EFFECTS OF BIOCHAR SUPPLEMENTATION IN SOIL FOR SPRING ONIONS (*ALLIUM FISTULOSUM* L.) CULTIVATION

By
MISS Saifon SINSAMUTTHAI

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Science (BIOSCIENCE FOR SUSTAINABLE AGRICULTURE)
Graduate School, Silpakorn University
Academic Year 2022

ผลของการเสริมถ่านไบโอชาร์ในดินเพื่อการปลูกต้นหอม (*Allium fistulosum* L.)

โดย
นางสาวสายฝน สินสมุทรไทย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิทยาศาสตรมหาบัณฑิต
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Title	Effects of Biochar Supplementation in Soil for Spring Onions (*Allium fistulosum* L.) Cultivation
By	MISS Saifon SINSAMUTTHAI
Field of Study	(BIOSCIENCE FOR SUSTAINABLE AGRICULTURE)
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MISS SAIFON SINSAMUTTHAI : EFFECTS OF BIOCHAR SUPPLEMENTATION IN SOIL FOR SPRING ONIONS (*ALLIUM FISTULOSUM* L.) CULTIVATION THESIS ADVISOR : ASSOCIATE PROFESSOR PANTIPA NA CHIANGMAI, Ph.D.

Biochar has been reported in terms of retaining moisture and increasing soil nutrients. That correspondents to the problem of growing spring onion *(Aliurmcepa var aggregatum*) in Cha-Am district in Phetchaburi province, which faces the problems of lack of water during growth. In this study, the effect of using bamboo biochar to maintain moisture in soil and promote spring onion plants on growth was evaluated. The spring onion planting experiments was conducted in agricultural area at Huai Sai Royal Development Study Center (RDSC), Cha-Am District, Phetchaburi Province. Four planting cycles of spring onion were conducted, each experiment consisted of two factors: bamboo biochar supplementaion in soil and watering at different frequencies. he bamboo biochar was obtained by burning in pyrolysis at temperature of about 400 °C. All planting cycles were carried out in pots using Sandy loam soil. However, only the first planting was conducted outside the greenhouse. From planting cycle one to four, the same potting soil was used to study the effect of biochar supplemention in each planting cycle. The results showed non-significant different in all growth-related characteristics, excluding bulb formation (BF) affected by biochar supplementation in first cropping: Crop 1. The benefit of biochar supplementation in soil on many agronomic characteristics was observed start in Crop 2-Crop 4. In Crop 3 and Crop 4, this result suggests that wtering every 8 days is not sufficient to promote the maximum spring onion growth and productivity (plant weight: PW and bulb weight: BW). Contrast, daily watering in greenhouse condition causes waterlogging. However, adding biochar can alleviate these problems; drought and excess water. Thus, the presence of interaction x watering was significant benefit effect. Clearly positive impact of soil supplemented with biochar and watering frequency showed on growth-related characteristics of spring onion in Crop 4. Therefore, excess water and water lacking in soil that affects plant growth can be alleviated by adding biochar for water absorption. These conclusions can be assessed from the changes of moisture content of soil (%MCS) with biochar enrichment and watering at different frequencies in Crop 4. The most notable things were found when used Scanning Electron Microscope (SEM) for bamboo biochar after planting in Crop 4. There are high levels of porosity in surface in the biochar treatment; which is mixed in the soil and is watered with daily frequency more than control and watering every 4 and 8 days. These observes from SEM perhaps related to water retention or nutrient release in each combination of those treatments

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Chapter 1

Introduction

1. Rational of the study

Soil is an important material for growing plants and is the major factor to indicate the success or not in yielding in finally. Good soil is composed of the excess of necessary components to plant growth such as water, air, and nutrients (Kalev & Toor, 2018). Moreover, microorganisms and other beneficial biotic living organisms also are essential for support plant growth such as earthworms, etc. All of these factors have been confirmed a profound effect on many stages on plant growth and development (Hayat et al., 2010). The agricultural area in Thailand has been reported is approximately 122.2 million rai (Pituya, 2015). However, not all agricultural areas right now are suitable to plant production for getting high yield. The main cause comes from the non-proper of soil composition. Caused by continuous and monoculture; only one crop species planting and long-term area using without soil improvement either physical or chemical properties (Jintaridth, 2017). Moreover, it came from the cause of improper to practice for soil conservation. An example in case of having heavy rain, which without covering the soil for planting, the loss of nutrients is easy to occur. When the soil lacks fertility, the plants grow poorly and produce less.

Problems of crop cultivation at present are caused by lack of soil improvement or wrong maintenance methods, including the condition of the problem area of the soil condition that is not suitable for planting crops. Especially, vegetables, as an economic crop are often planted repeatedly in the same place. For example, spring onion is a plant that can be grown all year round and drainage once a day is enough for water management. This plant species spends 60 days in cultivation period (Somtua, 2017). In terms of consumer health, spring onions could reduce fat in the blood, sweat, etc. It can be eaten fresh, cooked, or as side dish vegetables, as well as processing into pickles for export (Kotsombat, 2016). The high price of spring onion is observed ranging from 60-150 baht per kg.

Growing onions will face problems during the dry season because the plant needs water approximately 353.36 cubic meters / rai or average per day or 6.30 cubic meters/ throughout the planting life (Somtua, 2017). In the sandy loam area with good drainage, the plant can store less moisture. Also, when it comes to the dry season, the plants are unable to grow and stunted because of this lacking water condition. This results in reducing productivity, therefore, solving problems of soils with low water holding capacity, especially sandy loam or sandy soil is important. According to research by (Intanon, 2006), it showed an optimization of water holding capacity in sandy soil by using agricultural waste materials. It found that coconut coir can absorb water in the soil better than water hyacinth, sawdust and rice straw, respectively. However, those residues are often found in a certain area, making it difficult for farmers in different areas to look for these kinds of materials. Therefore, there is an idea to bring other materials that have hygroscopic properties, and easy to find in all areas to be used as biochar

Biochar became known for its many benefits. It is produced from agricultural residues (examples as corn cobs, bamboo stalk, corn stalks, durian husk, etc.). Benefits of biochar are both to assist reduce burning for crop residues, which is polluting and causing global warming and it is the way to increase farmers' income (Pituya, 2015). Biochar is charcoal obtained by pyrolysis at a temperature of 350-500 degrees Celsius, where the raw materials used for incineration are agricultural waste or residues (Chan et al., 2007). The quality of biochar obtained will vary which depend on different kinds of residue materials used and the porosity process. In porosity process, the sintering in the conventional method has more porous, and gained beneficial porosity for water retention (Mensah & Frimpong, 2018) ; (Huang & Gu, 2019). This means that biochar with many porous resulting in good water retention (Amonette et al., 2019);(Saengmanee P. & Chumsaeng, 2020). Soil could increase moisture percentage because the ability of soil water retention increased from adding biochar to soil. Moreover, the reducing nutrient leaching from soil was detected, results the plants to use water effectively under drought condition. Those enable the plant growth and increased productivity finally (Li et al., 2021).

Especially the sandy soil that has problems with holding water, adding large quantities of biochar more than 3 years can increased plant nutrients because the ability to exchange cations and the amount of water available is significantly increase (Prakongkep et al., 2020). Due to the porous structure of biochar reduces soil density thereby increasing water retention (Singh et al., 2019). For the efficiency of water retention of biochar, it allows the roots of plants to expand more easily in the soil. Plant roots are able to extract only the existing portion of the retaining layer of water (Adrias & del Rosario, 2017). Soil water retention at field capacitance saturation and permanent wilting points increases with increased use of biochar. For the ability of biochar supplementation in improving water retention, biochar could support plant cultivation in areas with limited water availability. Moreover, the negative charge biochar makes it possible to store nutrients, especially nutrients that are beneficial to plants as well as the habitats of microorganisms (Šimanský & Klimaj, 2017). Due to many benefits of biochar, it is suitable for the study used and soil improvement. It revealed the used of rice husk biochar and rice straw biochar to aid in water retention and increase the yield of the onion in plot as well (Hemowng et al., 2021).

2. Objectives

Study the effect of using biochar to increase the productivity in the sandy soil for spring onion plantation in Cha-Am district, Phechaburi province.

Chapter 2

Literature reviews

1. Biochar

1.1 Biochar production

Either burning raw materials; commonly are agricultural wastes, with and without oxygen, biochar is a product that can be established, thus, it is an organic material. Biochar has the character as charcoal that is organic matter, high stability, and porous characteristics. From these characteristics, biochar is one source of nutrients for plant growth and retain moisture in soil in the long period. Gaskin et al. (2010) reported that many nutrients, including macronutrient: such as phosphorus (P), potassium (K), nitrogen (N), magnesium (Mg), sulfur (S), calcium (Ca), and micronutrients were observed in biochar.

The benefits gained from nutrients in biochar depends on its porosity process such as firing temperature and the raw materials from different plant species (Pituya & 2018) To illustrate this, bamboo burned at 500 ◦C indicated the quantities of nutrients including 56.70 g/kg total carbon (C), 2.85 g/kg hydrogen (H), 3.2 g/kg P, 1.01 g/kg total N, and other elements such as sodium (Na), Ca, Mg, and K (Zhang et al., 2017). For rice straw burned at 500 ° C, it found the quantities of nutrients including 50.8 g/kg total C and 1.6 g/kg total N (Huang & Gu, 2019).

Additionally, biochar can be prepared from various agricultural wastes; such as durian peel, corn cob, rice husk, wood chips, bamboo shells, and wheatgrass (Nilsuwan, 2019). Nevertheless, biochar burned from bamboo is a good source for production by consideration from many things include its availability, high porosity, and high carbon component. These characteristics make bamboo biochar has been interesting for utilization to increase high value of this materials (Hernandez-Mena et al., 2014). When comparing between biochar from bamboo and wooden charcoal, the bamboo biochar has about five times greater porosity and more than ten times higher absorption efficiency. The carbon content of bamboo biochar is high, and it has low ash content after burning (Scurlock et al., 2000). The suggestion about bamboo biochar is this kind of biochar could be a big pool of carbon sequestration in soil together with soil enhancement (Hernandez-Mena et al., 2014). Another important point is that bamboo is an easy-to-propagate and high-yielding plant (Scurlock et al., 2000), and it can be planted everywhere in Thailand.

Positive results for biochar supplemented in soil was observed. Increasing nutrient availability was reported when biochar has been applied, caused nutrient uptake was increasing in the plant (Gaskin et al., 2010). An effective results in increasing the yields of - many crops is caused by supplemented soil with biochar such as in agronomy crops: corn, rice, soybean, and in horticulture crops: lettuce, tomato, and cabbage (Carter et al., 2013); (Yilangai et al., 2014); (Yooyen et al., 2015); (Kang et al., 2016); (Pandit et al., 2018).

1.2 Biochar production

1.2.1 Biomass as a raw material

Biochar can be produced from many kinds of raw materials by using modern pyrolysis technology. However, the use of agricultural waste or plant residues would be an advantage (kinds of manures, crop or wood residues, etc.) (Reyes-Torres et al., 2018). Usually, agricultural wastes cause management problems and lead to environmental and climate problems; the waste (residues) from plantation (Pituya, 2015). More than these, in many cases, wastes from industry and urban community have been chosen to produce biochar. Could to say that, biochar is a product to more than efficiency to increase plant productivity through soil improvement. It also alternative way to reduce environmental problems through changing the wastes to be practical agricultural materials (Reyes-Torres et al., 2018). For this reason, the availability and benefit of biochar are dependent on its raw material use and pyrolysis conditions.

1.2.2 Biochar burning process

Biochar production processes start from collecting the raw material which commonly found on farm or infield. Then, cleaning and cutting the raw materials into small pieces. Then, these materials were burned: either with low or without oxygen process at the temperatures of about 350–700°C (Huang & Gu, 2019). The pyrolysis process could categorize depended on burning temperature and duration of burning time (Pituya & 2018). Actually, for fast pyrolysis, raw materials were burned at temperatures above 500°C or at heating rates ≥ 1000°C/min for calculation in seconds (Pituya, 2015). Which, it is important step in process of produce bio-oil (Zhang et al., 2017). Slow pyrolysis then to conduct, opposite with fast pyrolysis: about 30 mins – few hours at about 250–500°C for complete pyrolysis process (Shibuya et al., 2013).

1.3 Biochar Properties

Biochar contains many kinds of elements mainly carbon, nitrogen, and other elements both micro– and micronutrients (examples as Ca, P, K, S, C, Mg, Fe, Zn and Na), those are required on plant development (Huang & Gu, 2019). Biochar has negative charge and the porous property helps soil to absorb or capture the nutrients (Ding et al., 2017). For different criteria factors such as raw material types or temperature in pyrolysis, biochar may have a large internal surface area with a value of about 10-400 m^2/g (Hernandez-Mena et al., 2014). From the burning of swine manure at 200 °C, the nutrients that can be measured were higher in P, K, Ca and Mg (1.72, 1.40, 1.36, and 1.10 g/kg, respectively) and lower in Cu, Zn, Fe, and Mn (0.031, 0.040, 0.273, and 0.048 g/kg, respectively) (Zhao et al., 2013).

The high porosity biochar increases soil moisture by retaining water in the porosity and enhancing soil porosity, thereby reducing soil density (Nelissen et al., 2015). Biochar from paper fiber sludge burned at 600 °C mixed with 5% biochar yielded soil water content from 26% to 38.4% rather than 33.3% of control in pepper (*Capsicum annuum*) cultivation (Horel et al., 2019).

Surface area of biochar helps absorb nutrients both outside and inside the pores. Since biochar is an anion, it is anionic charge on the surface area, which increases the Cation Exchange Capacity (CEC) with nutrients that are positively charged (Pituya, 2015). Thus, nutrients are accumulated to plants, with the size of the surface area dependent on the pyrolysis temperature (Ding et al., 2017). For example, pyrolysis at 250 to 600 °C of sugarcane residue increased the area from0.56 to14.1 m^2/g (Ding et al., 2014). Jintaridth (2017) reported using soil biochar from husk burning at 400 °C, added in soil in ratio at 3 tons per rai to grow baby corn. After harvesting, it was found increasing of mineral nutrients; P increased 97-219 mg/kg compared with 13 mg/kg P in control treatment, K increased 222-366 mg/kg compared with 60 mg/kg K in control treatment, Ca increased 8,865- 9,417 mg/kg compared with 849 mg/kg in control treatment and Mg increased 522-589 mg/kg compared with 348 mg/kg Mg in control treatment. Biochar amendment in soil promotes increasing air space and enabling the water retention in soil, and finally affects crop yield increasing. However, (Major et al., 2010) found that the benefit of biochar supplementation (20 t/ha^{-1}) on productivity were not found in maize cultivation compared with non-biochar used over the next three years.

More than effect of raw material used as biochar, temperature influences nutrients in biochar. As pyrolysis temperature in biochar producing process increases, element nutrients increased. Wheat straw was pyrolyzed at 200 °C resulted to increases in many nutrients; higher on K at 1.55 g/kg and lower in P, Ca, Mg, Fe and Mn as 0.022, 0.286, 0.089, 0.022, and 0.002 g/kg, respectively. However, in temperature for biochar pyrolysis increased at 500 °C, those elements quantities increased; 0.074 g/kg P, 5.180 g/kg K, 0.950 g/kg Ca, 0.295 g/kg Mg, 0.074 g/kg Fe, and 0.007 g/kg Mn (Zhao et al., 2013). However, there were some materials when sintered in increased temperature, the biochar nutrients decreased such as rice husk; C decreased by burning at 200-250 °C (20.5 g/kg) compared with at 500 °C (45.4 g/kg)

(Huang & Gu, 2019). Therefore, the calcination materials, the compaction, the mixing into the soil and the time of pyrolysis affect soil properties.

2. Spring onions

2.1 Problems growing spring onions

Spring onion is another important economic vegetable can be planted in almost all areas, spring onion planting area in Thailand since 2015. The cultivation areas and yield production was increasing during recorded in 2015-2017 (Information and Communication Technology Center, 2015). Cultivation area and yield production of spring onions in Thailand include at about 16,424 ha (total production as 204,670 t) in 2015, 9,945.76 ha (total output 87,350 t) in 2016, and 8,090.4 ha (total output 68,649 t) in 2017.

The main areas where spring onion cultivation is divided into occupations are mainly located in the northern, northeastern and western regions. Economic zones for spring onion cultivation have been declared divided into three regions: the northern region, which is Chiang Mai, Chiang Rai, Phayao, Lampang, Lamphun, and Uttaradit, the northeastern region is Chaiyaphum, Buriram, Nakhon Ratchasima, Sisaket, Ubon Ratchathani and the western region is Ratchaburi (Somtua, 2017). Spring onion is divided into plants that are in demand in the market because spring onion can be consumed fresh, both stem and tuber. It is popular to be used as a side dish and to decorate the page to be beautiful. At present, it is processed into pickled shallot sold to foreign countries including Asia, the Middle East, and Europe (Kotsombat, 2016).

Nutritional values and characteristics of spring onion compose with: in 100 g fresh weight, it contained 32 kg Cal, 16 mg Na, 7.3 g carbohydrate, and lower contents in protein, sugar, fiber and P as 1.8, 2.3, 2.6 g and 276 mg, respectively, and medicinal properties (Somtua, 2017). For medical properties, eating spring onion help body sweat, especially people with fever and heart, reduce fat in the blood (Kotsombat, 2016). The analysis on the important substance contain in the spring onion shows it has cycloalin that can dissolve blood clots that are clogged in blood vessels (Somtua, 2017).

2.2 Spring onion and spring onion planting

Spring onion also known as split onion, in which the scientific name is (*Allium fistulosum* L.). Spring onion leaves are green color and are hollow. The length of the leaves is approximately 30.48-50.8 cm. The Head of the spring onion is underground and is white and purple. There is a tillering, about 1.50-3.51 cm in diameter, a bouquet of white flowers. Fibrous roots long are 10.01-13.97 cm (Somtua, 2017). Its short roots make it intolerant of drought conditions. In cultural practice in the field, must keep the soil moist at all times.

Botanicals of the spring onion divide:
Kingdom : Plantae
Order : Asparagales
Family : Amaryllidaceae
Genus : Alliun
Species : *Allium fistulosum* L.

Spring onion can be grown in many areas, especially in hot and humid climates; about 25 ˚C (Kotsombat, 2016)). The proper soil condition should have a slightly acidic value of 6.5 (Somtua, 2017). Spring onion can be grown either with seeds or tubers. If the tubers are used, they must be soaked in water for germinated roots to occur before planting.

In planting practice, a distance between tubers in planting about four inches. Watering in the morning and evening every day was recommended. Water consumption throughout planting to harvest yield is about 220.85 cc, an average of 3.94 cc per day (Somtua, 2017). Supplement of chemical fertilizers was recommended by the Department of Agricultural Extension in 2017, add 15-15-15 (N-P-K) inorganic fertilizer at 33 kg/rai in 15 days after planting was suggested. Then, at 30 days after planting, chemical fertilizer of 46-0-0 (N-P-K) at 22 kg/rai was recommended. Harvest time is about at the age of 60 days after planting(Agriculture, 2010). The spring onion are different from onions that the spring onion in that they are splitted, and at harvesting time at about 60 days old, the plant is still fresh (Somtua, 2017). For the multiplier onion (*Allium ascalonicum*), it has harvesting time at the age of 90 days old and the plant is already dry. Moreover, the head of the onion (*Allium cepa*) is about three times larger than spring onion and multiplier onion, thick, and light brown bark (Kotsombat, 2016).

2.3 Problems growing spring onions

Spring onions cultivation is distributed throughout the country, which Ratchaburi province is the main province that grows the spring onion cultivation in Thailand. For Phetchaburi, about 1.04 ha of spring onions were grown with a total yield of 4.08 t in 2016 and 0.24 ha with a total yield of 1.5 t in 2017 (Information and Communication Technology Center, 2016). From the above information, it can be seen that the spring onion decreased in Phetchaburi province due to the lower rainfall and hot weather. Therefore, looking to find materials that help retain moisture in the soil and increase the nutrients; as well as adjust the soil structure, allowing the spring onion could grow as well under the dry condition. Problems with poorly drained soil cause disease with onion and soil that drains too well, such as sandy soil, but nutrients are low. When too much drainage makes the soil moisture less, plants can't use it.

However, in a hot and dry climate that there is little rainfall, planting spring onion still is interest from the farmer. However, the way to conserve moisture in the soil is a point to solve before. Moreover, water conservation in the soil during the growing in onion is to concern. The well ventilate of soil is one property of soil to reduce the disease infection or spread from soil causes in the final (Kotsombat, 2016).

3. Soil water retention capacity soil water

Soil is formed by the erosion of rocks and minerals, which consists of three elements: soil particles, which are formed by physical processes that contain minerals and organic matter (Elliot, 2016). Air is a gas that is inserted in the space between the soil grains where no water is present, called dry soil and water, inserted between the soil particle gaps when the grain space is filled with water is called saturated soil; when the gap contains both water and air, it is called unsaturated soil (Evans, 1996) (Figure 1). Water is essential for plant growth as it dissolves nutrients and helps move nutrients to the roots.

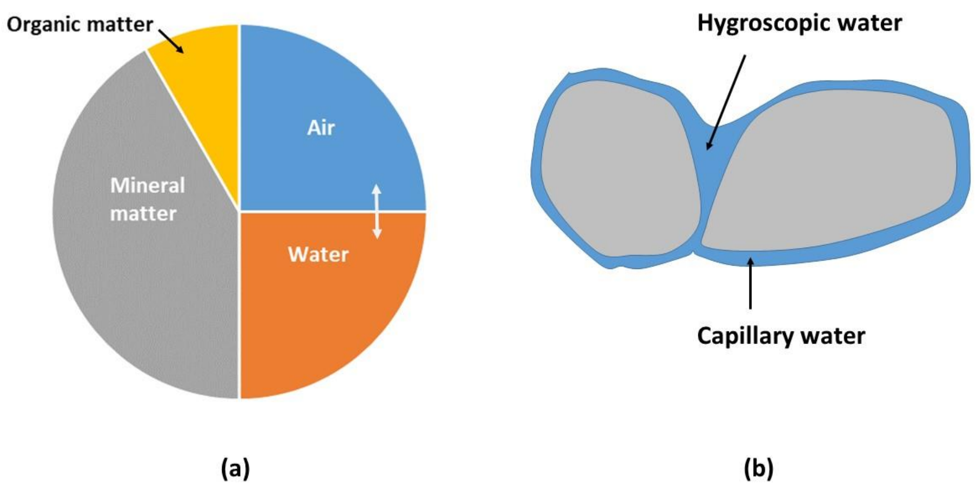


Figure 1 (a) Three-phase system of soil structure (b) The amount of water that is absorbed by soil particles

Source: Modified from (Chadha et al., 2019)

Analysis of water holding capacity (WHC), the method is as follows: put the soil in a container, saturate it with water by soaking for 24 hours, then allow the water to drain for 30 minutes and weigh the wet soil weight. The soil was then placed in an incubator at 110°C for 24 h. The soil was put in a disicater and left to cool for 15 minutes, weighed to the dry weight of the soil and calculated. The water holding capacity of the soil calculated from the formula explained by (Thitirojanawat, 1988) and (Charanworaphan, 2019) or Soil Amendment and analysis to certify product standards (Jain et al., 2004).

3.1 Forms of soil water storage

When it rains or waters the plants, water penetrates into the gaps between the soil and attaches to the soil grains by adhesive and cohesive forces. The larger the gap, the adhesive force between the water in the middle of the gap and the grain is less than that in the gap between the small grains. Therefore, when the sum of adhesive and cohesive forces is less than Earth's gravity, water flows from high to low. The water in the soil that flows for this reason is called “gravitational water” or free water. When the rain stops or watering stops, the water in the large gap will be completely drained 2 to 3 days before the harmful effects of the air plants will be replaced. The water in the smaller gap will can not be drained by gravity, but is still moving with capillary force water in a small gap called "capillary water", which is moving slowly. The loss of water by draining from the soil surface and absorbing it by plants decreases the water content of the soil. Until a certain point, the water in the soil can no longer move. Leaves a type of water that binds around the grains of the soil, is a thin layer, the roots cannot be absorbed, the plant will show signs of wilt, and if the plant is not irrigated at this time, the plant will die. Attached to the grain and unable to move by gravity or absorbing force, this is known as “hygroscopic water” (Wongmun et al., 2019).

3.2 Relationship between water distribution in the soil and available water for plants.

Water is trapped in the soil in different ways and not all plants can use it. Roots grow in moist soil and can absorb water until the water in the soil reaches a critical level. Then the roots will no longer be able to absorb that moisture. “Available Water” is called as water portion in the soil that the roots of plants can absorb and use for plant growth or development. It can be said that available water is the range levels of soil moisture between Permanent Wilting Point (PWP and Field Capacity (FC) (Chon, 2021). Withering of plants may occur several times before they reach their permanent wilting point, such as during the day in very hot weather, high winds causing the plant to lose water. When the rate of water absorption of plants from the soil is less than that of the leaves. The plant will have with symptoms (Figure 2). Which withering is permanent or temporary depends on the plant's water use rate, the depth and spread of the roots, as well as depend on absorption capacity of soil to hold back the water for use in plant. After the soil moisture decreases to the PWP if the plant is not watered, the amount of water in the soil is left with hygroscopic water; which the plant cannot absorb and will eventually die. This hygroscopic water soil moisture is referred to as Ultimate Wilting Point moisture, which is the moisture at which the plant begins to wilt from the oldest leaves until the entire plant wilts (Charanworaphan, 2019). Therefore, available water that soil can holding, it is the capacity that soil can retain the water in maximum rate, and plant can use for running it’s activities (Sharma, 2020).

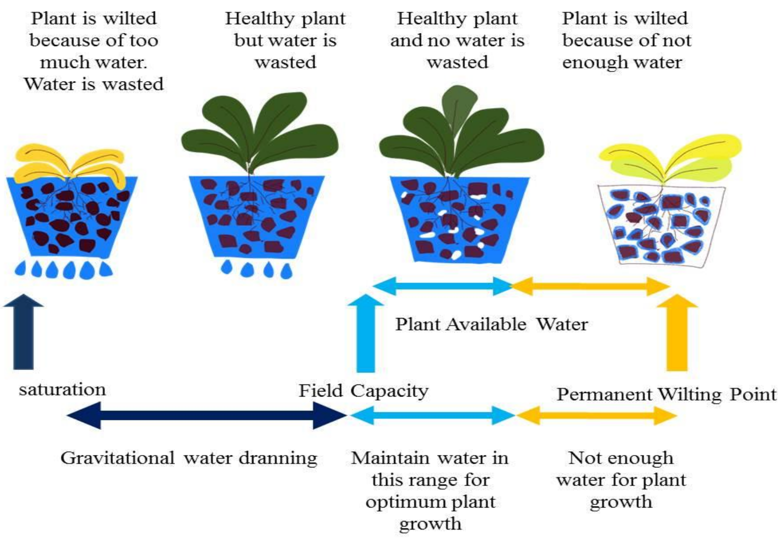


Figure 2 Soil water and plant growth.

Source; Modified from Sharma (2020)

3.3 Soil water retention capacity

For crop production, the ability of soil to retain the water and the ability that plant roots can use the soil water is the most important issue (Khetdan et al., 2017). Hence, kinds of soil textures are main parameter to determine the capacity of available water in soil; range from lowest available water capacity (coarse soils: sand, loamy sand, and sandy loam) to highest available water capacity (medium textured soil: fine sandy loam, silt loam, and silty clay loam) (Peterson, 2022) (Table 1).

Medium-textured soil with many pores can hold a lot of water. Coarse soils have small pores and small amounts hold little water. For clay soil has many tiny pores that hold a lot of water. However, clay soil has small pores making it difficult for water to flow through and hard for plant to absorb (Peterson, 2022) (Table 1).

Table 1 Range of available water capacity for different soil textures

Textural Class	Available water capacity (inches/foot of soil)
Course sand	0.25 - 0.7
Fine sand	0.75 - 1.00
Loamy sand	1.10 - 1.20
Sandy loam	1.25 - 1.40
Fine sandy loam	1.50 - 2.00

Silt loam	2.00 - 2.50
Silty clay loam	1.80 - 2.00
Silty clay	1.50 - 1.70
Clay	1.20 - 1.50

Source: Peterson (1999)

3.4 Related research

Water retention capacity (%WHC) is one in a soil quality measurement. This is because it is a soil quality factor corresponding to soil water retention and takes into account a number of soil property variables such as soil texture, porosity and soil organic matter (Brenda B. Lin, 2018). According to research by Charanworaphan (2019), water is a key variable for plant growth and yield. However, proper water management in each area has different patterns depending on the physical properties of the soil in that area, especially the soil texture. Soils with fine-grained soils, such as clay soils, have more water content in the soil at Field capacity (FC) than medium-bodied soils and coarse-grained soils, such as loam soils with FC value and sandy soils, which have the lowest FC values respectively. Determining the proper irrigation must take into account the physical properties of the soil. To provide the right amount of water for farming must take into account the factors of both soil and plants that are planted together. There are several soil factors that can explain soil moisture: Saturated Soil, Field capacity (FC), Wilting Point (WP), Permanent Wilting Point (PWP) (Charanworaphan, 2019).

.Chapter 3

Materials and Methods

1. Materials

1.1 Spring onions

The spring onion variety used in this study was 'Srisaket' variety received from Hupkapong Cooperative, Phetchaburi Province. This variety can grow in many types of soil, tolerance to diseases, and popular for cultivation in Thailand

1.2 Soil

Sandy soil from the agricultural area of The Huai Sai Royal Initiative Development Study Center, Cha-Am District, Phetchaburi Province, Thailand.

1.3 Bamboo wood

Bamboo that grows on the mountain in the area of Huai Sai Royal Development Study Center, coordinates at 47PPQ0252103567

1.4 Equipment for laboratory biochar furnaces

1.4.1) Electric Furnace
1.4.2) Clay pot with lid (Burning containers)
1.4.3) Giant acacia wood chips
1.4.4) Plastic zipper bag for containing biochar
1.4.5) Chemical pen
1.4.6) Biochar grinding machine

2. Methods

2.1 Preparation of biochar

Bamboo wood was dried under the sunlight for 15 days. The method to minimize moisture was carried out in accordance with the instructions and procedures of the IBI Biochar Certification Program Manual: Requirements and Procedures for Biochar Certification Version 2.1 (Pituya, 2015). The dried bamboo was placed in the container to prevent oxygen entered to the combustion. The bamboo was burned at 450-550 ºC for 3 hours. The bamboo biochar was kept in the sealed plastic bag for further used.

(A) (B) (C)

Figure 3 Biochar preparation using slow pyrolysis method (A) Burning of biochar. (B) Bamboo before burning (C) Bamboo biochar.

2.2 Application of biochar in spring onion planting

2.2.1 Exterimental location and time duration

The study was conducted in the agricultural area at The Huai Sai Royal Development Study Center, Cha-Am District, Phetchaburi Province, Thailand during March 2020 to September 2021 (Table 2).

2.2.2 Soil preparation and experimental design

The soil was weighted about 10 kg and put into each pot. The pot size was 30 cm in height x 30 cm in width. Soil water retention was measured before setting the experiment. The soil was watered at the first day and placed under the sunlight in the open-air condition. Soil samples were taken every day in triplicates. Fresh weight and dry weight (after dried in oven at 105°C, 24 hours) of soil were measured to calculated soil moisture retention.

<u>Experiment I (Crop 1) and Experiment II (Crop 2)</u>

To set up the experiment, the two factors 2x3 in Completely Randomized Design (CRD) with 10 replications was employed. Factor 1 is biochar and factor 2 is the frequency of watering. For factor 1, soil without biochar and soil mixed with biochar were prepared according to the ratio soil: biochar as 9 kg: 1 kg. Watering conditions were set up as 3 different methods including water daily, water every 2 days, and water every 3 days (Table 2).

<u>Experiment III (Crop 3) and Experiment IV (Crop 4)</u>

To set up the experiment, the two factors 2x3 in Completely Randomized Design (CRD) with 10 replications was employed. Factor 1 is biochar and factor 2 is the frequency of watering. For factor 1, soil without biochar and soil mixed with biochar were prepared according to the ratio soil: biochar as 9 kg: 1 kg. These soil were from the experiment II and were continuously used in the experiment III and IV.

Watering conditions were set up as 3 different methods including water daily, water every 4 days, and water every 8 days (Table 2).

2.2.3 Spring onion planting

The spring onion was soaked with water for 48 hours then planted in the pot three plants per pot. Watering was done according to each treatment by water the plant 2 liters per pot in the morning. Chemical fertilizer formula 15-15-15 and 46-0-0 were applied at 15 and 30 days after planting (Somtua, 2017) (Table 2). Weeds were removed by hand when necessary.

Table 2 Cultivation practices, temperature, day length and rainfall for cultivation in Crop 1 to Crop 4.

Crop	Places	Day/Months	Year	Amount of watering (per pot)	Fertilizer practice (N-P-K)
1	Outdoor	18 March – 6 May	2020	2 liters/two times per day	1) 46-0-0 at 2 g/pot, 15 DAP* 2) 15-15-15 at 2 g/pot for 2 times at 15 and 30 DAP
2	Greenhouse	26 June – 14 August	2020	2 liters/once per day	1) 46-0-0 at 2 g/pot, 15 DAP 2) 15-15-15 at 2 g/pot for 2 times at 15 and 30 DAP
3	Greenhouse	9 June – 28 July	2021	2 liters/once per day	1) 46-0-0 at 2 g/pot, 15 DAP 2) 15-15-15 at 2 g/pot for 2 times at 15 and 30 DAP
4	Greenhouse	20 August – 8 October	2021	2 liters/once per day	1) 46-0-0 at 2 g/pot, 15 DAP 2) 15-15-15 at 2 g/pot for 2 times at 15 and 30 DAP

* DAP = Day after planting

Continued

Crop	Temperature (°C)	Humidity (%)	Rainfall 24 hours	Evaporation (mm)	Wind speed	Temperature (°C) at soil surface
1	24.7–36.6 Average = 30.66	67.4–67.8 Average = 67.6	52.0–88.9 Average = 70.4	167.0–190.2 Average = 178.6	4.59–4.87 Average = 4.73	36.3–35.9 Average = 35.6
2	24.6–34.6 Average = 29.55	71.4–74.7 Average = 72.9	75.9–146.2 Average = 117.9	137.7–157.2 Average = 147.3	3.61–4.40 Average = 3.90	31.2–31.5 Average = 31.4
3	24.5–34.5 Average = 29.27	71.06–76.08 Average = 73.57	33.0–196.0 Average = 114.5	33.0–196.0 Average = 114.5	3.10–3.81 Average = 3.46	29.7–32.1 Average = 30.9
4	24.2–33.2 Average = 28.40	77.0–80.70 Average = 79.87	105.1–323.5 Average = 195.4	105.1–128.1 Average = 115.2	2.70–3.63 Average = 3.07	29.2–30.6 Average = 29.9

3. Data collection

3.1 Biochar properties

3.1.1 Scanning at the biochar surface

Scanning of biochar surface was conducted by using the Scanning Electron Microscope (SEM). For biochar, carbon-rich solid material is produced by biomass pyrolysis at a low temperature at final temperature of 450 °C. The surface morphology of bamboo biochar was defined by using Scanning Electron Microscope (SEM) (Model: MIRA4, resolution: 1.0 nm Secondary Electron Detector (SED), and 2.0 nm Backscattered Electron Detector (BSE), Energy Dispersive Spectrometry (EDS): Oxford/Ultim MaX 40 mm2, Manufacturer: (TESCAN).

3.1.2 Determination of pore size of biochar

2 mm bamboo biochars were used to reveal the average pore diameter and total pore volume by using the Barrett-Joyner- Halenda (BJH) method (Wijitkosum, 2022)

3.1.3 Water retention capacity measurement

Equipment

(1) measuring cup
(2) 4 position scales
(3) Oven
(4) Desiccator

Method

The crushed biochar was sieved with sieve plate number 8 with sieve size 2.38 millimeters. The biochar fine particles were heated at 105 °C for 24 hours in the oven. One hundred gram of dried biochar were washed in nil water for 24 hours, then weigh again. For the water retention capacity of biochar, it was calculated using the method reported by Song and Guo (2012). Noted that the volume of water absorbed by the biochar was record in millimeters.

Water retention capacity (%) =

$$\frac{\text{(Weight after soaking (g) - Weight before soaking (g))}}{\text{Weight before soaking (g)}} \times 100$$

3.1.4 Biochar sample preparation

Equipment

- Precision scale with 4 decimal places
- Hood
- Hot plate
- Erlenmeyer flask 250 ml or 500 ml.
- Watch glass
- Volumetric flask size 100 ml.
- Rubber policeman

Chemical

- Concentrated nitric acid (conc. HNO_3)
- Concentrated perchloric acid (conc. $HClO_4$)

Method

Hot plates are used for the degradation of samples as the following processes.

