International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531

(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Variability of Cone Index on Seedling Emergence Rate and Growth Establishment of Cowpea in a Sandy Loam Soil (*Eutric Leptosol*)

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Abstract

A field study using the Randomized Blocks Design on nine plots each 2.5 m wide by 2.0 m long planted with local cowpea variety was conducted to determine the spatial variability of Cone Index (CI) and its effect on seedling emergence and growth establishment under different tillage systems. Results of the different tillage systems revealed that effect of CI on seedling emergence rate and plant heights was significant ($p>0.01$ and $p>0.05$) at mean CI values 2.44, 2.25 and 1.86 MPa for Zero Tillage (T_0), Primary Tillage (T_1) and Secondary Tillage (T_2) respectively. Significant spatial variations of CI was observed within each of the tested plots with CI values ranging between 2.60 to 3.31 MPa for both T_0 and T_1 plots located centrally, while lower CI values between 1.18 to 1.89 MPa for T_2 plots were predominantly located at the periphery. Results revealed that the critical values, CI ($CI_{crit.}$), for T_0, T_1 and T_2 significant at $p>0.05$ was 0.32, 0.54 and 0.26 MPa respectively, suggesting that such CI around the mean values under different tillage systems influenced seedling emergence and plant heights. Moreover, the cowpea seedlings were shown to be non-significantly influenced by the CI at values greater than $CI_{crit.}$ Generally, for the different tillage operations, the cone index negatively correlated with both the seedling emergence rate and plant heights at $r^2=0.012$ and $r^2=0.038$ respectively. Seedling emergence rates were 62% for T_0, 78% for T_1 and 70% forT_2 with CI at over 2.5 MPa for T_0, between 2.0 to 2.55 MPa for T_1 and between 1.0 to 2.0 MPa for T_2. Plant heights varied on average between 4.6 for T_2 and 6.8 cm for T_0.

Key words: Cone index; Penetration resistance; Precision agriculture; Spatial variability; Seedling emergence rate;

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1. Introduction

The cowpea (*Vigna unguiculuta* L.) popularly known as *loputu* has been widely grown in parts of Central Equatoria State (CES) of South Sudan over three decades. Most farmers employ different tillage practices for cowpea production. While most farmers in Lainya and Yei River Counties of CES use both primary and secondary tillage operations to prepare the land prior to sowing, others simply sow cowpea seeds during primary tillage without being aware of the tillage effects on seed emergence rate and growth establishment. With protein content between 20-25%, cowpea would support about 1.2 million people as a key source of cheap protein for most low income communities. Cowpea seeds are consumed in pasted form as *pirinda* while the leaves are popularly consumed as green vegetable known as *ngete*.

Tillage and planting methods in most counties of CES involve broadcasting of cowpea seeds that are buried under big soil clods during primary tillage operations with minimal harrowing. Although such tillage practice is simple and labor saving, there is high probability for uneven planting depth, poor seed-soil contacts resulting into uneven germination rates and seed growth establishment. Conservational (*reduced*) tillage with minimal harrowing traditionally used by most farmers in CES might improve water infiltration and soil aeration owing to the presence of large preferential pathways, however, that may not be case for soil penetration resistance. Tillage practice may alter soil physical properties including porosity [1]; soil hydraulic properties [2, 3, 4, 5] and with available soil water content and suitable temperature influence soil microbial dynamics [6, 7, 8] reported on changes in soil penetration resistance that affected seedling emergence, plant population density, root distribution of maize yield. Similar findings on the effects of zero tillage as compared to conventional tillage on hydraulic conductivity was also reported by [9] and on soil strength [10, 11] and [12]. Similarly, [13] while working on two different secondary implements (*disc harrow and cultivator*) found out that wheat yield under cultivator was greater than under disc harrow, while [14] reported that ridge tillage resulted in lower penetration resistance and bulk density values in the upper 20 cm compared to conventional tillage and no-tillage.

Understanding the application of different tillage operations is important in order to assess the long term impacts of soil penetration resistance, seed germination rates and crop growth establishment. Increased consumer demand for low protein source in CES has increased public interest, a paradigm shift from traditional tillage systems to a more scientific approach that takes into account plant-soil-water interactions.

The objective of this study was to investigate the spatial variability of the penetration resistance as measured by the Cone Index on cowpea seedling emergence rate and establishment in a sandy loam soil (*Eutric Leptosol*) as well as gather information supporting the development of cowpea production systems in Central Equatoria State (CES) of South Sudan.

2. Materials and Methods

Field studies were conducted during the months of October to November 2012 at the demonstration and research farm of the Department of Agricultural Sciences of the College of Natural Resources and Environmental Studies, University of Juba, in Central Equatoria State. The study area as in Fig. 1 lies within the Green belt agro-ecological zone of South Sudan and is located between latitude 4°50’28’’ and longitude 31°35’24” with annual rainfall average of 650 mm mostly during the months of April to October. The climate of the area is tropical wet and dry climate with average temperatures ranging between 27C° during the rainy seasons to about 35°C during the dry season of November to March. According to the Harmonized World Soil Data (HWSD) Viewer 1.2, the soils can be predominantly classified as (*Soil Mapping Unit*: *Eutric Leptosols* (80%) with less associated *Lithic Leptosols* (20%). The soil texture is sandy clay loam (*USDA Texture Classification*: 45.5% sand, 43.9% silt and 10.6% clay), and drainage class (0-0.05%) is moderately well. The soil has humus content 2.95%, bulk density 1.34 g/cm³, pH (LaMotte STH Test Method) 7.2.

