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Modeling the Effect of Petroleum Produced Water on *Jatropha Curcas* L. Growth at Nursery Stage for Biofuel Production

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Abstract: Sudan is producing crude oil in resources-rich regions. With every single oil barrel that is produced, there are up to 10 barrels of water which are jointly produced. This water is highly polluted which can harm the environment, therefore a special treatment is needed before disposing the water. This research addresses the usage of the produced water in growing bio-fuel plants such as *Jatropha Curcas* L. The objective of this study is to examine the characteristics of the samples of the obtained water as well as to determine the effect of crude oil and NaCl concentrations on *Jatropha Curcas* L. The growth parameters such as stem height, stem diameter and number of leaves on sandy clay soil at Khartoum State, Sudan are also observed. The experimental treatments are simulated saline water of five levels in concentration in combination with five different levels of crude oil concentrations. Chemical analysis of water samples are obtained from Central Processing Facility (CPF) in Aljableen Town (White Nile State) showed that Sodium (Na) element has the highest level of concentration of about 1562 ppm, potassium (k), 79.15 ppm and salinity concentration of 2.80 g/L. No oil and grease were detected in the tested samples from Oil Facility. However, crude oil is added to the water in certain quantities during the experiment. The results showed a proportional relation between the stem height and salt concentration, but the oil concentration had a negative correlation with the stem height. The germination percentage was found to be 57.3% after 10 days of sowing the seeds. The tallest stem height of 14.1 cm during the experiment has been recorded with water oil content of 0.392 mL/L and 2.152 mL/L NaCl content. Statistics show that the highest mean stem height is 12.47 cm treated with simulated produced water of 1.176 mL/L of crude oil and 5.380 mL/L of NaCl while the severe damage to stem and leaves due to accumulation of oil particles has been recorded with simulated produced water of 1.568 mL/L of crude oil and 2.152 mL/L of NaCl salt. The output from the ANOVA shows that the stem height is changed significantly over levels of oil concentrations. Particularly, the stem height is negatively affected by high levels of oil concentration. A multiple regression model describing the relation between the Jatropha stem height and the concentrations of crude oil, NaCl and number of days was formulated as follows:

$$H = -2.7919 - [1.0833 \times oil] + [1.337737 \times salt] + [0.482443 \times days]$$

Keywords: *Biofuel*; *Jatropha Curcas* L; *plant growth; petroleum produced water; modeling.*

INTRODUCTION

The global interest in bio-fuels does not go unnoticed as the keen interest in bio-fuels is mainly inspired by climate change issues, aiming to reduce carbon dioxide emissions, as well as by geopolitical issues, aiming to reduce nations' dependence on fossil fuels [1]. Investments in fossil fuels substitution by bio-fuels should focus on bio-fuels extracted from perennials grown on abandoned agricultural or degraded lands, as these do not cause a carbon debt at land use change [2].

In this context, *Jatropha curcas* L. is promising as a sustainable bio-fuel option. With its seeds containing up to (35%) oil easily convertible into biodiesel, it's potential to reclaim wastelands, with positive effects on ecology and socio-economic development, and with its reputation of being a drought-resistant and easily establishing species, this small tree originating from central- and south- America is now planted on wastelands in the semi-arid tropics [2]. However, bio-fuels are highly controversial because their production holds significant economic, social and environmental risks such as; loss of biodiversity, water recharge, food security and negative carbon balance [1].

