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Temporal Changes in Growth and Development of Cereal Crops under Heterogeneous Soil Conditions

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Abstract: Natural and man made disturbances influence soil environment that in turn may reduce growth and yield of crop plants. Soil samples were collected from five disturbed sites and performance of three cereal crops (*Pennisetum typhoides*, *Sorghum bicolor* and *Zea mays*) was assessed under spatially disturbed soils. The responses of species were distinct for different growth and yield attributes studied under varied soil conditions. Seed germination and seedling growth appeared to be more prone to disturbed soil situations. However, later growth stages coped better with prevailing situations. Soil samples from an oil spilled field severely hampered the growth and yield of the species. *Z. mays* exhibited its potential for sustainable growth under spatially disturbed soils as compared to the other two species. The study suggested that disturbance by various means can render soil less productive therefore certain strategies should be developed by environmental scientists to save soil environment for sustainable agriculture.

Key words: Soil disturbance, cereal species, time course changes, growth, yield

INTRODUCTION

Soil anchor plants and acts as a storehouse of nutrients and moisture (Miller and Donahue, 1997). Seed germination, seedling recruitment and subsequent development of crops largely depend on optimum soil conditions. However, ever-increasing world population had resulted in a massive increase of industrial activities throughout the world which had rendered soils less productive for agriculture (Orcutt and Nilson, 2000).

Since industrial wastes contain a variety of solid and liquid contaminants such as poisonous salts, heavy metals, acids and alkalis that are ultimately accumulated in the soil as they ejected into water resources, re-channeled to irrigate crops grown in pre-urban areas (Ansari *et al*., 2001). The depositions of industrial wastes in soil have multiple adverse effects on plant performance in terms of growth and yield (Purohit and Ranjan, 2003). Thus, industrialization had resulted in extensive degradation of soil environment many countries of the world (Hussain *et al*., 1990). Similarly, oil spill causes insufficient soil aeration because of displacement of air spaces between the soil particles thus may cause anoxic conditions (IPIECA, 1995). Furthermore, the dynamic desert habitat is disturbed naturally, with extreme aridity, temperature, gales and poor soil texture that impede crop productivity (Shakhatreh *et al*., 2001).

Pennisetum typhoides, *Sorghum bicolor* and *Zea mays* occupy a very prominent position for diet and are a good source of carbohydrates, proteins and minerals. They possess an excellent ability to adapt and acclimatize to different soil situations (Fernandez and Reynolds, 2000). Moreover, their potential for growth and yield can vary considerably in relation to different soil conditions. Therefore, it is imperative to assess their relative growth and yield under naturally or anthropogenically disturbed environment. The foremost objectives of the study were to assess:

- Temporal changes in growth and development of these crop species
- To appraise the environmental disturbance which has greater inhibitory impact on plant
- To identify the species which have considerable potential to tolerate such soil conditions.

MATERIALS AND METHODS

Field study and selection of sites: Many sites in an area of 100 km from Multan, Pakistan (30.15 ^{0} N, 72.25 ^{0}E) were visited to make the choice for soil sampling. Soil was

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sampled from five disturbed sites while garden compost was used as control soil as it is considered as an optimum growth medium. The detail of sampling sites is as follows:

Soil samples	Type/site	Date of sampling	Type of Disturbance
Control	Garden compost	04-04-2004	None
I	General Bus Stand	09-04-2004	Trampling and smoke
II	Desert	12-04-2004	Water and nutrient deficiency
III	Ice factory, Multan.	13-04-2004	Factory effluents
IV	Oil depot	17-04-2004	Oil spill
V	Khawaja Tannery, Multan.	20-04-2004	Effluents of tannery i.e., sludge, fats, salts, chromium etc.

Soil sampling: An area of 1×1 m was marked at ten different locations at each of the above sites. Five to six kilogram soil was taken out from 5-25 cm depth from each marked area and was kept in properly labeled polyethylene bags. Soil samples collected from the same site were thoroughly mixed and were used as a growth medium.