(1) Weigh 1 g of toasted and ground samples with a balance. Put in 250 ml Erlenmeyer flask.

(2) Add 10 ml of conc. HNO_3 10 ml. and 5 ml of conc. $HClO_4$.

(3) Set the reaction mixture on the hot plate, wich in the hood, cover the Erlenmeyer flask with a watch glass. Digest sample temperature at 150°C

(4) When the brown smoke starts to fade away, it turns white. Accelerate the temperature to 220 °C. It takes about 3-4 hours to digest. Lift the flask off the stove.

(5) Use warm water to spray the inner part of the flask and the glass of the watch. Put a 100 ml flask through paper. Repeat the filter several times. The volume of the solution is 80-90 ml Adjust the volume of 100 ml Close the stopper, shake well and store for analysis for elements P, K, Ca, Mg.

3.1.5 pH

Equipment

- pH meter
- 4 decimal point scales
- Standard Buffer solution pH 4, 7 and 10
- Saturated 3M KCl electrolyte

Method

(1) Weigh 5 g of sample, add 10 ml of distilled water in case the sample absorbs a lot of distilled water. Add another 10 ml of distilled water and shake well. Set aside for about 30 minutes until the solution separates.

(2) Turn on the pH meter to warm for about 15 minutes.

(3) Sample uses standard buffer solution pH 4 and 7 to calibrate the unit.

(4) Take a sample to measure the pH.

(5) Rinse the glass electrode thoroughly with distilled water. and immersed in 3 M KCl solution.

3.1.6 Electric Conductivity (EC)

Equipment

- Electrical Conductivity meter
- 4 decimal point scales
- Shaker
- Conductivity calibration solution 1413 µS/cm (25°C) and Conductivity calibration solution 12880 µS/cm (25°C)

Method

(1) Weigh 3 g of sample, add 30 ml of distilled water (1:10 ratio), shake well for about 30 minutes with a shaker, and leave for 30 minutes until the solution is stratified.

(2) Turn on the Electrical Conductivity meter to warm for about 15 minutes.

(3) Use Conductivity calibration 1413 µS/cm and 12880 µS/cm to calibrate the unit.

(4) Take the sample to measure the EC in decisiemens per meter (dS/m). Switch off the machine.

(5) Clean the glass electrode with distilled water and dry it.

3.1.7 Chemical element composition

3.1.7.1 Total N

Equipment

- Electric scale with 4 decimal places
- Hood
- Kjeldahl digestion apparatus

- Kjeldahl distillation apparatus
- 800 ml Kjeldahl flask or 250 ml Digestion tube
- Erlenmeyer flask 500 ml or 250 ml
- Burette size 50 ml
- Pipette

Chemical preparation method

- Concentrated sulfuric acid (conc H_2SO_4)

- Commercial grade (NaOH) ratio 1:1; Prepared from flakes of sodium hydroxide 1 kg dissolved in 1 liter of distilled water dissolved in 1 liter of distilled water.

- Boric acid 3%; It is prepared from 300 g of boric acid dissolved in 10 liters of distilled water.

- Kjeltabs contains 3.5 g of K_2SO_4 and 3.5 mg of Se.

- Mixed indicators; Prepared by dissolving 0.22 g bromocresol green and 0.075 g methyl red in 96 ml of 95% ethyl alcohol added to NaOH 0.1 M, volume 3.5 ml, mixed together

- 0.1 M standard salt solution; The alkali solution was standardized with potassium acid phthalate ($KHC_8H_4O_4$) and dried at 120 °C for 2 h using phenolphthaleinas an indicator

Method

(1) Digestion

(1.1) Weigh the roasted and ground samples 0.5-1.00 g (baked at 65-70°C for 2 hours) on filter paper and wrapped in 800 ml Kjeldahl flask, adding 2 tablets of the finished substance.

(1.2) Add 20 ml of conc. H_2SO_4 to the Kjeldahl flask.

(1.3) Make blank and reference sample by the same method.

(1.4) digested in Kjeldahl digestion apparatus at about 100°C–250°C–400°C Until the solution is clear, about 2 hours, leave to cool, add 400 ml of distilled water.

(2) Distillation

(2.1) Kjeldahl; put 50 ml of boric acid solution into a 500 ml Erlenmeyer flask, 4-5 drops of Mixed indicator, and place on a distillate support from the distillation apparatus with the tip of the vial immersed in the boric solution. Add NaOH (1:1) 50 mL in a Kjeldahl flask containing sample solution, distilled (approximately 1 h) to a volume of 250 mL, titrated.

(2.2) Distiller for block; put 25 ml of boric acid in a 250 ml Erlenmeyer flask with 4-5 drops of mixed indicator. Add 40% NaOH solution to a glass tube containing 50 ml of sample solution from a 150 ml distillation apparatus. It takes about 7- 10 minutes for distillation and then titration.

(2.3) Titration

-Titrate the distilled liquid with 0.1 M standard HCl until the color of the solution changes from green to purple, i.e. the end point.

- Titrate the blank solution as well.

(2.4) Calculation

$$\% N = \frac{(a-b)c \times 1.401}{g}$$

a = mL of the sample titrated acid
b = mL of acid using blank titration.
c = molar acid concentration
g = dry weight of the analytical sample (g)

3.1.7.2 Total P

Equipment

- UV-spectrophotometer
- Hot plate
- Scale with 4 decimal places
- Laboratory glassware

Chemical preparation method

- Coloring agent ammonium vanadomolybdate or Barton's reagent. together with

Solution A-prepared from ammonium molybdate $(NH_4)_6Mo_7O_{24}\cdot4H_2O$) 25 g in 400 ml of distilled water.

Solution B-prepared from ammonium meta vanadate (NH_4VO_3)1.25 g in 300 ml of hot distilled water, left to cool, added 250 ml of HN $_3$.

Mix A and B together and adjust the volume to 1 L.

- Standard Phosphorus solution or stock standard solution 50 mg/L was prepared by weighing potassium dihydrogen phosphate (KH_2PO_4) dry at 105°C for 3 h by weighing 0.2195 g dissolved in 1 L volumetric distilled water to obtain a solution containing 50 mg/L of phosphorus.

Method

(1) Preparation of working standards: Pipette 0, 1, 2, 3 and 4 ml from the solution. Standard phosphorus 50 mg/L, add 25 ml volumetric flask, add 5 ml Barton. Adjust the volume of 25 ml with distilled water followed by shake well to prepare the concentration of P to 0, 2, 4, 6,8 mg/L.

(2) Preparation of the sample solution; Pipette 5 mL of the sample solution undergoing digestion was aspirated into a 25 mL volumetric flask, 5 mL Barton was added to 25 mL volumetrically with distilled water followed by shake well and leave it to color for at least 30 minutes.

(3) Before measurement, open the UV-spectrophotometer for about 30 minutes, wavelength 420 nm standard curve from working standard 0, 2, 4, 6,8 mg/L, and measure blank with reference and sample to be analyzed.

(4) Also measure the color concentration in the sample solution. UV Spectrophotometer The color intensity is directly proportional to the concentration of P (blank samples and reference samples do the same).

(5) Calculation

$$\% P = \frac{r \times 100 \times d.f. \times 100}{10^6 S}$$

Where r = machine-readable value (ppm)

d.f. = dilution factor

S = sample weight to be weighed

To obtain an analysis result in the form of P_2O_5, factor 2.2914 is multiplied by the resulting P.

3.1.7.3 Total K

Equipment

- Flame photometer
- Scale with 4 decimal places
- KCl AR. grade
- conc. HNO_3

Method

(1) Preparation of Stock standard solution (1000 ppm K); Dissolved Potassium Chloride (KCl) which dried at 110 °C for 24 h 1.9067 g in 200 mL distilled water, add 12 mL of concentrated nitric acid, adjust the volume to 1L with distilled water store and stored in a refrigerator at 4 °C to prepare a standard solution of 100 ppm K. Intermediate solution by pipetting 10 mL of stock solution 1000 ppm K into 100 mL volumetric flask, adjusting volume to 100 mL with distilled water.

(2) Preparation of working standard solution; Contains potassium at concentrations of 0, 2, 4, 6 and 8 ppm (Table 3)

Table 3 Preparation of potassium solution at concentrations.

Concentration of K in ppm/ml	At pipette from standard K 100 ppm
0	0
2	2
4	4
6	6
8	8

Source: (Agriculture, 2010)

Adjust the volume of solution in the volumetric flask to 100 ml with distilled water, shake well to prepare standard K at different concentrations

(3) To determine the concentration of K in the sample solution, turn on the Flame photometer about 30 minutes before operation. Dilute the sample solution with distilled water in a ratio of 1:10. Measure the concentration of the standard solution to compare it with the amount of K in the sample solution.

(4) Calculation of potassium content in the sample (ppm)

$$\% K = \frac{r \times 100 \times d.f. \times 100}{106\ S}$$

Where r = machine read value (ppm)

S = weight of sample to be weighed

d.f. = dilution factor

To obtain the analytical result in terms of K_2O, factor 1.205 multiplied by the K value.

1.3.7.4 Total Ca and Total Mg

Equipment

- Atomic Absorption Spectrophotometer
- laboratory glassware

Chemical

- $SrCl_2.6H_2O$
- Calcium and Magnesium Standard Solution

Method

(1) Prepared 2 L solution of strontium chloride ($SrCl_2.6H_2O$) at a concentration of 1,500 ppm.

(2) Prepared 0, 2, 4, 6, 8,10 ppm calcium standard solution and 0, 1, 2, 3, 4, 5 ppm magnesium standard solution both standards with 1,500 ppm $SrCl_2.6H_2O$, and adjust the volume to 100 cm^3

(3) Sample solution pipette Diluted with $SrCl_26H_2O$ at a concentration of 1,500 ppm for 10-30 cm^3

(4) Prepared solutions Measure the total calcium content and the total magnesium content was measured with an Atomic Absorption Spectrophotometer.

(5) Calculations

Calculation of calcium content in the sample solution

$$\%Ca = \frac{(r-b) \times 100 \times d.f.}{10^6 \times s} \times 100$$

$$\%CaO = \%Ca \times 1.4$$

Where r-b = read value (ppm) - blank
S = sample weight (g)
d.f. = dilution factor

Calculation of magnesium content in the sample solution

$$\%Mg = \frac{(r-b) \times 100 \times d.f.}{106 \times s} \times 100$$

$$\%MgO = \%Mg \times 1.66$$

Where r-b = read value (ppm) - blank
s = sample weight (g)
d.f. = dilution factor

1.3.7.6 Organic matter (OM)

Equipment

- Oven
- Hood
- Magnetic bar and Magnetic stirrer
- Various glassware and equipment in the laboratory

Chemical preparation method

- 1 N of potassium dichromate (1 N $K_2Cr_2O_7$) was prepared by dissolving 49.0400 g of potassium dichromate (annealed at 105°C) in distilled water, resulting in a total volume of 1 L.

- Concentrated sulfuric acid (conc. H_2SO_4) 98%

- 0.5 N ferrous ammonium sulfate [0.5 N Fe $(NH_4)_2(SO_4)_2.6H_2O$] 196.1 g was prepared by ferrous ammonium sulfate dissolved in distilled water, add 20 ml of conc. H_2SO_4, cool, adjust the volume with distilled water to a volume of 1 L. The amount of ferrous ammonium sulfate that reacts with potassium to get comate in the Blank solution will be calculated as normal. The real ferrous ammonium sulfate-*O*-phenanthroline ferrous sulfate indicator 0.025 M prepared by Dissolve 14.85 g of *O*-phenanthroline and 6.95 g of ferrous sulfate ($FeSO_4.7H_2O$) to 1 L with distilled water.

Method

(1) Digestion; Weighed the crushed sample of 100 mg into the 250 ml erlenmeyer flask add 10 ml of 1 N Potassium dichromate, add 10 ml of conc. H_2SO_4 inside a fume cupboard followed by shake well overnight.

(2) Titration; Added 100 ml of distilled water to item 1, left to cool at room temperature, added 0.5 mL indicator, and titrated with 0.5 N of ferrous ammonium sulfate until the endpoint changes from blue to reddish brown.
Read the volume of the titrant obtained to calculate

(3) Calculation using the Walkley-Black method

$$\%\ OC = \frac{[\text{meq } K_2Cr_2O_7 - \text{meq Fe } (NH_4)_2(SO_4)_2.6H_2O] \times 0.003 \times 100 \times f}{\text{g dry sample}}$$

$$= \frac{[N_1V_1\ K_2Cr_2O_7 - N_2V_2 Fe\ (NH_4)_2(SO_4)_2.6H_2O] \times 0.003 \times 100 \times f}{\text{g dry sample}}$$

Where N_1 = Normal of potassium dichromate solution.
V_1 = ml of potassium dichromate solution.
N_2 = Normal of ferrous ammonium sulfate solution.
V_2 = ml of ferrous ammonium sulfate solution.
f = correction factor of 1.3
g dry sample = dry weight of sample

The C/N ratio was analyzed as the value obtained from the calculation by using the analysis of organic carbon and Nitrogen is substituted in the formula.

$$\text{C/N ratio} = \frac{\%OC}{\%N}$$

3.1.8 Soil nutrient analysis before and after the spring onions cultivation

Soil collection equipment

- Hand shovel
- Medium plastic bucket
- Plastic cloth size 30 x 30 inches
- Plastic bags

Soil storage method

Cut the soil in the pot approximately 20 cm deep and dry the soil, sift the soil, take the soil in bags of approximately 1 kg. Repeat 2 samples and send the samples to the Land Development Science Office. Department of Land Development

3.1.8.1 Determination of pH

Brand pH meter was used to measure the pH of the soil in the laboratory by using Electrometric method or Potentiometric method from the formula

$$pH= -log[H^+]$$

Where pH = pH is alkaline.

Log = logarithm base 10

$[H^+]$ = concentration of The H^+ in solution is molar(M).

Method

Soil: Water Ratio 1:1 (Peech, 1965)

Equipment

- 50 ml beaker
- Glass rods
- Measuring cylinder size 10 ml.
- pH meter

Preparation of chemicals and solutions

- Distilled water
- pH 4 and pH7 standard buffer solutions.

Method

(1) Weigh 10 g of soil sample into a 50 ml beaker.

(2) Added 10 ml of distilled water by using a glass rod to stir evenly several times. Set aside for 30 minutes.

(3) The soil solution was measured for pH with a pH meter using standard pH 7 and pH 4 buffer solutions.

Severity level of soil reaction, pH (soil : water = 1:1) (Division & Staff, 1973); Soil survey division staff, 1993)(Staff., 1993). Soil rating and range of soil pH were presented in Table 4.

Table 4 Soil pH and soil rating.

Rating	Range
Ultra acid	< 3.5
Extremely acid	3.5-4.5
Very strongly acid	4.6-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	>9.0

Source: (Agriculture, 2010)

3.1.8.2 Analysis of Electrical conductivity; EC

Soil conductivity was measured in a soil-water solution, the soil-to-water ratio was 1:5 using EC units x 10^3 mmoh/cm (ds/m). Brand electrical conductivity meter was used.

Method of analysis

soil: water, ratio 1:5

Equipment

- Erlenmeyer flask 125 ml.
- Cone
- No. 5 filter paper
- Volumetric flask 1 L
- Filtering flask size 500 ml.
- Measuring cylinder size 50 ml.
- Thermometer
- Conductivity meter

Method for preparing the solution

- 0.01 M potassium chloride (KCl) standard solution was prepared by dissolved 0.7456 g potassium chloride (KCl) in distilled water followed by made a volume of 1 L by distilled water.

(1) Weigh 10 g of soil, add 125 ml of Erlenmeyer flask.

(2) Added 50 ml of distilled water, shake well for 2 hours, leave overnight, and then filtered

(3) Before taking the soil solution to measure the EC value with a conductivity meter. Adjust the instrument with 0.01 M KCl standard solution. The instrument reads approximately 1413 µS cm-1 at 25 °C.

(4) Take the soil solution 1:5 filtered to measure EC with a conductivity meter.

3.1.8.3 Analysis of organic matter; OM

Equipment

-Erlenmeyr flask size 250 ml

- Pipette size 10 ml
- Measuring cylinder size 25 and 50 ml
- Burette size 50 ml

Chemical preparation

-1 N Potassium dichromate ($K_2Cr_2O_7$) was prepared by dissolved 98.0 g of $K_2Cr_2O_7$ which annealed at 105 ˚c in distilled water followed by make a volume to 2 L

-Ferrous ammonium sulphate $[Fe(NH_4)_2 (SO_4)_2.6H_2O]$ 2 L.

-0.0025 M Orthophenanthrolin Indcator solution was prepared by dissolved 0.7 g ferrous sulfate ($FeSO_4.7H_2O$) and 1.48 g O-phnanthrolin in distilled water and adjusted volume 100 ml.

- Concentrated sulfuric acid (Conc. H_2SO_4)

Method

(1) Weighed 1 g of soil sample and put into 250 ml of Erlenmeyr flask.

(2) pipetted 10 ml of 1 N Potassium dichromate into (1) followed by added 15 ml of conc. sulfuric acid and shaked gently for 1-2 minutes then left for 30 minutes.

(3) Added about 50 ml of distilled water and let it cool followed by added 5 drops of orthophenantrolin indicator.

(4) titrated the soil sample solution with 0.5 N Ferrous ammonium sulphate to determine the amount of potassium dichromate remaining from the reaction until the color of the soil solution changes from green to reddish brown, and record.

(5) Make a blank just like soil analysis.

(6) Calculate the amount of organic carbon and organic matter

$$\%\ \text{Organic carbon} = \frac{(B-T)N}{B} \times \frac{100}{77} \times 3 \times \frac{100}{10^3} \times \frac{10}{W}$$

$$\%\ \text{Organic matter} = \%\ \text{Organic carbon} \times 1.724$$

Where N = Potassium dichromate concentration.
B = Ferrous ammonium sulphate volume titrated to blank (ml)
T = Volume of Ferrous ammonium sulphate titrated with soil sample (ml)
W = soil weight (g)

The organic matter values in soil and soil rating were presented in Table 5.

Table 5 Organic matter level (% Organic carbon x 1.724).

Rating	Range (percentage)
Very low (VL)	<0.5
Low (L)	0.5-1.0
Relatively low (ML)	1.0-1.5
Medium (M)	1.5-2.5
Relatively high(MH)	2.5-3.5
High (H)	3.5-4.5
Very high (VH)	>4.5

Source: (Agriculture, 2010)

3.1.8.4 Analysis of Cation exchange capacity ; CEC

Equipment

- Erlenmeyer flask size 125 ml
- Buchner funnel
- Filtering flask size 500 ml
- Filter paper No. 42
- Volumetric flask size 100 ml
- Kjeldahl flask 800 ml
- Burette size 50 ml
- Brand pH meter
- Distillation Furnace
- 4 decimal place scales
- Atomic absorption spectrophotometer brand
- Flame photometer brand

Chemical preparation

- 1 N Ammonium acetate solution (NH4OAc) pH7 was prepared by put 114 ml of glacial acetic acid 99.5% into 1 L volume of distilled water, adding 136 ml of concentrated ammonium hydroxide (conc. NH4OH) followed by adding 1,980 ml of distilled water, measure pH and adjust pH 7 with ammonium hydroxide, finally adjust the volume to 2 liters with distilled water.

- 10% ammonium oxalate solution [$(NH4)_2C_2O.4H_2O$] was prepared by dissolving 10 g of $(NH_4)_2C_2O.4H_2O$ in distilled water followed by adjusting the volume of 100 ml

- 50% ammonium hydroxide (NH_4OH) was prepared by take 50 ml of conc. NH_4OH into the 100 ml volumetric flask followed by adjust the volume to 100 ml with distilled water.

- 1 N ammonium chloride (NH_4Cl) was prepared by dissolve (NH_4Cl) 53.5020 g in distilled water and adjust to pH 7 with ammonium hydroxide followed by make the volume of 1 L distilled water

- 0.25 N ammonium chloride (NH_4Cl) was prepared by dissolved NH_4Cl 13.3755 g g in distilled water and adjust to pH 7 with ammonium hydroxide followed by make the volume of 1 L distilled water..

-0.1 N silver nitrate ($AgNO_3$)was prepared by dissolved 16.9910 g of $AgNO_3$ in distilled water and adjust the volume to 1 L.

- 95% ethyl alcohol

- 10% NaCl (Acidified solution) was prepared by dissolve 2000 g of NaCl in distilled water, add 8.7 ml of concentrated hydrochloric acid and adjust the volume to 20 L with distilled water.

- 40% sodium hydroxide (NaOH) was prepare by Dissolve 400 g of NaOH solution in distilled water followed by adjust the volume to 1 L.

- 3% boric acid (N_3 BO_3) was prepared by dissolved 30 g of N_3BO_3 in distilled water followed by adjust the volume to 1 L.

- 0.1 N HCl was prepared by take 9 ml of conc. HCl into distilled water and adjust to 1 L. Standardize the concentration of 0.1 N HCl by titrate with sodium hydroxide standard solution to provide a certain concentration. The sodium hydroxide standard solution was standardized from the titration with potassium hydrogen phthalate by used phenolphthalein is an indicator.

- Mixed indicator was prepare by dissolved bromogenated green 0.22 g in 96 ml of 95% ethyl alcohol and add 3.5 ml of 0.1 N sodium hydroxide.

Method

(1) Weigh 5 g of soil sample, add 125 ml of Erlenmeyer flask, add 1 N 60 ml of ammonium acetate solution (NH_4OAc), shake, leave overnight and filter by vacuum system.

(2) The soil sample was leached with 1 N ammonium acetate solution (NH_4OAc) until there was no calcium remaining. The test was carried out by boiling 10 ml of soil-washed solution in a test tube with 2-3 drops of 1 N ammonium chloride, 10% ammonium oxalate and 50% ammonium hydroxide. Sediment or turbid

(3) The soil solution obtained from the 1 N ammonium acetate solution was placed in a 100 ml measuring flask, adjusted to 100 ml with distilled water, and

the calcium and magnesium values were measured using an atomic absorption spectrophotometer at wavelength of 422 and 285 nm, and the potassium and sodium content were measured with a flame photometer at wavelength of 383 and 295 nm.

(4) The soil sample was leached with 1 N ammonium chloride for 4 times and washed with 1 time of 0.25 N ammonium chloride and washed with 95% ethyl alcohol about 150-200 ml until no chloride remained. (Tested using silver nitrate (0.1 N $AgNO_3$)

(5) Wash the soil sample with 10% acidified NaCl to obtain Na^+ replace NH_4^+ in the soil to get 225 ml of soil solution. Pour the soil solution into a kjeldahl flask and add a little pumice stone.

(6) Distilled the soil solution to remove NH_4^+ by adding 25 ml of 40% sodium hydroxide to make the alkaline solution. Distilled ammonia was captured with 50 ml of 3% boric acid.

(7) Distilled solution was dropped by 5 drops of mixed indicator, which turn from purple to green by titration with 0.1 N standard hydrochloric acid. The end point was observed by green solution turned to purple solution

(8) Make blank the same as the soil sample.

(9) Calculate the CEC value.

$$CEC = \frac{(A-B)\ N \times 100}{W} \text{ mg equivalent to 100 g soil (cmol/kg)}$$

Where A = volume of standard hydrochloric acid used Titrate with soil sample (ml)

B = volume of standard hydrochloric acid used Titrate with blank (ml)

N = standard hydrochloric acid concentration (normal)

W = weight in grams of soil sample

3.1.8.5 Exchangeable cation analysis (Exch. Ca^{2+}, Mg^{2+} and Na^+)

Equipment

-Test tube

-Dilutor

-Atomic absorption spectrophotometer

-Flame photometer

Chemical preparation

(1) 1,500 mg/L Strontium chloride ($SrCl_2$) was prepared by dissolved 4.6 g of $SrCl_2$ in 1 L of distilled water.

(2) 1000 mg/L Calcium standard solution was prepared by dissolved 1.2488 g of calcium carbonate, which dried at 105± 5 °C, in concentrated hydrochloric acid until completely adjusted to 500 ml volume with distilled water.

(3) 100 mg/L Calcium standard solution was prepared by pipette 25 ml of (2) into the 100 ml volumetric flask followed by adjust the volume to 100 ml with distilled water.

(4) Prepared the standard set of calcium solution include 2, 4, 6, 8, and 10 mg/L from 100 mg/L calcium standard solution (3) by adjust volume with $SrCl_2$ solution. Use these standard set of calcium solution for preparation the standard curve.

(5) Prepared the 1000 mg/L Magnesium standard solution by dissolved magnesium oxide 0.8289 g, dried at 100± 5°C in concentrated hydrochloric acid until completely dissolve followed by adjusted to 500 ml volume with distilled water.

(6) 100 mg/L Magnesium standard solution was prepared by pipette 10 ml of (5) into the 100 ml volumetric flask followed by adjust the volume to 100 ml with distilled water.

(7) Prepared the standard set of magnesium solution include 1, 2, 3, 4, and 5 mg/L from 100 mg/L magnesium standard solution (3) by adjust volume with $SrCl_2$ solution. Use these standard set of magnesium solution for preparation the standard curve.

(8) 1000 mg/L Sodium standard solution war prepared by dissolved 2.542 g of sodium chloride (NaCl) (dehydrated by heat with hot air oven at 105 w ± 5 °C) in concentrated hydrochloric acid until completely dissolved followed by adjusted to 500 ml with distilled water.

(9) 100 mg/L calcium standard solution was prepared by pipette 10 ml of (8) solution followed by adjusted to 100 ml volume with distilled water.

(10) Standard graph of sodium was prepare from standard sodium working solution which are series concentration of 0, 4, and 8 mg/L Na+.

Method

(1) The exchangeable calcium and magnesium content (Exch. Ca^{2+}, Mg^{2+}) were measured by the soil solution extracted from (4) and (7). The content of exchangeable calcium and magnesium was measured Atomic Absorption Spectrophotometer at a wavelength of 422 and 285 nm

(2) The exchangeable sodium content (Exch. Na^{+}) was analyzed by using the soil solution extracted from (9) to measure the exchangeable sodium content were measured by flame photometer at wavelengths 383 and 295 nm. The readings were graphed.

(3) Calculate

How to calculate the amount of Exch. Ca^{2+}, Mg^{2+}

1000 ml of the sample solution has a concentration = R mg

C ml of the sample solution has a concentration $= \frac{R \times C}{1000}$ mg

The sample using A g has a concentration $= \frac{R \times C}{1000}$ mg

If 100 g of the sample was used, the concentration $= \frac{R \times C \times 100}{1000 \times A}$ mg

$= \frac{R \times C}{10\ A}$ mg

The sample solution is diluted to df $= \frac{R \times C \times df}{10\ A}$ mg

$= \frac{R \times C \times df}{10\ A\ \text{eq.wt. Ca or Mg}}$ mg milligram equivalent per 100 g soil

Where A = soil sample weight (g)
Df = number of times the solution dilution.
C = final volume of sample solution (ml)
R = Calcium and magnesium content read from atomic absorption spectrophotometer (mg/ L)

Note eq.wt of Ca $= \frac{\text{molecular weight Ca}}{2}$

eq.wt of Mg $= \frac{\text{molecular weight Mg}}{2}$

How to calculate Na^{+}

$= \frac{R \times C \times df}{10\ A}$ mg equivalent to 100 g of soil.

Where A = soil sample weight (g)
Df = number of times the solution dilution.
C = final volume of sample solution (ml)
R = Calcium and magnesium content read from Flame photometer(mg/L)

3.1.8.6 Available Phosphorus; avail.P

Bray II (Bray & Kurtz, 1945)

Equipment

- Electric scale with 4 decimal places
- Erlenmeyer flask size 50 ml
- Test tube
- Filter paper No. 5 size 11 cm
- Pipette
- Auto dilutor

- Volumetric flask size 50 ml and 1 L
- Beaker size 2 L
- Spectrophotometer

Chemical preparation

(1) Bray II extraction (0.03 N NH_4F,0.1 HCl) was prepared by dissolved 11.01 g of ammonium fluoride (NH_4F) in 8 L of distilled water followed by, add 86 ml of hydrochloric acid (conc.HCl) Before transfer this solution to 10 L volumetric flask, adjust pH until obtain 1.5-1.6.

(2) Stock solution (Reagent A: Sulfuric-molybdate-tartrate solution). Dissolve 50 g ammonium molybdate A.R. [$(NH_4)_6Mo_7O_{24}.4H_2O$] in 200 mL of warm deionised water. Dissolve 1.213 g potassium antimonyl tartrate A.R. ($KSbO.C_4H_4O_6$) separately in 150 mL deionised water. Place 500 mL deionised water in a 2 L volumetric flask, slowly add 200 mL concentrated sulphuric acid with mixing. When cooled, add the cooled molybdate and tartrate solutions, mix, and bulk to volume with deionised water.

(3) Working solution, Reagent B. Dissolve ascorbic acid 1.76 g in 1,600 ml of deionised water, add substance (2) 40 ml, adjust the volume to 2 L with deionised water and set aside for 2 h.

(4) phosphorus standard solution 50 mg/L; Dissolve Potassium dihydrogen phosphate KH_2PO_4 which dried at 40 °C for 2 hrs) 0.2195 g in distilled water, acidified with 1-2 drops of sulfuric acid and adjusted to volume 1 L.

(5) Standard graph of phosphorus was prepare from standard phosphorus working solution which are series concentration of 0, 2, 4, 6, 8, 10 and 15 mg/L which adjust the volume by the Bray II extraction solution.

Method

(1) Weighed 1.0 g of soil sample and add 50 ml of Erlenmeyer flask.

(2) Add 10 ml of Bray II extraction solution, shake for 1 minute and filtered with No. 5 filter paper size 11.0 cm.

(3) Pipette the extracted solution in (2) at the ratio of 1 part per 16 parts working solution into a glass tube, leave it for half an hour and take it to read the concentration with a Spectrophotometer at a wavelength of 882 nm

(4) Make blank and standard set same as (3)

(5) Calculation

$$\text{Avail.P} = \frac{B \times df\text{ (sample)} \times R}{A \times df\text{ (standard)}} \quad \text{mg/kg}$$

Where A = soil sample weight (g)
B = extraction solution (ml)

R = read value compared to standard set
df = ratio (dilution factor)
Therefore, if there is no dilution

3.1.8.7 Analyze Available Potassium; avail. K (Jackson, 1958).

Equipment

-Erlenmeyer flask 50 ml
- No. 5 filter paper, size 12.50 cm.
-Pipette
-25 ml dispenser
- test tube
- Scales
- Shaker
- Auto dilutor
- Flame photometer
- pH meter

Chemical preparation

(1) 1 N Ammonium acetate solution pH 7.0; Mix 57 ml of glacial acetic acid and 68 ml of ammonium hydroxide (NH_4 OH) in distilled water, adjust the volume to 1 L, adjust pH to 7. Use acetic acid and add 1L distilled water.

(2) 1000 mg/L potassium standard solution; Dissolve 1.907 g of potassium chloride (KCl), which dried at 105 ±5 °C, in distilled water at a volume of 1 L.

(3) 100 mg/L potassium standard solution; Pipette Solution (2) 10 ml Adjust volume to 100 ml with distilled water.

(4) Standard set of potassium; Solution (3) to a concentration of 0, 5, 10, 15 and 20 mg/L with the extraction solution.

(5) Create a graph using Standard 10 mg/L, Which were measured by Flame photometer at wavelength of 383 nm.

Method

(1) Weigh 2.5 g of soil sample and put into 50 ml of Erlenmeyer flask.

(2) Add the extraction solution. (Section 1 from the preparation) 25 ml, shake for 30 minutes and filtered with No. 5 filter paper size 12.50 cm.

(3) Use standard solution (item 4 from the preparation) 10 mg/L to measure by Flame photometer.

(4) The content of K from the filtered solution from (2) was measured by Flame photometer .

(5) Calculation

$$\text{Avail.K} = \frac{D \times df \times B}{A} \text{ mg kg}^{-1}$$

Were A = soil sample weight (g)

B = volume of ammonium acetate solution used for extraction (ml)

D = concentration of K compared to standard concentration (mg kg^{-1}).

df = dilution factor

3.2 Determination of spring onion growth and yield

The shoot height, leaf length, number of leaves, tillering, and canopy width were measured every week after planting. After harvesting, the yield was determined and the onion size and weight were measured and compared among treatments.

Chapter 4

Results

Soil chemical/physical properties and moisture content

Determination the water retention capacity or available water (holding) capacity in sandy loam soil by dry basis was measured and presented in Table 6 and Figure 4. The available water or water holding capacity in sandy loam soil reducing after leaving it outdoors. Less than 10% for soil moisture content was recorded at 7 days after leaving (Table 7).

Table 6 Soil chemical and physical properties

Chemical and Physical parameters	**Values and recommendation**
Soil type	Sandy loam soil
Percent of organic matters	0.26 – very low
Available phosphorus (mg/kg)	4 – very low
Available potassium (mg/kg)	26 – very low
pH	7.7 – slightly alkaline
Electrical conductivity (dS/m)	0.08 – not salty soil
	For this soil should be nourished with organic fertilizer to improved soil structure (physical) and increase soil nutrients (chemical)

% soil available water (holding) capacity (dry soil weight at 105°C for 24 hours)

$$= \frac{(Wet\ soil\ weight\ (g) - Dry\ soil\ weight)}{Dry\ soil\ weight\ (g)} x100$$

Table 7 Percent of water holding capacity (WHC) of sandy loam soil.

Days alter the field capacity date	%WHC	Days alter the field capacity date	%WHC
0	28.64 ± 4.71	8	8.33 ± 0.93
1	23.91 ± 6.65	9	6.91 ± 0.03
2	15.90 ± 0.22	10	5.08 ± 0.53
3	13.52 ± 0.56	11	6.20 ± 0.19
4	14.09 ± 0.71	12	5.53 ± 0.06
5	13.64 ± 0.15	13	4.00 ± 0.15
6	12.43 ± 0.55	14	3.43 ± 0.34
7	9.71 ± 0.37		

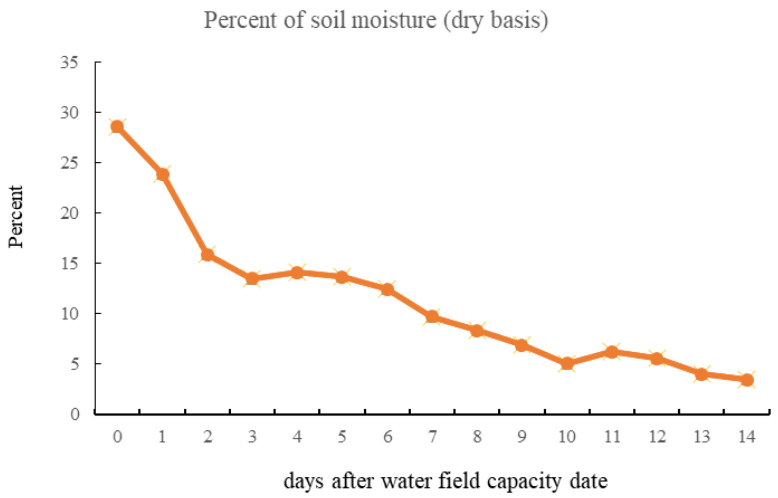


Figure 4 Percent of water holding capacity in sandy loam soil in the days after the water field capacity date.

Biochar chemical/physical properties and water retention capacity

For bamboo biochar used in this study was determined both chemical and physical properties present in Table 8.

Table 8 Bamboo biochar chemical and physical properties.

Chemical/physical parameters	Values
Biochar type	Bamboo biochar
Temperature of burning	450 °C
Total nitrogen (N, %)	0.80
Available phosphorus (P_2O_5, %)	0.30
Available Potassium (K_2O, %)	1.10
An exchangeable calcium (CaO, %)	0.53
An exchangeable magnesium (MgO; %)	0.28
Organic matter (%)	17.41
Carbon/Nitrogen (C/N ratio)	13
pH	7.31
Electrical conductivity (dS/m)	0.6
Multipoint BET (m^2/g)*	162.37
Total pore volume (cc/g)*	0.1055
Average pore diameter (nm)*	2.598
pH (1:1)*	9.5
EC(1:5) (dS/m)*	0.49
Bulk density (kg/m^3)	124g/lit = 124g/0.001 m^3 = 0.124 kg/0.001 m^3 = 124 kg/m^3

* Instrument used: Surface Area Analyzer (Quantachrome, Autosorb-1 MP)

The water retention capacity in percentage in bamboo biochar was measured and calculated as followed:

% water retention capacity in bamboo biochar (burned or pyrolyzed at 450°C, dry biochar weight at 105°C for 24 hours)

$$= \frac{(Weight\ after\ water\ absorption\ (g) - Weight\ before\ water\ absorption)}{Weight\ before\ water\ absorption\ (g)} x100$$

Percent of moisture content after bamboo biochar absorbed water was 202.13% or about 3.02 times when calculated by net weight ratio (Table 9).

