

Inter-Relationships between soil-plant transfer coefficient, Plant uptake factor and Translocation factor of heavy metals in roadside Grown wheat and Maize in Sudan Savanna Ecology of Nigeria.

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ABSTRACT

Phytoaccumulation of metals (Cd, Cr, Cu, Pb, Zn) in roadside grown wheat and maize varieties (Pavon-76, Siettecerras, Zea mays L. and Zea mays everta L.) and the toxicity and phytoremediation capability of the plants was investigated. Four sampling sites, roadside (SU 1, SU 3) and distant sites (SU 2 and SU 4) were selected by principle to represent the level of pollution near major traffic routes and were the reference sampling points. Whole plant metal levels of the four crops were determined using the multi-elemental technique- Energy Dispersive X-ray Fluorescent (EDXRF) and double beam AAS at A.B.U Zaria. Individual metal levels for each plant parts were also determined and used for computing the Plant uptake factor (PUF), soil-plant transfer coefficient (TC) and translocation factor (TF) for each metal. Pearson correlation analyses between the risk assessment factors of the metals were evaluated. Results revealed a positive significant ($P < 0.05$) relationship between PUF/TC and PUF/TF for Cr and Zn in Pavon-76 at SU 1, PUF/TC for Cr and Zn in the two species of Zea mays L. (SU 3 and SU 4) and Cu in Siettecerras (SU 2) indicates special ability or strong selective ability of each of the crops to accumulate certain metals. The inverse correlation between PUF/TC $\{-0.0797 = \text{Cu at SU 1}; -0.0317 = \text{Cd at SU 3}\}$, PUF/TF $\{-0.5926 = \text{Cd at SU 2}; -0.8058 = \text{Cr}, -0.6065 = \text{Cu}, -0.4492 = \text{Zn at SU 3}\}$ and TC/TF $\{-0.2145 = \text{Cd}; -0.2675 = \text{Cr}, -0.0124 = \text{Cu at SU 4}\}$, among the metals suggests a selective ability of each of these crops in accumulating these metals and that the source of Cd, Cr, Cu and Zn in the crops is mainly from the soil than from the atmosphere. The selected risk assessment factors have proven useful in attempting to estimate the degree of uptake of these metals in the crops.

Keywords : Phytoaccumulation, metals, Pavon-76, Siettecerras, *Zea mays* L, *Zea mays everta*

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I. INTRODUCTION

Heavy metals in high concentrations can cause severe phytotoxicity and may have significant influence on the evolution of tolerant plant populations. Therefore, it is possible to identify metal-tolerant plant species from natural vegetation in field sites that are contaminated with various heavy metals [1]. Hyperaccumulation of metals have been found in temperate as well as tropical regions throughout the plant kingdom, but is generally restricted to endemic plant species growing on mineralized soil and related rock types [2]

Heavy metals are chemical elements mostly with density greater than 5g/cm³ found in all kinds of soils, rocks and water in terrestrial and freshwater ecosystems. The very low general level of their content in soils and plants as well as the definite biological roles of most of them makes them microelements [3]. They occur in typical background concentrations in these ecosystems. However anthropogenic releases can result in higher concentrations of these metals relative to their normal background values. When these occur, heavy metals are considered serious pollutants because of toxicity, persistence and nondegradable conditions in the environment, thereby constituting threat to human beings and other forms of biological life. [4] - [8]

The soil-plant interface acts as a barrier that limits transmission of many heavy metals through the soil-crop-animal food chain, with the exception of Cd, Zn, Mo,

and Se. Heavy metal pollution of soil entails plant uptake causing accumulation in plant tissues and eventual phytotoxicity and change of plant community [9] - [11]. The mechanism of uptake of trace elements by plants is essentially by root uptake and by foliar absorption, including deposition of particulate matter on the plant leaves. Given the foregoing, it is imperative to continue to conduct research on heavy metals and their impacts on the environment and propose ways by which the negative impacts can be mitigated. One of such studies is reported in this paper.

A convenient way for quantifying the relative differences of bioavailability of metals to plants is the transfer quotient. So for human Health Risk Index (HRI), transfer quotient should be assessed [12]. The transfer quotient for Cd and Cu were higher than other for metals, such as Pb and Fe [13]. The higher transfer quotient of heavy metal indicates the stronger accumulation of the respective metal by that vegetable. Transfer quotient of 0.1 indicates that plant is excluding the element from its tissues [14], [15] also argued that the greater the transfer coefficient, especially for values than 0.50, the greater the chances that vegetables will be subject to metal contamination by anthropogenic activities and so the need for environmental monitoring of the area will be required [16]. Therefore, assessing the concentrations of pollutants in different components of the ecosystem has become an important task in preventing risk to natural life and public health.