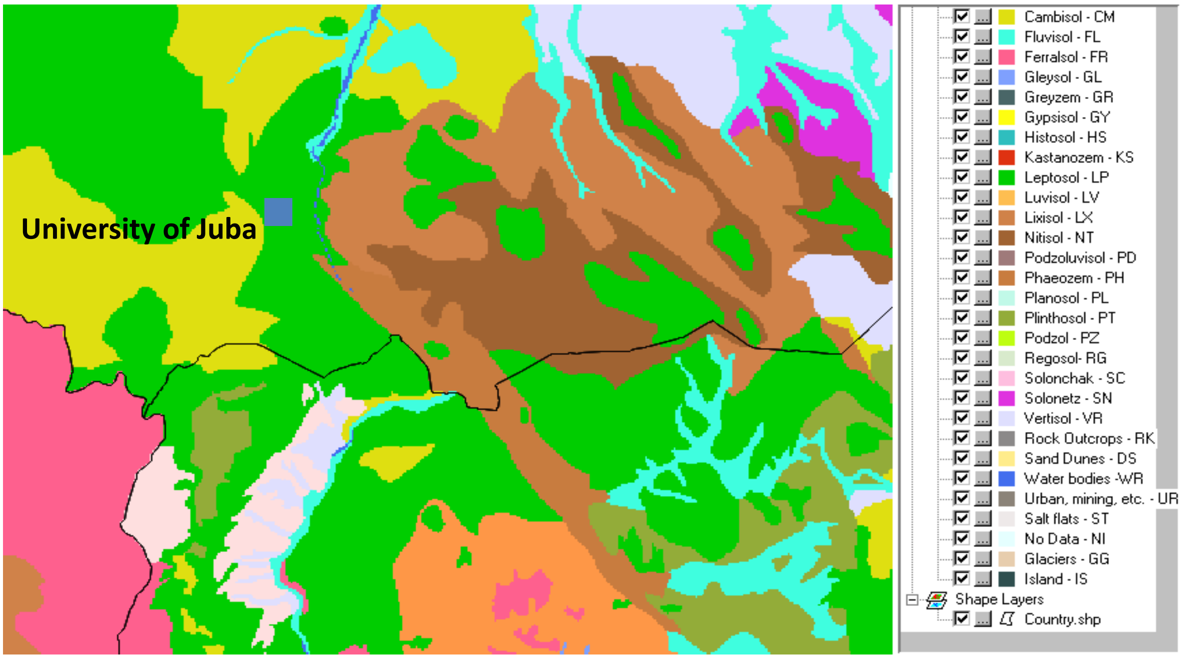

Fig. 1. Map showing the position of the University of Juba and the surrounding soil type.
Source: HWSD Viewer 1.2"

The experiment was conducted at the research and demonstration farm of the Dept. of Agricultural Sciences, University of Juba from October to November 2012. The experiment was designed in a randomized block design with three replicates with a main factor of tillage, i.e. Zero Tillage (T_0) as T_0I, T_0II, T_0III, Primary Tillage (T_1) as T_1I, T_1II, T_1III and Secondary Tillage (T_2) as T_2I, T_2II and T_2III (Table 1). The study area was divided into 9 plots each 2.5 m long and 2.0 m wide as in Figure 2.

Table 1. Different soil tillage operations used in the experiment.

Tillage operation	Material and methods
Zero Tillage (T_0)	No plough +direct seeding
Primary Tillage (T_1)	Hand hoe (*kopu*) + direct seedling
Secondary Tillage (T_2)	Hand hoe (*kopu*) + harrow (*kopu*) + direct seeding

The experiment comprised three adjacent plots which were initially fallow and had not been used for over two years. Local cowpea variety was ridge-planted in 4 rows within each plot and spaced 40 cm apart at a rate of 2 seeds per hole. Planting commenced on the 13th October 2012 to a depth of 0.05 m. The Zero Tillage (T_0) was done by directly placing the seeds into the holes of the plots initially cleared of any plant residues. The traditional hoe (*kopu*) was used for Primary Tillage (T_1) by manually tilling the soil to a depth of 30 cm. The *kopu* was used for harrowing during Secondary Tillage (T_2) that followed T_1 where large soil clods were broken down to ensure a finer seed bed prior to planting.

