FFECT OF USE OF DOMESTIC WASTEWATER FOR IRRIGATION ON PLANT UTRIENTS: CASE STUDY OF SPINACH (*Spinacia oleracea*)

BY

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MATRIC No. 2004/18401EA

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

FEBRUARY, 2010

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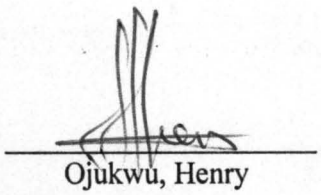
BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN AGRICULTURAL & BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

FEBRUARY, 2010

DECLARATION

I hereby declare that this project work is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished work were duly referenced in the text.



Ojukwu, Henry

10/2/2020

Date

CERTIFICATION

This is to certify that "Effect of Use of Domestic Wastewater for Irrigation on Plant Nutrients: Case Study of Spinach (*Spinacia oleracea*)" by Ojukwu, Henry, meets the regulations governing the award of the degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

Mrs. H. I. Mustapha Supervisor	16.02.10 Date
Engr. Dr. A. A. Balami Head of Department	16.02.10 Date
Engr. Prof. G.O. Chukwuma External Examiner	10-02-10 Date

DEDICATION

This project work is dedicated to the Glory of Almighty God, who made it possible for me to conduct the project work and achieve my goal without hindrance.

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I give an unreserved praise and glory to God almighty, beside which there is no other god, the most merciful, the creator who in his infinite mercy inspired, guided and directed me throughout the period of my studies and carried me through this work.

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ABSTRACT

In assessing the effect of the use of wastewater for irrigation on spinach (*Spinacia oleracea*), series of analysis on the physiochemical and biological properties before and after planting was carried out on the wastewater, and the soil. A plant tissue analysis was also carried out making reference to two different plots (one irrigated with potable water and the other with wastewater). The average findings in the wastewater are DO (3.55ppm), EC (619ds/cm), TDS (414.73mg/l), SS (21mg/l), hardness (106mg/l), pH (7.56), ammonia (41.21mg/l), nitrate (182.45mg/l), nitrite (0.805mg/l), hydroxide (0mg/l), Cl (23.98mg/l), F (0.06mg/l), Mg (1.1mg/l), Ca (40.48mg/l), Na (31.5mg/l), K (15.41mg/l), COD (170mg/l) and BOD_5 (16mg/l). The soil analysis results before irrigation, after irrigation with wastewater and after irrigation with potable respectively are pH (1.68, 5.40, 5.68), bulk density (1.40, 1.55, 1.40g/kg), CEC (12.53, 8.60, 12.54Cmolkg^{-1}), EA (0.61, 0.83, 0.61Cmolkg^{-1}), OM (4.81, 3.38, 4.81%), N (0.01, 0.089, 0.098%), P (4.10, 3.80, 4.20ppm), K (0.33, 0.44, 0.34Cmolkg^{-1}). The plant tissue analysis per 100g of edible potion shows moisture (89.07, 90.80g), protein (2.70, 2.79g), fat/oil (0.36, 0.31g), ash (2.41, 2.50g), fibre (1.78, 2.00g), carbohydrate (5.46, 3.60g), Ca (95.00, 97.00mg), Fe (1.93, 1.21mg), Mg (75.00, 76.10mg), P (45.10, 47.40mg), K (530.00, 543.00mg) and vitamin C (24.10, 25.40mg). From the soil analysis results above, the wastewater irrigated soil readily gives up more mineral nutrient to the plant which consequently causes toxicity in the plant and in comparison with the USDA standard nutritional value for spinach (*Spinacia oleracea*), this toxicity effect causes the nutritional value of the wastewater irrigated spinach to have a greater deviation from the USDA standard unlike the potable water irrigated spinach whish has a lesser deviation. The most effective method to prevent occurrence of a toxicity problem is to choose irrigation water that has no potential to develop a toxicity problem, leaching to correct the problem after it has been recognized from plant symptoms, use tolerant crops and good cultural practices.

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NOTATIONS/ABBREVIATIONS

g	-	Gram
mg	-	Milligram
L	-	Litre
mg/L	-	milligram per Litre
me/L	-	milliequivalent per Litre
ds/m	-	DeciSiemen per metre
NTU	-	Nephelometric Turbidity Units
ppm	-	Part Per Million
N	-	Nitrogen
P	-	Phosphorus
Ca	-	Calcium
Mg	-	Magnesium
Cu	-	Copper
Fe	-	Iron
K	-	Potassium
Na	-	Sodium
Cl	-	Chlorine
SO_4^{2-}	-	Sulphate
CO_3^{2-}	-	Carbonate
HCO_3^-	-	Bicarbonate
BOD	-	Biological Oxygen Demand

COD	-	Chemical Oxygen Demand
CEC	-	Cation Exchange Capacity
DO	-	Dissolved Oxygen
EA	-	Exchangeable Acid
EC	-	Electrical Conductivity
FAO	-	Food and Agricultural Organization
ICARDA	-	International Centre for Agricultural Research in the Dry Areas
IWMI	-	International Water Management Institute
NIMET	-	Nigeria Meteorological Station
OC	-	Organic Carbon
OM	-	Organic Matter
OMAFRA	-	Ontario Ministry of Agriculture, Food and Rural Affairs
PWGS	-	Potable Water Grown Spinach
PWIS	-	Potable Water Irrigated Soil
SBI	-	Soil Before Irrigation
SS	-	Suspended Solid
TDS	-	Total Dissolved Solid
USDA	-	United State Department of Agriculture
WHO	-	World Health Organization
WWGS	-	Wastewater Grown Spinach
WWIS	-	Wastewater Irrigated Soil

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Irrigation is an important aspect of Water Resource Engineering (Soil and Water Conservation / Management). It is the artificial application of water to agricultural land in areas with insufficient rainfall during a certain period of the year or all year round in order to ensure a good crop development (Random House Dictionary, 2009).

The ***questions*** that are often asked before and after irrigation are carried out are; how often should the irrigating be done [irrigation frequency], How long should it be carried out [irrigation period], what quantity of water is required [crop water requirement], Ways and means to convey and apply the water. But one question that is neglected and yet very important consideration that influences (positively or negatively) the growth/nutrient of agricultural plants is ***what type of water is being used/applied.*** Whenever potable water is scarce, wastewater (water of marginal quality) will have to be considered for use in agriculture. Although there is no universal definition of wastewater, but for all practical purposes it can be ***defined*** as any water that has been adversely effected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentration (Wikipedia, September 2007).

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic

organic chemicals from the process industries and homes. Also among the inorganic substances present includes a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, etc. Pathogenic viruses, bacteria, protozoa and helminthes may be present in raw municipal wastewater at various levels, (Wikipedia, September 2007).

The above enumerated compositions of a municipal/domestic wastewater may be hazardous or friendly meaning that it might have positive or negative effect on the growth/nutrient of agricultural plants. This may sometimes depend also on the type and nature of the crop being cultivated (Feenstra *et al.*, 2000)

1.1.1 Positive Effects of Wastewater Irrigation

Many wastewater irrigators are not land-owned farmers, but landless people that rent small plots to produce income-generating crops such as vegetables that thrive when watered with nutrient-rich sewage. Across Asia, Africa and Latin America these wastewater micro-economies support countless poor people in various ways namely; conserves water, low-cost method for sanitary disposal of municipal wastewater, reduces pollution of rivers, canals and other surface water resources, conserves nutrients and reducing the need for artificial fertilizer, increases crop yields (for some plants to which it is favorable), (Feenstra *et al.*, 2000).

1.1.2 Potential Negative Effects of Wastewater Irrigation

Concern for human health and the environment are the most important constraints in the reuse of wastewater. The negative effects on the use of wastewater for irrigation purpose sometimes outweigh its advantages (positive effects). It posses health risks for irrigators and communities with prolonged contact with untreated wastewater and consumers of vegetables

irrigated with wastewater, contamination of groundwater (nitrates), build-up of chemical pollutants in the soil (heavy metals), creation of habitats for disease vectors, The accelerated growth of algae and other water plants in canals in reservoirs is one of the potential negative impacts of wastewater irrigation. These negative trends of problems caused by the reuse of wastewater for irrigation can be minimized or controlled by strategic means (management practices) such as planting of crops with high/marginal tolerance to wastewater effect, involvement in some preliminary water treatment process before use. Also in order to safeguard the of the farmer (irrigator), it is the duty of the extension workers/agent to orientate the rural farmer on the hazard posed on their health when they are continuously exposed to wastewater without safety wears such safety boot, safety gloves etc. (Feenstra *et al.*, 2000)

1.2 Statement of the Problem

Sewage, industrial and agricultural wastewaters are increasingly being used for irrigation projects. This is normally re-sorted to in areas where there is no availability of other sources of water. Wastewater contains impurities; careful consideration must be given to the possible long-term effects on soils (salinity and sodicity) and plants (toxicity; nutrient and trace elements depletion) that occur normally. Toxicity normally results when certain ions are taken up by plants with the soil water and accumulate in the leaves during water transpiration to such an extent that the plant is damaged. The degree of damage depends upon time, concentration of toxic material, crop sensitivity and crop water use and, if damage is severe enough, crop yield and nutrient is reduced. Common toxic ions in irrigation water are chloride, sodium, and boron, all of which will be contained in sewage. Manageable if associated problems with these impurities are understood and allowances made for them.

1.3 Objectives of the Study

The objectives of this study/project include;

1. To analyze the toxicity of the municipal wastewater used for the irrigation.
2. To also analyze toxic level of the soil before and after irrigation as it affects the nutrient level of the plant.
3. To carefully monitor and analyze the impact of the wastewater on the soil and its relative effect on spinach growth and spinach nutritive value/level.

1.4 Research Questions

The research questions include;

i. What are the properties of the wastewater?

ii. What are the properties of the non irrigated soil?

iii. What are the properties of the wastewater irrigated soil?

iv. What are the impacts of the wastewater properties on the soil relative to the plant?

v. Can irrigation with wastewater increase or decrease the nutrient value of a spinach?

1.6 Justification of the Study

Concern for human health and the environment are the most important constraints in the reuse of wastewater. While the risks do need to be carefully considered, the importance of this practice for the livelihoods of countless smallholders(peasant farmers) must also be taken into account. Due to the ignorance and low literacy level of rural farmers, they continuously,

for a long term period irrigate with wastewater not knowing its positive and negative impacts on the soil, on the level of their yield and on the nutrient level of their yield.

This study would aid the agricultural extension workers/agents to reach the rural farmers letting them know both the positive and negative impacts of wastewater irrigation. Also letting them know the kind of soil and plant the wastewater irrigation would best favor both in a long term and short term periods.

1.7 Scope of the Study

This study would involve series of analysis to be carried out on the wastewater, the soil, and on spinach plant. Making reference to two different plots (one irrigated with potable water and the other with wastewater).

Soil-Plant analysis, this will aid in the determination of the nutrient status of spinach and the soil in which it is grown. It will also be used to detect or confirm nutrient deficiency or toxicity on plants. Plant analysis is useful for diagnosing many suspected nutrient disorders, determining the efficiency of wastewater irrigation and the impact on soil property/characteristics. Monitoring of time and rate of germination, Monitoring of the Physical appearances at early, growing and matured stages, Monitoring the growing/maturity period relative to the standard growing period of the plant, knowing the plant population at matured stage are not exceptions.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

Sewage, often untreated, is used to irrigate 10 percent of the world's crops, according to the first ever global survey of wastewater irrigation. This is a largely hidden practice and is outlawed in many countries. However, many farmers, especially those in urban areas, use sewage because it is free and abundant, even during droughts, and, being full of nitrates and phosphates, acts as an effective fertilizer. In parts of Mexico, Jordan, Israel and Tunisia, sewage is treated to remove pathogens to make it safe for irrigation. But in India, China and Pakistan, treatment is rare, exposing crops to disease-causing pathogens and toxic industrial waste. Consumers would rather not eat food that has been grown with sewage, but they are often unaware how it has been produced (Scott *et al.,* 2004).

Kiziloglu *et al.* (2006) reported that the use of wastewater for irrigation is increasingly being considered as a technical solution to minimize soil degradation and to restore nutrient content of the soils. The aim of this study is to increase fertility and minimize degradation of the soils irrigated with wastewater. A field experiment was conducted to investigate the effects of the controlled plot and that irrigated with wastewater. Wastewater irrigation significantly affected soil chemical properties especially at 0 – 30cm soil depth and plant nutrient contents after one year. Application of wastewater increased soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant – available P, and micro – elements and decreases soil pH. Wastewater increased also yield and N, P, K, Fe, Mn, Zn, Cu, B and Mo content of cabbage plants. Undesirable side effects were not observed in plant heavy – metals content, due to salinity and toxic concentration of metals from the application of wastewater to the soil.

Sites irrigated with wastewater for 10, 5, and 2 years and site not irrigated were sampled for soil and plant chemical analysis to evaluate its long term effect. Long term wastewater irrigation increased salts, organic matter and plant nutrients in the soil. Soil pH was not consistently affected. Soil Cu was not affected by wastewater application while Zn, Fe and Mn were not consistently affected. Wastewater irrigation had no significant effect on soil heavy metals (Pb and Cd) regardless of duration of wastewater irrigation. The barley biomass increased with added wastewater and nutrients provided with the wastewater. However, longer period of wastewater application (10 years) resulted in lower biomass production but remained higher than that of the control plants. Plant essential nutrients (Total-N, NO_3, P, and K) were higher in plants grown in soils irrigated with wastewater. Plant Cu, Zn, Fe, Mn increased with 2 years of wastewater irrigation, then reduced with longer period. Plant Pb and Cd increased with wastewater irrigation and their levels were higher the longer the period of wastewater irrigation. Based on these results, it can be concluded that proper management of wastewater irrigation and periodic monitoring of soil and plant quality parameters are required to ensure successful, safe, long-term wastewater irrigation (Rusan *et al.*, 2007).

2.1 Water Sources and Wastewater

The distribution of vegetation over the surface of the earth is controlled more by the availability of water than by any other single factor. It is not enough that there is water available for the plants. The quality of irrigation water must be determined since all natural waters contain dissolved salts, which when present in large quantities can be detrimental and harmful to agricultural crops.

Rainwater and groundwater sourced from wells, dams and rivers contain varied amount and types of salts. A given supply of water, particularly surface water, is continually

changing in composition and water composition can also vary greatly from one source to another. It is for this reason that water analysis is necessary in order to measure the salinity or mineral salt content of the water and this in turn is used to determine its suitability for irrigation.

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources (Calf and Eddy, 1991)

Sewage is correctly the subset of wastewater that is contaminated with feces or urine, but is often used to mean any waste water. "Sewage" includes domestic, municipal, or industrial liquid waste products disposed of, usually via a pipe or sewer or similar structure, sometimes in a cesspool emptier. The physical infrastructure, including pipes, pumps, screens, channels etc. used to convey sewage from its origin to the point of eventual treatment or disposal is termed sewerage (Calf and Eddy, 1991)

2.1.1 Wastewater Constituents

The composition of wastewater varies widely. This is a partial list of what it may contain: Water (> 95%), Pathogens such as bacteria, viruses, prions and parasitic worms. Non-pathogenic bacteria (> 100,000 / ml for sewage), Organic particles such as faeces, hairs, food, vomit, paper fibers, plant material, humus, etc. Soluble organic material such as urea, fruit sugars, soluble proteins, drugs, pharmaceuticals, etc. Inorganic particles such as sand, grit, metal particles, ceramics, etc. Soluble inorganic material such as ammonia, road-salt, sea-salt, cyanide, hydrogen sulfide, thiocyanates, thiosulfates, etc. Animals such as protozoa,

insects, arthropods, small fish, etc. Macro-solids such as sanitary napkins, nappies/diapers, condoms, needles, children's toys, dead pets, body parts, etc. Gases such as hydrogen sulfide, carbon dioxide, methane, etc. Emulsions such as paints, adhesives, mayonnaise, hair colorants, emulsified oils, etc. Toxins such as pesticides, poisons, herbicides, etc. (Calf and Eddy, 1991)

Table 2.1 shows the levels of the major constituents of strong, medium and weak domestic wastewaters. In arid and semi-arid lands, water use is fairly low and sewage tends to be strong as indicated in Table 2.1 for Niamey, Niger republic, where water consumption is 90L/day per person.

Table 2.1: Major Constituents of Typical Domestic Wastewater

CONSTITUENT	CONCENTRATION		
	Strong	**Medium**	**Weak**
Total solid	1200	700	350
Dissolved solid	850	500	250
Suspended solid	350	200	100
Nitrogen (N)	85	40	20
Phosphorus	20	10	6
Chlorine	110	50	30
Hardness ($CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

source: W.H.O (1997)

Table 2.2: Chemical Composition of Wastewater in Alexandra Egypt

Constituent	Unit	Concentration
EC	ds/m	3.10
pH		7.80
SAR		9.30
Na_{2+}	Me/l	24.60
Ca^{+}	Me/l	1.50
Mg^{2+}	Me/l	3.20
K^{+}	Me/l	1.80
Cl^{-}	Me/l	62.00
SO_4^{2-}	Me/l	35.00
CO_3	Me/l	1.10
NCO_3	Me/l	6.60
NH_4^{+}	Me/l	2.50
NO_3^{+}	Me/l	10.10
P	Me/l	8.50

Source: Ghaffar *et al.*, 1988

Sewage water also may contain a variety of inorganic substances from domestic and industrial sources (see Table 2.2) including a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, leads, mercury, zinc etc. even if toxic materials are not

present in concentration they are still likely to affect humans. They might as well be at phototoxic levels, which will limit their agricultural use.

Table 2.3: Limits for Metals in Treated Wastewater for Irrigation

Metals	Limits (mg/l)
Aluminum	5.0
Arsenic Table	0.10
Beryllium	0.10
Boron	0.75
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Copper	0.2
Fluoride	1.0
Iron	5.0
Lead	1.5
Lithium	2.5
Manganese	0.2
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Vanadium	0.1
Zinc	2.0

Source: Ghaffar *et al.*, 1988

Ammonia and ammonium salts are always present, being produced by the decomposition of complex nitrogenous organic matter. Also present are sulphur and phosphorus – containing compounds, the decomposition of which leads to the objectionable odor associated with sewage. Sewage also contains living matter, especially bacteria, viruses, helminthes and protozoa (Table 2.3) which are excellent medium for the transmission and spread of a wide range of communicable diseases.