Cultural techniques

Germination experiment: Seeds of the three crop species were obtained from ICI Pakistan Ltd. A total of fifty-four Petri dishes were labeled and filled with five different types of soil samples. Thirty seeds of each species were placed in each soil sample. All samples were soaked with 25 mL of distilled water. The experiment was laid down in a Randomized Block Design (RBD). There were made three replications for each soil treatment. The experiment was carried out at room temperature (20±5°C) and watered as and when needed. A seed was considered to be germinated when both embryonic axes; radicle and plumule had emerged out 0.2 cm. The number of seeds germinated was counted and records were made for the elongation of embryonic axes. Water absorption by germinating seeds was recorded by taking dry weight measurements of seeds and after 24 h of imbibitions and was expressed as percentage.

Growth experiment: This experiment was conducted in the wire netting glass house at the Botanic Garden, Bahauddin Zakariya University, Multan. Fifty-four cemented mosaic pots (40 cm internal diameter) were filled with 5 kg of six types of soils (Table 1). Twelve seedlings (one week old) of comparable size of each species were transplanted into these pots and allowed to establish for another week. The experiment was laid in a Randomized Block manner as in the germination experiment. The experiment was carried out at 14 h day length and 30±5°C. All pots were watered regularly. Growth attributes; plant height (cm), number of leaves/plant, leaf area (cm^2), fresh weight and dry biomass (g) were recorded after four, eight and sixteen weeks of growth. Yield and yield attributes; ear length (cm) and 1000 seeds weight (g) were recorded at maturity (16 weeks).

Statistical analysis: Mean values are presented on the basis of their respective control values and standard error were calculated. Data presented on percentage basis was Arcsine transformed. A two-way analysis of variance was carried out using MS Excel, 2000 in order to reveal effects of different soil samples on various growth attributes as well as to elucidate inter-specific differences.

RESULTS

Germination attributes: Soil heterogeneity had a significant ($p<0.001$) influence on seed germination of the three species (Table 1). Soils from sites I and IV caused a significant inhibitory effect as all the three species showed reduced germination. Responses of the species were considerably variable ($p<0.001$). The highest germination percentage was recorded for *S. bicolor* at the control while *P. typhoides* showed greater germination in soil samples collected from sites II and III. However, for *Z. mays* had the maximum germination percentage was recorded in the soil that was sampled from site V (Fig. 1).

Different soil samples significantly ($p<0.001$) influenced the emergence of both radicles and plumules (Table 1). There had been observed a greater inhibitory effect of soil I and IV on the elongation of embryonic axes in all three species. However, the responses of the species varied considerably ($p<0.001$). *Z. mays* had the maximum radicle length in soil of the site II and produced longer plumules in all soil types except soil IV. *S. bicolor* developed longer radicles and plumules in soil from site III but no consistent responses were observed for *P. typhoides* under different soil samples (Fig. 1).

When seeds were imbibed under different soil samples, water absorption was significantly ($p<0.001$) reduced and considerable ($p<0.001$) inter-specific differences were observed (Table 1). The lowest moisture was absorbed by he seeds in soil sample I. However, the responses of the species were inconsistent under different soil samples. *P. typhoides* had the maximum water absorption in soil type III, IV and V. *Z. mays* had the lowest water absorption under the same soil samples while the seeds of *S. bicolor* absorbed the lowest water content under soil sample IV (Fig. 1).

Growth attributes

Plant height (cm): All the species exhibited greater plant height in the soil, which was used as a control. A consistent ($p<0.001$) decline in height was observed in all

Table 1: Summary of analysis of variance (mean squares) for various attributes of three cereal crops under heterogeneous soil conditions