Jatropha curcas L. takes a special place in this debate, as it is claimed to produce bio-fuel and enhance socio-economic development while reclaiming marginal and degraded lands in arid and semi-arid regions without competing with food crops production or depleting natural carbon stocks and ecosystem services. Consequently *Jatropha curcas* L., despite the fact that it is largely undomesticated, needs resources like any crop to achieve high productivity. If *Jatropha* competes for land with food crops or high carbon stocks, it would lose its acclaimed sustainability advantages. It's believed that the current knowledge gaps and uncertain economic perspectives, together with competition on the global bio-fuel market, might drive *Jatropha* investors away from marginal or degraded lands towards agricultural lands that are valuable for biodiversity, in order to reduce financial or economical risks. As an alternative, it's believed that the global hype could be harnessed to increase rural development by considering relatively large-scaled, community-based *Jatropha* initiatives using petroleum produced water as the main water resource for irrigating *Jatropha* in these remote areas as one of the proposed beneficial uses [1], with the advantages of reducing the costs of treating and removing the produced water contaminants, and the development of remote areas. Petroleum produced water is defined as the water that exists in subsurface formations and is brought to the surface during oil and gas production. Large volumes of water produced during oil and gas extraction are generated in drought prone locations that are also experiencing an increase in population [3]. Produced water is a waste byproduct of the oil and gas industry; for every barrel of oil produced, approximately 10 barrels of brackish or saline water is generated. Presently over 5 billion gallons of produced water are generated a day [4].

The quality of this water varies significantly based on geographical location, type of hydrocarbon produced, and the geochemistry of the producing formation. In general, the total dissolved solids concentration can range from 100 mg/L to over 400,000 mg/L. Silt and particulates, sodium, bicarbonate, and chloride are the most commonly occurring inorganic constituents in produced water. Benzene, toluene, ethyl-benzene, and xylene (BTEX) compounds are the most commonly occurring organic contaminants in produced water [3]. The environmental concerns associated with produced water are degradation of soils, ground water, surface water, and ecosystems they support [5]. Because produced water contains elevated levels of dissolved ions (salts), hydrocarbons, and trace elements, untreated produced water discharges may be harmful to the surrounding environment. Large water volumes also can cause environmental impacts through erosion to large land area disposal basins, and pipeline and road infrastructure. Water hauling spills and unplanned discharges are all risks when managing produced water. Because produced water is viewed as a waste by product to the oil and gas industry, historically, the most commonly practiced management strategies are aimed at disposal rather than beneficial use. The most common practices for produced water disposal include land application or discharge, subsurface injection, and offsite trucking [3]. Produced water quantities in Sudan oil fields increased largely in recent years as the oil production increased and the old fields matured. In Sudan Approximately 1.2 million barrels a day of water are produced in (GNPOC) oil fields today. A bioremediation project was constructed in Heglig Oil Field to treat water coming from the central processing facility (CPF) using large beds of reed plants. Another small project was constructed in Adar oil fields to treat about 10 thousand barrels of water a day, but water needs further treatment to meet Sudan environmental regulations [6].

In the past, this water was handled as a waste and re-injected, often at significant cost to the producer. As the world demand for fresh water supplies, is increasingly turning to desalination to create fresh water. Because of the large volumes of produced water being generated, the treatment of this water is increasingly being looked at as a way to supplement our limited fresh water resources in many countries. Although several solutions were introduced concerning the use of produced water; several issues still need to be addressed including the costs of treatment and removal of the contamination, the treatment level required for beneficial reuse, and the regulatory and policy issues associated with produced water used for beneficial reuse. Consequently, the problem intended to be solved by this study work, is to investigate the effects of untreated produced water on the growth of *Jatropha Curcas* L. for bio-fuel production on the remote areas for the benefits of the poor small holders and growers.

MATERIALS AND METHODS

The goal of this research is to study the effect of simulated produced water on Jatropha curcas L. growth under Khartoum State conditions.

2.1. Experimental site

The experimental site had the following characteristics: Air temperature was (T_a, [℃]) 44 - 22℃ during the entire experiment, with an average relative humidity (RH, [%]) ranging between (7- 49%). The soil texture was sandy clay. The chemical analysis of the irrigation water is presented in Table 1. The locally obtained Produced Water sample is shown in **Fig.1**.

