EFFECTS OF SOIL AMENDMENTS AND WATERING MANAGEMENT ON GROWTH AND YIELD OF OKRA (*Abelmoschus esculentus* L. Moench)

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UNIVERSITI MALAYSIA SABAH
2013

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JUDUL: EFFECTS OF SOIL AMENDMENTS AND WATERING MANAGEMENT ON GROWTH AND YIELD OF OKRA (Abelmoschus esculentus L. Moench)

IJAZAH: DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

SAYA: NUR AZIDAH BT. PIAKONG (HURUF BESAR)

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NUR AZIDAH BINTI PIAKONG

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

CROP PRODUCTION PROGRAMME
SCHOOL OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2013

DECLARATION

I hereby declare that this dissertation is based on my original work except for citations and quotations which have been duly acknowledge. I also declare that no part of this dissertation has been previously or concurrently submitted for a degree at this or any other university.

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ACKNOWLEDGEMENT

First and foremost I would like to express my gratitude to Allah S.W.T. Alhamdulillah, with His grace and blessings; I am able to complete this dissertation. I submit my highest appreciation and gratitude to my supervisor, Dr. Mohamadu Boyie Jalloh, for his guidance, support and encouragement to me throughout this project. I'm grateful for the knowledge he shared and his advices, without them I won't be able to complete this dissertation. Special thanks to my examiners, Assc. Prof. Tuan Haji Dandan @ Ame Bin Haji Alidin and Assc. Prof. Dr. Harpal Singh Saini, for their guidance and advices during the completion of this dissertation. To all the lecturers of School of Sustainable Agriculture (SSA), thank you for all your teachings and encouragements, it has been an honour to be a student of this school, and to receive knowledge from you. Not forgetting the non-academic staffs, lab assistants, science officers and agricultural officers of SSA, thank you for the help and guidance during my studies here.

Finally I would like to express my outmost gratitude to my family and friends, who stood by me through this journey; they have been my greatest support and strength. To my beloved parents, Piakong Mohd. Tuah and Nur Shiqah Abdullah @ Chuah Kim Hong, my sisters, Nur Sulina Piakong and Nurul Atiqah Piakong, my dear friends, the BR09s and especially to my closest friends, Yusrina Mohd. Yamin, Nurul Azzah Zainal, Darnah Mau, Siti Hawa Hajira Mohd. Husin, Nor Fadzillah Bacho and Adelia Adnan, thank you for your endless love, patience and encouragement.

ABSTRACT

This study was conducted to evaluate the effects of soil amendments and watering management on growth and yield of Okra (*Abelmoschus esculentus* L. Moench). This field study used a completely randomized design as factorial experiment which took about 6 months from July to December 2012. The two factors were: (i) soil amendments viz. sand, biochar and biochar+sand (ii) watering management viz. watering in the morning and evening (30ml+30ml watering volume), watering only in the morning (60ml watering volume), and watering only in the evening (60ml watering volume). There were a total of nine treatments and each treatment was replicated four times. Plant height, vegetative dry weight, root dry weight, number of days to flowering, number of fruits per plant, fruit length, fruit fresh weight and soil pH were measured. Data were analyzed by two-way Analysis of Variance (ANOVA) at 5% level of significance and Tukey's Test for mean separation. There was significant interaction between soil amendments and watering management on mean of plant height at the 6^{th} week and root dry weight. Treatment T6 (biochar amendment; watering only in the evening) showed the highest mean of plant height (65.93cm), 41% higher compared to the control treatment, T1 (sand amendment; watering both in the morning and evening). Treatment T8 (Biochar+sand amendment; watering only in the morning) showed the highest mean of root dry weight (9.55g), which was 69% higher than the control treatment. There was significant effect of soil amendment on mean of vegetative dry weight, number of fruits per plant and soil pH. Biochar+sand amendment showed the highest mean of vegetative dry weight (20.92g), 64% higher than sand amendment. Biochar amendment showed the highest mean of number of fruit per plants (log_{10} 0.55), 40% higher than sand amendment. The potential yield of treatment T7 (biochar+sand amendment; watering both in the morning and evening) was the highest (8.11 tonnes ha^{-1}), 35% higher than the control treatment (5.29 tonnes ha^{-1}) and 19% higher than the optimal yield of okra (6.6 tonnes ha^{-1}). The best treatment that can be recommended to farmers is treatment T6. Compared to control treatment (T1), treatment T6 showed 41% higher mean of plant height, 68% higher mean of root dry weight and 34.5% higher in potential fruit yield per hectare. It can be concluded that biochar amendment application into soil enhanced plant growth and yield of okra plant. Treatments with biochar and biochar+sand amendment showed higher mean of vegetative part dry weight, total plant dry weight, number of fruit per plants. Soil amended with biochar and biochar+sand also increased soil pH from pH 4.9 to the range between pH 6 and pH 7. For future studies it is recommended that drought stress study can be done by using more sophisticated method such as drip irrigation, in order to study the effect of water deficit on plant grown on biochar amended soil.