Table 2.4: Possible Levels of Pathogens in Wastewater

Type of Pathogen		Possible Concentration Per Litre in Municipal Wastewater
Viruses:	Enteroviruses	5000
Bacteria:	Pathogenic E. coli	?
	Salmonella spp.	7000
	Shigella spp.	7000
	Vibrio cholerae	1000
Protozoa:	Entamoeba histolytica	4500
Helminthes:	Ascaris Lumbricoides	600
	Hookworms	32
	Schistosoma mansoni	1
	Taenia saginata	10
	Trichuris trichiura	120

Source: Feachem *et al.*, (1983)

2.1.2 Wastewater Quality Indicators

Tchobanoglous *et al.*, (2003) stated that any oxidizable material present in a natural waterway or in an industrial wastewater will be oxidized both by biochemical (bacterial) or chemical processes. The result is that the oxygen content of the water will be decreased. Basically, the reaction for biochemical oxidation may be written as:

Oxidizable material + bacteria + nutrient + $O_2 \rightarrow CO_2 + H_2O$ + oxidized inorganics such as NO_3 or SO_4

Oxygen consumption by reducing chemicals such as sulfides and nitrites is typified as follows:

$$S^{2-} + 2O_2 \rightarrow SO_4^{2-}$$

$$NO_2^- + \tfrac{1}{2} O_2 \rightarrow NO_3^-$$

Since all natural waterways contain bacteria and nutrient, almost any waste compounds introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the Biochemical oxygen demand (BOD).

Oxidizable chemicals (such as reducing chemicals) introduced into a natural water will similarly initiate chemical reactions (such as shown above). Those chemical reactions create what is measured in the laboratory as the Chemical oxygen demand (COD).

pH is an indicator of the acidity or basicity of water but is seldom a problem by itself. The normal pH range for irrigation water is from 6.5 to 8.4; pH values outside this range are a good warning that the water is abnormal in quality. Normally, pH is a routine measurement in irrigation water quality assessment.

Table 2.5: Parameters Used in the Evaluation of Agricultural Water Quality

Parameters	Symbol	Unit
PHYSICAL		
Total dissolved solids	TDS	mg/l
Electrical conductivity	Ec_w	dS/m
Temperature	T	°C
Colour/Turbidity		NTU/JTU
Hardness		mg equiv. $CaCO_3$/l
Sediments		g/l
CHEMICAL		
Acidity/Basicity	pH	me/l
Calcium	Ca^{++}	me/l
Magnesium	Mg^{++}	me/l
Sodium	Na^{+}	me/l
Carbonate	CO_3^{--}	me/l
Bicarbonate	HCO_3^{-}	me/l
Chloride	Cl^{-}	me/l
Sulphate	SO_4^{--}	
Sodium adsorption ratio	SAR	
Boron	B	mg/l
Trace metals		mg/l
Heavy metals		mg/l
Nitrate-Nitrogen	$NO_3^{-}N$	mg/l
Phosphate Phosphorus	$PO_4^{-}P$	mg/l
Potassium	K	mg/l

Source: Kandiah (1990)

2.1.3 Wastewater Reuse for Irrigation

Adequate treatment of wastewater prior to use is undoubtedly a good principle; however, in most developing countries, limited financial resources severely constrain wastewater treatment options, making land application an appealing alternative. The need for low-cost sanitary disposal of wastewater has resulted in its widespread use for agricultural and aquacultural purposes. The most significant wastewater reuse takes place in arid regions where other sources of water are not available. Israel is at the forefront of wastewater reuse, with fully 70 percent of the total agricultural demand for water in 2040 projected to be met by effluent (Haruvy, 1997). Similarly, a review of water resources in Palestine identified recycled wastewater as the primary water source for future irrigation demand (Sbeih, 1996). Where other water sources are scarce, wastewater is often a contested resource. (Bell *et al.*1983) present a number of interesting historical cases of legal battles over the right to existing wastewater flows in the western United States. Generally, little interest was expressed in water quality, although the Clean Water Act has brought water quality to the forefront of water reuse concerns. The city of Lubbock, Texas presents an interesting case study (Fedler *et al.*1987), with increasing commercial demand for wastewater that had originally been land-applied as a disposal mechanism.

2.1.3.1 Benefits of Wastewater Reuse

Along with reuse of a valuable water resource, the appropriate use of the nutrients found in wastewater has been a primary objective of most wastewater reuse systems. Nutrient cycling has been the predominant objective of wastewater irrigation for centuries. In China, wastewater reuse in agriculture is a traditional practice. However, as wastewater treatment capacity is increased, greater quantities of sludge are being generated with a new set of land application challenges (Wang, 1997). With industrial discharges, the heavy metal content of

sludge has increased dramatically in China, posing a human health risk (Yediler *et al.*, 1994). Raw sewage used for irrigation in India over a 15-year period was reported to have improved the soil structure (Mathan, 1994). At a separate site, wastewater irrigation over 15 years increased soil nutrients and organic carbon content without increasing heavy metals to toxic levels (Gupta *et al.*, 1998). Even in cases where wastewater is treated at the primary level (e.g., stabilization ponds) for subsequent discharge into the environment, the nutrients may be beneficially used.

The impact of wastewater irrigation on household income was considerable as wastewater farmers earned approximately US$300/annum more than farmers using freshwater. Both case studies showed the importance of wastewater irrigation on local livelihoods.

2.1.3.2 Associated Problems Of Wastewater Reuse

The quality of irrigation water is judged by the amount of suspended and dissolved materials it contains. Suspended materials include eroded soil particles, seeds, leaves and other debris. The most common cations (positively charged ions) dissolved in irrigation water are calcium, magnesium, sodium and potassium. Bicarbonate, sulphate and chloride are the most common anions (negatively charged ions). Other solutes, nitrates, carbonates and the trace elements such as boron are occasionally present, (Ibrahim, 2006). Furthermore he noted that dissolved materials in irrigation water are described by total concentration of ions (without reference to the specific ion) and by identity and concentration of the specific ions present. Crop yield can be reduced significantly when the total concentration of ions dissolved in the irrigation water usually called the salinity of irrigation water is high enough. High amounts of exchangeable sodium can cause soil particle dispersion that reduces soil

structure and restricts air and water movement into and within the soil. Sodium, chlorine, boron, and other ions are toxic to many plants when present in sufficient concentrations.

Untreated wastewater is used for irrigation in over 80% of all Pakistani communities with a population of over 10,000 inhabitants. The absence of a suitable alternative water source, wastewater's high nutrient value, reliability, and its proximity to urban markets are the main reasons for its use. Two case studies in Pakistan studied the impact of untreated wastewater use on health, environment, and income. The results showed a high increase in hookworm infections among wastewater users and a clear over-application of nutrients through wastewater. Heavy metal accumulation in soil over a period of 30 years was minimal in Haroonabad, a small town with no industry, but showed initial signs of excess levels in soil and plant material in Faisalabad, a city with large-scale industry.

The salinization/sodification hazards posed by irrigation with wastewater can be readily predicted on the basis of the amount and type of salt contained in the water. Irrigation development should not therefore be undertaken without prior analysis and appraisal of the water to be used for irrigation. He distinguished three different hazards which include: salinity hazard, sodicity hazard, toxicity hazard (Ibrahim, 2006).

I. Salinity Hazard

The salinity of irrigation water is the sum of all the ionized dissolved salts in the water without reference to the specific ion present. It is measured by electrical conductivity, (EC) of the irrigation water since the EC is directly related to concentration of the salt.

Salinity hazard refers to the danger that the use of irrigation water will lead to osmotic problems in the soil/plants. This hazard may be diagnosed on the basis of the EC-value of the irrigation water. EC is the measure with which an electrical current will pass through a

solution. It is the reciprocal of electrical resistivity. Salt in soil or water reduces water availability to the crop to such an extent that yield is affected. (Ibrahim, 2006).

II. Sodicity Hazard (Soil Infiltration Effect)

This refers to dispersion problems, caused by relatively high percentage occupancy of the soil exchange complex by Na^+ which results in poor soil structure due to easy dispersion of the colloids in the soil. This hazard can be appraised on the basis of two main diagnostic parameters (EC-value and SAR-value). In general problems are not experienced in the soil with ES-value <15% (Egharevba, 2002). Sodium adsorption ratio (SAR) is the ratio for soil extracts or and irrigation waters used to express the relative activity of sodium ions in exchange reaction with soil (Michael, 2003).

The exchangeable-sodium-percentage (ESP), the sodium-adsorption-ratio (SAR) and the adjusted SAR of the soil extract or irrigation waters are used to evaluate the exchangeable sodium status of the soil and irrigation waters (Ibrahim, 2006). ESP is the degree of saturation of the soil exchange complex with sodium and may be calculated by the formula, ESP (Michael, 2003)

$$ESP = \frac{Exchangeable\ sodium\ (milliequivalent\ per\ 100g)}{Cation\ Exchange\ Capacity\ (milliequivalent\ per\ 100g)} \times 100$$

Cations exchange capacity (CEC) is the total quantity of cations which a soil can absorb by cation exchange, usually expressed in milliequivalents per 100 grams. Measured values of cation exchange capacity depend somewhat on the method used for its determination, (Michael, 2003).

Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next.

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate in to the soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factor such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate. The two most common water quality factors which influence the normal infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. A low salinity water or water with high sodium to calcium ratio will decrease infiltration. Both factors may operate at the same time, (Ibrahim, 2006). The infiltration rate generally increases with increase in salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium – the sodium adsorption ratio. Therefore, two factors, salinity and SAR, must be considered together for a proper evaluation of the ultimate effect on water infiltration rate.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where Na, Ca and Mg are sodium, calcium and magnesium are in milliequivalent per litre (meq/L) from water analysis.

According to Smedema and Rycroft (1988),

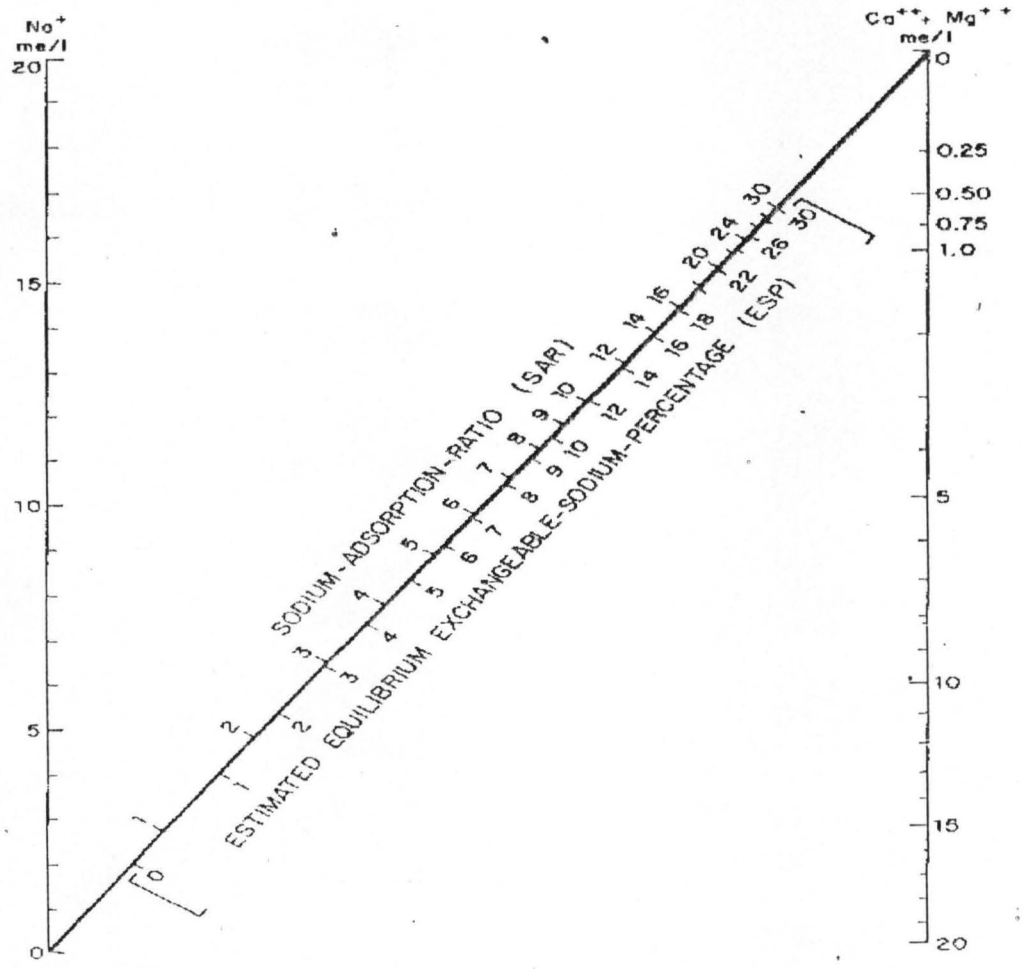
ESP can be computed by theoretical relationship

$$ESP = \frac{100(0.015SAR)}{1 + 0.015SAR}$$

However, its use is limited by many factors. An empirical relationship between ESP and SAR for soils which has reached equilibrium with the applied irrigation water is, (Landon Ed, 1991)

$$ESP - \frac{100(0.01475SAR - 0.0126)}{0.01475SAR + 0.9874}$$

This can be expressed in form of nomogram given in fig. 2.1. It determines SAR values from for irrigation water and estimates the corresponding ESP. The method is generally suitable for solution with total concentrations between about 39 and 110meq/L; outside this range other regression equations apply.



Source: US Salinity Laboratory, 1954

Fig.2.1: A Nomogram for Determining Sodium Adsorption Ratio

III. Toxicity Hazard

Toxicity problems occur if certain constituent (ions) in the soil or water are taken up by the plant and accumulates the concentration high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The ions of primary concern are chloride, sodium and boron. Irrigation water that contains certain ions at concentrations above threshold values can cause plant toxicity problems. Toxicity normally results in impaired growth, reduced yield, changes in the morphology of the plant and even its death. The degree of damage depends on the crop, its stage of growth, the concentration of the toxic ion, climate and soil conditions. The most common phytotoxic ions that may be present in municipal sewage and treated effluents in concentrations such as to cause toxicity are: boron (B), chloride (Cl) and sodium (Na). Hence, the concentration of these ions will have to be determined to assess the suitability of waste-water quality for use in agriculture. (FAO, 1985).

2.2 Soil and Soil Properties

Soil is generally referred to as the topmost part of the earth crust. According Microsoft Encarta, (2009) soil is the loose material that covers the land surface earth and support growth of plants. In general, soil is an unconsolidated, or loses, combination of inorganic and organic materials. The inorganic components of soil are principally the products of rocks and minerals that have been gradually broken down by weather, chemical action, and other natural processes. The organic materials are composed of debris from plants and from the decomposition of the many tiny life forms that inhabit the soil.

Soil is the main source of nutrients for crops. Soil also provides support for plant growth in various ways. Knowledge about soil health and its maintenance is critical to sustaining crop productivity. The health of soils can be assessed by the quality and stand of the crops grown on them. However, this is a general assessment made by the farmers. A

scientific assessment is possible through detailed physical, chemical and biological analysis of the soils. Essential plant nutrients such as N, P, K, Ca, Mg and S are called macronutrients, while Fe, Zn, Cu, Mo, Mn, B and Cl are called micronutrients. It is necessary to assess the capacity of a soil to supply nutrients in order to supply the remaining amounts of needed plant nutrients (total crop requirement - soil supply). Thus, soil testing laboratories are considered nerve centres for nutrient management and crop production systems.

The idea that one could test or analyze a soil and obtain some information about its properties, especially its acidicity or alkalinity and its nutrient status is long established, and can be traced back to the beginning of scientific enquiry about the nature of soil. Analysis of plant to reflect fertility status of the soil in which it grew is more recent, although visual crop observation are as old as the ancient Greeks, if not older. In the last few decades, spurred on by commercialization of agriculture and the demand for increased output from limited and even diminishing land resources, both soil and plant analysis have been developed still evolving. However, if soil testing is to be an effective means of evaluating fertility status of soils, correct methodology is absolutely essential. A soil or a field may be assessed for its capability of providing a crop with essential nutrients in several ways: field plot fertilizer trial; green house pot experiments; crop deficiency symptoms; plant analysis; rapid tissue or sap analysis; biological test such as growing microorganisms; and soil testing prior to cropping (Ryan and Matar, 1992).

All approaches can be used in research, the latter one is the most amenable, and one upon which recommendation for farmers can be based. On the other hand, plant analysis is a postmortem approach and one that should be interpreted in the light of soil test results. (Ryan and Matar, 1992)

Soil test is now an intrinsic part of modern farming. Testing primarily focuses on the elements most demand by crop: nitrogen (N), phosphorus (P), and potassium (K). Depending

on the soil types, in some regions tests are often conducted for secondary nutrients: calcium (Ca), magnesium (Mg), sulphur (S). In drier areas, micronutrients such as Iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B) are often measured, since deficiencies of these elements are more frequently associated with calcareous soils. Indeed such areas may also have excessive or toxic level of some elements, like Boron (B), and Sodium (Na). (Ryan and Matar, 1992)

As nutrient behavior in soils is governed by soil properties and environmental conditions, measurement of salinity, organic matter (OM), calcium carbonate ($CaCO_3$), texture, soil separate, pH etc. are necessary.

2.2.1 Soil Texture

The weathering processes of rock result in the formation of soil, in wide range of particle sizes from stones, to gravel, to silt and to very small clay particle. Soil texture is therefore the degree of fineness or coarseness of the soil.

Forth (1990) specifically stated that, texture is the relative proportion of sand, silt, and clay in a soil. Once the percentage of sand, silt, and clay is measured, the soil may be assigned a textural class using the USDA textural triangle (Fig.2.2). Within the textural triangle are various soil textures which depend on the relative proportions of the soil fractions.

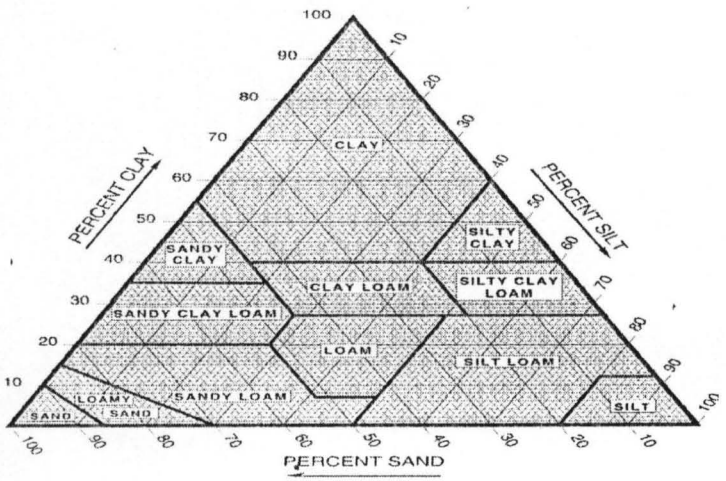


Fig.2.2: The USDA Soil Textural Triangle

2.2.2 The Soil Separates

Individual soil particles vary widely in any soil type. Similarly, as these particles are cemented together, a variety of aggregate shapes and sizes occur. Soil separates are the size groups of mineral particles less than 2 millimeters (mm) in diameter or the size groups that are smaller than gravel. Table2.1 shows the characteristics of some soil separates, (Forth, 1990).