Table 1. Produced water sample analysis results

Test name	Unit	Test result
Salinity	g/L	2.800
Oil and grease	mg/L	0.000
K	ppm	79.150
Ca	ppm	6.645
Mg	ppm	3.794
Na	ppm	1562

Fig 1. Locally obtained produced water sample

2.2. Experimental Procedure

Jatropha fruits were obtained from Blue Nile state, which lay (490 km) distant, south east of Khartoum, capital of Sudan. The fruits were husked manually as shown in **Fig. 2**. Virgin soil was brought from a farm located in west Omdurman, Khartoum state, a regime affected by desertification; in order to simulate the conditions of the remote areas, where the petroleum facilities that generate produced water lay. The *Jatropha* was propagated by seeds, and before sowing them, they were overnight soaked in water for 24 hours, to improve the germination percentage. The seeds were subsequently sown in 75 polyethylene buckets 30 cm in diameter filled with soil to an average depth of 15 cm. The experiment was conducted during April-May 2014, and the seeds were sown in the buckets in Thursday, the 17th of April, after watering the seed beds sparingly and soils were kept loose to prevent cracking. A factorial experiment was organized (see Figure 3), in which treatments consist of combinations of five levels for two factors i.e.; a design of 5 crude oil concentrations × 5 NaCl concentrations and 3 replicates were used.

Fig. 2. Jatropha seeds

Fig. 3. Experimental setup

The factors accommodated were; the amount of crude oil in the Simulated Produced Water in ppm (40–2,000 ppm) [3], and the amount of NaCl salt in the irrigation water (2.152-5.380 ppm) [7].

Table 2 clarifies the concentrations of crude oil and NaCl used in the experiment. The experiment design consists of five groups, each group indicates a certain level of salinity (5.380, 4.573, 3.766, 2.959 and 2.152) mL/L, and consists of three replicates. Every three replicates of the same group were watered with saline water of the same level of crude oil concentration (2.000, 1.568, 1.176, 0.784 and 0.392) mL/L. Watering of the seeds started at the same time for all the replications, subsequently after the seeds were sown. Seedlings were raised in the nursery stage for a period of 10 days and growth variables were measured on a daily basis including, stem height, stem diameter and number of leaves.

Recording of the growth parameters started on Wednesday, 23rd of April, six days after sowing the seeds. The germination percentage was calculated after ten days from the day seeds were sown, by dividing the number of seedlings by the total number of seeds sown (see **Figs 4** and **5**).

Table 2. Crude Oil and NaCl Concentrations used in the Experiment

Crude Oil (ml/l)		NaCl (ml/l)	
$\boldsymbol{VH_O}$	2.000	VH_S	5.380
$\boldsymbol{H_O}$	1.568	H_S	4.573
$\boldsymbol{M_O}$	1.176	M_S	3.766
$\boldsymbol{L_O}$	0.784	L_S	2.959
$\boldsymbol{VL_O}$	0.392	VL_S	2.152

Fig. 4. Germination process

Fig. 5. Jatropha seedling

1.3 Statistical Analysis

All results were statistically analyzed with the Statistical Package for the Social Sciences (SPSS) software using repeated measures, two-way ANOVA. The 'two way' part of the name means that the two independent variables that have been manipulated in the experiment are (oil/salt concentrations) ranging from (0.392 to 2.000) mL/L for the crude oil, and (2.152 to 5.380) mL/L for the NaCl salt. The 'repeated measure' part of the name implies that the same participants (crude oil/ NaCl concentrations) have been used in all conditions (5 levels).

The two-way ANOVA with factors; crude oil concentration treatment (five levels) and salt concentration (five levels) was performed separately on the recorded stem heights. Repeated measures ANOVA with between subject factors crude oil concentrations and salt concentrations was applied on the stem heights (within subject factor = mL/L, 5 levels).

A multiple regression model, estimating the average stem height on day (*i*), as a function of crude oil concentration, salt (NaCl) concentration and the number of days since watering started, where the concentrations of crude oil and NaCl and number of days are the input variables (independent variables). The objective is to explain the variation in stem height, using the variation in the independent variables. Microsoft office excel software was used in order to obtain descriptive statistics analysis and plot the relations between the average stem heights and oil concentrations, and between the average stem heights and salt concentrations. All statistical analyses were performed with Microsoft Office Excel (v12.0), (office 2007) and IBM SPSS Statistics 20.0 (SPSS Inc., Chicago, IL).