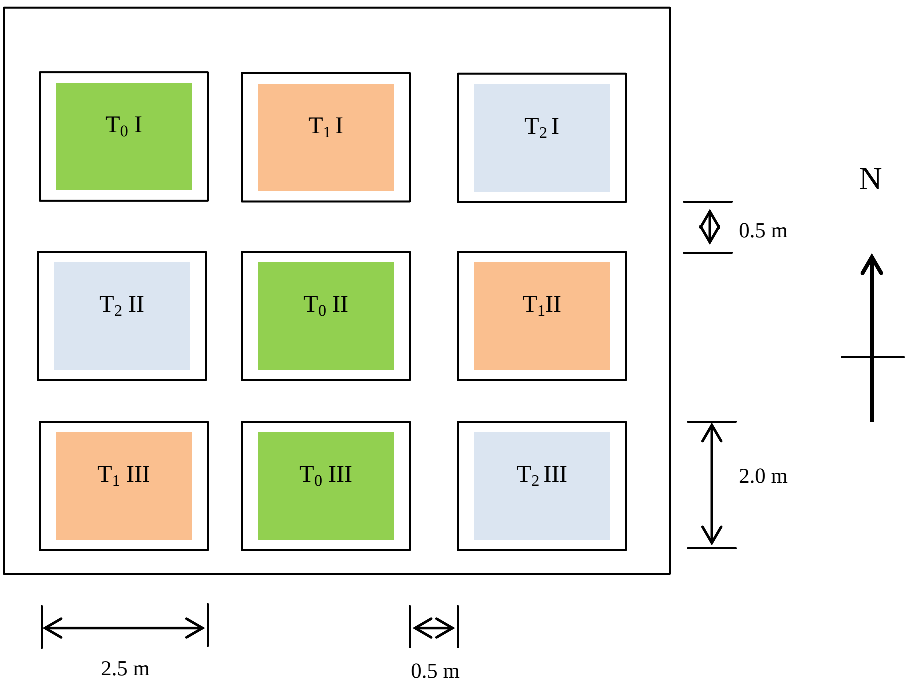

Fig. 2. Overview of experimental plots at research facility of the Department of Agricultural Sciences, University of Juba.

Penetration Resistance (PR) as measured by the Cone Index (CI) in Megapascal (MPa) of each of the plots was determined using a Penetrologger (**Eijkelkamp Penetrologger SN**) with a Cone type 1.0 cm^2, 60° and a penetration speed of 2 cm/s to maximum depth of 30 cm of the rhizosphere immediately after the tillage operations. A total of 26 penetrations were randomly done, 3 per each plot at a distance of more than 1 meter from the preceding operation. No any other penetrations were done after and during seed germination.

Quantitative and qualitative analysis in terms of germination rate, plant height, number and quality of leaves after germination of the different tillage treatments were compared and evaluated at the different CI.

2.1 Geo-statistical analysis

The spatial variability of the penetration resistance measured in terms of cone index was geo-statistically analyzed using the geo-statistical software GS+^{TM} Version 9 (*Gamma Design Software, LLC, Plainwell Michigan, USA*, 2001) to quantify isotropic spatial variability and semi-variogram models for the soil cone index. Spherical, exponential, Gaussian and linear semi-variogram models were considered in selecting the best fitting model based on the values of weighted residual sums of squares, regression coefficient (r^2) and relative spatial structure indicator (Nugget/Sill) that indicated spatial dependency. For the GS+ Version 9, the semi-variance is defined by the following equation:

$$\gamma(h) = \sum_{i=1}^{N(h)} [2(x_i + h) + 2(x_i)]^2 \quad (1)$$

where γ(h) is the experimental semi-variogram value at distance interval h; N(h) is number of sample value pairs within the distance interval h; and z (x_i+h) is sample value at two points separated by the distance interval h. All pairs of points separated by distance h (lag h) were used to calculate the experimental variogram. Several variogram functions were evaluated to choose the best fit with the data. Spherical or Gaussian models were fitted to the empirical semi-variograms. The spherical model used was defined as:

$$\gamma(h) = C_0 + C\,[{}^1/_2\,(h/A_0) - {}^1/_2\,(h/A_0)]^3, \qquad \text{for } h \le A_0 \quad (2)$$

$$\gamma(h) = C_0 + C, \qquad \text{for } h > A_0 \quad (3)$$

where γ(h) = semi variance for interval distance class h, h = the lag distance interval, C_0 = nugget variance ≥ 0, C = structural variance ≥ C_0, and A_0 = range parameter. In the case of the spherical model, the effective range A = A_0. Meanwhile, the Gaussian model used was defined as:

$$\gamma(h) = C_0 + C\,(1 - \exp\,(\frac{-h}{A_0})] \quad (4)$$

where γ(h) = semi-variance for interval distance class h, h = lag interval, C_0 = nugget variance ≥ 0, C = structural variance ≥ C_0, and A_0 = range parameter. In the case of the exponential model, the effective range A = $3A_0$, which is the distance at which the sill (C + C_0) is within 5% of the asymptote (the sill never meets the asymptote in the exponential or Gaussian models).

Different classes of spatial dependence for the soil variables were evaluated by the ratio between the nugget, semi-variance and the total semi-variance [15] Cambardella et al (1994). For the ratio lower than 25%, the variable was considered to be strongly spatially dependent, or strongly distributed in patches; For the ratio between 26 and 75%, the soil variable was considered to be moderately spatially dependent, For the ratio greater than 75%, the soil variable was considered weakly spatially dependent; and for the ratio of 100%, or if the slope of the variogram was close to zero, the soil variable was considered non-spatially correlated (pure nugget). Interpolation was performed using either by the ordinary kriging, the Inverse Distance Weighting (IDW) or simulation method and the spatial trend visualized using contour maps.

The variogram plots the semi-variance statistic y (h) for a range of distance intervals h:

$$y(h) = \frac{1}{2N} \sum_{i=1}^{n} [z(x_i) - z(x_i + h)]^2 \quad (5)$$

where y(h) is the semi-variance, N(h) is the number of observation pairs separated by a distance h, x_i is the value of the variable of interest at location x_i, and z(x_i + h) is its value at location at distance h from x_i.

2.2 Statistical analysis

The one-way analysis of variance (ANOVA) was applied to assess the effects of tillage treatments as influenced by the CI on cowpea seedling emergence rates and establishment. Following the ANOVA test, the F-test was performed to compare differences in means of the parameters at significance level of $p \geq 0.05$. The average seedling rate and growth establishment for each individual test plot replicate under the different tillage operation was geo-statistically determined and spatially correlated with the cone index.

