ROOT GROWTH AND MOISTURE UTILIZATION BY COWPEA (*Vigna unquiculata*) GROWN ON CRUDE-OIL POLLUTED SOIL

Essien, O. E.

ABSTRACT

Department of Agricultural and Food Engineering, University of Uyo, P. O. Box 4309, Uniuyo Post Office Uyo.e-mail:toessien@yahoo.com

Daily and cumulative root elongation (Re) and crop evapotranspiration (ETa) were quantified and regressional relationship was established in an experiment on cowpea (vigna unquiculata) grown on soil polluted by crude-oil in comparison to those grown on unpolluted (control) and remediated soils. Direct measurement of crop consumptive use (ETa) by soil moisture depletion and root elongation by conventional measurement of roots of seedlings was carried out at weekly intervals for five weeks after emergence (WAE). Descriptive statistics, correlation and regression, as well as curve fitting to establish functional relationships were processed using SPSS ver. 17 package. Exponential regression function (R^2 = 0.96) fitted root elongation-vs-ETa association for vigna unquiculata grown on unpolluted and remediated soils while linear function (R^2= 0.927) fitted crude-oil polluted soils. Degraded soil reduced the plant water use capacity of vigna unquiculata to transpire in the 4th and 5th WAE when flowering and leaf maturity have occurred, and also stunted root growth. The peak growth rates of cowpea root were 3.72 and 3.18 (80%) cm day^{-1} in unpolluted and remediated soils respectively and reduced to 0.43 cm day^{-1} (12%) in polluted soil.

Keywords: Root elongation, water use, cowpea, crude-oil polluted soil, exponential relation.

INTRODUCTION

Adequate available water in the soil, in quality and quantity, offers resourceful environment under a given atmosphere for sustainability of plant growth. Of the amount of water consumed by crops only about one percent is used for fluids in the plants while the rest is used to control the heat of the plant, that is, to satisfy the crop evapotranspiration (ETa) under the ambient environment (Michael and Ojha, 2006; Seckler, 1996). Thus, ETa requirement depletes available water requirement which distresses plants growth. However, no appreciable reduction in water use takes place until soil moisture depletion reaches a critical point that available water no longer supports crop consumptive use (ETa), which critical points depends on soil and crop type, water quality and climate (Feddes *et al*, 1978).

Roots is one agent of bioturbation or soil ecosystem engineer (Moreira *et al*, 2008) which while extending itself to provide anchorage, follow the interstices in the soil as the path of least sliding resistance to probe the soil for water, soluble nutrients and oxygen in the soil's pore spaces, and enlarge the pores as they elongate. Root extraction of soil water has a definite pattern, depending on soil type which requires them to elongate to reach moisture in the depth of the root zone. Thus they are the main factor limiting the complete utilization of soil water by crops (Zhang, *et al*, 2004). Thus in an adequately watered soil root growth sustains plant growth under some root-to-shoot ratios. Where and when the available water in the soil is distressed while the environmental water demand (potential evapotranspiration, ETo, which is always there and of which ETa is a factored proportion) subsists, then soil moisture suction (or soil moisture deficit level) may reach below the atmosphere pressure to permanent wilting point or eventually to plant death if the drying condition in the soil persists. Crude oil spillage on agricultural soil has effect similar to soil drying. It blocks the soil pores with its large hydrophobic hydrocarbon molecules, which being denser than water and air, expel them. These actions reduce water availability and create anaerobic condition in the soil pores which causes soil bacteria to biodegrade the oil hydrocarbon bonds, releasing carbon and carbon gas into the pores of the rootzone soil, thereby causing carbon dioxide toxicity, soil drying and gradual wilting of plant to its eventual death (Amakiri and Onoteghara, 1989; Abii and Nwosu 2009; Essien and John, 2010). Certain crops, especially grasses, vegetables and annuals are very sensitive to soil moisture stress and chemical toxicity (Suresh, 2008).