Table 2.6: Characteristics of Soil Separate

Separate	Diameter mm[a]	Diameter mm[b]
Very coarse sand	2.00 – 1.00	-
Coarse sand	1.00 – 0.50	2.00 – 0.20
Medium sand	0.50 – 0.25	-
Fine sand	0.25 – 0.10	0.2 – 0.02
Very fine	0.10 – 0.05	-
Silt	0.05 – 0.002	0.02 – 0.002
Clay	Below 0.002	Below 0.002

Source: Forth, 1990

(a) **United States Department Of Agriculture**
(b) **International Soil Science Society System**

2.2.3 Soil Textural Classes

The texture of a soil is expressed with the use of class names. A loamy soil contains 7 to 27 percent clay, 28 to 50 percent silt, and between 22 and 52 percent sand. Soils in the loam class are influence almost equally by the three separates – sand, silt, clay. For sandy soils (sand and loam sand), the properties and use of the soil are influenced mainly by the sand content of the soil. For clay (sandy clay, clay, silty clay), the properties and use of the soil are influenced mainly by high clay content (Forth, 1990).

Textural class names containing the terms 'sand' or 'sandy' are modified with the adjective very fine, fine, 'coarse', or 'very coarse', in accordance with the particle size range of the sand separate as given in USDA system.

Very coarse particles, the size of which varies between 2mm and 25mm are considered to be part of the soil mass, though not part of the fine earth, also influence certain soil properties and, therefore if present in noticeable quantities, they are noted in textural class name by additions such as gravelly, 'cherty', 'slaty' or 'stony' (Agricultural Compendium, 1989).

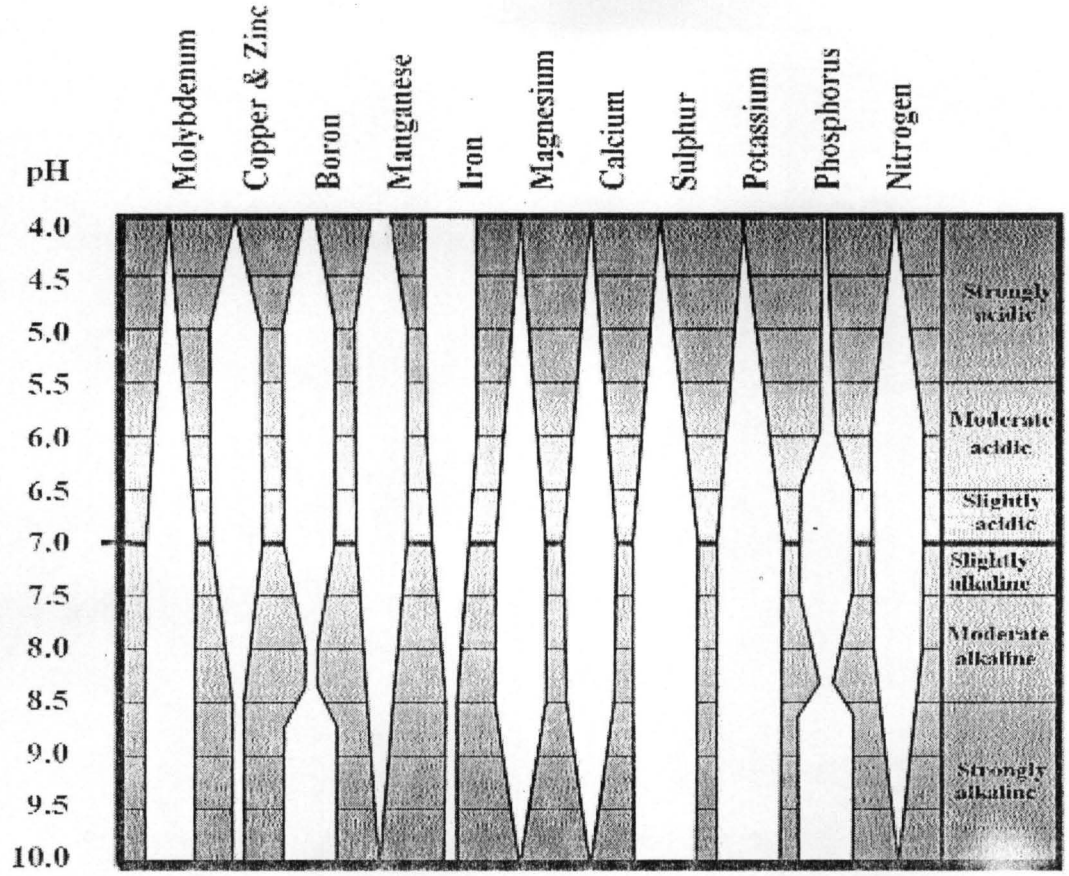
2.2.4 Soil pH

The pH is defined as the negative log of the hydrogen ion activity. Since pH is log arithmic, the H-ion concentration in solution increases ten times when its pH is lowered by one unit. The pH range normally found in soil varies from 3 to 9. Various categories of soil pH may be arbitrarily described as follows: strong acid (pH<5.0), moderate to slightly acidic (5.0 – 6.5), neutral (6.5 – 7.5), moderately alkaline (7.5 – 8.5), and strongly alkaline (pH>8.5) (McKeague, 1984).

Significance of pH lies in its influence on availability of soil nutrients, solubility of toxic nutrient elements in the soil, physical break down of root cells, cation exchange capacity in soils whose colloids (clay/humus) are pH-dependent, and on biological activity. At high pH values, availability of phosphorus (P) and most micronutrients except boron (B) and molybdenum (Mo) tends to decrease (Mclean, 1982).

Acid soils are rare in semi-arid dry land areas of the world; they tend to occur in temperate and tropic areas where rainfall is substantial; conversely, soils of drier areas are generally alkaline, that is above pH 7.0, as a result of the presence of calcium carbonate ($CaCO_3$); they visibly effervesce (fizz) when 10% hydrochloric acid is added drop wise to the soil. Thus, soil pH is one of the most common measurements in soil laboratories. It reflects whenever a soil is acidic, neutral or alkaline (McKeague, 1984).

Below is a figure showing the relative impact of soil pH levels on plant nutrient level Jones *et al.*, (2001).



Source: Jones *et al.*, (2001).

Fig.2.3: Influence of Soil pH on Plant Nutrient Availability

2.3 Plant Nutrient

The role of plant nutrients in crop production is well established. There are 16 essential plant nutrients. These are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), sulphur (S), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl). These nutrient elements have to be available to the crops in quantities as required for a yield target.

Any limiting or deficient nutrient (or nutrients) will limit crop growth. The required nutrients may come from various sources, such as the atmosphere, soil, ***irrigation water***, mineral fertilizers, manures and biofertilizers. The combinations, quantities and integration of nutrients to be supplied from various sources (integrated plant nutrient supply) depend on various factors including the type of crop, soils, availability of various resources, and ultimately on economic considerations, such as the level of production and the costs of inputs and outputs. Integrated nutrient management (INM) is a well-accepted approach for the sustainable management of soil productivity and increased crop production. To implement this approach successfully, well-equipped testing laboratories, among other things, are needed in order to evaluate the nutrient supplying capacities of various sources. Accurate and timely analysis helps in determining the requirements of plant nutrients so as to arrange their supply through various sources.

2.3.1 Reasons for Plant Nutrient Analysis

For irrigated crops, plant analysis can be used as an aid in making decisions about nutrient applications such as nitrogen and some micronutrients. One example is petiole testing in irrigated potatoes. Nitrate nitrogen levels in the potato petiole are determined weekly, and the information is used to help make nitrogen fertilization decisions all season long. Plant analysis is also used in fruit and vegetable crops as a guide for nutrient application during the season.

Plant analysis is a good way to confirm that your fertility management plan is working. Plant analysis can be used to evaluate new fertilizer placement and timing techniques. The information collected can then be used to make necessary adjustments to your fertility plans.

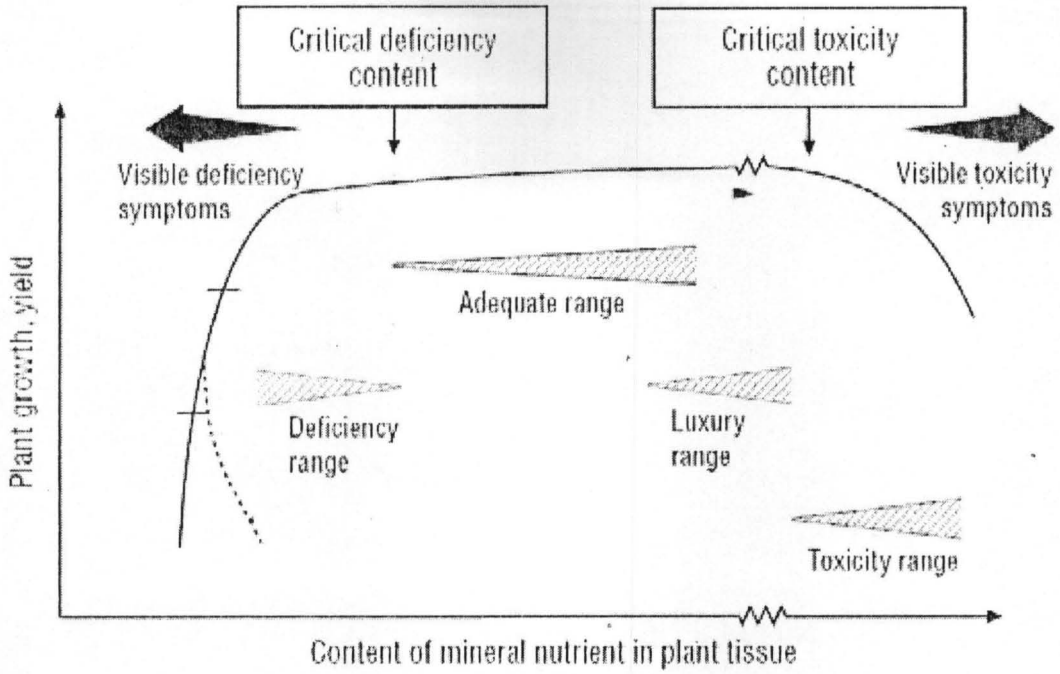
Nutrient deficiency symptoms should be confirmed with plant analysis. Using visible symptoms to identify which nutrient is deficient is very difficult. One example of this

difficulty is distinguishing between nitrogen and sulfur deficiencies in a crop such as wheat. Plant analysis may confirm a suspected nutrient deficiency or it may indicate that another nutrient is the problem.

Plants can experience nutrient deficiencies without expressing any visual symptoms. These plants are said to be experiencing "hidden" hunger. While no symptoms are present, these minor nutrient deficiencies can still cause yield losses of 10-15%. (uploaded from www.agviselabs.com)

2.3.2 Diagnosing Nutrient Disorders in Plants

Marschner, (1995) gives a much-cited illustration of the response of plant growth to the content of mineral nutrient in tissue. Figure 2.4 gives an adaptation used in the most recent edition of the Soil Fertility Handbook (OMAFRA, 2006). The complex shape of the curve gives rise to varying definitions of "critical content" in the literature. Some critical values are given as levels below which a certain percentage of yield reduction is expected. These can differ greatly from a critical value for maximum yield, or maximum economic yield. The slope of the approach to a critical value also varies greatly among nutrients and crop species. Additionally, the dotted line shows a potentially significant difficulty confounding the interpretation of plant analysis – the possibility of a C-shaped curve, also known as the Piper-Steenbjerg effect; a phenomenon that potentially makes the interpretation of a given nutrient level in tissue highly ambiguous.



Source: Marschner, 1995. *Mineral Nutrition of Higher Plants.*

Fig.2.4: Relationship of Plant Growth to Mineral Content in Plant Tissue

Epstein & Bloom, (2005) define "critical concentration" as "the concentration of a nutrient in the tissue just below the level that gives optimal growth." They suggest that a 10% reduction in growth occurs at the critical concentration. Marschner (1995) referred to this level as the Critical Deficiency Concentration, and noted that in low input systems, it may be taken as that where a 20% yield reduction occurs.

Nutrient deficiency symptoms should be confirmed with plant analysis. Using visible symptoms to identify which nutrient is deficient is very difficult. One example of this difficulty is distinguishing between nitrogen and sulfur deficiencies in a crop such as wheat. Plant analysis may confirm a suspected nutrient deficiency or it may indicate that another nutrient is the problem.

Soil testing on a regular basis and fertilizing according to soil test recommendations are critical parts of a sound nutrient management program, but nutrient disorders

(deficiencies or excesses of specific nutrients) can still occur for a variety of reasons. In addition to nutrient amounts, the balance between different nutrients can play an important role in the development of nutritional problems in a crop. Tools for diagnosing nutrient disorders in growing crops include plant tissue analysis and visual symptoms of nutrient deficiency and toxicity (Bierman and Rosen, 2006)

2.3.3 Nutrient Interactions

(Bierman and Rosen, 2006) also stated that both nutrient supply and nutrient balance play important roles in plant nutrition. Changing the level of one nutrient in the soil will often affect the uptake or transport within the plant of another nutrient. Therefore, the effects of one nutrient element on the uptake or use of another nutrient element, nutrient interactions, also have to be considered in a complete nutrient management program. Assessment of nutrient interactions should include the relationship between nutrient supply in the soil and plant growth, as well as between nutrient concentrations in plant tissue and plant growth. Although interactions between nutrients can be either positive or negative, it is usually the negative interactions that are the most documented.

Nutrient interactions can become a factor in plant growth in two situations: 1) when the levels of two nutrients are both near the deficiency range, and 2) when one nutrient is supplied in excessive amounts while another is at a level considered only marginally sufficient. The precise nature of nutrient interactions depends on the nutrients involved and can vary for different plant species. In many cases, the mechanism for the interaction may not be completely understood. Nutrient interactions may be the result of precipitation reactions occurring in the soil solution, which reduces availability for plant uptake, or the result of competition during nutrient uptake, translocation, or metabolic function within the plant. Some important nutrient interactions include ammonium-calcium, phosphorus-iron, phosphorus-copper, phosphorus-zinc, and potassium-magnesium-calcium.

Nutrient interactions and proper nutrient balance need to be considered in relation to nutrient supply – the actual amounts of plant-available nutrients in the soil. Nutrient supply is important because "optimum nutrient ratios" in soil or in plant tissue can still be obtained even when nutrient amounts are not in the sufficiency range. Two nutrients could both be in the deficient range, or both could be in the toxic range, yet the ratio between them could be in optimum balance.

Although knowing the symptoms associated with nutrient deficiencies or toxicities is essential for every grower, it is important to remember that once visual symptoms are present reductions in crop yield or quality have often already occurred In most cases, symptoms of nutritional disorders occur in defined patterns and are specific for each nutrient. Elements that are mobile in plants generally induce deficiencies on the older (lower) leaves first, while immobile elements induce deficiencies on the younger (upper) leaves first. In some cases, pesticide toxicity or disease symptoms may resemble nutrient deficiencies or toxicities. In addition, symptoms of nutritional disorders are often species or variety dependent. Use of ***soil*** and ***plant tissue analysis*** should be used to help confirm whether the symptoms truly are nutritional.

Below is a table showing the standard nutritional level of spinach (*Spinacia Oleracea*). A standard analysis from the USDA national nutrient database.

Table 2.7: USDA Standard Nutritional Level for Spinach

Nutrients	Units	Value Per 100 Gram Of Edible Portion	Number of data point	Std Error
PROXIMATES:				
Water	g	91.40	1	0
Energy	kcal	23	0	0
Energy	kJ	97	0	0
Protein	g	2.86	9	0.112
Total lipid (fat)	g	0.39	7	0.032
Ash	g	1.72	8	0.035
Carbohydrate, by difference	g	3.63	0	0
Fibre, total dietary	g	2.2	1	0
Sugars, total	g	0.42	0	0
Sucrose	g	0.07	8	0.036
Glucose (dextrose)	g	0.11	8	0.032
Fructose	g	0.15	8	0.07
Lactose	g	0.00	1	0
Maltose	g	0.00	1	0
Galactose	g	0.10	1	0
MINERALS:				
Calcium, Ca	mg	99	9	4.996
Iron, Fe	mg	2.71	10	0.522
Magnesium, Mg	mg	79	7	4.794
Phosphorus, P	mg	49	7	3.479
Potassium, K	mg	558	10	28.703

Sodium, Na	mg	79	10	10.835
Zinc, Zn	mg	0.53	7	0.039
Copper, Cu	mg	0.130	7	0.007
Manganese, Mn	mg	0.897	6	0.048
Selenium, Se	mcg	1.0	5	0.335
VITAMINS:				
Vitamin C, total ascorbic acid	mg	28.1	7	4.129
Thiamin	mg	0.078	9	0.008
Riboflavin	mg	0.189	9	0.008
Niacin	mg	0.724	9	0.032
Pantothenic acid	mg	0.065	6	0.008
Vitamin B-6	mg	0.195	6	0.008
Folate, total	mg	194	6	35.597
Folic acid	mg	0	0	0
Folate, food	mg	194	6	35.597
Folate, DFE	mcg_DFE	194	0	0
Vitamin B-12	mcg	0.00	0	0
Vitamin A, IU	IU	9377	0	0
Vitamin A, RAE	mcg_RAE	469	0	0
Retino	mcg	0	0	0
Vitamin E (alpha-tocopherol)	mg	2.03	7	0.152
Tocopherol, beta	mg	0.00	7	0
Tocopherol, gamma	mg	0.18	7	0.036
Tocopherol, delta	mg	0.00	7	0
Vitamin K (phylloquinone)	mcg	482.9	1	0
LIPIDS:				
Fatty acids, total saturated	g	0.063	0	0
4:0	g	0.000	0	0

6:0	g	0.000	0	0
8:0	g	0.000	0	0
10:0	g	0.000	0	0
12:0	g	0.000	0	0
14:0	g	0.010	1	0
16:0	g	0.049	1	0
18:0	g	0.004	1	0
Fatty acids, total monounsaturated	g	0.010	0	0
16:1 undifferentiated	g	0.005	1	0
18:1 undifferentiated	g	0.005	1	0
20:1	g	0.000	0	0
22:1 undifferentiated	g	0.000	0	0
Fatty acids, total polyunsaturated	g	0.165	0	0
18:2 undifferentiated	g	0.026	1	0
18:3 undifferentiated	g	0.138	1	0
18:4	g	0.000	0	0
20:4 undifferentiated	g	0.000	0	0
20:5 n-3	g	0.000	0	0
22:5 n-3	g	0.000	0	0
22:6 n-3	g	0.000	0	0
Cholesterols	mg	0	0	0
Phytosterols	mg	9	0	0
AMINO ACIDS:				
Tryptophan	g	0.039	19	0
Threonine	g	0.122	19	0
Isolencine	g	0.147	19	0
Lencine	g	0.223	19	0
Lysine	g	0.174	23	0

Methionine	g	0.053	23	0
Cystine	g	0.035	8	0
Phenylalanine	g	0.129	19	0
Tyrosine	g	0.108	8	0
Valine	g	0.161	19	0
Arginine	g	0.162	18	0
Histidine	g	0.064	18	0
Alanine	g	0.142	7	0
Aspartic acid	g	0.240	7	0
Glutamic acid	g	0.343	7	0
Glycine	g	0.134	7	0
Proline	g	0.112	6	0
Serine	g	0.104	7	0
OTHERS:				
Alcohol, ethyl	g	0.0	0	0
Caffeine	mg	0	0	0
Theobromine	mg	0	0	0
Carotene, beta	mcg	5626	5	766.716
Carotene, alpha	mcg	0	4	0
Cryptoxanthin, beta	mcg	0	4	0
Lycopene	mcg	0	7	0
Lutein + zeaxanthin	mcg	12198	7	1930.873

Source: USDA National Nutrient Database, Release 17 (2004)

This project is targeted at evaluating the impacts the municipal wastewater used for irrigating on spinach via the soil and relating its results to class of plants that have similar tolerance as spinach on the application of waste water. The above reviews often do not consider the role or part played by the soil as a medium through which the wastewater

affects the plant nutrient i.e. neglecting the nutrient interaction between the soil and the plant as it affects the plant nutrients. This study will cover the changes in soil physiochemical characteristics as caused by the wastewater application and its corresponding effect/impact on plant nutrient having compared with the above standard nutritional values in Table 2.7

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The project study area is located in Soje few kilometers from the Minna Railway Station and 300m from the West of Morris Fertilizer Company. The municipal/domestic wastewater derives its source from Minna township. The wastewater flows through an unlined channel and land owners (farmers) linear to the flow takes advantage of its continuous flow for irrigation as shown in plates 3.1-3.3 below.