Attributes	$MS_{species}$	Significance	MS_{soil}	Significance	$MS_{interaction}$	Significance
Germination						
Germination percentage	2612.87	***	6751.97	***	1940.15	***
Radicle length (cm)	6.52	***	8.38	***	1.83	***
Plumule length (cm)	48.84	***	50.26	***	17.55	***
Seed moisture content (%)	141.05	***	175.42	***	87.07	***
Growth after 4 weeks						
Plant height (cm)	324.92	***	1159.17	***	13.25	*
Number of leaves	4.79	*	38.72	***	2.39	*
Leaf area (cm^2)	721.60	***	2075.26	***	132.18	***
Fresh biomass/plant (g)	1.08	*	221.02	***	1.32	*
Dry biomass/plant (g)	0.44	*	53.23	***	0.80	*
Growth after 8 weeks						
Plant height (cm)	14.76	NS	4215.66	***	66.78	*
No. of leaves	13.16	*	94.53	***	4.83	*
Leaf area (cm^2)	8327.22	***	6053.30	***	134.19	***
Fresh biomass/plant (g)	7462.92	***	25082.36	***	420.07	***
Dry biomass/plant (g)	8736.97	***	14948.05	***	919.64	***
Growth after 16 weeks						
Plant height (cm)	115.26	*	4209.19	***	36.48	*
Leaf area (cm^2)	7417.01	***	24543.75	***	396.27	***
Fresh biomass/plant (g)	484.43	*	111939.10	***	729.03	*
Dry biomass/plant (g)	788.11	***	90501.37	***	1075.88	***
Yield attributes						
Ear length (cm)	193.16	***	334.21	***	13.87	***
1000 Seeds weight (g)	21714.10	***	2045.06	***	906.04	***

MS = Mean Square, NS = Non Significant, *, **, *** = Significant at p = 0.05, 0.01 and 0.001, respectively

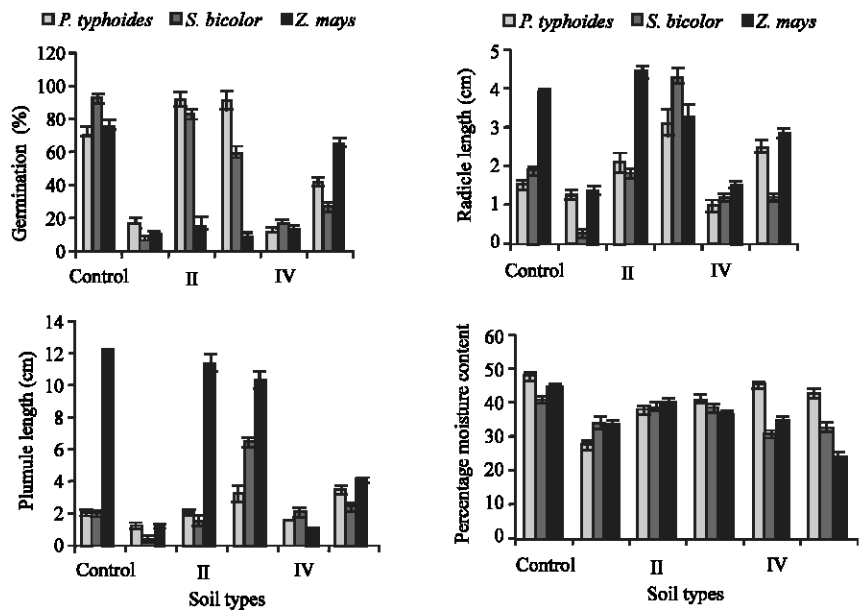

Fig. 1: Germination and initial growth attributes (±SE) of three cereal crop species under heterogeneous soil conditions (n = 3)

three species in soil samples I and IV when growth was observed after four weeks (Table 1). However, plant height was not much influenced by the soil samples of sites II, III and V. *Z. mays* had greater plant heights in all soil samples after four weeks. The responses of *P. typhoides* and *S. bicolor* were comparable at the control (Fig. 2).

After eight weeks of growth, *P. typhoides* had the greatest plant height in soil III while *Z. mays* and *S. bicolor* also had the longer plants in soil V. The lowest height of plant was observed for *Z. mays* in soil sample II and the same was true for *S. bicolor* in soil sample III (Fig. 2)

Soil sample of site I had a greater inhibitory effect on the height of the *P. typhoides* at maturity. The responses of *S. bicolor* and *Z. mays* at maturity were same under soil sample of the site I. *S. bicolor* plants had the lowest plant height. However, on the other hand *P. typhoides* had