3. Results and Discussion

Figure 2 showed the progress of the cone index as a function of depth for the different tillage systems T_0, T_1 and T_2. Generally, the T_0 replications showed CI values between 2.0 and 4.2 MPa in the first 30 cm of the soil, while this was between 1.2 and 3.0 MPa for both T_1 and T_2 respectively, with mean values that were significantly lower.

3.1 Cone Index, CI

The effects of the different tillage systems on seedling emergence rate and establishment (Fig. 4) showed significant ($p>0.05$) differences in the untilled (T_0), tilled (T_0) and (T_2) using the traditional hoe (*kopu*). Contour map of the predicted cone index showed some spatial variability across the field (Fig. 3) with CI values ranging between 2.36 to 3.31 MPa for T_0 predominating especially within plots that were centrally located. Meanwhile, for T_1 system, the CI was between 1.89 and 2.13 MPa with exceptional cases up to 3.12 MPa, while the T_2 between 1.18 and 1.89 MPa were localized at the periphery of the test site. Our results are in good agreement with those of [16] who reported that non-tillage practices increased the penetration resistance of the soil when compared to conventional or reduced tillage at 21-30 cm depth. Similar results of greater compaction under non-tillage than conventional tillage in a Vertisol were also found by [17] and [18]. Both T_0 and T_1 showed CI values that exceeded the critical root limiting CI value of 2.0 MPa for normal root growth suggested by [19].

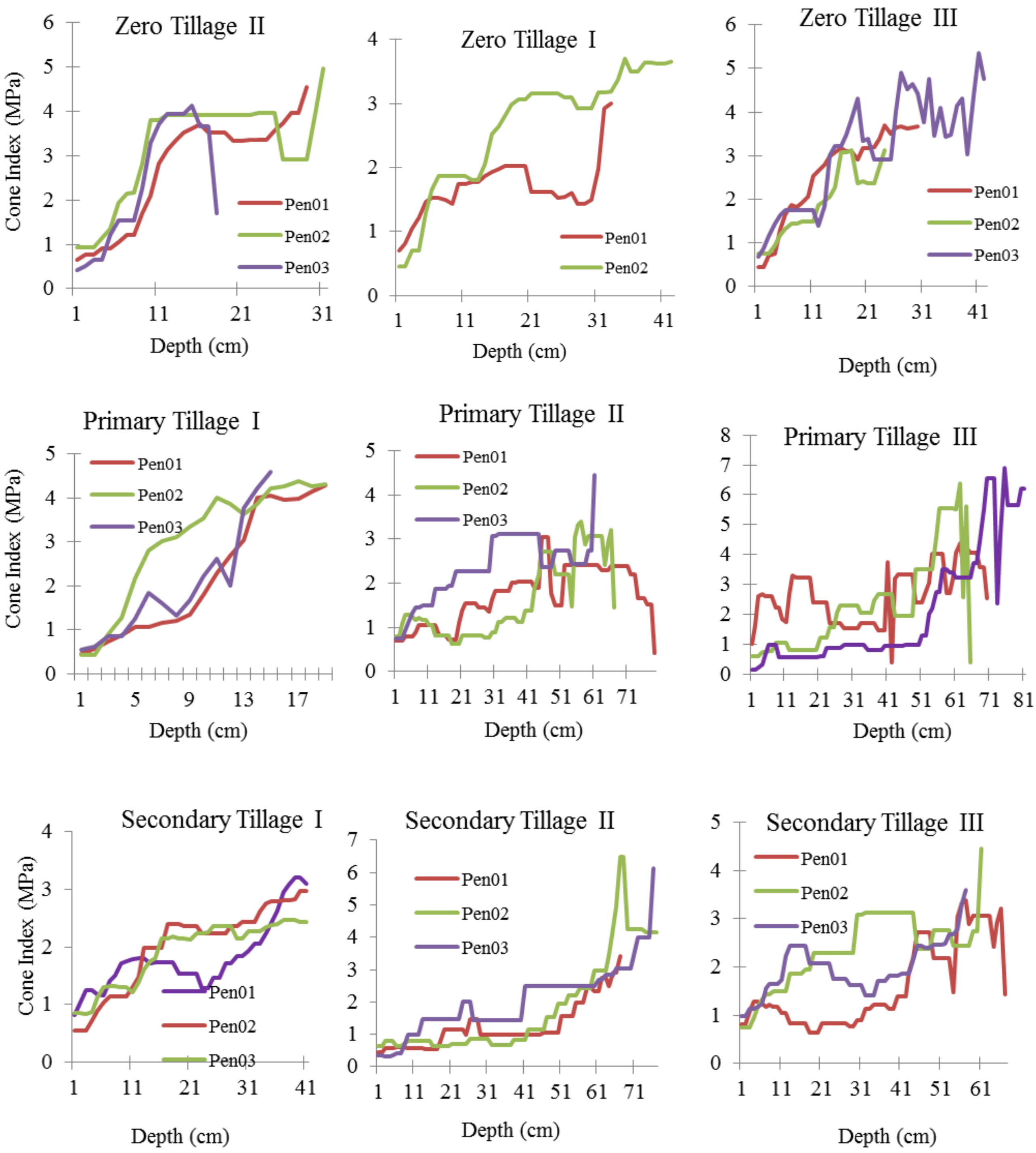

Fig. 3. Course of penetration resistance curves measured in Megapascal (MPa) as function of depth for the different tillage operations.