Table 9 Water absorption in bamboo biochar (mean ± standard deviation).

	Water absorption (times)	% Water retention capacity
Bamboo biochar	3.02 ± 0.02	202.13 ± 1.50

Growth-related characteristics and yield in spring onion cultivated in Crop 1 to Crop 4

Agronomic characteristics in spring onion cultivated in Crop 1

In crop 1, PH was significantly affected by biochar factor in all weeks, the values decreased at supplementation of biochar (Table 10). Compared with PH at week five to week seven, PH values in adding biochar decreased higher values compared with without biochar at week one to week four. PH in all weeks not significantly affected by watering factor and by the biochar × watering interaction, excluded at week 3. PH at week three significant affected by the biochar × watering interaction, high values were observed at without biochar with watering every two and three days (Table 10).

Table 10 Analysis of variance (ANOVA) and means (± standard deviation) in plant height (PH) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 1.

Treatments	**PH-W1**[1]	**PH-W2**	**PH-W3**	**PH-W4**
P-value (Biochar)	3.09 x10^{-6}**[3]	7.58x10^{-5}**	6.29x10^{-6}**	0.002**
biochar	1.41±1.08 Y[4]	6.05±2.26 Y	15.29±2.32 Y	19.07±2.10 Y
Without biochar	3.21±1.61 X	9.08±2.80 X	18.84±3.43 X	22.60±5.84 X
P-value (Watering)	0.417 NS[2]	0.465 NS	0.205 NS	0.088 NS
Every day	2.07±1.29	6.78 ± 3.54	16.24±2.42	19.30±2.08
Every 2 days	2.62±1.23	7.69 ± 2.65	17.14±3.84	22.33±7.14
Every 3 days	2.23±2.23	7.96 ± 2.78	17.81±3.78	20.89±2.88
P-value (Biochar × watering)	0.089 NS	0.966 NS	0.019*	0.306 NS
Biochar, Every day	1.41±1.28	5.28±2.90	15.79±2.06 c	18.61±2.00
Biochar, Every 2 day	2.03±0.98	6.31±2.03	15.25±2.54 c	19.56±2.16
Biochar, Every 3 day	0.78±0.57	6.41±2.00	14.82±2.49 c	19.05±2.24
Without biochar, Every day	2.73±0.95	8.48±3.61	16.70±2.77 bc	19.98±2.04
Without biochar, Every 2 day	3.22±1.20	9.08±2.54	19.03±4.09 ab	25.10±9.27
Without biochar, Every 3 day	3.68±2.35	9.50±2.65	20.80±2.05 a	22.73±2.24
CV(%)	58.13	34.49	16.13	20.44
Overall mean	2.31	7.54	17.06	20.84

Treatments	**PH-W5**	**PH-W6**	**PH-W7**
P-value (Biochar)	0.001**	0.007**	0.001**
biochar	20.65±2.02 Y	21.92±1.91Y	21.03±2.09 Y
Without biochar	22.61±2.50 X	23.46±2.41X	23.01±2.21 X
P-value (Watering)	0.507 NS	0.474 NS	0.507 NS
Every day	21.43±1.83	22.31±1.94	21.60±2.56
Every 2 days	21.36±2.58	22.62±2.54	22.41±2.04
Every 3 days	22.10±2.91	23.13±2.39	22.05±2.49
P-value (Biochar × watering)	0.067 NS	0.073 NS	0.867 NS
Biochar, Every day	21.34±1.84	22.41±1.79	20.67±2.13
Biochar, Every 2 day	20.28±1.97	21.20±1.56	21.22±1.45
Biochar, Every 3 day	20.35±2.27	22.14±2.28	21.21±2.68
Without biochar, Every day	21.52±1.92	22.22±2.18	22.53±2.71
Without biochar, Every 2 day	22.44±2.75	24.05±2.59	23.61±1.87
Without biochar, Every 3 day	23.86±2.42	24.12±2.15	22.89±2.08
CV(%)	10.25	9.33	9.98
Overall mean	21.63	22.69	22.02

[1/] PH -Wn = Plant height at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

LN was significantly affected by biochar supplementation in weeks two, three, and five, higher values were observed in soil without biochar (Table 11). Only week three was significantly affected by the watering factor, higher values were found in plants that received watering every two and three days (Table 11). For biochar × watering interaction, two of seven weeks: week three and four, were significantly affected by this interaction, however, the values mean was varied between two weeks. Nevertheless, the higher value was observed at no supplementation biochar with watering every two and three days (Table 11).

Table 11 Analysis of variance (ANOVA) and means (± standard deviation) in leaf number (LN) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 1.

Treatments	**LN-W1**[1]	**LN-W2**	**LN-W3**	**LN-W4**
P-value (Biochar)	0.398 NS[2]	0.0006**[3]	0.001**	0.076 NS
biochar	3.30±2.94	6.46±2.33Y[4]	9.39± 1.69 Y	19.26±4.54
Without biochar	3.85±1.44	9.11±3.06 X	11.26±2.91 X	21.49±5.92
P-value (Watering)	0.188 NS	0.180NS	0.001**	0.010 NS
Every day	2.79±1.56	6.59±3.20	8.86±1.85 B	19.40±4.72
Every 2 days	4.19±2.52	8.32±3.39	10.92±2.66 A	22.28±4.98
Every 3 days	3.99±2.35	8.08±2.26	11.20±2.48 A	19.43±5.99
P-value (Biochar × watering)	0.932 NS	0.556 NS	0.044*	0.005**
Biochar, Every day	2.53±1.94	5.06±2.21	8.90±1.65 b	20.47±3.50 ab
Biochar, Every 2 day	4.00±3.52	6.73±2.24	9.53±1.91 b	21.87±4.62 ab
Biochar, Every 3 day	4.00±4.06	7.30±2.21	9.73±1.55 b	15.43±2.70 c
Without biochar, Every day	3.12±0.91	8.33±3.40	8.82±2.13 b	18.33±5.68 bc
Without biochar, Every 2 day	4.30±1.91	9.90±3.69	12.30±2.65 a	22.70±5.54 ab
Without biochar, Every 3 day	3.98±1.11	8.87±2.12	12.67±2.40 a	23.43±5.74 a
CV(%)	61.39	34.74	20.20	23.43
Overall mean	3.61	7.76	10.33	20.37

Treatments	**LN-W5**	**LN-W6**	**LN-W7**
P-value (Biochar)	0.022*	0.906 NS	0.318 NS
biochar	20.52±3.91 Y	20.61±3.42	17.74±3.65
Without biochar	23.50±5.66 X	20.77±6.18	18.84±4.87
P-value (Watering)	0.474 NS	0.858 NS	0.388 NS
Every day	22.00±5.13	21.20±5.41	19.25±5.40
Every 2 days	22.97±5.13	20.47±4.27	17.40±3.42
Every 3 days	21.07±4.97	20.40±5.32	18.23±3.85
P-value (Biochar × watering)	0.365 NS	0.363 NS	0.123 NS
Biochar, Every day	21.17±3.81	19.93±3.71	17.33±4.15
Biochar, Every 2 day	22.10±4.71	21.50±3.72	18.27±3.37
Biochar, Every 3 day	18.30±1.97	20.40±2.94	17.63±3.73
Without biochar, Every day	22.83±6.29	22.47±6.66	21.17±6.02
Without biochar, Every 2 day	23.83±5.64	19.43±4.73	16.53±3.41
Without biochar, Every 3 day	23.83±5.58	20.40±7.15	18.83±4.08
CV(%)	22.19	24.50	23.07
Overall mean	22.01	20.69	18.29

[1/] LN-Wn = leaf number at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

For LL, the higher mean values in all weeks were detected at without biochar in soil (Table 12). Non-significant affected by watering frequency in all weeks. For biochar × watering interaction, three in seven weeks were significantly affected by this interaction, including week three, five and six. Plant grown in soil with without biochar and watering every two and three days had higher mean values of LL (Table 12).

Table 12 Analysis of variance (ANOVA) and means (± standard deviation) in leaf length (LL) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in week 1-week 7 in Crop 1.

Treatments	LL-W1[1]	LL-W2	LL-W3	LL-W4
P-value (Biochar)	$1.35x10^{-5}$**[3]	$4.57x10^{-5}$**	$2.62x10^{-5}$**	0.002**
biochar	1.04±0.78 Y[4]	5.30±1.93Y	14.29±2.34 Y	18.34±2.13 Y
Without biochar	2.24±0.87 X	8.12±2.59X	17.65±3.59 X	20.39±2.81 X
P-value (Watering)	0.345 NS[2]	0.589 NS	0.133 NS	0.110 NS
Every day	1.53±0.90	6.10 ± 3.06	14.95±2.63	18.45±2.11
Every 2 days	2.04±0.95	6.80 ± 2.48	16.22±3.95	19.67±2.92
Every 3 days	1.69±1.20	7.00 ± 2.61	16.74±3.55	19.99±2.81
P-value (Biochar × watering)	0.609 NS	0.925 NS	0.022*	0.127 NS
Biochar, Every day	0.99±0.64	4.93±2.48	14.66±2.30 b	18.21±2.29
Biochar, Every 2 day	1.44±0.95	5.44±1.75	14.29±2.70 b	18.64±2.19
Biochar, Every 3 day	0.65±0.72	5.44±1.77	13.92±2.16 b	18.18±2.10
Without biochar, Every day	2.08±0.79	7.44±3.27	15.25±3.03 b	18.69±2.02
Without biochar, Every 2 day	2.40±0.79	8.16±2.42	18.15±4.17 a	20.70±3.29
Without biochar, Every 3 day	2.21±1.04	8.56±2.42	19.55±2.07 a	21.79±2.23
CV(%)	48.07	35.03	17.73	12.35
Overall mean	1.75	6.68	15.97	19.37

Treatments	LL-W5	LL-W6	LL-W7
P-value (Biochar)	$1.75x10^{-5}$**	0.013*	0.044*
biochar	19.26±1.95 Y	20.92±1.93 Y	20.71±2.14 Y
Without biochar	21.85±2.48 X	22.30±2.36 X	22.96±5.59 X
P-value (Watering)	0.778 NS	0.733 NS	0.241 NS
Every day	20.32±1.66	21.31±1.78	20.87±2.34
Every 2 days	20.80±2.65	21.73±2.57	21.54±1.83
Every 3 days	20.53±3.26	21.78±2.39	23.10±6.86
P-value (Biochar × watering)	0.014*	0.033*	0.565 NS
Biochar, Every day	20.02±1.66 cd	21.55±1.61 abc	20.41±2.47
Biochar, Every 2 day	19.56±1.75 cd	20.20±1.45 c	20.52±1.32
Biochar, Every 3 day	18.18±2.10 d	21.00±2.50 bc	21.21±2.54
Without biochar, Every day	20.62±1.69 bc	21.07±1.99 bc	21.34±2.24
Without biochar, Every 2 day	22.04±2.89 ab	23.26±2.58 a	22.56±1.72
Without biochar, Every 3 day	22.88±2.40 a	22.57±2.11 ab	24.99±9.22
CV(%)	10.36	9.63	19.36
Overall mean	20.55	21.61	21.84

[1/] LL-Wn = leaf length at week 1,...,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

The mean values of BF in all weeks were not significant affected by the biochar × watering interaction and by each factor: biochar and watering frequency (Table 13).

Table 13 Analysis of variance (ANOVA) and means (± standard deviation) in bulb formation (BF) (number) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 1.

Treatments	**BF-W1**[1]	**BF-W2**	**BF-W3**	**BF-W4**
P-value (Biochar)	0.204 NS[2]	0.824 NS	0.972 NS	0.775 NS
biochar	1.93±0.51	3.59±0.91	4.92±1.04	5.19±0.96
Without biochar	2.18±0.77	3.53±0.87	4.93±1.13	5.11±1.18
P-value (Watering)	0.793 NS	0.252 NS	0.641 NS	0.851 NS
Every day	1.98±0.87	3.30±1.04	4.87±1.26	5.10±1.26
Every 2 days	2.07±0.60	3.63±0.47	5.12±0.94	5.27±1.01
Every 3 days	2.19±0.49	3.79±0.99	4.80±1.03	5.08±0.95
P-value (Biochar × watering)	0.150 NS	0.886 NS	0.895 NS	0.821 NS
Biochar, Every day	1.85±0.25	3.43±0.82	4.90±1.09	5.07±1.05
Biochar, Every 2 day	1.67±0.52	3.67±0.52	5.17±1.03	5.43±1.11
Biochar, Every 3 day	2.42±0.62	3.80±1.48	4.70±1.06	5.07±0.72
Without biochar, Every day	2.15±1.31	3.13±1.31	4.83±1.47	5.13±1.50
Without biochar, Every 2 day	2.32±0.52	3.60±0.46	5.07±0.90	5.10±0.92
Without biochar, Every 3 day	2.08±0.39	3.78±0.73	4.90±1.05	5.10±1.17
CV(%)	32.21	25.30	22.61	21.54
Overall mean	2.08	3.55	4.93	5.15

Treatments	**BF-W5**	**BF-W6**	**BF-W7**
P-value (Biochar)	0.738 NS	0.479 NS	0.610 NS
biochar	5.42±1.09	5.55±0.83	5.28±1.05
Without biochar	5.31±1.40	5.34±1.24	5.13±1.10
P-value (Watering)	0.771 NS	0.844 NS	0.596 NS
Every day	5.20±1.43	5.35±1.21	5.17±1.25
Every 2 days	5.48±1.06	5.55±1.01	5.40±1.05
Every 3 days	5.42±1.27	5.43±0.97	5.05±0.91
P-value (Biochar × watering)	0.960 NS	0.968 NS	0.775 NS
Biochar, Every day	5.20±1.12	5.43±0.59	5.24±1.09
Biochar, Every 2 day	5.60±1.15	5.70±1.05	5.60±1.06
Biochar, Every 3 day	5.47±1.07	5.50±0.87	5.00±1.02
Without biochar, Every day	5.20±1.75	5.27±1.65	5.10±1.46
Without biochar, Every 2 day	5.37±1.00	5.40±1.00	5.20±1.04
Without biochar, Every 3 day	5.37±1.51	5.37±1.12	5.10±0.83
CV(%)	24.12	20.06	21.13
Overall mean	5.37	5.44	5.21

[1/] BF -Wn = Bulb formation (number) at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability.

PC of the plant was significantly affected by biochar supplementation in three of seven weeks, higher mean values in week significant observed at plant grown in soil without biochar (Table 14). Three weeks: weeks 1, 2, and 4, were significantly affected by watering frequency, higher mean values were found at watering every two and three days (Table 14). The interaction of biochar × watering significantly affected PC in three weeks: weeks 3, 4, and 6. In these weeks significantly affected by interaction of biochar × watering, higher mean values was found in plant received soil non supplemented with biochar at watering in all frequencies (Table 14).

Table 14 Analysis of variance (ANOVA) and means (± standard deviation) in plant canopy (PC) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 1.

Treatments	**PC-W1**[1]	**PC-W2**	**PC-W3**	**PC-W4**
P-value (Biochar)	0.031*[3]	0.144 NS	0.003**	0.114 NS
biochar	1.89± 0.46 Y[4]	2.71±0.51	3.47±0.85 Y	3.67±0.72
Without biochar	2.21±055 X	2.94±0.65	4.10±0.85 X	3.98±0.85
P-value (Watering)	0.035*	0.011*	0.079 NS	0.035*
Every day	1.92±0.37 B	2.52 ±0.39 B	4.11±0.85	3.48±0.61 B
Every 2 days	2.36±0.58 A	3.16±0.64 A	3.68±0.87	3.93±0.79 AB
Every 3 days	1.95±0.56 B	2.86±0.59 AB	3.57±0.93	4.07±0.88 A
P-value (Biochar × watering)	0.304 NS[2]	0.059 NS	0.009**	0.031*
Biochar, Every day	1.91±0.19	2.66±0.36	4.22±0.81 a	3.65±0.78 bc
Biochar, Every 2 day	2.13±0.74	2.82±0.69	3.28±0.64 b	3.76±0.74 bc
Biochar, Every 3 day	1.57±0.29	2.70±0.62	2.92±0.48 b	3.61±0.72 bc
Without biochar, Every day	1.94±0.54	2.29±0.35	3.99±0.90 a	3.31±0.35 c
Without biochar, Every 2 day	2.49±0.45	3.39±0.51	4.08±0.92 a	4.10±0.84 ab
Without biochar, Every 3 day	2.14±9.58	2.94±0.59	4.22±0.81 a	4.52±0.81 a
CV(%)	23.61	18.40	20.53	18.95
Overall mean	2.07	2.84	3.79	3.83

Treatments	**PC-W5**	**PC-W6**	**PC-W7**
P-value (Biochar)	0.197 NS	0.992 NS	$2.29x10^{-5}$**
biochar	3.43±0.65	6.11±0.91	3.17±0.53 Y
Without biochar	3.68±0.86	6.11±1.03	3.89±0.65 X
P-value (Watering)	0.041*	0.771 NS	0.667 NS
Every day	3.21±0.67	5.99±1.16	3.51±0.67
Every 2 days	3.66±0.75	6.19±0.80	3.63±0.73
Every 3 days	3.79±0.79	6.15±0.93	3.46±0.68
P-value (Biochar × watering)	0.425 NS	0.030*	0.403 NS
Biochar, Every day	3.25±0.44	5.53±0.94 b	3.23±0.63
Biochar, Every 2 day	3.50±0.95	6.35±0.86 ab	3.12±0.59
Biochar, Every 3 day	3.53±0.48	6.45±0.69 a	3.17±0.40
Without biochar, Every day	3.17±0.87	6.45±1.22 a	3.78±0.63
Without biochar, Every 2 day	3.81±0.48	6.04±0.73 ab	4.13±0.47
Without biochar, Every 3 day	4.05±0.98	5.85±1.07 ab	3.75±0.80
CV(%)	20.70	15.35	16.92
Overall mean	3.55	6.11	3.53

1/ PC-Wn = Plant canopy at week 1,...,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

At the harvesting stage, four of seven characteristics were significantly affected by biochar supplementation, including LRL, RL, PW, and BW (Table 15) (Figure 5). All characteristics significantly affected by biochar adding, plant grown in soil without biochar showed higher values more than supplementation with biochar. All characteristics were not significantly affected by watering factor and biochar × watering interaction (Table 15).

Table 15 Analysis of variance (ANOVA) and means (± standard deviation) at harvesting stage (week 8) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequenies in Crop 1.

Treatments	**LN-H**[1]	**LL-H**	**LRL-H**	**RL-H**
P-value (Biochar)	0.081 NS[2]	0.311 NS	0.003**[3]	4.19x10^{-5}**
biochar	16.44±4.00	20.44±2.18	27.74±2.40 Y[4]	4.48±0.74 Y
Without biochar	18.74±5.84	21.04±2.30	29.76±2.64 X	5.48±0.99 X
P-value (Watering)	0.800 NS	0.538 NS	0.300 NS	0.108 NS
Every day	17.22±5.64	21.13±2.40	29.43±3.03	5.32±1.08
Every 2 days	18.20±4.43	20.33±1.48	28.19±2.13	4.87±1.11
Every 3 days	17.37±5.35	20.76±2.70	28.62±2.84	4.76±0.75
P-value (Biochar × watering)	0.184 NS	0.424 NS	0.616 NS	0.675 NS
Biochar, Every day	14.47±2.97	20.32±2.37	28.06±2.82	4.73±0.89
Biochar, Every 2 day	17.33±3.94	20.14±1.33	27.12±1.61	4.33±0.75
Biochar, Every 3 day	17.53±4.53	20.88±2.76	28.04±2.72	4.40±0.56
Without biochar, Every day	19.97±6.44	21.95±2.25	30.80±2.70	5.91±0.94
Without biochar, Every 2 day	19..07±4.92	20.53±1.68	29.27±2.11	5.42±1.17
Without biochar, Every 3 day	17.20±6.32	20.65±2.80	29.21±2.98	5.12±0.76
CV(%)	28.47	10.90	8.81	17.38
Overall mean	17.59	20.74	28.75	4.98

Treatments	**BF-H**	**PW-H**	**BW-H**
P-value (Biochar)	0.456 NS	4.16x10^{-5}**	0.0007**
biochar	5.58±1.12	3.40±0.94 Y	14.71±3.07 Y
Without biochar	5.35±1.21	4.67±1.22 X	18.21±4.15 X
P-value (Watering)	0.421 NS	0.374 NS	0.805 NS
Every day	5.38±1.35	4.15±1.44	16.02±4.23
Every 2 days	5.74±1.18	3.75±1.20	16.77±4.27
Every 3 days	5.26±0.89	4.20±1.12	16.60±3.72
P-value (Biochar × watering)	0.735 NS	0.752 NS	0.988 NS
Biochar, Every day	5.34±0.98	3.37±1.01	14.17±3.11
Biochar, Every 2 day	5.93±1.28	3.17±0.84	15.03±3.82
Biochar, Every 3 day	5.47±1.09	3.67±0.98	14.94±2.38
Without biochar, Every day	5.43±1.70	4.93±1.40	17.87±4.53
Without biochar, Every 2 day	5.54±1.09	4.33±1.26	18.50±4.14
Without biochar, Every 3 day	5.04±0.59	4.73±1.02	18.26±4.18
CV(%)	21.57	27.27	22.88
Overall mean	5.47	4.03	16.46

[1/] LN= leaf number, LL= leaf length, LRL= leaf to root length, RL= root length, BF= bulb formation, PW= plantlet weight, BW= bulb weight at harvesting stage (H). [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

Figure 5 Performance of spring onions at harvesting stage in Crop 1 (From left to right: biochar + watering every day, biochar + watering every two days; biochar + watering every three days; without biochar + watering every day; without biochar + watering every two days; without biochar + watering every three days).

Agronomic characteristics in spring onion cultivated in Crop 2

In crop 3, for PH, five of seven weeks were significantly affected by biochar supplementation, higher mean values were found at soil amendment by biochar in these weeks (Table 16). For watering significantly affected PH in all weeks, watering in every day and every two days had higher mean values more than watering in every three days. Biochar × watering interaction was significantly affected to PH in three of seven weeks: week 2, 5, and 6. In three weeks that significantly affected by biochar × watering interaction, significantly low mean was found in plants grown in soil that was not supplemented with biochar and watered every three days (Table 16).

Table 16 Analysis of variance (ANOVA) and means (± standard deviation) in plant height (PH) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 2.

Treatments	**PH-W1**[1]	**PH-W2**	**PH-W3**	**PH-W4**
P-value (Biochar)	$2.08x10^{-6}$**[3]	0.0001**	0.0001**	0.001**
biochar	18.91±1.69 X[4]	24.90±1.75 X	29.43±2.49 X	32.06±2.64 X
Without biochar	16.14±2.50 Y	22.90±2.63 Y	27.42±2.66 Y	30.02±2.82 Y
P-value (Watering)	0.019*	0.0001**	0.0002**	$9.1x10^{-5}$**
Every day	16.87±1.94 B	24.13±2.10 A	29.08±2.33 A	31.75±2.40 A
Every 2 days	18.59±2.64 A	25.15±1.73 A	29.59±2.20 A	32.32±2.15 A
Every 3 days	17.11±2.72 B	22.43±2.65 B	26.61±2.79 B	29.05±3.05 B
P-value (Biochar × watering)	0.292 NS[2]	0.049*	0.239 NS	0.274 NS
Biochar, Every day	17.90±1.21	24.92±1.66 ab	29.52±2.59	32.27±2.59
Biochar, Every 2 day	19.74±2.02	25.53±1.80 a	30.53±1.89	33.18±1.83
Biochar, Every 3 day	19.07±1.32	24.26±1.71 ab	28.25±2.62	30.74±3.01
Without biochar, Every day	15.84±2.03	23.34±2.27 b	28.65±2.10	31.23±2.20
Without biochar, Every 2 day	17.44±2.77	24.76±1.66 ab	28.64±2.17	31.46±2.19
Without biochar, Every 3 day	15.15±2.30	20.59±2.10 c	24.97±1.91	27.36±2.06
CV(%)	11.50	7.87	7.85	7.56
Overall mean	17.52	23.90	28.43	31.04

Treatments	**PH-W5**	**PH-W6**	**PH-W7**
P-value (Biochar)	0.006**	0.095 NS	0.609 NS
biochar	33.54± 2.71 X	33.84±2.61	34.62±3.01
Without biochar	31.90±3.12 Y	32.79±3.61	34.26±3.27
P-value (Watering)	$3.49x10^{-7}$**	$2.75x10^{-6}$**	0.0004**
Every day	34.11±2.35 A	34.85±2.14 A	36.10±2.56 A
Every 2 days	33.87±2.27 A	34.28±2.69 A	34.75±3.02 A
Every 3 days	30.18±2.69 B	30.82±3.06 B	32.46±2.73 B
P-value (Biochar × watering)	0.033*	0.003**	0.081 NS
Biochar, Every day	33.96±2.68 ab	34.02±2.22 ab	35.38±2.78
Biochar, Every 2 day	34.74±2.44 a	34.79±2.86 ab	34.78±3.61
Biochar, Every 3 day	31.91±2.42 b	32.71±2.52 b	33.69±2.60
Without biochar, Every day	34.27±2.10 a	35.67±1.80 a	36.83±2.23
Without biochar, Every 2 day	33.00±1.81 ab	33.76±2.54 ab	34.71±2.50
Without biochar, Every 3 day	28.44±1.67 c	28.94±2.35 c	31.23±2.36
CV(%)	6.77	7.22	7.89
Overall mean	32.72	33.32	34.44

[1/] PH -Wn = Plant height at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

For LN, three in seven weeks were significantly affected by supplementation with biochar: week 3, 4, and 5. In three weeks affected by biochar amendment, higher mean values were observed in soil supplemented with biochar (Table 17). In two weeks: week two and six, were significantly affected by watering frequency, higher values were found at watered every day (Table 17). Only week two was significantly affected by biochar × watering interaction, highest LN was found at soil supplemented with biochar with watered every day and without biochar with watering every two days (Table 17).

Table 17 Analysis of variance (ANOVA) and means (± standard deviation) in leaf number (LN) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 2.

Treatments	**LN-W1**[1]	**LN-W2**	**LN-W3**	**LN-W4**
P-value (Biochar)	0.112 NS[2]	0.052 NS	0.023*	0.042*
biochar	13.13±2.56	20.65±4.71	22.66±4.13 X	26.05±5.16 X
Without biochar	11.83±3.54	18.68±4.98	20.08±4.52 Y	22.87±6.76 Y
P-value (Watering)	0.839 NS	0.015*[3]	0.804 NS	0.609 NS
Every day	12.56±3.10	20.98±5.63 A[4]	20.67±4.25	25.53±6.14
Every 2 days	12.73±2.81	20.43±4.39 A	21.73±3.84	24.02±6.71
Every 3 days	12.16±3.59	17.57±4.09 B	21.50±5.40	23.83±5.81
P-value (Biochar × watering)	0.207 NS	8.38×10^{-6}**	0.100 NS	0.101 NS
Biochar, Every day	13.18±2.39	24.90±4.13 a	21.40±3.72	27.60±6.61
Biochar, Every 2 day	12.50±2.30	17.87±3.48 b	22.07±4.16	23.37±4.31
Biochar, Every 3 day	13.70±3.05	19.17±3.34 b	24.50±4.22	27.18±3.37
Without biochar, Every day	11.93±3.70	17.07±3.99 b	20.33±4.87	23.47±5.13
Without biochar, Every 2 day	12.95±3.35	23.00±3.73 a	21.40±3.68	24.67±8.69
Without biochar, Every 3 day	10.62±3.54	15.97±4.29 b	18.50±4.87	20.47±5.91
CV(%)	24.85	19.53	20.03	24.21
Overall mean	12.48	19.66	21.37	24.46

Treatments	**LN-W5**	**LN-W6**	**LN-W7**
P-value (Biochar)	0.018*	0.080 NS	0.151 NS
biochar	30.39±5.72 X	33.26±7.56	33.61±6.06
Without biochar	26.62±6.54 Y	29.98±7.59	31.12±8.47
P-value (Watering)	0.057 NS	0.029*	0.003 NS
Every day	30.80±6.38	35.12±7.65 A	36.50±7.66
Every 2 days	28.55±5.92	30.50±7.24 B	31.33±6.09
Every 3 days	26.17±6.27	29.23±7.26 B	29.27±6.75
P-value (Biochar × watering)	0.469 NS	0.120 NS	0.086 NS
Biochar, Every day	33.97±5.39	39.10±6.32	37.57±5.87
Biochar, Every 2 day	29.43±5.46	29.77±7.58	30.30±5.13
Biochar, Every 3 day	27.77±4.85	30.90±5.41	32.97±5.25
Without biochar, Every day	27.63±5.88	31.13±6.95	35.43±9.31
Without biochar, Every 2 day	27.67±6.52	31.23±7.21	32.37±7.04
Without biochar, Every 3 day	24.57±7.34	27.57±8.70	25.57±6.17
CV(%)	20.92	22.46	20.45
Overall mean	28.51	31.62	32.37

[1/] LN-Wn = leaf number at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

Five in seven weeks, LL was significantly affected by biochar amendment, these weeks had higher mean values in plants grown in soil amended with biochar (Table 18). For LL, all weeks were significantly affected by watering frequency, the value showed higher at watered every day and every two days (Table 18). Two weeks: week 2 and 5 were significantly affected by biochar × watering interaction, the lowest values were observed at soil was non-supplemented with biochar with watered every three days (Table 18).

Table 18 Analysis of variance (ANOVA) and means (± standard deviation) in leaf length (LL) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in week 1-week 7 in Crop 2.

Treatments	LL-W1[1]	LL-W2	LL-W3	LL-W4
P-value (Biochar)	$7.77x10^{-7}$**[3]	$2.94x10^{-10}$**	0.006**	0.029*
biochar	17.86±1.40 X[4]	23.70±1.80 X	28.01±2.84 X	30.57±3.17 X
Without biochar	15.02±2.61 Y	19.69±4.89 Y	26.18±2.90 Y	28.99±2.79 Y
P-value (Watering)	0.018*	$9.80x10^{-12}$**	0.0001**	0.001**
Every day	15.83±2.25 B	22.70±2.13 B	27.88±2.41 A	30.25±2.62 A
Every 2 days	17.49±2.33 A	23.98±1.77 A	28.40±2.14 A	31.20±2.12 A
Every 3 days	16.00±2.74 B	18.40±5.34 C	25.02±3.24 B	27.89±3.41 B
P-value (Biochar × watering)	0.226 NS[2]	$4.62x10^{-9}$**	0.399 NS	0.998 NS
Biochar, Every day	17.09±1.14	23.53±1.68 ab	28.36±2.61	31.02±2.69
Biochar, Every 2 day	18.46±1.74	24.41±1.51 a	29.14±1.90	31.97±1.94
Biochar, Every 3 day	18.02±0.94	23.15±2.09 ab	26.54±3.41	28.71±3.88
Without biochar, Every day	14.56±2.41	21.86±2.28 b	27.39±2.22	29.48±2.43
Without biochar, Every 2 day	16.52±2.52	23.55±1.99 ab	27.66±2.19	30.44±2.09
Without biochar, Every 3 day	13.98±2.42	13.65±2.40 c	23.50±2.32	27.07±2.85
CV(%)	11.97	9.29	9.19	9.14
Overall mean	16.44	21.69	27.10	29.78

Treatments	LL-W5	LL-W6	LL-W7
P-value (Biochar)	$1.26x10^{-6}$**	0.266 NS	0.266 NS
biochar	32.19±3.53 X	32.66±3.41	32.66±3.41
Without biochar	28.29±6.37 Y	31.82±3.48	31.82±3.48
P-value (Watering)	$1.40x10^{-13}$**	$3.73x10^{-5}$**	$3.73x10^{-5}$**
Every day	32.90±2.30 A	33.88±2.04 A	33.88±2.04 A
Every 2 days	32.83±2.27 A	33.19±2.74 A	33.19±2.74 A
Every 3 days	24.99±6.24 B	29.64±3.76 B	29.64±3.76 B
P-value (Biochar × watering)	$5.34x10^{-7}$**	0.182 NS	0.182 NS
Biochar, Every day	32.86±2.72 a	33.35±2.15	33.35±2.15
Biochar, Every 2 day	33.69±2.37 a	33.82±2.79	33.82±2.79
Biochar, Every 3 day	30.03±4.36 b	30.79±4.37	30.79±4.37
Without biochar, Every day	32.93±1.94 a	34.40±1.89	34.40±1.89
Without biochar, Every 2 day	31.98±1.92 ab	32.56±2.68	32.56±2.68
Without biochar, Every 3 day	19.95±2.59 c	28.49±2.80	28.49±2.80
CV(%)	9.18	8.97	8.97
Overall mean	30.24	32.24	32.24

1/ LL-Wn = leaf length at week 1,...,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

For BF, a significant difference was observed in two weeks: week 1 and week 3, the higher mean values were found in plants grown in soil supplemented with biochar (Table 19). Watering frequency was not significantly affected to BF in all weeks (Table 19). Only one week at week 1 was significantly affected by biochar × watering interaction, the lowest mean value was observed without biochar and watered every three days (Table 19).

Table 19 Analysis of variance (ANOVA) and means (± standard deviation) in bulb formation (BF) (number) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 2.

Treatments	**BF-W1**[1]	**BF-W2**	**BF-W3**	**BF-W4**
P-value (Biochar)	0.007**[3]	0.0801 NS	0.006**	0.898 NS
biochar	5.82±1.04 X[4]	5.68±0.95	6.59 ±1.11 X	6.39±1.20
Without biochar	5.04±1.20 Y	5.21±1.11	5.73±1.22 Y	6.34±1.45
P-value (Watering)	0.562 NS[2]	0.405 NS	0.796 NS	0.883 NS
Every day	5.64±1.05	5.67±1.06	6.28±1.29	6.48±1.15
Every 2 days	5.36±1.05	5.23±0.99	6.03±0.94	6.28±1.25
Every 3 days	5.30±1.43	5.43±1.11	6.17±1.47	6.33±1.59
P-value (Biochar × watering)	0.018*	0.119 NS	0.175 NS	0.069 NS
Biochar, Every day	6.00±0.75 a	5.97±0.69	6.73±0.91	6.53±0.86
Biochar, Every 2 day	5.27±1.09 ab	5.10±1.09	6.10±1.08	5.80±1.25
Biochar, Every 3 day	6.20±1.09 a	5.97±0.84	6.93±1.26	6.83±1.31
Without biochar, Every day	5.28±1.21 ab	5.37±1.30	5.83±1.49	6.43±1.42
Without biochar, Every 2 day	5.45±1.07 a	5.37±0.91	5.97±0.84	6.77±1.11
Without biochar, Every 3 day	4.40±1.15 b	4.90±1.13	5.40±1.29	5.83±1.75
CV(%)	19.69	18.62	18.94	20.61
Overall mean	5.43	5.44	6.16	6.37

Treatments	**BF-W5**	**BF-W6**	**BF-W7**
P-value (Biochar)	0.209 NS	0.132 NS	0.270 NS
biochar	6.96±1.40	7.15±1.48	7.25±1.57
Without biochar	6.50±1.42	6.60±1.36	6.80±1.59
P-value (Watering)	0.901 NS	0.750 NS	0.687 NS
Every day	6.83±1.32	6.98±1.38	7.25±1.69
Every 2 days	6.72±1.46	6.68±1.39	6.82±1.47
Every 3 days	6.63±1.53	6.97±1.59	7.02±1.62
P-value (Biochar × watering)	0.069NS	0.093NS	0.220NS
Biochar, Every day	6.93±1.13	7.33±1.48	7.57±1.71
Biochar, Every 2 day	6.50±1.64	6.43±1.57	6.57±1.56
Biochar, Every 3 day	7.44±1.36	7.70±1.21	7.63±1.34
Without biochar, Every day	6.73±1.54	6.64±1.25	6.93±1.70
Without biochar, Every 2 day	6.93±1.31	6.93±1.21	7.07±1.42
Without biochar, Every 3 day	5.83±1.29	6.23±1.63	6.40±1.71
CV(%)	20.65	20.41	22.47
Overall mean	6.73	6.88	7.03

1/ BF -Wn = Bulb formation (number) at week 1,…,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There were significant differences in the mean of PC affected by biochar supplementation at weeks 4 and 6, added biochar had higher mean values than non-added biochar (Table 20). For watering, there were significantly affected by this factor on PC in one of seven weeks: week 3, the higher mean values were found at watered every day and every two days (Table 20). However, PC was non-significantly different affected by biochar × watering interaction in all weeks (Table 20).

Table 20 Analysis of variance (ANOVA) and means (± standard deviation) in plant canopy (PC) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 2.