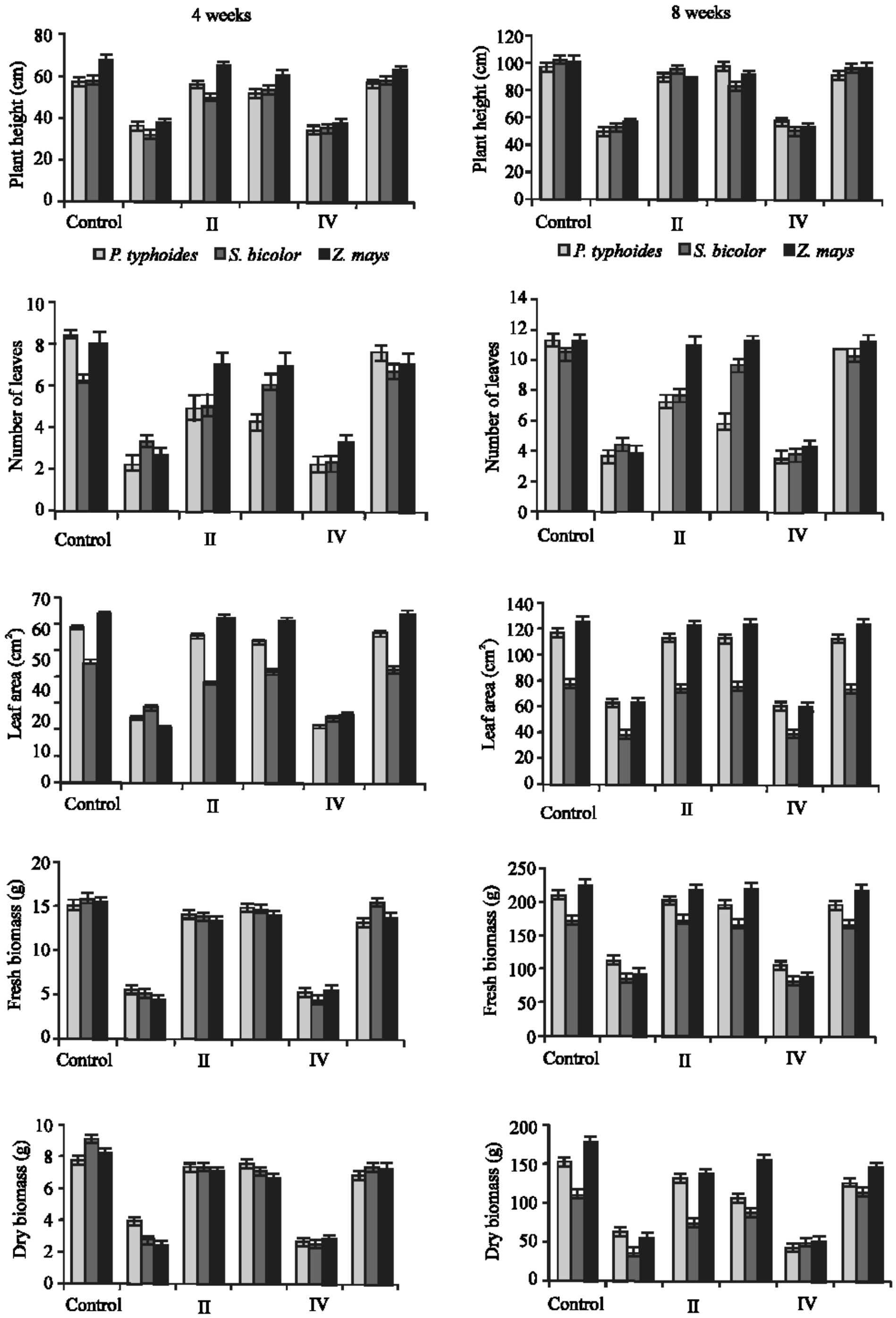

Fig. 2: Various growth and yield attributes (±SE) of three cereal crop species after 4 and 8 weeks of growth under heterogeneous soil conditions (n = 3)

greater plant height in soil IV as compared to other species. The reduction in plant height in the soil samples II, III and V was significantly ($p<0.05$) variable (Table 1).

