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Influence of diesel contamination in soil on growth and dry matter partitioning of *Lactuca sativa* and *Ipomoea batatas*

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Abstract

Phytotoxic effect of diesel contaminated soil was investigated on growth and dry matter partitioning in *Lactuca sativa* and *Ipomoea batatas* in greenhouse pot experiment at two concentration range (0-30 ml and 0-6 ml diesel kg^{-1} soil) for 14 weeks. The results indicated that whole plant biomass, stem length, root length, number of leaves and leaf chlorophyll in two plants were negatively correlated with increasing diesel concentrations. The critical concentration of diesel associated with 10 % decrease in plant growth was 0.33 ml for lettuce and 1.50 ml for sweet potato. Thus, growth of lettuce in diesel contaminated soil was more sensitive than sweet potato. The pattern of dry matter partitioning between root and shoot in both plants were similar. In 0-6 ml diesel contamination range, allocation of dry matter to shoot system was favoured resulting in high shoot: root ratio of 4.54 and 12.91 for lettuce and sweet potato respectively. However, in 0-30 ml diesel contamination range, allocation of dry matter to root was favoured, which may have been an adaptive mechanism in which the root system was used for storage in addition to increasing the capacity for foraging for mineral nutrients and water. Although lettuce accumulated more metals in its tissue than sweet potato, the tissue mineral nutrients in both species did not vary to great extent. The critical diesel concentration for toxicity suggested that the cause of mortality and poor growth of sweet potato and lettuce grown in diesel contaminated soil was due to presence of hydrocarbons in diesel.

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Introduction

Petroleum diesel is a yellow viscous liquid obtained from fractional distillation of crude oil (Wang *et al.,* 2004). It is mainly a complex mixture of saturated and unsaturated hydrocarbons with general chemical formula $C_{12}H_{23}$, the number of C and H may range approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$ (Ogbo, 2009). The non-hydrocarbon components of diesel include heavy metals such as iron, lead, manganese vanadium and nickel (Wyszokowski and Ziolkowska 2008). Several elements including sulphur, nitrogen, phosphorus, calcium, chlorine, fluorine, potassium and sodium have also been reported in diesel (Adam and Duncan, 1999). Diesel is considered to be the most phytotoxic product of crude oil (Njoku *et al*., 2009). Phytotoxic effect of diesel is dependent mostly on its aromatic hydrocarbons and to a lesser extent on aliphatic hydrocarbons (Alkio *et al*., 2005). Monocyclic aromatic hydrocarbons (BTEX) cause acute injury to plants, while polycyclic aromatic hydrocarbons (PAH) cause chronic injury (Alkio *et al*., 2005). Aliphatic hydrocarbons are highly volatile and less toxic to plants (Alkio *et al*., 2005).

Diesel spill on land reduces toxicity of diesel hydrocarbons due to evaporation and degradation processes (Bayram *et al*., 2009; Akujobi *et al*., 2011). Diesel contaminated soil affects physiological processes of plants like reduction in transpiration due to physical interference of water transport in plants (Adam and Duncan, 2002; Gelpke, 2011), reduced or increased respiration and reduction in photosynthesis (Akujobi, 2011). Diesel pollution also inhibits translocation of water and plant nutrients which leads to decreased growth and biomass production (Daniel-Kalio and Pepple, 2006; Adenipekun *et al.,* 2008).

Worldwide consumption of diesel is continuously increasing as a fuel forcar engines, industrial trucks, generators and in several agricultural machineries (Haller *et al*., 2013; Ogbo, 2009). Increased use of diesel has led to an increase in accidental spills on land and water resulting in environmental pollution (Gelpke, 2011). Diesel spill on cultivable land is common in many countries as several agricultural machineries use diesel as fuel. With ever increasing world population and to meet the rising food demand, use of machinery on agricultural land is inevitable (FAO, 2011). Hence, it is important to elucidate the effects of diesel spill on soil and crop productivity and also determine options for ameliorating the phytotoxic effects of diesel contamination in soil and on crop growth.

All the reported studies of the effects of diesel spillage have involved plants that get established from seeds like *Corchorus olitorius* Linn (Adenipekun *et al*., 2008), *Solanum melongena* (Akujobi *et al*., 2011). Lettuce is mainly grown for its leaves and it is widely eaten as salad. Sweet potato produces large sweet tasting tubers which are used as root vegetable, its young shoots and leaves are also eaten as greens by humans. Thus, it is currently not known how plants that are established from cuttings and other vegetative propagules compare with those that are established from seeds in tolerating diesel toxicity. The present study was thus designed to compare the effects of diesel pollution on establishment and vegetative growth of lettuce grown from seed and sweet potato grown from cuttings.

