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Assessing the Spatial-Temporal Variability of Soil Moisture Content on Cowpea Phenology using the CROPGRO Cowpea Model

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ABSTRACT

The significance of spatial-temporal soil moisture variations on phenology parameters (vegetative growth, plant height, Leaf Area Coefficient, number of pods/plant of cowpea (Vigna unguiculata (Walp. L) cultivated under irrigation conditions were investigated. Results revealed that soil moisture deficit (SMC<15%) at germination stage significantly reduced plant height, number of pods per plant and subsequently yield. The plant height at SMC<15% was on average about 0.8 m, at SMC 15-20% over 1.2 and at 21-30% 0.9 m. Flowering and pod setting stages were delayed by about 14 days within plants that only had SMC <15% than those with SMC>15%. Isotropic variogram for plant height 4 DAP during germination was better described using the spherical model with weak spatial dependency = 77.1% and range A_0 =1.59 m suggesting strong plant height variations within short range conditioned by soil moisture deficit. The isotropic variogram for plant height at 35 DAP was better described using Gaussian model with strong spatial dependency at 14% (A_0=6.94 m) and at 46 and 52 DAP were better described using the spherical model with strong spatial dependencies at 11.3% (A_0=1.58 m) and 14.2% (A_0=2.87 m) respectively. This suggested that cowpea plant heights for SMCs 15-20 and 21-30% were more or less uniform with no significant difference ($p<0.05$) 45-52 DAP, but rather at podsetting 53 DAP thereafter. The results further showed that for different cowpea growth stages, different amounts of soil moisture was needed and that soil moisture above 23%, 52 DAP (especially during pod setting) induced an excess water stress factor that tended to enhance further vegetative growth and therefore delayed flowering and podsetting.

Keywords: plant height, spatial dependency, leaf area coefficient, phenology

INTRODUCTION

Cowpea (*Vigna unguiculata (*Walp. L) is an all-round crop that is consumed in larger parts of Greater Equatoria region of South Sudan. As one of the most resistant drought legumes [1], the green tender leaves, unripe pods and mature seeds serve as cheap sources of protein [2]. One of the main challenges of rain-fed cowpea production in South Sudan is to understand the spatial-temporal variations of soil moisture contents as currently influenced by erratic rain patterns both in intensity and coverage during the rainy season. This is particularly necessary, since all physiological processes during phenology of cowpea are affected by amounts of soil moisture. Soil moisture is influenced by the spatial variations of soil properties that influence soil water holding capacities [3] and how these properties influence the removal of excess water in/on the soil during the critical growing periods. Water stress has been reported to have significant effect on the growth and biological nitrogen fixation in cowpea plants [4]; [5]. Similarly, a decrease in soil water potential could markedly affect root hair and retard nodule growth and nitrogen fixation [6].

In this study, *Vigna unguiculata* plants in a randomized block design were grown under three different treatments and subjected to different soil moisture content (SMC) levels. The objective of the study was to therefore assess the effects of spatial and temporal variations of SMC on the phenology of cowpea plants after subjection to the different treatments.

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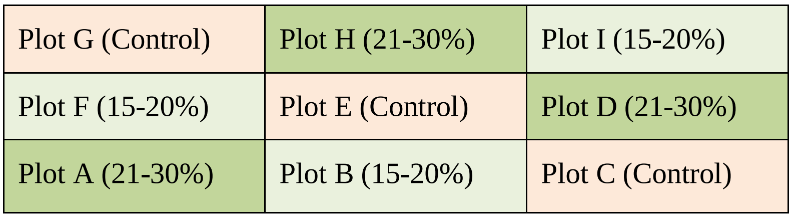
MATERIALS AND METHODS

Study Site Description

The experiment was conducted at Research and Demonstration Farm of the Department of Agricultural Sciences, College of Natural Resources and Environmental Studies (CNRES), University of Juba, South Sudan between 14th May and 1st August 2015. The study area lies within the Green agro- ecological zone of south Sudan and is located between latitude $4^0$50'28" and longitudes 31^0 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 27^0C during the rainy seasons to about 35^0C during the dry season of November to March.

A randomized block design was used with 3SMC treatments (<15%, 15-20% and 21-30%), 9 plots of each measured 2.0 m x 1.6 m. 6 plots (Figure 1) were pre-irrigated; 3 to SMC level 15-20% and 3 for SMC level 21-30%) and the rest 3 plots were as control. Two seeds per hole were placed at planting depth 5 cm and planting distance 30 cm (Table 2). Flooding irrigation was conducted whenever necessary to maintain the pre-set SMC level and was measured using a 4-pin Eijkelkamp soil moisture sensor Theta-probe, measuring range 5% - 55% soil moisture and accuracy ±5. Data collection included growth parameters: plant height; Leaf Area Coefficient; number of pods per plant, i.e. from 1st to 15th trifoliate stages that included flowering, pod-setting and physiological maturity. Standard meter rule was used to measure seedling height as well as length and width of leaves for the determination of leaf area coefficient. The simulated growth parameters were estimated using the CROPGRO Cowpea Model of the DSSAT 4.5 software and the spatial-temporal changes of the growth parameters estimated using the XLSTAT 2014 software.



Plot G (Control)	Plot H (21-30%)	Plot I (15-20%)
Plot F (15-20%)	Plot E (Control)	Plot D (21-30%)
Plot A (21-30%)	Plot B (15-20%)	Plot C (Control)

Figure1. *Overview of experimental plots at the Research and Demonstration Farm, Department of Agricultural Sciences, University of Juba*

According to the Harmonized World Soil Data (HWSD) Viewer 1.2, the soil can be predominantly classified as *Eutric Leptosol* as shown in the Table 1.