However, heavy metal behaviour still differs individually and other soil physical properties, like texture, might play an important role in heavy metal behaviour in soils. Today it is commonly accepted that soil type plays an important role in heavy metal bioavailability and toxicity [17] [18]. However, many ecotoxicological studies have reported that heavy metals in plants are largely from the soil. The use of roadside grown cereal crops in a rural setting devoid of urbanization except the presence of a major Highway in this study is to view ecotoxicity beyond the soil with respect to atmospheric pollution. The significance of this study is to also emphasize the role of the risk assessment factors or techniques in predicting potential transfer of metals in food chain contamination and the level of toxic stress in the most widely consumed varieties of wheat and maize in northern Nigeria. Furthermore, to evaluate their roles as passive bioindicators and/or biological monitors due to their ability to assimilate metals from the surrounding environment, and as potential phyto-remediators of polluted agricultural lands. However, there is no empirical data on the interrelationship between the three selected risk assessment factors of selected metals on roadside grown wheat and maize in a Sudan ecological zone in Nigeria. This is because majority of risk assessment techniques focus on uptake of chemicals from mine tailings, sludge or biosolids by vegetables.

Therefore, the objectives of this present study was to investigate the existence of any relationships between the selected toxicity factors or risk assessment factors (PUF/TC, PUF/TF, TC/TF) for each metal (Cd, Cr, Cu, Pb, Zn) in the roadside grown cereal crops designating the

four sampling sites by correlation analysis; usage of risk assessment factors to evaluate possible health risks to humans through food chain transfer and; to understand the uptake pathway of these metals in the cereal crops.

II. MATERIALS AND METHODS

The selection of sampling sites and sampling units were by principle to represent the level of pollution in regions and towns with highest level of pollution, and also determined by possible pollutants at specific regions of interest [19]. This study being an ecotoxicological research, all sampling sites were selected by principle to represent the level of pollution near major traffic routes and were reference sampling points [19]. The bulk of the land space of Kano state is classified as the Sudan Savannah and a small portion of Sahel Savannah in the extreme north-eastern tip of the State. [20] The study area located in rural setting was chosen because it was devoid of any industrial, commercial and residential activities except the presence of the major highway - Kano-Zaria Highway, in order to assess trace metal levels in the crop plants due to atmospheric pollutants.

The research was conducted at Kadawa across the southern Sudan savannah zone of Kano State. The global positioning system (GPS) was used in recording the coordinates of the sampling units. Table 1 shows the decimated latitudes and longitudes readings of the sampling sites. Two sampling units SU 1 (Pavon-76 farm) at a distance of 50metres and SU 3 (yellow maize farm) at a distance of 100metres from the Kano-Zaria Highway respectively represented the experimental site, Doruwa Salau. Doruwa Salau has minimal residential and commercial activities and at close proximity to the highway at a distance of 345.79metres with extensive cultivation of rice, maize, millet, guinea corn, cowpea, garden egg, water melon and wheat along the roadside. The site had an average daily traffic density of 19,288, being the main exit from Kano State to various major towns of the country. At the Irrigation Research Station (IRS), the control site, two sampling unit SU 2 (Siettecerras) at a distance of 1934.61metres and SU 4 (popcorn) at a distance of 2184.61metres from the Kano-Zaria Highway were selected. The control site has been extensively used by private institutions, government researchers and both corporate and international research institutes and had an average daily traffic density of 3. Both sites are significant for dry season (irrigation) farming and have irrigation channels connected to the Hadejia - Jama'are River Basin Dam which empties into the Tiga dam that provides water for dry season irrigation of farmlands within and outside the irrigation research station, Kadawa.