Materials and Methods

The present study was conducted at the University of Zululand in Kwa-Zulu Natal province of South Africa. Agriculturally productive soil was collected from University's farm. Diesel was purchased from Zulu Oil company at Empangeni. Two concentration ranges (0-6 ml kg^{-1} and 0-30 ml kg^{-1}) of diesel were selected for conducting the experiments. Soil was uniformly mixed with different concentrations of diesel in 20 l pots. Diesel concentration ranging between 0-30 ml included 0, 5, 10, 15, 20, 25 and 30 ml diesel kg^{-1} soil. Phytotoxic effect of diesel contaminated soil was severe on growth of lettuce and sweet potatoes at 0-30 ml diesel concentration. Hence, plants were then treated with diesel concentration in the range of 0-6 ml which included 0, 1, 2, 3, 4, 5 and 6 ml diesel kg^{-1} soil. This was done to facilitate to determine accurate critical concentration of toxicity of diesel. The pots in each case were laid in a completely randomised design (CRD). Three replicates were maintained for each treatment. Soil without diesel treatment served as control. Soil samples were taken for chemical analyses from the potted soil before and after diesel treatment and also at the time of harvesting from each replicates.

Seedlings of lettuce were raised in a rainproof nursery using hygromix as growth medium. After 4 weeks of growth, vigorous seedlings of equal size were transplanted to the pots. Two seedlings were planted in each pot. Sweet potato cuttings were planted with three buds below soil and two buds above soil level. Pots were arranged 30 cm within row and rows were 1 m apart. The pots were kept moist throughout the period of experiment. The plants were grown for 14 weeks.

The mortality of plants in each replication of treatments was determined weekly by counting the number of plants that died. After 14 weeks of growth in the pots, 10 leaves were randomly selected per plant per treatment replication and their chlorophyll content was estimated by Chlorophyll meter CCM-200 from centre of each leaf. Plants were harvested carefully pulling them out of the soil to avoid damage to roots. Roots were washed to remove soil. Plants were then separated into leaves, stems and roots. The length of roots and stems were measured. Plants parts were oven dried at 65°C until constant weight was obtained after which their dry weights were determined.

The youngest fully matured leaves were separated and used for tissue chemical analyses. They were ground to pass through a 0.84 mm sieve. After grinding, representative sub samples (5 g) were taken and wet digested in 1.0 M hydrochloric acid (HCl). The digest was filtered through a #1 Whatman filter paper. An aliquot of 10 ml was transferred to a centrifuge tube and analysed by ICP atomic emission spectrometer to determine P, K, Ca, Mg, Na, Cu, Mn and Zn content. Total carbon and nitrogen were analysed by the Automated Dumas dry combustion method using LECO CNS 2000 (Leco Corporation, Michigan, USA; Matejovic, 1996). Soil was analysed before diesel contamination, at planting and at the time of harvest. Soil was analysed for the following parameters; soil texture, pH total carbon, nitrogen phosphorus, potassium, zinc, copper, manganese, acidity, calcium, magnesium, calcium and magnesium.

Statistical analyses : The data of soil analysis, plant growth and leaf tissue analyses were first subjected to ANOVA using Gen Stat Release 12.1 (PC/Windows Vista) (VSN International Ltd., 2009). The significance differences between means of treatments were checked by lsd (5%). Where necessary, the data were also subjected to correlation and regression analyses. Thus, mathematical functions expressing correlation and regression relationship between diesel concentrations and biomass of plants and plant parts were obtained using curve fitting programme of TableCurve 2D v5.01.01 (Systat Software Inc., San Jose, CA, USA, 2002).

Results and Discussion

All the seedlings of lettuce and sweet potato cuttings grown in control soil survived to maturity. The least diesel concentration at which mortality occurred was 15 ml diesel kg^{-1}soil in both lettuce and sweet potato plants. Diesel concentration ranging between 0-30 ml kg^{-1}showed a strong positive correlation between diesel contamination in soil and mortality of both lettuce (r^2 = 0.999) and sweet potato (r^2= 0.944)

(Fig. 1). However, mortality in lettuce occurred between 4th and 6th week after seedlings were transplanted in diesel contaminated soil, while in sweet potato mortality occurred earlier at 2nd and 3rd week after planting the cuttings in soil contaminated with diesel in the range of 0-30 ml kg^{-1} soil . Diesel spills on agricultural land have generally been reported to cause mortality and reduction in growth of *Avena sativa*, *Zea mays* (Wyszkowski and Wyszkowska, 2005) and *Schinus terebinthifolus* (Bona *et al*., 2011).