ABSTRAK

Kajian ini telah dijalankan untuk menilai kesan bahan perapi tanah dan pengurusan penyiraman pada pertumbuhan dan hasil bendi (*Abelmoschus esculentus* L. Moench). Kajian ini menggunakan reka bentuk "completely randomized" faktorial yang mengambil masa kira-kira 6 bulan dari bulan Julai hingga Disember 2012. Dua faktor tersebut adalah: (i) bahan perapi tanah iaitu pasir, biochar dan biochar + pasir (ii) pengurusan penyiraman: penyiraman pada waktu pagi dan petang (30ml+30 ml isipadu penyiraman), menyiram hanya pada waktu pagi (60ml isipadu penyiraman), dan menyiram hanya pada waktu petang (60ml isipadu penyiraman). Terdapat sejumlah sembilan rawatan dan setiap rawatan direplikasi sebanyak empat kali. Ketinggian pokok, berat kering vegetatif, berat kering akar, bilangan hari untuk berbunga, bilangan buah bagi setiap pokok, panjang buah, berat basah buah dan pH tanah telah diukur. Data dianalisis oleh ANAVA 2 arah pada aras 5% tahap perbezaan bererti dan ujian Tukey untuk pemisahan min. Terdapat interaksi yang bererti antara pindaan tanah dan pengurusan penyiraman ke atas min ketinggian tumbuhan pada minggu ke-6 dan berat kering akar. Rawatan T6 (biochar; penyiraman hanya pada waktu petang) menunjukkan min tertinggi bagi ketinggian tumbuhan (65.93cm), 41% lebih tinggi berbanding rawatan kawalan, T1 (pasir; penyiraman pada waktu pagi dan petang). Rawatan T8 (biochar + pasir; menyiram hanya pada waktu pagi) menunjukkan min tertinggi berat akar kering (9.55g), yang merupakan 69% lebih tinggi daripada rawatan kawalan. Bahan perapi tanah memberi kesan signifikan terhadap min berat kering vegetative, bilangan buah bagi setiap pokok dan pH tanah. Biochar + pasir menunjukkan min tertinggi bagi berat kering vegetatif (20.92g), 64% lebih tinggi daripada amendemen pasir. Biochar menunjukkan min tertinggi bilangan buah bagi setiap pokok (log10 0.55), 40% lebih tinggi daripada pasir. Unjuran hasil rawatan T7 (biochar+pasir; penyiraman pada waktu pagi dan petang) adalah yang tertinggi (8.11 tan ha^{-1}), 35% lebih tinggi daripada rawatan kawalan (5.29 tan ha^{-1}) dan 19% lebih tinggi daripada hasil optimum bendi (6.6 tan ha^{-1}). Rawatan terbaik yang boleh disyorkan kepada petani adalah rawatan T6. Berbanding dengan rawatan kawalan (T1), rawatan T6 menunjukkan min 41% lebih tinggi bagi min ketinggian pokok, min 68% lebih tinggi bagi berat kering akar dan unjuran hasil adalah 18% lebih tinggi dari hasil optimum bendi. Kesimpulannya, aplikasi biochar sebagai bahan perapi tanah berkesan dalam meningkatkan pertumbuhan dan hasil bendi. Bahan perapi tanah biochar dan biochar + pasir menunjukkan min yang lebih tinggi bagi berat kering vegetatif, jumlah berat kering pokok dan bilangan buah setiap tumbuhan. Bahan perapi tanah biochar dan biochar + pasir juga meningkatkan pH tanah dari pH 4.9 kepada pH 6 sehingga pH 7. Untuk kajian masa depan ia adalah disyorkan bahawa kajian cekaman kekeringan boleh dilakukan dengan menggunakan kaedah yang lebih canggih seperti pengairan titisan, dalam usaha untuk mengkaji kesan defisit air pada tumbuhan yang ditanam di atas tanah yang diaplikasikan dengan biochar.