3. RESULTS AND DISCUSSION

The results, being the significant parameter for assessing the credibility of the research, were validated for the final growth parameters and discussed as follows:

3.1 General Results

Results that indicate the achievement of the project's main objective are presented in the following points:

- The *Jatropha* seeds that were irrigated with non-treated produced water showed significant progress, as the seeding growth was evaluated in term of measurement of three growth parameters. The results showed significant differences for all growth characteristics of the two treatments, five levels each.
- The total percentage of germination after a period of dormancy of three days and a total of ten days after the seeds were sown, was found to be 57.3%.
- The highest number of leaves during the experiment period was recorded after approximately two weeks from date of sowing (fourteen days). This is an indication to the adaptation of the seedlings to high salt concentrations in the irrigation water.

The maximum stem height obtained during the experiment was approximately 14.1 cm in average with very low concentration of crude oil of 0.392 mL/L, and very low salt concentration of 2.152 mL/L in the water, with an average stem diameter of 0.4 cm. Three replicates are presented in **Fig. 5**.

3.2. Crude oil concentration's main effect

Descriptive statistics showed that the highest mean height was 12.47 cm treated with simulated produced water of 1.176 mL/L of crude oil and 5.380 mL/L of NaCl. The lowest mean height was 0.00 cm treated with simulated produced water of 1.568 mL/L of crude oil and (2.152) mL/L of NaCl salt.

Table 3 shows the result of Mauchly's sphericity test for each of the three effects in the model (two main effects and one interaction). The significance values ($p < 0.05$) of these tests shows that for the main effects of oil, salt and oil/salt

Fig. 6. Jatropha seedlings during Nursery Stage (replicates watered with simulated water of high oil concentration and medium NaCl concentration)

Table 3. Mauchly's Test of Sphericity[b]

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
OIL	0.028	97.862	9	0.000	0.470	0.501	0.250
SALT	0.045	84.789	9	0.000	0.399	0.419	0.250
OIL * SALT	0.000	811.804	135	0.000	0.177	0.198	0.063

[a] May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

[b] Design: Intercept.
Within Subjects Design: OIL + SALT + OIL * SALT

interaction indicate that the assumption of sphericity is not met i.e. the equality of the variances of differences between levels of the repeated measures factors, it can be concluded that there are significant differences between the variance of differences for oil and NaCl concentrations. Crude oil concentration of 0.784 mL/L resulted in the highest mean stem height which equals to (4.713) cm. **Fig. 7** illustrates the relation between the average stem height and the crude oil concentrations. The graph indicates that high concentrations of crude oil results in shorter stems, with a peak average stem height of approximately 4.71 cm at a concentration of 0.784 mL/L.

3.3. Salt (NaCl) concentration's main effect

The main effect reflects in that very high concentration of salt results in greater growth parameters. Contrasts must be studied to break this effect down further. **Fig. 8** illustrates the relation between the average stem height and the salt concentrations. The graph indicates that high concentration of salt results in longer stems, with the longest stem height of approximately (9.15) cm at a concentration of (5.38) ml/l.

3.4 Salt (NaCl), Oil interaction

Essentially, the stem height changes significantly over levels of oil concentrations. In other words the stem height increased with high levels of oil concentration. Looking at low concentrations of salt, the stem height was relatively short regardless of how the oil concentration was. The stem height was not affected by salt concentrations: high oil concentrations give short stems at high salt concentrations.