In the present study, a negative correlation was noted between diesel concentration@ 0-30 ml kg^{-1} soil and growth parameters(root length, stem length, number of leaves)and leaf chlorophyll content in lettuce and sweet potato plants. Reduction in growth was accompanied by reduction in chlorophyll content and leaf area (Table 1) as a result of reduced photosynthesis. A progressive decrease in leaf chlorophyll with increasing diesel concentration in soil has also been reported in cereals (Seklemora *et al*., 2001) and *Solanum melongena* (Akujobi *et al*., 2011).However, the toxic effect of diesel @ 0-6ml kg^{-1} soil was insignificant on growth of both plants and high correlation only occurred between diesel contamination in soil and stem length, chlorophyll content in sweet potato, respectively.

Plants of lettuce and sweet potato treated with diesel in the range of 0-6 ml kg^{-1} and 0-30 ml kg^{-1} soil significantly affected dry matter of both plants. A maximum reduction in dry weight of root and stems of lettuce was observed at 2 ml diesel kg^{-1} soil and stem weight at 3 ml diesel kg^{-1} soil (Table 2). However in sweet potato, dry weight of root and stem decreased in a concentration dependent manner while maximum reduction in leaf dry weight was noted at 5 ml diesel kg^{-1} soil, respectively (Table 3). Generally, shoot: root ratio of lettuce varied less than that of sweet potato in response to increasing diesel contamination in soil. Also, the shoot: root of both species varied more in 0-30 ml diesel kg^{-1} soil contamination treatments when compared with that of 0-6 ml diesel kg^{-1} soil concentration range treatments (Fig. 4). Furthermore, the response of shoot: root ratio to diesel soil contamination differed in two plant species. The root to : shoot ratio of lettuce was not significantly affected by diesel contamination at 0–6 ml kg^{-1} soil contamination. However, in sweet potato significant ($p<0.05$) changes occurred as diesel contamination in soil concentration increased. Regression performed on data obtained in two diesel concentration range treatments indicated a strong correlation between the level of diesel soil contamination and shoot: root ratio in both species (Fig. 4).

Lettuce was more sensitive to diesel contamination in soil than sweet potato. The average critical concentration for toxicity of diesel was 0.33 ml for lettuce and 1.50 ml for (Fig. 2) sweet potato (Fig. 3) respectively. Hence, as little as 0.33 ml of diesel kg^{-1} of soil was enough to cause 10 % reduction in plant biomass in lettuce, whereas 4.5-fold in this amount was required to cause 10 % reduction in plant biomass of sweet potato.

Higher sensitivity of lettuce than sweet potato was probably due to the fact that lettuce is propagated from seedlings, which had little carbohydrate reserves. Unlike sweet potato cuttings, this obviously contained higher amount of carbohydrate reserves. Hence, sweet potato was able to make faster growth in diesel contaminated soil (Myers and Kitajima, 2007). Negative correlation between petroleum level in soil and biomass of crop plants like *Zea mays*, *Vigna radiata*, *Sorghum vulgare*, *Pennisetum glaucum Commelina benghalensis*, *Corchorus litorius and Schinustere binthifolius* have previously been reported (Luhach and Chaudhry, 2012; Brandt *et al.,* 2006; Daniel-Kalio and Pepple, 2006; Adenipekun *et al*., 2008 and Bona *et al*., 2010).

Previous studies have attributed the cause of reduced growth and plant mortality due to diesel contamination in soil

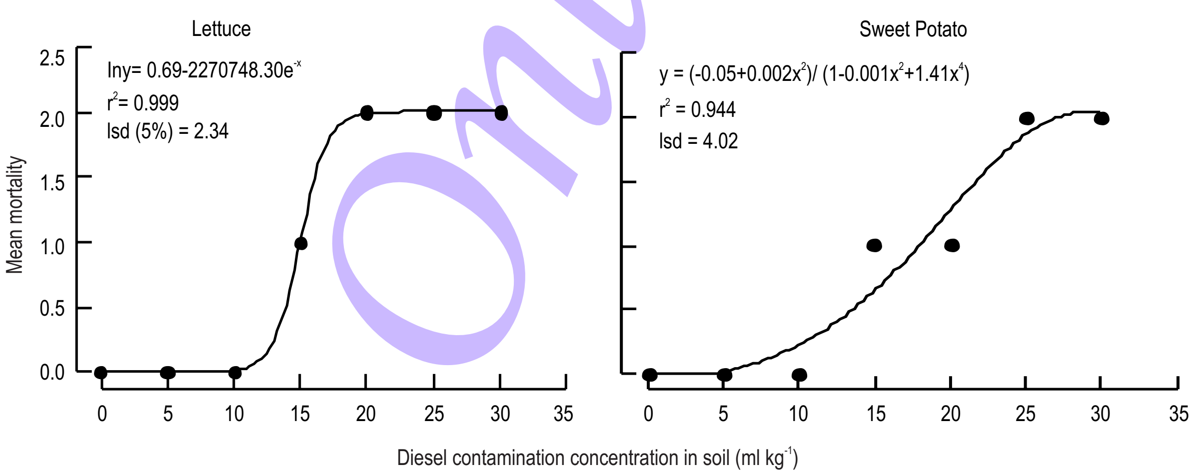

Fig. 1 : Relationship between diesel contamination in soil and mean mortality of lettuce and sweet potato