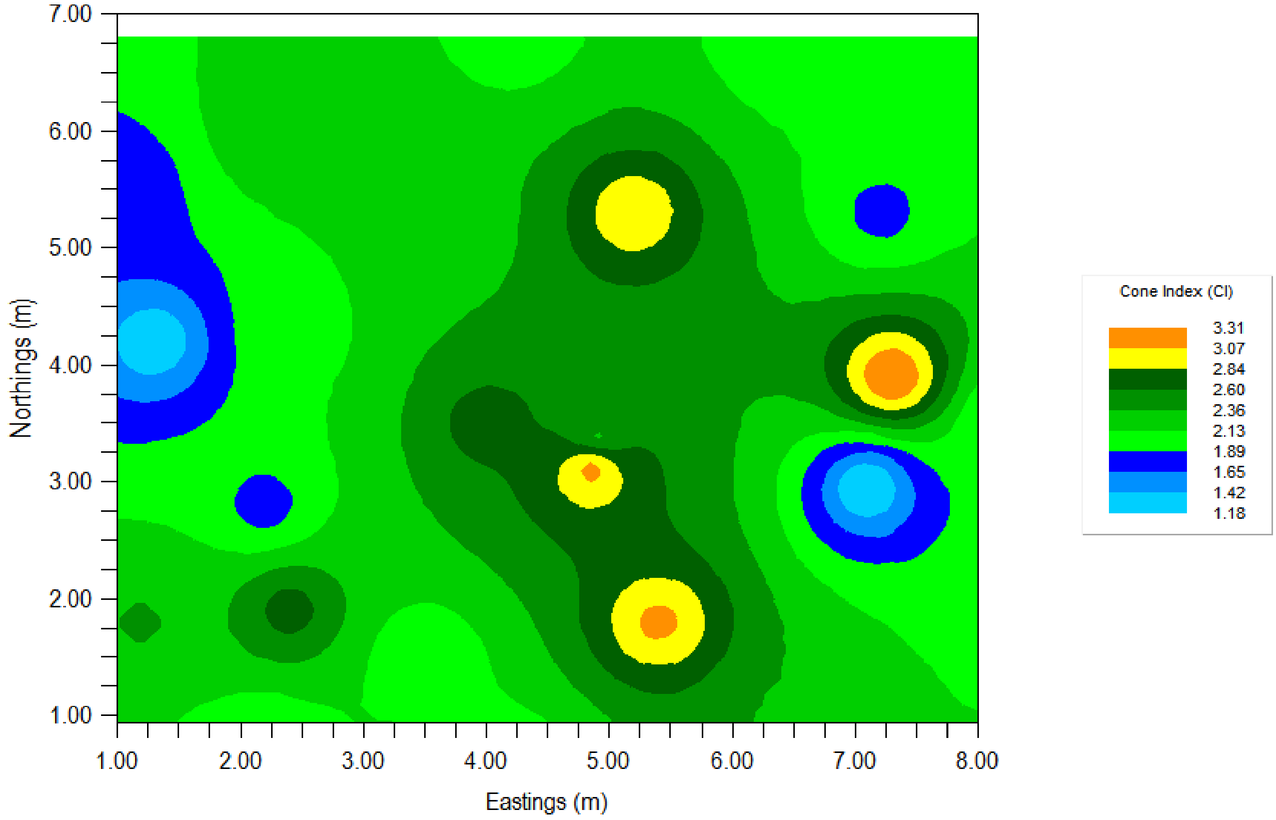

Fig. 4. Interpolated map using the IDW on the spatial distribution of the Cone Index of the differently tilled experimental plots. Research Facility, Department of Agricultural Sciences, University of Juba.

Table 2. Geo-statistical parameters of cone index in a sandy loam soil (*Eutric Leptosol*) from the demonstration farm of the Dept. of Agric. Sciences, Univ. of Juba.

Variogram type

	Gaussian	Exponential
Nugget (C_0)	0.065	0.059
Sill (C_0+C)	0.361	0.364
Spatial class (%)	18.01*	16.21*
Range, A_0(m)	0.95	0.43
RSS	3.69E-04	4.59E-04
r^2	0.94	0.94

Spatial class: 0-25% Strongly dependent, *S;
25-75% Moderately dependent, **M;
>75% Weakly dependent, W;
RSS = Residual Sum of Squares

As shown in Figure 5, the variability of the cone index showed spatial dependence that was best fit by both the exponential and Gaussian semi-variogram models with r^2 = 0.94 and strong spatial dependencies for the Gaussian and exponential models at 18% and 16% respectively (Table 2). The semi-variances after the 0.43 and 0.95 m range values for both models respectively appeared to be nearly constant over the entire separation distances indicating that the variability of the cone index was spatially independent. Sampling distance less than the range A_0, a distance over which observed data points exhibited spatial dependency was important in ensuring the quality of spatial variability analysis and interpolation for un-sampled locations using geo-statistical techniques [20].