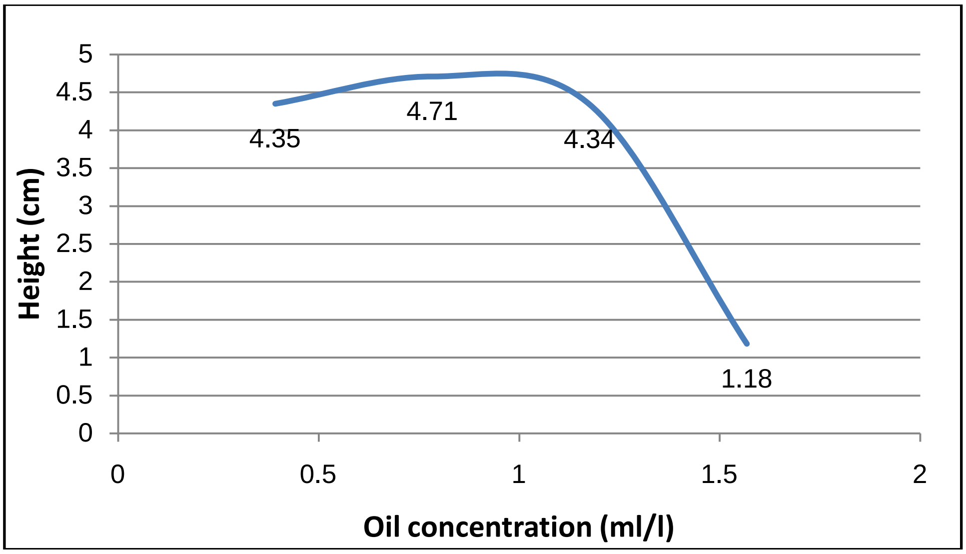

Fig. 7. Stem Height/ Oil Concentration Relationship

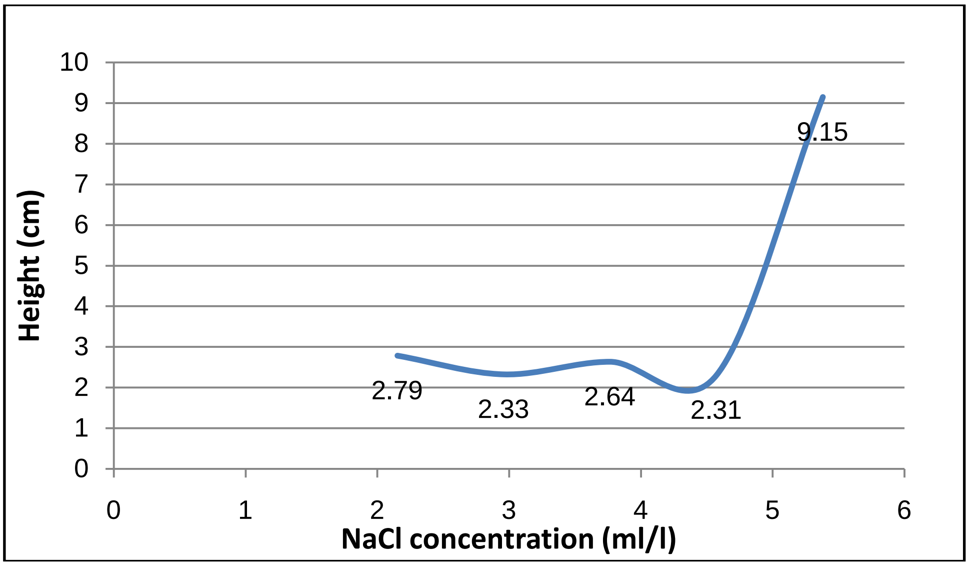

Fig. 8. Stem Height/ NaCl Concentration Relationship

3.5 Jatropha growth multiple regression model

Tables 4, 5 and **6** represent the regression analysis output. The multiple correlation co-efficient is 0.4136. This indicates that the correlation among the independent and dependent variables is positive. The value of multiple R is closer to 0 than to 1, this means that there is no linear relationship between the variables. The coefficient of determination, R^2, is 71.11%. This means that close to 71% of the variation in the dependent variable (stem height) is explained by the independent variables i.e. the output variable's variance is well explained by the input variable's variance.

The independent variables that statistically are significant in explaining the variation in the stem height are the oil concentration and the salt concentration, as indicated by: (1) calculated t-statistics that exceed the critical values, and (2) the calculated p-values that are less than the significance level of 5%.