Treatments	PC-W1[1]	PC-W2	PC-W3	PC-W4
P-value (Biochar)	0.052 NS[2]	0.483 NS	0.171 NS	0.050*
biochar	2.38±0.31	2.54±0.31	3.35±0.51	3.62±0.60 X
Without biochar	2.15±0.53	2.67±0.98	3.17±0.54	3.34±0.53 Y
P-value (Watering)	0.975 NS	0.880 NS	0.018*[3]	0.075 NS
Every day	2.26±0.42	2.53±0.36	3.44±0.49 A[4]	3.68±0.61
Every 2 days	2.26±0.37	2.64±0.37	3.35±0.54 A	3.48±0.58
Every 3 days	2.28±0.55	2.64±1.17	3.00±0.48 B	3.28±0.49
P-value (Biochar × watering)	0.242 NS	0.978 NS	0.285 NS	0.392 NS
Biochar, Every day	2.32±0.34	2.45±0.34	3.58±0.54	3.95±0.65
Biochar, Every 2 day	2.28±0.26	2.55±0.30	3.29±0.48	3.50±0.49
Biochar, Every 3 day	2.53±0.30	2.60±0.32	3.18±0.49	3.42±0.58
Without biochar, Every day	2.19±0.50	2.62±0.39	3.29±0.43	3.42±0.47
Without biochar, Every 2 day	2.23±0.47	2.72±0.43	3.40±0.61	3.45±0.69
Without biochar, Every 3 day	2.04±0.64	2.68±1.67	2.82±0.42	3.14±0.36
CV(%)	19.38	28.95	15.30	15.84
Overall mean	2.27	2.60	3.26	3.48

Treatments	PC-W5	PC-W6	PC-W7
P-value (Biochar)	0.177 NS	0.044*	0.008 NS
biochar	3.95±0.53	4.17±0.65 X	4.77±0.89
Without biochar	3.57±1.40	3.88±0.58 Y	4.24±0.74
P-value (Watering)	0.289 NS	0.0007 NS	0.0008 NS
Every day	3.79±0.72	4.29±0.67	4.96±0.98
Every 2 days	4.01±1.61	4.17±0.44	4.54±0.59
Every 3 days	3.48±0.53	3.62±0.57	4.01±0.70
P-value (Biochar × watering)	0.524 NS	0.428 NS	0.767 NS
Biochar, Every day	4.16±0.51	4.53±0.70	5.30±1.05
Biochar, Every 2 day	4.00±0.49	4.19±0.43	4.71±0.50
Biochar, Every 3 day	3.68±0.52	3.81±0.64	4.28±0.78
Without biochar, Every day	3.42±0.72	4.05±0.58	4.61±0.81
Without biochar, Every 2 day	4.02±2.28	4.15±0.47	4.36±0.64
Without biochar, Every 3 day	3.28±0.49	3.44±0.45	3.74±0.52
CV(%)	28.20	13.73	16.47
Overall mean	3.76	4.03	4.50

[1/] PC-Wn = Plant canopy at week 1,...,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

At the harvesting stage in crop 2, significantly affected by biochar supplementation was found in two of seven characteristics: RL and BW, the higher mean values were observed at soil amended with biochar supplementation (Table 21).

Table 21 Analysis of variance (ANOVA) and means (± standard deviation) at harvesting stage (week 8) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 2.

Treatments	LN-H[1]	LL-H	LRL-H	RL-H
P-value (Biochar)	0.111 NS[2]	0.556 NS	0.383 NS	1.18×10^{-7}**
biochar	37.49±8.14	32.36±2.38	41.15±3.51	5.84±1.51 X
Without biochar	34.19±8.68	32.72±3.25	40.41±4.31	4.27±0.96 Y
P-value (Watering)	0.020*[3]	0.0004**	0.008**	0.0104*
Every day	40.02±8.47 A[4]	34.26±2.32 A	42.12±3.45 A	4.79±1.16 B
Every 2 days	34.00±7.92 B	32.33±2.34 B	41.32±3.14 A	5.63±1.46 A
Every 3 days	33.50±7.91 B	31.03±2.89 B	38.90±4.47 B	4.74±1.69 B
P-value (Biochar × watering)	0.171 NS	0.014*	0.0002**	6.91×10^{-6}**
Biochar, Every day	43.00±6.69	33.10±2.36 b	40.00±3.18 b	4.60±1.46 b
Biochar, Every 2 day	32.90±7.84	31.84±1.89 bc	42.16±2.75 ab	6.75±1.13 a
Biochar, Every 3 day	36.57±7.01	32.12±2.85 bc	41.29±4.42 ab	6.16±1.10 a
Without biochar, Every day	37.03±9.32	35.42±1.69 a	44.24±2.25 a	4.99±0.79 b
Without biochar, Every 2 day	35.10±8.26	32.82±2.74 b	40.49±3.42 b	4.50±0.64 b
Without biochar, Every 3 day	30.43±7.88	29.93±2.62 c	36.50±3.14 c	3.31±0.57 c
CV(%)	21.98	7.37	8.00	19.80
Overall mean	35.84	32.54	40.78	5.05

Treatments	BF-H	PW-H	BW-H
P-value (Biochar)	0.370 NS	0.089 NS	0.024*
biochar	7.36±1.72	3.09±0.81	19.23±5.95 X
Without biochar	6.99±1.51	2.78±0.76	16.13±5.60 Y
P-value (Watering)	0.453 NS	0.0003**	0.005**
Every day	7.52±1.61	3.33±0.69 A	20.57±6.19 A
Every 2 days	6.90±1.61	3.07±0.77 A	17.48±4.98 AB
Every 3 days	7.10±1.63	2.40±0.65 B	15.00±5.49 B
P-value (Biochar × watering)	0.066 NS	0.477 NS	0.033*
Biochar, Every day	7.84±1.72	3.63±0.58	23.30±5.92 a
Biochar, Every 2 day	6.43±1.79	3.20±0.74	16.50±4.91 bc
Biochar, Every 3 day	7.80±1.39	2.43±0.65	17.90±5.14 b
Without biochar, Every day	7.20±1.52	3.03±0.69	17.83±5.41 b
Without biochar, Every 2 day	7.37±1.35	2.93±0.81	18.47±5.10 b
Without biochar, Every 3 day	6.40±1.62	2.37±0.67	12.10±4.31 c
CV(%)	21.91	23.69	29.15
Overall mean	7.17	2.93	17.68

[1/] LN= leaf number, LL= leaf length, LRL= leaf to root length, RL= root length, BF= bulb formation, PW= plantlet weight, BW= bulb weight at harvesting stage (H). [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

Six of seven characteristics had significantly affected by watering frequency, excluding BF. In characteristics were significantly affected by the watering factor, although the higher values in watering frequencies were varied in each characteristic, the lowest mean values were observed at watering every three days in all characteristics (Table 21) (Figure 6). For biochar × watering interaction significantly affected to four of seven characteristics, including LL, LRL, RL, and BW. For soil was not added biochar with watering every day had the highest mean values in two characteristics including LL and LRL. However, LRL and RL showed higher mean values in soil supplemented with biochar and watering every two days and three days.

For BW, the highest mean value was found in soil supplemented with biochar and watered every day. All characteristics were significantly affected by the interaction between biochar and watering, the lowest mean value was observed in soil was not supplemented with biochar and watering every three days (Table 21).

Figure 6 Performance of spring onions at harvesting stage in Crop 2 (From left to right: biochar + watering every day, biochar + watering every two days; biochar + watering every three days; without biochar + watering every day; without biochar + watering every two days; without biochar + watering every three days).

Agronomic characteristics in spring onion cultivated in Crop 3

In crop 3, for PH in all weeks were significantly affected by biochar, added biochar had higher mean values than non-added biochar in all those characteristics (Table 22). Five in seven weeks, excluding week 1 and week 2, watering every day and every four days had higher mean values on PH than watering every eight days (Table 22). Interaction of biochar × watering showed significantly affected on PH at week 1 and week 2, supplementation with biochar and watering every four days had the highest mean values. In soil was non-supplemented with biochar and watering every four days and eight days had lower mean values at week 2 (Table 22).

Table 22 Analysis of variance (ANOVA) and means (± standard deviation) in plant height (PH) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 3.

Treatments	PH-W1[1]	PH-W2	PH-W3	PH-W4
P-value (Biochar)	0.001**[3]	0.001**	0.0005**	0.005**
Biochar	12.38±3.44 X[4]	19.46±3.74 X	25.26±2.59 X	28.10±3.00 X
Without biochar	9.69±3.08 Y	16.63±2.87 Y	22.63±3.35 Y	25.90±3.50 Y
P-value (Watering)	0.254 NS[2]	0.250 NS	0.004**	0.003**
Every day	10.53±3.50	17.88±3.32	24.38±3.24 A	27.13±3.63 A
Every 4 day	11.99±4.33	18.96± 4.24	25.20±2.83 A	28.63±2.61 A
Every 8 day	10.58±2.41	17.30±3.10	22.27±3.07 B	25.25±3.19 B
P-value (Biochar × watering)	0.040*	0.026*	0.216 NS	0.190 NS
Biochar, Every day	11.47±3.13 b	18.24±3.93 b	24.87±1.93	27.24±2.98
Biochar, Every 4 day	14.78±3.74 a	21.95±3.28 a	27.21±2.14	30.12±2.55
Biochar, Every 8 day	10.90±2.12 b	18.18±2.93 b	23.72±2.51	26.95±2.60
Without biochar, Every day	9.60±3.76 b	17.52±2.76 b	23.89±4.24	27.06±4.35
Without biochar, Every 4 day	9.19±2.86 b	15.96±2.71 c	23.19±1.84	27.14±1.71
Without biochar, Every 8 day	10.27±2.74 b	16.41±3.17 c	20.82±3.00	23.54±2.87
CV(%)	28.22	17.49	11.43	10.93
Overall mean	11.04	18.04	23.95	27.00

Treatments	PH-W5	PH-W6	PH-W7
P-value (Biochar)	0.007**	0.044*	0.0009**
Biochar	29.18± 2.67 X	29.95±2.73 X	31.67± 2.60 X
Without biochar	27.30±3.69 Y	28.64±3.29 Y	28.99±3.25 Y
P-value (Watering)	1.81×10^{-6}**	2.94×10^{-6}**	0.0007**
Every day	28.62±3.17 B	29.52±3.01 B	30.31±3.17 A
Every 4 day	30.40±1.84 A	31.40±1.84 A	31.81±2.21 A
Every 8 day	25.70±3.01 C	26.98±2.54 C	28.43±3.15 B
P-value (Biochar × watering)	0.26 NS	0.584 NS	0.283 NS
Biochar, Every day	29.01±2.71	30.01±2.67	31.16±2.85
Biochar, Every 4 day	31.12±1.83	31.76±2.21	32.57±2.01
Biochar, Every 8 day	27.40±2.14	28.10±2.14	30.38±2.62
Without biochar, Every day	28.22±3.68	29.04±3.40	29.47±3.39
Without biochar, Every 4 day	29.69±1.63	31.04±1.40	31.04±2.24
Without biochar, Every 8 day	24.00±2.85	25.86±2.50	26.47±2.37
CV(%)	9.10	8.40	8.68
Overall mean	28.24	29.30	30.18

1/ PH -Wn = Plant height at week 1,…,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

Two in seven weeks: weeks 1 and 6 showed significantly affected by biochar on LN, the higher mean values were observed in plants grown in soil supplemented with biochar (Table 23). Together, two in seven weeks, but in weeks 2 and 7, PH was significantly affected by watering in these weeks. Which, the higher mean values on PH were found at watering every 4 days, and at watering both every day and every four days in week 2 and week 7, respectively (Table 23). For biochar × watering interaction was not significantly different affected on PH in all weeks (Table 23).

Table 23 Analysis of variance (ANOVA) and means (± standard deviation) in leaf number (LN) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 3.

Treatments	**LN-W1**[1]	**LN-W2**	**LN-W3**	**LN-W4**
P-value (Biochar)	0.039**[3]	0.630 NS	0.595 NS	0.596 NS
Biochar	13.70±3.97 X[4]	22.10±5.88	26.26±7.34	26.87±7.62
Without biochar	11.82±2.89 Y	21.37±6.49	25.32±5.84	25.88±6.29
P-value (Watering)	0.213 NS[2]	0.014*	0.481 NS	0.696 NS
Every day	12.20±3.52	19.12±6.07 B	24.43±6.60	25.25±7.72
Every 4 day	13.88±4.16	24.70±6.66 A	27.03±7.25	26.93±6.91
Every 8 day	12.20±2.81	21.38±4.45 AB	25.90±5.94	26.93±6.35
P-value (Biochar × watering)	0.408 NS	0.449 NS	0.916 NS	0.940 NS
Biochar, Every day	12.80±4.11	20.80±7.08	25.03±8.22	25.97±9.78
Biochar, Every 4 day	15.67±4.15	24.10±5.61	27.87±7.14	26.97±6.86
Biochar, Every 8 day	12.63±3.21	21.40±4.80	25.87±7.11	27.67±6.52
Without biochar, Every day	11.60±2.91	17.43±4.62	23.83±4.87	24.54±5.40
Without biochar, Every 4 day	12.10±3.51	25.30±7.84	26.20±7.64	26.90±7.32
Without biochar, Every 8 day	11.77±2.44	21.37±4.33	25.93±4.90	26.20±6.45
CV(%)	26.99	26.97	26.26	27.24
Overall mean	12.76	21.73	25.79	26.37

Treatments	**LN-W5**	**LN-W6**	**LN-W7**
P-value (Biochar)	0.414 NS	0.027*	0.132 NS
Biochar	28.43±7.74	31.93±7.96 X	32.94±11.58
Without biochar	26.90±6.45	27.52±6.66 Y	29.61±6.59
P-value (Watering)	0.474 NS	0.711 NS	0.002**
Every day	27.40±7.53	29.32±8.40	33.03±9.86 A
Every 4 day	29.18±8.04	30.85±8.05	35.10±8.77A
Every 8 day	26.42±5.59	29.02±6.51	25.70±7.38 B
P-value (Biochar × watering)	0.588 NS	0.743 NS	0.114 NS
Biochar, Every day	29.50±8.67	32.40±10.08	36.60±12.86
Biochar, Every 4 day	29.03±8.18	33.12±6.92	38.13±7.76
Biochar, Every 8 day	26.77±6.80	30.27±7.05	24.10±8.66
Without biochar, Every day	25.30±5.90	26.24±5.12	29.47±3.39
Without biochar, Every 4 day	29.33±8.33	28.57±8.79	32.07±9.03
Without biochar, Every 8 day	26.07±4.42	27.77±6.02	27.30±5.86
CV(%)	26.06	25.28	27.00
Overall mean	27.67	29.73	31.28

[1/] LN-Wn = leaf number at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

In all weeks, biochar supplementation in soil was significantly affected increasing the value of LL (Table 24). Watering frequencies had significantly affected on LL in five of seven weeks, excluding weeks 1 and 2. In those five weeks, the higher mean values were observed at watering every day and every four days (Table 24). For biochar × watering interaction significantly affected on LL in weeks 1 and 2, the higher mean values were found in soil supplemented with biochar and watering every 4 days, non-significant different was found among others (Table 24).

Table 24 Analysis of variance (ANOVA) and means (± standard deviation) in leaf length (LL) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in week 1-week 7 in Crop 3.

Treatments	LL-W1[1]	LL-W2	LL-W3	LL-W4
P-value (Biochar)	0.001**[3]	0.0003**	0.0003**	0.003**
Biochar	11.34±3.29 X[4]	18.35±3.52 X	24.04±2.92 X	26.57±2.97 X
Without biochar	8.81±2.70 Y	15.33±2.83 Y	21.13±3.25 Y	24.23±3.50 Y
P-value (Watering)	0.320 NS[2]	0.260 NS	0.007**	0.001**
Every day	9.82±3.08	16.96 ± 3.18	23.01±3.19 A	25.67±3.47 A
Every 4 day	10.86±4.18	17.58± 4.28	23.81±3.47 A	27.04±2.83 A
Every 8 day	9.55±2.18	15.99± 2.93	20.92±3.00 B	23.50±3.10 B
P-value (Biochar × watering)	0.035*	0.043*	0.341 NS	0.316 NS
Biochar, Every day	10.57±2.95 b	17.59±3.61 b	23.83±2.03	26.02±2.77
Biochar, Every 4 day	13.52±3.75 a	20.52±3.50 a	25.97±2.95	28.68±2.56
Biochar, Every 8 day	9.94±2.01 b	16.95±2.58 b	22.31±2.67	25.00±2.47
Without biochar, Every day	9.08±3.17 b	16.33±2.72 b	22.20±3.98	25.32±4.18
Without biochar, Every 4 day	8.21±2.67 b	14.64±2.69 b	21.66±2.52	25.39±2.09
Without biochar, Every 8 day	9.15±2.38 b	15.03±3.07 b	19.52±2.74	21.99±3.03
CV(%)	28.55	18.13	12.74	11.51
Overall mean	10.08	16.84	22.58	25.40

Treatments	LL-W5	LL-W6	LL-W7
P-value (Biochar)	0.017*	0.031*	0.001**
Biochar	27.97±2.69 X	28.90±2.75 X	30.17±2.55 X
Without biochar	26.27±3.65 Y	27.45±3.43 Y	27.81±3.38 Y
P-value (Watering)	1.28×10^{-5}**	4.56×10^{-6}**	0.0004**
Every day	27.54±3.09 A	28.49±2.96 B	29.23±3.15 A
Every 4 day	29.10±2.07 A	30.25±2.02 A	30.64±2.10 A
Every 8 day	24.72±3.06 B	25.78±2.76 C	27.11±3.28 B
P-value (Biochar × watering)	0.293 NS	0.649 NS	0.364 NS
Biochar, Every day	27.78±2.59	28.91±2.49	30.04±2.64
Biochar, Every 4 day	29.85±1.99	30.86±2.14	31.50±1.70
Biochar, Every 8 day	26.28±2.34	26.93±2.21	28.98±2.74
Without biochar, Every day	27.30±3.65	28.07±3.44	28.42±3.54
Without biochar, Every 4 day	28.36±1.96	29.64±1.79	29.79±2.19
Without biochar, Every 8 day	23.17±2.98	24.63±2.88	25.23±2.72
CV(%)	9.79	9.05	9.14
Overall mean	27.12	28.17	28.99

[1/] LL-Wn = leaf length at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

BF in crop 3 had significantly affected by biochar supplementation in weeks 1 and 2, the higher mean values were observed in soil supplemented with biochar in both weeks (Table 25). For the effect of watering frequency, BF at only week 7 was significantly affected with the higher mean values were found at watering every day and every four days (Table 25). At only week 6 showed significantly affected by biochar × watering interaction on BF, the lower mean values were recorded at biochar supplementation with watering every four days and at without biochar supplementation with watering every eight days (Table 25).

Table 25 Analysis of variance (ANOVA) and means (± standard deviation) in bulb formation (BF) (number) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 3.

Treatments	**BF-W1**[1]	**BF-W2**	**BF-W3**	**BF-W4**
P-value (Biochar)	0.0002**[3]	8.53x10^{-5}**	0.735 NS	0.581 NS
Biochar	3.77±1.25 X[4]	5.42±0.64 Y	6.21±2.28	6.54±1.38
Without biochar	2.66±0.95 Y	4.69±0.65 X	6.38±1.37	6.36±1.17
P-value (Watering)	0.238 NS[2]	0.756 NS	0.445 NS	0.951 NS
Every day	3.52±1.05	4.97±0.65	5.97±2.24	6.38±1.33
Every 4 day	2.92±1.37	5.12±0.82	6.72±2.04	6.45±1.52
Every 8 day	3.18±1.26	5.09±0.78	6.20±1.15	6.52±0.97
P-value (Biochar × watering)	0.124 NS	0.916 NS	0.566 NS	0.971 NS
Biochar, Every day	3.67±1.16	5.30±0.57	5.60±3.00	6.43±1.47
Biochar, Every 4 day	3.63±1.57	5.47±0.79	6.57±2.14	6.53±1.56
Biochar, Every 8 day	4.00±1.07	5.50±0.59	6.47±1.57	6.67±1.22
Without biochar, Every day	3.37±0.96	4.63±0.55	6.33±1.12	6.33±1.25
Without biochar, Every 4 day	2.23±0.65	4.77±0.72	6.87±2.03	6.37±1.55
Without biochar, Every 8 day	2.37±0.85	4.67±0.74	5.93±0.38	6.37±0.66
CV(%)	33.63	13.21	30.15	20.48
Overall mean	3.21	5.06	6.30	6.45

Treatments	**BF-W5**	**BF-W6**	**BF-W7**
P-value (Biochar)	0.249 NS	0.542 NS	0.890 NS
Biochar	7.42±1.55	6.97±1.91	7.17±2.17
Without biochar	6.96±1.60	7.25±1.82	7.10±1.81
P-value (Watering)	0.101 NS	0.310 NS	0.006**
Every day	7.13±1.51	7.27±2.02	7.33±1.10 A
Every 4 day	7.75±1.85	7.43±2.10	8.00±2.18 A
Every 8 day	6.68±1.19	6,62±1.32	6.07±1.19 B
P-value (Biochar × watering)	0.632 NS	0.020**	0.404 NS
Biochar, Every day	7.63±1.78	7.67±2.56 ab	7.77±2.50
Biochar, Every 4 day	7.90±1.24	6.37±1.41 b	8.03±2.10
Biochar, Every 8 day	6.73±1.47	6.87±1.49 ab	5.70±0.95
Without biochar, Every day	6.64±1.05	6.87±1.32 ab	6.90±1.32
Without biochar, Every 4 day	7.60±2.37	8.50±2.19 a	7.97±2.38
Without biochar, Every 8 day	6.63±0.91	6.37±1.16 b	6.43±1.34
CV(%)	21.56	24.79	26.08
Overall mean	7.19	7.11	7.13

[1/] BF -Wn = Bulb formation (number) at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability

For PC at two of seven weeks: weeks 1 and 3 were significantly affected by biochar factor, the higher mean values were recorded in soil supplemented with biochar (Table 26). Effect of watering showed significantly on PC at only week 2, the watering every day had a higher mean value and followed by watering every four days and eight days, respectively (Table 26). The interaction of biochar × watering was non-significantly affected on PC in all weeks (Table 26).

Table 26 Analysis of variance (ANOVA) and means (± standard deviation) in plant canopy (PC) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 3.

Treatments	**PC-W1**[1]	**PC-W2**	**PC-W3**	**PC-W4**
P-value (Biochar)	0.007**[3]	0.107 NS	0.015*	0.052 NS
Biochar	2.52±0.59 X[4]	3.53±0.95	3.78±0.76 X	4.01±0.80
Without biochar	2.08±0.58 Y	3.20±0.63	3.31±0.73 Y	3.60±0.79
P-value (Watering)	0.934 NS[2]	0.049*	0.085 NS	0.449 NS
Every day	2.31±0.76	3.62±0.88 A	3.71±0.69	3.92±0.83
Every 4 day	2.33±0.65	3.45±0.87 AB	3.68±0.93	3.88±0.98
Every 8 day	2.26±0.44	3.02±0.59 B	3.24±0.63	3.62±0.59
P-value (Biochar × watering)	0.555 NS	0.365 NS	0.552 NS	0.653 NS
Biochar, Every day	2.59±0.73	3.99±0.92	4.06±0.64	4.21±0.71
Biochar, Every 4 day	2.60±0.63	3.51±1.01	3.94±0.81	4.13±0.94
Biochar, Every 8 day	2.36±0.40	3.08±0.77	3.34±0.70	3.69±0.70
Without biochar, Every day	2.03±0.71	3.25±0.70	3.36±0.56	3.63±0.88
Without biochar, Every 4 day	2.06±0.58	3.39±0.76	3.42±1.01	3.62±0.99
Without biochar, Every 8 day	2.16±0.48	2.95±0.36	3.14±0.57	3.55±0.48
CV(%)	26.05	23.16	20.65	21.10
Overall mean	2.30	3.36	3.54	3.81

Treatments	**PC-W5**	**PC-W6**	**PC-W7**
P-value (Biochar)	0.749 NS	0.424 NS	0.090 NS
Biochar	4.16±0.85	4.39±0.78	4.77±0.79
Without biochar	4.10±0.72	4.24±0.69	4.42±0.79
P-value (Watering)	0.532 NS	0.174 NS	0.485 NS
Every day	4.21±0.87	4.54±0.76	4.66±0.67
Every 4 day	4.21±0.76	4.32±0.80	4.71±0.95
Every 8 day	3.97±0.72	4.10±0.61	4.42±0.77
P-value (Biochar × watering)	0.445 NS	0.483 NS	0.626 NS
Biochar, Every day	4.38±1.05	4.72±0.83	4.73±0.75
Biochar, Every 4 day	4.29±0.75	4.44±0.69	5.02±0.79
Biochar, Every 8 day	3.82±0.69	4.01±0.72	4.58±0.85
Without biochar, Every day	4.05±0.68	4.35±0.66	4.59±0.61
Without biochar, Every 4 day	4.13±0.80	4.19±0.92	4.40±1.04
Without biochar, Every 8 day	4.11±0.75	4.18±0.50	4.26±0.70
CV(%)	19.26	16.98	17.45
Overall mean	4.13	4.32	4.60

1/ PC-Wn = Plant canopy at week 1,...,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

At the harvesting stage, four of seven characteristics were significantly affected by biochar: LL, LRL, PW, and BW, the higher mean values were observed at biochar supplemented into soil (Table 27) (Figure 7). Six of seven characteristics showed significantly affected by watering, every day and every four days of watering had the higher mean values than every eight days of watering in all characteristics (Table 27). For RL, there were only characteristics that had a significant difference affected by biochar × watering interaction, added biochar with watering every day and every eight days showed highest mean values (Table 27).

Table 27 Analysis of variance (ANOVA) and means (± standard deviation) at harvesting stage (week 8) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 3.

Treatments	**LN-H**[1]	**LL-H**	**LRL-H**	**RL-H**
P-value (Biochar)	0.132 NS[2]	0.001**	0.005**	0.052 NS
Biochar	32.94±11.58	30.17±2.55 X	39.52±4.23 X	4.15±1.10
Without biochar	29.61±6.59	27.81±3.38 Y	36.81±3.75 Y	3.62±1.03
P-value (Watering)	0.002**[3]	0.0004**	0.002**	0.597 NS
Every day	33.03±9.86 A[4]	29.23±3.15 A	39.29±5.04 A	3.81±1.43
Every 4 day	35.10±8.77 A	30.64±2.10 A	39.56±2.61 A	4.08±0.86
Every 8 day	25.70±7.38 B	27.11±3.28 B	35.64±3.50 B	3.77±0.91
P-value (Biochar × watering)	0.114 NS	0.364 NS	0.348 NS	0.040*
Biochar, Every day	36.60±12.86	30.04±2.64	41.57±5.18	4.56±1.46 a
Biochar, Every 4 day	38.13±7.76	31.50±1.70	40.21±3.01	4.18±0.97 a
Biochar, Every 8 day	24.10±8.66	28.98±2.74	36.77±2.86	3.71±0.63 ab
Without biochar, Every day	29.47±3.39	28.42±3.54	37.00±3.91	3.07±0.98 b
Without biochar, Every 4 day	32.07±9.03	29.79±2.19	38.91±2.10	3.97±0.77 ab
Without biochar, Every 8 day	27.30±5.86	25.23±2.72	34.52±3.85	3.82±1.15 ab
CV(%)	27.00	9.14	9.48	26.50
Overall mean	31.28	28.99	38.16	3.88

Treatments	**BF-H**	**PW-H**	**BW-H**
P-value (Biochar)	0.890 NS	0.0003**	0.0002**3
Biochar	7.17± 2.17	3.19±0.87 X	18.96± 6.59 X
Without biochar	7.10±1.81	2.44±0.91 Y	12.91±5.43 Y
P-value (Watering)	0.006**	$1.66x10^{-5}$**	0.028*
Every day	7.33±2.00 A	3.33±1.05 A	17.83±7.50 A
Every 4 day	8.00±2.18 A	2.98±0.59 A	16.93±6.06 A
Every 8 day	6.07±1.19 B	2.13±0.78 B	13.03±5.79 B
P-value (Biochar × watering)	0.404 NS	0.741 NS	0.779 NS
Biochar, Every day	7.77±2.50	3.70±0.96	20.93±8.26
Biochar, Every 4 day	8.03±2.10	3.27±0.54	19.27±5.68
Biochar, Every 8 day	5.70±0.95	2.60±0.73	16.67±5.41
Without biochar, Every day	6.90±1.32	2.97±1.05	14.73±5.41
Without biochar, Every 4 day	7.97±2.38	2.70±0.51	14.60±5.76
Without biochar, Every 8 day	6.43±1.34	1.67±0.50	9.40±3.47
CV(%)	26.08	26.57	36.60
Overall mean	7.13	2.82	15.93

[1/] LN= leaf number, LL= leaf length, LRL= leaf to root length, RL= root length, BF= bulb formation, PW= plantlet weight, BW= bulb weight at harvesting stage (H). [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,…) in the same column means significant difference at 0.05 level of probability.

Figure 7 Performance of spring onions at harvesting stage in Crop 3 (From left to right: biochar + watering every day, biochar + watering every four days; biochar + watering every eight days; without biochar + watering every day; without biochar + watering every four days; without biochar + watering every eight days).

Agronomic characteristics in spring onion cultivated in Crop 4

In crop 4, for PH in seven weeks, the significant difference in five weeks were observed that affected by biochar supplementation: week 3, 4, 5, 6, and 7, the higher mean values were observed in soil supplemented with biochar (Table 28). PH in all seven weeks was significantly affected by watering frequency. For PH in those weeks, watering every day showed the highest mean values in all weeks. While, watering every four days and eight days were the same as mean values in weeks 1 and 2, however, in other weeks, watering every four days had the higher mean values than watering every eight days (Table 28). The biochar × watering interaction was not found significantly affected on PH in any weeks (Table 28).

Table 28 Analysis of variance (ANOVA) and means (± standard deviation) in plant height (PH) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**PH-W1**[1]	**PH-W2**	**PH-W3**	**PH-W4**
P-value (Biochar)	0.088 NS[2]	0.061 NS	0.002**	0.005**
Biochar	8.25±1.95	18.03±2.49	23.28±3.56 X	25.59±3.87 X
Without biochar	7.19±2.15	17.03±1.50	21.21±2.37 Y	23.64±3.20 Y
P-value (Watering)	0.0008**[3]	$3.35x10^{-5}$**	$1.31x10^{-7}$**	$4.2x10^{-9}$**
Every day	9.51±1.71 A[4]	19.51±1.88 A	25.47±2.83 A	28.73±2.15 A
Every 4 day	7.23±1.56 B	16.98±1.52 B	21.63±1.71 B	23.68±2.30 B
Every 8 day	6.41±1.71 B	16.10±1.08 B	19.63±1.21 C	21.43±1.15 C
P-value (Biochar × watering)	0.723 NS	0.102 NS	0.078 NS	0.702 NS
Biochar, Every day	9.74±1.99	20.81±1.71	27.51±2.11	30.08±2.30
Biochar, Every 4 day	7.77±1.83	17.01±1.88	22.16±1.68	24.51±2.28
Biochar, Every 8 day	7.23±1.28	16.27±0.62	20.17±0.98	22.17±0.76
Without biochar, Every day	9.29±1.59	18.21±0.90	23.43±1.76	27.39±0.74
Without biochar, Every 4 day	6.68±1.16	16.95±1.29	21.11±1.76	22.84±2.22
Without biochar, Every 8 day	5.59±1.80	15.94±1.48	19.09±1.26	20.68±1.00
CV(%)	21.21	7.90	7.35	6.95
Overall mean	7.72	17.53	22.24	24.61

Treatments	**PH-W5**	**PH-W6**	**PH-W7**
P-value (Biochar)	$8.29x10^{-5}$**	0.008**	$3.40x10^{-5}$**
Biochar	27.69± 3.98 X	29.07±4.06 X	29.27±4.23 X
Without biochar	23.68±2.89 Y	26.12±4.07 Y	24.57±4.05 Y
P-value (Watering)	$1.43x10^{-5}$**	$2.61x10^{-5}$**	$1.23x10^{-6}$**
Every day	29.06±3.84 A	31.39±3.12 A	30.95±3.34 A
Every 4 day	25.16±3.05 B	27.28±3.45 B	26.93±3.46 B
Every 8 day	22.83±2.24 C	24.10±2.70 C	22.88±3.54 C
P-value (Biochar × watering)	0.357 NS	0.706 NS	0.973 NS
Biochar, Every day	31.91±2.16	32.98±2.28	33.44±2.10
Biochar, Every 4 day	26.95±2.86	29.22±2.74	29.26±2.90
Biochar, Every 8 day	24.20±2.13	25.00±2.26	25.11±2.54
Without biochar, Every day	26.21±2.87	29.81±3.23	28.45±2.27
Without biochar, Every 4 day	23.37±2.17	25.34±3.14	24.59±2.21
Without biochar, Every 8 day	21.46±1.42	23.20±3.05	20.65±3.05
CV(%)	9.04	10.19	9.42
Overall mean	25.68	27.59	26.92

[1/] PH -Wn = Plant height at week 1,...,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

PH in six of seven weeks, excluding week 1, were significantly affected by biochar supplementation, the higher mean values were found in plants grown in soil supplemented with biochar (Table 29). For watering, PH in all seven weeks was significantly affected by this factor, and watering every day had the highest mean values in all weeks, however, watering every day and every four days were not significantly different at weeks 4 and 7 (Table 29). PH at weeks 1 and 3 was significantly different affected by biochar × watering interaction, biochar supplementation with watered every day showed highest mean values (Table 29)

Table 29 Analysis of variance (ANOVA) and means (± standard deviation) in leaf number (LN) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**LN-W1**[1]	**LN-W2**	**LN-W3**	**LN-W4**
P-value (Biochar)	0.210 NS[2]	0.003**	0.006**	0.004**
Biochar	13.62±4.32	23.40±5.77 X	32.09±5.96 X	35.29±5.50 X
Without biochar	12.47±2.63	19.69±4.98 Y	27.71±5.57 Y	30.44±5.74 Y
P-value (Watering)	0.0003**[3]	3.95×10^{-7}**	8.07×10^{-5}**	0.0003**
Every day	15.97±3.29 A[4]	27.20±5.19 A	34.40±6.21 A	36.93±6.05 A
Every 4 day	12.30±2.70 B	20.60±2.19 B	30.33±3.52 B	33.47±63.46 A
Every 8 day	10.87±2.72 B	16.83±2.98 C	24.97±4.33 C	28.20±5.14 B
P-value (Biochar × watering)	0.007**	0.186 NS	0.048*	0.082 NS
Biochar, Every day	18.60±0.96 a	30.53±1.66	39.27±2.40 a	41.80±2.46
Biochar, Every 4 day	12.60±3.33 bc	22.00±1.93	30.99±2.01 b	34.20±0.51
Biochar, Every 8 day	9.67±1.25 c	17.67±1.67	26.00±1.49 bc	29.87±2.91
Without biochar, Every day	13.33±2.47 b	23.87±5.49	29.53±4.67 b	32.07±4.13
Without biochar, Every 4 day	12.00±2.26 bc	19.20±1.46	29.67±4.77 b	32.73±5.03
Without biochar, Every 8 day	12.07±3.39 bc	16.00±3.94	23.93±6.10 c	26.53±6.64
CV(%)	18.84	14.31	13.22	12.49
Overall mean	13.04	21.54	29.90	32.87

Treatments	**LN-W5**	**LN-W6**	**LN-W7**
P-value (Biochar)	0.005**	0.0008**	0.0008**
Biochar	35.27±5.68 X	35.84±6.69 X	35.89±6.39 X
Without biochar	30.22±6.37 Y	29.93±6.05 Y	29.93±6.28 Y
P-value (Watering)	0.0002**	1.94×10^{-5}**	2.99×10^{-5}**
Every day	37.47±6.22 A	38.33±6.59 A	37.67±6.53 A
Every 4 day	32.97±3.89 B	33.13±3.75 B	34.13±3.73 A
Every 8 day	27.80±5.35 C	27.20±5.39 C	26.94±5.60 B
P-value (Biochar × watering)	0.132 NS	0.087 NS	0.099 NS
Biochar, Every day	42.02±2.01	43.80±2.52	43.00±2.86
Biochar, Every 4 day	33.60±2.13	34.67±1.85	35.27±2.12
Biochar, Every 8 day	30.00±2.48	29.07±2.90	29.40±3.72
Without biochar, Every day	32.73±5.20	32.87±4.09	32.33±4.08
Without biochar, Every 4 day	32.33±5.34	31.60±4.73	33.00±4.86
Without biochar, Every 8 day	25.60±6.80	25.33±6.95	24.47±6.43
CV(%)	13.46	12.75	12.90
Overall mean	32.74	32.89	32.91

1/ LN-Wn = leaf number at week 1,...,n 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

In six of seven weeks, excluding week 1, LL was significantly affected by biochar, soil supplementation with biochar had the higher mean values in all these weeks (Table 30). Clearly, in all seven weeks, LL had the highest values with a significant difference at watering every day in all weeks, followed by watering every four days and every eight days (Table 30). Only in week 3, LL was significantly affected by biochar × watering interaction, the higher mean value was found at supplemented biochar with watering every day. Although at watering either four days or eight days were not significantly different between with and without biochar in week 3, higher mean values were observed at biochar supplementation (Table 30).