Number of leaves: ANOVA (Table 1) clearly indicated that species varied considerably ($p<0.05$). After four weeks of growth, the maximum number of leaves was observed at the control and all soil samples had differentially ($p<0.001$) affected this attribute in all three species. *Z. mays* had significantly more leaves as compared to other two species in soil samples II, II and V (Fig. 2). Similarly, *P. typhoides* also had greater number of leaves in soil V while *S. bicolor* produced greater number of leaves in soil I.

There had been observed an increase in number of leaves after 8 weeks (Fig. 2). The responses of species were significantly ($p<0.05$) variable in different soil samples. The maximum number of leaves was observed in all the three cereal species at the control and in the soil sample collected from site V. *Z. mays* showed greatest number of leaves While, the reverse was true for *P. typhoides* under soil sample II and III. All species had consistently a fewer leaves in soil samples collected from site I and IV (Fig. 2).

Leaf area (cm^2): A variety of soil samples had caused significant ($p<0.001$) changes in the leaf area of the cereal species (Table 1). All the species had the maximum leaf area at the control. A marked reduction in leaf area was observed in soil samples that were collected from site I and IV in all three species. *Z. mays* had the greatest leaf area in soil sample IV while *S. bicolor* excelled for leaf area in soil sample I (Fig. 2).

After 8 weeks of plant growth the maximum reduction in the leaf area was noticed in *Z. mays* under soil samples of the sites I and IV. Disturbed soil samples had also influenced the expansion of leaves in *S. bicolor* which had the lowest mean values for leaf area in all soil samples. Soil samples I and IV significantly affected ($p<0.001$) this attribute in all three cereal species at maturity. The data revealed differential ($p<0.001$) responses of the adult plants to soil heterogeneity (Fig. 2).

Biomass production

Fresh and dry biomass/plant (g): Soil differences had a significant ($p<0.001$) influence on fresh and dry biomass production of the species (Table 1). Soil samples I and IV had consistently caused greater inhibitory effects on biomass as a constant decline in fresh biomass of plants was observed in all three species after four, eight and sixteen weeks of growth. All the species exhibited greater biomass production at the control except *P. typhoides*. *Z. mays* which produced considerably lower fresh and dry weight of plants after four weeks but showed sustainable biomass production after eight and sixteen weeks of growth. *S. biclor* did not maintain a steady increase in biomass with the passage of time as there was a consistent decline after 8 and 16 weeks of growth under prevailing soil conditions (Fig. 2).