Vigna unquiculata is edible economic crop and its growth varies with water/nutrient availability. It is known that toxicity in soil blights cowpea root against growth (Gupta and Gupta, 2008). The seeds, the pods and/or leaves are consumed as green vegetables or for pasturage, hay, ensilage, and spicy staples like "akara" and "moin-moin" are made from it. The seeds geminate as epigeal with stout taproot and a later with lateral roots near the soil surface; the length of the reproductive period varies, the earlier cultivars taking 30 days from planting to flowering, and less than 60 days to mature seeds (Grubben and Denton, 2004; Duke, 1983; Shackleton *et al*, 2009).

If water is highly polluted, it cannot offer any use to crop and the effect of blending with more dilution water cannot be valid for highly toxic substances such as heavy metals (Kopittke *et al*, 2007). Therefore planting these soil water- sensitive-crops on crude-oil polluted soil may enable root response to tension in root water utilization to be observed early. Kopittke *et al* (2007) found that within 13 days after emergence, chemical (heavy metal) toxicity in soil was able to affect adversely root growth in plant. *Vigna unquiculata* plant if cultivated under rain-fed or in dry season under ample irrigation condition flowers and matures in a short period of 30 – 90 days for some earliest cultivars (Grubben and Denton, 2004), as such early detection of environmental stress due to soil moisture availability problem that could offset the expected economic advantage of cowpea would need to be detected early. Therefore, this investigation will focus on the early growth stages of the crop after germination in order to detect early any distressed performance that may warrant early arrest or soil amelioration. Also ETa have been numerically simulated using root water uptake (Nyambayo and Potts, 2009) and such a functional relationship will be obtained for further research into ETa – root growth in degraded soils.

Therefore the objectives of the study were: (1). To measure and evaluate crop water use (represented by ETa) through soil moisture depletion and root growth response for vigna unquiculata planted on crude-oil polluted soil and compare with its performance from unpolluted soil; (2).To establish any metric relationship between root growth performance and water consumptive use under the defined soil conditions in the same environment.

MATERIAL AND METHODS

Root elongation (Re) and crop evapotranspiration (ETa) were determined by Laboratory experiment on samples of representative soils. Soil samples were taken with soil auger and carried in black polythene bags Soil Laboratory, University of Uyo for laboratory measurement of moisture content, soil bulk and dry densities and porosity in the usual methods (Liu and Evett, 2000).

Laboratory determination of crop evapotranspiration

Actual evapotranspiration was determined as crop consumptive use using soil moisture depletion measurement and evaluation (Michael and Ojha, (2006).

Three empty sterilized containers of equal dimension, 60cm diameter by 30cm depth, were weighed and filled with the unpolluted soil samples to three-quarter full, then reweighed on a top loading weighing scale. Bean seeds (*Vigna unquiculatal)* were planted on two of the containers (B and C) and allowed to germinate. Equal volume of water was added to the containers while two of them (B and C) were polluted by the addition of crude oil and re-weighed ensuring that the two containers (B and C) carried equal weight. Container A was the Control. Before planting in container C, the polluted soil was treated with chemical degreaser/detergent to reclaim the soil, hence it was considered as remediated soil. Daily weights were recorded and the depleted water was regularly replenished and the quantity noted. The change in weight between the successive weekly measurements was the loss of water and was regarded as crop consumptive use or crop evatranspiration loss. Also, soil moisture content was determined by the usual standard (Liu and Evett, 2000) and the change in moisture content within the weekly period was the depleted available water and equal to Eta (Michael and Ojha, 2006).

Measurement of elongation of roots

After germination (five days), water was topped up, and fertilizer added, then a further three days passed before measurement of root elongation commenced. To achieve this, some seedlings from each container were carefully uprooted so as not to break the roots and the lengths of their tap roots were measured with thread and metre rule; then the average taken. Measurement was taken weekly for five weeks to cover period from germination to flowering (Grubben and Denton, 2004).

Water deficit in plant

The leaves from the uprooted seedlings were cut immediately and weighed; then placed in an oven to dry at 80^oC for 24 hours. The difference between the wet and dry weight gave the average water deficit in the leaf.

Data analysis

Mean, range, standard deviation (Sd) and covariance (CV) were computed using statistical package SPSS ver 17. Linear regression analysis, coefficient of determination between root elongation (Re) and ETa, correlation, ANOVA and significant differences and paired sample test between values from treatment and control soils. Curve-fitting for daily ETa and Re, and between Re and ETa were performed using the same SPSS ver. 17 package.