Plate 3.1: Unlined Wastewater Channel

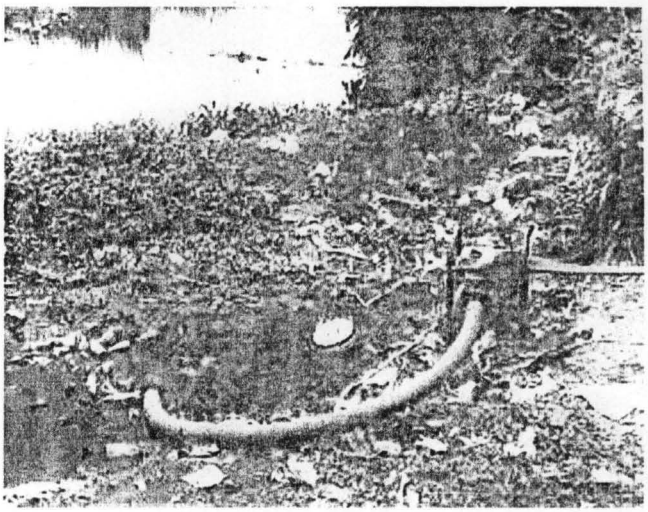


Plate 3.2a: Wastewater being Pumped to the Farm

Plate 3.2b: Pump Repositioning

Plate 3.3: Irrigated farm

Figure 3.1 shows the position of the project study area on a map (abridged Niger State map). Niger state is situated in the middle belt of the Federal Republic of Nigeria. It lies in the Savanna zone of the tropics between latitude (8^0 10^1N and 11^0 30^1N) and longitude (3^0

30^{1}E and 7^{0} 30^{1}E). Its climate is influenced mainly by the rain-bearing South West monsoon winds from the oceans and the dry dusty or harmattan North East winds (air masses) from the Sahara desert. There are mainly the rainy and the dry seasons. The rainy season begins in April and ends in October and the dry season starts in November and ends in March. Thus this study was undertaken during the dry season. Rain starts in April and ends in October with an average rainfall of 103.3mm annually. The average temperature ranges from 22.5°C minimum to 33.6°C maximum annually. It has an average annual relative humidity of 50.2% (NIMET, Minna).

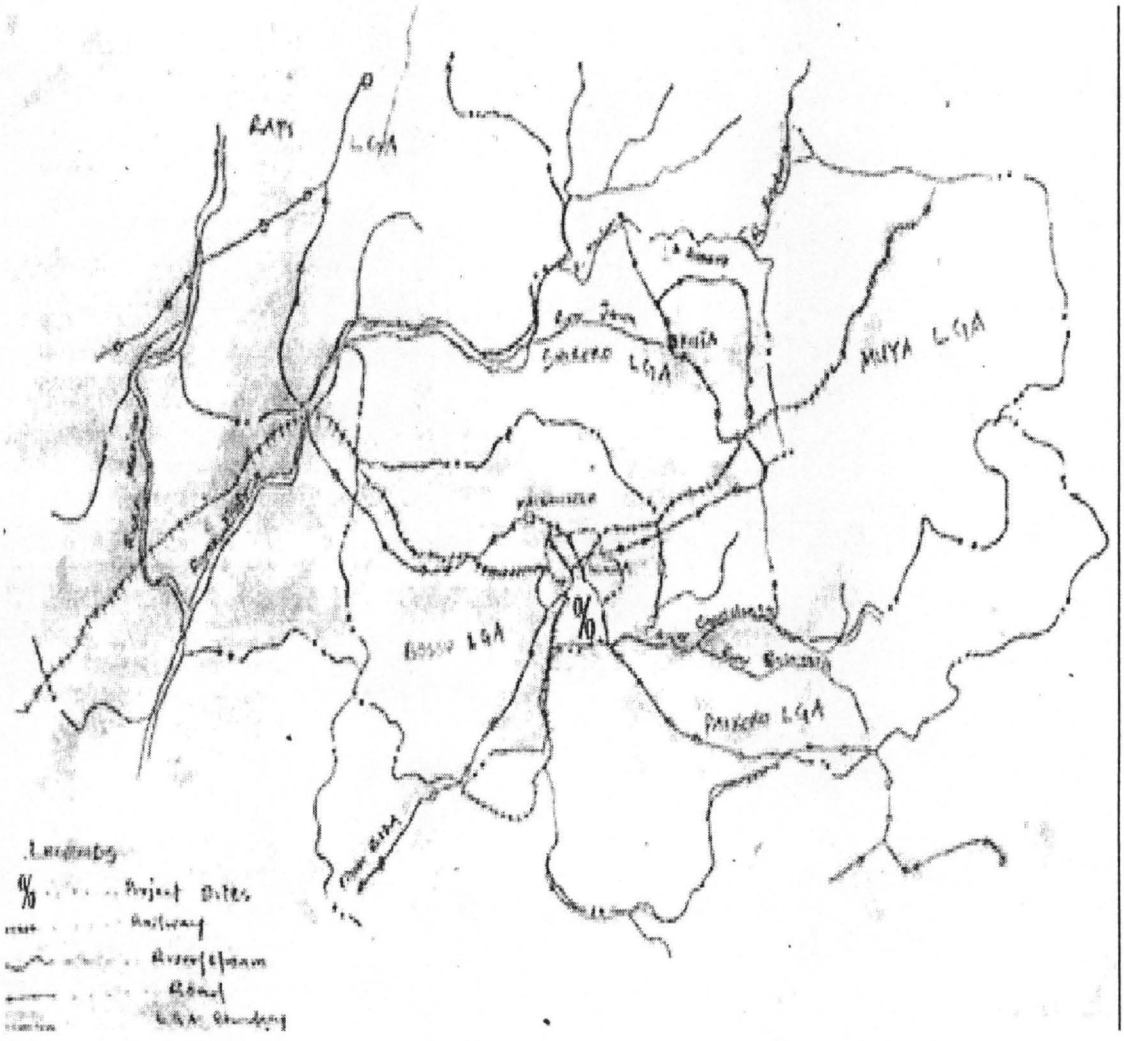


Fig.3.1: An Abridge Map of Niger State Showing the Study Site [%]

3.2 Soil Sampling and Methods

Soil analysis is a valuable tool if its limitations are recognized and used. In conjunction with plant analysis, it becomes a more powerful tool. Soil contain nutrient elements in varying concentrations and the main objective of this soil sampling is to collect a small amount of soil samples weighing about one kilogram that will represent the soil in a large area. Since only small amount of soil sample is used for the analysis and results will be projected for a large quantity, the soil samplings were done before the planting (before irrigating) and after the growing period of the plant (irrigated soil) both on the controlled plot and on the wastewater irrigated plot. Samples were taken at several points of both the controlled plot and the wastewater irrigated plot from a depth of 25cm. Various point samples taken on each plot of size 6ft × 8ft and were mixed together in a plastic bag so as to have a composite sample as shown in Figures 3.2 and 3.3

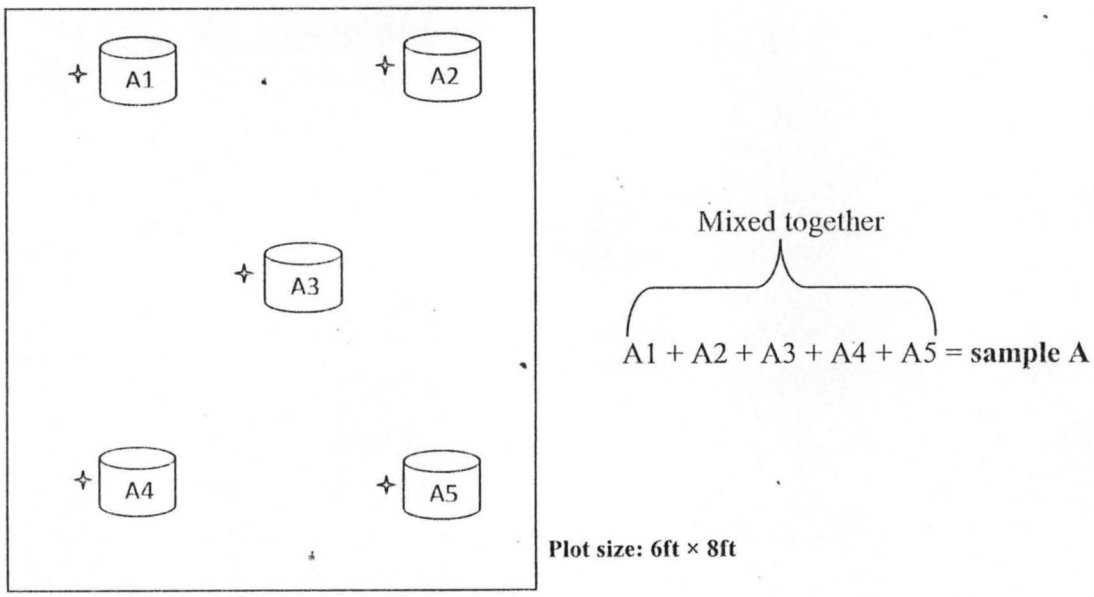


Fig.3.2: Soil Sampling Method for Plot A, the Potable Water Irrigated Plot

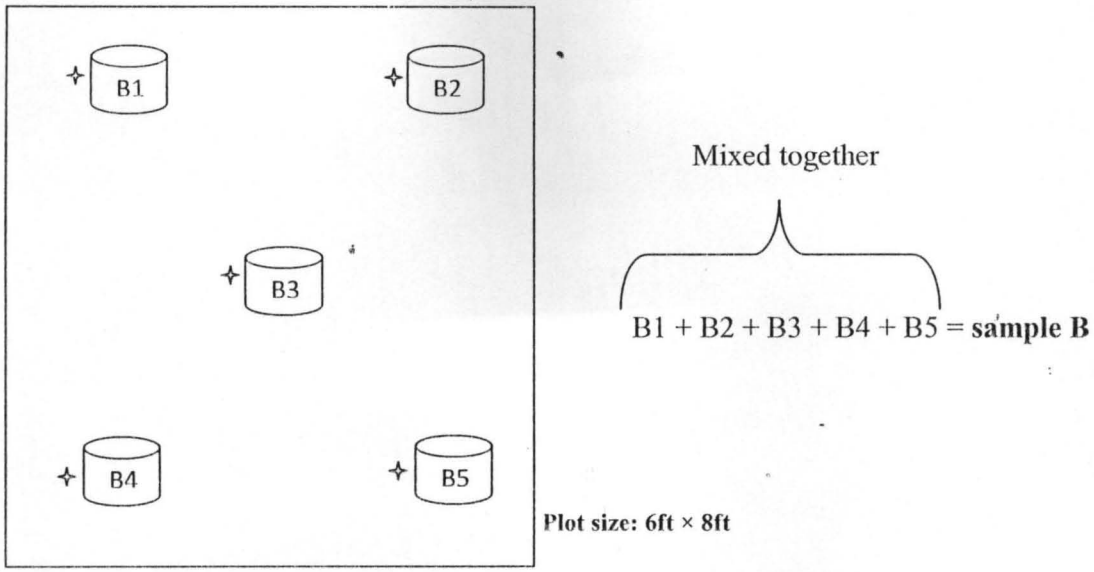


Fig.3.3: Soil Sampling Method for Plot B, the Wastewater Irrigated Plot

The soil samples before being sent to the laboratory for the analysis were treated by drying at room temperature for three days. 450g of each sample was sent to the laboratory for the analysis. Analyses were carried out using glass electrode pH meter for the pH analysis, bouyoucos method for particle size analysis, macro-kjeldahl method for Nitrogen and other minerals (see appendix A).

3.3 Wastewater Sampling and Methods

The distribution of vegetation over the surface of the earth is controlled more by the availability of water than any other single factor. It is not enough that there is water available for plants, the quality of the irrigation water must be determined since all natural water contain dissolved salts, which when present in large quantities can be detrimental and harmful to agricultural crops.

The wastewater samples were collected using a 1.5litres plastic container. The container was initially washed using detergents and properly rinsed. At the point of sampling, the container was also rinsed using the wastewater several times before the sampling. The

sample was collected by dipping the container into the stream of wastewater at different point to get a composite sample.

Major and trace constituents in the wastewater were measured by a combination of spectroscopic and automated flow analyzers (see appendix B). Water tests performed were routine water chemistry, physical parameters of water, nutrient in water, water elemental analysis, microbiology and toxicity in water.

3.4 Plant Sampling and Methods

Plant sampling has been widely used as an aid in the determination of the nutrient status in crops and the soil in which they grow. Plant and soil testing enables scientific assessment of the needs of plants for nutrient element and of the capacity of the soil to supply them. The nutrient elements enters the plant in ionic form from the soil solution. Ion transport to the root surface may take place through ion diffusion and bulk transport (mass flow). Mass flow is the sweeping along of ions as water moves to the root (Motsara and Roy, 2008). Plant analysis can also be used to detect or confirm nutrient deficiencies or toxicity in plants. It is an effective method of monitoring nutritional uptake by plants when used in conjunction with soil analysis.

Samples were collected at maturity stage of the spinach (*Spinacia Oleracea*) plant. Taking a minimum of 40-55 spinach samples from both the controlled plot and the wastewater irrigated plot. The collected samples were prepared by cutting with a knife to smaller sizes the edible part (the leaf), transferred into a plastic bag and labeled appropriately with a pen before taking them to the laboratory for analysis

The samples (spinach) were analyzed for their proximate, minerals and vitamin C content. The proximate analysis include; moisture, protein, fat/oil, ash, fibre and

carbohydrate. The minerals include; calcium, iron, magnesium, phosphorus, sodium and zinc (see appendix C).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Wastewater Analysis

Wastewater contains a variety of organic and inorganic substances from domestic and industrial sources. The results of wastewater analysis are presented in Table4.1 below

Table 4.1: Onstream Average Wastewater Analysis Result

Parameters	Unit	Average Value
Temperature	^{0}C	28.4
Dissolved oxygen	ppm	3.55
Electrical Conductivity	ds/cm	619
Total dissolved solid	mg/L	414.73
Turbidity	NTU	19.79
Suspended solid	mg/L	21
Colour	TCU	246
pH		7.56
Ammonia	mg/L	41.21
Nitrate	mg/L	182.45
Nitrite	mg/L	0.805
Sodium	mg/L	31.5
Potassium	mg/L	15.41
Calcium hardness	mg/L	101
Magnesium hardness	mg/L	5
Hardness	mg/L	106
Carbonate	mg/L	0
Bicarbonate	mg/L	166
Alkalinity	mg/L	166

COD	mg/L	170
BOD_5	mg/L	16
Hydroxide	mg/L	0
Chloride	mg/L	23.98
Fluoride	mg/L	0.06
Magnesium	mg/L	1.1
Calcium	mg/L	40.48

4.1.1 Physiochemical Analysis

I. Temperature:- This is a measure of how cold or hot the wastewater sample is. There are no set standard for temperature but 0^0C is the freezing point of pure water sample, while 100^0C is its boiling point (Ayers and Westcot, 1994). Different organisms (micro and macro) can survive under varying water temperatures, temperature of the wastewater as an infinitesimal effect on plant nutrient via the soil since it practically diminishes/vary with period and medium, meaning that the temperature of the wastewater applied to the soil can be altered by the ambient environmental weather condition.

II. pH:- This is an indication of the acidity or basicity of water but is seldom a problem by itself. The main use of pH in water analysis is for detecting abnormal water. The normal pH range for irrigation is 6.5 to 8.4; pH value outside this range would be a good warning that the water is abnormal in quality (Motsara and Roy, 2008). Irrigation water with pH outside the normal range may cause a nutritional imbalance or may contain toxic ions. The municipal wastewater pH result of 7.56 satisfies the pH standard of irrigation water but more is required to meet full standard, meaning that away from pH, there are so many other analytical parameter in their standards that tells if irrigation water is safe to use.

III. **Total Hardness:-** This is due primarily to calcium and secondary to magnesium carbonates bicarbonates (Motsara and Roy, 2008). Thus, wastewater to be used for irrigation, the hardness must not exceed 150mg/l. The municipal wastewater total hardness result of 106mg/l satisfies the total hardness standard of irrigation water but away from total hardness, there are so many other analytical parameter in their standards that will jointly tells if irrigation water is safe to use.

IV. **Dissolved Oxygen:-** Knowing the amount of dissolved oxygen in water is important for microorganisms and plants to survive. Dissolved oxygen between 910ppm is considered very high while 4ppm is very bad. If dissolved oxygen is too low in irrigation water as in the wastewater analysis result (3.55ppm), this is an indication that the bacteria concentration is high and if used for irrigation, portends danger to plant growth and nutrient (Motsara and Roy, 2008)

V. **Chloride (Cl), Fluoride (Fl), and Sodium (Na):-** These are toxic ions. Irrigation water that contain these ions at threshold value can cause plant toxicity problems. Such as impaired growth, reduced yield, changes in morphology of plant and even death. For safety, chlorine and sodium should be present in irrigation in the range (0 – 30mg/L) and (0 – 40mg/L) respectively (FAO, 1994). From the wastewater analysis, chlorine (23.98mg/L) and sodium (31.5mg/L) are within the safe range.