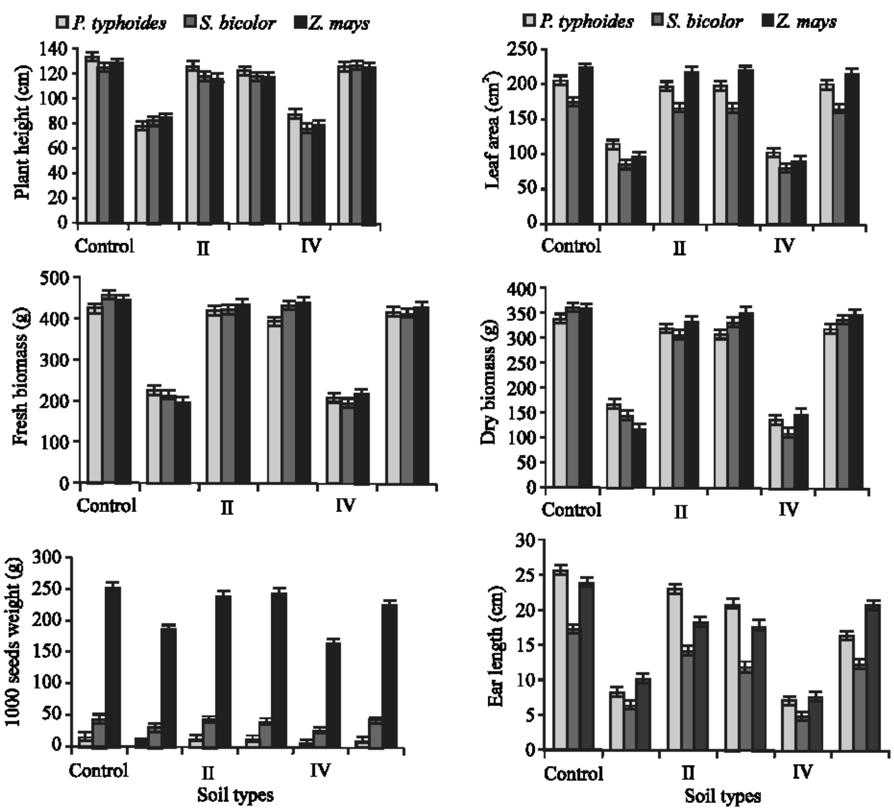

Fig. 3: Various growth and yield attributes (±SE) of three cereal crop species at maturity (16 weeks) under heterogeneous soil conditions (n = 3)

Yield and yield attribute

Ear length (cm): All the three species showed longer ears at the control soil but a reduction ($p<0.001$) in ear length occurred in response to different types of soil disturbances (Table 1). The maximum reduction of the ear was observed in soil samples I and IV. The response of all species was considerably variable. *P. typhoides* exhibited greater ear length under control and soil samples from sites II and III. *Z. mays* produced longer ears under soil samples I, IV and V. The lowest ear length was recorded for *S. bicolor* under different soil types (Fig. 3).

1000 seed weight (g): A significantly differential influence ($p<0.001$) of soil samples became evident as the yield component had been reduced in response to disturbed soil samples as compared to the control. The maximum reduction in seed weight was observed in soil samples from site I and IV in all three species. Statistical analysis of the data revealed a highly significant contrast ($p<0.001$) between different species with respect to their yield attribute (Table 1). The maximum seed weight was recorded for *Z. mays* at all soil types while *P. typhoides* appeared prone to soil heterogeneity and produced the lowest values for this attribute. Intermediate responses were recorded for *S. bicolor* (Fig. 3).

DISCUSSION

The present study has reported various germination, growth, yield and yield attributes of *Pennisetum typhoides*, *Sorghum bicolor* and *Zea mays* in relation to different soil samples collected from a variety of disturbed sites. The soils that were disturbed naturally or anthropologically had differentially influenced various growth attributes observed. However, the growth of the species was profoundly better when grown under garden compost.

The results clearly indicated that seed germination had decreased considerably in response in soil samples collected from different disturbed sites. Although, germination percentage was significantly greater in garden compost in all species but *P. typhoides* exhibited the greatest germination in soil samples II that was sampled from desert.

Water uptake by germinating seeds is crucial for the emergence of radicle and plumule. The results presented here suggested that the maximum water absorption had occurred in garden compost for all species. The enhanced water up take in garden compost may be due to its greater water holding capacity. Quick leaching of water in sandy soil is also well known therefore water absorption was significantly lower in sand. Thus, these results are supportive to the findings of Passioura (1996). The soils of other sites (oil spilled fields and tannery) are known to restrict osmotic movement of water as these soils contain appreciable amount of solutes. Thus, hindrance of water uptake by germinating seeds might occur because of low osmoticum of the medium as suggested by Naidoo (1985) Nevertheless, *P. typhoides* had shown quick water absorption as soon as it becomes available.

The data obtained for the radicle and plumule length demonstrated that the maximum emergence of embryonic axes was in sand for *Z. mays*. Since sand is a loose textured soil and pose less physical resistance for emerging radicles and plumules. Likewise, *S. bicolor* had longer radicles and plumules in samples taken from ice factory. Although, ice factory effluent are known to contain some amount of sodium and ammonium ions but did not appear to influence seed germination of this species. However, greater inhibition of embryonic axes in *S. bicolor* signifies embryonic growth sensitivity to disturbed soil by tannery effluents that can be attributed to the presence of heavy metal ions in tannery effluents that affect cell division and differentiation as reported by Omarov (2000). Moreover, the inadequate soil aeration due to the presences of oil in soil samples I and IV also resulted in a greater damage to germinating seeds and these results are comparable to Atuanya (1987).

As mere germination of a species in hostile environment does not guarantee its subsequent successful growth, therefore, studies of plant growth at various growth stages are necessary to assess the subsequent development of a crop (Huang and Redman, 1995). Furthermore, early vegetative growth can be used as a predictive stage for crop establishment in disturbed environment (Chen and Li, 2000) where certain early growth traits can be used as predictors in appraising the over all performance of cereal crops.