A total of 288 plant samples and 208 corresponding soil samples were collected from four sampling units. Four crops namely *Triticum aestivum* - wheat (Pavon- 76 or Samwhit-6) and *Zea mays* - yellow maize (2:95 TZEE- Y), *Triticum aestivum* - wheat (Siettecerras or Samwhit-5) and *Zea mays everta* - popcorn were collected in a completely randomized block design setup. Four replicate samples each of leaves, stems and roots of the four crops were obtained at six selected growth stages namely 15 days

(germination or seedling), 30 days (tillering), 45 days (shooting and booting), 60 days (earring or heading), 75 days (flowering and grain formation) and 90 days (maturity). Plant samples from both maize and wheat were harvested fortnightly according to the growth stages rather than by calendar days because the growth rates of the cultivars were slightly dissimilar. The leaves, stems and roots each of the four crops were placed under running tapwater to washed off soil particles, separated and placed in large paper bags to air-dry at room temperature and later ground using a grinding mill model Foss Cyclotec™ 1093 based on Tecator™ technology. The ground plant samples were then well packaged in readiness for laboratory analyses. The soil samples were collected in triplicates using a soil auger at the maximum sampling depth of 25cm and taken to the laboratory where they were air-dried and grounded into smooth powder using a porcelain mortar and pestle. The trace metal contents of the four crops and the corresponding soil samples were determined. The concentrations of Cr, Cu and Zn were determined using the multi-elemental technique- Energy Dispersive X-ray Fluorescent (EDXRF) at Center for Energy Research (CERT), while the concentrations of Cd and Pb were determined using the double beam spectrophotometer at National Animal Production Research Institute (NAPRI), Ahmadu Bello University, Zaria.

III. DATA ANALYSIS AND GRAPHICAL PRESENTATION

The data for trace metal analyses was used to work out the risk assessment factors namely soil-plant transfer factor (TC), plant uptake factor (PUF) and translocation factor (TF). TC was calculated by dividing the concentration of a metal in the cereal crop (DW) by the total metal concentration in the soil [21]- [23], [1].

$$TC = \frac{\text{Content of heavy metal in plant (mg kg}^{-1}\text{)}}{\text{Content of heavy metal in soil (mg kg}^{-1}\text{)}}$$

$PUF = C_p/C_{so}$, where, C_p and C_{so} are metal concentrations in aerial parts of the plant ($\mu\text{g g}^{-1}$) and in soil ($\mu\text{g g}^{-1}$), respectively [24,1].

$TF = C_s/C_r$, where, C_s and C_r are metal concentrations ($\mu\text{g g}^{-1}$) in the shoot and root, respectively. In all cases, a greater than unity value indicates anthropogenic contamination, while a ratio close to unity or less than one indicates natural sources. Pearson correlation coefficient analysis was used to investigate the relationship among the toxicity factors.

IV. RESULTS AND DISCUSSION

The leaves, stems, roots of *Triticum aestivum* L. var. Pavon-76, Siettecerras, *Zea mays* L. var. yellow maize and *Zea mays everta* L. var. popcorn and soils metal levels were used to compute the plant uptake factor (PUF), translocation factor (TF) and soil-plant transfer coefficients (TC) as represented in the equations in Materials and

Methods. The computed TC, PUF and TF for both experimental and control sites are presented in Tables 2, 3, 4 and 5. Furthermore, the correlation coefficients among the pairs of the factors (TC, PUF and TF) to establish the existence of any relationship were determined and the outcomes presented in Table 6.

Coefficient analyses between PUF/TF, TC/TF and TC/PUF for Cd, Cr, Cu, Pb and Zn are shown in Table 6. There was positive significant relationship ($p < 0.05$) between the PUF/TF for Cr in Pavon-76 and Cu in Siettecerras. The PUF and TF signify the ability of plant to accumulate trace metals [25], [26]. Transfer factors can be used to estimate a plant's potential for phytoremediation purpose. According to [27] - [30], crops absorbed and transport metals from the soil, and stored them in the aerial plant parts. However, in contrast to this research, the existence of a relationship between PUF and TF for Cr and Cu (Pavon-76 farm closest (345.79m) to the Highway (SU 1) and Siettecerras farm at distance of 1934.61m from the Highway (SU 2) indicates special ability of the crop to absorb and transport Cr and Cu from the polluted atmosphere as well as storing them in the aerial plant parts resulting to higher concentration of metals in the leaves.

Also there was significant positive relationship between PUF/TC for Zn in Pavon-76, for Cr in *Zea mays* L. and Zn in (yellow maize) and *Zea mays everta* L.. The significant relationship between the TC/PUF for Zn and Cr in *T. aestivum* var. Pavon -76 farm closest (345.79m) to the Highway (SU1), *Zea mays* L.- yellow maize farm at distance of 345.79m from the Highway (SU 3) and *Zea mays everta* L. - popcorn farm farthest from the Highway at a distance of 2184.61m (SU 4) suggests that the levels of Cr and Zn in the crops came from both the atmosphere and the soil as earlier mentioned.