VI. **Total Dissolved Solids:-** This is a measure of the impurities in a water sample. It can also be referred to as the total salt concentration of a water sample. It is one of the most important agricultural water quality parameters. Plant growth, crop yield and quality of produce are affected when the total dissolved solid in the irrigation water is above 2000mg/L (Ayers and Westcot, 1994). From the municipal wastewater analysis result, in composition, it

contains 414.73mg/L of total dissolved solid which is satisfactory compared to the FAO standard in Table4.2

VII Nitrates:- This represents the final product of the biochemical oxidation of ammonia. In water, the presence of nitrate is probably due to the presence of nitrogen organic matter and to some extent, of vegetable origin, for only small quantities are naturally present in water. However, wastewater may contain high nitrates. The use of wastewater for irrigation should be of immense benefit because the nitrate centered of wastewater might reduce the requirements for commercial fertilizer. Nitrate content may be considered toxic if it exceeds 10mg/L (FAO, 1994). From the municipal wastewater analysis, the nitrate content is very high (182.45mg/L) which poses great threat (toxicity) on plant nutritional value.

4.1.2 Bacteriological Analysis

Biological Oxygen Demand and Chemical Oxygen Demand:- Biological Oxygen Demand (BOD) is usually measured by allowing a sample of wastewater to stand at 20^0C for five days and calculating the amount of oxygen used up during the oxidation of the organic matter by bacteria. Chemical Oxygen Demand (COD) is the equivalent amount oxidizing chemical required to act on behalf of the bacteria. The essence of this analysis is to know the amount of biodegradable organic matter in wastewater sample.

Table 4.2: Laboratory Determinations Needed to Evaluate Common Irrigation Water Quality Problems

Water parameters	Unit	Range in irrigation water
Electrical conductivity	ds/m	0 – 3
Total dissolved solid	mg/L	0 – 2000
Calcium	mg/L	0 – 20
Magnesium	mg/L	0 – 5
Sodium	mg/L	0 – 40
Carbonate	mg/L	0 – 1
Bicarbonate	mg/L	0 – 10
Chlorine	mg/L	0 – 30
Sulphate	mg/L	0 – 20
Nitrate	mg/L	0 – 10
Ammonium	mg/L	0 – 5
Phosphate	mg/L	0 – 2
Potassium	mg/L	0 – 2
Boron	mg/L	0 – 2
pH	1 – 14	6.0 – 8.5
Sodium adsorption ratio	mg/L	0 – 15

Source: FAO, 1994

4.2 Soil Analysis

The soil composes of various physical and chemical properties (see Table 4.2) which develops or neutralizes by the nature of the irrigation water applied thereby, positively or negatively affecting plant (spinach) growth and nutrient level. The results of the soil samples analyses are thus presented in the Table below.

Table 4.3: Soil Samples Analysis Results

Parameters	Unit	SBI	WWIS	PWIS
pH		1.68	5.40	5.68
Organic carbon	%	0.64	0.46	0.66
Organic matter	%	4.81	3.38	4.81
Total nitrogen	%	0.01	0.089	0.098
Phosphorus (p)	ppm	4.10	3.80	4.20
Sodium (Na)	$Cmolkg^{-1}$	6.10	0.48	0.62
Potassium (K)	$Cmolkg^{-1}$	0.33	0.44	0.34
Magnesium (Mg)	$Cmolkg^{-1}$	10.93	6.85	10.95
Exchangeable acid	$Cmolkg^{-1}$	0.61	0.83	0.63
Cation exchange capacity	$Cmolkg^{-1}$	12.53	8.60	12.54
Bulk density	g/kg	1.40	1.55	1.40

SBI – Soils Before Irrigation
WWIS – Waste Water Irrigated Soil
PWIS – Potable Water Irrigated Soil

Soils may have large amount of nutrient reserved in them. All or a part of these reserves may not be of use to crops because they may not be in plant available form (Motsara

and Roy, 2008). Apart from nutrients, soil pH estimation is also critical in the assessment of soil health. In general, most plants grow by absorbing nutrients from the soil. Their ability to do this depends on the nature of the soil and its location due to variation in weather/climate. The makeup of a soil (soil texture) and its acidity (pH) determines the extent to which nutrient are available to the plant (Jones et al., 2001). Fig 2.3 explains impacts of pH on plant nutrient.

4.2.1 pH

The pH range normally found in soils varies from 3 to 9 (ICARDA, 2001) and most nutrient element are available in the pH range of 5.5 to 6.5 (Motsara and Roy, 2008). The potable water irrigated soil (PWIS) satisfy the above criteria unlike the wastewater irrigated soil (WWIS). Significance of pH lies in its influence on the availability of soil nutrients, solubility of toxic elements in the soil and physical break down of root cells (ICARDA, 2001)

Figure 2.3 explains the impact of soil pH on plant nutrient. At high pH values, availability of Phosphorus (P) and most micro nutrients, except Boron (B) and Molybdenum (Mo), tends to decrease. From the municipal wastewater analysis result the pH value of PWIS is very low (1.68) which is away from the 3 – 9 range of a normal soil and 5.5 – 6.5 range of nutrient available soil. Compared to the WWIS of pH 5.4 which is could be considered to contain more nutrient element.

4.2.2 Organic Matter and Organic Carbon

Soil organic matter represents the remains of roots, plant materials, and soil organisms in various stages of decomposition and synthesis. This is variable in composition though occurring in relatively small amount in the soil. Organic matter (OM) has a major influence in soil aggregation, nutrient reserve/availability, moisture retention, and biological activities (ICARDA, 2001).

Making a clear comparison of both soil samples from the analysis result, the potable water irrigated soil (PWIS) contains more organic matter content than the wastewater irrigated soil (WWIS). Therefore, PWIS will be advantageous in nutrient reserve/availability, moisture retention and biological activities. Municipal wastewater will contain high organic content because it is untreated and might readily reduce when it gets into the soil medium.

4.2.3 Cation Exchange Capacity (CEC)

Many mineral elements in the soil are negatively charged and consequently attract and retain cations such as Potassium (K^+), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Ammonium (NH_4^+). Cation exchange is a reversible process, thus, nutrient elements can be held in the soil not lost through leaching, and can subsequently be released for crop uptake (ICARDA, 2001).

A higher CEC value reflects the dominance of soil minerals (Motsara and Roy, 2008). Therefore PWIS of a higher CEC (12.54Cmolkg^{-1}) would have more dominance of soil nutrient than WWIS with 8.60Cmolkg^{-1} CEC value which will subsequently be released into roots for plant growth.

4.2.4 Total Nitrogen (N)

Total nitrogen includes all forms of inorganic nitrogen such as NH_4, NO_3, and NH_2 (Urea), and organic nitrogen compounds such as proteins, amino acid and other derivatives. Nitrogen is a part of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy. Helping plants in rapid growth and improving the quality of leaf (www.agr.state.nc.us). Nitrogen is needed in large percentage and Therefore by comparison, the potable water irrigated soil (PWIS) is better-off having higher total nitrogen composition of 0.098% compared to 0.089% of wastewater irrigated soil (WWIS). Total nitrogen in the soil is subject to several changes (transformation) that dictates the availability of nitrogen to plants. This could be caused by the rate of

mineralization (rate at which bacteria digest organic materials and releases nitrogen to the soil). This variation can also be caused by soil temperature and water content which directly influence the activities and growth of bacteria/microorganisms in the soil (O'Leary *et al.,* 2002).

4.2.5 Phosphorus (P) and Potassium (K)

Like Nitrogen, phosphorus and potassium are essential part of the process of photosynthesis and Involved in the formation of oil, sugar and starch. Phosphorus helps with the transformation of solar energy into chemical energy; proper plant maturation; withstanding stress; effects rapid growth; encourages blooming; root growth and potassium reduces diseases and builds up protein (www.agr.state.nc.us). Phosphorus is classified as a macronutrient because it is needed by plants in relatively large amounts (Busmen *et al.,* 2002). PWIS have higher phosphorus domination of 4.2ppm compared to 3.8ppm composition of WWIS. Considering the range of positive significance of phosphorus to plant (spinach) growth, PWIS is better-off in the stimulation of early plant growth and hastens maturity.

4.3 Plant (Spinach) Nutrient Analysis

Plant nutrient analysis is categorized into classes as proximate analysis, mineral analysis and vitamin analysis as shown in Table 4.4

Table 4.4: Plant (Spinach) Nutrient Analysis Result

Nutrient	Unit	WWGS	PWGS
PROXIMATE:			
Water	g	89.07	90.80
Protein	g	2.70	2.79
Fat/Oil	g	0:36	0.31
Ash	g	2.41	2.50

Carbohydrate	g	5.46	3.60
Fibre	g	1.78	2.00
MINERALS:			
Calcium, Ca	mg	95.00	97.00
Iron, Fe	mg	1.93	1.21
Magnesium, Mg	mg	75.00	76.10
Phosphorus, P	mg	45.10	47.40
Potassium, K	mg	530.00	543.00
VITAMINS:			
Vitamin C	mg	24.10	25.40

Values are in per 100g of edible portion

WWGS – waste water grown spinach
PWGS – potable water grown spinach

Proximates are the food substances in plant that influence growth of living orgarnism including human being (MSRT, 2002). Examples are enlisted above with their respective evaluated composition per 100g of edible portion in spinach (*Spinacia Oleracea*).

Mineral nutrients are defined as all the inorganic elements or inorganic molecules that are required for life. As far as human nutrition is concerned, the inorganic nutrient include sodium, potassium, chlorine, calcium, phosphate, sulphate, iron, copper, zinc, manganese, iodine, selenium and molybdenum (MSRT, 2002). But in this study, the mineral nutrient analyzed are listed aboye.

For better examination and evaluation, Plate 4.1-4.6 shows the observable physical growth difference of both samples under the same growing condition from germination to maturity

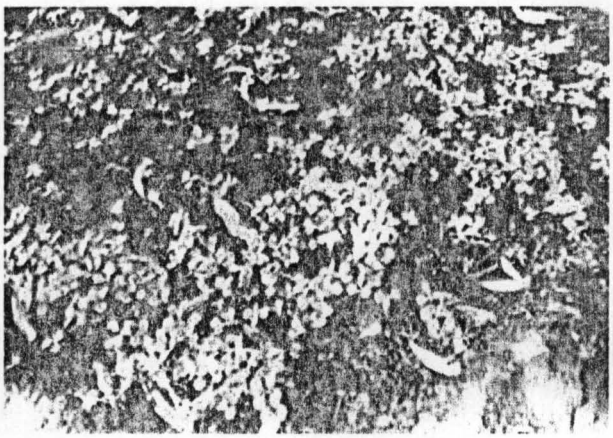


Plate 4.1: Germination Stage of WWGS

Plate 4.2: Germination Stage of PWGS

Plate 4.3: Growing Stage of WWGS

Plate 4.4: Growing Stage of PWGS

Plate 4.5: Maturity Stage of WWGS

Plate 4.6: Maturity Stage of PWGS

Table 4.5: Observable Physical Growth Differences between WWGS and PWGS

GROWTH STAGES	WWGS	PWGS
Germination	Lesser plant population at germination	Greater plant population
Growing Period	- High prevalence of weeds which hinders growth	- Less prevalence of weeds
	- Plant population declines	- Plant population increases
Maturity	-By weeding, productivity can be reclaimed	- Also necessary
	- Comparing the population at germination to that at maturity, the WWGS is favoured	- Comparing the population at germination to that at maturity, the plantation is not favoured

4.3.1 Comparison and Evaluation of Plant (Spinach) Analysis Result

Table 4.6 shows the standards of the analyzed nutritional levels of spinach (*Spinacia Oleracea*) sourced from the USDA National nutrient database, 2004 (see Table 2.7) and comparisons of both WWGS and PWGS to those of the USDA standard values having considered the standard error involved.

Table 4.6: Comparison and Evaluation of Plant (Spinach) Analysis Result

NUTRIENT	Unit	USDA	(±) Std Error	WWGS	WWGS*	PWGS	PWGS*
PROXIMATE:							
Water	g	91.40	0	89.07	87.07	90.80	90 80
Protein	g	2.86	0.112	2.70	2.81	2.79	2.90
Fat/Oil	g	0.39	0.032	0.36	0.39	0.31	0.34
Ash	g	1.72	0.035	2.41	2.45	2.50	2.54
Carbohydrate	g	3.63	0	5.46	5.46	3.60	3.60
Fibre	g	2.2	0	1.78	1.78	2.00	2.00
MINERALS:							
Calcium, Ca	mg	99	4.996	97.00	101.2	95.00	99.2
Iron, Fe	mg	2.71	0.522	1.21	1.73	1.93	2.45
Magnesium, Mg	mg	79	4.794	76.10	80.89	75.00	79.79
Phosphorus, P	mg	49	3.479	47.40	50.88	45.10	48.58

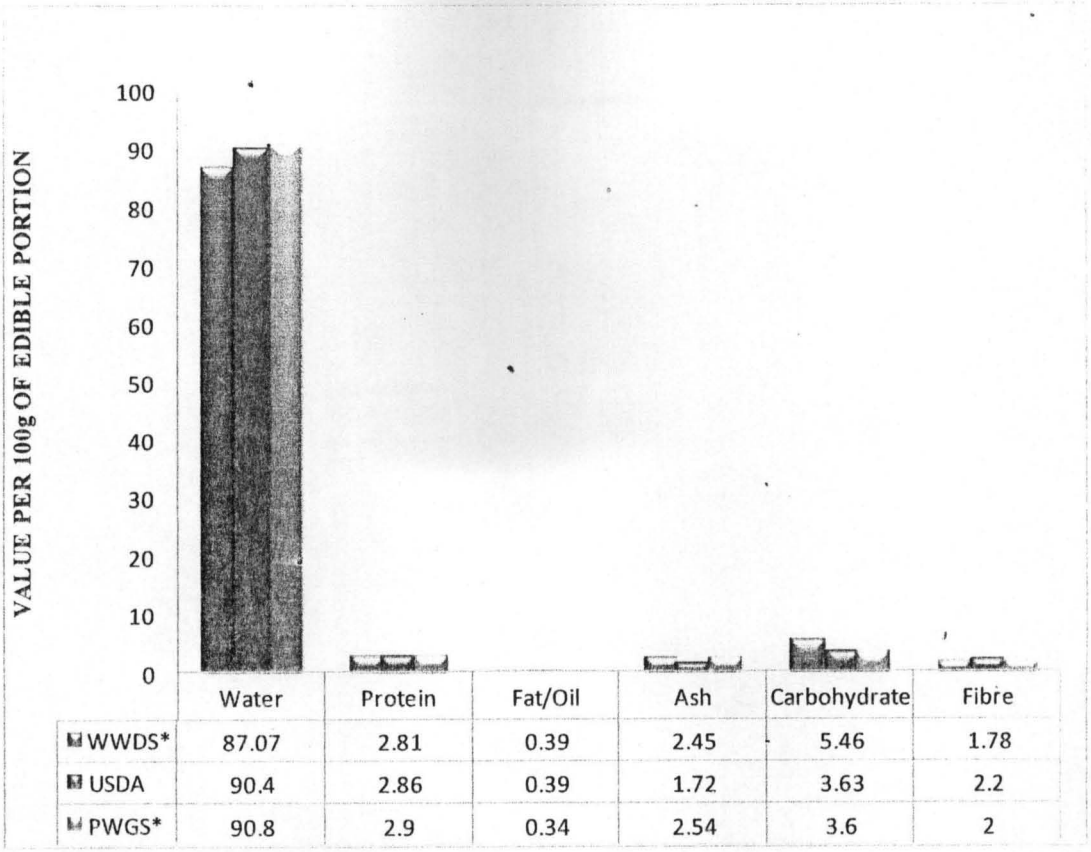
Potassium, K	mcg	558	28.703	543.00	571.70	530.00	558.70
VITAMINS:							
Vitamin C	mg	28.1	4.129	25.4	29.53	24.1	28.22

Values are in per 100g of edible portion

WWGS* – waste water grown spinach having compared with the USDA's
PWGS* –potable water grown spinach having compared with the USDA's

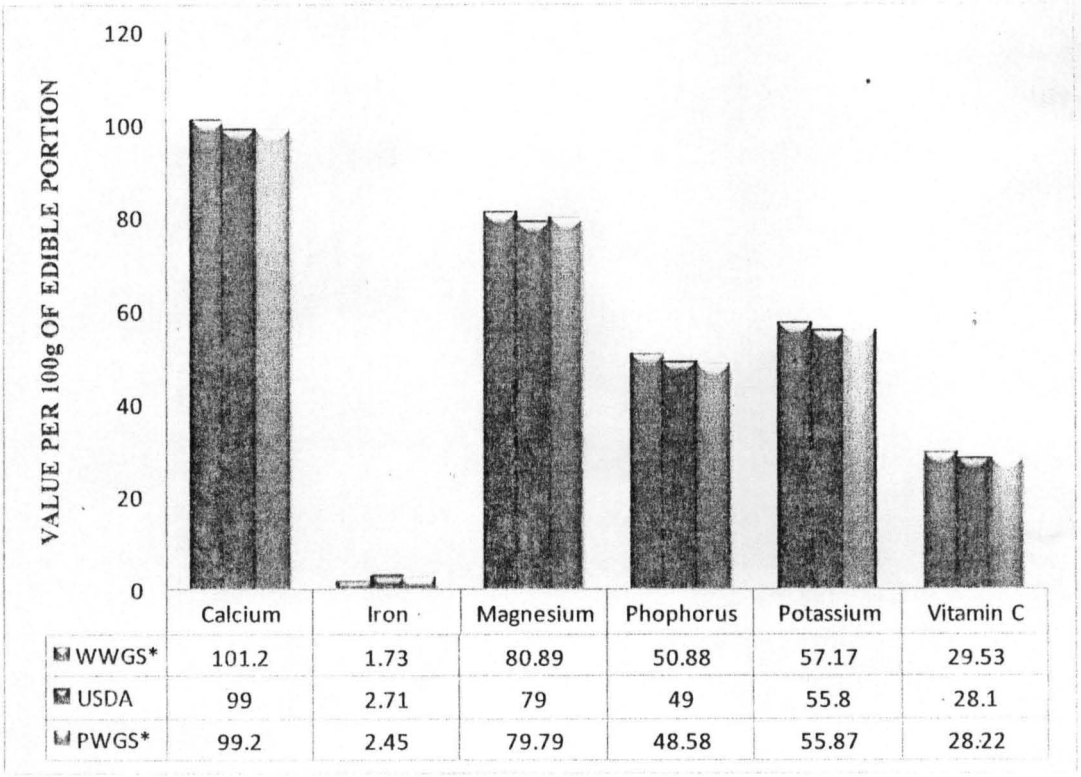
Evaluation and comparison of portable water grown spinach (PWGS) and wastewater grown spinach (WWGS) by a simple arithmetic of adding or subtracting the standard allowable error of the USDA to the analysis result of the PWGS and WWGS to give an evaluated/compared value as PWGS* and WWGS* respectively. That is,

$$\text{PWGS} \pm \text{Std Error} = \text{PWGS}^*$$



	Water	Protein	Fat/Oil	Ash	Carbohydrate	Fibre
WWDS*	87.07	2.81	0.39	2.45	5.46	1.78
USDA	90.4	2.86	0.39	1.72	3.63	2.2
PWGS*	90.8	2.9	0.34	2.54	3.6	2

Fig.4.1: Pictorial Comparison of Proximates



	Calcium	Iron	Magnesium	Phophorus	Potassium	Vitamin C
WWGS*	101.2	1.73	80.89	50.88	57.17	29.53
USDA	99	2.71	79	49	55.8	28.1
PWGS*	99.2	2.45	79.79	48.58	55.87	28.22

Fig.4.2: Pictorial Comparison of Minerals

From the above figures, the nutritional level of the potable water grown spinach (PWGS) is generally closer to the USDA standard nutritional level for spinach except for fat/oil in the proximates where the wastewater grown spinach (WWGS) is the same as the USDA standard nutritional value for spinach having considered the standard error. The reason being that the wastewater irrigated soil (WWIS) readily and excessively gives up mineral nutrient to the plant (see Fig 4.2) that nurtures the growth of fat/oil in plants. Figure 4.2 depicts that toxicity (excess of plant mineral nutrient) problem occurs in WWGS having exceeded the USDA's standard. This could be detrimental to human health.