Table1. *Some of the physical and chemical properties of sandy loam soil (Eutric Leptosol) at the Research and Demonstration Farm, Dept. of Agricultural Sciences, University of Juba*

Soil physical and chemical features	Description
Soil mapping unit*	Eutric leptosol
Texture Classification	Sandy loam
Drainage Class (0-0.5)	Moderately well
Sand (average)	48.9%
Silt (average)	43.7%
Clay (average)	7.4%
pH (LaMotte STH Test Method)	7.0
Nitrate nitrogen	22.68 kg/ha
Phosphorus	170.1 kg/ha
Sulphate	1000ppm (parts per million)
Iron	1.36 kg/ha
Magnesium	Medium
Calcium	396.9 kg/ha
Bulk density (gm/cm^3)	1.34
Humus content	2.95%

***Source:** *Harmonize World Soil Data viewer version 1.2*

In our study, we used the Leaf Area Coefficient (LAC) instead of the Leaf Area Index (LAI) used in the CROPGRO Cowpea model. The LAC is a dimensionless number and product of leaf length and leaf width. Leaves from 3 geo-referenced plants per each plot representing the different SMC treatments were identified and the leaf growth systematically monitored during phenology.

The LAC was estimated as follows:

$$\text{LAC} = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{(\sum_{i=1}^{n} x_i)^2 (\sum_{i=1}^{n} y_i)^2}} \qquad (1)$$

Where x=leaf length (cm) and y=maximum leaf width (cm) and n_i = number of readings of chosen leaf during phenology. The LAC at the different SMCs were compared and aligned to the LAI of the CROPGRO model. For purposes of estimating the LAI using the CROPGRO model, soil moisture input variables were set at: for control (SMC<15%) , this was set at 10%; for SMC 15-20% was set at 17% and SMC 21-30% was set at 25%.

DATA ANALYSIS

The several sample test based on Kruskal-Wallis for equal medians between the different treatments was used to test significant differences at (p=0.05) using Windows-based PAST3 software.

The spatial and temporal variations of cowpea phenology in terms of water requirement was geo-statistically analyzed using the geo-statistical software GS+ version 9 (Gamma Design Software, LLC, Plainwell Michigan, USA, 2001) to evaluate isotropic spatial variability and semi-variogram models of cowpea plants under different treatments of soil moisture content. Spherical and Gaussian variogram models were regarded 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 showed spatial dependency. For the GS + version 9, the semi-variance is defined by the following equation:

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

Table2. *Relevant default data used to run the phenology of cowpea in a sandy loam soil under different treatments of moisture content.*

Crop Type	cowpea
Variety /Cultivar	local variety
Planting Date	14/5/ 2015
Emergence Date	18/5/2015
Plants/ plot	20
Planting depth	0.03 m
Seeds/hole	2 seeds/hole
Planting Spacing	0.3 m
Rain fall	depending on rainfall regularity
Plot Area	1.92 m^2
Irrigation Scheduled	plots B, F and I were irrigated with the amounts of water range between 15-20% at interval of 3-4 days and plots A, D and H were also irrigated with water >21-30% at interval of 1-2 days. While plots C, E and G was left under rain-fed and natural conditions with soil moisture content often <15%.
Chemical application	malathion, mercapto-thion with active ingredient of 50% EC. This is abroad spectrum pesticides for control of sucking and chewing pests on vegetables fruits and food crops. Average application rate of 0.5l/ha.
Application Dates	26th June- 2015 and 20th July -2015
Application Method	foliar spraying

Where $\gamma(h)$ 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-variogram. The spherical model used was defined as:

$$\gamma(h) = C_0 + C\,[½\,(h/A_0) - ½\,(h/A_0)]^3, \quad \text{for } h \leq A_0 \tag{3}$$

$$\gamma(h) = C_0 + C, \quad \text{for } h > A_0 \tag{4}$$

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:

$$\gamma(h) = C_0 + C\,(1-\exp(-h/A_0)] \tag{5}$$

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 in the exponential or Gaussian models*). Different classes of spatial dependence of the cowpea plant variables were evaluated by the ratio between the nugget, semi-variance and the total semi-variance according to [7]. 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 cowpea plants variable was considered to be moderately spatially dependent, for the ratio greater than 75% the cowpea plants variable was considered to be spatially weak.

STATISTICAL ASSESSMENT AND MODEL PERFORMANCE

The best fit between the predicted and observed values of plant height and SMC variability on cowpea phenology were evaluated using three statistical parameters: Root Mean Square Error (RMSE) and Index of Agreement *d* and Standard Error SE. [8] and were computed using equations:

$$\text{RMSE} = \left[\frac{\sum_{\text{i}=1}^{\text{n}}(\text{P}_\text{i}-\text{O}_\text{i})^2}{n}\right]^{1/2} \tag{6}$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i^{\circ} - |O_i^{\circ}|)^2}\right] 0 \leq d \leq 1 \tag{7}$$

$$SE = \left(\frac{Standard\ deviation}{\sqrt{n}}\right) * 100 \tag{8}$$

Where n is the number of observed values, P_{i} and O_{i} are the predicted and observed values respectively for the *i*-th data pair, $P_i^{\circ} = P - \vec{O}$ and $O_i^{\circ} = O - \vec{O}$ and $\vec{O}$ is the mean of the observed values. The departure from 0 of the index agreement *d*, can be used as a measure of under- or over prediction of the observed values by the model. A value of 1 for the index of agreement (*d*) indicates a good agreement between the simulated and observed data [9].