The substrate heterogeneity had a significant impact early growth attributes (plant height, fresh biomass, dry biomass, leaf number and leaf area) where soil samples of the sites I and IV had greatly retarded the growth of the species at their early establishment. By contrast, the growth of all three species after 4 weeks was profoundly greater when seedlings were allowed to establish under garden compost. Hence, early vegetative growth of plants appeared to be more prone to various environmental constraints and similar findings have been reported by Sharma *et al.* (1980). However, the greatest sensitivity of plants to a soil of an oil spilled field is not unexpected because Pezeshki *et al.* (2001) had described that oil is actually very complex compound, made up of hundreds of hydrocarbons, causes serious harm to juvenile plants.

The performance of the species for biomass production was profoundly better in the garden compost while an appreciable decline in fresh biomass was observed in soils sampled from of the sites I and IV. The decline in fresh biomass is an indicative of low carbon assimilation due to low water availability under prevailing soil situations (Zidan and Elewa, 1995).

Accordingly reduction in biomass can be ascribed to the peculiar soil types of sites I and IV that were compressed and less aerated because of oil spill. The compaction is accompanied by low water movement and nutrient availability. Therefore, an overall decrease in biomass is presumably due to restricted movement of water and nutrients. Independent study of Spory (2002) has also described the similar reasons for vulnerable seedling growth of some other crops.

All species produce significantly greater biomass under soil samples II and III. Although these soils also contains Na and NH_4 but the better performance of the species can be explained in the light of Huang and Redman, (1995); who reported that lower concentration of the essential nutrient promote growth rather than its inhibition. Thus differential ability of plants presumably allowed their early establishment on a varied soil conditions and is well reported for other cereal species (Spory, 2002).

It has been emphasized by number of workers that performance of the species may vary with the age of the plant where adult plants can cope better with different environmental constraints (Sharma *et al.*, 1980). Growth responses after 8 weeks were found consistent with early growth of the species under varied soil conditions. However, temporal changes have caused a shift in growth traits of *Z. mays.* Susceptible early vegetative growth of the species did not correspond with its later growth stages and consequently a degree of endurance varied with the stages of crop development in *Z. mays* that is comparable to Sharma *et al.* (1980).

The foliar traits were profoundly affected by soil samples (I and IV) collected from oil-spilled areas. Therefore, the poor development can be attributed to the excessive concentration of various elements that affect initiation of leaf primordia and its expansion as well as due to soil compaction that reduces aeration particularly in an oil-spilled field. Many other workers (Huh, 2002; Cramer and Quarrie, 2002) reported poorly developed plants in oil-polluted soils. Therefore, these results are in conformity to the above researchers.

The study indicated that the tolerance of the species varied with the time course changes in growth and development of the species. *Z. mays* showed susceptible early vegetative stage but later on, showed better growth and yield. Thus resistance of adult plants in relation to changing habitat situations can be ascertained for this species. Likewise, a consistent degree of tolerance for various growth traits was observed for *P. typhoides* at 4 and 8 weeks. However, the species could not show any tolerance for yield and yield attributes.

Based on these results it can be concluded that soil disturbance by different sources has a significant impact on plant growth. There was found an affirmative relationship between vegetative growth and yield of the plants. Early growth stages were found to be more prone to various constrains imposed by different disturbed soils while adult plants appeared to be less susceptible to these conditions. The soil of an oil-spilled field had imposed greater inhibitory effects on plant performance. Thus it can be suggested that oil-spilled field can cause substantial crop losses. Similarly, other industrial effluents had also affected the plant growth and can render soils less productive. Garden compost appeared to be an optimum medium for plant growth. Therefore, these species can be more productive if cultivated under soil conditions analogous to garden compost. *Z. mays* excelled for growth and yield attributes and consistently performed better in relation to various soil conditions. *P. typhoides* also showed an optimum growth in sand while the responses of *S. bicolor* were poor in terms of plant growth and yield. Thus this study affirmed that these cereal species had differential abilities to accommodate a wide array of disturbances of soil.

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