Considering the relative impact of the soils pH on the respective plant (spinach) nutrient, pH values of WWIS and PWIS have no much difference in value (5.4 and 5.68 respectively) to show visible variations in their impacts on plant nutrient considering the descriptive nature of Figure 2.3. But from all indication, as it relates to this study, wastewater irrigated soil (WWIS) readily gives up more mineral element to plant which consequently causes toxicity. This is also the reason why on analyzing the soil samples after harvest, the WWIS composes of lesser percentages mineral elements available compared to the potable water irrigated soil (PWIS) because it readily and excessively releases its mineral content to the plant thereby causing toxicity.

4.4 Impact of Mineral Toxicity in Human

Mineral toxicity may also relate to toxicity that can be the result of certain diseases or injuries. For example, hemochromatosis results from iron toxicity; wilson's disease results from copper toxicity and severe trauma can lead to hyperkalemia (potassium toxicity) (MSRT, 2002).

4.4.1 Calcium and Phosphate Toxicity

Calcium and phosphate are closely related nutrients. Calcium toxicity is rare, but over consumption of calcium supplements may lead to deposits of calcium phosphate in the tissues

of the body, shrinking the brain cells, coma, paralysis of the lung muscles and death (MSRT, 2002).

4.4.2 Iron Toxicity

Iron toxicity can result to vomiting, diarrhea, abdominal pain, seizures, and possibly coma. In the second period of iron poisoning, the patient's symptoms appears to improve; however, this phase is followed by a terminal phase in which shock, low blood sugar levels, liver damage, convulsions, and death occur (MSRT, 2002).

4.4.3 Nitrate Toxicity

Nitrate is naturally present in green leafy vegetables. It is rapidly converted into nitrite by the bacteria that live in the mouth as well as in the intestine and then absorbed into the bloodstream, Poisoning by nitrite results in inability of hemoglobin to carry oxygen throughout the body. This condition can be seen by the blue colour of the skin. Adverse symptom occurs when over 30% of the hemoglobin has been converted to methemoglobin. These symptoms include cardiac arrhythmias, headache, nausea, and vomiting, and in severe cases, seizure (MSRT, 2002).

4.4.4 Potassium Toxicity

The normal level of potassium in the bloodstream is in the range 3.5 – 5.0mM, while levels of 6.3 – 8.0mM (severe hyperkalemia) results in cardiac arrhythmias or oven death due to cardiac arrest (MSRT, 2002).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

After careful analysis and testing of the wastewater, the soils and the spinach plant samples, it is clearly convincing that standard nutrient, mineral and vitamin cannot be attained or reached for vegetable crops and plants that have similar salt tolerance to that of spinach (*Spinacia Oleracea*) when wastewater irrigation is adopted. Having compared to those irrigated with potable water and relating both to the standard spinach nutritional level of the USDA nutrition database, 2004

As it relates to this study, wastewater irrigated soil (WWIS) readily gives up mineral element to plant which consequently causes toxicity (excess of mineral nutrient). This is also the reason why on analyzing the soil samples after harvest, the WWIS composes of lesser percentages mineral elements available compared to the potable water irrigated soil (PWIS) as WWIS readily and excessively releases its mineral content to the plant. Although, the WWIS show an appreciable physical growth than the PWIS but unlike the PWIS that lesser deviation it has wider deviation from its standard nutritional value of the USDA which is detrimental to the health of the consumers. Thus, farmer would rather adopt the irrigation with wastewater so as to make better profits considering the physical size of the plant.

5.2 Recommendation

Obviously, the most effective method to prevent occurrence of a toxicity problem is to choose irrigation water that has no potential to develop a toxicity problem. But if such water is not available, there often management options that can be adopted to reduce toxicity and improve yields.

5.2.1 Leaching (Washing Away of Minerals)

Leaching can be used to prevent a toxicity problem or correct the problem after it has been recognized from plant symptoms or damages caused to the crops. This is achieved by washing the minerals so as to reduce its toxicity

5.2.2 Crop Selection

Selection of more tolerant crop offers a very practical solution to toxicity problem. From this study and research, it is recommended that for vegetable crops and crops that are moderately sensitive to salt as spinach such as cabbage (*Oleracea Capitata*), lettuce (*Letuca Sativa*), pepper (*Capsicum Annum*), potato (Solanum Tuberosum), tomato (*Lycopersicon Lycopersicum*), and watermelon (*Citrullus Lanatus*), (FAO,1999) should not be irrigated with wastewater because of the prevalence of toxicity and toxic mineral element that hinders their growth and consequently depletes their nutritional value.

5.2.3 Cultural Practices

Since leaching is the principal method of toxic ion control, cultural practices to aid in management of irrigation water at the farm level are the keys to success. Cultural practices which offer better control and distribution of water include land grazing, profile modification, and artificial drainage if natural drainage is inadequate.

5.2.4 Blending Water Supplies

If an alternative water supply is available, but may not fully be adequate in quantity and quality, a blend of waters may offer an overall improvement in quality and reduce potential toxicity problem.

As it relates to this study (research work), Heavy Metals [metals that are often toxic to organisms, having relative density of 5.0 or higher e.g. lead, mercury, copper, cadmium, chromium, zinc, arsenic etc. Microsoft Encarta, (2009)] could cause considerable negative

impacts on the growth and nutritional value of spinach and other related vegetable crops. Thus, a further study is recommended on assessing the impacts of metals present in wastewater reused for irrigation as it affects nutrient.

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APPENDICES

Appendix A: Water Analysis

1.0 WATER pH

Methodology: the pH value of each sample was measured using the pH meter. The pH meter was first calibrated, and then its electrode and surrounding area was rinse with distilled water using the squeeze bottles and dried with soft tissue. A dry 100mL beaky deep was filled to the 50mL line with the water sample. The electrode was immersed into the water. The sample was stirred once and then the displayed value was allowed to stabillised. The value was read and recorded and the same procedure was repeated for the rest sample.

2.0 ELECTRICAL CONDUCTIVITY

A CMD 800 hydro check conductivity meter was used to determine the conductivity of the effluent sample. Before meaningful and repeatable measurement of conductivity was made, the setting for cell constant K and sample temperature were made for specific conductivity at 25°C or at least known for absolute measurement. To view the cell constant K, µs (micro siemens) was switched on to by key A. Then C + A (hold) – K was displayed. Making measurement, key A was switched on and cell inserted into test solution and then the reading was displayed.

3.0 TOTAL DISSOLVED SOLIDS (TDS)

Methodology: The water sample is filtered through a standard glass fibre filter, and the filtrate is evaporated to dryness in a weighed dish and dried at 180°C. The increase in weight over that of the empty dish represents the total dissolved solids.

Materials

- Evaporating dishes: porcelain, platinum, high-silica glass (e.g Vycor), stainless steel or aluminium. Platinum or Vycor are preferable. Porcelain dishes are not recommended owing to a tendency to lose weight. However, they may be used if the other materials are not available. Platinium dishes are not available in many laboratories owing to their high cost.
- Buchner funnel and suction flask or Millipore filtration unit
- Glass fibre filter paper, whatman GF/C, or similar
- Hot water bath

Experimental procedure: heat evaporating dish of approximate size in oven at 180°C for 1hour. Cool in a dessicator and weigh. Measure accurately at a volume (100-500mL) of well mixed sample and pass through the filter under slight suction. Wash any remaining solid from the measuring cylinder with three successive 10mL portion of laboratory water and pass the washings through the filter. Transfer filtrates to a pre-weighed evaporating dish and evaporate to dryness on a hot water bath. If filtrate value exceeds dish capacity, add successive portions to the same dish after evaporation.dry for at least 1hour in an oven at 180°C, cool in a desicator and weigh. Calculate the total dissolved solids (TDC) using the same equation as in total solids.

Notes

1. Residues dried at 180°C will lose almost all mechanically included water
2. Highly mineralized water from arid and semi arid regions containing high levels of calcium, magnesium, chloride and /or sulphate content may be hygroscopic and require prolonged dried, efficient desiccation and rapid weighing. Samples high in bicarbonate may require prolonged drying at 180°C to ensure complete conversion of bicarbonate to carbonate.

For accurate work, repeat the drying, desiccating and weighing cycle as for total solids

4.0 DETERMINATION OF CHLORIDE

A suitable portion of the sample was diluted to100ml. 3ml Al $(OH)_3$ suspension was added, mixed, left to settle, and then filtered. If sulfate, sulfide or sulfite is present, 1ml H_2O_2 is added and stirred for about 1 minute. 1ml K_2CrO_4 indicator solution is then added and titred with standard $AgNO_3$ titrant to a pinkish yellow end point. It is important to be consistent in end – point recognition.

5.0 NITRATE

Methodology: Two moles of NO_3^- react with one mole of chromotropic acid to form a yellow reaction product, the absorbance of which is measured at 410nm. The method can be used to determine nitrate concentrations in the range 0.1 – 5mg NO_3^- - NL^{-1}. It is necessary to eliminate interference by nitrate, residual chlorine and certain oxidants which yield yellow colour when they react with chromotropic acid. Interference from residual chlorine and oxidizing agent can be eliminated by addition of sulfite. Urea eliminates nitrite interference by converting it to N_2 gas. Addition of antimony can mark up to 2000mg $Cl^- L^{-1}$.

Materials:

- Spectrophotometer
- Cooling bath
- Stock nitrate solution, 100µg NO_3^-N mL^{-1}. Prepare by diluting a commercially available 1000mg L^{-1} solution. Otherwise prepare as follows dry sodium nitrate ($NaNO_3$) in an oven at 105°C for 24hours. Dissolve 0.607g of the dried salt in water and dilute to 100mL.

- Working nitrate solution. 10μg NO_3^- - N mL^{-1}. Pipette 50mL o the stock solution into a 500 mL volumetric flask and make up to the mark with water.

- Sulphite – urea reagent. Dissolve 5g urea and 4g anhydrous Na_2SO_3 in water and dilute to 100mL.

- Antimony reagent. Heat 0.5g of antimony metal in 80 mL of concentrated H_2SO_4 until all the metal has dissolved. Cool the solution and cautiously add to 20mL iced water. If crystals form after standing overnight, redissolve the heating.

- Purified chromotropic acid solution (0.1%). Boil 125 mL of water in a beaker and gradually add 15 g of 4, 5-dihydroxyl-2, 7-naphthalene-disulfonic acid disodium salt, while stirring constantly. Add 5g of decolourising activated charcoal and boil the mixture for 10minute. Add water to make up for loss due to evaporation. Filter the hot solution through cotton wool. Add 5g of activated charcoal to the filtrate and boil for 10minutes. Remove the charcoal completely from the solution by filtering, first through cotton wool and then through filtered paper. Cool and add slowly 10mL o concentrated H_2SO_4. Boil the solution down to 100mL in a beaker and stand overnight. Transfer crystals of chromotropic acid to a Buchner funnel and wash thoroughly with 95% ethyl alcohol until crystals are white.dry the crystals in an oven at 80°C. prepare a 0.1% solution by dissolving 100mg of the purified chromotropic acid in 100mL of concentrated H_2SO_4 and store in a brown bottle. This solution is stable for two weeks. If the sulphuric acid is free from nitrate impurities the solution should be colourless.

- Sulphuric acid, concentrated high purity.

Experimental procedure: *(a) storage of samples;* result form most reliable when nitrate ion is determined in fresh samples. For short term preservation of up to 1day, samples can be stored in refrigerator at 4°C. if it is not possible to carry out the analysis promptly, samples can be preserved by adding 0.5-1.0mL of concentrated H_2SO_4 per litre of sample and store at 4°C.

(b) Analyses; prepare nitrate standards in the range 0.1-5 mg $NO_3^-NL^{-1}$ by pipetting 1, 5, 10, 20, 40 and 50mL of the working nitrate solution into a series of 100mL volumetric flasks and making up to the mark with water. Filter the sample if significant amounts of suspended matter are present. Pipette 2mL aliquots of samples, standards and a urea reagent to each flask. Place flasks in a trey of cool water with a temperature between 10-20°C and add 2mL of the antimony reagent swirl the flasks when adding to each reagent. After the flasks have stood in the bath for about 4 minute. Add 1 mL of the antimony reagent. Swirl the flasks again and allow to stand in the cooling bath for another 3 minute. Make up to the mark concentrated H_2SO_4 . stop and mix with contents by inverting them 4 times. Allow the flasks to stand at room temperaturefor 45 minute and again adjust the volume to 10mL with concentrated H_2SO_4. Finally, mix very gently to avoid introducing gas bubbles. Allow the flasks to stand for at least 15 minutes before measuring the absorbance at 410 nm using a 1cm cell with water in the reference cell. Subtract the absorbance reading of the water blank from the absorbances of samples and standard. Prepare a calibration graph of net absorbance against mg NO_3^- - NL^{-1} based on the standard measured and read off directly the concentration of NO_3^- (expressed as mg NL^{-1}) in the samples.

6.0 MEASUREMENT OF CONDUCTIVITY

A CMD 800 hydro check conductivity meter was used to determine the conductivity of the effluent sample. Before meaningful and repeatable measurement of conductivity was made, the setting for cell constant K and sample temperature were made for specific

conductivity at 25°C or at least known for absolute measurement. To view the cell constant K, μs (micro siemens) was switched on to by key A. Then C + A (hold) – K was displayed. Making measurement, key A was switched on and cell inserted into test solution and then the reading was displayed.

7.0 TURBIDITY DETERMINATION

The JMP turbidity meter was placed on a flat and level surface which was calibrated with the recommended standards. The prepared sample was placed and aligned with the meter's index mark. The vial is pushed until it is fully snapped in. The vial is covered with the light shield cap and turned on by pressing the ON key. A value appears after about 12 seconds. This is the turbidity value.

8.0 ALKALINITY MEASUREMENT

100ml of the sample was measured out into a 250ml beaker and titrated using 0.02M H_2SO_4. 3 – 4 drops of bromeresol green indicator was put and titrated till the colour changed from green to yellow.

$$Alkalinity = \frac{(A - B) \times 50000}{ml\ of\ sample}$$

Where A = ml standard acid used for sample

B = ml standard acid used for blank

N = Normality of acid used (0.02M)

9.0 CHEMICAL OXYGEN DEMAND TEST

10ml of the effluent sample was transferred into a conical flask and diluted to 100ml with pure water. 2ml of 8% NaOH solution was added and the mixture heated to boil. 10ml

of $KMnO_4$ was added and boiling continued for about 15 minutes. Finally, 10ml oxalic acid was added and the solution was back titrated hot.

$$COD = \frac{ml\ of\ 0.1M\ KMnO_4 \times 0.08NaOH \times 1000}{ml\ of\ sample}$$

Appendix B: Soil Analysis

1.0 SOIL MOISTURE

The procedure for determining the soil moisture is:

1. Put 100 g of soil sample in the aluminium moisture box and place in the oven after removing the lid of the box.

2. Keep the sample at 105 °C until it attains a constant weight. This may take 24–36 hours.

3. Cool the sample, first in the switched-off oven and then in a desiccator.

4. Weigh the cooled sample. The loss in weight is equal to the moisture contained in 100-g soil sample.

The percentage of moisture is calculated as:

$$moisture\ content = \frac{oven\ dry\ soil - dry\ wt.\ of\ soil}{loss\ in\ wt.} \times 100$$

2.0 SOIL pH

The apparatus required in order to measure soil pH consists of:

- A ph meter with a range of 0–14 pH;
- A pipette/dispenser;
- Some beakers;
- A glass rod.

The reagents required are:

- Buffer solutions of pH 4, 7 and 9.
- Calcium chloride solution (0.01M): dissolve 14.7 g of $CaCl_2.2H_2O$ in 10 litres of water to obtain 0.01M solution.

The procedure for measuring soil pH is:

1. Calibrate the pH meter, using two buffer solutions, one should be the buffer with neutral pH (7.0) and the other should be chosen based on the range of pH in the soil. Put the buffer solutions in the beakers. Insert the electrode alternately in the beakers containing the two buffer solutions, and adjust the pH. The instrument indicating pH as per the buffers is ready to test the samples.

2. Place 10.0 g of soil sample into a 50-ml or 100-ml beaker, add 20 ml of $CaCl_2$ solution (use water instead of $CaCl_2$ solution throughout the procedure where water is used as a suspension medium).

3. Allow the soil to absorb the $CaCl_2$ solution without stirring, then stir thoroughly for 10 seconds using a glass rod.

4. Stir the suspension for 30 minutes, and record the pH on the calibrated pH meter.

Based on soil pH values. Acid soils need to be limed before they can be put to normal agricultural production. Alkali soils need to be treated with gypsum in order to remove the excessive content of Na.

pH range Soil reaction rating

< 4.6 Extremely acidic

4.6–5.5 Strongly acidic

5.6–6.5 Moderately acidic

6.6–6.9 Slightly acidic

7.0 Neutral

7.1–8.5 Moderately alkaline

> 8.5 Strongly alkaline

3.0 ORGANIC CARBON / ORGANIC MATTER

The apparatus required using this method consists of:

- A sieve;
- A beaker;
- An oven;
- A muffle furnace.

The procedure is:

1. Weigh 5.0–10.0 g (to the nearest 0.01 g) of sieved (2 mm) soil into an ashing vessel (50-ml beaker or other suitable vessel).