TABLE OF CONTENTS

Content | **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF FORMULAE

LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

AFED	Arab Forum for Environment and Development
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
cm	Centimetre
CRD	Complete Randomized Design
DAFF	Department of Agriculture, Forestry and Fisheries, Republic of South Africa.
DAS	Days After Sowing
DOA	Department of Agriculture
EPA	United States Environmental Protection Agency
FAMA	Federal Agriculture Marketing Authority
FAO	Food and Agriculture Organization of the United Nation
g	gram
$g\ cm^{-1}$	gram per centimetre
kg^{-1}	per kilogram
m	metre
SSA	Sekolah of Sustainable Agriculture
SPSS	Statistic Package for Social Science
$t\ ha^{-1}$	tonnes per hectare
$t\ cob\ ha^{-1}$	tonnes of cob per hectare
UMS	Universiti Malaysia Sabah
UN	United Nations
USDA	United States Department of Agriculture
WAS	Week(s) After Sowing

CHAPTER 1

INTRODUCTION

1.1 Background

Soil amendments are often mixed into soil as planting medium for plants. Planting medium provides support, anchorage and also serves as reservoir of water and nutrients for plants. Some common planting medium are sand, coco peat and peat moss. Soil amendments improve soil physical characteristics, decrease bulk density and increase soil aeration. Biochar is an organic material that is highly porous and has a large surface area. It is a product of the pyrolysis process where biomass is thermally converted into char otherwise known as biochar and bioenergy in the absence or very low presence of air (Venuturupalli, 2010). It is used as a soil amendment, which has the potential to increase nutrient availability, boost nutrient retention and moisture holding capacity and nutrients retention in soils.

Agriculture accounts for 70% of fresh water utilization (FAO, 2011). The rapid increase of human population and food demand has led to water becoming a scarce resource. In Malaysia, the total water withdrawal was 13.210 km^3 in the year 2005, of which 4.530km^3 (34%) was allocated for agriculture, 3.902km^3 (30%) for municipalities and another 4.788km^3 (36%) for industrial purposes (AQUASTAT, 2011). Efforts are being made to reduce water used by crops without affecting production and to 'produce more crops per drop' (Morison *et al.*, 2008). There is a need to explore water saving methods in crop production. A good planting medium increases the water and nutrients use efficiency of crops, improves soil moisture retention and plant nutrients availability. Increasing water holding capacity of soil reduces the irrigation frequency and there is no significant loss on crop yield (Verheijen *et al.*, 2010).

Okra (*Abelmoschus esculentus* (Linn.) Moench) is a vegetable plant that originated from Africa. It is widely cultivated in tropical, subtropical and warm temperate regions of the world. The fruit is a rich source of dietary fibre, vitamins and minerals. The mucilaginous content of okra helps smooth peristalsis of digested food particles, thus aids in food digestion (DAFF, 2012). Production area of okra in Sabah in 2010 was 61.4 hectares, with production of 688.8 tonnes and net income per hectare for one season range between RM7000 to RM25, 000 (DOA, 2010).

1.2 Justification

Water is a scarce resource and there is an urgent need to explore water saving strategies. Biochar is gaining more attention for its potential to alter soil crop interactions through physical, chemical and biological mechanisms. The properties of biochar which include surface area, pore size distribution and water retention capacity can affect the availability of nutrients, water and agrichemicals in the soil (Rahman *et al.*, 2010). Studies are necessary to explore or determine the potential of biochar amendment to planting medium and the effect on watering needs. This study was undertaken for this purpose.