RESULTS AND DISCUSSION

Daily crop evapotranspiration, ETa

Fig. 1 shows graphic waveform of the daily ETa by *vigna unquiculata* for the period from 1-5 weeks after emergence (WAE).The waveform is made up of two components: the stud or base and the wavy spikes or saw-toothed top

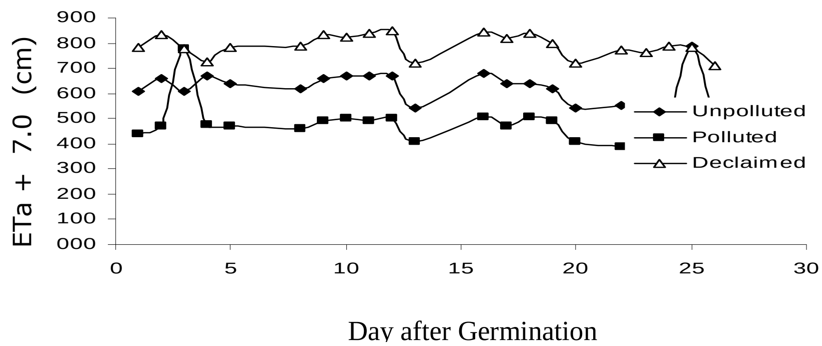

Fig. 1: Daily Variation of ETa with time by *V. unquiculata* grown on crude oil polluted, remediated and control soil.

superimposed on the nearly constant base. The magnitude of the spikes is the sum of top width and standard deviations. Thus,

Daily ETa = (uniform base + mean of ripple portion) ± std deviation from the ripple mean. (1)

The two components vary significantly ($p<0.01$)) for crop performance on the three soil treatments. The daily deviations from the maximum evapotranspirative loss (E_{max}-E_{min}) was equal to 3.2 mm for the control, 4.2 mm for the polluted soil and 1.4 mm for the remediated soils. Thus, the highest deviation (4.2 mm) showed that the highest fluctuation in water loss was from the polluted soil, while those for the control / and remediated soils showed the lowest. The band width of the top ripples was 6.2 mm, 4. 8 mm and 7.9 mm for crops on unpolluted, polluted and remediated soils, respectively.

Given Eqn 1 above, the daily ETa on each soil treatment varied numerically as follows: daily ETa is 7.62 ± 0.04 cm for unpolluted soil, 7.48 ± 0.08cm for polluted soil and 7.79 ± 0.04 for remediated soil (Table 1). Comparatively, the widest ETa deviation (± 0. 08 cm or 0.36 – 0.78 cm, Table 1) confirmed by its widest CV of 17. 70% (Table 1) was from crops grown on the crude-oil polluted soil, eventhough it recorded the least consumptive use of soil water. Obviously, this widest deviation shows unsteady fluctuation of water vapour or ETa; the least consumptive use shows that water imbibition by root was hindered or highly depleted. This may happen when toxicity has developed in the soil to reverse or constrain water imbibition or, when soil water is drying up thereby imposing suction stress at the energy–limited stage of soil water withdrawal. At that point, the hydraulic transport of water from subsurface to the soil surface was unable to supply water demand at the potential evaporation rate, assuming sparsely-covered or bare soil at the early stage of the crop (Ritchie and Johnson, 1990).

The lower volume of soil water and dry density in crude-oil–polluted agricultural soils (Table 2) should be noted in this respect. Also the percentage mass of plant water was very low in the crop planted on the degraded soil; transfer of water from root to shoot was highly impaired occasioning a comparatively low mean value of daily consumptive use to be registered (Table 2 and Fig. 1.) The mean ETa amplitude was about the same in the 1st and 2nd WAE because, at that stage, foliage cover was sparse and ETa mainly evaporation component from the soil at energy–limited stage (Ritchie and Johnson, 1990). But from the 4th WAE, when ETa moved to the soil–limited stage, marginal differences in amplitude were observed between ETa from the polluted soil and those from the control/ and remediated soils, where moisture content was also slightly but significantly ($p < 0.05$) higher than in the polluted soil. This effect on daily ETa was observed throughout the early stages of growth of *Vigna Unquiculata*. For the observed period of 6 decades (about 5 WAE), the daily amplitude of ETa, for crops on polluted soil, was reduced by 4.0mm, from 7.784 cm in the 3rd to 4th WAE to 7.384 cm in the 4th to 5th WAE (Fig 1). This daily ETa is soil-moisture dependent. Moisture content (m.c) in crude-oil degraded-soil was low at 7.04%, which was 40% less than 11.7% in the control soil and 25% less than the level in remediated soil (9.40%). Thus a maximum loss of 40% in soil moisture resulted from soil drying effect of hydrophobic hydrocarbon molecules of crude oil on agricultural soil.