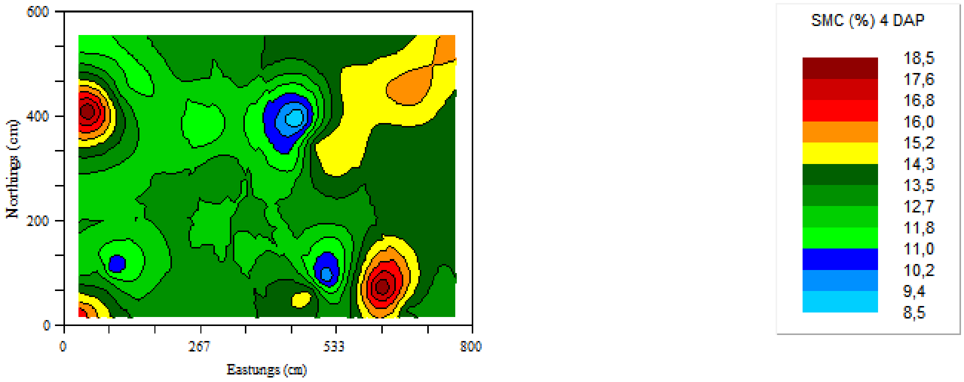
RESULTS AND DISCUSSION

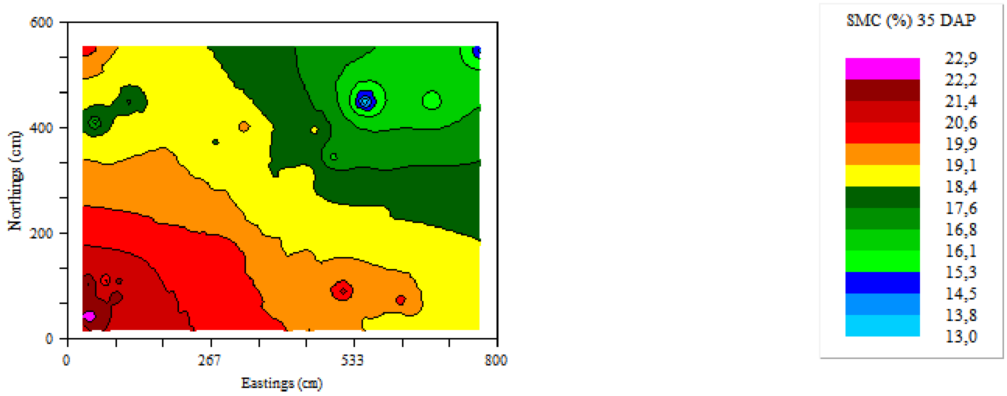
Plant Height

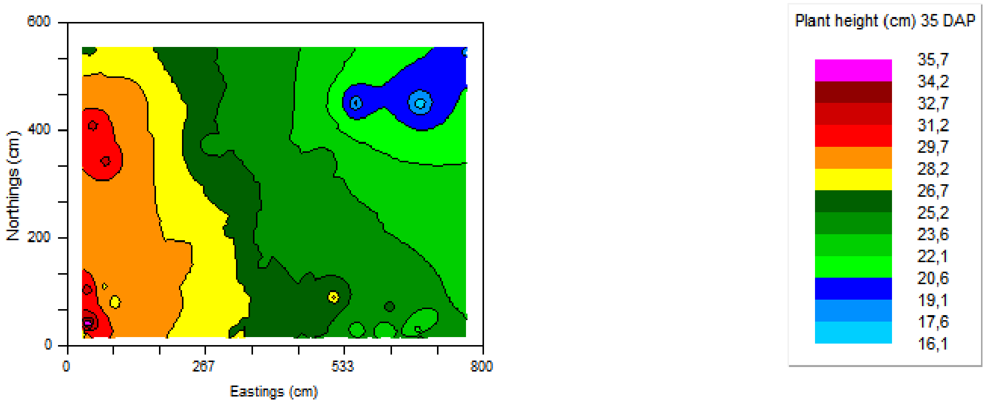
Spatial and temporal variations in the SMC significantly affected the plant height. Maximum plant height were attained 4 DAP in plots D and H with SMC between 20-30% as well as B, F, I with SMC at 15-20% which was on average about 4.7 cm. No germination occurred in Plots C, E and G with SMC < 15% 4 DAP except after 7 days and was about 6.2 cm. Water scarcity significantly delayed germination time, growth establishment and plant height which was about 26 to 45% shorter than plants in plots A, D, H, B, F and I. Similar findings on reduced plant height due to water scarcity on wheat varieties were reported by [10]; on sunflower varieties by [11].

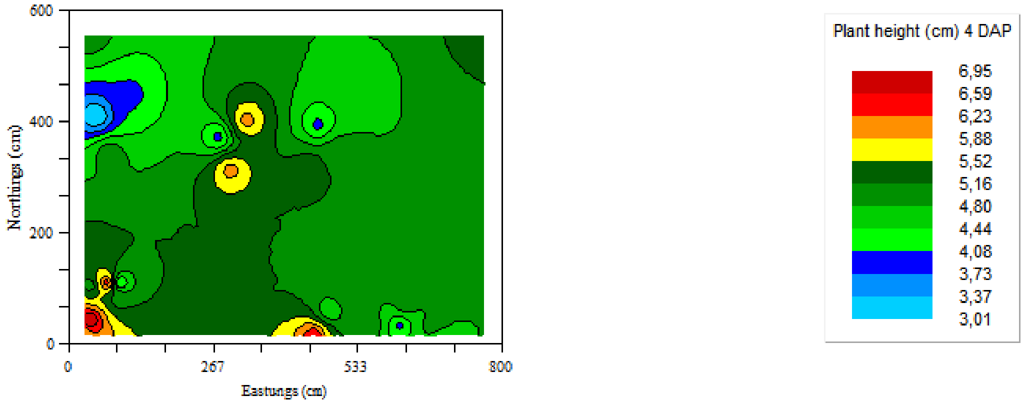
About 15 mm of rainfall during the 2 week of May 2015 led to water logged conditions, especially in Plot A with SMC 20-30% during germination that led to reduced plant height of about 3.5 cm, 4 DAP as compared to the rest of the plots under similar soil moisture conditions. Similar findings on the effect of water logged conditions on plant height were reported by [12]. At the third trifoliate leave stage, 35 DAP, plant height in Plots A, D and H with SMC 20-30% had attained heights of between 28-36 cm, whereas those with SMC <15% were between 16-22 cm and about 39 to 43% shorter. At the fourth trifoliate leave stage (*flowering stage*), 46 DAP, plant heights were significantly influenced by the SMC. Interestingly, at SMC 15-20% high plant heights between 45-55 cm were attained especially in Plots A and some parts of Plot B. Plant heights between 32-43 cm, were attained at soil moisture values greater than 30% suggesting the negative influences of SMC during flowering stage.