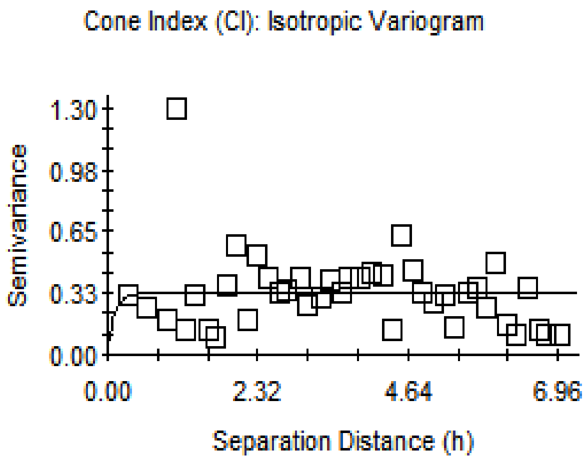

Fig. 5. Isotropic variogram for the cone index with the Gaussian model fits for sandy loamy soil (*Eutric Leptosol*). Research and demonstration facility, Department of Agricultural Sciences, University of Juba.

3.2 Seedling emergence rate at 5 and 9 DAP

Significant ($p>0.05$) treatment differences in seedling emergence rates were found between the different tillage treatments (Ftreatment=2.132, df=4). Generally, seedling emergence rates 5 DAP on average were 37.1%, 58.8% and 59.7% for T_0, T_1 and T_2 respectively at average CI values 2.44, 2.25 and 1.86 MPa (Table 2). The low seedling emergence rate at 5 DAP especially for T_0 was due to the high degree of compaction as indicated by the high CI with less significant differences between T_1 and T_2.

Table 2. The effects of different tillage systems as influenced by the cone index on the seedling emergence rate of a cowpea in a sandy loam *Eutric Leptosol*.

Treatments	Replications	Seedling Emergence Rate (%) Days After Planting (DAP)						
		5	6	7	8	9	Mean	CI (MPa)
T_0	ToI	31.9	62.5	66.7	73.6	75.0	61.94±15.7*	2.02
	T_0II	41.7	62.5	63.9	66.7	65.3	60.02±9.27	2.74
	T_0III	37.5	59.7	73.6	79.2	80.1	66.02±16.02	2.55
T_1	T_1I	62.5	77.9	79.2	87.5	94.5	80.32±10.75	2.43
	T_1II	68.1	83.4	87.5	88.9	88.9	83.36±7.89	2.06
	T_1III	45.8	69.4	79.2	83.3	87.5	73.04±14.88	2.26
T_2	T_2I	70.8	87.5	86.1	88.9	97.2	86.10±8.57	1.92
	T_2II	31.9	45.8	45.8	47.2	47.2	43.58±5.87	1.69
	T_2III	76.4	80.6	86.1	84.7	86.1	82.78±377	1.97

* The numbers following ± sign indicate the standard deviation

The best seedling emergence rate of 60 to 69% 5 DAP appeared in plots T_1II, T_2I and T_2 III located at the extreme right end of the demonstration field with CI values ranging between 1.89 to 2.13 MPa as in Figure. 6. The possible reason for the high emergence rate in these plots was the low penetration resistance due to increased soil pulverization and better structure formation from T_2 operations. Conversely, reduced emergence rate between 37 to 43% with zero tillage (T_0) was found predominantly at the left hand corner of the demonstration plots and was due to the high penetration resistance between 2.25 and 2.44 MPa. Unexpectedly low emergence rates were also found within the T_1 and T_2 plots and attributable to the poor execution of the tillage operations. Ideally, T_2 operations to a depth of 30 cm would enhance better soil structure formation necessitating higher emergence. This however, was not the case. At 9 DAP, more than 80% of all plots had seedling germination rates between 70% to 93% except at T_2 II and T_1III plots with germination rates as low as 60%.

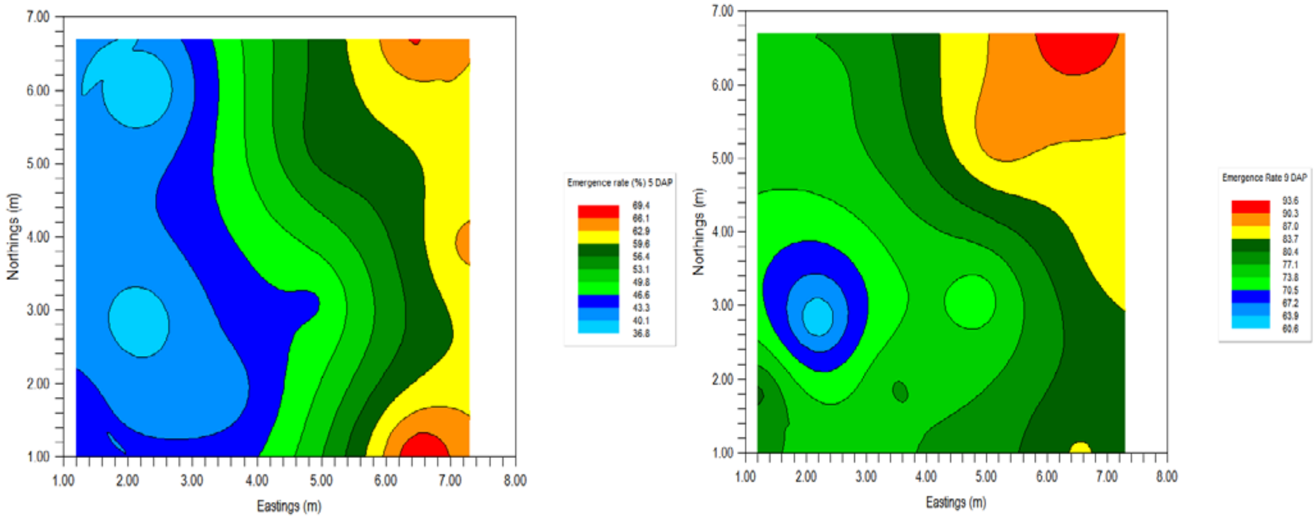

Fig. 6. Interpolated Distance Weighted (IDW) generated contour maps showing the spatial distribution of the seedling emergence rate at 5 (a) and 9 DAP (b) of cowpea. Research and demonstration facility, Department of Agricultural Sciences, University of Juba.