The non - existence of a significant relationship between the TF/TC shows that a larger percentage of the stem trace metal levels in the two cultivars each of *Triticum aestivum* and *Zea mays* L. could be of atmospheric origin. There were no values for correlations between TC/PUF and PUF/TF in Siettecerras, yellow maize and popcorn for Pb. Soil Pb was not detected during the trace metal analysis, which was the reason for no PUF values.

There was inverse correlation between TC/TF, PUF/TF and TC/PUF for certain metals at the four sampling sites reflecting that the concentration of such metals in the cereal crops occurs independently of each other. For instance, in the case of TC/TF the analysis shows that the metal levels in the plant transferred from the soil is independent of the metals translocated from the roots to the soil. Similarly, the metal levels in the aerial plants (leaf and stem) was independent of the metal levels in the soil-root phase with respect to routes of contamination (PUF/TF and PUF//TC).

Correlation between TC/TF was negative for Cu and Pb at SU 1; Cd at SU 2 and for Cd, Cr, Cu and significant difference for Pb at SU 2. The negative correlation remarks that the proximity of SU 1 at a distance of 345.79m to the Kano-Zaria Highway with its high traffic

density is independent of the high levels of Pb and Cu particulates in the soil. Copper is used as components of vehicle lubricating oils. It is also used in the manufacture of some components of vehicle engines [31]. Pb is added to fuel as an anti-knocking component for smooth running of the car engine. Similarly, the inverse relationship for Cd at SU 2 reveals a far-distance transport or dispersal of Cd at SU 2 at a distance of 1934.61m from the Highway resulting to lower Cd levels in the soil.

A higher inverse correlation and significant value for Cu at SU 3 and high value for Cr shows the influence of traffic density and distance in the TC/TF values, since Cu and Cr are components of vehicular parts. The closer the sampling site to the highway- a direct source of pollution, the higher the deposition, absorption and assimilation of metals from the aerial plant parts to the soil resulting to subsequent translocation from roots to stems. In contrast, a lower value for Cd and Pb levels in *Zea mays* L. was influenced by meteorological factors like wind [32], mobile nature of the particulates [33] resulting to wider dispersion. The dominant wind direction and speed is also due to the presence of the Tiga dam around the site.

Cd and Pb had a low inverse correlation for TC/TF while Cr and Cu had a lower inverse correlation all at SU 4, reflects the influence of distance, for instance the farther the sampling site from the Highway, the lower the value and vice-versa. *Zea mays everta* L. is the farthest sampling site from the Highway at a distance of 2184.61m.

The negative correlation between PUF/TF was observed at SU 2 for Cd (-0.5926) shows that Cd levels in Pavon-76 is derived from the aerial plant parts and translocated from the soil through the root to the stem. However, the influence of distance is non-evident in this case. This could be related to the species' (Sietteceros) ability to accumulate Cd. The uptake of contaminants by plants is a complex biological process and there is no accurate theoretical robustic method for predicting the concentration of contaminants in plant materials [34]. However, empirical formulas have been derived by numerous sources to simulate contaminant uptake by plants [34].

The physical and chemical parameters of the soils obtained from SU 1, SU 2, SU 3 and SU 4 sampling units in the study area are shown in Table 13. Soil factors like pH, particle size distribution, textural class, organic matter, CEC, cultivars, climatic factors and water used for irrigation in the study area influenced the proportion of soil metals [35], [36]. The mobility and availability of heavy metals in soil are generally low, especially when soil is high in pH, clay and organic matter [37], [38] as well as the growth stages [39], [40], [35]. pH values in this study ranged from 4.66 - 6.41 indicating slightly acidic soils (Table 2). The optimum pH range for most plants is between 5.5 and 7.0; however, many plants have adapted to thrive at pH values outside their range. Metal mobility has also been shown to increase with decreasing soil pH. The pH and textural class of the soils probably increased the levels of Cr, Cu and Zn in these cultivars. Texture plays an

important role in heavy metal behaviours like heavy metal mobility, bioavailability and toxicity in the soils and plants [17], [18]. In this study, the textural class with moderate pore spaces contributed to retaining the dissolved forms of the metals in the soils. However, the slightly acidic pH values obtained in the present study caused the increased immobility of metals in the soils, thus explaining the positive significant relationship of Cr and Zn in Pavon-76 for sandy clay loam, Cu in Sietteceros for sandy loam soils, Cr in *Zea mays* L., and Zn in *Zea mays* L. for sandy loam and *Zea mays everta* L. in sandy clay loam soils among the risk assessment factors. Furthermore, the organic matter content (Table 7) could have bounded the metals in non-leachable forms thereby reducing their mobility [41], [35]. The study area which is devoid of commercial, industrial and residential activities except for the presence of a major highway suggests that, it might have attained or reached a state of equilibrium where no further change takes place.