2. Place the ashing vessel with soil in a drying oven set at 105 °C and dry for 4 hours. Remove the ashing vessel from the drying oven and place in a dry atmosphere. When cooled, weigh to the nearest 0.01 g. Place the ashing vessel with soil into a muffle furnace, and bring the temperature to 400 °C. Ash in the furnace for 4 hours. Remove the ashing vessel from the muffle furnace, cool in a dry atmosphere, and weigh to the nearest 0.01 g.

The percentage of OM is given by:

$$percentage\ organic\ matter\ = \frac{(w1 - w2)}{w1} \times 100$$

Where:

W1 is the weight of soil at 105 °C;

*W*2 is the weight of soil at 400 °C.

The percent of organic C is given by: % OM × 0.58.

4.0 TOTAL NITROGEN

The apparatus required for this method consists of:

- A Kjeldahl digestion and distillation unit;
- Some conical flasks;
- Some burettes;
- Some pipettes.

The reagents required are:

- Tetraoxosulphate(vi)acid (93–98 percent).
- Copper sulphate ($CuSO_4.H_2O$)
- Potassium sulphate 35-percent sodium hydroxide solution: dissolve 350 g of solid NaOH in water and dilute to 1 litre.
- 0.1m NaOH: prepare 0.1m NAOH by dissolving 4.0 g of NaOH in water and make the volume up to 1 litre. Standardize against 0.1m potassium
- Hydrogen phthalate or standard H_2SO_4.
- 0.1m HCl or 0.05m H_2SO_4: prepare approximately the standard acid solution and standardize against 0.1m sodium carbonate.
- Methyl red indicator.
- Salicylic acid for reducing NO_3 to NH_4, if present in the sample.
- Devarda's alloy for reducing NO_3 to NH_4, if present in the sample.

The procedure is:

1. Weigh 1 g of soil sample. Place in a Kjeldahl flask.

2. Add 0.7 g of copper sulphate, 1.5 g of K_2SO_4 and 30 ml of H_2SO_4.

3. Heat gently until frothing ceases. If necessary, add a small amount of paraffin or glass beads to reduce frothing.

4. Boil briskly until the solution is clear and then continue digestion for at least 30 minutes.

5. Remove the flask from the heater and cool, add 50 ml of water, and transfer to a distilling flask.

6. Place accurately 20–25 ml of standard acid (0.1M HCl or 0.05M H_2SO_4) in the receiving conical flask so that there will be an excess of at least 5 ml of the acid. Add 2–3 drops of methyl red indicator. Add enough water to cover the end of the condenser outlet tubes.

7. Run tap-water through the condenser.

8. Add 30 ml of 35-percent NaOH in the distilling flask in such a way that the contents do not mix.

9. Heat the contents to distil the ammonia for about 30–40 minutes.

10. Remove the receiving flask and rinse the outlet tube into the receiving flask with a small amount of distilled water.

11. Titrate excess acid in the distillate with 0.1M NaOH.

12. Determine blank on reagents using the same quantity of standard acid in a receiving conical flask.

The calculation is:

$$percent\ N = \frac{1.401\ [(V1M1 - v2m2) - (V3M1 - V4M2)}{W} \times df$$

Where:

$V1$ – millilitres of standard acid put in receiving flask for samples;

$V2$ – millilitres of standard NaOH used in titration;

$V3$ – millilitres of standard acid put in receiving flask for blank;

$V4$ – millilitres of standard NaOH used in titrating blank;

$M1$ – molarity of standard acid;

$M2$ – molarity of standard NaOH;

W – weight of sample taken (1 g);

df – dilution factor of sample (if 1 g was taken for estimation, the dilution factor will be 100).

Note: 1 000 ml of 0.1M HCl or 0.05M H_2SO_4 corresponds to 1.401 g of N.

- The following precautions should be observed:
- The material should not solidify after digestion.
- No NH_4 should be lost during distillation.

- If the indicator changes colour during distillation, determination must be repeated using either a smaller sample weight or a larger volume of standard acid.

5.0 AVAILABLE POTASSIUM

The apparatus required consists of:

- A multiple dispenser or automatic pipette (25 ml);
- Some flasks and beakers (100 ml);
- A flame photometer.

The reagents required are:

- Molar neutral ammonium acetate solution: Dissolve 77 g of ammonium acetate ($NH_4C_2H_3O_2$) in 1 litre of water. Check the pH with bromothymol blue or with a pH meter. If not neutral, add either ammonium hydroxide or acetic acid as per the need in order to neutralize it to pH 7.0.
- Standard potassium solution: Dissolve 1.908 g of pure KCl in 1 litre of distilled water. This solution contains 1 mg K/ml. Take 100 ml of this solution and dilute to 1 litre with ammonium acetate solution. This gives 0.1 mg K/ml as a stock solution.
- Working potassium standard solutions: Take 0, 5, 10, 15 and 20 ml of the stock solution and dilute each volume separately to 100 ml with the molar ammonium acetate solution. These solutions contain 0, 5, 10, 15 and 20 µg K/ml, respectively.

The procedure is:

1. Preparation of the standard curve: Set up the flame photometer by atomizing 0 and 20 µg K/ml solutions alternatively to readings of 0 and 100. Atomize intermediate working standard solutions and record the readings. Plot these readings against the respective K contents and connect the points with a straight line to obtain a standard curve.

2. Extraction: Add 25 ml of the ammonium acetate extractant to a conical flask fixed in a wooden rack containing 5 g of soil sample. Shake for 5 minutes and filter.

3. Determine the potash in the filtrate with the flame photometer.

The calculation is:

$$K\left(Kg/_{ha}\right) = \frac{A}{1000000} \times 25 \times \frac{2000000}{5}$$

Where:

A = content of k (µg) in the sample, as read from the standard curve;

Volume of the extract = 25 ml;

Weight of the soil taken = 5 g;

Weight of 1 ha of soil down to a plough depth of 22 cm is taken as 2 million kg.

6.0 EXCHANGEABLE CALCIUM AND MAGNESIUM

The apparatus required consists of:

- A shaker;
- A porcelain dish;
- Some beakers;
- A volumetric/conical flask.

The reagents required are:

- Ammonium chloride – ammonium hydroxide buffer solution: Dissolve 67.5 g of ammonium chloride in 570 ml of concentrated ammonium hydroxide, and make up to 1 litre.
- Standard 0.01N Ca solution: Take accurately 0.5 g of pure calcium carbonate and dissolve it in 10 ml of 3N HCl. Boil to expel CO_2 and then make the volume up to 1 litre with distilled water.
- EDTA solution (0.01N): Take 2.0 g of versenate, dissolve in distilled water and make the volume up to 1 litre. Titrate it with 0.01N Ca solution and make the necessary dilution so that its normality is exactly equal to 0.01N.

- Muroxide indicator powder: Take 0.2 g of muroxide and mix it with 40 g of powdered potassium sulphate. This indicator should not be stored in the form of solution, otherwise it oxidizes.
- Sodium diethyl dithiocarbamate crystals: These are used to remove interference by other metal ions.

The procedure is:

1. Put 5 g of air-dried soil sample in a 150-ml conical flask and add 25 ml of neutral normal ammonium acetate. Shake on a mechanical shaker for 5 minutes and filter through No. 1 filter paper.

2. Take a suitable aliquot (5 or 10 ml) and add 2–3 crystals of carbamate and 5 ml of 16 percent NaOH solution.

3. Add 40–50 mg of the indicator powder. Titrate it with 0.01N EDTA solution until the colour changes gradually from orange-red to reddish-violet (purple). Add a drop of EDTA solution at intervals of 5–10 seconds, as the change of colour is not instantaneous.

4. The end point must be compared with a blank reading. If the solution is overtitrated, it should be backtitrated with standard Ca solution; thus, the exact volume used is found.

5. Note the volume of EDTA used for titration.

The calculation is:

If N_1 is normality of Ca^{2+} and V_1 is volume of aliquot taken and N_2V_2 are the normality and volume of EDTA used, respectively, then:

$N_1V_1 = N_2V_2$

$$N1 = \frac{N2V2}{V1} \times \frac{Normality\ of\ EDTA\ \times Vol.of\ EDTA}{ml\ of\ aliquot\ taken}$$

Here, N_1 (normality) = equivalent of Ca^{2+} present in 1 litre of aliquot. Hence, Ca^{2+} me/litre is:

$$\frac{Normality\ of\ EDTA\ \times Vol.\ of\ EDTA}{ml\ of\ aliquot\ taken} \times 100$$

Appendix C: Plant Analysis

1.0 DRY ASHING

High-temperature oxidation destroys the OM. The plant sample is ashed at 500–600 °C by placing a suitable weight (0.5–1.0 g) of the sample in a silica crucible and heating it in a muffle furnace for 4–6 hours. The ash residue is dissolved in dilute HNO_3 or HCl, filtered through acid-washed filter paper in a 50/100-ml volumetric flask, and the volume is made up to the mark. The estimation of K, Ca, Mg and micronutrients (including B and Mo) is carried out in the dry-ashed sample solution. Dry ashing is a preferred method for the analysis of P, K, Ca, Mg and trace elements, especially B and Mo. It is a relatively simple method and requires very little operational attention. It does not involve the use of perchloric acid. It also avoids the use of boiling acids. However, at times, incomplete recovery of some elements may be caused by:

_ Volatilization of elements such as S (also Se and halogens). To avoid loss of S, $Mg(NO_3)_2$ should be mixed with plant samples while dry ashing.

_ Retention of elements such as Cu on the walls of silica crucibles. Hence, platinum crucible should be used.

_ Formation of compounds that are not completely soluble in the acid used for digestion.

A blank should always be carried out to account for any contamination

through the acids used in the digestion.

2.0 NITROGEN

Total N in plants is estimated by the Kjeldahl method. In plants, N is present in protein form, and digestion of the sample with H_2SO_4 containing digestion mixture (10 parts potassium sulphate and 1 part copper sulphate) is required for estimation. Sample size may be 0.5–1.0 g depending on the type of crop and the plant part.

The procedure for sample digestion, distillation and estimation of N is the same as for total N estimation in soil.

3.0 PHOSPHORUS

The P content of the plant sample is converted to orthophosphates by digestion with an acid mixture (di-acid or tri-acid). The digested sample is used for P estimation. When orthophosphates are made to react with molybdate and vanadate, a yellow-coloured vanadomolybdophosphoric heteropoly complex is formed.The intensity of the yellow colour is directly proportional to the concentration of P present in the sample, which can be read on the spectrophotometer.

The apparatus required consists of:

- A digestion block;
- A spectrophotometer;
- Some beakers/flasks.

The reagents required are:

- Ammonium molybdate – ammonium vanadate in HNO_3 (vanadomolybdate): Dissolve 22.5 g of $(NH_4)_6MO_7O_2.4H_2O$ in 400 ml of distilled water. Dissolve 1.25 g of ammonium vanadate in 300 ml of boiling distilled water. Add the vanadate solution to the molybdate solution and cool to room temperature. Add 250 ml of concentrated HNO_3 and dilute to 1 litre.
- Standard phosphate solution: Dissolve 0.2195 g of analytical-grade KH_2PO_4 and dilute to 1 litre. This solution contains 50 µg P/ml.

The procedure is:

1. Preparation of the standard curve: Put 0, 1, 2, 3, 4, 5 and 10 ml of standard solution (50 µg P/ml) in 50-ml volumetric flasks. Add 10 ml of vanadomolybdate reagent to each flask and

make up the volume. The P contents in these flasks are 0, 1, 2, 3, 4, 5 and 10 µg P/ml, respectively.

The standard curve is prepared by measuring these concentrations on a spectrophotometer (420 nm) and recording the corresponding absorbances.

2. Take 1 g of plant sample and digest as per the wet digestion method, and make the volume up to 100 ml.

3. Put 5 ml of digest in a 50-ml volumetric flask, and add 10 ml of vanadomolybdate reagent.

4. Make up the volume with distilled water, and shake thoroughly. Keep for 30 minutes.

5. A yellow colour develops, which is stable for days and is read at 420 in spectrophotometer.

6. For the observed absorbance, determine the P content from the standard curve.

The relevant calculation is:

$$P\ content\ (g)\ in\ 100g\ samples\ (\%P) - \frac{C \times df \times 100}{1000000} - \frac{C \times 1000 \times 100}{1000000} - \frac{C}{10}$$

Where:

C = concentration of P (µg/ml) as read from the standard curve;

df = dilution factor, which is 100 × 10 = 1 000, as calculated below:

• 1 g of sample made to 100 ml (100 times);

• 5 ml of sample solution made to 50 ml (10 times).

1 000 000 = factor for converting µg to g.

4.0 POTASSIUM

The acid-digested or dry-ashed plant sample is used for determining K.

The apparatus required consists of:

- An AAS;
- Some volumetric flasks.

The reagents required are:

- Di-acid/tri-acid digestion mixture.
- KCl (AR-grade) standard solution: Dissolve 1.908 g of pure KCl in 1 litre of distilled water. This solution contains 1 mg K/ml. Take 100 ml of this solution and dilute to 1 litre. This will give 100 µg K/ml as stock solution. KCl working standard solution: Put 5, 10, 15 and 20 ml of stock solution in 100-ml volumetric flasks. Make up the volume. This will give 5, 10, 15 and 20 µg K/ml, respectively.

The procedure is:

1. Set up the AAS and standardize. The relevant parameters for K estimation on an AAS are:

lamp current = 6 m A°;

wavelength = 766.5 mm;

linear range = 0.4–1.5 µg/ml;

slit width = 0.5 mm;

integration time = 2 seconds;

flame = air acetylene.

2. Preparation of the standard curve: Prepare the standard curve using 0, 5, 10,15 and 20 µg K/ml. The curve will show a linear relationship between the concentration of K and absorbance on a specific wavelength as read from the AAS.

3. Acid-digest 1 g of plant sample and make up to 100 ml. Keep the sample for estimation in the range 5–10 mg K/kg (5–10 µg K/ml) by further diluting as appropriate.

4. Prepare a blank in the same way without adding plant digested material.

5. Take an aliquot of 5 ml for estimation and make up to 100 ml. Atomize on the calibrated AAS, on which the standard curve has also been prepared.

6. Record the absorbance against each sample.

7. From the standard curve, note the concentration of K for the particular absorbance observed for the sample.

The relevant calculation is:

$$K\ content\ (g)\ in\ 100g\ samples\ (\%K) = \frac{C \times df \times 100}{1000000} = \frac{C \times 2000 \times 100}{1000000} = \frac{C}{5}$$

Where:

C = concentration of K (µg/ml) as read from the standard curve;

df = dilution factor, which is 100 × 20 = 2 000, as calculated below:

• 1 g of sample made to 100 ml (100 times);

• 5 ml of sample solution made to 100 ml (20 times).

1 000 000 = factor for converting µg to g.

5.0 CALCIUM

Estimation by AAS is described here. However, Ca estimation in the acid digest can also be done by the EDTA titration method.

The apparatus required consists of:

- An AAS;
- Some volumetric flasks;
- A fumehood;
- A hotplate;
- A muffle furnace (when dry ashing has to be done).

The reagent required is:

Standard Ca solution: Take 0.2247 g of primary standard $CaCO_3$ and add 5 ml of deionized water. Add about 10 ml of HCl to ensure complete dissolution of $CaCO_3$. Dilute to 1 litre with deionized water. This will give Ca solution of 100 µg Ca/ml. Dilute 10 ml of this solution to 100 ml to obtain 10 µg Ca/ml.

The procedure is:

1. Take 1 g of prepared plant sample. Digest in di-acid, and make the volume up to 100 ml.

2. Dilute the sample solution to 10–20 times depending on expected content of Ca, which can be estimated from the standard curve prepared for the purpose.

3. Set up and calibrate the AAS using the relevant parameters:

_ lamp current = 10 m A0;

_ wavelength = 422.7 nm;

_ linear range = 1–4 µg/ml;

_ slit width = 0.5 nm;

_ integration time = 2 seconds;

_ flame = nitrous oxide acetylene.

4. After setting the AAS, atomize the standard solutions of different concentrations of Ca and record the absorbance for the respective concentrations of Ca. Plot the concentration of Ca on the x-axis and the corresponding absorbance on the y-axis in order to prepare the standard curve.

5. Put 5 ml of the sample solution in a 100-ml volumetric flask and make up the volume, atomize, and observe the absorbance. Note the corresponding concentration for the absorbance recorded that represents the content of Ca in the sample solution.

The relevant calculation is:

$$Ca\ content\ (g)\ in\ 100g\ samples\ (\%Ca) = \frac{C \times df \times 100}{1000000} = \frac{C \times 2000 \times 100}{1000000} = \frac{C}{5}$$

Where:

C = concentration of Ca (µg/ml) as read from the standard curve;

df = dilution factor, which is 100 × 20 = 2 000, as calculated below:

• 1 g of sample made to 100 ml (100 times);

• 5 ml of sample solution made to 100 ml (20 times).

1 000 000 = factor for converting µg to g.

6.0 MAGNESIUM

Estimation by AAS is described here. However, Mg estimation in the acid digest can also be done by the EDTA titration method as described for soils.

The apparatus required consists of:

- An AAS;
- Some volumetric flasks.

The reagent required is:

Standard Mg solution: Dissolve 10.141 g of $MgSO_4.7H_2O$ in 250 ml of deionized water, and make the volume up to 1 litre. This will give 1 000 µg Mg/ml solution. Under this procedure, the preparation of the standard curve, the estimation and the calculation procedure are the same as described for Ca estimation (above). The relevant parameters for estimation by AAS are:

_ lamp current = 3 m A0;

_ wavelength = 285.2 mm;

_ linear range = 0–0.5 µg/ml;

_ slit width = 0.5 mm;

_ integration time = 2 seconds;

_ flame = air acetylene.