Water deficit in plant leaves

All plants transfer far more water from leaves to the atmosphere than the water they contain (Seckler 1996; Syvertsen and Hanlong, 2008); therefore, the low value of ETa from crops on polluted soil in the early stages of growth, especially in the 4th–5th WAE compared to the higher values in the control soil, could signify that the mass of plant water in the leaves were markedly deficient in the leaves of *Vigna Unquiculata* from the crude-oil degraded soil. The differences in water deficit in the leaves and the percentage mass water in the plant (Table 2) attest to the inference stated above. Values in Table 2 indicate that the volume of leaf water deficit increased at the same rate for crops planted in both polluted and unpolluted soils in 2nd and 3rd WAE, but in the 5th WAE a significant difference was recorded. The difference in leaf moisture deficit between crops on the control and polluted soils in the 5th WAE was 11.9% of the values (5.86 ml) in the polluted soil in the same period; which implies higher leaf moisture deficit in crops on degraded soil. Also, the loss in leaves water from the degraded soil in the 5th WAE was 22% (double) the quantity in leaves from crop on control soil (6.4 ml). Thus the leave dry mass showed very low foliage productivity on the degraded soil (Table 2). But the reference mc of 11.7% in the control soil was itself a depleted level. Therefore the 40% soil moisture depletion in the crude-oil polluted soil was effectively more than the maximum allowed depletion (MAD) depth of 45% in soils for pulses and beans (Suresh, 2008). Thus the drying soil surrounding the roots in the degraded soil might have caused the generation of absciscic acid (ABA) in the root tips in response. This was transported to the leaves through the xylem system with the transpiration stream and acted as a root-to-shoot chemical signal inducing stomatal closure (Davies and Zhang, 1991), thereby significantly ($P< 0.01$) reducing ETa transfer to the atmosphere, hence reducing crop utilization of soil water (Plauborg *et al,* 2010).

Table 1: Rates of crop evapotranspiration and root of *vigna unquiculata* grown on treated crude-oil polluted and control soils.

Soil treatment	Range (cm)	Mean (cm)	Sd (±)	CV%	F- value	significant
Crop ETa						**
Control	7+(0.49–0.78)	7.62	0.07	11.18	12.1	
Polluted	7+(0.36–0.78)	7.48	0.08	17.76		
Remediated	7+(0.71–0.85)	7.79	0.04	5.66		
Re						
Control	6.4-4.98	13.47	7.78	69.3		**
Polluted	5.67-8.08	7.35	2.96	47.6		
Remediated	6.38-19.50	11.13	4.77	24.5	4.49	

** Significant at $p < 0.01$

Table 2: Leaf moisture deficit, dry weight and percentage mass of water of *Vigna Unquiculata* grown on crude-oil polluted, remediated and control soils.

Soil treatment	Week after emergence			
	2nd	3rd	4th	5th
Leaf water deficit				
Control soil	4.4	6.4	6.4	5.6
Polluted soil	4.3	4.8	4.96	5.10
Unpolluted soil	4.35	5.4	5.4	5.4
Mass of plant water,%	70	75	74	74
Control soil	70	62	61	56
Polluted soil	70	70	68	63
Unpolluted soil				
Dry density				
Control soil	1.8	1.62	74	74
Polluted soil	1.7	1.4	61	56
Unpolluted soil	1.75	1.58	68	63

Therefore, the drying soil indicated non-availability of water such that the roots were drying rather than penetrating to probe the soil for subsoil water (if any); the taproot of *vigna unquiculata* was becoming stunted, branched and weak even as the drying soil became more compact or resistant to root sliding movement (Suresh, 2008, Zhang *et al*, 2004).