It can be mentioned that water stress with SMC < 15% significantly resulted not only into delayed seed germination and shorter plants during vegetative stages, but also showed plant height variability. However, low SMC<15% tended to enhance flowering especially at the tenth trifoliate stage where less soil moisture is required. Whereas plants in Plots A, D and H with SMCs 20-30% as well as those in B, F and I with SMC 15-20%, plants flowered relatively early, and in Plots C, E and G flowering occurred 15 days later.









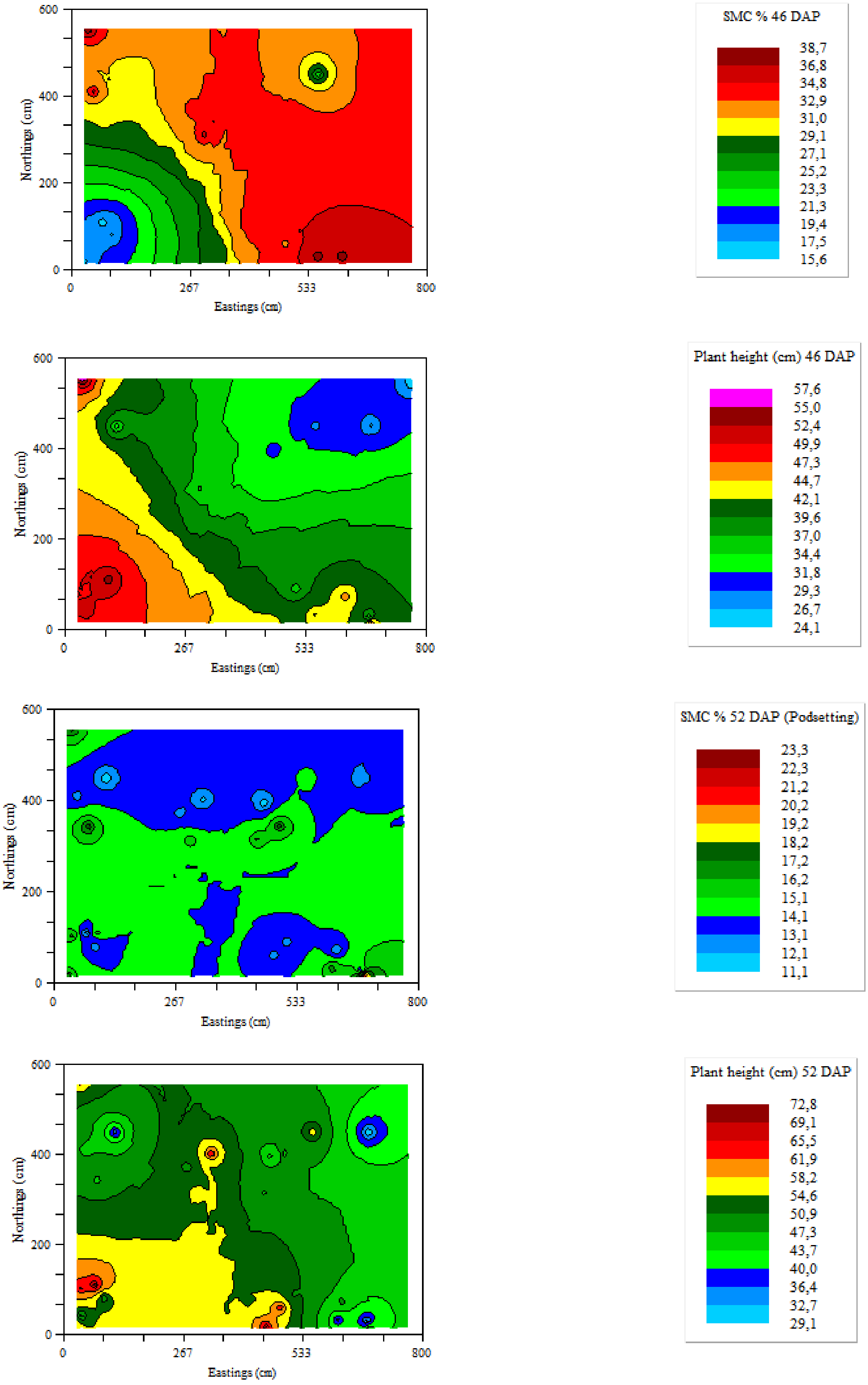


Figure2. *Spatial-temporal variations of SMC and plant height during phenology of cowpea*

The predicted and observed plant heights at the different SMCs was compared (Figure 3). With SMC <15%, the observed plant heights during the first 55 DAP was underestimated with an overestimation thereafter Figure 3 (a). In Figure 3(b), all three treatments gave better model fit during the first 25 DAP, however with slight overestimation. Generally, the predicted SMC at 15-20% gave the best fit during and after podsetting till physiological maturity. For SMC 21-30% (Figure 3c) and after flowering, the model overestimated the plant heights but then gave better fit aligned to the SMC <15% treatment after podsetting. Implications are that cowpea would require around 15-20% SMC between germination and flowering stages with more SMC around 20-30% during podsetting. SMC <15% would have adverse effects on plant height during the early stages of vegetative growth.