Table 1 : Effects of diesel contamination in soil on root length, stem length, number of leaves and chlorophyll content of lettuce and sweet potato at 14 WAP

Diesel ml kg^{-1}	Root length	Stem length	Number of leaves	Chl content	Root length	Stem length	Number of leaves	Chl content
	Lettuce				Sweet potato			
	Treatments in the 0-6 ml kg^{-1} concentration range				Treatments in the 0-6 ml kg^{-1} concentration range			
0	14.67^{a}	12.67^{a}	28.00^{a}	10.87^{a}	31.67^{a}	41.7^{ab}	87.00^{a}	46.70^{a}
I	12.67^{ab}	8.67^{b}	28.00^{a}	9.63^{ab}	32.00^{a}	43.0^{ab}	80.30^{ab}	43.30^{ab}
2	9.33^{b}	6.00^{d}	21.67^{b}	8.93^{b}	32.67^{a}	45.0^{a}	85.30^{ab}	35.00^{bc}
3	10.00^{b}	7.00^{cd}	21.00^{b}	8.87^{b}	33.00^{a}	43.0^{ab}	85.70^{ab}	29.70^{c}
4	12.00^{ab}	10.33^{ab}	25.00^{ab}	9.73^{ab}	32.33^{a}	37.7^{ab}	76.00^{ab}	31.70^{bc}
5	12.67^{ab}	9.67^{b}	21.33^{b}	8.33^{b}	18.33^{b}	40.3^{ab}	66.70^{b}	29.30^{c}
6	11.00^{b}	9.33^{bc}	22.33^{b}	7.97^{b}	15.33^{b}	35.0^{ab}	67.00^{b}	28.70^{c}
lsd	3.06	2.45	5.21	1.75	4.10	9.05	19.8	8.90
r^2	-0.594	-0.755	-0.526	-0.768	-0.871	-0.884	-0.819	-0.873
	Treatments in the 0-30 ml kg^{-1} concentration range				Treatments in the 0-30 ml kg^{-1} concentration range			
0	24.00^{a}	9.67^{a}	49.00^{a}	12.53^{a}	19.50^{a}	40.67^{a}	95.30^{a}	46.0^{a}
5	11.67^{b}	3.67^{b}	22.30^{b}	8.67^{b}	16.17^{ab}	15.67^{b}	18.80^{b}	36.3^{b}
10	10.67^{b}	2.00^{b}	11.30^{b}	7.63^{b}	16.50^{ab}	10.67^{c}	11.80^{b}	30.3^{bc}
15	9.33^{b}	2.07^{b}	9.30^{b}	7.50^{b}	13.67^{ab}	10.33^{c}	16.00^{b}	29.0^{bc}
20	8.50^{b}	1.33^{cd}	8.50^{b}	7.30^{b}	16.33^{ab}	11.33^{c}	12.30^{b}	26.3^{c}
25	8.00^{b}	1.20^{d}	9.00^{b}	6.60^{c}	13.00^{b}	8.33^{cd}	8.80^{b}	22.3^{c}
30	7.67^{b}	1.23^{d}	8.00^{b}	6.17^{c}	12.50^{b}	6.33^{d}	10.00^{b}	21.0^{c}
lsd	3.84	0.97	17.03	0.96	6.48	3.99	17.28	9.13
r^2	-0.977	-0.993	-0.981	-0.996	-0.987	-0.985	-0.988	-0.993

Values with similar superscripts along the same column are not significantly different ($p<0.05$)

largely due to deficiency of S, N, P, K, Ca or Mg (Dimitrow and Markow, 2000; Wyszokowski and Ziolkowska, 2008; Bayram *et al*., 2009; Hochmuth *et al*., 2012). In the present study symptoms like wilting, stunted growth and leaf chlorosis was observed in both plants. Similar morphological changes were reported in *Avena sativa* and *Zea mays* (Wyszkowski and Wyszkowska, 2005) and *Solanum melongena* (Akujobi *et al*., 2011). Although diesel contamination affected the mineral and heavy metal contents of sandy loam (containing 18 % clay, 8 % silt and 74 % coarse silt and sand) soil used in the present study; changes in macro and heavy metals did not vary to a great extent and also did not follow a definite pattern at planting and harvesting of crops. All the nutrients, organic carbon and pH were within the optimum range required for growth of lettuce and sweet potato.