The total amount of heavy metals is usually not an accurate indication of phytotoxicity. The metals in water soluble and exchangeable fractions would be readily available to higher plant roots and thus are a better indicator of immediate phytotoxicity [42].

V. CONCLUSION

In this study, the positive significant ($P < 0.05$) relationship between PUF/TC and PUF/TF for Cr and Zn in Pavon-76 at SU 1, PUF/TC for Cr and Zn in the two species of *Zea mays* L. (SU 3 and SU 4) and Cu in Sietteceros (SU 2) indicates special ability or strong selective ability of each of the crops to accumulate certain metals. The inverse correlation among the risk factors (PUF/TF, PUF/TC and TC/TF) for Cd, Cr, Cu and Zn reflects their origin from the soil than from the atmosphere and selective ability of all the four crops in accumulating these metals from the soil as well as from the atmosphere. The Pavon-76, sietteceros and popcorn have phytoextractor potentials for bioremediation approach to reclaim lands polluted with metals. However, non-edible cultivars of these crops should be developed to study their hyper-accumulation and phytoextraction potentials for certain metals. The risk assessment methods could also be used as a diagnostic tool in monitoring traffic density pollution damage to agricultural crops.

Table 1: GPS readings of the four Sampling Units

Sampling Units	GPS readings
CONTROL SITE SU 2	A = N11°38.68'; E008°38.167'; Elevation = 1615ft
	B = N11°38.626'; E008°25.815'; Elevation = 1620ft
	C = N11°38.698'; E008°25.841'; Elevation = 1608ft
	D = N11°38.646'; E008°25.866'; Elevation = 1614ft
SU 4	A = N11°38.601'; E008°25.916'; Elevation = 1615ft
	B = N11°38.547'; E008°25.937'; Elevation = 1608ft
	C = N11°38.608'; E008°25.932'; Elevation = 1606ft
	D = N11°38.554'; E008°25.954'; Elevation = 1609ft
EXPERIMENTAL SITE SU 1 and SU 3	A = N11°39.776'; E008°25.191'; Elevation = 1627ft
	B = N11°39.742'; E008°25.207'; Elevation = 1635ft
	C = N11°39.759'; E008°25.240'; Elevation = 1616ft
	D = N11°39.790'; E008°25.230'; Elevation = 1626ft

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Table 2: Transfer Coefficient (TC) of the Pavon-76 and Yellow Maize at the Six growth stages at Doruwa Salau closest to the Kano-Zaria road (Experimental Site)

Growth stages, Species, Sites	Trace Metal (mg/kg)				
	Cd	Cr	Cu	Pb	Zn
A1	0.6729	0.0407	0.1495	3.2553	2.0011
A3	0.2999	0.0200	0.0658	1.6330	0.5504
B1	0.4265	0.0305	0.1632	6.3222	0.1372
B3	0.2086	0.0061	0.0815	3.6414	0.4586
C1	0.3940	0.0330	0.1946	1.0133	0.8045
C3	0.4172	0.0297	0.2038	0.5216	1.1315
D1	0.3225	0.0294	0.1634	2.6799	0.1395
D3	0.4062	0.0216	0.0541	1.3347	0.0741
E1	0.4860	0.0193	0.1796	2.0449	0.6421
E3	0.6960	0.0328	0.3002	2.5523	0.8053
F1	0.7618	0.0272	0.1526	1.2765	0.1138
F3	0.8267	0.0451	0.2210	3.9682	0.1088

KEY

A = 15 days (germination stage)
 B = 30 days (tillering stage)
 C = 45 days (shooting stage)
 D = 60 days (heading stage)
 E = 75 days (flowering stage)
 F = 90 days (ripening stage)

SOURCE: PhD THESIS 2015

1 = Pavon-76 at Doruwa Salau,
 3 = Yellow Maize at Doruwa Salau,

Table 3: Transfer Coefficient (TC) of Siettecerras and Popcorn at the Six growth stages at the Irrigation Research Station (IRS) (Control site)