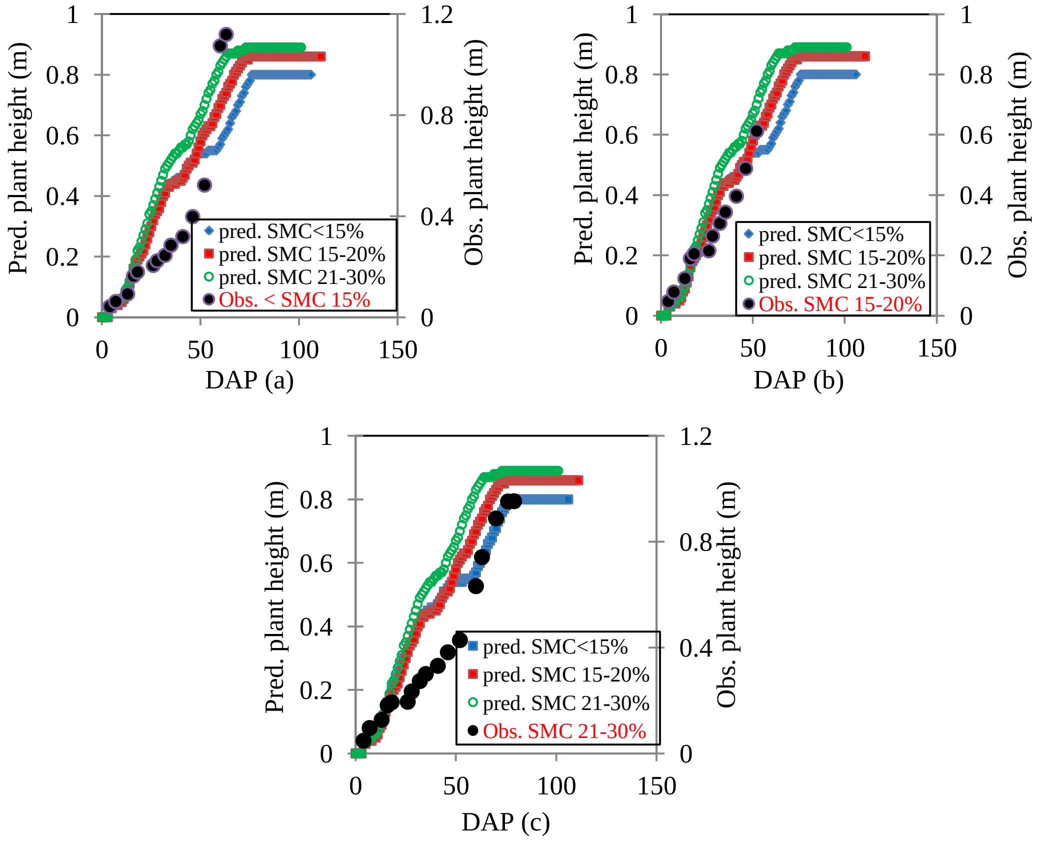


Figure3. *Simulated and observed measurements of plant heights during phenology of cowpea.*

Table3. *Calibration data of plant height (m) during the different phenological stages of a cowpea used in the CROPGRO Cowpea Model. Research and Demonstration Farm, Dept. of Agricultural Sciences, University of Juba.*

DAP	Phenological stage	SMC<15% (control)			SMC 15-20%			SMC 21-30%		
		Obs.	Pred.	RMSE	Obs.	Pred.	RMSE	Obs.	Pred.	RMSE
4	Two leaf	0.042	0.029	0.320	0.047	0.029	0.322	0.048	0.029	0.155
16	3rd Trifoliate	0.163	0.159		0.189	0.159		0.182	0.159	
41	9th Trifoliate	0.285	0.439		0.343	0.439		0.300	0.519	
52	Flowering	0.519	0.389		0.488	0.509		0.382	0.620	
60	Podsetting	0.540	0.523		0.612	0.610		0.428	0.699	
89	Physiological maturity	0.800	1.478		1.600	0.860		0.953	0.889	

SE for SMC<15%: 0.058; SMC15-20%: 0.067 and SMC 21-30%: 0.073

d values for SMC<15%: 0.782; SMC 15-20%: 0.319 and SMC 21-30%: 0.768

For purposes of calibration during the different phenological stages (Table 3), variables such as: two leaf, 3rd and 9th trifoliate stages, flowering, podsetting and physiological maturity were chosen. The range of these parameters especially for cowpea grown at SMC <15% and those at SMC 21-30% lie close to the plant or canopy height (*m*) values reported by [13] for fast maturing cowpea variety UCR368. The calibration process revealed that the model over-predicted plant height under all tested SMC ranges from 4 DAP (*two leaf stage*) till podsetting 60 DAP. There was generally 'good' agreement between predicted and observed plant height during podsetting till physiological maturity as shown by the high *d*-value error for SMC<15% and SMC 21-30%. The RMSE was low for all the

SMC treatments between 0.16 and 0.32. The Standard Error in predicting plant height especially after podsetting for the different SMC treatments was less than 0.1 or (10%) and was therefore considered good.

Water stress at SMC <15% during germination, growth establishmengt and vegetative growth resulted in the lowest plant height than under SMCs 15-20 and 21-30%. The variation in plant height was between 5.3 and 20.4% taller than those under SMC <15%. Similarly, water stress at SMC <15% and at about 46 DAP and the days preceeding flowering at 60 DAP (Figure 3) witnessed an increase in plant height by about 6.4 to 35.9% at SMCs 15-20 and 21-30% respectively, suggesting the positive effect water stress had on flowering of cowpea and podsetting. This is attributable to the physiological stress engendered by water insufficiency, whereby plants tend to grow taller in an effort to scramble for nutrients [14]; [15]; [16] around the growth environment. Similar observation was mentioned in the annual report of the Science Daily (2008) for plants growing under water limiting condition contrary to our findings where adequate SMCs at 15-20 and 21-30% had both positive effects on plant height during phenology.

Figure 4 shows, that the simulated and observed plant heights were scattered more or less equally about the 1:1 line for all three different treatments. There were only slight deviations in the model simulations suggesting that the cowpea phenology in Plots B, F, I and C, E and G were simulated reasonably well as shown by the high correlation coefficient (r^2). The less accurate simulation of plant height between 35 to 52 DAP especially in Plots A, D and H (SMC 21-30%) probably reflects such factors extreme high water surplus that were are not considered in the model input.