Appendix D: Climatological Data

Table D1: Monthly Rainfall (mm) in Minna from (1999 – 2008)

YEAR/MONTH	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1999	0.0	7.9	0.0	35.7	102.8	164.2	243.9	245.7	237.1	212.2	0.0	0.0
2000	0.3	0.0	0.0	3.6	135.9	161.0	208.8	308.5	303.0	153.4	0.0	0.0
2001	0.0	0.0	0.0	93.9	139.0	331.7	244.6	230.2	298.8	25.7	0.0	0.0
2002	0.0	0.0	5.7	98.8	42.6	201.0	143.2	226.5	260.6	180.3	0.0	0.0
2003	0.0	5.7	0.0	17.4	114.6	203.1	123.0	191.6	188.2	192.4	2.3	0.0
2004	0.0	0.0	0.0	32.2	151.9	194.9	210.3	211.4	241.5	77.6	0.0	0.0
2005	0.0	0.0	0.0	49.1	87.0	207.0	294.2	127.8	216.6	94.8	0.0	0.0
2006	11.2	0.0	TR	29.9	195.0	107.7	229.7	317.1	360.5	172.1	0.0	0.0
2007	0.0	0.0	0.4	73.1	156.6	123.9	314.0	310.1	330.1	115.1	0.0	0.0
2008	0.0	0.0	0.0	40.2	146.8	132.7	305.1	244.3	258.9	141.2	0.0	0.0

Table D2: Monthly Mean Relative Humidity (%) in Minna from (1999 – 2008)

YEAR/MONTH	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1999	25	30	44	42	58	66	75	-	75	66	36	30
2000	32	22	28	50	57	-	76	79	76	65	33	33
2001	23	23	39	57	61	70	76	79	73	52	32	37
2002	20	23	37	55	54	66	76	76	72	65	31	26
2003	32	32	31	49	54	71	75	78	73	66	37	23
2004	24	21	26	54	65	71	71	77	71	64	33	26
2005	20	31	36	46	61	70	76	74	71	64	33	26
2006	34	37	36	41	67	60	74	79	74	68	30	19
2007	19	25	35	50	64	71	75	80	72	66	42	29
2008	22	22	35	44	61	66	75	79	70	63	29	31

Source: NIMET, Minna

Table D3: Monthly Maximum and Minimum Temperatures (°C) in Minna from (1999 – 2008)

	JAN		FEB		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPT		OCT		NOV		DEC	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1999	35.4	20.7	37.0	22.8	38.3	25.8	37.0	25.2	34.2	23.7	31.4	22.7	29.1	22.3	28.6	22.1	29.5	21.9	31.3	22.0	35.7	20.1	34.9	19.5
2000	35.7	21.7	34.8	22.4	28.1	25.3	37.3	26.2	35.1	25.9	30.6	21.9	29.2	22.0	28.9	21.5	30.2	21.7	31.5	21.6	35.4	18.8	34.8	18.9
2001	34.8	19.8	36.1	22.2	38.9	24.8	36.3	24.4	33.7	24.2	30.9	21.9	29.2	21.9	28.3	21.7	29.5	20.9	33.0	21.1	36.0	19.4	36.4	20.0
2002	33.5	20.2	37.0	22.2	38.6	25.8	35.8	25.1	35.7	24.9	32.0	22.0	29.9	22.6	29.4	22.3	29.8	21.9	31.3	21.8	34.7	20.0	34.9	19.5
2003	35.3	20.9	38.2	24.0	39.0	26.0	37.0	25.8	35.7	25.5	30.7	23.0	29.8	22.7	29.5	22.5	29.7	22.2	32.2	22.8	38.4	21.3	35.0	19.5
2004	35.1	20.8	37.0	23.6	38.4	25.7	37.0	26.2	33.1	24.0	30.6	22.9	29.8	20.7	27.8	20.4	30.3	20.4	31.7	21.6	34.2	21.0	35.6	18.8
2005	33.7	19.7	38.3	25.4	39.4	26.4	37.6	26.1	33.7	24.1	31.4	22.9	29.4	22.5	28.8	22.7	30.5	22.4	31.5	21.8	35.1	20.3	35.5	19.8
2006	35.7	22.8	37.5	24.6	37.6	26.2	38.4	26.0	32.0	23.7	31.5	23.4	30.1	22.5	28.5	22.2	30.1	21.9	31.3	22.3	33.9	20.4	34.5	20.1
2007	33.7	20.5	37.2	23.5	38.2	25.4	36.0	24.4	32.8	24.2	30.3	22.8	29.5	22.3	28.2	21.9	30.0	21.9	31.7	22.5	34.3	21.6	35.4	20.5
2008	32.7	20.5	35.6	22.3	38.6	25.7	36.4	25.2	33.3	23.6	31.9	23.1	29.5	22.1	28.6	22.2	30.3	22.1	32.2	22.2	36.0	19.7	35.6	20.9

Source: NIMET, Minna

Appendix E: Relative Salt Tolerance of Agricultural Crops

TOLERANT	
Fibre, Seed and Sugar Crops	
Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Jojoba	*Simmondsia chinensis*
Sugarbeet	*Beta vulgaris*
Grasses and Forage Crops	
Alkali grass	*Puccinellia airoides*
Alkali sacaton	*Sporobolus airoides*
Bermuda grass	*Cynodon dactylon*
Kallar grass	*Diplachne fusca*
Saltgrass, desert	*Distichlis stricta*
Wheatgrass, fairway crested	*Agropyron cristatum*
Wheatgrass, tall	*Agropyron elongatum*
Wildrye, Altai	*Elymus angustus*
Wildrye, Russian	*Elymus junceus*
Vegetable Crops	
Asparagus	*Asparagus officinalis*
Fruit and Nut Crops	
Date palm	*Phoenix dactylifera*
MODERATELY TOLERANT	
Fibre, Seed and Sugar Crops	
Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Rye	*Secale cereal*
Safflower	*Carthamus tinctorius*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Triticale	*X Triticosecale*
Wheat	*Triticum aestivum*
Wheat, Durum	*Triticum turgidum*
Grasses and Forage Crops	
Barley (forage)	*Hordeum vulgare*
Brome, mountain	*Bromus marginatus*
Canary grass, reed	*Phalaris, arundinacea*
Clover, Hubam	*Melilotus alba*
Clover, sweet	*Melilotus*
Fescue, meadow	*Festuca pratensis*
Fescue, tall	*Festuca elatior*
Harding grass	*Phalaris tuberose*
Panic grass, blue	*Panicum antidotale*
Rape	*Brassica napus*
Rescue grass	*Bromus unioloides*
Rhodes grass	*Chloris gayana*

Grasses and Forage Crops	
Ryegrass, Italian	*Lolium italicum multiflorum*
Ryegrass, perennial	*Lolium perenne*
Sudan grass	*Sorghum sudanense*
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*
Trefoil, broadleaf	*L. corniculatus arvenis*
Wheat (forage)	*Triticum aestivum*
Wheatgrass, standard crested	*Agropyron sibiricum*
Wheatgrass, intermediate	*Agropyron intermedium*
Wheatgrass, slender	*Agropyron trachycaulum*
Wheatgrass, western	*Agropyron smithii*
Wildrye, beardless	*Elymus triticoides*
Wildrye, Canadian	*Elymus Canadensis*
Vegetable Crops	
Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*
Fruit and Nut Crops	
Fig	*Ficus carica*
Jujube	*Ziziphys jujube*
Olive	*Olea europaea*
Papaya	*Carica papaya*
Pineapple	*Ananas comosus*
Pomegranate	*Punica granatum*

MODERATELY SENSITIVE

Fibre, Seed and Sugar Crops	
Broadbean	*Vicia faba*
Castorbean	*Ricinus communis*
Maize	*Zea mays*
Flax	*Linum usitatissimum*
Millet, foxtail	*Setaria italic*
Groundnut/peanut	*Arachis hypogaea*
Rice, paddy	*Oryza sativa*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus palustris*
Grasses and Forage Crops	
Alfalfa	*Medicago sativa*
Bentgrass	*Agrostisstoloniferapalustris*
Bluestem, Angleton	*Dichanthium aristatum*
Brome, smooth	*Bromus inermis*
Buffelgrass	*Cenchrus ciliaris*
Burnet	*Poterium sanguisorba*
Clover, alsike	*Trifolium hydridum*
Grasses and Forage Crops	
Clover, Berseem	*Trifolium alexandrinum*
Clover, ladino	*Trifolium repens*

Clover, red	*Trifolium pretense*
Clover, strawberry	*Trifolium fragiferum*
Clover, white Dutch	*Trifolium repens*
Corn (forage) (maize)	*Zea mays*
Cowpea (forage)	*Vigna unguiculata*
Dallis grass	*Paspalum dilatatum*
Foxtail, meadow	*Alopecurus pratensis*
Grama, vlue	*Bouteloua gracilis*
Lovegrass	*Eragrostis sp.*
Milkvetch, Cicer	*Astragalus deer*
Oatgrass, tall	*Arrhenatherum, Danthonia*
Oats (forage)	*Avena saliva*
Orchard grass	*Dactylis glomerata*
Rye (forage)	*Secale cereal*
Sesbania	*Sesbania exaltata*
Siratro	*Macroptilium atropurpureum*
Sphaerophysa	*Spaerophysa salsula*
Timothy	*Phleum pretense*
Vetch, common	*Vicia angustifolia*
Vegetable Crops	
Broccoli	*Brassica oleracea botrytis*
Brussel sprouts	*B. oleracea gemmifera*
Cabbage	*B. oleracea capitata*
Cauliflower	*B. oleracea botrytis*
Celery	*Apium graveolens*
Corn, sweet	*Zea mays*
Cucumber	*Cucumis sativus*
Eggplant	*Solanum melongena esculentum*
Kale	*Brassica oleracea acephala*
Kohlrabi	*B. oleracea gongylode*
Lettuce	*Latuca sativa*
Muskmelon	*Cucumis melon*
Pepper	*Capsicum annum*
Potato	*Solanum tuberosum*
Pumpkin	*Cucurbita peop pepo*
Radish	*Raphanus sativus*
Spinach	*Spinacia oleracea*
Squash, scallop	*C. pepo melopepo*
Sweet potato	*Ipomoea batatas*
Tomato	*Lycopersicon lycopersicum*
Turnip	*Brassica rapa*
Watermelon	*Citrullus lanatus*
Fruit and Nut Crops	
Grape	*Vitis sp.*
SENSITIVE	
Fibre, Seed and Sugar Crops	
Bean	*Phaseolus vulgaris*
Guayule	*Parthenium argentatum*

Sesame	*Sesamum indicum*
Vegetable Crops	
Bean	*Phaseolus vulgaris*
Carrot	*Daucus carota*
Okra	*Abelmoschus esculentus*
Onion	*Allium cepa*
Parsnip	*Pastinaca sativa*
Fruit and Nut Crops	
Almond	*Prunus dulcis*
Apple	*Malus sylvestris*
Apricot	*Prunus armeniaca*
Avocado	*Persea Americana*
Blackberry	*Rubus sp.*
Boysenberry	*Rubus ursinus*
Cherimoya	*Annona cherimola*
Cherry, sweet	*Prunus avium*
Cherry, sand	*Prunus besseyi*
Currant	*Ribes sp.*
Gooseberry	*Ribes sp.*
Grapefruit	*Citrus paradise*
Lemon	*Citrus limon*
Lime	*Citrus aurantifolia*
Loquat	*Eriobotrya japonica*
Mango	*Mangifera indica*
Orange	*Citrus sinensis*
Passion fruit	*Passiflora edulis*
Peach	*Prunus persica*
Pear	*Pyrus communis*
Persimmon	*Diospyros virginiana*
Plum: Prune	*Prunus domestica*
Pummelo	*Citrus maxima*
Raspberry	*Rubus idaeus*
Rose apple	*Syzgium jambos*
Sapote, white	*Casimiroa edulis*
Strawberry	*Fragaria sp.*
Tangerine	*Citrus reticulate*

Source: FAO (1985)

Appendix F: Chloride Tolerance of Some Fruit Crop Cultivars and Rootstocks

Crop	Rootstock or Cultivar	Maximum Permissible Cl^- Without Leaf Injury[1]	
		Root Zone (Cl_e) (me/l)	Irrigation Water (Cl_w)[2 3] (me/l)
	Rootstocks		
Avocado ***(Persea americana)***	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus ***(Citrus spp.)***	Sunki Mandarin	25.0	16.6
	Grapefruit		
	Cleopatra mandarin		
	Rangpur lime		
	Sampson tangelo	15.0	10.0
	Rough lemon		
	Sour orange		
	Ponkan mandarin		
	Citrumelo 4475	10.0	6.7
	Trifoliate orange		
	Cuban shaddock		
	Calamondin		
	Sweet orange		
	Savage citrange		
	Rusk citrange		
	Troyer citrange		
Grape*(Vitis spp.)*	Salt Creek, 1613-3	40.0	27.0
	Dog Ridge	30.0	20.0
Stone Fruits ***(Prunus spp.)***	Marianna	25.0	17.0
	Lovell, Shalil	10.0	6.7
	Yunnan	7.5	5.0
	Cultivars		
Berries ***(Rubus spp.)***	Boysenberry	10.0	6.7
	Olallie clackberry	10.0	6.7
	Indian SUmmer Raspberry	5.0	3.3
Grape*(Vitis spp.)*	Thompson seedless	20.0	13.3
	Perlette	20.0	13.3
	Cardinal	10.0	6.7
	Black Rose	10.0	6.7
Strawberry ***(Fragaria spp.)***	Lassen	7.5	5.0
	Shasta	5.0	3.3

[1] **For some crops, the concentration given may exceed the overall salinity tolerance of that crop and cause some reduction in yield in addition to that caused by chloride ion toxicities.**

[2] **Values given are for the maximum concentration in the irrigation water. The values were derived from saturation extract data (EC_e) assuming a 15-20 percent leaching fraction and $EC_d = 1.5\ EC_w$.**

[3] **The maximum permissible values apply only to surface irrigated crops. Sprinkler irrigation may cause excessive leaf bum at values far below these.**

Source: Adapted from Maas (1984).

Appendix G: Relative Boron Tolerance of Agricultural Crops

TOLERANCE	
VERY SENSITIVE (<0.5 mg/l)	
Lemon	*Citrus limon*
Blackberry	*Rubus spp.*
SENSITIVE (0.5-0.75 mg/l)	
Avocado	*Persea americana*
Grapefruit	*Citrus X paradise*
Orange	*Citrus sinensis*
Apricot	*Prunus armeniaca*
Peach	*Prunus persica*
Cherry	*Prunus avium*
Plum	*Prunus domestica*
Persimmon	*Diospyros kaki*
Fig, kadota	*Ficus carica*
Grape	*Vitis vinifera*
Walnut	*Juglans regia*
Pecan	*Carya illinoiensis*
Cowpea	*Vigna unguiculata*
Onion	*Allium cepa*
SENSITIVE (0.75-1.0 mg/l)	
Garlic	*Allium sativum*
Sweet potato	*Ipomoea batatas*
Wheat	*Triticum eastivum*
Barley	*Hordeum vulgare*
Sunflower	*Helianthus annuus*
Bean, mung	*Vigna radiate*
Sesame	*Sesamum indicum*
Lupine	*Lupinus hartwegii*
Strawberry	*Fragaria spp.*
Artichoke, Jerusalem	*Helianthus tuberosus*
Bean, kidney	*Phaseolus vulgaris*
Bean, lima	*Phaseolus lunatus*
Groundnut/Peanut	*Arachis hypogaea*
MODERATELY SENSITIVE (1.0-2.0 mg/l)	
Pepper, red	*Capsicum annuum*
Pea	*Pisum sativa*
Carrot	*Daucus carota*
Radish	*Raphanus sativus*
Potato	*Solanum tuberosum*
Cucumber	*Cucumis sativus*

MODERATELY TOLERANT (2.0-4.0 mg/l)	
Lettuce	*Lactuca sativa*
Cabbage	*B. oleracea capitata*
Celery	*Apium graveolens*
Turnip	*Brassica rapa*
Bluegrass, Kentucky	*Poa pratensis*
Oats	*Avena sativa*
Maize	*Zea mays*
Artichoke	*Cynara scolymus*
Tobacco	*Nicotiana tabacum*
Mustard	*Brassica juncea*
Clover, sweet	*Melilotus indica*
Squash	*Cucurbita pepo*
Muskmelon	*Cucumis melo*
TOLERANT (4.0-6.0 mg/l)	
Sorghum	*Sorghum bicolor*
Tomato	*L. lycopersicum*
Alfalfa	*Medicago sativa*
Vetch, purple	*Vicia benghalensis*
Parsley	*Petroselinum crispum*
Beet, red	*Beta vulgaris*
Sugarbeet	*Beta vulgaris*
VERY TOLERANT (6.0-15.0 mg/l)	
Cotton	*Gossypium hirsutum*
Asparagus	*Asparagus officinalis*

Source: Maas (1984)

Appendix H: Guideline for Interpretation of Water Quality for Irrigation

		DEGREE OF RESTRICTION ON USE		
Parameters	**Unit**	**None**	**Slightly to moderate**	**Severe**
EC_W	ds/m	<0.7	0.7 – 3.0	>3.0
TDS	mg/l	<450	450 – 2000	>2000
Na = Surface irr.	SAR	<3	3 – 9	>9
= Sprinkler irri.	me/l	<3	>3	
Cl = Surface irr.	me/l	<4	4 - 10	>10
= Sprinkler irri.	me/l	<3	>3	
Nitrate	mg/l	<5	5 – 30	>30
pH			Normal range 6.5 – 8.4	

Source: FAO, 1994

Appendix I: Recommended Concentration of Trace Elements in Irrigation Water

Elements	Recommended max. conc. (mg/l)	Remark
Aluminium (Al)	50	Can cause non-productivity in acid soils (pH<5.5) but more alkaline soil at pH>7.0 will precipitate the ion and eliminate any toxicity.
Arsenic (As)	0.10	Toxicity to plants varies widely, ranging from 12mg/l for sudan grass to less than 0.05mg/l for rice.
Beryllium (Be)	0.10	Toxicity to plants varies widely, ranging from 5mg/l for kale to 0.5mg/l for bush beans.
Cadmium (Cd)	0.01	Toxic to beans, beets and turuips at concentrations as low as 0.1mg/l in nutrient solutions. Conservative limits recommended due to its potentials for accumulation in plants and soils to concentration that may be harmful to human.
Cobalt (Co)	0.05	Toxic to tomato plants at 0.1mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Chromium (Cr)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Copper (Cu)	0.20	Toxic to a number of plants at 0.1mg/l in nutrient solution.
Fluoride (F)	1.0	Inactivated by neutral and alkaline soils.
Iron (Fe)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposit on plants,

		equipments and buildings.
Lithium (Li)	2.5	Tolerated by most crops up to 5mg/l; mobile soil. Toxic to citrus at low concentration (<0.075mg/l). act similar to boron.
Manganese (Mn)	0.20	Toxic to a number of crops at few-tenths to a few mg/l, but usually only in acid soils.
Molybdenum (Mo)	0.01	Not toxic to plants at normal concentration in soil and water. Can be toxic to livestock if forage is grown in soils with high concentration of available molybdenum.
Nickel (Ni)	0.20	Toxic to a number of plants at 0.5mg/l; reduced toxicity at neutral or alkaline pH.
Lead (Pb)	5.0	Can inhibit pant cell growth at very high concentration.
Selenium (Se)	0.02	Toxic to plants at concentration as low as 0.025mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentration.
Tin (Sn)		
Titanium (Ti)	-	Effectively excluded by plants; specific tolerance unknown.
Tungsten (W)		
Vanadium (V)	0.10	Toxic to many plants at relatively low concentration.
Zinc (Zn)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH>6.0 and in fine textured or organic soil.

Source: FAO, 1994

Appendix J: Some Useful Relationships

$1g = 1000mg = 1000000\mu g$

$1\mu g = 0.001mg = 0.000001g$

$1l = 1000ml$

$1ml = 0.001l$

$ppm = \mu g/l$

$ppm = mg/l$