Growth stages, Species, Sites	Trace Metal (mg/kg)				
	Cd	Cr	Cu	Pb	Zn
A2	0.1382	0.0137	0.1265	1.5383	0.5449
A4	0.8062	0.0370	0.0588	6.3751	3.3876
B2	0.5683	0.0259	0.1359	3.9784	0.0603
B4	1.1942	0.0607	0.3545	4.8655	0.2666
C2	0.4005	0.0223	0.1688	2.2816	0.4931
C4	1.0901	0.0421	0.2092	2.7253	1.6746
D2	1.1137	0.0607	0.3051	3.7462	0.4043
D4	0.6440	0.0348	0.3001	1.6443	0.2240
E2	0.8394	0.0302	0.2338	2.0983	0.7811
E4	0.3828	0.0299	0.0777	0.5615	1.3516
F2	0.3110	0.0335	0.1389	2.1568	0.1080
F4	0.4678	0.0536	0.1321	2.4951	0.1634

KEY

A = 15 days (germination stage)
 B = 30 days (tillering stage)
 C = 45 days (shooting stage)
 D = 60 days (heading stage)
 E = 75 days (flowering stage)
 F = 90 days (ripening stage)

SOURCE: PhD THESIS 2015

2 = Siettecerras at the IRS
 4 = Popcorn at the IRS

Table 4: The Plant Uptake factor (PUF) and translocation factor (TF) of the Cereal Crops with respect to the six Growth Stages at Doruwa Salau (Experimental Site - S1).

Growth Stages, Sites, Crops	Cd		Cr		Cu		Pb		Zn	
	PUF	TF	PUF	TF	PUF	TF	PUF	TF	PUF	TF
A1	2.357	1.8	0.213	6.535	6.098	8.796	<u>400</u>	0.625	2.616	0.990
A3	2.46	2	0.127	0.944	0.525	1.214	5.25	0.285	0.716	1.377
B1	2.545	2	0.091	0.583	4.741	1.087	45	1.166	0.127	0.370
B3	0.666	0.4	0.047	6	2.518	1.360	<u>1300</u>	0.774	0.401	0.847
C1	1.384	1	0.134	1.053	2.232	0.838	3.5	0.363	1.196	1.642
C3	1.375	0.8	0.119	1.035	7.403	0.849	3	0.75	1.320	0.715
D1	1.538	1.333	0.138	0.933	5.935	0.864	23	3.5	0.180	1.248
D3	5.5	2	0.148	0.506	1.887	1.591	5.375	10.333	0.091	1.121
E1	3.636	1.667	0.139	1.005	6.725	1.204	6.125	0.75	1.010	1.183
E3	1.714	0.416	0.142	1.049	49.6	0.779	9	1.5	1.685	2.537
F1	3.058	1.272	0.167	0.823	0.893	1.282	5.75	2	0.176	1.116
F3	1.8	1.142	0.219	0.606	2.276	0.987	<u>720</u>	1.166	0.119	0.669

SOURCE: PhD THESIS 2015

Underlined numbers = soil Pb was not detected, PUF not computed

Bolded numbers = Highest and lowest value

KEY

A = 15 days (germination stage) E = 75 days (flowering stage) 1 = Pavon-76 at Doruwa Salau,

B = 30 days (tillering stage) F = 90 days (ripening stage) 3 = Yellow Maize at Doruwa Salau,

C = 45 days (shooting stage) D = 60 days (heading stage)

Table 5: The Plant Uptake factor (PUF) and translocation factor (TF) of the Cereal Crops with respect to the six Growth Stages at the Irrigation Research Station IRS (Control Site - S2)