The mass percentage of leaves water content showed remarkable difference between the plant on polluted soil with 60.9 and 56.3% on the 4th and 5th WAE compared to the control soil with 74.3 and 73. 8 % respectively in the same period. Thus, degraded soil reduced the plant water capacity to transpire in the 4th and 5th WAE when flowering and foliage maturing in vegetable cowpea (*Vigna Unquiculata)* were ready for commercial harvest (AVRDC-RCA, 2002; Shackleton *et al*, 2009).

ETa Predictive Functions

The graph of cumulative ETa against days of growth on soil treatments is given in Fig 2 and 3. Ideally the curve should converge at a lower portion towards a steady state equilibrium value after sufficient number of days as depicted by the logarithmic curve (broken lines in Fig 2 and 3). However, it shows a linear profile (solid lines in Figure 2 and 3) apparently because the loss of water from the plant continued daily at nearly the same rate without reaching equilibrium with the ambience, being limited by the leaves stomatal conductance (Plauborg et al, 2010). Curve-fitting, used the same model for regressional relationship between ETa and days of growth after emergence. The linear form showed the best simulation model, and gave the following functions:

For crops on control soil, ETa = 7.7971t –0.013, with R^2=1 (1)

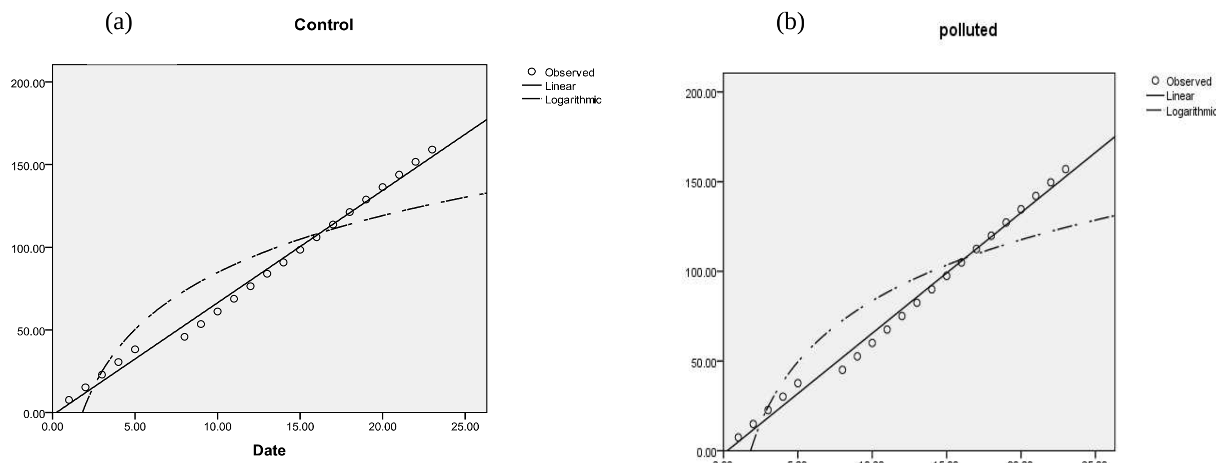

Fig. 2: Daily Variation of ETa by *V. unquiculata* grown on (a) Control soil and (b) crude oil Polluted soil

For crops on polluted soil, ETa = 7.3824t+0.885,
with R^2=0.999 (2)

For crops on remediated soil, ETa 7.6243t– 0.099, with R^2=1 (3)

Where t is the days of growth after crop emergence and ETa was crop water use in cm.

Where t is the days of growth after crop emergence and Eta was crop water use in cm. all curves indicated little or no unexplained deviations, showing that the accumulated ETa directly increased with days of growth, which was normal. However, difference existed between the linear and logarithmic functions as indicated by their CV and standard error of estimate (Table 3).