1.3 Objective

The objectives of this study are:

1. To evaluate the effects of soil amendment and watering management on growth, development and yield of okra *(A. esculentus)*.
2. To determine the effects of soil amendment and watering management on soil pH.

1.4 Hypothesis

It is expected that the various soil amendments and watering management will affect the growth, development, yield of okra, as well as soil pH.

CHAPTER 2

LITERATURE REVIEW

2.1 Okra

Okra (*Abelmoschus esculentus* (L.) Moench) belongs to the Malvaceae family. Okra is known by many local names such as Lady's fingers in England, Kopi Arab in Indonesia, Bhindi in India and Bendi in Malaysia. It is an annual plant which originated from Africa. It is sensitive to frost and low temperature (Holmes and Kerbie, 2009). It is now widely cultivated in tropical and subtropical regions of the world as either garden crops or cultivated on large commercial farms, India being the number largest producer. It is popular in India as it is easy to cultivate, produce dependable yield and adaptable to varying moisture conditions (Tripathi, 2011).

It requires warm temperature for growth. The optimum growth temperature range is between 20-30°C and okra thrives well on drained sandy loam soils with soil pH between 5.8 and 6.5 (DAFF, 2012). Okra needs a relatively high quantity of water for growth, despite its drought tolerance characteristics. The optimum yield for okra is approximately 6.6 tonnes per hectare (Benchasri, 2012). In Malaysia the recommended varieties for cultivation are MKBe1 and MKBe2. This is because they are high yielding, quite resistant to pests and diseases, and suitable for Malaysian climatic condition. The main cultivation areas for okra in Malaysia are in Johor, Perak, Kedah, Kelantan and Penang (FAMA, 2008).

Okra is an erect annual herb that can grow up to 4 meters tall and leaves are spirally arranged with leaves blades up to 50 cm diameter. The life cycle of okra has been differentiated into four main parts which include seed, seedling, vegetative and reproductive stage. Seed diameter is 3-6 mm and the colour is gray to black, which will germinate at about 5-7 days after sowing. During seedling stage, which usually lasts about two weeks after seedling germination, okra plant will develop at least 3-4 leaves and the height is about 12-18cm. Okra plant enters vegetative stage after four weeks of seed germination, where it will develop more than 8 leaves and leaves will become bigger. In addition stem length will increase and arranged spirally. Usually after 5 weeks of germination, okra plant will reach the reproductive stage, and flowering will start to occur (FAO, 2002a). Despite being drought tolerant, okra, like most vegetables, have critical stages of growth during which water stress reduces the yield considerably. The flowering and fruit development stages are critical stages for irrigation (Gopalakrishnan, 2007).

Okra is cultivated mainly for its young immature fruits. The fruits can be eaten raw or cooked usually used in stews and soups as a thickener, and also pickled or dried for export purpose or later use. Edible cooking oil that is equal to other cooking oil can be produced from the ripe seeds. This edible oil from okra seeds is common in Mediterranean countries. The seeds are also roasted and ground to be used as a substitute for coffee. Fibers obtained from the stem are used for cord and the mucilage is used for medical and industrial purposes. Leaves are fed to cattle as feeds and in Turkey it is used as medicine to reduce and soothe inflammation (FAO, 2002; DAFF, 2012). Okra is beneficial to human nutrition as it can provide fats, proteins, carbohydrates, minerals and vitamins. The nutritional benefits of okra fruits have reawakened the interest commercial production of the crop. It is reported to be one of the vegetables in the world with the highest antioxidants content (Benchasri, 2012) .

2.2 Water Scarcity

Agriculture consumed the largest amount of water, which withdraws 70% of water from aquifers, streams and lakes (FAO, 2011). However, water use in agriculture is often highly inefficient as only a small fraction of water for irrigation is effectively used for plant growth, while the rest is drained or lost via evapotranspiration (AFED, 2010). Driven by the growth of human population and increasing demand of food, irrigated areas increased dramatically especially during the twentieth century. Irrigation accounts approximately 40% of the world food production, including most of its horticultural output, from estimated 300 million hectares (20%) of agricultural land worldwide, but this has resulted in surface and ground depletion of water flows, often with severe consequences for aquatic ecosystem and those dependent on them (Turral *et al.*, 2011; Döll and Siebert, 2002; Morrison *et al.*, 2008).