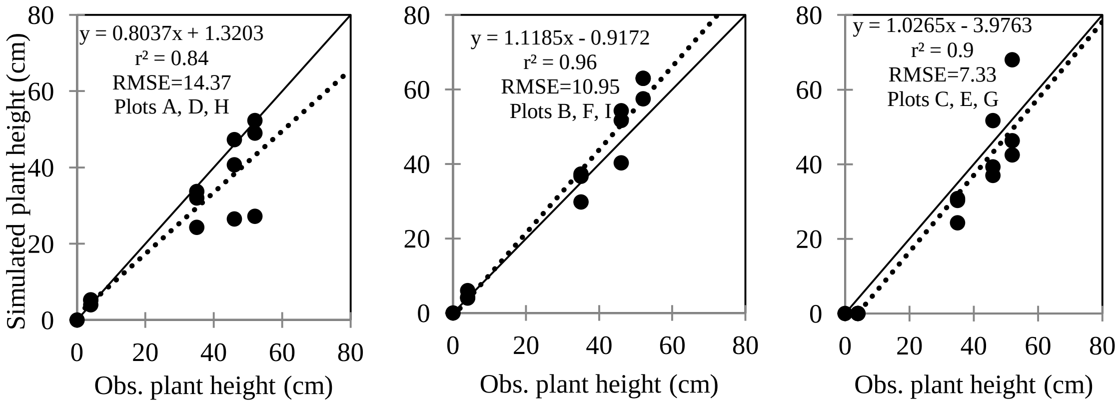


Figure4. *Simualted and observed plant heights during phenology of cowpea after different treatments. Regression equations for Plots BFI: $y=1.11x-0.65$, $r^2=0.99$; ADH: $y=0.81x+0.84$, $r^2=0.99$; CEG: $y=0.91x+0.44$, $r^2 0.98$.*

During the early stages of growth up to about 35 cm, the model simulated the plant heights for all SMCs in the different plots quite well. Thereafter, the model slightly underestimated plant height up to about 50 cm especially in Plots B, F and I but fairly well for Plots A, D, H, C, E and G. At about 55cm, the model simulated plant height, in Plots C, E and G fairly well, however it overestimated plant height in Plots A, D and H with an underestimation in Plots B, F and I. The deviations between simulated and observed plant heights as a function of both time and SMCs were rather small under water stress conditions and increased with SMC. For Plots C, E and G (SMC <15%), the RMSE was 1.55 cm, for Plots B, F and I (SMC 15-20%) the RMSE was 7.45 cm and in Plots A, D and H (SMC 21-30%) the RMSE was 7.74 cm. Similarly, at 4, 35, 46 and 52 DAP, the RMSEs were 0.83, 5.16, 4.54 and 7.61 cm respectively. Comparison between simulated and observed values of the SMCs showed that most simulated values for the three treatments 35-52 DAP fell below 1:1 line (Figure 5) except for the first 7 DAP. This implies that, the model overestimeated the SMC during phenology for the three different treatments. This could be attributable to the fact that averages of the highest and lowest SMC values for each plot were considered which perhaps did not reflect the exact SMC value as captured by the Theta moisture sensor device. It also underscores the scaling-effects and SMC variability even across short distances or range (A_0) especially 52 DAP as shown in Table 4.

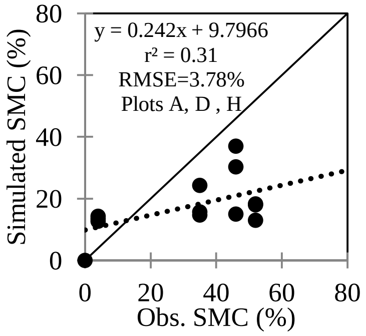


Figure5. *Comparison between the simulated and observed soil moisture contents during phenology of cowpea of different plots subjected to varying applications of soil water*

The size of RMSE three in all Plots was below 10% indicating that the model did not explain most of the variations in observed at <15%, 15-20 and 21-30%. However, at <15% the simulated values were slightly above or closer to the 1:1 line. Considering the relatively low (r^2) and low variance (RMSE <10%), our analysis indicated that the CROPGRO default soil moisture equations was under-predicted and did not adequately simulate the spatio-temporal variations of the SMCs in the different plots.

Table4. *Geostatistical moments of SMC during phenology of cowpea*

Parameter	4 DAP	35 DAP	46 DAP	52 DAP
Model	Spherical	Gaussian	Gaussian	Gaussian
Nugget variance, C_0	0.380	2.85	12.45	64.70
Sill, $C+C_0$	6.593	13.97	95.6	129.00
Range (cm), A_0	139.00	561.00	298.00	400.00
R^2	0.06	0.91	0.59	0.33
RSS	379	14.1	38540	23157
$C_0/C+C_0$	0.058 (5.8%)	0.204 (20.4%)	0.130 (13.02%)	0.502 (50.2%)

0-0.25 or 0-25% strong dependency; 0.25-0.75 or 25-75% moderate dependency; >0.75 or >75% weak dependency