3.3   Plant height 5 and 9 DAP

Results as in Figure 7 for 5 DAP showed that treatment effects on plant height was significant ($p>0.05$, $F_{treatment}=2.132$, df = 4). The treatment effects as influenced by the penetration resistance or cone index were significant. The tallest plant height for T_1 was 4.2 cm at the extreme left lower corner of the demonstration plots and the shortest plant height for T_0 was 2.9 cm located at the upper left corner (Figure 7).

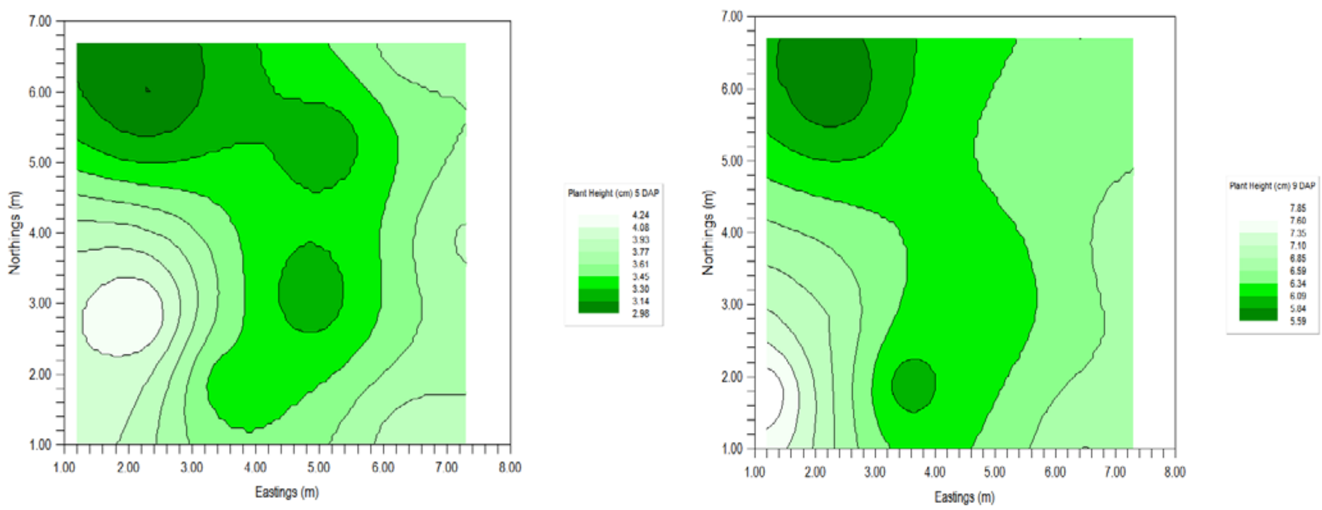

Fig. 7. Interpolated Distance Weighted (IDW) generated contour maps showing the spatial distribution of plant height (cm) at 5 and 9 DAP of cowpea. Research and demonstration facility, Department of Agricultural Sciences, University of Juba.

Similar results 9 DAP showed that treatment effects on plant height was significant ($p>0.05$, $F_{treatment}=2.132$, df=4) as influenced by the penetration resistance or cone index. The tallest plant height was 7.9 cm at the extreme left lower corner of the demonstration plots under T_1 and the shortest plant height for T_0 was 5.6 cm located at the upper left corner. Generally, plant heights increased within as well as between the different tillage operations. Significant increases (Table 2) of about 20% and 18% between T_0 and T_1 and between T_1 and T_2 were observed respectively, indicating the important role of the penetration resistance in limiting plant height.

Table 3: The effects of the different tillage systems as influenced by cone index on the seedling height (cm) of a cowpea in a sandy loam *Eutric Leptosol*.

Treatments	Replications	**Seedling Heights (cm)** Days After Planting (DAP)						
		5	6	7	8	9	Mean	CI (MPa)
T_0	ToI	2.91	3.07	4.28	4.78	5.28	4.06±0.93*	2.02
	T_0II	3.08	4.31	4.69	5.47	5.95	4.7±0.99	2.74
	T_0III	3.22	4.03	4.32	5.13	5.39	4.42±0.78	2.55
T_1	T_1I	3.14	4.60	5.21	6.09	3.92	4.59±1.02	2.43
	T_1II	3.85	4.87	5.59	7.17	6.94	5.68±1.25	2.06
	T_1III	4.09	5.33	6.62	5.32	6.43	5.56±0.91	2.26
T_2	T_2I	5.75	4.76	5.56	5.74	6.34	5.63±0.51	1.92
	T_2II	5.47	5.29	6.24	6.45	6.96	6.08±0.62	1.69
	T_2III	8.52	8.06	5.58	5.67	7.01	6.97±1.20	1.97