Population growth and the rising demand for food supplies are the major causes for water scarcity. The human population relies greatly on agriculture to produce food, so increased food production means using greater quantities of water (Phocaides and Bazza, 2001). On average, every calorie consumed in our food requires a litre of water to be produced, not including the water usage of food processing industries. If each person on earth consumed a diet of 2500 calories per day, at least 2500 litres of water required to fulfill the calories consumed (Charters and Varma, 2011).

By the year 2050, the world population is expected to reach 9 billion (UN, 2009); therefore the great challenge is to increase food production with less water, particularly in areas with limited water and land resources. There has been an increase interest in deficit irrigation which is an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with the expectation that effects on yield is minimal. Deficit irrigation can lead to greater economic gain and maximizing yield per unit of water for a given crop, particularly under water scarce and drought conditions. Therefore farmers can use water more efficiently. However, this practice requires farmers to have a precise knowledge of crop responses to water as drought tolerance varies considerably with species, cultivar and growth stage (FAO, 2002).

2.3 Deficit Irrigation Studies

Several studies have been conducted to investigate the effects of deficit irrigation on crop growth and productivity. Deficit irrigation has the potential to be adopted into agricultural systems to reduce water consumption in agricultural activities. In a study conducted by Cui *et al.* (2008), regulated deficit irrigation was applied on field grown pear-jujube trees to investigate its effect on water consumption, yield and fruit quality. Different deficit irrigation levels at different growth stage had significant effects on the fruit yield and quality. Moderate and severe water deficits at bud burst to leafing and fruit maturation increase fruit yield. When compared to full irrigation application, water consumption is reduced and irrigation water is saved by 13%-25% and it is recommended that regulated deficit irrigation is adopted as beneficial agricultural practice in the production of pear-jujube fruit.

An investigation of the effect of full irrigation, deficit irrigation and partial root zone drying on plant biomass, irrigation water productivity, nitrogen use efficiency of tomato and soil microbial C/N ratio was done by Li *et al.* (2010). The results showed that full irrigation treatment produced significantly higher dry biomasses of leaves, stems and fresh weight of fruits and water productivity of aboveground dry biomass production than either deficit irrigation or partial root zone drying. However in deficit irrigation, the fruit irrigation water productivity was higher than that of full irrigation, and harvest index in deficit irrigation and partial root zone drying were higher than full irrigation. In addition, a significant increase in the soil microbial C/N ratio was obtained in both deficit irrigation and partial root zone drying. The ratio of fungal biomass was higher at low soil water content.

Carnation plants were subjected to different levels of irrigation to determine the physiological and morphological responses, as well as to evaluate the regulated deficit irrigation as a possible technique for saving water through the application of controlled drought stress in a study conducted by Alvares *et al.* (2009). Moderate deficit irrigation (70% of the control) showed a slightly reduced total dry weight, plant height and leaf area, while the severe deficit irrigation (50% of the control) reduced all the plant size parameters. Carnation plants under the regular deficit irrigation showed similar leaf area but increased flower weight and total dry weight compared to the control treatment during the blooming phase. Periods of water stress during the vegetative phases had almost no effect on head dimensions and it increased flowering intensity, practically, during the entire blooming phase. Further research in ornamental plants is needed to ascertain the optimal timing, frequency, duration and severity of regular deficit irrigation.

Jalota *et al.* (2006) found out that under limited irrigation water availability the only possible way to enhance real water crop production in cotton-wheat system is through insured irrigation water applications at flowering to boll formation stage of cotton and at grain development stage of wheat crop. A study by Ahmadi *et al.,* (2010) showed that different soils will affect water-saving irrigation strategies. It was concluded that application of water-saving irrigations in sandy loam and coarse sand is recommended to achieve the highest water productivity.

Mild (50-60% of field capacity) and severe (40-50% of field capacity) controlled soil water deficit were applied at both the seedling and the stem elongation stages of maize in a study conducted by Kang *et al.* (2000). Soil water deficit at the seedling stage had no significant influence on the final yield, but the water stressed plants at the seedling stage were better adapted to the later soil water deficit at the stem elongation stage. Grain yield of plots that were well irrigated during seedling stage was substantially reduced by the soil drying at the stem-elongation stage. It was recommended that dry soil at the seedling stage plus a mild soil drying at the stem elongation stage is the optimum irrigation method for maize production in semi-arid area.