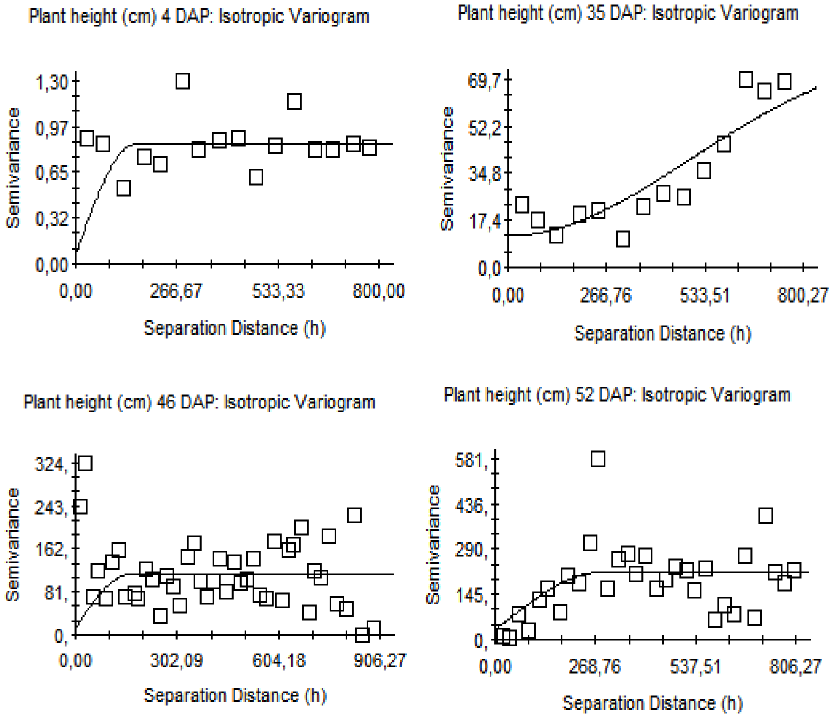


Figure6. *Isotropic variograms as shown by the Gaussian and spherical models for the development in plant height during phenology of cowpea in a sandy loam soil (Eutric Leptosol) at the Demonstration and Research Farm, Dept. of Agricultural Sciences, Univ. of Juba (2015)*

Figure 6 showed the isotropic variograms of plant height during different growing dates of cowpea using both the Gaussian and spherical models. Generally, the plant heights during growth showed strong spatial dependency between 11% and 14.2% (Table 5) especially between DAP 35 to 52.

An exceptional case of weak spatial dependency was at DAP 4 (*during seed emergence or germination*) with lowest range values A_0 at 1.54 m (Figure 6) suggesting growth inhomogeneity in all the plots during this period. Strong spatial dependency was attained with each growth stage as the plant heights in all plots were more or less attained similar heights.

Table5. *Geostatistical moments of plant heights during phenology of cowpea*

Parameter	4 DAP	35 DAP	46 DAP	52 DAP
Model	Spherical	Gaussian	Spherical	Spherical
Nugget variance, C_0	0.06	11.7	12.80	30.784
Sill, $C+C_0$	0.845	83.40	113.70	217.00
Range (cm), A_0	154.00	694.00	158.01	287.00
R²	0.001	0.815	0.212	0.306
RSS	0.885	1083	234126	293095
$C_0/C+C_0$	0.771 (77.1%)	0.140 (14.0%)	0.113 (11.3%)	0.142 (14.2%)

0-0.25 or 0-25% strong dependency; 0.25-0.75 or 25-75% moderate dependency; >0.75 or >75% weak dependency

Leaf Area Coefficient

The LAC in the CROPGRO model appeared to predict the time series of observed leaf area coefficient fairly well for all the different soil water treatments (Figure 7). The most accurate simulations of LAC to the observed LAC values occurred for the SMC 15-20% treatment with the lowest RMSE (0.16) and highest *d* value (0.85) (Table 4). This was followed by treatment SMC 21-30% with RMSE (0.23) and *d* (0.77) while the poorest was at SMC <15% with RMSE (0.55) and *d* value (0.45). Poor simulations were observed for both treatments at SMC <15 and 21-30% especially during vegetative stage till pod-setting (4 to 63 DAP) and suggested the inability of the CROPGRO model to accurately simulate leaf growth during this period. The results showed that both low SMC (<15%) and high SMC (21-30%) were extreme soil water ranges that neither enhanced nor favoured foliar development at the vegetative and flowering stages respectively indicating the time-bound water needs of cowpea plants during phenology. Although there were no significant differences in the LAC (Table 5) under the different SMC treatments, for purposes of water use efficiency and resourcefulness, sustaining SMC at 15-20% during cowpea phenology is adequate enough.

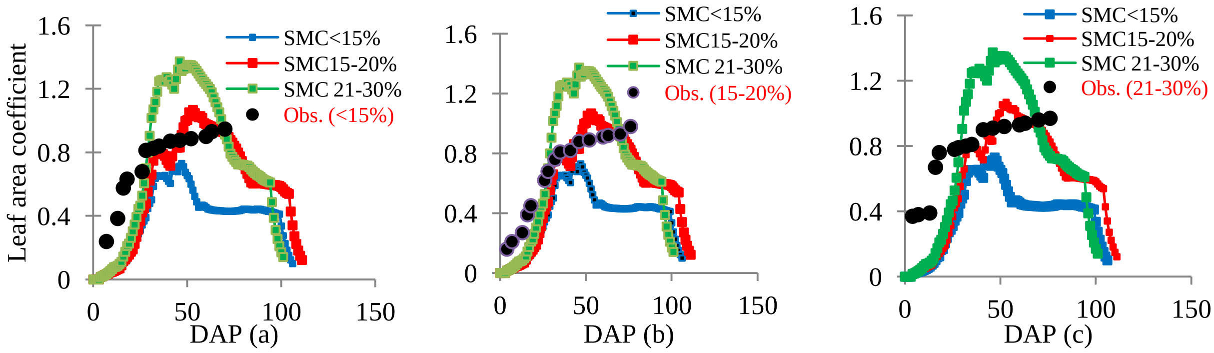


Figure7. *The relationship between the leaf area coefficient and DAP during phenology of cowpea. (Red label shows range of SMC treatments)*

SMC on Pod and Seed Yield

Responses of pod yield per plant as well as of the number of seeds per pod were among the most visible variables that were conditioned by variations of SMC. On average, the number of pods/plant were 5 for SMC<15%, 11 for SMC 15-20% and about 7 for SMC 20-30%.

