (LLWR) for Root Growth for No Tillage

	NT 0-25	NT 25-50	NT 50-75	NT 75-100
Bulk Density – ρb(g/cm^3)	1.59	1.58	1.56	1.53
FC-ψ_m = -0.001MPa(θ_{vfc})	0.078	0.11	0.12	0.14
WP- ψ_m = -1.5MPa (θ_{vwp})	0.027	0.056	0.057	0.089
PR-Q = 2MPa	0.009	0.013	0.019	0.02
% porosity-ε_a = 0.10 (aeration limit)	0.295	0.288	0.286	0.304
LLWR	0.05	0.05	0.06	0.05

As presented in Table 3.3, water content for the higher limit of LLWR was determined by the field capacity rather than the air filled porosity, while the lower limits of LLWR was determined by wilting point rather than soil strength. The highest LLWR was 0.06cm^3/cm^3 and this was at 50-75cm soil depth, LLWR was constant at 0.05cm^3/cm^3 for 0-25cm, 25-50cm and 75-100cm the soil depths. From figure 3.8, the portion between the field capacity and permanent wlting point represents the least limiting water range. Increase in LLWR with sudden decrease resulted in decrease in bulk density which is in agreement with Calonego et al (2011), which reported increase in LLWR with sudden decrease with an increase in bulk density. The least limiting water range was found to be lowest in no tillage with a mean of 0.052cm^3/cm^3, followed by conservative tillage with a mean of 0.06cm^3/cm^3 and conventional tillage with a mean of 0.07cm^3/cm^3. This is in agreement with Kahlon and Katrina (2017) which recorded lowest mean limiting water range of 0.15m^3/m^3 at no tillage and highest mean LLWR of 0.26m^3/m^3 at deep tillage. Linear regression shows that there are significant differences ($P<0.05$) for bulk densities and Least Limiting Water Range at different tillage methods, the p-values are 0.03, 0.05 and 0.03 for no tillage, conservative tillage and conventional tillage respectively (Table 3.4). Also R^2 values of 0.99, 0.98 and 0.99 were obtained for no tillage, conservative tillage and conventional tillage respectively (Table 3.5). this is in agreement with Kahlon and Karitika (2017) which also recorded a high correlation coefficient of 0.85.

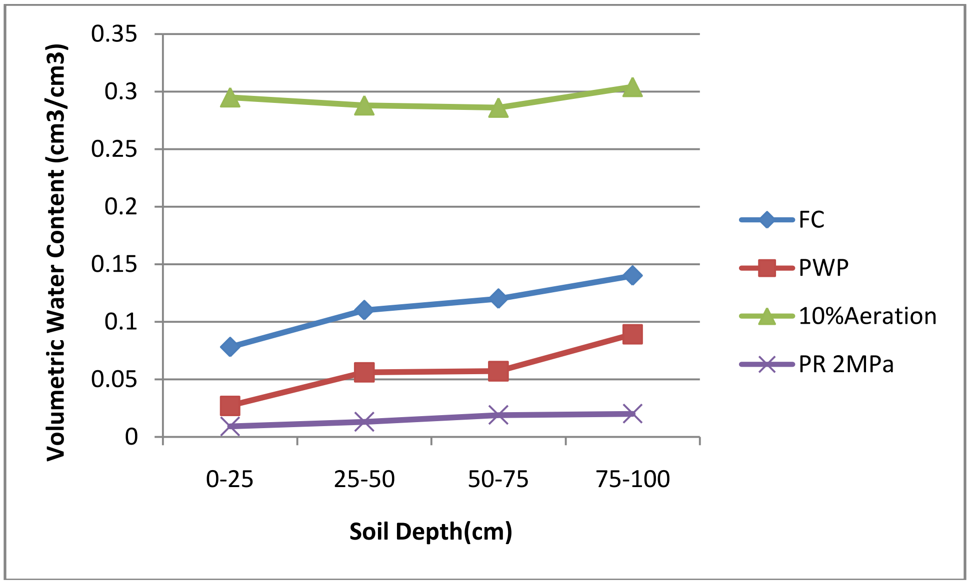

Fig 3.8 Graphical representation of least limiting water range for no tillage

Table 3.4: ANOVA for Bulk Density and Least Limiting Water Range

	Df			SS			MS			F			P-value @0.05		
Tillage	NT	CST	CVT	NT	CST	CVT	NT	CST	CVT	NT	CST	CVT	NT	CST	CVT
Regression	1	1	1	0.0085	0.010	0.0124	0.0085	0.010	0.0124	259.1	155.7	253.25	0.03	0.05	0.03
Residual	2	2	2	6.59E-05	0.00014	9.82E-05	3.29E-05	7.02E-05	0.0001						
Total	3	3	3	0.0086	0.0121	0.013									

Table 3.5: R^2, Multiple R, Standard Error and Observation Table for Bulk Density and Least Limiting Water Range

Tillage	Multiple R	R Square	Standard Error	Observation
No Tillage	0.996	0.992	0.005739	3
Conventional	0.996	0.992	0.007	3
Conservative	0.993	0.987	0.0083	3

4.0 Conclusion

The least limiting water range determined from the field capacity, wilting point, moisture content at penetration resistance and moisture content at 10% aeration, can be a measure of management effects on soil productivity and when maximized, can be the potential of soil crop production. It also identified critical periods of stress on the plant that can reduce production. LLWR not only determines soil physical factors that limits soil growth but also determines soil quality. In this study for the three tillage methods (conventional, conservative and no tillage) at different soil depths, the upper range of LLWR was determined by field capacity and the lower range was determined by permanent wilting point, inside this range, crop growth is least limiting while outside the range, crop growth is most limiting. The average LLWR for conventional tillage, conservative tillage and no tillage were found to be 0.066, 0.056 and 0.052 respectively, this shows that LLWR increased with intensity of tillage. The average bulk densities were found to be 1.45g/cm^3, 1.54g/cm^3, and 1.56g/cm^3 for conventional tillage, conservative tillage and no tillage respectively, this shows that bulk density decreased with increase in intensity of tillage.

Linear regression shows that there are significant differences ($P < 0.05$) for bulk densities and Least limiting Water Range at different tillage methods, the p-values are 0.03, 0.05 and 0.03 for no tillage, conservative tillage and conventional tillage respectively. Also R^2 values of 0.99, 0.98 and 0.99 were obtained for no tillage, conservative tillage and conventional tillage respectively.

5.0 Recommendations

- Exploring the variables and responses using other types of irrigation such as Sprinkler and Surface irrigation.
- Replicating the work in another environment

Acknowledgements
First of all, we thank the Almighty God for his mercies and for giving me the strength to get this work to this stage. The authors wish to express my appreciation to all the people that contributed in various stages of this work, some of them are; Engr Dr J.T. Nwabanne, Engr Dr C.O. Nwajinka, Engr Chinedu Umembamalu, Engr Dr Mike Okechukwu of Agricultural and Bioresources Engineering, UNN. Our sincere gratitude goes to other members of staff of Agricultural and Bioresources Engineering, UNIZIK.

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