Mineral nutrients in leaves of lettuce and sweet potato (Tables not shown) did not vary to a great extent, and most of the mineral nutrients except N were within the optimum range for normal functioning of both test plant species. Leaf N levels were marginal in both lettuce and sweet potato plants, but could not be attributed to diesel pollution since it was also marginally deficient in control plants. Hence, N deficiency could not have been the cause of mortality and poor growth in lettuce and sweet potato grown in diesel contaminated soil in the present study.

Heavy metal toxicity due to petroleum contamination in *Zea mays* (Ogbo, 2009) and *Phaseolus vulgaris* (Ade-Ademilua and Mbamalu, 2008) has been reported. In 0-30 ml kg concentration range; although, Fe accumulated to toxic level in leaves of sweet potato at 20 and 30ml diesel kg soil, its accumulation could not be held responsible for reduced plant growth because the growth of sweet potato was also severely reduced at other concentration levels other than 20 and 30 ml. In lettuce, Zn and Fe accumulated in leaves to toxic level when grown above 15 ml diesel kg-1 soil. Nonetheless, at critical diesel concentration in soil for toxicity, the concentration of these two nutrients interpolated from the relationship between relative plant biomass and Zn or Fe concentration was below toxic level (Table 4).

Thus, nutrient toxicity could not account for decrease in plant growth, at least at critical diesel concentration for toxicity for lettuce and sweet potato. Therefore, the cause of mortality and poor growth of sweet potato and lettuce grown in diesel contaminated soil might have been due to direct toxicity of diesel hydrocarbons. A further proof that diesel hydrocarbon was involved is that mortalities occurred at the earlier stages of growth of the two species in diesel contaminated soil. The mortalities in both species occurred at relatively early stages of growth of crops. No mortality occurred after 6 and 3 weeks of growth in diesel contaminated soil in lettuce and sweet potato, respectively. Non-mortality at later stages of growth in two species might be due to reduction of diesel hydrocarbons in soil since hydrocarbons are volatile in nature and tend to evaporate from soil (Hejaziand Husain, 2004; Serrano *et al.,* 2007),

Table 2 : Effect of diesel contamination in soil on the dry matter and shoot: root ratio of lettuce leaf, stem and root at 14 WAP

Diesel (ml kg^{-1})	Root dry weight (g)	Stem dry weight (g)	Leaf dry weight (g)	Shoot dry weight (g)	Whole plant dry weight (g)	Shoot/root ratio
0	4.50	8.50	15.23	23.73	28.23	5.36
1	4.33	6.67	13.03	19.7	24.03	4.53
2	2.67	5.00	6.67	11.67	14.33	4.44
3	3.17	2.83	10	12.83	16	4.06
4	3.00	4.83	9.67	14.5	17.5	4.81
5	3.33	4.67	10	14.67	18	4.44
6	2.83	3.50	8	11.5	14.33	4.11
MEAN	3.40	5.14	10.37	15.51	18.92	4.54
$LSD_{0.05}$	1.13	1.92	4.62	6.01	6.76	1.47
0	5.20	5.02	21.67	26.68	31.88	5.21
5	0.97	0.73	6.2	6.93	7.9	8.09
10	0.633	0.38	1.42	1.8	2.43	2.83
15	0.47	0.33	0.77	1.1	1.57	2.61
20	0.30	0.20	0.45	0.65	0.95	2.39
25	0.40	0.27	0.5	0.77	1.17	1.94
30	0.18	0.25	0.37	0.62	0.8	3.36
MEAN	1.16	1.03	4.48	5.51	6.67	3.78
$LSD_{0.05}$	0.43	0.84	2.84	3.52	3.24	4.13

Table 3 : Effect of diesel contamination in soil on the dry matter and shoot: root ratio of sweet potato leaf, stem and root at 14 WAP