Table 3: Statistical differences between linear and logarithmic curves for ETa-vs-day graphs

				Linear model			Logarithmic model		
Soil treatment	Mean	Sd±	CV	R^2	Adj R^2	Se	R^2	Adj R^2	Se
A	84.0	47.3	56.34	0.994	0.993	3.991	0.826	0.817	20.094
B	82.0	45.8	48.4	0.9993	0.993	4.008	0825	0.816	19.898
C	86.0	48.4	56.4	0.993	40.992	4.241	0.814	0.814	20.856

Note: a = control, b = polluted soil, c = remediated soil.

The linear model performed better than logarithmic model: $R^2_{linear} > R^2_{log}$; the standard error of estimates (Se) for logarithmic model was 5 times larger than that of the linear model, i.e. $Se_{Ln} \geq 5\ Se_{Linear}$.

Model equations, Eqs (1) and (3) show that at the emergence of crop, the crop ETa was insignificant. Whereas for the polluted soil, ETa had a unique value (i.e. ETa >1.10) showing that while cowpea emerged but was yet to unfurl its leaves, the polluted soil was being dehydrated because of water molecule expulsion by the hydrophobic hydrocarbon molecules.

Implications on leaf productivity

Leaves stomatal conductance is a crucial factor controlling both photosynthesis and transpiration in plants. This ensures the energy balance in the soil-plant-atmosphere-continuum and the upscale from leaf to canopy yields under ambience humidity and temperature (Ball et al, 1987; Davies and Zhang, 1991; Plauborg et al, 2010). The low mean ETa in the degraded soil was significantly different from the values in the control and remediated soils, and indicated deficit soil moisture which imposed poor stomatal conductance, poor photosynthesis and, as such, low leaf yield.

The reduced ETa amplitude in degraded soil (0.162 cm) was higher than 0.10 and 0.00 cm in the control and remediated soils respectively. This lag-time reduction in ETa was in line with the empirical fact that ETa does not decline immediately after crop emerges and grows but will change after a time lag as the soil moisture content depletes. Feddes et al (1978) stated that no appreciable reduction in water use takes place until soil moisture declines to a point that ETa is significantly inhibited, which depends on crop soil type and climate! Thus, the reduction in ETa in the 4th -5th WAE indicated a serious decline in soil moisture content affecting root water uptake unlike in the other soils.

Rate of growth in soil treatments

The daily increment in root elongation was plotted against days of growth to observe the daily performances on the three soil treatments (Fig. 3). The peak growth rates were: 3.72cm for the control soil, 0.43 cm (12%) for polluted soil and 3.18cm (86%) for remediated soil.

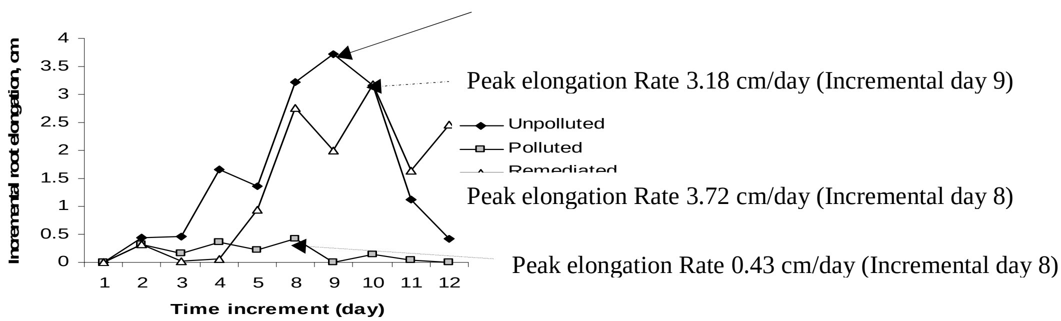

Fig. 3: daily increment of root elongation by *V.unquiculata* grown on unpolluted, polluted and remediated soils

Root elongation (Re)

Daily root penetration profile was drawn as a graph of cumulative root penetration (Re) with days of growth (Fig 4). The mean of root penetration in the control soil was 0.9 cm day^{-1} on the 12th day after germination, which was incremental day 3 in the 2nd WAE. Then, it increased sharply at a very high rate of 3.00 cm day^{-1} in the rest of the period before tending to stabilize, indicating an exponential progress. For the polluted soil, a linear profile was the only visible shape of the growth curve. Thus, the root in polluted soil did not show accelerated growth but rather turned stunted. This is explained by its small standard deviation (Sd) of ±2.95 cm day^{-1} for a mean of 7.35 cm day^{-1} (CV = 40%) compared to a mean of 13.4 cm day^{-1} with Sd 0 ±7.7 cm (CV 58%) for the unpolluted soil, which is about two times the mean for root growth in polluted