Table6. *Interactive effects of variable soil moisture contents on leaf area coefficient during phenology of cowpea*

DAP	Phenological stage	SMC<15% (control)				SMC 15-20%				SMC 21-30%			
		Obs.	*d.*	RMSE	median	Obs.	*d.*	RMSE	median	Obs.	*d*	RMSE	median
4	Two leaf	0.37	0.45	0.55	0.81ns	0.16	0.85	0.16	0.79ns	0.20	0.77	0.23	0.84ns
16	3rd Trifoliate	0.67				0.39				0.58			
41	9th Trifoliate	0.90				0.82				0.87			
52	Flowering	0.52				0.89				0.89			
60	Podsetting	0.93				0.91				0.90			
76	Physiological maturity	0.97				0.98				0.98			

Standard Error (SE): SMC <15% 0.05; SMC 15-20%: 0.07; SMC 21-30%: 0.05; ns not significant at p<0.05 by the Kruskal-Wallis test for equal medians

It is evident from results that extreme water stress (*moisture deficit and over-surplus*) had adverse effects not only on germination rate (*for SMC <15% in Plots C, E and G)* but also delayed flowering and therefore pod-setting due to over surplus (*for SMC 21-30% in Plots A, D and H*) that apparently prolonged the vegetative stage showed significantly higher number of pods/plant. Most optimal soil moisture range was SMC 15-20% in Plots B, F and I. Similar observations on the effects of soil moisture on the number of pods/plant was reported by [17].

The yield reduction under severe moisture stress conditions ranged between 36.4% and 54.5% for SMCs <15% and 21-30% respectively. Furthermore, our results underpin the implications of erratic, and often high and low rainfall due to climate change that may affect cowpea yield, especially if no controlled irrigation or drainage intervention measures are undertaken to maintain optimal cowpea yield.

CONCLUSION

Cowpea is known to be a drought tolerant crop. However, extreme drought and over surplus of soil moisture does not only affect seed germination, vegetative growth but ultimately crop yield. Our results showed that cowpea requires adequate soil moisture 15% > SMC (θ) < 30% for optimal growth and yield. The results of the model simulation showed that the CROPGRO Cowpea Model was effective in explaining the spatio-temporal soil moisture requirements on the phenology of cowpea and can be used to simulate growth with acceptable accuracy. The model is particularly sensitive to soil moisture variations. Additional data collection and validation should be carried out to test these results, so that the model may be used as a decision-making tool in production and research, simulating seasonal cowpea production, predicting response patterns to water stress, and supporting recommendations for precise farming.

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REFERENCES

[1] Dadson, R. B., Hashem, F. M., Javaid, I., Joshi, J., Allen, A. L. Allen and T. E. Devine., 2005, Effect of water stress on the yield of cowpea (*Vigna unguiculat* L. Walp.) genotypes in the delmarva region of the United States. J. Agron. Crop Sci., 191, 210-217.

[2] Lomeling, D and Abass, A. A., 2014, Variability of Cone Index on Seedling Emergence Rate and Growth Establishment of Cowpea in a Sandy Loam Soil (Eutric Leptosol). International Journal of Sciences: Basic and Applied Research (IJSBAR), 14(1), 34-48.

[3] Sadler, E.J., Bauer, P.J., Busscher, W.J., Millen, J.A., 2000b. Site-specific analysis of a droughted corn crop: II. Water use and stress. Agron. J. 92 (3), 403–410.

[4] Gomes da Silveira, J. A., Lobo da Costa, R. C., Oliveira, J. T. A., 2001. Drought-induced effects and recovery of nitrate assimilation and nodule activity in cowpea plants inoculated with Bradyrhizobium spp. under moderate nitrate level, Brazilian Journal of Microbiology, 32 (3), 187-194.

[5] Marino, D., Frendo, P., Gonzalez, E. M., Puppo, A., and Arrese, C., 2007, NADPA recycling systems in oxidative stressed nodules: a key role for the NADP + dependent isocitrate dehydrogenase. Planta, 225,413-421.

[6] Hsiao, T.C. and Xu L. K., 2000, Sensitivity of growth of roots versus leaves to water stress: Biophysical analysis and relation to water transport. Journal of Experimental Botany 51,1595-1616.

[7] Cambardella, C.A., Moorman, T.B., Novak, J.M., Parkin, T.B., Karlen, D.L., Turco R.F and & Konopka, A.E.,1994, Field-scale variability of soil properties in central lowa soils. Soil Science Society of American Journal., vol. 58, 1501-1511.

[8] Boote, K. J, Minguez, M. I and Sau, F., 2002, Adapting the CROPGRO-legume model to simulate growth of faba bean. Agron J. 94, 743–756.

[9] Willmott CJ. Some comments on the evaluation of the model performance. Bull. American Meteorol Soc. 1982; 63(11),1309-1313.

[10] Mirbahar, A. A, Markhand, G. S, Mahar, A. R, Abro, S. A, Kanhar, N. A., 2009, Effect of water stress on yield and yield components of wheat (Triticum aestivum L.) varieties. Pak. J. Bot. 41(3), 1303-1310.

[11] Ahmad, S., Ahmad, R., Ashraf, M. Y., Ashraf, M., Waraich, E.A., 2009, Sunflower (Helianthus annuus L.) response to drought stress at germination and seedling growth stages. Pak. J. Bot., 41(2), 647-654.

[12] Hadi, F., Hussain, F. and Arif, M., 2012, Effect of different water treatments on growth behaviour of Cowpea (Vigna unguiculata subsp. Unguiculata Journal of Scientific Research and Reviews. 1(1), 1 – 6.

[13] Lomeling, D., Kenyi, M. M., Abass, A. A., Otwari, S. M., and Khater, Y. M., 2014, 1nternational Journal of Plant & Soil Science, 3(7), 824-844.

[14] Science Daily, 2008, Nitrogen fixation process in plants to combat drought in various species of legumes. Science Daily. http://www.scienedaily.com/releases/2008/01/080123085302.htm. Accessed 31/04/2016.

[15] Onuh, M. O. and Donald, K. M., 2009, Effects of Water Stress on the Rooting, Nodulation Potentials and Growth of Cowpea (Vigna unguiculata (L) Walp). Science World Journal, 4(3), 31-34.

[16] Scholz, F. G., Bucci, S. J. Goldsteem, Meinzer, F. C. & Tranco, A. C., 2002, Hydraulic redistribution of soil water by neotrpical savanna tress. Tree Physiology 22,603- 612.

[17] Abayomi, Y. A. and Abidoye T. O., 2009, Evaluation of cowpea genotypes for soil moisture stress tolerance under screen house conditions. African Journal of Plant Science. 3(10), 229-237.

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