Diesel (ml kg^{-1})	Root dry weight (g)	Stem dry weight (g)	Leaf dry weight (g)	Shoot dry weight (g)	Whole plant dry weight (g)	Shoot/root ratio
0	2.43	4.60	18.33	22.93	25.37	9.82
1	2.37	4.07	18.00	22.07	24.43	9.48
2	2.10	4.10	17.37	21.47	23.57	10.25
3	1.73	4.37	16.13	20.50	22.23	12.05
4	1.97	2.97	16.53	19.50	21.47	10.18
5	0.97	3.13	13.43	16.57	17.53	18.24
6	0.80	2.40	13.47	15.87	16.67	20.35
MEAN	1.77	3.66	16.18	19.84	21.61	12.91
$LSD_{0.05}$	0.63	0.81	3.92	4.02	4.12	6.06
0	24.00	4.77	15.47	20.23	44.20	0.84
5	1.33	0.67	1.40	2.07	3.40	1.56
10	1.27	0.57	0.77	1.33	2.60	1.05
15	1.97	1.13	1.30	2.43	4.40	1.23
20	2.13	1.00	1.07	2.07	4.20	0.97
25	1.67	0.73	0.80	1.53	3.20	0.92
30	2.15	0.50	0.60	1.10	3.30	0.51
MEAN	4.93	1.34	3.06	4.40	9.30	0.89
$LSD_{0.05}$	7.88	1.35	2.86	3.67	10.01	0.91

biodegradation (Barrutia *et al*., 2011; Onuoha *et al.,* 2011). Dry matter partitioning was insignificant in both lettuce and sweet potato plants treated in the range 0-6 ml diesel kg^{-1} soil (Table 5). Lettuce and sweet potato plants allocated more dry matter in shoot than root with exception to sweet potato treated with diesel in the range 0-30 ml kg^{-1} soil. In general, both lettuce and sweet potato plants grown in diesel contaminated soil ≤ 6 ml kg^{-1} soil allocated more dry matter in shoots as compared to roots. However, at diesel concentrations >6ml kg^{-1}soil (sweet potato) and ≥ 10 ml (lettuce) allocation of dry matter in roots improved resulting in lower shoot: root ratio (Fig.4). Allocation of dry matter in roots was more pronounced in sweet potato as compared to lettuce (Table 5). It must be noted that in shoot percentage of leaves was more than that of stem (Table 5). Diesel contamination in soil has been reported to cause unfavourable soil conditions like water stress, accumulation of heavy metals and oxygen deficiency for plant growth (Ogbo, 2009). Zharare and Scogings (2011) reported that plants change their pattern of allocation of dry matter in response to environmental stress. In the present study, allocation of more dry matter in roots at diesel concentration ≥ 10

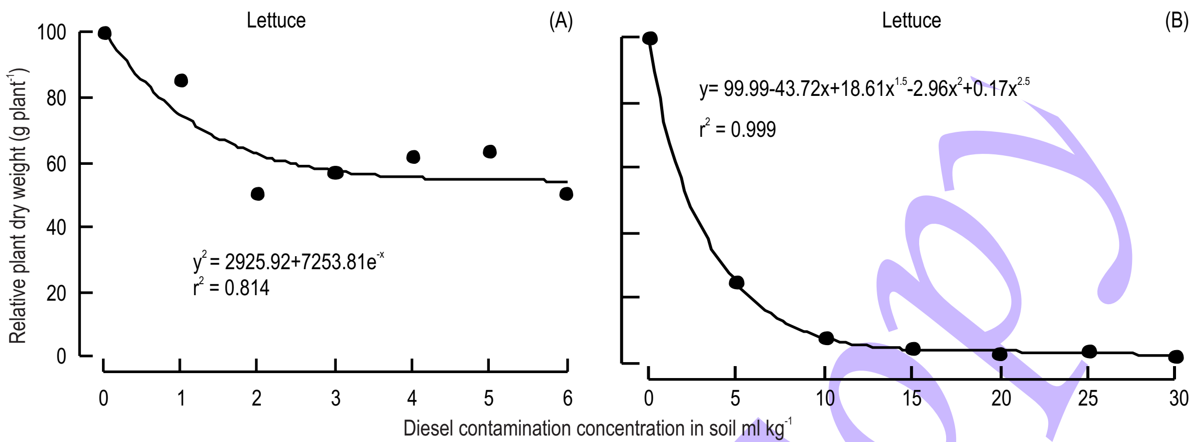

Fig. 2 : Effect of Effect of diesel contamination in soil on relative whole plant weight of lettuce for the 0-6 ml kg^{-1} (A) and 0-30 ml kg^{-1} (B) diesel contamination concentration range treatments at 14 WAP