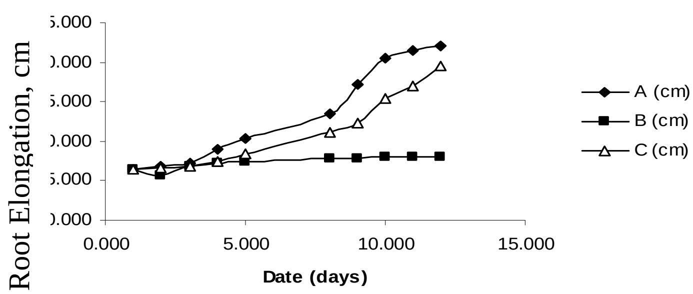

Fig. .4: Temporal Variation of Root Elongation (Re) of V.unquiculata grown on unpolluted (A), polluted (B) and remediated (C) soils. (NB: Measurement started 1 week after germination)

soil (Table 1). The Sd of ± 7.7cm^{-1} day for the control and remediated soil samples indicates a wide growth range from the mean and implies accelerated root growth in the two soils.
Curve fittings gave a linear profile for both control (unpolluted) and remediated soil as follows:

Control soil, Re = 2.0431t + 2.23, R^2=1.949 (1)
Polluted soil, Re = 0.1884t + 6.12, R^2=0.817 (2)
Remediated soil, Re =7.6243t–0.099, R^2=0.924 (3)

where Re is daily root elongation and t is number of days of growth.
The polluted soil showed a flatter linear profile than other soils (Fig. 4). Eqs 4 and 6 gave coefficients of determination (R^2) of 95 and 92% respectively, indicating that the associations had 5 and 8 % deviations, which were not linear in relationship. This could account for the exponential end of the curve that was not predicted by the linear curve above (Fig 4). With the maximum root depth of 0.60 – 0.9m or 0.75 m average (Pereira and Allen, 1999), the ratio of cowpea root elongation on treated soils to maximum root depth was 30% and 26% attainment for unpolluted and remediated soils respectively, but reduced to only 11% in polluted soils.

Paired sampled test of performance

Paired samples test statistics for cumulative crop ETa and Re in control and degraded soils for total growth days is given in Table 4. The mean difference in cumulative ETa between crop on control and oil-polluted soils was 1.222 cm with the standard deviation estimated within 95% confidence interval. The t-statistics showed that a significant difference (P <0.01) existed between the mean of ETa on control and oil-polluted soils. Also, a significant difference (p < 0. 01) was observed between cumulative Re on control and oil polluted soils. Thus, in comparative terms, crude-oil polluted soil significantly (p<0.01) reduced root elongation even within 4 to 5 weeks after emergence.

Table 4: Paired-samples test comparing cum. ETa and root elongation of *Vigna Unquiculata* grown on control and crude-oil degraded soils.

Paired samples	Mean	Sd±	Se	Lower	Upper	t	Df	Sig. (p<0.01)
Cum. ETa ctr. vs. Pol.	1.22	9.588	0.128	0.854	1.390	8.737	20	0.000
Re. ctrl vs. Pol.	5.018	5.715	1.650	1.390	8.649	3.042	11	0.011

Ctrl= control; Pol = Polluted soil; Cum, = cumulative sum

The paired sample correlation between cumulative Re for control and polluted soils was r= 0.795, showing 20% unexplained deviations in their regression, which may be due to the imbalance between rate of Re in normal soil and in polluted soil. The correlation between cumulative ETa on other soil treatments was perfect (r =1.0) and daily ETa was only 1.9cm different, but the Sd was only ±1.5 cm different while CV was about the same (Table 5).