Table 30 Analysis of variance (ANOVA) and means (± standard deviation) in leaf length (LL) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in week 1-week 7 in Crop 4.

Treatments	LL-W1[1]	LL-W2	LL-W3	LL-W4
P-value (Biochar)	0.169NS[2]	0.048*	0.0002**	0.0008**
Biochar	7.44±2.00	17.11±2.26 X	22.26±3.37 X	24.40±4.02 X
Without biochar	6.67±2.06	16.19±1.61 Y	20.11±2.01 Y	22.10±2.81 Y
P-value (Watering)	0.0001 **[3]	$3.34x10^{-6}$**	$6.49x10^{-9}$**	$3.57x10^{-9}$**
Every day	8.97±1.60 A[4]	18.67±1.72 A	24.18±2.61 A	27.21±2.63 A
Every 4 day	6.64±1.42 B	16.13±1.19 B	20.75±1.46 B	22.42±2.06 B
Every 8 day	5.55±1.40 B	15.15±0.97 B	18.63±1.18 C	20.12±1.26 C
P-value (Biochar × watering)	0.803 NS	0.145 NS	0.015*	0.164 NS
Biochar, Every day	9.10±1.89	19.76±1.60	26.32±1.80 a	29.18±2.24
Biochar, Every 4 day	7.14±1.75	16.16±1.12	21.22±1.64 b	23.02±2.42
Biochar, Every 8 day	6.07±1.24	15.41±0.72	19.24±0.67 cd	21.00±0.48
Without biochar, Every day	8.84±1.48	17.58±1.07	22.04±0.83 b	25.24±0.92
Without biochar, Every 4 day	6.13±0.91	16.09±1.40	20.28±1.24 bc	21.83±1.67
Without biochar, Every 8 day	5.03±1.48	14.90±1.19	18.01±1.31 d	19.24±1.18
CV(%)	21.16	7.31	6.19	7.05
Overall mean	7.05	16.65	21.19	23.25

Treatments	LL-W5	LL-W6	LL-W7
P-value (Biochar)	$1.48x10^{-5}$**	0.0001**	$6.19x10^{-6}$**
Biochar	26.56±4.21 X	27.66±4.34 X	28.38±4.37 X
Without biochar	22.64±3.03 Y	24.04±3.67 Y	23.62±3.53 Y
P-value (Watering)	$9.47x10^{-8}$**	$8.94x10^{-8}$**	$2.41x10^{-7}$**
Every day	28.45±3.50 A	30.00±3.01 A	29.81±3.28 A
Every 4 day	24.21±2.80 B	25.70±3.03 B	26.29±3.71 B
Every 8 day	21.14±2.18 C	21.85±2.43 C	21.89±2.89 C
P-value (Biochar × watering)	0.186 NS	0.685 NS	0.714 NS
Biochar, Every day	31.38±1.85	32.30±2.13	32.42±2.23
Biochar, Every 4 day	25.72±2.61	27.31±2.61	28.92±2.88
Biochar, Every 8 day	22.57±1.47	23.37±2.10	23.79±2.52
Without biochar, Every day	25.52±1.64	27.70±1.61	27.20±1.48
Without biochar, Every 4 day	22.69±2.25	24.09±2.73	23.65±2.33
Without biochar, Every 8 day	19.72±1.85	20.34±1.79	19.99±1.87
CV(%)	8.06	8.50	8.70
Overall mean	24.60	25.85	26.00

[1/] LL-Wn = leaf length at week 1,...,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

At weeks 1 to 4, BF was significantly affected by biochar, the higher mean values were recorded at biochar supplementation (Table 31). BF in all seven weeks was significantly affected by watering, the higher mean values were found at watering every day, the lower values and were similar in mean values between at watering every four days and eight days (Table 31). However, the biochar × watering interaction was not significantly affected on BF in all weeks (Table 31).

Table 31 Analysis of variance (ANOVA) and means (± standard deviation) in bulb formation (BF) (number) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**BF-W1**[1]	**BF-W2**	**BF-W3**	**BF-W4**
P-value (Biochar)	0.0002**[3]	5.84x10^{-5}**	0.0001**	0.003**
Biochar	5.04±1.84 X[4]	6.16±1.45 X	7.35±1.29 X	7.96±1.43 X
Without biochar	3.73±0.89 Y	4.60±0.98 Y	5.80±1.02 Y	6.56±1.29 Y
P-value (Watering)	4.39x10^{-7}**	5.62x10^{-5}**	0.001**	0.004**
Every day	5.97±1.49 A	6.57±1.41 A	7.50±1.40 A	8.03±1.21 A
Every 4 day	3.80±1.10 B	5.10±1.11 B	6.53±1.07 B	7.57±1.21 A
Every 8 day	3.40±0.49 B	4.47±0.97 B	5.70±1.15 B	6.17±1.54 B
P-value (Biochar × watering)	0.058 NS[2]	0.521 NS	0.878 NS	0.676 NS
Biochar, Every day	7.13±1.07	7.60±1.09	8.40±1.09	8.87±1.17
Biochar, Every 4 day	4.33±1.39	5.80±1.02	7.27±0.95	8.00±1.16
Biochar, Every 8 day	3.67±0.53	5.07±0.92	6.40±1.09	7.00±1.49
Without biochar, Every day	4.80±0.69	5.53±0.80	6.60±1.09	7.20±0.45
Without biochar, Every 4 day	3.27±0.28	4.40±0.72	5.80±0.56	7.13±1.21
Without biochar, Every 8 day	3.13±0.30	3.87±0.61	5.00±0.74	5.34±1.18
CV(%)	18.60	16.27	14.33	15.90
Overall mean	4.39	5.38	6.58	7.26

Treatments	**BF-W5**	**BF-W6**	**BF-W7**
P-value (Biochar)	0.167 NS	0.211 NS	0.055 NS
Biochar	8.09±1.41	8.04±1.59	7.78±1.33
Without biochar	7.42±1.67	7.47±1.50	6.98±1.27
P-value (Watering)	0.002**	0.001**	0.002**
Every day	8.83±1.33 A	8.93±1.22 A	8.40±1.17 A
Every 4 day	7.90±1.27 A	7.77±1.33 B	7.27±1.11 B
Every 8 day	6.53±1.21 B	6.57±1.46 C	6.47±1.06 B
P-value (Biochar × watering)	0.782 NS	0.443 NS	0.860 NS
Biochar, Every day	9.27±1.04	9.53±1.32	8.93±0.98
Biochar, Every 4 day	8.00±1.03	7.67±1.18	7.53±1.37
Biochar, Every 8 day	7.00±1.25	6.93±1.09	6.87±0.77
Without biochar, Every day	8.40±1.55	8.33±0.85	7.86±1.19
Without biochar, Every 4 day	7.80±1.59	7.87±1.61	7.00±0.85
Without biochar, Every 8 day	6.07±1.09	6.20±1.19	6.07±1.23
CV(%)	16.50	15.85	14.72
Overall mean	7.76	7.76	7.38

[1/] BF -Wn = Bulb formation (number) at week 1,…,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability

PC in six of seven weeks had the higher mean values at soil supplemented with biochar with significant difference (Table 32). All seven weeks, PC was significantly affected by watering frequency, the higher mean value was found at watering every day. At weeks 3 to 7, there was a significant difference between watered every four days and eight days that higher values were observed at watering every four days (Table 32). Five in seven weeks, PC was significantly affected by biochar × watering interaction, the highest values were found at supplementation the soil with biochar and watering every day (Table 32).

Table 32 Analysis of variance (ANOVA) and means (± standard deviation) in plant canopy (PC) (cm) at week 1-week 7 in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**PC-W1**[1]	**PC-W2**	**PC-W3**	**PC-W4**
P-value (Biochar)	0.143 NS[2]	0.039*	0.0002**	0.0001**
Biochar	2.28± 0.74	4.03±1.38 X	5.04±1.29 X	5.39±1.21 X
Without biochar	2.00±0.57	3.52±0.80 Y	4.16±0.64 Y	4.57±0.79 Y
P-value (Watering)	0.0004**[3]	$2.89x10^{-7}$**	$2.96x10^{-7}$**	$1.11x10^{-8}$**
Every day	2.76±0.56 A[4]	5.01 ±0.98 A	5.64±1.19 A	6.12±0.93 A
Every 4 day	1.89±0.42 B	3.41±0.44 B	4.34±0.64 B	4.71±0.59 B
Every 8 day	1.77±0.53 B	2.91±0.59 B	3.81±0.31 C	4.13±0.52 C
P-value (Biochar × watering)	0.835 NS	0.102 NS	0.003**	0.013*
Biochar, Every day	2.97±0.75	5.62±1.10	6.62±0.73 a	6.90±0.60 a
Biochar, Every 4 day	2.03±0.50	3.55±0.47	4.55±0.57 b	4.78±0.59 bc
Biochar, Every 8 day	1.85±0.44	2.91±0.53	3.94±0.25 bc	4.50±0.37 c
Without biochar, Every day	2.55±0.21	4.40±0.16	4.65±0.49 b	5.33±0.25 b
Without biochar, Every 4 day	1.75±0.31	3.27±0.41	4.13±0.70 bc	4.63±0.64 c
Without biochar, Every 8 day	1.70±0.66	2.90±0.71	3.68±0.33 c	3.76±0.37 d
CV(%)	23.95	16.78	11.82	9.87
Overall mean	2.14	3.77	4.60	4.98

Treatments	**PC-W5**	**PC-W6**	**PC-W7**
P-value (Biochar)	$2.03x10^{-5}$**	$3.01x10^{-5}$**	0.001**
Biochar	5.60±1.27 X	5.75±1.26 X	5.53±1.20 X
Without biochar	4.61±0.62 Y	4.79±0.74 Y	4.75±0.84 Y
P-value (Watering)	$9.70x10^{-8}$**	$8.73x10^{-8}$**	$3.19x10^{-7}$**
Every day	6.11±1.18 A	6.28±1.17 A	6.20±1.08 A
Every 4 day	4.98±0.65 B	5.16±0.55 B	4.92±0.71 B
Every 8 day	4.23±0.33 C	4.37±0.61 C	4.31±0.35 C
P-value (Biochar × watering)	0.004**	0.001**	0.005**
Biochar, Every day	7.07±0.81 a	7.31±0.54 a	7.11±0.24 a
Biochar, Every 4 day	5.37±0.40 b	5.21±0.61 b	5.01±0.35 bc
Biochar, Every 8 day	4.35±0.24 d	4.75±0.46 b	4.49±0.22 cd
Without biochar, Every day	5.14±0.39 bc	5.25±0.42 b	5.29±0.71 b
Without biochar, Every 4 day	4.59±0.64 cd	5.12±0.54 b	4.83±0.99 bcd
Without biochar, Every 8 day	4.10±0.38 d	3.99±0.51 c	4.13±0.38 d
CV(%)	10.03	9.82	10.86
Overall mean	5.10	5.27	5.14

[1/] PC-Wn = Plant canopy at week 1,...,n [2/] NS means non-significant difference at 0.05 level of probability. [3/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [4/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

At the harvesting stage in crop 4, six in seven characteristics, excluding BF were significantly affected by biochar, the higher mean values were observed at supplemented soil with biochar (Table 33).

Table 33 Analysis of variance (ANOVA) and means (± standard deviation) at harvesting stage (week 8) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	LN-H[1]	LL-H	LRL-H	RL-H
P-value (Biochar)	0.0008**[3]	$3.00x10^{-6}$**	0.013*	$6.39x10^{-5}$**
Biochar	35.89±6.39 X[4]	29.54±4.21 X	39.79±4.56 X	5.92±1.35 X
Without biochar	29.93±6.28 Y	23.62±3.53 Y	36.21±4.60 Y	3.94±0.83 Y
P-value (Watering)	$2.99x10^{-5}$**	$2.26x10^{-5}$**	0.001**	0.419 NS
Every day	37.67±6.53 A	30.24±3.67 A	41.95±3.92 A	5.31±1.93
Every 4 day	34.13±3.73 A	26.29±3.71 B	36.90±3.53 B	4.83±1.00
Every 8 day	26.94±5.60 B	23.21±4.63 C	35.15±4.51 B	4.66±1.48
P-value (Biochar × watering)	0.099 NS[2]	0.882 NS	0.574 NS	0.344 NS
Biochar, Every day	43.00±2.86	33.29±2.23	44.45±3.84	6.67±1.92
Biochar, Every 4 day	35.27±2.12	28.92±2.88	38.96±2.46	5.45±0.86
Biochar, Every 8 day	29.40±3.72	26.43±4.34	35.96±2.40	5.65±0.95
Without biochar, Every day	32.33±4.08	27.20±1.48	39.45±2.05	3.95±0.26
Without biochar, Every 4 day	33.00±4.86	23.65±2.33	34.84±3.38	4.22±0.75
Without biochar, Every 8 day	24.47±6.43	19.99±1.87	34.33±6.19	3.67±1.27
CV(%)	12.90	10.10	9.64	22.73
Overall mean	32.91	26.58	38.00	4.93

Treatments	BF-H	PW-H	BW-H
P-value (Biochar)	0.055 NS	0.005**	0.001**
Biochar	7.78±1.33	2.81±1.05 X	16.73±8.12 X
Without biochar	6.98±1.27	2.09±0.53 Y	11.20±4.89 Y
P-value (Watering)	0.002**	0.0006**	$2.15x10^{-6}$**
Every day	8.40±1.17 A	3.17±1.11 A	20.83±6.95 A
Every 4 day	7.27±1.11 B	2.27±0.52 B	12.50±4.16 B
Every 8 day	6.47±1.06 B	1.92±0.41 B	8.57±3.55 C
P-value (Biochar × watering)	0.860 NS	0.217 NS	0.126 NS
Biochar, Every day	8.93±0.98	3.80±1.24	25.60±6.26
Biochar, Every 4 day	7.53±1.37	2.60±0.44	15.13±4.09
Biochar, Every 8 day	6.87±0.77	2.03±0.38	9.47±2.75
Without biochar, Every day	7.86±1.19	2.53±0.51	16.07±3.54
Without biochar, Every 4 day	7.00±0.85	1.93±0.37	9.87±2.23
Without biochar, Every 8 day	6.07±1.23	1.80±0.45	7.67±4.33
CV(%)	14.72	26.11	29.17
Overall mean	7.38	2.45	13.97

1/ LN= leaf number, LL= leaf length, LRL= leaf to root length, RL= root length, BF= bulb formation, PW= plantlet weight, BW= bulb weight at harvesting stage (H). 2/ NS means non-significant difference at 0.05 level of probability. 3/ *,** means significant different at 0.05 and 0.01 levels of probability, respectively. 4/ Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

Six of seven characteristics, excluding RL were significantly affected by watering frequency. The highest mean values in all characteristics that significantly affected by watering at watered every day. PW was not significantly different between watering every four days and eight days, however, BW showed a higher value at watering every four days; compared with watering every eight days (Table 33) (Figure 8). For the interaction of biochar × watering, there was no significant difference in all characteristics at the harvesting stage (Table 33).

Figure 8 Performance of spring onions at harvesting stage in Crop 4 (From left to right: biochar + watering every day, biochar + watering every four days; biochar + watering every eight days; without biochar + watering every day; without biochar + watering every four days; without biochar + watering every eight days).

The changes in the growth-related characteristics of the spring onion were compared from the four planting cycles (Crop 1 to Crop 4)

Growth-rate and yield characteristics of spring onions continuously planted in the same soil in pots for four cycles of planting are shown in Figures 9-15. The results showed that the lowest mean in LN appeared in the first crop and increased in the second crop. However, the results of the third and fourth cycles of planting tended to be slightly lower than those in the second planting cycle (Figure 9). Although spring onions grown in biochar enriched soil and watered daily had the lowest LN in the first cycle, the increase was higher in subsequent cycles than in other treatments. Spring onions with lower LN than other treatments in every planting cycle were planted in non-biochar soil and watered at the lowest frequency.

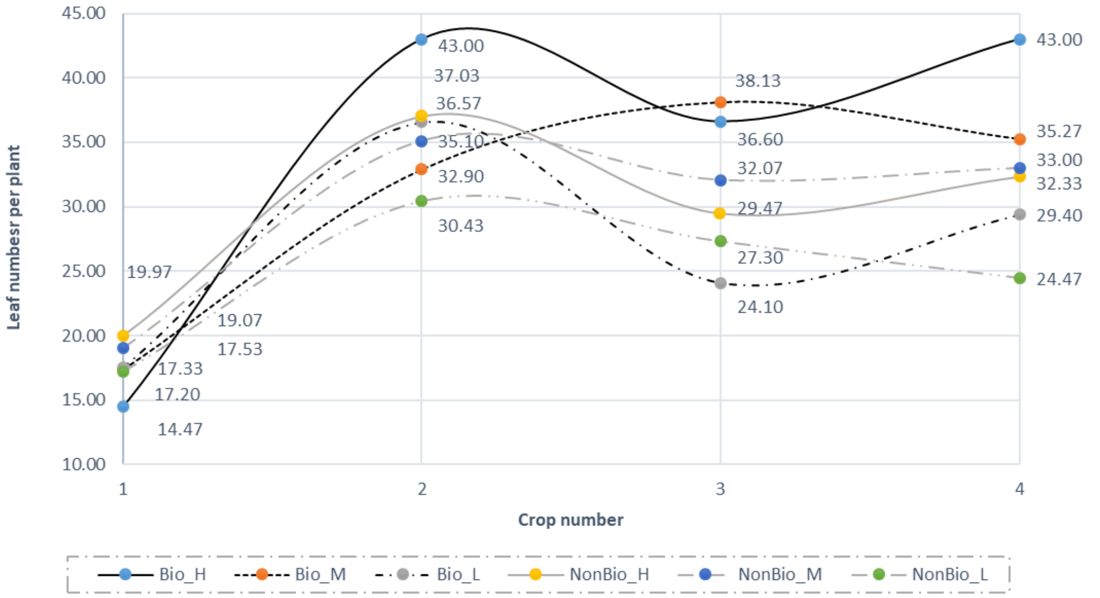


Figure 9 Changing on leave numbers (LN) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

The presence of LL was similar to LN of spring onion, i.e. the lowest mean was found in the first planting cycle and higher in the second planting cycle (Figure 10). However, LL trait continued to decline in the third and fourth planting cycles except for spring onions grown in biochar enriched soil and watered daily. The follow highest values of LL were found in soil biochar enrichment in both medium and low-frequency of watering and in soil without the addition of biochar and with daily watering. Likely as LN (Figure 9), spring onions with lower LL than other treatments in every planting cycle were planted in non-biochar soil and watered at the lowest frequency.

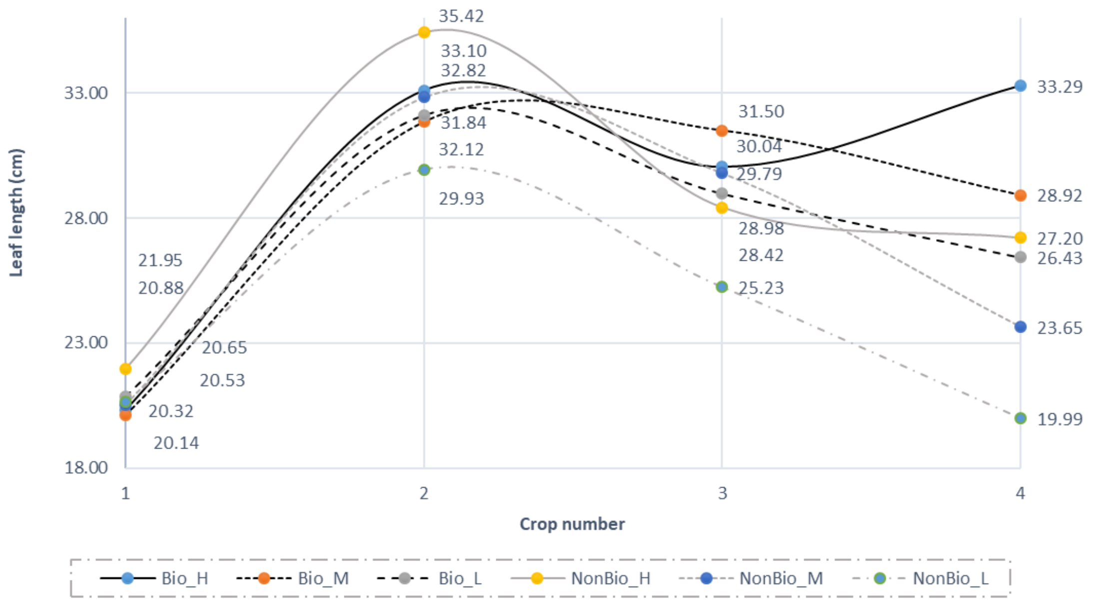


Figure 10 Changing on leave length (LL) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

For LRL, the response to biochar supplementation and different frequencies of watering had similar effects on LN and LL that the lowest values and highest values were observed in Crop 1 and Crop 2, respectively (Figure 11). It was noted that the total length above and below the soil in the third and fourth planting cycles was similar and not much different from the second planting cycle, which was similar to LN (Figure 9).

The presence of each treatment corresponded to the LL characteristics (Figure 10), where spring onions planted in biochar enriched soil with daily watering continued to increase up to the fourth cycle of planting. For onion growing in non-charcoal enriched soil with high-frequency watering, although it was the highest in the second cycle planting, the value declined sharply in the next cycle (Table 11).

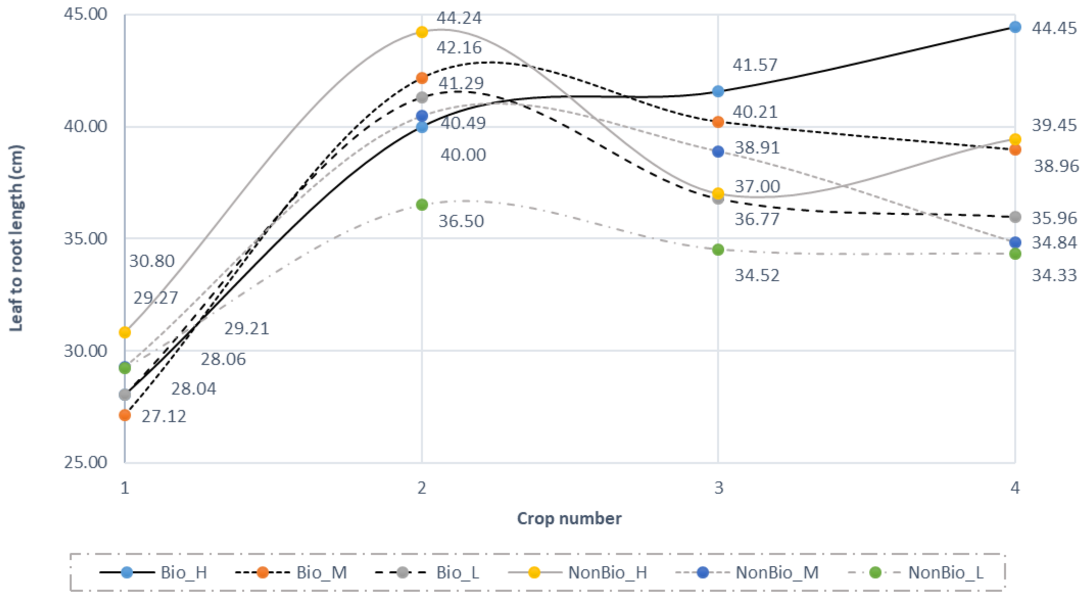


Figure 11 Changing on leave to root length (LRL) of spring onions at harvesting stage since Crop 1 to Crop 4.
Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

RL was markedly lower in the third cycle of planting (Figure 12). The results showed that the values were relatively similar between each of the biochar treatments with the different irrigation frequencies in the first and third planting cycles. However, significantly different in mean values in each treatment in the second and fourth planting cycles.

The curves of soil supplemented with charcoal and daily irrigation tended to increase in contrast to other treatments. However, when planting spring onions in biochar enriched soil at all three irrigation frequencies, RL increased in the second and third planting cycles. In all three irrigation frequencies, the RL was continuously decreased in the four planting cycles of spring onions in non-charcoal supplemented soil (Figure 12).

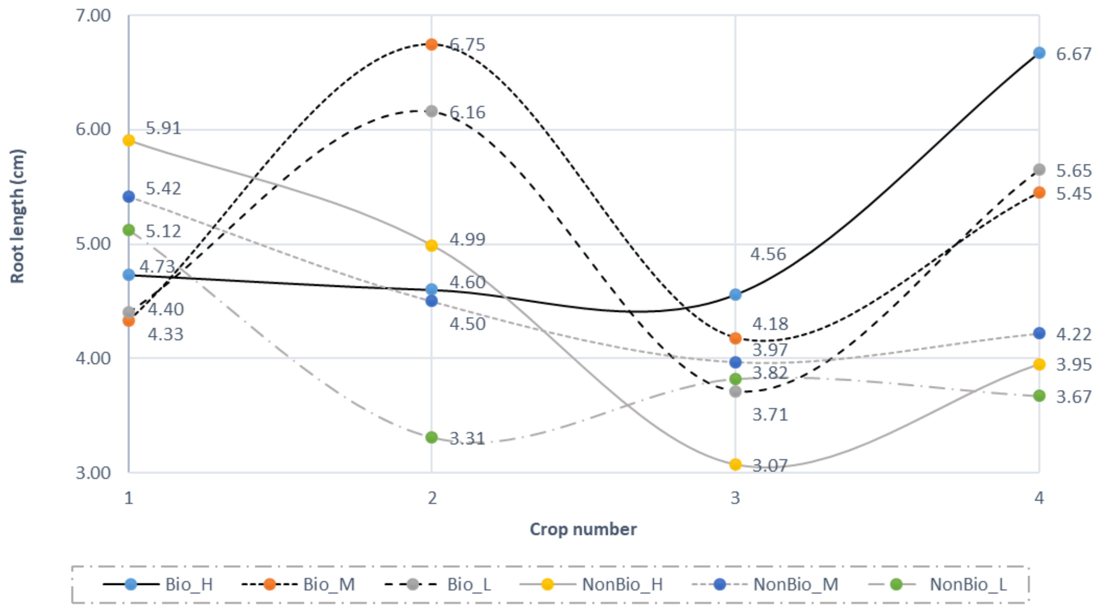


Figure 12 Changing on root length (RL) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

BF in spring onions tended to increase values from the first to third planting cycles, but slightly decreased in the fourth planting cycle. Except for the spring onions that were planted in biochar enriched soil and watered daily, the BF continued to increase until the fourth cycle of planting (Figure 13). While at low watering frequency, it was found that bulb production was less than in other treatments, but in the soil with biochar supplementation, the value was higher (Figure 13).

The influence of both factors, biochar and watering frequency, became apparent and resulted in the mean difference in BF in different treatments during in second and onward planting cycles.

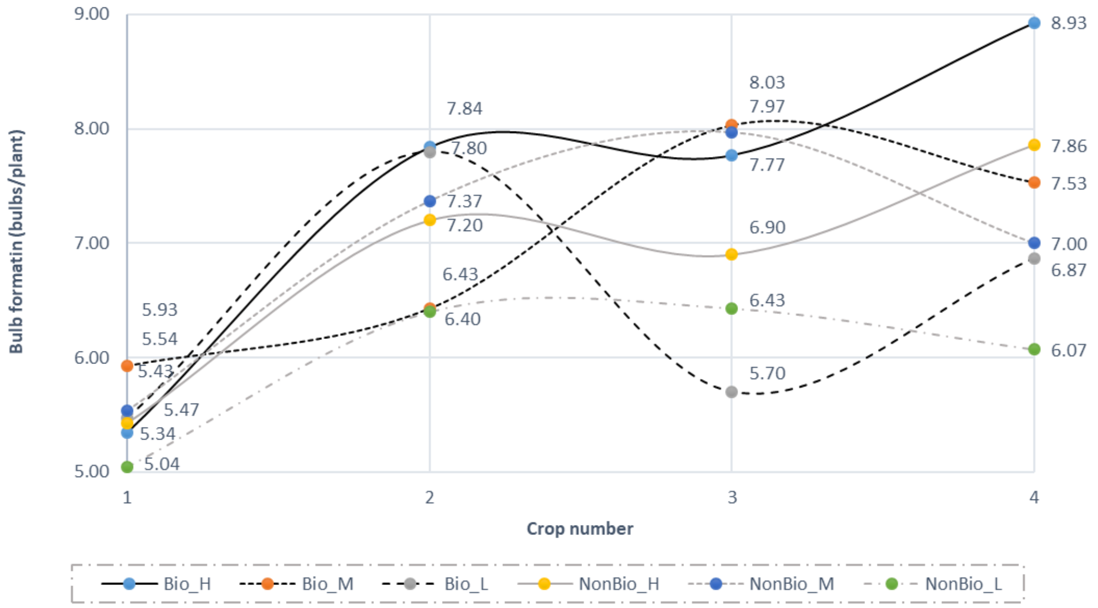


Figure 13 Changing on bulb formation (BF) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

For fresh bulb weight per plant or PW trait, spring onions were the highest mean value at the first cycle of planting and lower at the second to fourth cycles of planting. However, the treatment where soil was supplemented with charcoal and watered at high and medium frequencies were relatively stable values compared to other treatments (Figure 14). The greatest reductions in PW in the second to fourth cycles of planting were spring onions grown in non-charcoal enriched soil with the lowest watering frequency (Figure 14).

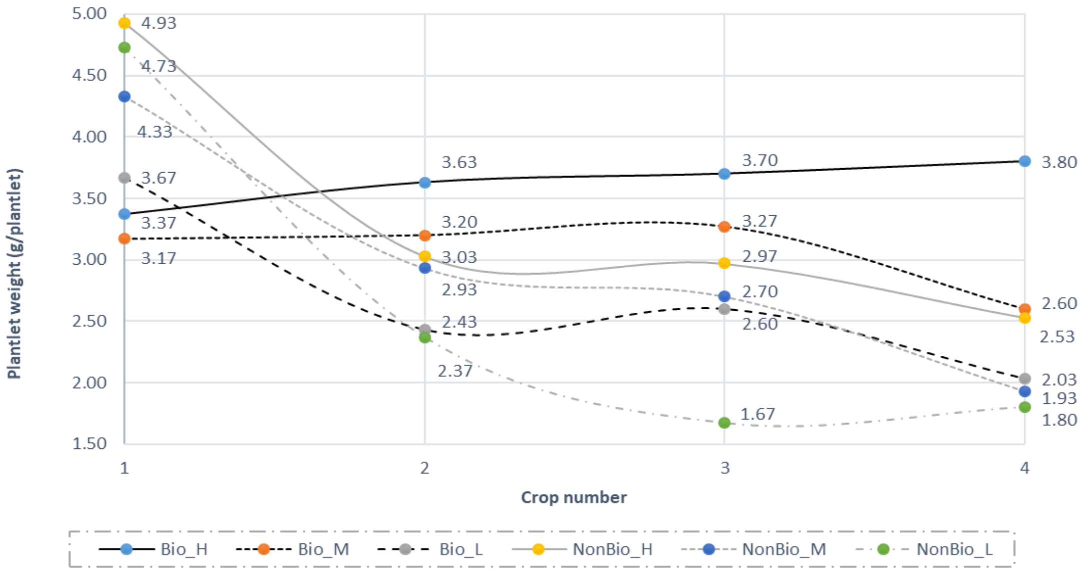


Figure 14 Changing on plantlet weight (PW) (g/plantlet) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

For fresh bulbs' weight per clamp or BW trait, spring onions' response to the four planting cycles varied in different treatments (Figure 15). The curve that tended to increase with increasing planting cycles was for spring onions grown in biochar enriched soil and watered daily. Conversely, the continuous decline in BW values in the four cycles was for spring onions grown in non-biochar-enriched soil with low-frequency irrigation. The rest of the treatments were similar values in the first to third planting cycles and began to clear decline in the fourth planting cycle. However, in non-biochar-enriched soils, the decrease in the BW values shown in the graphs began to decline in the third planting cycle (Figure 15).

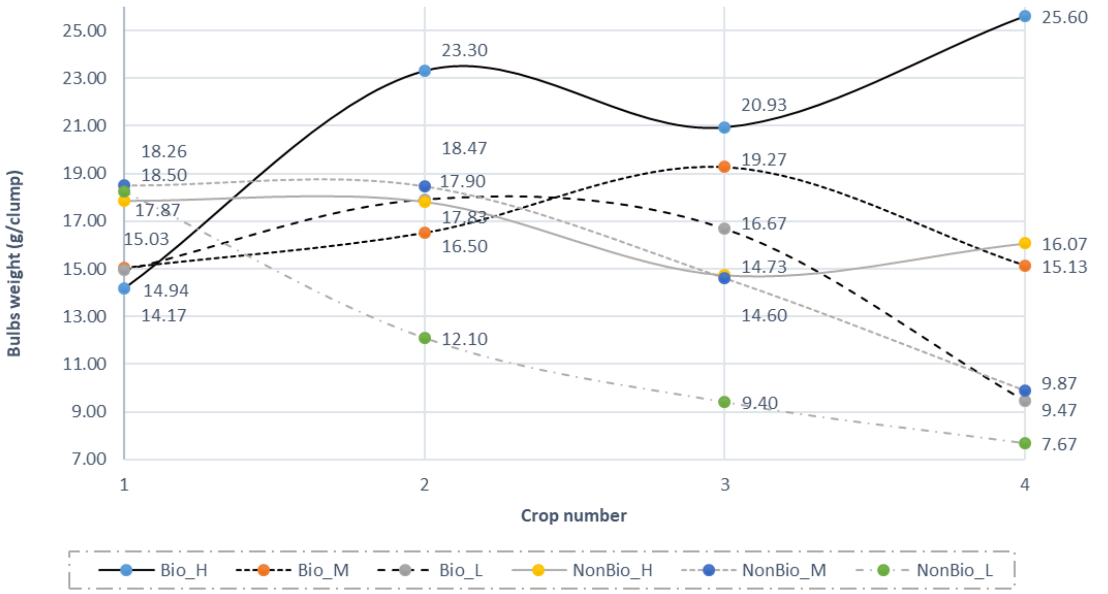


Figure 15 Changing on bulbs weight (BW) (g/clump) of spring onions at harvesting stage since Crop 1 to Crop 4.

Note: Bio_H: biochar + watering at high frequency; Bio_M: biochar + watering at moderate frequency; Bio_L: biochar + watering at low frequency; NonBio_H: without biochar + watering at high frequency; NonBio_M: without biochar + watering at moderate frequency; NonBio_L: without biochar + watering at low frequency. Watering at high frequency = watering every day; watering at moderate frequency = watering every 2 days in Crop 1 and 2, and every 4 days in Crop 3 and 4; watering at low frequency = watering every 3 days in Crop 1 and 2, and every 8 days in Crop 3 and 4.

Changes of moisture content of soil (%MCS) with biochar enrichment and watering at different frequencies in Crop 4

watering studies were performed daily, every four days, and every eight days according to each treatment. Thus, every four and every eight days, the percentage (by weight) of soil moisture content (%MCS) was increased in those treatments until no statistically significant difference was observed compared to daily watering. The results of weekly soil moisture percentage analysis were presented separately; from weeks 1 to 8 at the harvesting stage of spring onions, as shown in Tables 34-41 and Figures 16-18.

The positive influence of biochar enriched soil on moisture retentions was observed from the second to the seventh day after planting (DAP) and watering. Although overall %MCS decreased on 1 DAP both at added biochar and without biochar in the soil (Table 34). The influence of watering on %MCS was found from the third day onwards. There were lower soil moisture values for the watering every 4 days and every 8 days, and the two watering frequencies were not statistically different. On 5 DAP, %MCS of 4 days watering increased to the same as the daily watering. While watering every 8 days showed that %MCS is reduced to 60%. However, on 6 DAP, differences in %MCS were observed due to immediate watering frequencies, with the highest values being daily watering, followed by 4 and 8 days watering, respectively. On 7 DAP, watering every eight days had reduced %MCS to 40.5%.