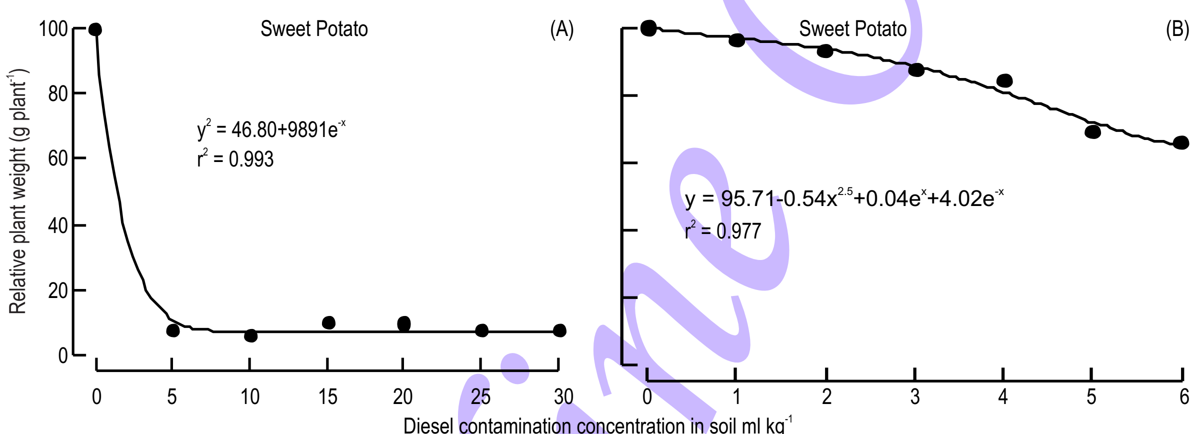

Fig. 3 : Effect of diesel contamination in soil on relative whole plant weight of sweet potato for the 0-6 ml (A) and 0-30 ml (B) diesel contamination concentration range treatments at 14 WAP

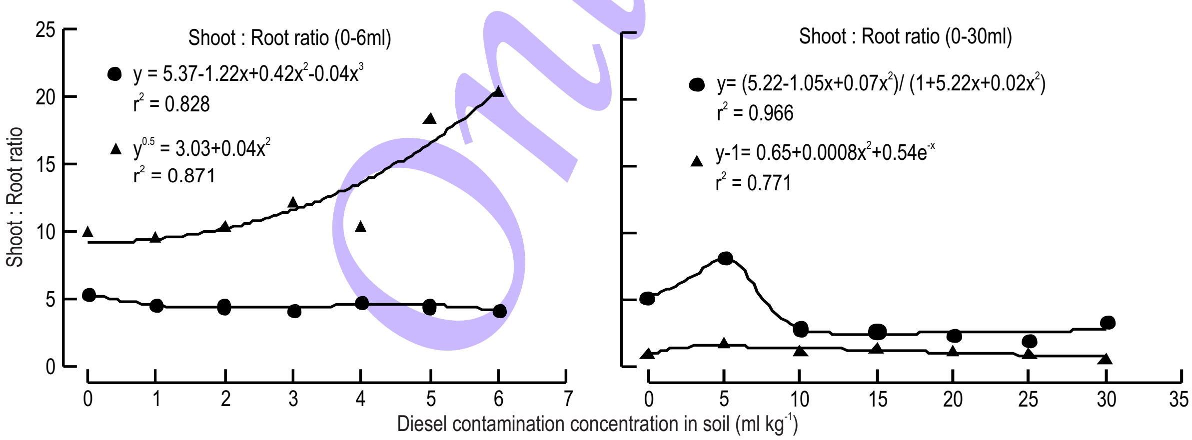

Fig. 4 : Relationship between shoot : root ratio and diesel contamination concentration in soil for Lettuce (●) and sweet potato (▲) at 0-6 ml kg^{-1} soil and 0-30 ml kg^{-1} soil diesel contamination range treatments

Table 4 : Concentrations of mineral nutrients in the leaves of lettuce and sweet potato at critical diesel concentrations for toxicity

Nutrients	Lettuce			Sweet potato		
	Critical concentration for toxicity (ml kg^{-1})			Critical concentration for toxicity (ml kg^{-1})		
	0-30ml*	0-6ml*	Average	0-30ml*	0-6ml*	Average
S (%)	0.19	0.35	0.27	0.34	0.58	0.46
N (%)	1.64	4.70	3.17	2.57	4.56	3.56
P (mg kg^{-1})	0.45	0.82	0.64	0.46	0.39	0.43
K (mg kg^{-1})	6.18	10.40	8.29	5.85	6.57	6.21
Ca (mg kg^{-1})	1.25	1.37	1.31	2.01	1.57	1.79
Mg (mg kg^{-1})	2.25	0.58	1.41	0.54	0.79	0.66
Na (mg kg^{-1})	980.00	750.00	865.00	1000.00	800.00	900.00
Al (mg kg^{-1})	270.00	230.00	250.00	375.00	330.00	352.50
Zn (ppm)	83.00	5.60	44.30	45.00	44.00	44.50
Cu (ppm)	5.92	5.24	5.58	6.00	5.50	5.75
Fe (ppm)	305.00	120.00	212.50	450.00	230.00	340.00
Mn (ppm)	42.00	28.00	35.00	46.00	62.00	54.00