Table 5: Summary of paired samples statistics for cumulative ETa and Re of *Vigna Unquiculata* as affected by polluted, remediated and normal soils

Treatment	Cum ETa	Sd (±)	Cv %	Re	Mean	Sd(±)	CV %
Control	84.0	47.3	56.3	22.00	11.222	7.777	69.3
Polluted	82.1	45.8	55.5	8.10	6.204	2.956	47.6
Unpolluted	85.8	48.4	56.4	19.50	11.13	4.77	24.5

Relationship of Re with ETa

Graphical plot of Re against ETa (Fig 5, and 6) used ETa as independent variable, being exogenous-atmosphere driven, which was actually uncontrollable, while the root elongation was the dependent variable, as an endogenous system response. The shape of the curve in Figure 5 is sigmoidal for the control soil, with an exponential function given as:

$Re=4.9976e^{0.1608ETa}$, $R^2 = 0.969$ (6)

Table 6: Comparatively descriptive statistics for different functional relationships between Re and ETa.

Function type	R^2	adjR^2	Se	F	Significant
Linear	0.949	0.942	1.526	147.914	0.00**
Logarithmic	0.773	0.744	3.212	27.198	0.001**
Exponential	0.967	0.096	232.422	232.422	0.00**

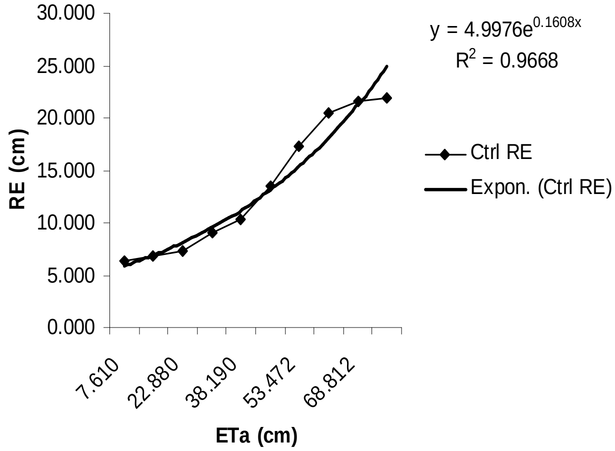

Fig. 5: Root Elongation Vs Crop evapotranspiration for V. unquiculata grown in unpolluted Soil

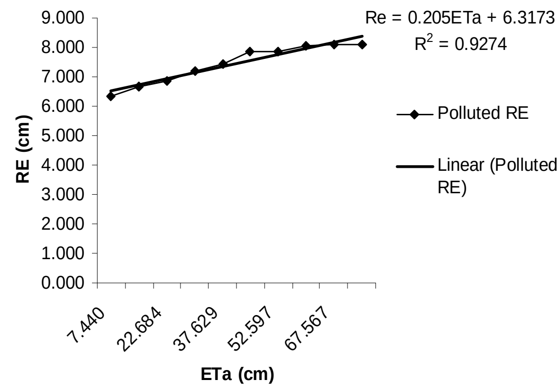

Fig. 6: Root Elongation Vs Crop evapotranspiration for V. unquiculata grown in crude oil polluted Soil

CONCLUSION

Vigna unquiculata seeds were planted in treated crude-oil polluted soil, remediated soil and (unpolluted) or control soil to compare root elongation and water utilization by crop evapotranspiration and relate their performance by mathematical functions.

Significant differences ($p<0.01$) were observed on ETa of *vigna unquiculata* grown on crude-oil treated, remediated and control soils. The remediated soil behaved similar to the control (unpolluted) soil. Percentage leaf water mass in *vigna unquiculata* was remarkably different between plants grown in polluted soil (61%) and those in control soil (74%) from the 4th week after emergence. Thus, degraded soil reduced the plant water capacity to transpire in the 4th and 5th WAE when flowering and foliage maturity in cowpea took place.

The peak growth rate of root of *vigna unquiculata* grown in crude oil polluted soil was reduced to 0.43 cm day^{-1} (12%) compared to 3.72 cm day^{-1} in the control soil and 3.18 cm day^{-1} (86%) in remediated soil. The mean root elongation in polluted soil did not show accelerated growth unlike in control soil, but rather turned stunted as in hydrated soil. Exponential growth function (R^2=0.967) best described Re vs ETa association in control soil while a linear relationship (R^2=0.927) fitted their association in crude-oil polluted soil.

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