Table 4. Regression Analysis

Regression Statistics	
Multiple R	0.4136
R Square	0.7111
Standard Error	4.8509
Observations	750

Table 5. The ANOVA Output

	df	SS	MS	F	*P value*
Regression	3	3622.36	1207.45	51.31	0.037*
Residual	746	17554.52	23.53		
Total	749	21176.89			

*NS, *, **: Not significant, significant at p= 0.05 and significant at p= 0.01, respectively*

Table 6. Jatropha growth multiple regression model

	Coefficients	St Error	P-value	t- Stat	Lower 95%	Upper95%
Intercept	-2.7919	0.777175	-3.592365	0.000349	-4.31761	-1.26619
oil	-1.0833	0.313061	-3.46036	0.00057	-1.69789	-0.46872
Salt	1.337737	0.147189	9.088546	8.9E-19	1.048783	1.626692
day	0.482443	0.061676	7.822282	1.77E-14	0.361365	0.603521

The results of the estimated regression line include the estimated coefficients, the standard error of the coefficients, the calculated t-statistic, the corresponding p-value, and the bounds of the 95% confidence intervals.

- The relationship between the oil concentrations and the stem height is **negative**: the higher the oil concentrations, the lowest the stem heights.
- The salt concentration is **positively** related to the stem height, and this may be due to an interaction with the crude oil concentration variable; because higher salt concentrations tend to inhibit the plant growth.
- The relationship between the number of days and the stem height is **positive**: the stem height increases as it ages.

The regression model describing the relationship between the concentrations of crude oil in (mL/L), the concentration of the salt (NaCl) in (mL/L) and the number of days (*N*), with the growth parameter under consideration, i.e. the stem height is extracted from Table 6 as follows:

$$H(cm) = -2.7919 - [1.0833 \times oil] + [1.337737 \times salt + 0.482443 \times N\ days \quad (1)$$

The regression line obtained indicates that for each unit increase in oil concentration, the stem height decreases with 1.0833 units. For each unit increase in NaCl concentration, the height increases with 1.337737 units and as the number of day increases by one unit, the height increases with 0.482443 units as well.

4. CONCLUSIONS AND RECOMMENDATIONS

The experiment aiming to determine the effect of the simulated produced water was successfully accomplished, with significant random variations in the seedlings height and number of leaves per seed with the crude oil and NaCl concentrations. The germination percentage during the nursery stage was 57.3%, and the cause of the deficiency in this percentage was the covering of seeds with crude oil.

Descriptive statistics showed that the highest mean height was 12.47 cm treated with simulated produced water of 1.176 mL/L of crude oil and 5.380 mL/L of NaCl. The lowest mean height was 0.00 cm treated with simulated produced water of (1.568) mL/L of crude oil and 2.152 mL/L of NaCl.

The regression analysis showed that the relationship between the oil concentrations and the stem height is negative: the higher the oil concentrations, the lowest the stem height, the salt concentration is positively related to the stem height and the relationship between the number of days and the stem height is positive.

Attention should be given to prevent the buildup of a hard pan of oil or a thick layer over long durations of irrigation. Reconsideration of disturbing the soil before planting the seeds and planting the seeds in ridges might be effective. Drip irrigation would appear to be the most obvious option for irrigating Jatropha plants, with the area watered being right at the area of the roots. The type of outlet chosen should suit the water quality; to prevent the suspended particles in the produced water blocking the outlets. Reconsideration of applying both fertilizer and full field pruning operations is important**.** Produced water should be viewed as a resource which must be recovered and added to the water budget.

Produced water contains small amounts of emulsified oil, organic compounds including dissolved hydro-carbons, organic acids, phenols, inorganic compounds, dissolved solids and natural low-radioactive elements, which could have significant effect on seed and oil yields on the long terms, in this context extensive experiments should be conducted. A statistical system for Jatropha data should be designed and implemented for monitoring, evaluation, and planning purposes. More attention should be paid to accurate data collection, preparation, and analysis.

The Jatropha industry consists of three stages: plantation stage, extraction stage, and biodiesel production stage. The project should test the second two stages—the international market has a number of small units that could satisfy this objective. Jatropha as a source of bio-fuel must be part of the renewable energy strategy in Sudan. Plans to promote its use should be taken seriously. All expansion areas for Jatropha plantation must be near treated wastewater plants in the desert or on marginal lands. Its cultivation must be totally prohibited on agricultural lands.

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