* The numbers following ± sign indicate the standard deviation

Table 5 showed the significant (p>0.05) effect of the different tillage systems as influenced by the cone index on plant height. On average, the plant height for T_0 9 DAP was 4.39 cm, while this was 5.28 cm for T_1 and 6.23 cm for T_2 respectively indicating a 17% increase between T_0 and T_1 and 30% between T_0 and T_2. These results showed that different tillage systems influenced growth rate and so thereby heights of cowpea plants. Similar finding on growth characteristics of barley was observed by [21] and on maize seedlings [22] and on coffee seedlings [23]. A change in tillage operation T_0 with mean cone index 2.44 MPa to T_1 at 2.25 MPa showed a 20% increase in plant height while this was about 18% from tillage T_1 with mean cone index 2.25 MPa to T_2 at 1.86 MPa. From the foregoing argument, it can be construed that reduction in cone index during each tillage operation must have enhanced root development, free movement of water, solute and air thereby necessitating optimal plant growth [24]. Similar findings of higher cone index values on soil water dynamics under T_0 than those under conventional T_1 or T_2 tillage operations was also reported by [25, 26] and on nutrient transport [27] Lomeling (2013).

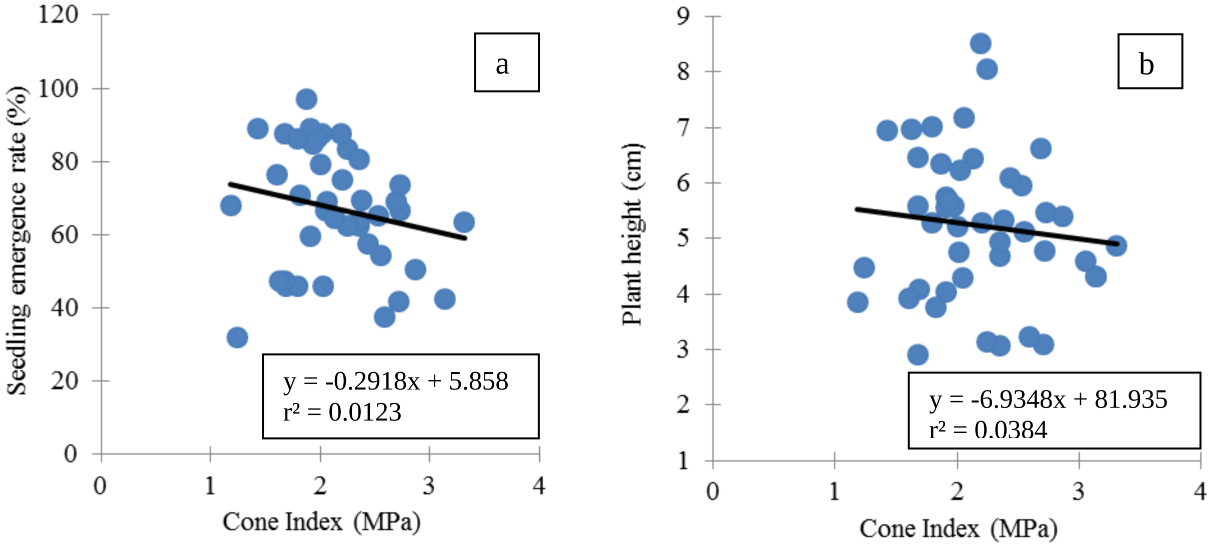

Figure 8: Correlation between (a) seedling emergence rate and (b) plant height (cm) with cone index under different tillage operations in a sandy loam *Eutric Leptosol*.

For the different tillage operations, the cone index generally ranged between 1.5 to 3.2 MPa with average value of 2.4 MPa. T_0 ranged over 2.5 MPa, T_1 between 2.0 to 2.55 MPa while T_2 of over 1.0 to 2.0 MPa. Figure 8a illustrates the negative relationship between the cone index and seedling emergence rate. This implied that increased cone index negatively influenced the seedling emergence rate which though with a low regression coefficient at r^2=0.012 was however, discernible. Similarly, Figure 8b showed the negative correlation between cone index and plant height with low regression coefficient at r^2=0.038 suggesting that increasing cone index reduced the plant height to on average between 4.6 for T_2 and 6.8 cm for T_0.

4. Conclusion

In this study, seedling emergence rate and growth establishment in terms of increase in height of cowpea plants were shown to exhibit significant negative correlation with the cone index under different tillage systems. Visual observation within the experimental plots revealed that the spatial variability for cowpea seedling emergence exhibited salient patterns within the tested plots as influenced by the cone index. Generally, it was possible to delineate areas of low from those of high seedling emergence as influenced by cone indices.

The T_0 operation had adverse effects on the seedling emergence rate and establishment of cowpea than under both T_1 and T_2 operations. Despite the small differences in CI values between T_0 and T_1 at 0-30 cm tillage depth, significant differences in seedling emergence rates and establishment were discernible. Our results suggested that since these agronomic features were adversely affected, the T_0 and T_1 tillage options, these tillage operations should be discarded in such soils as sandy loam *Eutric Leptosol*.

High penetration resistance within the rhizosphere significantly affected seedling emergence rates and establishment and indeed water flow and nutrient uptake. The overall goal of precision farming as shown by our study was to delineate inherent in-field spatial variability of such soil features as penetration resistance in the most accurate manner.

Using site-specific management approaches, high penetration resistance areas could be reliably delineated from low ones thus allowing for differential management options.

Acknowledgments

The authors acknowledge and thank the USAID-funded RHEA project at the College of Natural Sciences and Environmental Studies, University of Juba for providing the funds to carry out this research. Our gratitude also goes out to Mustafa Kenyi Mogga, Sebit Mathew Otwari and Khater Mohammed, all graduate students at the Department of Agricultural Sciences for their support on this study.

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