There were significant differences affected by the interaction of biochar × watering on %MCS from 4 DAP to 7 DAP (Table 34). Higher mean values on %MCS were found at watering every day both supplemented and non-supplemented with biochar in soils on those days (4 DAP to 7 DAP). Compared to 4 and 8 days of watering, biochar enrichment resulted in a higher %MCS at 4 DAP. At 4 DAP, the %MCS in soil with biochar and watering every 8 days was higher than that of 4 days and 8 days of watered soil without biochar. For every 8 days of watering when biochar was added to soil, %MCS values on 4 DAP and 7 DAP were 75% and 57%, respectively. While every 8 days watering when no biochar was added to the soil, %MCS values on 4 DAP and 7 DAP were 60% and 24%, respectively (Table 34).

The second week of planting was significant differences affected by both factors, biochar and watering, and interaction between them (Table 35). Soil enrichment had a statistically significant positive effect on the weekly %MCS. The watering factor was highest each week when water was given daily. However, the watering every four days in the watering cycle (at 9 DAP) showed that %MCS was not as high as the watering every day.

At 8 DAP, a significant difference was observed in %MCS affected by the interaction of biochar × watering. Differences in %MCS were found that higher value at watering every four days with biochar enriched and unenriched soils, respectively. Followed by biochar unenriched soil and water for four days, and the lower and lowest values were observed at biochar unenriched soil with watering at four and eight days, respectively (Table 35).

Correspondingly, between the first and second weeks, the effect of moderate (every 4 days) and low watering (every 8 days) in the absence of biochar enrichment was lower than in the treatments with biochar enrichment at 11 DAP and 14 DAP. Nevertheless, the degree of difference in the four treatments (biochar and watering at every 4 and every 8 days) was different on both days at 11 DAP and 14 DAP (Table 35).

Table 34 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 1 (day 1 – day 7) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	Day 1	Day 2	Day 3	Day 4
P-value (Biochar)	1.000 NS[1]	0.007 **	6.89×10^{-5} **	1.54×10^{-7} **
Biochar	93.3±2.4	91.7±3.1 X	86.7±6.5 X	81.7±10.6 X
Without biochar	93.3±2.4	88.3±3.6 Y	79.3±8.4 Y	70.0±17.3 Y
P-value (Watering)	5.26×10^{-8} **[2]	0.183 NS	2.23×10^{-7}**	1.39×10^{-13} **
Every day	90.5±1.6 B[3]	90.5±1.6	91.5±2.4 A	94.0±2.1 A
Every 4 day	95.0±0.0 A	91.0±3.9	78.5±6.3 B	66.0±11.0 B
Every 8 day	94.5±1.6 A	88.5±4.7	79.0±7.4 B	67.5±8.9 B
P-value (Biochar × watering)	0.243 NS	0.088 NS	0.151 NS	9.48×10^{-4} **
Biochar, Every day	91.0±2.2	91.0±2.2	93.0±2.7	95.0±0.0 a
Biochar, Every 4 day	95.0±0.0	92.0±4.5	83.0±4.5	75.0±6.1 b
Biochar, Every 8 day	94.0±2.2	92.0±2.7	84.0±6.5	75.0±5.0 b
Without biochar, Every day	90.0±0.0	90.0±0.0	90.0±0.0	93.0±2.7 a
Without biochar, Every 4 day	95.0±0.0	90.0±3.5	74.0±4.2	57.0±5.7 c
Without biochar, Every 8 day	95.0±0.0	85.0±3.5	74.0±4.2	60.0±3.5 c
CV(%)	1.38	3.32	5.04	5.78
Overall mean	93.3	93.3	83.3	75.8

Treatments	Day 5	Day 6	Day 7
P-value (Biochar)	4.46×10^{-8} **	2.49×10^{-7} **	1.07×10^{-8} **
Biochar	86.3±11.6 X	82.3±14.6 X	77.7±16.4 X
Without biochar	79.7±22.5 Y	73.3±28.3 Y	65.0±31.1 Y
P-value (Watering)	2.00×10^{-16} **	2.00×10^{-16} **	2.00×10^{-16} **
Every day	94.5±1.6 A	94.0±2.1 A	94.0±2.1 A
Every 4 day	94.5±1.6 A	90.5±2.8 B	79.5±6.0 B
Every 8 day	60.0±12.0 B	49.0±15.4 C	40.5±17.7 C
P-value (Biochar × watering)	2.03×10^{-11} **	9.01×10^{-10} **	4.57×10^{-9} **
Biochar, Every day	94.0±2.2 a	94.0±2.2 a	94.0±2.2 a
Biochar, Every 4 day	94.0±2.2 a	90.0±3.5 a	82.0±5.7 b
Biochar, Every 8 day	71.0±4.2 b	63.0±4.5 b	57.0±2.7 c
Without biochar, Every day	95.0±0.0 a	94.0±2.2 a	94.0±2.2 a
Without biochar, Every 4 day	95.0±0.0 a	91.0±2.2 a	77.0±5.7 b
Without biochar, Every 8 day	49.0±2.2 c	35.0±5.0 c	24.0±4.2 d
CV(%)	2.69	4.45	5.78
Overall mean	83.0	77.8	71.3

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

Table 35 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 2 (day 8 – day 14) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**Day 8**	**Day 9**	**Day 10**	**Day 11**
P-value (Biochar)	1.01×10^{-11} **[2]	0.027 *	0.332 NS	1.22×10^{-5} **
Biochar	72.3±20.1 X[3]	92.3±2.6 Y	89.7±5.2	85.0±7.1 X
Without biochar	58.3±33.8 Y	94.0±2.1 X	88.0±6.5	78.7±11.7 Y
P-value (Watering)	2.00×10^{-16} **	0.004 **	6.37×10^{-4}**	7.03×10^{-13} **
Every day	95.0±0.0 A	95.0±0.0 A	94.0±2.1 A	94.0±2.1 A
Every 4 day	69.0±7.0 B	92.0±2.6 B	85.0±5.8 B	75.0±6.2 B
Every 8 day	32.0±17.0 C	92.5±2.6 B	87.5±4.9 B	76.5±5.8 B
P-value (Biochar × watering)	1.51×10^{-10} **	0.232 NS[1]	0.607 NS	0.003 **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	94.0±2.2 a	94.0±2.2 a
Biochar, Every 4 day	74.0±4.2 b	91.0±2.2 b	87.0±5.7 b	80.0±3.5 b
Biochar, Every 8 day	48.0±2.7 d	91.0±2.2 b	88.0±4.5 ab	81.0±2.2 b
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	94.0±2.2 a	94.0±2.2 a
Without biochar, Every 4 day	64.0±5.5 c	93.0±2.7 ab	83.0±5.7 b	70.0±3.5 c
Without biochar, Every 8 day	16.0±2.2 e	94.0±2.2 a	87.0±5.7 b	72.0±4.5 c
CV(%)	4.84	2.08	5.19	3.86
Overall mean	65.3	93.2	88.8	81.83

Treatments	**Day 12**	**Day 13**	**Day 14**
P-value (Biochar)	1.80×10^{-6} **	1.05×10^{-5} **	4.45×10^{-6} **
Biochar	80.3±11.3 X	85.3±13.2 X	81.3±15.4 X
Without biochar	71.0±18.0 Y	78.7±23.3 Y	70.7±27.0 Y
P-value (Watering)	7.61×10^{-15} **	2.00×10^{-16} **	2.00×10^{-16} **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	66.0±8.8 B	93.5±2.4 A	84.5±6.0 B
Every 8 day	66.0±8.8 B	57.5±12.1 B	48.5±15.5 C
P-value (Biochar × watering)	7.74×10^{-4} **	6.56×10^{-8} **	5.38×10^{-6} **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	73.0±4.5 b	93.0±2.7 a	87.0±5.7 b
Biochar, Every 8 day	73.3±4.5 b	68.0±5.7 b	62.0±7.6 c
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	59.0±5.5 c	94.0±2.2 a	82.0±5.7 b
Without biochar, Every 8 day	59.0±5.5 c	47.0±4.5 c	35.0±5.0 d
CV(%)	5.40	4.04	6.58
Overall mean	75.7	82.0	76.0

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There were statistically significant because of the positive influence of charcoal supplementation on 5 out of 7 days in the second week of spring onion planting (Table 36). For watering, on 17 DAP, %MCS was as high as the daily watering in every 8 days watering. There was the interaction of biochar × watering on %MCS at 15-16 DAP and 20-21 DAP. Statistically, differences were observed between treatments, especially watering every 4 days and 8 days, in enriched and non-fortified soils with biochar observed at 16 and 21 DAP (Table 36).

Table 36 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 3 (day 15 – day 21) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**Day 15**	**Day 16**	**Day 17**	**Day 18**
P-value (Biochar)	$4.04x10^{-8}$ **[2]	$1.31x10^{-7}$ *	0.569 NS[1]	0.610 NS
Biochar	75.0±18.2 X[3]	70.0±23.0 X	94.0±2.1	91.0±5.1
Without biochar	62.7±30.1 Y	57.0±32.4 Y	94.3±1.8	90.3±4.4
P-value (Watering)	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **	0.002 **	0.0001 **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	72.5±6.8 B	65.0±10.0 B	92.5±2.6 B	87.0±4.8 B
Every 8 day	39.0±15.6 C	30.5±13.4 C	95.0±0.0 A	90.0±3.3 B
P-value (Biochar × watering)	$5.54x10^{-7}$ **	$6.23x10^{-5}$ **	0.720 NS	0.768 NS
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0	95.0±0.0
Biochar, Every 4 day	77.0±4.5 b	73.0±4.5 b	92.0±2.7	87.0±5.7
Biochar, Every 8 day	53.0±5.7 d	42.0±7.6 d	95.0±0.0	91.0±4.2
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0	95.0±0.0
Without biochar, Every 4 day	68.0±5.7 c	57.0±6.7 c	93.0±2.7	87.0±4.5
Without biochar, Every 8 day	25.0±5.0 e	19.0±4.2 e	95.0±0.0	89.0±2.2
CV(%)	6.16	7.55	1.68	3.90
Overall mean	68.8	63.5	94.2	90.7

Treatments	**Day 19**	**Day 20**	**Day 21**
P-value (Biochar)	0.034 *	0.0004 **	0.001 **
Biochar	85.0±8.2 X	80.0±11.6 X	84.3±13.1 X
Without biochar	82.0±10.0 Y	74.3±15.5 Y	80.3±20.2 Y
P-value (Watering)	$5.13x10^{-11}$ **	$7.33x10^{-15}$ **	$2.00x10^{16}$ **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	78.0±5.4 B	69.0±6.6 B	92.0±2.6 B
Every 8 day	77.5±4.2 B	67.5±5.9 B	60.0±8.5 C
P-value (Biochar × watering)	0.288 NS	0.025 *	$4.13x10^{-6}$ **
Biochar, Every day	95.0±0.0	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	80.0±6.1	73.0±6.7 b	91.0±2.2 a
Biochar, Every 8 day	80.0±3.5	72.0±2.7 b	67.0±4.5 b
Without biochar, Every day	95.0±0.0	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	76.0±4.2	65.0±3.5 c	93.0±2.7 a
Without biochar, Every 8 day	75.0±3.5	63.0±4.5 c	53.0±4.5 c
CV(%)	4.37	4.88	3.64
Overall mean	83.5	77.2	82.3

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There was a statistically significant effect on %MCS due to biochar, watering, and the interaction of biochar × watering at week 4 (Table 37). Significant differences between treatments for both watering factor and interaction of biochar × watering were observed on 5 out 7 days. However, clearly different between those treatments were found at 22 DAP – 24 DAP.

Table 37 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 4 (day 22 – day 28) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	Day 22	Day 23	Day 24	Day 25
P-value (Biochar)	3.69×10^{-5} **[2]	1.97×10^{-5} **	1.06×10^{-7} **	0.029 *
Biochar	80.0±15.6 X	74.3±18.9 X	69.3±23.1 X	93.3±2.4 Y
Without biochar	72.7±24.8 Y	64.7±29.0 Y	57.7±32.5 Y	94.7±1.3 X
P-value (Watering)	2.00×10^{-16} **	2.00×10^{-16}**	2.00×10^{-16} **	0.004 **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	84.0±3.9 B	73.5±7.1 B	65.5±9.0 B	94.5±1.6 A
Every 8 day	50.0±11.8 C	40.0±13.5 C	30.0±12.2 C	92.5±2.6 B
P-value (Biochar × watering)	1.07×10^{-5} **	3.79×10^{-5} **	2.88×10^{-5} **	0.119 NS[1]
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0
Biochar, Every 4 day	85.0±3.5 b	76.0±8.2 b	72.0±4.5 b	94.0±2.2
Biochar, Every 8 day	60.0±5.0 c	52.0±4.5 c	41.0±4.2 d	91.0±2.2
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0
Without biochar, Every 4 day	83.0±4.5 b	71.0±5.5 b	59.0±7.4 c	95.0±0.0
Without biochar, Every 8 day	40.0±6.1 d	28.0±5.7 d	19.0±4.2 e	94.0±2.2
CV(%)	5.24	7.19	6.68	1.68
Overall mean	76.3	69.5	63.5	94.0

Treatments	Day 26	Day 27	Day 28
P-value (Biochar)	0.002 **	0.0002 **	1.40×10^{-8} **
Biochar	91.3±5.2 X	85.0±8.9 X	80.7±11.0 X
Without biochar	87.3±6.5 Y	79.0±11.8 Y	71.0±17.7 Y
P-value (Watering)	1.26×10^{-7} **	6.21×10^{-12} **	2.00×10^{-16} **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	89.5±5.5 B	77.0±6.3 B	66.5±8.8 B
Every 8 day	83.5±4.1 C	74.0±6.6 B	66.0±8.1 B
P-value (Biochar × watering)	0.056 NS	0.016 *	1.98×10^{-5} **
Biochar, Every day	95.0±0.0	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	93.0±4.5	82.0±4.5 b	74.0±4.2 b
Biochar, Every 8 day	86.0±4.2	78.0±7.6 b	73.0±4.5 b
Without biochar, Every day	95.0±0.0	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	86.0±4.2	72.0±2.7 c	59.0±4.2 c
Without biochar, Every 8 day	81.0±2.2	70.0±0.0 c	59.0±2.2 c
CV(%)	3.54	4.60	4.17
Overall mean	89.3	82.0	75.8

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There was a statistically significant effect on %MCS due to biochar, watering, and the interaction of biochar × watering at week 5 (Table 38). Significant differences between treatments for both watering factor and interaction of biochar × watering were found in every day since 29 DAP to 35 DAP. However, clearly different between those treatments were found at 29 DAP – 32 DAP, and at 35 DAP.

Table 38 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 5 (day 29 – day 35) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	Day 29	Day 30	Day 31	Day 32
P-value (Biochar)	$7.83x10^{-11}$ **[1]	$5.56x10^{-7}$ **	$5.76x10^{-8}$ **	$2.01x10^{-9}$ **
Biochar	85.7±13.7 X[2]	82.0±16.7 X	75.7±19.9 X	69.0±24.0 X
Without biochar	79.3±23.0 Y	73.0±26.0 Y	64.0±30.4 Y	57.0±34.6 Y
P-value (Watering)	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	95.0±0.0 A	88.5±5.8 B	77.0±7.5 B	67.5±7.5 B
Every 8 day	57.5±10.3 B	49.0±12.0 C	37.5±13.8 C	26.5±13.6 C
P-value (Biochar × watering)	$3.09x10^{-13}$ **	$1.38x10^{-6}$ **	$2.49x10^{-6}$ **	$2.00x10^{-7}$ **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	95.0±0.0 a	91.0±6.5 ab	82.0±5.7 b	73.0±4.5 b
Biochar, Every 8 day	67.0±2.7 b	60.0±3.5 c	50.0±3.5 d	39.0±2.2 d
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	95.0±0.0 a	86.0±4.2 b	72.0±5.7 c	62.0±5.7 c
Without biochar, Every 8 day	48.0±2.7 c	38.0±2.7 d	25.0±5.0 e	14.0±4.2 e
CV(%)	2.10	4.65	5.90	5.50
Overall mean	82.5	77.5	69.8	63.0

Treatments	Day 33	Day 34	Day 35
P-value (Biochar)	0.044 *	$5.15x10^{-4}$ **	$3.34x10^{-6}$ **
Biochar	93.7±2.3 Y	92.7±4.6 X	85.3±7.4 X
Without biochar	94.7±1.3 X	87.7±6.5 Y	79.0±12.1 Y
P-value (Watering)	0.006 **	$4.77x10^{-5}$ **	$3.10x10^{-14}$ **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	94.5±1.6 A	88.5±7.1 B	75.5±6.0 B
Every 8 day	93.0±2.6 B	87.0±5.4 B	76.0±6.1 B
P-value (Biochar × watering)	0.0005 **	$5.30x10^{-4}$ **	$8.18x10^{-4}$ **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	95.0±0.0 a	95.0±0.0 a	81.0±2.2 b
Biochar, Every 8 day	91.0±2.2 b	88.0±5.7 b	80.0±3.5 b
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	94.0±2.2 a	82.0±2.7 c	70.0±0.0 c
Without biochar, Every 8 day	95.0±0.0 a	86.0±5.5 bc	72.0±5.7 c
CV(%)	1.37	3.79	3.51
Overall mean	94.2	90.2	82.2

[1/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [2/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There was a statistically significant effect on %MCS due to biochar, watering, and the interaction of biochar × watering at week 6, excluded 41 DAP (Table 39). However, clearly different between those treatments were found at 36 DAP, 39–40 DAP, and 42 DAP.

Table 39 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 6 (day 36 – day 42) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	Day 36	Day 37	Day 38	Day 39
P-value (Biochar)	$2.37x10^{-7}$ **[2]	$6.65x10^{-8}$ **	$1.69x10^{-13}$ **	$2.76x10^{-11}$ **

Biochar	80.0±11.3 X[3]	85.7±13.9 X	83.0±17.6 X	77.0±19.7 X
Without biochar	70.7±18.2 Y	78.0±23.6 Y	71.0±26.3 Y	63.7±30.2 Y
P-value (Watering)	$2.87x10^{-16}$ **	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	65.0±7.8 B	94.0±2.1 A	88.5±7.1 B	78.0±8.2 B
Every 8 day	66.0±9.1 B	56.5±11.8 B	47.5±12.5 C	38.0±14.2 C
P-value (Biochar × watering)	$1.78x10^{-4}$ **	$7.94x10^{-9}$ **	$1.63x10^{-10}$ **	$1.35x10^{-8}$ **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	72.0±2.7 b	95.0±0.0 a	95.0±0.0 a	85.0±5.0 b
Biochar, Every 8 day	73.0±4.5 b	67.0±4.5 b	59.0±2.2 c	51.0±2.2 d
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	58.0±2.7 c	93.0±2.7 a	82.0±2.7 b	71.0±2.2 c
Without biochar, Every 8 day	59.0±6.5 c	46.0±4.2 c	36.0±4.2 d	25.0±5.0 e
CV(%)	4.77	3.46	2.90	4.50
Overall mean	75.3	81.8	77.0	70.3

Treatments	Day 40	Day 41	Day 42
P-value (Biochar)	$8.62x10^{-13}$ **	0.327 NS[1]	0.0003 **
Biochar	70.3±23.3 X	94.7±1.3	93.7±2.3 X
Without biochar	56.3±34.4 Y	95.0±0.0	90.3±4.0 Y
P-value (Watering)	$2.00x10^{-16}$ **	0.383 NS	$5.27x10^{-5}$ **
Every day	95.0±0.0 A	95.0±0.0	95.0±0.0 A
Every 4 day	67.5±8.6 B	95.0±0.0	90.0±3.3 B
Every 8 day	27.5±14.6 C	94.5±1.6	91.0±3.9 B
P-value (Biochar × watering)	$6.68x10^{-10}$ **	0.383 NS	0.014 *
Biochar, Every day	95.0±0.0 a	95.0±0.0	95.0±0.0 a
Biochar, Every 4 day	75.0±5.0 b	95.0±0.0	92.0±2.7 b
Biochar, Every 8 day	41.0±2.2 d	94.0±2.2	94.0±2.2 ab
Without biochar, Every day	95.0±0.0 a	95.0±0.0	95.0±0.0 a
Without biochar, Every 4 day	60.0±0.0 c	95.0±0.0	88.0±2.7 c
Without biochar, Every 8 day	14.0±4.2 e	95.0±0.0	88.0±2.7 c
CV(%)	4.47	0.96	2.33
Overall mean	63.3	94.8	92.0

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There was a statistically significant effect on %MCS due to biochar, watering, and the interaction of biochar × watering at week 7, excluded 49 DAP (Table 40). Nevertheless, clearly different between those treatments were found at 43–44 DAP, and 46–48 DAP.

Table 40 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 7 (day 43 – day 49) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	Day 43	Day 44	Day 45	Day 46
P-value (Biochar)	0.001 **[2]	$2.23x10^{-5}$ **	$6.92x10^{-3}$ **	$5.37x10^{-5}$ **
Biochar	87.3±6.5 X[3]	81.3±10.3 X	85.3±13.2 X	80.7±17.4 X
Without biochar	83.3±8.8 Y	75.7±14.5 Y	81.3±20.3 Y	72.7±24.7 Y

P-value (Watering)	2.31x10^{-11} **	2.00x10^{-16} **	2.00x10^{-16} **	2.00x10^{-16} **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	81.0±4.6 B	70.0±5.3 B	94.0±2.1 A	86.0±4.6 B
Every 8 day	80.0±4.7 B	70.5±6.0 B	61.0±9.4 B	49.0±11.5 C
P-value (Biochar × watering)	0.049 *	4.15x10^{-3} **	1.02x10^{-4} **	5.30x10^{-4} **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	84.0±4.2 b	74.0±2.2 b	93.0±2.7 a	89.0±2.2 ab
Biochar, Every 8 day	83.0±4.5 b	75.0±3.5 b	68.0±5.7 b	58.0±8.4 c
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	78.0±2.7 c	66.0±4.2 c	95.0±0.0 a	83.0±4.5 b
Without biochar, Every 8 day	77.0±2.7 c	66.0±4.2 c	54.0±6.5 c	40.0±5.0 d
CV(%)	3.48	3.76	4.49	5.83
Overall mean	85.3	78.5	83.3	76.7

Treatments	**Day 47**	**Day 48**	**Day 49**
P-value (Biochar)	1.58x10^{-7} **	1.66x10^{-8} **	0.533 NS[1]
Biochar	75.3±21.2 X	69.3±23.8 X	94.3±1.8
Without biochar	64.3±29.8 Y	56.7±33.6 Y	94.7±1.3
P-value (Watering)	2.00x10^{-16} **	2.00x10^{-16} **	0.319 NS
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0
Every 4 day	77.5±6.3 B	66.0±8.1 B	94.0±2.1
Every 8 day	37.0±13.2 C	28.0±14.0 C	94.5±1.6
P-value (Biochar × watering)	1.89x10^{-5} **	5.83x10^{-6} **	0.081 NS
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0
Biochar, Every 4 day	83.0±2.7 b	73.0±2.7 b	93.0±2.7
Biochar, Every 8 day	48.0±8.4 d	40.0±7.9 d	95.0±0.0
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0
Without biochar, Every 4 day	72.0±2.7 c	59.0±4.2 c	95.0±0.0
Without biochar, Every 8 day	26.0±4.2 e	16.0±4.2 e	94.0±2.2
CV(%)	5.90	6.73	1.53
Overall mean	69.8	63.0	94.5

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

There was a statistically significant effect on %MCS due to biochar, watering, and the interaction of biochar × watering at week 8 (Table 41). Nevertheless, clearly different between those treatments were found at 51–52 DAP, and 55–56 DAP.

Table 41 Analysis of variance (ANOVA) and means (± standard deviation) in soil moisture content (MCS) (% by volume) at week 8 (day 50 – day 56) in spring onion (var. Uttaradit) supplemented soil with bamboo biochar (ratio 9:1 w/w) under different watering frequencies in Crop 4.

Treatments	**Day 50**	**Day 51**	**Day 52**	**Day 53**
P-value (Biochar)	1.21x10^{-6} **[1]	5.06x10^{-7} **	1.90x10^{-8} **	4.87x10^{-5} **
Biochar	93.7±2.3 X[2]	87.0±6.5 X	79.3±11.6 X	84.3±14.5 X
Without biochar	88.0±5.9 Y	79.7±11.6 Y	71.3±17.6 Y	79.0±23.5 Y
P-value (Watering)	2.39x10^{-6} **	4.22x10^{-13} **	2.00x10^{-16} **	2.00x10^{-16} **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A

Every 4 day	88.0±4.2 B	78.0±6.3 B	65.0±7.1 B	94.0±2.1 A
Every 8 day	89.5±6.4 B	77.0±7.1 B	66.0±7.0 B	56.0±10.5 B
P-value (Biochar × watering)	$1.50x10^{-4}$ **	$2.69x10^{-4}$ **	$2.58x10^{-5}$ **	$8.36x10^{-8}$ **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	91.0±2.2 b	83.0±2.7 b	71.0±2.2 b	93.0±2.7 a
Biochar, Every 8 day	95.0±0.0 a	83.0±4.5 b	72.0±2.7 b	65.0±5.0 b
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	85.0±3.5 c	73.0±4.5 c	59.0±4.2 c	95.0±0.0 a
Without biochar, Every 8 day	84.0±4.2 c	71.0±2.2 c	60.0±3.5 c	47.0±4.5 c
CV(%)	2.66	3.56	3.54	3.67
Overall mean	90.8	83.3	75.3	81.7

Treatments	**Day 54**	**Day 55**	**Day 56**
P-value (Biochar)	$7.11x10^{-8}$ **	$1.18x10^{-11}$ **	$4.04x10^{-9}$ **
Biochar	80.7±18.4 X	76.3±21.3 X	69.3±25.3 X
Without biochar	71.7±26.0 Y	63.3±29.1 Y	56.7±33.1 Y
P-value (Watering)	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **	$2.00x10^{-16}$ **
Every day	95.0±0.0 A	95.0±0.0 A	95.0±0.0 A
Every 4 day	87.0±5.4 B	77.0±10.1 B	67.0±10.6 B
Every 8 day	46.5±10.8 C	37.5±11.6 C	27.0±11.4 C
P-value (Biochar × watering)	$3.95x10^{-6}$ **	$4.82x10^{-8}$ **	$7.12x10^{-6}$ **
Biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Biochar, Every 4 day	91.0±4.2 a	86.0±4.2 b	76.0±6.5 b
Biochar, Every 8 day	56.0±4.2 c	48.0±2.7 d	37.0±4.5 d
Without biochar, Every day	95.0±0.0 a	95.0±0.0 a	95.0±0.0 a
Without biochar, Every 4 day	83.0±2.7 b	68.0±2.7 c	58.0±2.7 c
Without biochar, Every 8 day	37.0±4.5 d	27.0±4.5 e	17.0±4.5 e
CV(%)	4.15	4.30	6.34
Overall mean	76.2	69.8	63.0

[1/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [2/] Different upper case letters (X, Y or A, B, C or a, b, c,...) in the same column means significant difference at 0.05 level of probability.

The change in soil moisture of various treatments on 1 DAP to 17 DAP is shown in Figure 16. %MCS was relatively constant when watering every day both with and without biochar enrichment to the soil. The curve with the lowest continuous values was non-biochar-reinforced soils with low watering, i.e. every 8 days. The next least moisture treatment is watering every 8 days in biochar enriched soil. However, the differences between these two lines are quite high as well. The lowest point of the graph during the first 17 days after planting showed that the soil without biochar and watering every 8 days was 16% and 18% MCS on 8 DAP and 16 DAP, respectively. The 4 days of moderate watering, both supplemented and non-supplemented biochar to the soil, kept %MCS in the middle of the treatments as well. However, added biochar in soil showed a higher %MCS than non-added biochar at watering every 4 days. %MCS of the 4 days watering was highest values on 5 DAP, 9 DAP, 13 DAP, and 17 DAP. While, at watering every 8 days, %MCS showed the highest values on 9 DAP and 17 DAP.

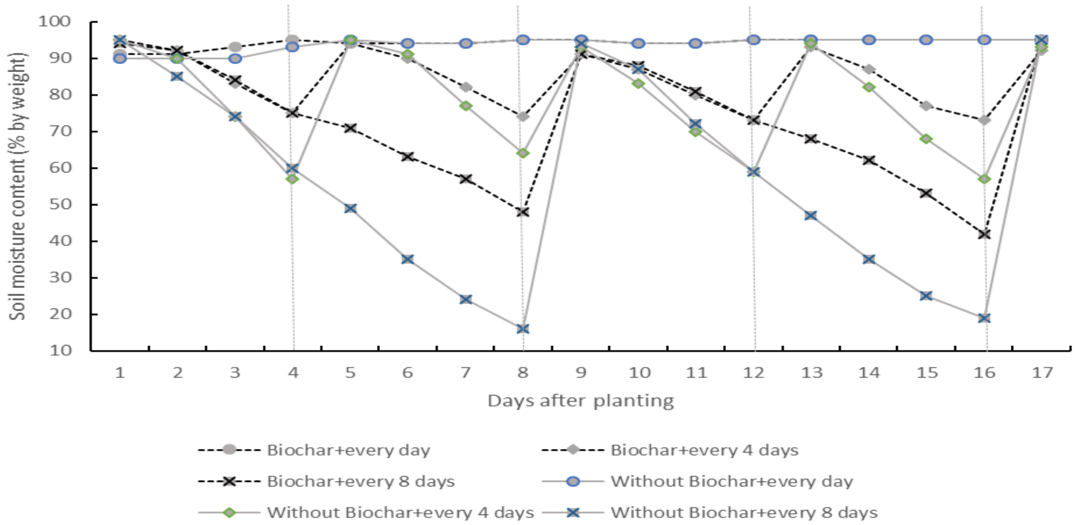


Figure 16 Changing on moisture content of soil with biochar enrichment and watering at different frequencies at 1 to 17 days after planting for planting spring onions in Crop 4.

At the start of growing period of spring onions, the change in soil moisture of various treatments on 18 DAP to 32 DAP is shown in Figure 17. Similar to Figure 13, in this period, %MCS was relatively constant when watering every day both with and without biochar enrichment to the soil. The curve with the lowest continuous values was non-biochar-reinforced soils with low watering, i.e. every 8 days. The next least moisture treatment is watering every 8 days in biochar enriched soil. However, the differences between these two lines are quite high as well. The lowest point of the graph in this period showed that the soil without biochar and watering every 8 days was 19% and 14% MCS on 24 DAP and 32 DAP, respectively. At watering every 4 days, both supplemented and non-supplemented biochar to the soil, kept %MCS in the middle of the treatments as well. However, added biochar in soil showed a higher %MCS than non-added biochar at watering every 4 days. %MCS of the 4 days watering was highest values on 21 DAP, 25 DAP, and 29 DAP. While, at watering every 8 days, %MCS showed the highest values on 25 DAP. Therefore, during the 25 DAP – 27 DAP, the difference in %MCS in various treatments was found to be relatively low.

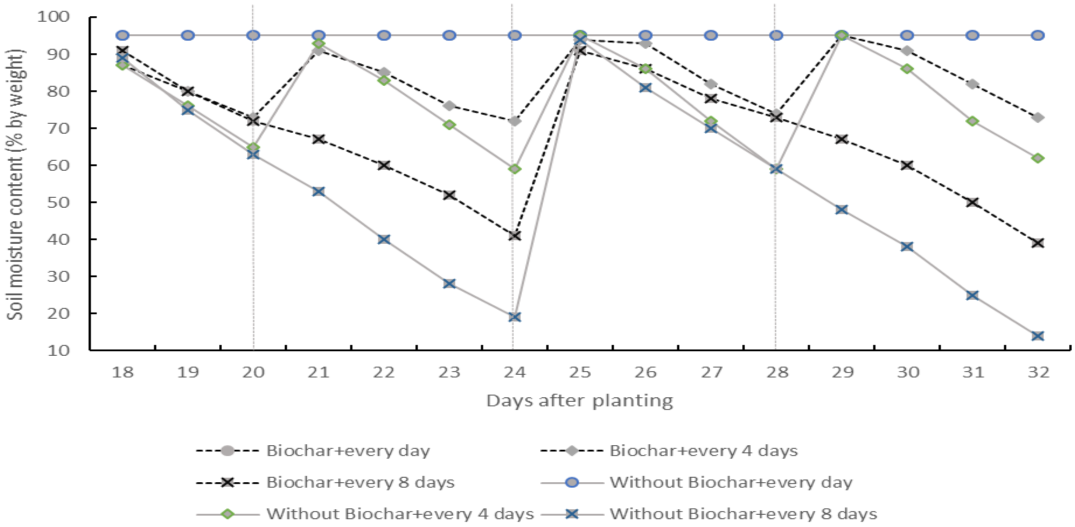


Figure 17 Changing on moisture content of soil with biochar enrichment and watering at different frequencies at 18 to 32 days after planting for planting spring onions in Crop 4.

In the growing period to the stage of harvesting of spring onions in Crop 4, the change in soil moisture of various treatments on 33 DAP to 56 DAP is shown in Figure 18. This graph pattern is similar to Figures 16–17, in this period, higher values of %MCS were relatively constant at watering every day both with and without biochar enrichment to the soil classified as the first group. The second group of graphs with higher values after the first group, i.e., watering every 4 days, both with and without biochar in soils, which adding biochar had the value is clearly higher. However, these two treatments have a greater distance of graphs from each other than at 18 DAP – 32 DAP as shown in Figure 17. The lowest values were observed at the low watering frequency at watering every 8 days both with- and without biochar-reinforced soil, which adding biochar had the value is clearly higher. The differences between these two lines are quite high as well. Again, these two treatments have a greater distance of graphs from each other than at 18 DAP – 32 DAP as shown in Figure 17. The lowest point of the graph in this period showed that the soil without biochar and watering every 8 days was 14%, 16%, and 17% MCS on 40 DAP, 48 DAP, and 56 DAP, respectively. %MCS of the 4 days watering was highest values, close to daily watering, on 36 DAP, 40 DAP, 44 DAP, 48 DAP, and 52 DAP. While, at watering every 8 days, %MCS showed the highest values, close to daily watering, on 40 DAP and 48 DAP. Therefore, during the 33 DAP – 34 DAP, 41 DAP – 42 DAP, and 49 DAP – 50 DAP, the difference in %MCS in various treatments was found to be relatively low.

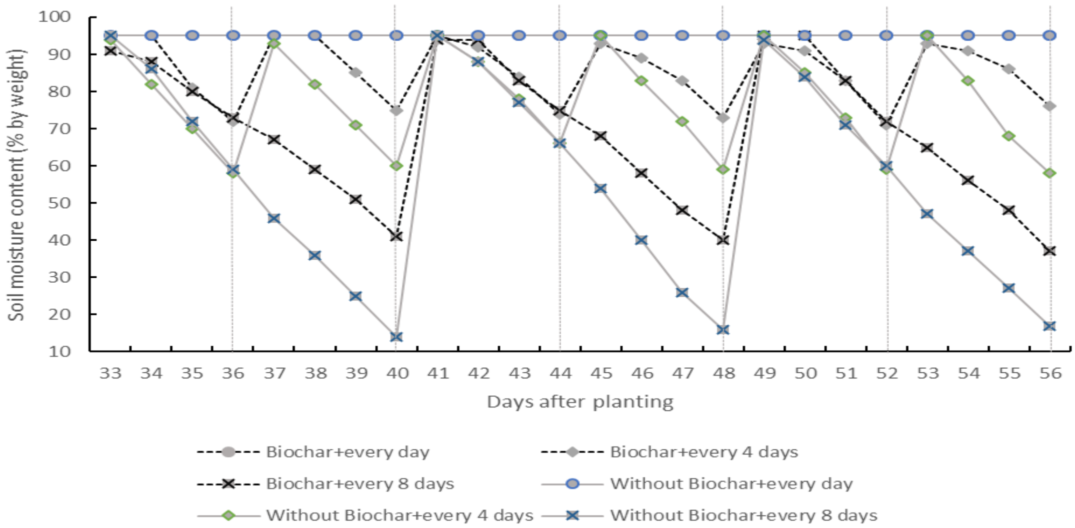


Figure 18 Changing on moisture content of soil with biochar enrichment and watering at different frequencies at 33 to 56 days after planting for planting spring onions in
Crop 4.

Soil and bamboo biochar chemical and physical properties after planting in Crop 4.

Both physical and chemical analyzes of soil after the fourth cycle of planting were determined and are shown in Tables 42-44. For cation exchange capacity (CEC), there were significantly affected by watering frequency, but non-significantly affected by biochar supplementation (Table 42). The higher mean value was determined at watering every day (7.71 cmol/kg), and lower mean values were found at watering every 8 days (6.83 cmol/kg) (Table 30). However, the interaction of biochar × watering affected CEC, the higher value was observed without biochar and watering every day (Table 42). For available phosphorus and potassium, there were non-significant affected by all factors, biochar and watering frequency, and interaction of biochar × watering (Table 42).