*diesel contamination in soil range ml diesel kg^{-1} soil)

Table 5 : Effect of diesel concentration in soil on the dry matter partitioning of lettuce and sweet potato leaf, stem and root

Diesel (ml kg^{-1})	Lettuce				Sweet potato			
	% DM leaf	% DM stem	% DM root	% DM shoot	% DM leaf	% DM stem	% DM root	% DM shoot
0	53.50	30.39	16.13	83.87	71.93	18.34	9.73	90.27
1	54.20	27.71	18.08	81.92	73.56	16.83	9.61	90.39
2	46.60	34.78	18.58	81.42	73.57	17.49	8.95	91.05
3	62.40	17.86	19.78	80.22	72.46	19.69	7.85	92.15
4	56.00	26.77	17.24	82.76	77.04	13.78	9.19	90.81
5	54.40	26.53	19.12	80.88	76.32	18.06	5.62	94.38
6	55.70	24.36	19.91	80.09	80.96	14.28	4.76	95.24
MEAN	54.70	26.91	18.41	81.59	75.12	16.92	7.96	92.04
$LSD_{0.05}$	8.52	5.72	4.49	4.49	5.50	4.31	2.74	2.74
0	67.80	15.60	16.60	83.40	36.50	11.30	52.20	47.80
5	76.70	9.70	13.60	86.40	41.10	17.70	41.20	58.80
10	57.80	15.90	26.20	73.80	32.10	19.00	48.90	51.10
15	48.50	22.10	29.40	70.60	30.20	22.30	47.50	52.50
20	48.00	20.70	31.30	68.70	25.80	23.70	50.60	49.40
25	44.30	21.70	34.00	66.00	22.70	18.90	58.50	41.50
30	43.30	29.10	27.60	72.40	21.00	17.50	61.40	38.60
MEAN	55.20	19.30	25.50	74.50	29.90	18.60	51.50	48.50
$LSD_{0.05}$	21.41	11.54	14.09	14.09	17.59	13.93	22.16	22.16

ml kg^{-1} soil (lettuce) and 0-30 ml kg^{-1} soil (sweet potato) occurred due to unfavourable conditions caused due to diesel contamination in soil. Allocation of more dry matter in roots in both species may due to adaptive mechanism in which root system is used for storage in addition to increasing the capacity for foraging for mineral nutrients and water. It has been reported that plants can fully exploit their environment through storage rather than changing its allocation to some pattern that would be inappropriate for normal growth of plants, during unfavourable environment (Zharare and Scogings, 2011). Sweet potato may not have found this adaptive system difficult since it is tuberous root.

Diesel contamination in soil induced phytotoxicity on growth of lettuce and sweet potato plants. Phytotoxicity of diesel on growth of lettuce and sweet potato was concentration dependent. Lettuce was more sensitive to diesel contamination than sweet potato. Diesel contamination in soil also affected the pattern of dry matter partitioning between root and shoot in both plants. At lower diesel concentration, allocation of dry matter to shoot was favoured. The practical implication of the present study is that lettuce can be recommended for evaluating diesel contaminated soil as lettuce is more sensitive to contamination than sweet potato. Hence, the present study confirms the recommendation of lettuce by USEPA for acute toxicity test of hydrocarbon polluted soil (Da Silva Júnior, 2013; Fletcher, 1991). Since sweet potato is more tolerant to diesel contamination, it can be recommended for phytoremediation of diesel contaminated soil. However, the disadvantage of using sweet potato is that it is not a nitrogen fixer, and hence N fertilizer application is always essential. Another disadvantage of using sweet potato for phytoremediation purpose is that, the biomass of sweet potato is relatively small as compared with other plants like *Glycine max* that has been recommended for phytore mediation of diesel and crude oil (Barrutia *et al*., 2011; Njoku *et al*., 2009) contaminated soil. However, storage root of sweet potato may be an advantage. It has been reported that plants with large root biomass are good for phytoremediation of crude oil contaminated soil (Issoufi, 2005). Using sweet potato for phytoremediation of diesel contaminated soil may be strengthened by the ability of storing roots to absorb substantial quantity of diesel hydrocarbons and heavy metals from soil (not measured in this study). In addition to the advantage associated with storage root system in sweet potato, the process of harvesting sweet potato, which involves substantial digging of soil will enhance natural attenuation of diesel contaminated soil (Serrano *et al.,* 2007). Sweet potato can also serve dual purposes of being an economic crop while being used for soil remediation purposes, as the harvested tubers could be used to feed large ruminants (subject to the level of the contamination of the tuber). It is therefore important that further research should be conducted to confirm the suitability of sweet potato for phytoremediation of diesel contaminated soil.

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