Growth Stages, Sites, Crops	Cd		Cr		Cu		Pb		Zn	
	PUF	TF	PUF	TF	PUF	TF	PUF	TF	PUF	TF
A2	1.307	1.666	0.126	0.955	1.888	0.750	<u>880</u>	1.45	0.524	0.715
A4	3.1	1.333	0.134	2.476	2.585	0.519	<u>900</u>	0.95	4.748	2.600
B2	1.692	2.428	0.123	0.811	0.643	0.617	<u>1780</u>	5.333	0.044	0.067
B4	3.230	1.5	0.160	1.246	9.091	0.305	<u>620</u>	0.625	0.343	1.042
C2	2	0.571	0.109	1.058	3.982	0.685	25.5	7.666	0.690	3.272
C4	2.285	0.33	0.121	0.940	3.958	1.567	<u>560</u>	1.714	2.548	0.914
D2	2.285	0.833	0.130	0.894	1.555	0.750	<u>660</u>	5	1.428	2.636
D4	2	0.75	0.193	0.858	0.826	0.336	<u>400</u>	1.5	0.227	0.446
E2	3.636	1	0.136	0.943	7.606	2.557	16	2	0.849	0.587
E4	1.375	2	0.136	1.020	0.336	0.115	<u>220</u>	<u>60</u>	1.959	3.725
F2	1.263	2.666	0.153	1.108	3.189	0.798	<u>880</u>	2.5	0.148	0.380
F4	2	2.5	0.322	1.051	1.505	1.350	<u>720</u>	1.666	0.187	1.789

SOURCE: PhD THESIS 2015

Underlined numbers = soil Pb was not detected, PUF not computed

Bolded numbers = Highest and lowest value

KEY

A = 15 days (germination stage)

E = 75 days (flowering stage)

2 = Siettercerros at the IRS,

B = 30 days (tillering stage)

F = 90 days (ripening stage)

4 = Popcorn at the IRS

C = 45 days (shooting stage)

D = 60 days (heading stage)

Table 6: Correlation Coefficient Analyses Between PUF/TF, TC/TF and TC/PUF

Risk Assessment Techniques	Sampling Units	Heavy Metals				
		Cd	Cr	Cu	Pb	Zn
PUF/TF	SU 1	0.4737	0.8210*	0.3377	0.2345	0.2114
TC/TF	SU 1	0.1090	0.7204	-0.5322	-5.3895	0.1473
TC/PUF	SU 1	0.5356	0.4695	-0.0797	0.9712 *	0.9958*
PUF/TF	SU 2	-0.5926	0.2925	0.8909*	ND	0.6699
TC/TF	SU 2	-0.4537	0.1725	0.3505	0.5206	0.2849
TC/PUF	SU 2	0.6858	0.2912	0.2336	ND	0.6026
PUF/TF	SU 3	0.1230	-0.8058	-0.6065	ND	-0.4492
TC/TF	SU 3	-0.3594	-0.7316	-0.9082*	-0.2960	0.2560
TC/PUF	SU 3	-0.0317	0.9140*	0.7534	ND	0.8915*
PUF/TF	SU 4	-0.2145	-0.2675	-0.0124	ND	0.4699
TC/TF	SU 4	-0.6020	-0.0642	-0.0985	-0.5950	0.4731
TC/PUF	SU 4	0.7817	0.4285	0.6257	ND	0.9986*

*0.05

PUF = Plant Uptake Factor

TF = Translocation Factor

TC = Soil-plant transfer coefficient

SU 1 = Wheat (Pavon-76) on DoruwaSalau at close proximity to the Kano-Zaria road

SU 2 = Wheat (Siettecerras) at the Control Site (Irrigation Research Station-IRS), Kadawa

SU 3 = Yellow Maize on DoruwaSalau at close proximity to the Kano -Zaria road

SU 4 = Popcorn at the Control Site (Irrigation Research Station-IRS), Kadawa

Table 7: Physicochemical Parameters of Soils from Doruwa Salau at close proximity to the Kano- Zaria road and from the Irrigation Research Station before sowing

pH Site	% Sand	% Silt	% Clay	Textural Class	H ₂ O 1:1	HCL 1:1	% OC	% OM	CEC
SU 1	62.9	15.2	21.9	Sandy Clay loam	6.41	5.77	0.88	1.50	7.25
SU 2	75.5	12.4	12.1	Sandy loam	5.48	4.66	0.65	1.12	5.9
SU 3	71.6	13.5	14.9	Sandy loam	5.75	4.86	1.82	1.05	6.3
SU 4	60.5	17.2	22.3	Sandy clay loam	6.21	5.40	0.78	1.36	8.01

KEY

SU 1 = Wheat (Pavon-76) on DoruwaSalau at close proximity to the Kano-Zaria road

SU 2 = Wheat (Siettecerras) at the Control Site (Irrigation Research Station-IRS), Kadawa

SU 3 = Yellow Maize on DoruwaSalau at close proximity to the Kano -Zaria road

SU 4 = Popcorn at the Control Site (Irrigation Research Station-IRS), Kadawa

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