For exchangeable calcium (Ex. Ca), there were significantly affected by biochar enriched soil, the higher mean value was observed at without biochar (Table 43). However, the watering frequency and the interaction of biochar × watering were non-significantly affected to Ex. Ca (Table 43). For exchangeable magnesium (Ex. Mg), there were non-significantly affected by both biochar enriched soil and watering frequency, by the interaction of biochar × watering (Table 43). Watering frequency showed a significant affected on exchangeable sodium (Ex. Na) (Table 43). Higher Ex. Na was observed at watering every four and every eight days, and lower at watering every day. There were non-significantly affected by biochar enriched soil and interaction of biochar × watering to Ex. Na (Table 43).

Table 42 Soil chemical properties (cation exchange capacity, available phosphorus and available potassium) in each treatment after cultivation in Crop 4.

Treatments	**Cation exchange capacity (CEC, cmol/kg)**	**Available phosphorus (mg/kg)**	**Available potassium (mg/kg)**
P-value (Biochar)	0.055 NS[1]	0.357 NS	0.086 NS
Biochar	6.95±0.47	450.0±14.7	296.5±144.7
Without biochar	7.48±0.95	469.5±34.7	188.5±62.3
P-value (Watering)	0.046 *[2]	0.949 NS	0.082 NS
Every day	7.71±1.14 A[3]	455.2±23.9	143.2±36.5
Every 4 day	7.11±0.39 AB	462.0±21.7	264.5±156.2
Every 8 day	6.83±0.42 B	462.0±40.8	319.8±74.5
P-value (Biochar × watering)	0.011*	0.953 NS	0.614 NS
Biochar, Every day	6.76±0.46 b	444.0±14.1	161.0±52.3
Biochar, Every 4 day	7.38±0.29 b	449.5±19.1	347.5±212.8
Biochar, Every 8 day	6.72±0.51 b	456.5±19.1	381.0±21.2
Without biochar, Every day	8.66±0.15 a	466.5±31.8	125.5±0.7
Without biochar, Every 4 day	6.85±0.33 b	474.5±20.5	181.5±19.1
Without biochar, Every 8 day	6.94±0.47 b	467.5±67.2	258.5±34.6
CV(%)	5.39	7.36	37.66
Overall mean	7.22	459.75	242.5

Table 43 Soil chemical properties (exchangeable calcium, magnesium and sodium) in each treatment after cultivation in Crop 4.

Treatments	**Exchangeable Calcium (cmol/kg)**	**Exchangeable Magnesium (cmol/kg)**	**Exchangeable Sodium (cmol/kg)**
P-value (Biochar)	0.005**	0.889 NS	0.475 NS
Biochar	13.44±2.04 Y[4]	2.47±0.36	0.34±0.11
Without biochar	18.54±1.96 X	2.50±0.30	0.38±0.17
P-value (Watering)	0.328 NS	0.418 NS	0.016 *
Every day	14.79±4.24	2.37±0.40	0.23±0.05 B
Every 4 day	16.05±2.73	2.44±0.31	0.38±0.08 A
Every 8 day	17.14±3.20	2.64±0.23	0.46±0.14 A
P-value (Biochar × watering)	0.615 NS	0.123 NS	0.101 NS
Biochar, Every day	11.46±0.71	2.10±0.25	0.24±0.08
Biochar, Every 4 day	14.17±2.50	2.64±0.32	0.42±0.10
Biochar, Every 8 day	14.70±1.39	2.68±0.23	0.36±0.08
Without biochar, Every day	18.12±2.99	2.64±0.33	0.22±0.02
Without biochar, Every 4 day	17.92±1.41	2.24±0.18	0.34±0.04
Without biochar, Every 8 day	19.58±2.22	2.60±0.33	0.56±0.12
CV(%)	12.65	11.16	22.27
Overall mean	15.99	2.48	0.358

For organic matter (OM), there were non-significantly affected by biochar enriched soil, watering and the interaction of biochar × watering (Table 44). However, pH showed significantly affected by soil supplementation with biochar, the higher mean value was found without biochar supplementation in soil. For factors of watering and the interaction of biochar × watering, there were non-significantly affected on soil pH (Table 44). Electrical conductivity (EC) had significantly affected by factors of biochar and watering and the interaction of biochar × watering (Table 44). Adding biochar showed a higher mean value of EC than without biochar supplementation in soil. For watering frequencies, watering every eight days was a higher value of EC than watering every day and every four days. For the interaction of biochar × watering, higher values were found at biochar enriched soil and watering every four days and eight days (Table 44).

Table 44 Soil chemical and physical properties (organic matter, pH, and electrical conductivity) in each treatment after cultivation in Crop 4.

Treatments	**Organic matter (%)**	**pH**	**Electrical conductivity (dS/m)**
P-value (Biochar)	0.682 NS	0.0004**	0.031*
Biochar	1.29±0.49	7.27±0.23 Y	0.96±0.43 X
Without biochar	1.18±0.27	7.84±0.16 X	0.68±0.26 Y
P-value (Watering)	0.846 NS	0.054 NS	0.008**
Every day	1.18±0.58	7.72±0.26	0.53±0.14 B
Every 4 day	1.34±0.27	7.52±0.43	0.81±0.42 B
Every 8 day	1.18±0.32	7.42±0.38	1.13±0.26 A
P-value (Biochar × watering)	0.529 NS	0.198 NS	0.034 *
Biochar, Every day	1.34±0.95	7.55±0.07	0.44±0.18 c
Biochar, Every 4 day	1.50±0.22	7.15±0.07	1.15±0.21 a
Biochar, Every 8 day	1.02±0.00	7.10±0.14	1.30±0.21 a
Without biochar, Every day	1.01±0.00	7.90±0.28	0.62±0.00 bc
Without biochar, Every 4 day	1.18±0.23	7.90±0.00	0.46±0.05 c
Without biochar, Every 8 day	1.34±0.46	7.74±0.09	0.97±0.24 ab
CV(%)	36.46	1.86	20.94
Overall mean	1.23	7.56	0.82

[1/] NS means non-significant difference at 0.05 level of probability. [2/] *,** means significant different at 0.05 and 0.01 levels of probability, respectively. [3/] Different upper case letters (X, Y or A, B, C) in the same column means significant difference at 0.05 level of probability.

The chemical and physical properties of biochar in different frequency of watering after Crop 4 for spring onion planting was shown in Table 45. The values of potassium (K) of biochar in the different watering frequencies were the same at 0.30%. However, other characteristics both chemical and physical properties showed quite different values. For the rest of the characteristics (nitrogen, organic matter, C/N ratio and EC) except phosphorus (P) and pH, the biochar treatments that were mixed in the soil that were watered daily were lowest values. The highest values on those characters were biochar in soil received the watering every 8 days and followed by the watering every 4 days. For phosphorus (P), the highest value was found in biochar that mixed in soil that was watering every 8 days. However, similar value of P in biochar mixed in soil that was watering every day and every 4 days. Contrary to the pH in biochar found that received the watering every day was the highest value and followed by watering every 4 days and every 8 days.

Table 45 Bamboo biochar chemical and physical properties in each treatment after cultivation in Crop 4.

	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Organic matter (%)	Carbon/ Nitrogen (C/N ratio)	pH	EC dS/m
Biochar, Watering Every day	0.92	0.16	0.30	17.76	11.50	6.55	0.71
Biochar, Watering Every 4 days	0.95	0.15	0.30	30.80	19.00	6.28	0.94
Biochar, Watering Every 8 days	1.01	0.19	0.30	36.13	21.00	6.18	1.58

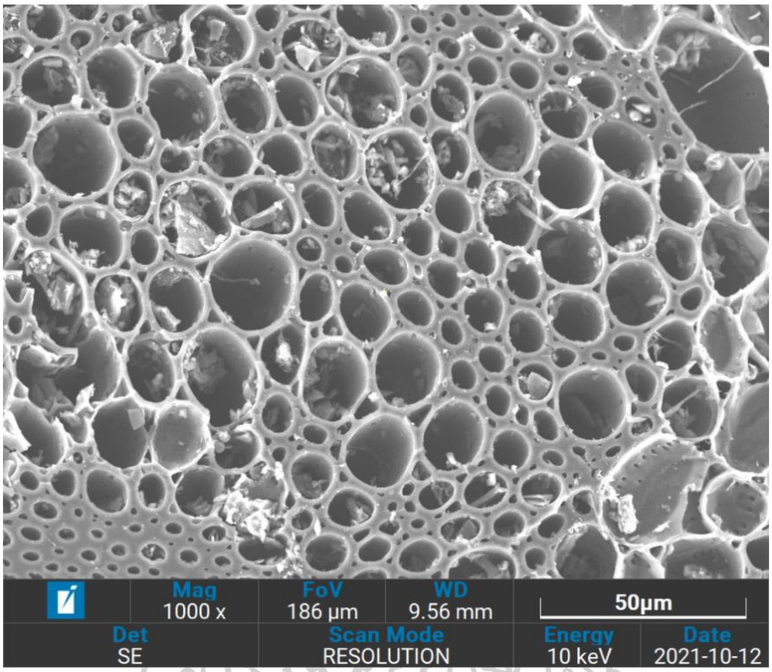
Scanning bamboo biochar surface by Scanning Electron Microscope (SEM)

For biochar, carbon-rich solid material is produced by biomass pyrolysis at a slow temperature at final temperature of 450°C. The surface morphology of bamboo biochar was determined using Scanning Electron Microscope (SEM) shown in Figures 19-23. These figures (Figures 19-23) led to the shape of bamboo biochar by using SEM. Both cross– and longitudinal sections represented the surface of biochar in control (not added in soil), supplemented in soil, and received the watering at different frequencies every 4 days and 8 days.

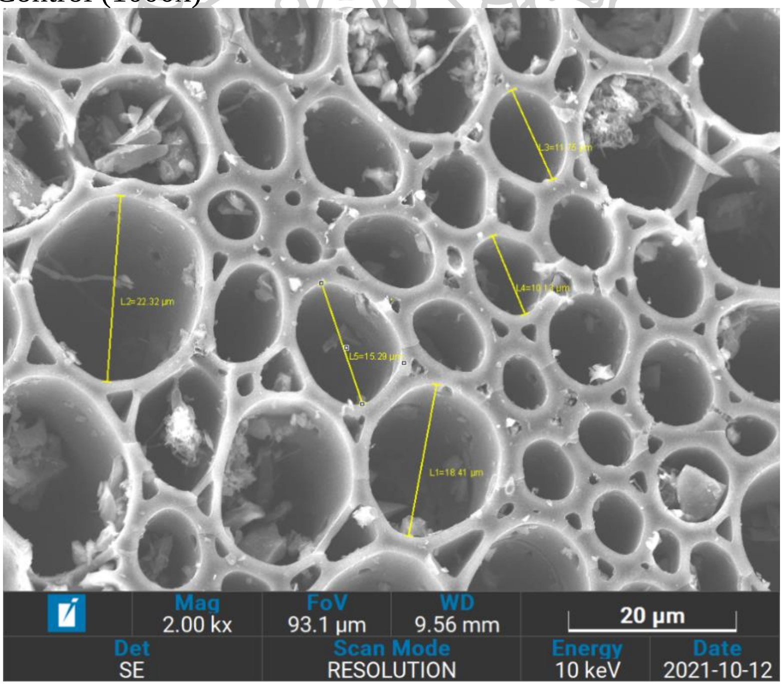
Images of biochar at control or non–adding in soil for planting in cross-section showed

Biochar control treatment has sharp holes, and there were no fragments of biochar from burning blocking the holes. Characteristics of the bamboo biochar are new and the porosity of the cross-sectional holes is clear because it was not mixed with the soil for planting, thus, is a control image to compare with others (Figure 19A–B). Cross–sectional pores were measured with sizes ranging from 10.13–18.41 µm (Figure 19B).

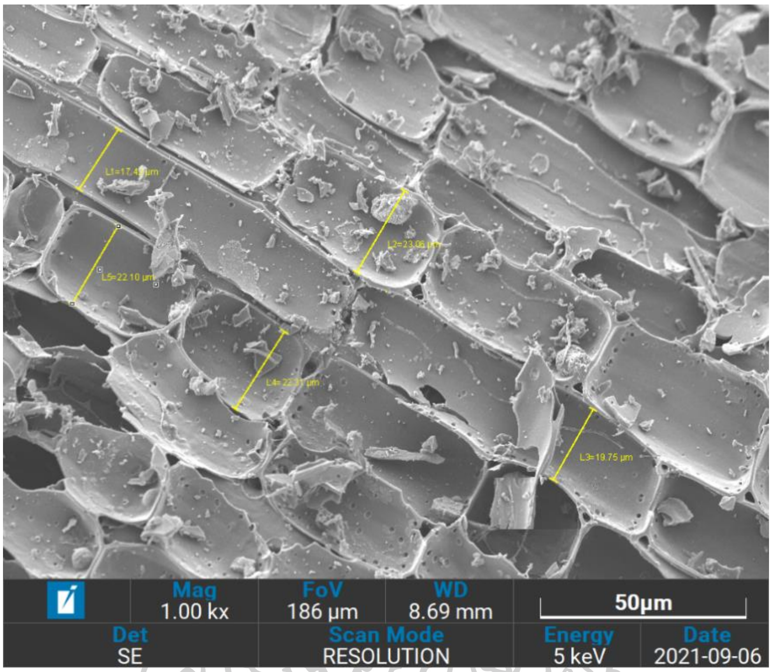
When cross-sectioning of the control biochars (Figure 19 C–D), the surface of the segment was smooth and non-porous. These observable things will allow the bamboo biochar to retain both moisture and nutrient as well.



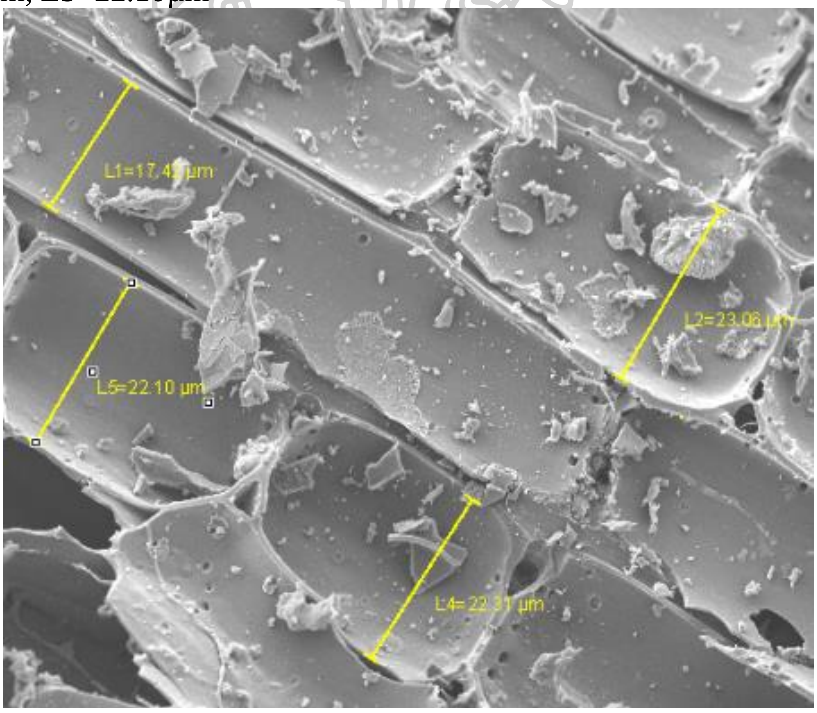
A. Biochar–Control (1000x)



B. Biochar-Control (2000x): L1=18.41µm, L2=22.32µm, L3=11.75µm, L4=10.13µm, L5=15.29 µm



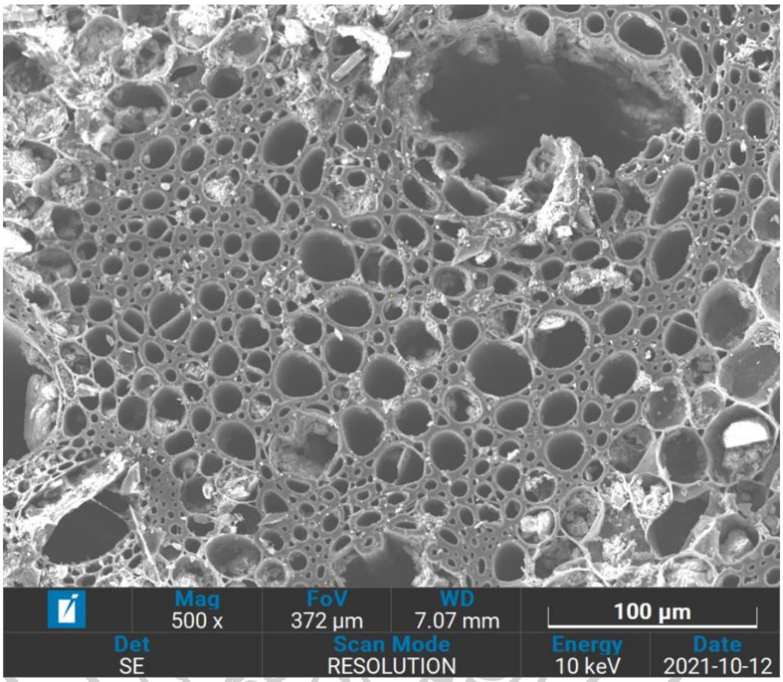
C. Biochar- Control (1000x): L1=17.42µm, L2=23.06µm, L3=19.75µm, L4=22.31µm, L5=22.10µm



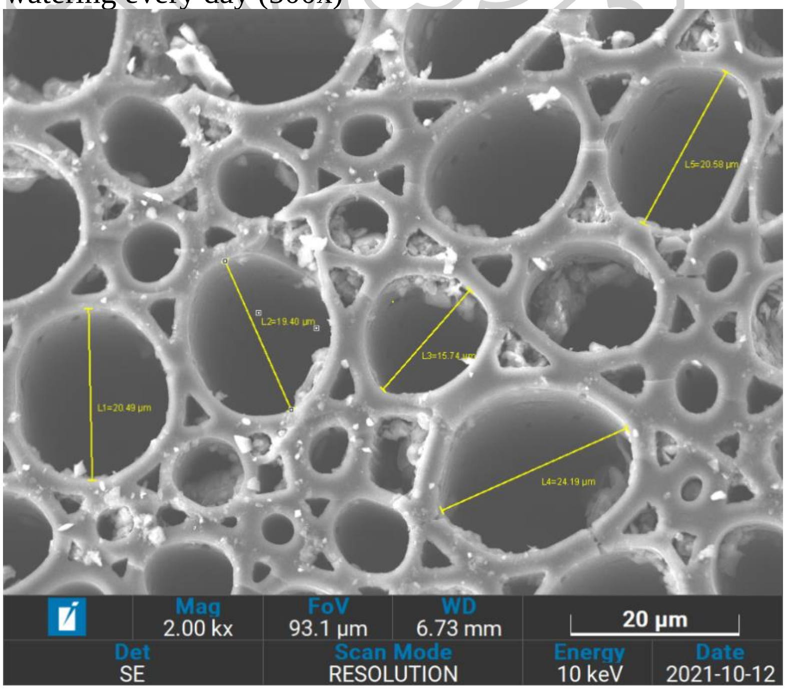
D. Biochar- Control (1000x)

Figure 19 Scanning electron microscope images by cross section at 500x (A) and 1000x (B), and longitudinal section at 1000x (C) of bamboo biochar (Control–not added in soil) obtained at 450 ˚C

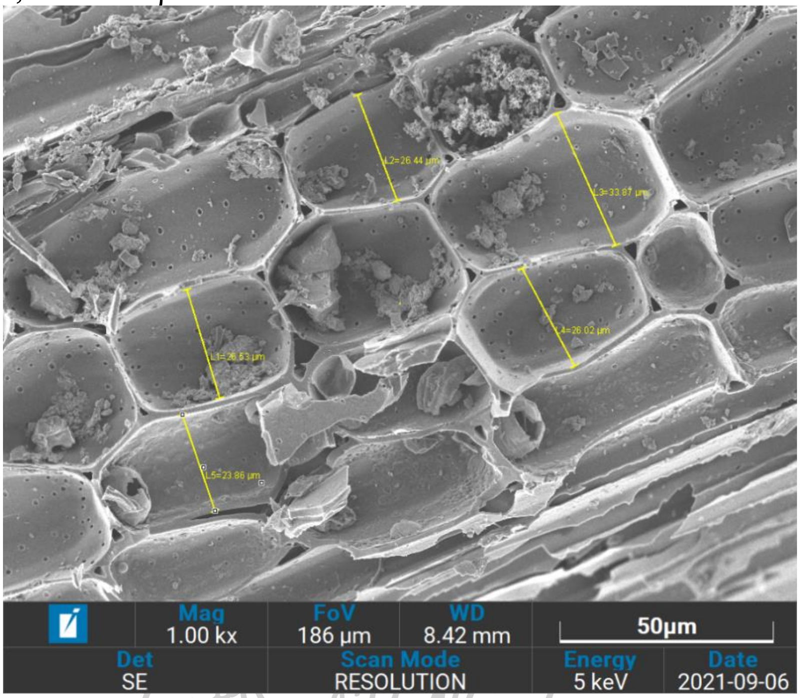
The biochar that is watered every day, refers to the biochar added to the soil for the second to fourth cycles of spring onion planting. These five–hundredfold (500x) cross-sectional images of SEM showed in wide view the obstruction of the duct with biochar debris (Figure 20A). The cross-section at 2000x is a measurement of the conveying pipe gap in the biochar at watering every day (Figure 20B). Considering this image, it was no different from the control biochar. However, a cross-sectional image of the biochar supplemented in the soil and subjected to watering every day showed different results from the control biochar. The biochar treatment that was watering every day has internal walls of many porous (Figure 20C–D).



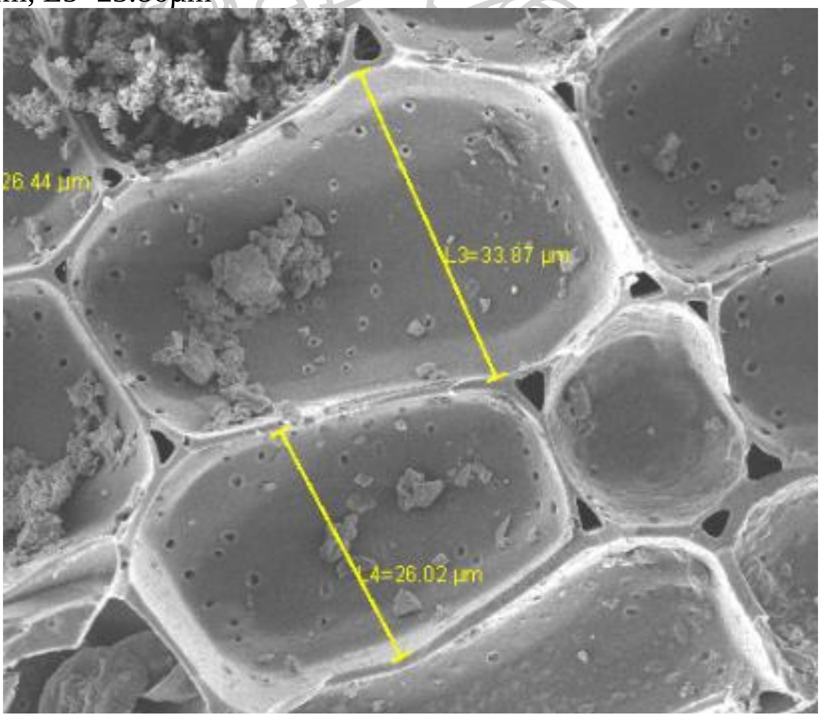
A. Biochar– watering every day (500x)



B. Biochar– watering every day (2000x): L1=20.49µm, L2=19.40µm, L3=15.74µm, L4=24.19µm, L5=20.58µm



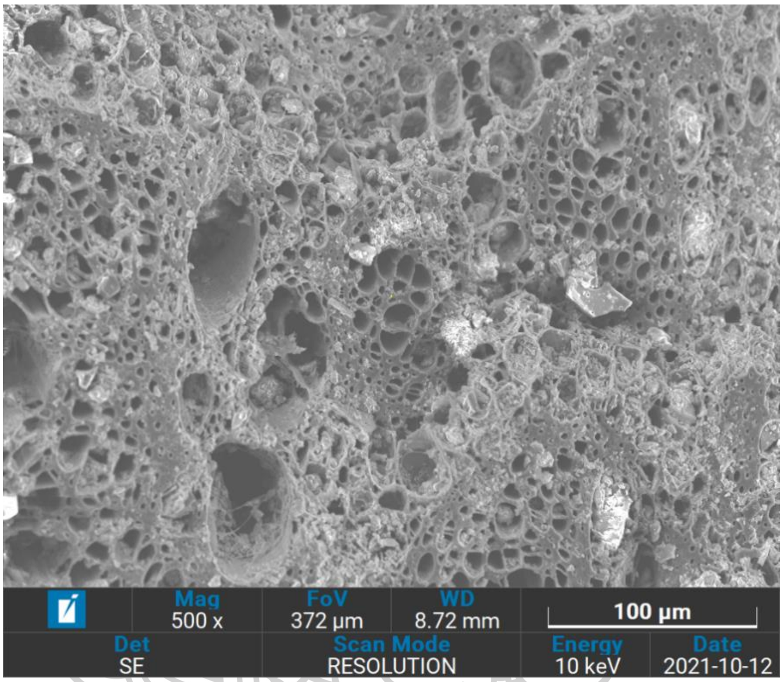
C. Biochar– watering every day (1000x): L1=26.53µm, L2=26.44µm, L3=33.87µm, L4=26.02µm, L5=23.86µm



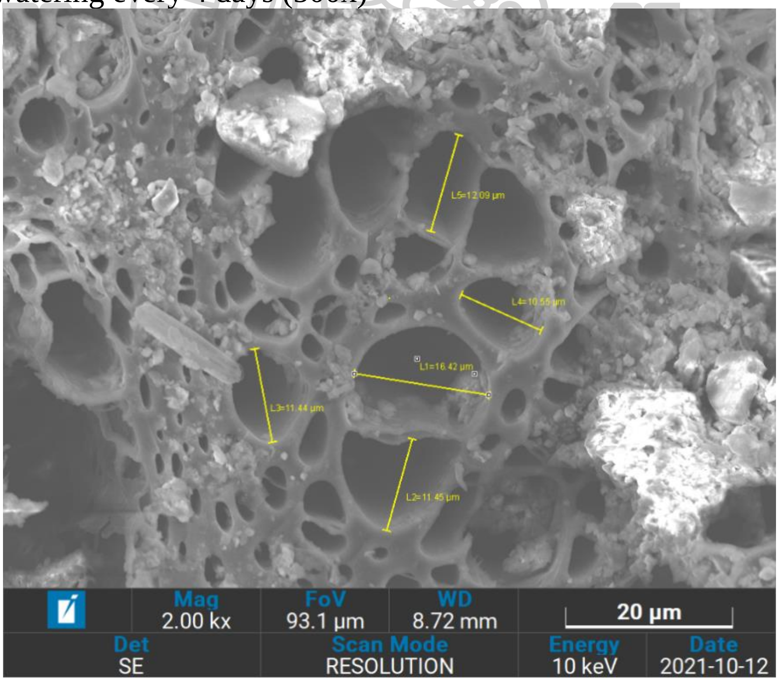
D. Biochar– watering every day (1000x)

Figure 20 Scanning electron microscope images by cross section by cross section at 500x (A) and 2000x (B), and longitudinal section at 1000x (C) of bamboo biochar has been supplemented with cultivated soil under every day watering during Crop 2–4.

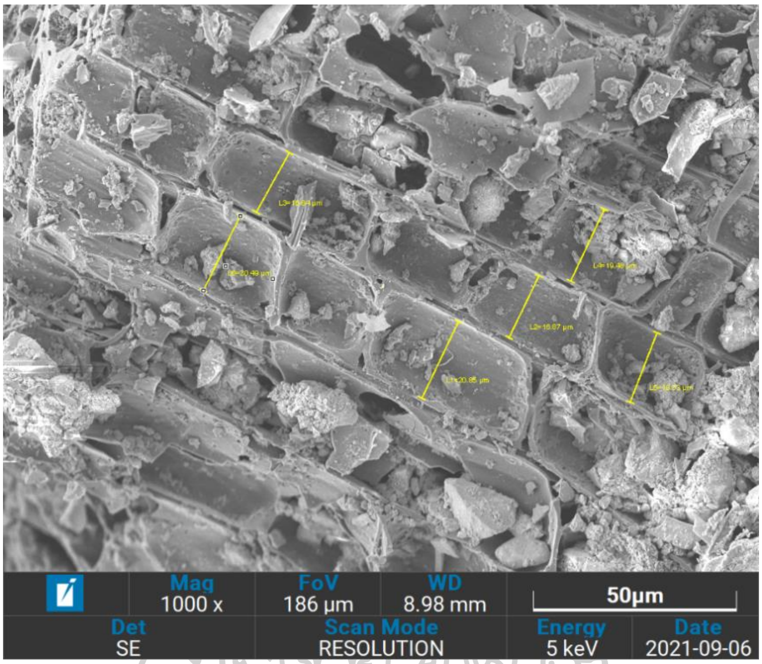
For bamboo biochar at watering every 4 days used in the second to fourth planting cycles, the pores of the adsorbents and pores sizes in diameter are visible by using SEM shown in Figure 21A–D. A cross-sectional image of biochar is presented in Figures 21A–B. The bamboo biochar surface has many macropores with variable pores sizes. Longitudinal–sectional biochar image is shown in Figure 21C–D. The surface was thick and has a smaller pore volume compared with biochar at watering every day (Figure 21D).



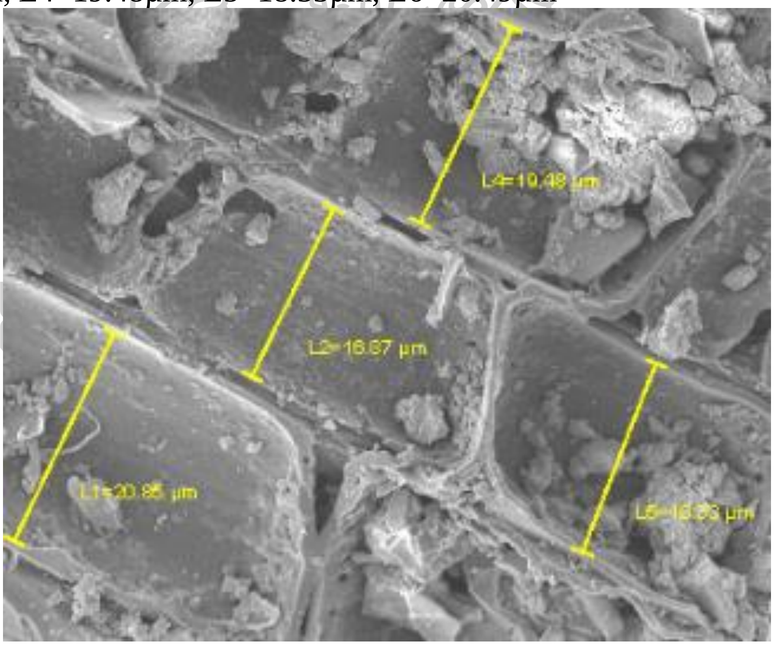
A. Biochar–watering every 4 days (500x)



B. Biochar–watering every 4 days (2000x): L1=16.42µm, L2=11.45µm, L3=11.44µm, L4=10.55µm, L5=12.09µm



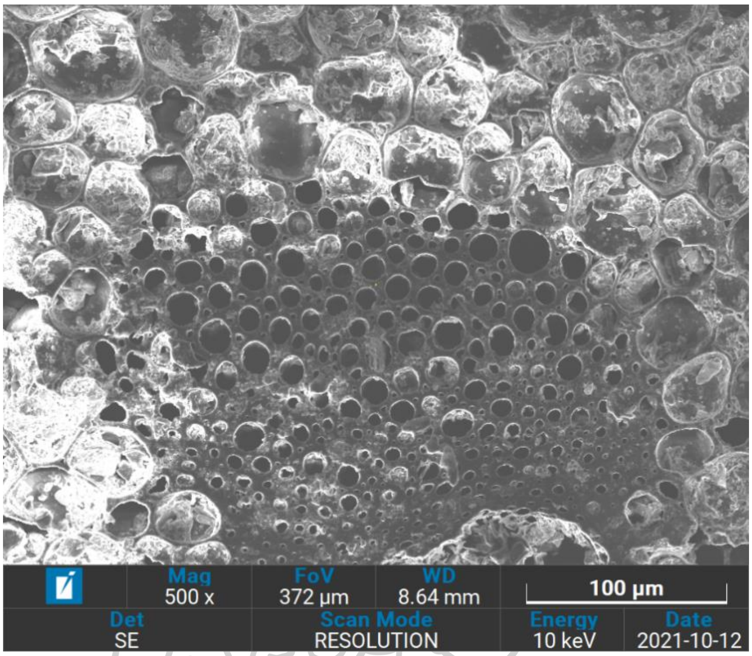
C. Biochar–watering every 4 days (1000x): L1=20.85µm, L2=16.87µm, L3=16.84µm, L4=19.48µm, L5=18.33µm, L6=20.49µm



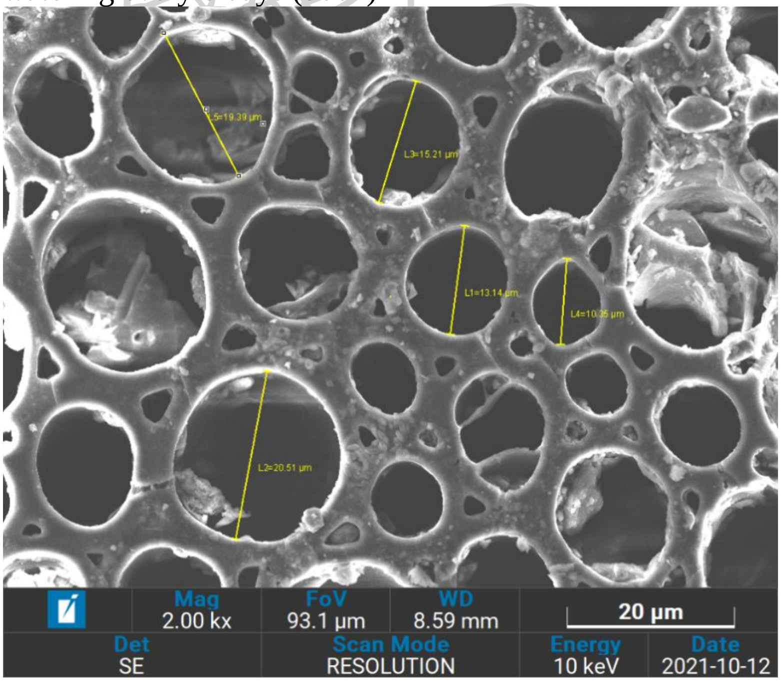
D. Biochar–watering every 4 days (1000x)

Figure 21 Scanning electron microscope images by cross section by cross section at 500x (A) and 2000x (B), and longitudinal section at 1000x (C) of bamboo biochar has been supplemented with cultivated soil under every 4 days watering during Crop 2–4.

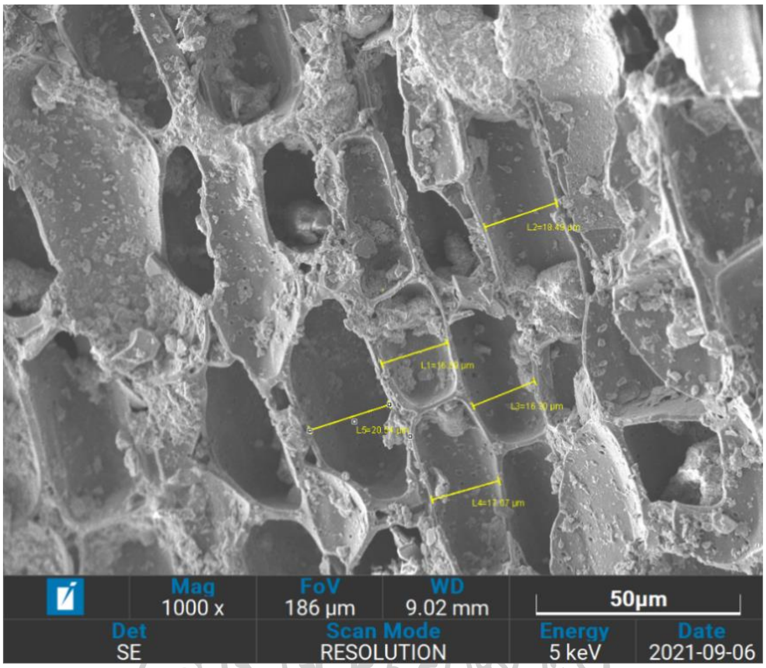
For bamboo biochar at watering every 8 days used in the second to fourth planting cycles, the pores of the adsorbents and pores sizes in diameter are visible by using SEM shown in Figure 22A–D. A cross-sectional image of biochar is presented in Figures 22A–B. The bamboo biochar surface has many macropores with variable pores sizes. Longitudinal–sectional biochar image is shown in Figure 22C–D. The surface was thick and has a smaller pore volume compared with biochar at watering every day (Figure 21D).