2.4 Planting Medium

Planting medium acts as the anchor to support plants and also as the reservoir of water and nutrients. According to Lambeth (1979), planting medium is described as the various combinations of vermiculite, perlite and clay having superior properties to be used as potting mixtures to grow plants. Soil amendments are mixed into the soil, which serve as the planting medium for plant growth. Soil amendments can be organic or inorganic. Examples of organic soil amendments are manure and compost whereas sand, vermiculite and perlite are examples of inorganic soil amendments (Rakow, 1992).

In vegetable planting, water drainage, texture and structure of soil are the factors need to be considered for successful production. Soil amendments are often used to improve the soil structure in order to obtain the desirable soil conditions for vegetable growth (Riofrio and Wittmeyer, 1992). Soil quality is restored with the addition of soil amendments by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities and alleviating compaction. Soil with high bulk density is generally too dense to contain enough pore space to allow water to diffuse through the soil and keep it well aerated (EPA, 2006).

Moisture availability and rate of release are determined by several factors, which are, the dynamics of soil water, intake rate and run-off, redistribution of water in the soil profile, drainage and evaporation. Soil water capacity in sandy or gravelly soil can be improved by adding organic matter, while in a heavy clay soil; water drainage can be improved by amending with large particle mineral materials (Rakow, 1992).

2.5 Soil Physical Properties

2.5.1 Soil Texture

'Weathering' is the physical and chemical breakdown of rocks and minerals, which results in soil texture. Materials will weather at different rates because of the differences in composition and structure, thus affecting the soil texture (McCauley et al., 2005). Soil texture is the relative amounts of the different soil size particles, or the fineness or coarseness of the mineral particles in the soil. It is determined by the relative amount of sand, silt and clay in the fine earth fraction (Daniels *et al.*, 2006). The rate of water drained through a saturated soil is affected by soil texture. In addition, soil texture also influences the amount of water that is available to the plants. Water holding capacity of clayey soil is greater than in sandy soil. Well drained soils generally have good soil aeration which is favorable for healthy root growth, thus a healthy crop (Berry *et al.*, 2007).

2.5.2 Soil Structure and Aggregate

The primary building blocks of soil are sand, silt and clay. The combination or arrangement of primary soil particles into aggregates is called soil structure (USDA, 2008). Soil structure is described in terms of its form and stability. Structural form can be considered from the arrangement of the primary particles in aggregates or the consequences of this arrangement for the size, shape and continuity of the pore space between and within the aggregates. Stability is the ability of soil aggregates to resist disintegration when disruptive forces associated with tillage and water or wind erosion are applied (Gardner *et al.*, 1999). Plant growth is affected by soil structure in many ways. Roots grow rapidly in friable soil, but water and nutrient uptake of plants may be limited because of inadequate contact with the solid and liquid phase of the soil. In hard soil, this contact is more intimate, but root growth is inhibited, causing poor foraging ability of roots and eventually plants will become short of water or nutrients (Passioura, 1991).

Soil structure has major importance related to most of the soil functions, such as water entry, transmission and storage, solute flow, cycling and steering nutrients and sustaining biological productivity, thus affecting the soil productivity and environmental quality. Soil structure and macropores are vital to each of these functions based on the influence on water and air exchange, plant root exploration and habitat for soil organisms (USDA, 2008; Omar, 2007). Many soils, even hard soil, contain continuous macropores that provide niches for plant roots to grow in and increase the extent of the root system, but the roots are clumped within, hence the extraction of water and nutrients from the soil between the macropores is considerably slowed. In adverse conditions, other than affecting the ability of roots to grow and to supply water to the leaves, it may also induce hormone signals that slow down growth of shoots, even if the plant is able to take up adequate water and nutrients (Passioura, 1991).

2.5.3 Soil Porosity and Bulk Density

Pore space is the portion of the soil volume that is not occupied by or isolated by solid materials. Pore space characterizes a soil porosity and pore size distribution (Nimmo, 2004). The porosity of soil is the volume of soil voids or pore space. It is expressed in relation to the bulk volume of the soil (FAO, 1995). Soil porosity depends on several factors, including packing density, the breadth of the particle size distribution, the shape of the particle and cementing (Nimmo, 2004). Permeability is the capacity of sediment or soil to transmit water, which is closely related to soil porosity. It is controlled by the pore size and the degree to which they are interconnected. Sandy soils are very permeable since there is a relatively high percentage of void spaces between sand grains and the pore spaces are large and interconnected. In general, materials of large particles which are consistently aggregated will be more permeable. A soil may have high porosity, but as the pore spaces are not well connected the permeability will be low (Wards, 1993).

Bulk density is the measure of the packing or compression of the sand, silt and clay constituent of the soil (FAO, 1995). Bulk density is calculated as the dry weight of soil divided by its volume (g cm^{-3}). This volume includes the volume of soil particles and the volume of pore among soil particles. Bulk density is dependent on soil texture, (sand, silt and clay), organic matter particles, and their packing arrangement. Soil that is loose, porous and high in organic matter generally has a relatively lower bulk density. Sandy soil has less total pore space than silt and clay soils, which contributes to its relatively high bulk density (USDA, 2008).

2.6 Soil chemical properties

2.6.1 Soil pH

The acidity and alkalinity of soil's solution is measured by soil pH. The definition of soil pH is the negative logarithm of the hydrogen in concentration [H^+]. Soil pH is influenced by both acidic and base-forming ions in the soil. Common acid forming cations are hydrogen (H^+), aluminum (Al^{3+}) and iron (Fe^{2+} and Fe^{3+}). On the other hand, common base forming cations include calcium (Ca^+), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) (Mc Cauley *et al.*, 2005). Soil pH will change over time influenced by factors such as parent material, weathering and current agricultural practice. Soil pH of 5.2-8.0 provides an optimum condition for the majority of agricultural plants. Plants have a wide variation in acidity and alkalinity tolerance.

Some grow well in acidic pH range, while others are very sensitive to small changes in acidity and alkalinity (Lake, 2000). Soil pH influences the nutrient availability to plants and the activity of microorganisms inside the soil.

When pH decreases below 5.5, aluminum and manganese will increase and may reach a point where it is toxic towards the plants. Excess Al^{3+} in the soil solution interfere with root growth and inhibit the uptake of certain nutrient ions by plants, such as Ca^{2+} and Mg^{2+}. Phosphorus will form insoluble compounds with aluminum and iron in acidic soils and it will not be readily available for plant (Beegle and Lingenfelter, 1995). The microbial activities mostly occur in soil pH of 5.0-7.0. Microorganisms associated with nitrification require a certain pH range in order to function effectively. In extreme acidity or alkalinity, various earthworm species will disappear (Lake, 2000).

2.6.2 Cation Exchange Capacity (CEC)

Exchange capacity is the ability of the soil to return and supply nutrients to a crop. Cation exchange capacity (CEC) is the measurement of the soil's capacity to retain and release elements such as potassium, calcium, magnesium and sodium. Clayey soil and soil with high organic matter content tend to have high CEC whereas sandy soils are low CEC. Soil CEC is relatively constant over time (Marx *et al.*, 1999). High CEC is an indicator of more clay, poor internal drainage, limited structure and soil compaction while Low CEC indicates sandy soil texture that is prone to drought and needs to be amended with more organic matter to improve water holding capacity, but have open grainy structure that resist compaction. Soil pH and CEC are closely related as soil pH has a direct relationship to the quantity of negative charges contributed by organic matter. As soil pH increases, the quantity of negative charges increases (Daniels et al., 2006).

Clay minerals and organic matter contained in all soils that typically possess negative electrical surface charges. These negative charges are present in excess of any positive charges that may exist, which gives soil a net negative charge. Negative surface charges attract positively charged cations and prevent them from leaching. Electrostatic positive charges hold these ions against leaching; however they are not permanently bound to the particles of the soil surface. Cations that are retained by soil can be exchanged by other cations in the soil solution (Daniels *et al.*, 2006).

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