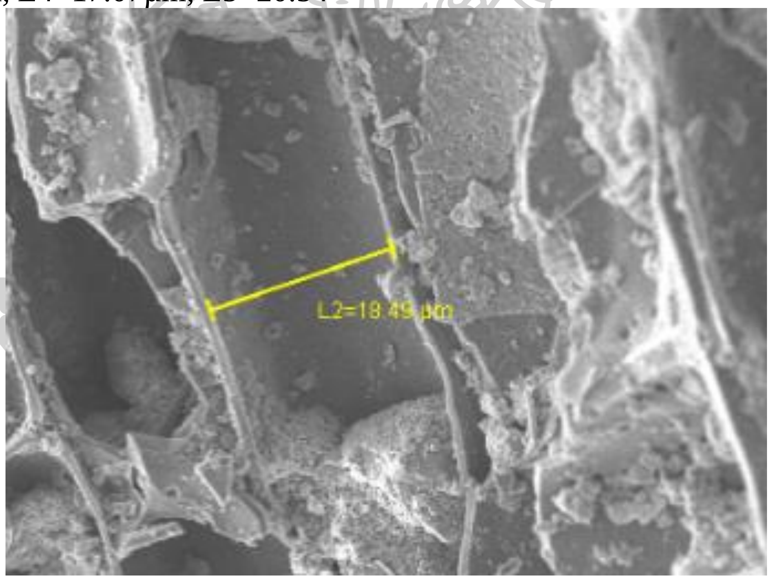
A. Biochar– watering every 8 days (500x)



B. Biochar– watering every 8 days (2000x): L1=13.14µm, L2=20.51µm, L3=15.21µm, L4=10.35µm, L5=19.39µm



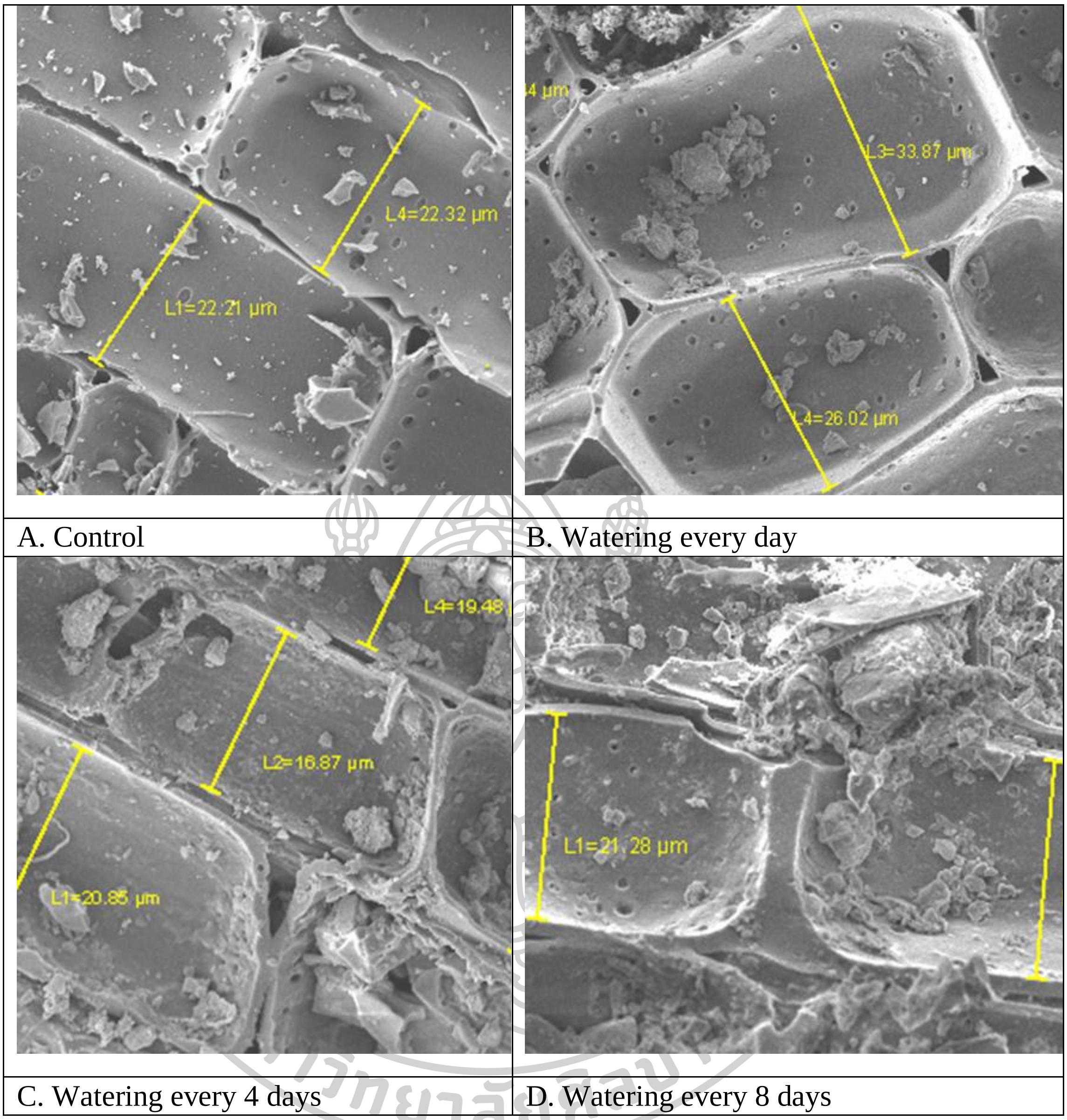
C. Biochar– watering every 8 days (1000x): L1=16.89µm, L2=18.49µm, L3=16.30µm, L4=17.07µm, L5=20.54



D. Biochar– watering every 8 days (1000x)

Figure 22 Scanning electron microscope images by cross section by cross section at 500x (A) and 2000x (B), and longitudinal section at 1000x (C) of bamboo biochar has been supplemented with cultivated soil under every 8 days watering during Crop 2–4.

Again, small pores size at the surface in longitudinal section between biochar at control (Figure 23A) and watering in different frequencies (Figures 23B–D) were presented. Many small pores in surface inside were clearly observed in biochar at watering every day than others.



A. Control | B. Watering every day | C. Watering every 4 days | D. Watering every 8 days

Figure 23 Scanning electron microscope images by cross section to compare between pores on bamboo biochar surface for longitudinal section (1000x).

DISCUSSION

Growth-related characteristics and yield in spring onion cultivated in Crop 1 to Crop 4

Soil moisture content in sandy loam soil had decreased values less than 6 days after soil at the field capacity date (Table 6-7 and Figure 4). For this means, within seven days after pouring the water at field capacity in sandy loam soil, in this case, the plants can absorb the moisture from the soil. However, it does not guarantee adequate moisture levels for plants' requirements; however, this moisture level is not reached to permanent wilting point. For available water (holding) capacity of sandy loam soil was reported as 20% with 2.4 inches/foot (in/ft) of total available water: between 15-25% for sandy soil and 35-45% for loam soil at field capacity for soil moisture content (volumetric). Addition, the permanent wilting point in sandy soil about 5-10% and 10-15% for loam soil for soil moisture content (volumetric)(NRCCA 2010).

Comparing between moisture content percentages, higher capacity for water holding was observed in bamboo biochar (202.13% moisture content), temperature of pyrolysis at 450 °C, more than soil (28.64% soil moisture content) about 7 times (Table 7-9). Biochar’s characteristics such as shape, particle size and the structure are the keys play roles to storage the water, and results to increase the water retention in soil (Liu et al., 2017).

This is the reason in the objective of supplementation with bamboo biochar is to increase water retention in soil. However, the appropriate combination among biochar, soil, and the plant should be considered because it relates to increasing root ability to use nutrients and air content in the soil in terms of the balance between soil, plant, and atmosphere (Gliniak, 2019). For this reason, the amount for supplementing any biochar types should study on their abilities through many properties. Of course, biochar has distinctive feature is its increased water absorption to increase the moisture content of the soil containing biochar. The water holding capacity of biochar is one capacity parameter was measured to support the idea of supplementation in the soil before planting the spring onion. However, biochar in smaller-coarse form was processed by grinding (<2.36 mm sizes) before the supplementation into the soil, not as in pellets form. Thus, the function at high efficiency for carrier the nutrient and water retention may reducing compared with pellets form (Li et al., 2021).

Moreover, the characteristics of biochar is varies according to many factors such as types of biomass and the temperature and residence time that related to pore size and pore distributions on biochar surface area or call as porosity of biochar (Gray, 2014). The hydrophobicity of biochar is the property relate to the capacity of water retention. Fresh biochar showed negative feature for water absorbed capacity through the high surface energy which reducing the penetration of water through macropores on biochar surface (Li et al., 2013). In addition, the degree of hydrophobicity depended on the temperature for burning the biomass, higher hydrophobicity was reported at low temperature (less than 400°C), and lower hydrophobicity was found at high temperature (higher than 500°C) (Gray, 2014);

(Kameyama et al., 2019). However, the process of burning the bamboo used moderate temperature (at 450°C).

The capacity of biochar is not only to absorb water but also absorb nutrient, coincident between increasing water retention and reducing the drainage of fertilizer in soil (Li et al., 2021).

Agronomic characteristics in spring onion cultivated in Crop 1

In crop 1, all characteristics in many weeks, excluding BF, were significantly affected by supplementation with biochar showed negative effect on those characteristics (Table 10-15 and Figure 5). First of all, it is important to understand the properties and benefits of biochar. Biochar, a porous carbonaceous solid produced by various biomass either from byproduct in agriculture or feedstock (Liao et al., 2020). Benefit of biochar in agriculture to reduce the problem of low nitrogen (N) use efficiency caused by leaching, runoff, and the emission of nitrous oxide (N_2O) into the atmosphere (Case et al., 2012); (Güereña et al., 2013); (Liao et al., 2020). Biochar can improve N efficiency by recycling this element between soil and plant in soil-plant systems (Gul & Whalen, 2016). More than the physical properties of biochar to reduce the loss of N in the soil, biochar has been reported to increase both the quantity and quality of soil microbes: such as the activity of microbe (Kim et al., 2014), increase the major element in microbes such as carbon (C), N, and phosphorus (P), and to promote the network complexity of bacterial community (Zhou et al., 2019). All results affected by biochar application resulted to promote the availability of plant nutrients (Zhang et al., 2017). Nevertheless, the effect of nitrogen and biochar application: nitrification rate in soil, were observed in lately growth stage such as flowering and harvesting stages, but not at seedling and booting stage. Slow-release of nitrogen until the late crop growth period is the main key to promoting productivity in plants (Gao et al., 2015). However, in fewer doses (less than 1 ton/ha), biochar mixed with urea is not found to promote plant growth, but can increase grain yield finally through N available for plants uptake (Gombert et al., 2010); (Li et al., 2013). That is, different growth stages may be affected by the addition of biochar differently.

Nevertheless, there were non-significant effects of supplementation of biochar derived from the olive mill solid waste (OMSW) to maize growth, although biochar can promote some elements available in the soil and in shoot of plants: increase in elements such as K, Na and Zn, and decrease some nutrients: include Ca, Mg, P, and Mn (Alazzaz et al., 2020).

Due to biochar is the alkaline in nature properties, it has been reported is suitable to amend in acidic soil more than alkaline soil (Dai et al., 2014); (Glaser & Lehr, 2019). Moreover, for biochar, the positive effect for application in plants is not always consistent (Alazzaz et al., 2020), (Jones et al., 2012); (Van Zwieten et al., 2010). The positive or negative effects of amendment biochar also depended on kind of soil, in maize production, there were no improvement because of biochar supplementation in calcareous soil (Farrell et al., 2014). For the properties of alkaline soils such as calcareous soil, it can promote the insoluble compounds of elements (Ca, Mg, and P), resulted to these elements were decreased in shoot content (Chintala et al., 2014). Moreover, one of the various reasons depended on the structure and chemicals of biochar that affects the productivity of plants and the soil fertile (Alazzaz et al., 2020).

Effectiveness of using the biochar by amendment into the soil for water retention in soil was reported depending on its properties such as particle shape and size (intrapores; pores inside of particles) and the structure (Liu et al., 2017). However, for practice in the field, preparing the biochar in fine particles can fill pores between the soil particles, resulting in a positive impact on water absorption in soil because of the changes in intrapores (the pore space between particles) and pore size by reducing their sizes (Masiello et al., 2015); (Liu et al., 2017).

In this study, non-benefit on plant growth was not observed at Crop 1 for the supplementation of biochar in soil. Although to regard with increased water retention when biochar was applied. It should consider the availability of nutrients in soil caused by these nutrients has been absorbed into biochar pores and in case the replacement of soil with coarse particles of biochar. In material and methods in this study, size of biochar particles are >2.36 mm by use sieve no. 8 for sorting. Thus, for this size particle of biochar, >2.36 mm, it was categorized in coarse to parent biochar (0.853-2.00 mm to 2.00-2.30 mm) (Liu et al., 2017).

Focusing on watering, the higher mean values were observed at watered every two days and three days in two of seven characteristics in some weeks such as LN in week 3 and PC in week 2 and 4 (Table 11 and 14). Due to size of biochar interpore effect on water retention or increase field capacity. Thus, in case that flooding or over moisture content from watering, amendment with fine particles of biochar may result in negative impact to plant growth (Li et al., 2017). That might explain why the mean values for some growth-related characteristics for some weeks is higher at every two and three days watering compared to daily watering: LN-W3, PC-W2, PC-W4 (Table 11 and 14). In addition, a positive effect was found in plant growth in soil that the absence of biochar, resulted in higher mean values than in biochar supplementation: PH-W3, LN-W3, LN-W4, LL-W5, LL-W6, PC-W3, PC-4, and PC-W6 (Table 10-12 and 14). In addition to moisture or water, which is an important factor for plant growth, the air between soil particles or soil porosity is also very important. Soil air permeability is one parameter to assess soil characteristic such as soil compaction (A. M. Tang et al., 2011). For crop 1, the experimental practice was conducted in the plastic pot outdoor. Although this experiment escaped from the effect of rainfall in season (March 18 – May 6, 2020), the soil moisture content at all treatments of watering frequencies: every two and three days, were likely high percentages (13.52-23.91%) as a trial in this soil before the experiment started (Table 7). At the harvesting stage, four in seven characteristics were significantly negatively affected by supplemented biochar: LRL, RL, PW, and BW (Table 15). Thus, the spring onion productivity in crop 1 showed negative affected when plants' growth in soil was amended with biochar. Moreover, the frequencies of watering: every day, every two days, and every three days, could not assess the benefit of supplementation of biochar in soil, in this season.

Agronomic characteristics in spring onion cultivated in Crop 2

In Crop 2, all seven characteristics were significantly positively affected by amendment biochar in soil, however, there were significantly affected in varies in different characteristics in different weeks (Table 16-21 and Figure 6). The soil enriched with biochar in different watering frequencies in each treatment in Crop 2 continued by using the soil from the previous experiments in Crop 1.

Responses in the second experiment in Crop 2 differed from the first experiment in Crop 1 in that the influence of biochar addition may result from changes in both the structure and the properties of biochar affecting nutrient availability in the soil. Assessment maize growth and soil quality (232%-514% for organic matter and 110%-230% for macronutrients) showed higher values in soil supplemented with digestate-enriched biochar compared with unenriched biochar and control treatment. However, maize yield was lower about 20%-25% when grown in soil supplemented with digestate-enriched biochar compared with chemical fertilizer treatments (Kizito et al., 2019). The question is how long it takes for the biochar to release nutrients into the soil. More than that, the reason for lower yields of maize in soil supplemented with digestate-enriched biochar compared to chemical fertilizer has been explained as the issue of slower mineralization and short term to release adsorbed nutrients (Kizito et al., 2019). More benefits of biochar amendment could be observed in the long-term to plant growing depending on the quality and quantity of organic matter in soil; because it is related to the gradual release of nutrients into the soil (Kizito et al., 2019). However, it was possible to ignore the impact of organic matter in soil affecting the growth and yield of spring onions in biochar enriched soils in Crop 1. In other words, in Crop 1, the lower spring onions growth in all characteristics, excluding BF at many weeks and yield at harvesting stage in soil supplemented with biochar (Table 10-15) are likely a result of incomplete digestion of biochar rather than the short-term release of nutrients from biochar. However, continuous use of soil enriched and unenriched with biochar from the first cycle (Crop 1); in each treatment, for planting in the second cycle (Crop 2) may result in more complete biochar digestion. This allows the benefit of soil nutrient release to be assessed by both growth-related characteristics and yields in second cycle (Crop 2) (June 26 – August 14, 2020) in spring onions (Table 16-21). In other words, the recycle nutrients from digestates enriched biochar in soil could occur in second planting in term of continuous planting in same plot or same soil.

The greater productivity in spring onions in this study may be consistent with other studies. The greater some nutrients were observed in soil amended with biochar including K, and Na, but lower P, while, lower nutrients of Zn, Ca, and Mn (Novak et al., 2009). (Ding, 2010) reported a cumulative reduction in NH_4^+-N loss (about 15%) at over 70 days when added bamboo charcoal, pyrolyzed at 600°C, in sandy silt soils.

However, the benefit of biochar is varied because it is related to several factors such as nutrient forms, rates of nutrient release, crop species, and over time (Mukherjee & Zimmerman, 2013). Which, the structure and the properties either physical or chemical of biochar as factors related to nutrient loss rate of biochar in linear correlation coefficients (Mukherjee & Zimmerman, 2013). There was reduction of plant development in soil amended with biochar, it has been explained about the reduction of ammonium availability (Deenik et al., 2010). This result is the reason for the nutrient adsorption in biochar and resulted in decreasing amount of available nutrients in the soil (Kameyama et al., 2012). For slowly release nutrient or high absorption in biochar related to its properties in several factors- examples as large surface area, high porosity, and the ability to exchange the ion (Liang et al., 2006).

Moreover, aged biochar showed high ability to exchange anion more than recently produced biochar, but in fresh biochar could absorb NH_4^+ and could release exchangeable NO_3^- and PO_4^3 (Chan et al., 2008); (Mukherjee et al., 2011); (Mukherjee & Zimmerman, 2013)

Moreover, micropores surface area which carries its acidity results to contain biochar C and N, trend to susceptible to leaching (Mukherjee et al., 2011). High temperature biochar normally showed increase biochar surface area, results to show higher nutrient absorption (Mukherjee & Zimmerman, 2013). The interaction between soil and biochar was reported, nutrient forms can release from soil and biochar, and nutrients leachates could absorb by both of them too. Higher temperature biochar or aged biochar is recommended for sandy soil because the characteristics of biochar as lower release sudden pulses of nutrients consistent with the less able to nutrient retention in sandy soil (Mukherjee & Zimmerman, 2013). To describe about happening in this study, sandy loam soil in this study release nutrients more slowly than sandy soils. In addition, the positive results seen in the addition of biochar observed in the second planting cycle may be due to the slow nutrient release of the bamboo biochar (later than 49 days or seven weeks of the spring onion planting life).

Thus, nutrient leaching assessment should measure the amount of nutrient accumulated in soil, plant, biochar, soil microbial consumption, the transformation of nutrients (stimulated by amendment with biochar), and leached nutrient from the soil (Mukherjee & Zimmerman, 2013). Whereas, the benefit of nutrients on microbial activity may respond to amend the biochar since on weeks to longer periods (Bruun et al., 2008); (Zimmerman et al., 2011).

Agronomic characteristics in spring onion cultivated in Crop 3

The soil and biochar used in each treatment in pots in Crop 2 continued to be planted in Crop 3 (June 9 – July 28, 2021) for spring onion planting with an increase in soil content to the same ratio between these crops as 9:1 v/v (soil: biochar). Due to the entering of the rainy season, the experimental pots have been placed in the greenhouse. Thus, the watering frequency in Crop 3 was changed be watering every day, every 4 days, and every 8 days.

The positive role of biochar amendment was observed to promote spring onions' growth characteristics (Table 22-26) and yield (PW and BW) (Table 27 and Figure 7). The greater respond to biochar supplementation was found on PH and LL. Actually, PH was measured from soil surface to the height of the longest leaf of spring onion plant in each pot. Therefore, PH and LL were similar except LL was measured from all leaves and averaged (Table 22 and 24). Although in the third planting cycle (Crop 3), the usual fertilization is still applied to all pots as in the last two planting cycles (Crop 1-2). The predominance of plants grown in biochar enriched soil is likely due to its water retention and nutrient release properties. For LN and BF, there were significantly affected by biochar in fewer week numbers (Table 23 and 25). Either LN or BF is related to the number of bulbs per plant. For this evidence, the benefit of adding bamboo biochar should consider on PW and BW together (Table 27). In this study, highest mean values were observed at soil supplemented with biochar on either PW and BW at harvesting stage (Table 27).

The results showed higher productivity of spring onion planting in two planting cycles from adding biochar only once in the first planting. The capacity of nutrient release; in case applied only once in the soil, varies according to several factors since the type of feedstock or by-product or during the process to produce the biochar (El-Naggar et al., 2019). For sandy and sandy loam soils, they are as the target have been improved by biochar supplementation (El-Naggar, Lee, et al., 2018).). For primary purpose of supplement soil with biochar, it is to promote increased water availability in soil by enhancing the ability to retain water in soil (Lehmann et al., 2003); (Mohamed et al., 2016). Other benefits are promoting aeration in soil (Cayuela et al., 2013), reducing nutrient leaching in soil by increasing available nutrient by increase the retention in soil (El-Naggar, Shaheen, et al., 2018), promoting the activity of soil microbial (Igalavithana et al., 2017), and increasing organic carbon content (El-Naggar et al., 2018).

Negative impact of soil supplemented with biochar in Crop 1 may result from the reduction either on plant nutrient uptake capacity or carbon mineralization in soil, especially in soil containing low organic carbon (Ippolito et al., 2012); (Kuppusamy et al., 2016). Nevertheless, in this study, bamboo biochar was produced at moderate pyrolytic temperature (≥ 450 °C), may not cause to high adsorb plant nutrients. (El-Naggar et al., 2019) reviewed that at high pyrolytic temperature for biochar production (≥ 600 °C) resulted in the restriction of plant uptake nutrients because of high adsorption of plant nutrient by biochar.

The extension of the watering time as it was grown in greenhouse conditions in Crop 3 showed different mean values on plant growth parameters affected by the watering frequency distinct from the two experiments conducted outdoors (Table 22-27). Significantly affected on all plant growth-relate characteristics in some weeks by watering frequency showed higher mean values at watering every day and every 4 days. There is a distinctly lowest mean at watering every 8 days compared to other frequencies. This result suggests that watering every 8 days is not sufficient to promote the maximum spring onion growth and productivity (PW and BW). However, the presence of interaction of biochar × watering in this plant cycle required both factors in each combination to assess their effect on spring onion growth. For PH and LL, the highest mean was found at soil supplemented with biochar and watering every 4 days (Table 22 and 24). Conversely, watering every 4 days in biochar unenriched soil was found to be the least mean of the two characteristics, including PH and LL. Compared to biochar enrichment in soil, daily watering was found to be less on average for both of PH and LL than every 4 days watering. Therefore, based on the results of these characteristics, it is possible that biochar when added to the soil would absorb excess water that could negatively affect spring onion growth. However, daily watering is likely to have a significant negative impact on spring onions growth, so even adding biochar may not mitigate much. Therefore, the mean at daily watering did not differ between supplementation and non-supplementation biochar in these growth characteristics (PH and LL). For moderate watering at four days, adding biochar could promote both moisture retention as well as to release the nutrients from the biochar, resulting in to increase in PH and LL in spring onion plants. However, for PH, watering at every 4 days may not be sufficient to meet the needs of spring onion plants as well. The observation was that in soil without enrichment and watering at every 4 days (15.96 cm), PH was lower than that of daily watering (18.24 cm) at week 2 (Table 22). Likewise, there is no argument that watering every 8 days is unlikely to suffice the needs of spring onion plants as well. Adding biochar will partially mitigate the effect, therefore, the mean of plant height at watering every 8 days was higher with supplemented biochar (18.18 cm) compared with non-supplementation (16.41 cm) at week 2.

Spring onion plants are highly variable on water requirement caused by differences in growing conditions relate to season, location, agroclimatic. Three growth stages of spring onion are sensitive to water deficiency such as emergence, transplanting, and bulb formation, the water insufficient resulted in the small size of bulbs and multi-bulbs. However, in situations of water excess, the quality of crop yield can also be affected(Pérez Ortolá, 2015). For the onion, it was reported to have a range of water requirement ranged at 350 to 3750 m^3/fed for half to one month in irrigation period (Metwally, 2011). Water available for onions growth can promote many characteristics; both on growth–related traits (plant height, leave numbers per plant, bulb and neck sizes, and dry matter of bulb yield (Kadayifci et al., 2005); (Metwally, 2011).

At 10 tons/ha adding by weight biochar in soil showed increased in soil moisture status at field capacity (52.55%) and water holding capacity (31.59%) compared with control treatment (49.09% and 28.90%). Moreover, at 10 tons/ha (5.12 and 28,260 kg/ha), 20 tons/ha (6.00 and 31,302 kg/ha) and 30 tons/ha (7.3 and 33,198 kg/ha) biochar adding in soil by weight showed higher on both the number of plantlets per hill and yield per hectare compared with control treatment in spring onion (4.28 and 24,479 kg/ha) (Adrias & del Rosario, 2017).

Agronomic characteristics in spring onion cultivated in Crop 4

The results of spring onions grown in Crop 4 (August 20 – October 8, 2021) are presented in Table 28-33 and Figure 8. The positive impact of soil supplemented with biochar showed on growth-related characteristics of spring onions, most characteristics were significantly affected since weeks 2-7. Careful consideration revealed that the significance of biochar supplementation was clearly greater at nearly all weekly intervals (weeks 2-7) than the last two cycles of planting: Crop 2-3. In particular, BF was found to be significantly less affected by biochar supplementation in the previous planting cycles compared with other characteristics when considered weekly. However, in Crop 4, BF was significantly positively affected by adding biochar in weeks 1-4 (Table 31). Although at the harvesting stage, all characteristics, excluding BF was a non-significant difference between adding or non-adding biochar in soil (Table 33). Bulb onion is one characteristic sensitive to its genetic and environments: nutrient and propagation media, photoperiod and biotic stresses (Lee et al., 2013):(Khosa et al., 2018). Onion productivity has many parameters; bulb size is one as plays key role for productivity (Ikeda et al., 2020).

For onions, the production can sow to harvest in many seasons. However, the time appropriate for sowing has been studied in many climates and environments (Caruso et al., 2014);(Ikeda et al., 2019). Bulb start development and development were reported induced by critical day-length and depended on temperature and its genetics as well (Ikeda et al., 2020). In Japan, bulb size or diameter is one criterion for sale (≥ 5 cm) (Ikeda et al., 2020). Could observation that when bulb development starts, leaf blade development will be stopped (Brewster, 1982). Thus, a close relationship between the number of leaf blades and the size of the bulb in the harvesting stage (Ikeda et al., 2019). However, bulb size was found affected by day length and temperature (Ikeda et al., 2019), bulb development, and final onion productivity are varying among Crop 1-4. (Ikeda et al., 2020) reported that bulb growth was promoted greater at long day-lengths, however, at longer or shorter than the critical day-length and short day-lengths showed this trait was limited.

The influence of watering was evident that daily watering had the highest effect on water available and use for spring onions growth in Crop 4, followed by watering every 4 days and every 8 days, respectively; presented in all characteristics (Table 28-33). However, interaction of biochar × watering was observed on some characteristics in some weeks including LN (Table 29), LL (Table 30), and PC (Table 32). Biochar supplementation affects when high amounts of water are required, which is given daily. The results of the study found that adding biochar gave different characteristics higher than without biochar. Therefore, excess water that affects growth can be alleviated by adding biochar for water absorption in soil. Biochar supplementation also had a positive effect on characteristics in situations when mild water deficiency and high water deficiency at watering every 4 days and every 8 days. That is probably a result to maintain soil moisture in the presence of biochar in soil. Moreover, it was found that every 8 days watering and added biochar in soil showed mean characteristics, LN, LL, and PC, similar to that of every 4 days watering in non-biochar soil. This reflects the ability to maintain the moisture content of biochar in conditions of dehydration in planting.

The changes in the growth-related characteristics of the spring onion were compared from the four planting cycles (Crop 1 to Crop 4)

Growth-rate and yield characteristics of spring onions continuously planted in the same soil in pots for four cycles of planting are shown in Figures 9-15. However, outdoor planting is done only in the first round of planting. Growing plants in hot climates in confined spaces such as pots affect soil moisture and the plant's ability to absorb nutrients for growth. Planting under high temperatures, plants lose water via many physiological responses such as transpiration and evaporation (Chadha et al., 2019). This reason could induce water deficit in plants and maybe explained the impact on the number of characteristics in spring onion was lower mean values in the first cycle of planting, including LN, LL, LRL, and BF (Figures 9-11 and 13).

Nevertheless, there are two reasons why spring onions grown in biochar enriched soil and watered daily in the first planting cycle had fewer leave numbers than other treatments. The first is that the daily dose of watering may exceed the plant's needs and reduce the amount of air in the spaces between soil particles (soil porosity), affected to plants growth. However, according to flooding-sensitive plants, they are severe affect from less soil aeration and showed negative plant growth (Wright et al., 2017). The second is the fact that biochar has the ability to absorb nutrients in the soil through its porosity. In addition, it is not readily released in the early stages of biochar adding, due to the character of biochar as a slow-release nutrient, slow-release fertilizer, and controlled-release fertilizer (Marcińczyk & Oleszczuk, 2022). Thus, the benefit of fertilizer added to soil in the first cycle of planting maybe not be readily used within this planting cycle.

An event that supports the idea of a slow-release nutrient as is the benefit of biochar supplementation is that relatively low mean values of LN, LL, LRL, and BF were found between treatments both enriched and non-enriched soil treatments in Crop 1. Meanwhile, different mean values on LN were found in different treatments in the subsequent planting cycles, Crop 2-4. Spring onions grown in biochar enriched soil were relatively higher mean values than those that were untreated biochar. Mean values were found to be lower than other treatments in soils with the lowest water frequency: every three days in Crop 2 and every eight days in Crop 3 and 4, both enriched and non-enriched soil with biochar. These demonstrate the importance of moisture as a primary factor to promote plant growth (Gontia & Tiwari, 2010). Tezera (2022) reported in onions that the critical stress level of moisture stress in the soil since at 75% (329.1 mm) of a full supplied irrigation at crop water requirement (ETc) (422.1 mm)]. Water stress could be affected yield components and onion bulb yield. Comparing the effect of moisture stress between growth parameters on onions, the most sensitive parameter was leaf height (decrease at 90% ETc, 384.9 mm) and followed by leaf number per plant (decrease at 80% ETc, 347.4 mm) and plant height (decrease at 75% ETc, 329.1 mm), respectively (Tezara, 2022). However, all important yield components and yield, including total bulb yield (t/ha) (9.71% reduction), bulb diameter (7.53% reduction), and average bulb weight (g/bulb) (11.40% reduction) was a significant reduction in mean values since at 80% ETc (347.4 mm). At 40% ETc (198.8 mm), these three characteristics including total bulb yield, bulb diameter, and average bulb weight were decreased in means values compared with at 100% ETc treatment as 51.27%, 40.45%, and 71.26%, respectively (Tezara, 2022).

However, biochar supplementation also had a beneficial effect on plants under these lowest watering frequencies. The combination between water management and the use of biochar in the soil began to show results from the second planting cycle onwards. The differences were seen due to the interaction of the two factors: biochar × watering.

As for RL, it is an expression that is different from the other growth characteristics of the spring onions. There was quite a noticeable difference in RL between treatments since the first planting cycle (Figure 12). However, the length of the root alone may not reflect the symptoms of a plant's lack of water or nutrients. This is because there are other root-related characteristics that need to be considered together in order to assess the water deficit in plants such as root density, root weight, seminal root length, lateral root length, etc. (Boudiar et al., 2020). The presence of long roots with less root density may be that the plant is deprived of water or nutrient in the soil. Therefore, increasing the root length will increase the water availability of deeper soil levels. However, the presence of the above-ground part of the plant (shoot dry weight, leaf area, leaf number, and tillering) must also be considered in relation to the underground part of the plant (root) (length, density, thickness). In the case of plants having a high growth rate presented above the soil also means having a root that is rich and growing as well. It was found that under water-deficient in barley cultivation, the root parameter was reduced less than that of the above-ground part (Boudiar et al., 2020).

The different curve tending from others: with an increasing trend in values in the third and fourth cycles of planting, is the treatment of enrichment of biochar in soils with high-frequency irrigation (Figure 12). The changes in root system architecture were reported caused by the changes in water availability in soil (Boudiar et al., 2020). This explains what happens to the RL that differs from other growth characteristics in the spring onion.

When considering only the yield characteristics, i.e. BF, PW and BW, it was found that bulb formation capacity was increased in planting cycles two to four compared to the first planting cycle (Figure 13). However, the weight of the bulbs found in each sub-plant in plot in the second to fourth planting cycles was reduced in size from the first planting cycle (Figure 14). This may be a feature of underground competition that showed the compensation of the number of bulbs and the size/weight of the bulbs.

Assessing the yield performance for all four planting cycles, BW in the first to third planting cycles was very similar in several treatments. However, BW began to decline in the fourth planting cycle (Table 15). Causes can be explained is that although fertilization, urea, in every planting cycle, successive plantings in the same soil (in pot) may cause a corresponding decrease in other soil nutrients and affect the lower yield or BW value of spring onions in finally. That is, in monoculture practice, a continuous manner required nourishing the soil with fertilizer with a variety of nutrient compositions (Suran et al., 2021). In this case, organic fertilizers or other nutrients should be applied after the third planting cycle of onion planting.

The exception was for two treatments where BW were found across four different growing cycles. It was found that without the addition of biochar and low-frequency watering, BW was significantly reduced from the second planting cycle onwards (Table 15). That shows the importance of the influence of the enriched biochar in the soil in cases where the plants receive low water availability. While in conditions where the plot receives more water than needed, such as daily water intake, may change the physical properties of soil and promote an enrichment of soil biochar helps in water retention (Marshall et al., 2019). This result makes the soil sparse and increases soil aeration (Van Zwieten et al., 2010). Moreover, biochar application results to suppress greenhouse gas emissions from sandy loam soil, i.e. nitrous oxide (N_2O) (Case et al., 2012).

In addition to biochar helping the soil can absorb water for longer, it also promotes to achieve the proper release of nutrients at different times to aid growth. As a result, the yield of onions grown in biochar enriched soil and daily watered was consistently higher in all planting cycles (Table 15). For water holding capacity, it can increase although adding biochar only 5 or 10% amendment (Case et al., 2012).

Changes of moisture content of soil (%MCS) with biochar enrichment and watering at different frequencies in Crop 4

The results of the changes in %MCS were presented each week until the harvesting stage (Tables 34-41) and three graphs depended on different stages of onions growth (Figures 16-18). Clearly, the positive influence of biochar enriched soil and watering in all weeks. However, differences in values affected by the interaction of biochar × watering vary each day in different weeks after planting. A reduction of %MCS was observed since 1 DAP in the first week. That means, a decrease of %MCS, although starting of spring onions growth, as an effect of evaporation that depended on the environment, i.e. temperature, wind speed, air relative humidity etc. (Yamanaka et al., 1997). In Crop 4, the first week of planting started on August 20th – August 27th, 2021, or the rainy season in Thailand (Table 2). However, spring onions were studied under greenhouse conditions. Thus, environmental factors such as rainfall and wind speed were not affected plant growth. Nevertheless, on the days without rainfall, the evaporation affected the %MCS resulting in decreasing these values.

Water evaporation is categorized and affected by internal and external factors. External factors affected water evaporation such as atmospheric factors: temperature, humidity, etc. Internal factors affected water evaporation including water content conditions and the covering of the soil surface (C.-S. Tang et al., 2011); (An et al., 2018). Drought conditions for planting are affected by temperature and moisture conditions as well (An et al., 2018). Moreover, the interaction of water draining is affected by the kinds of soil, and evaporation results in water loss from soil.

The difference of %MCS was found in the four-day watering group with a greater percentage of soil moisture reduction than in the daily watering group at 3 DAP (Table 34). That showed that four-day watering had a negative impact on soil moisture, resulting in lower values compared to the daily watering in the control group. The difference in watering on 4 DAP between the daily and four-day watering groups was found because soil moisture was measured in the morning before watering according to each treatment (Table 34). Moreover, starting on 4 DAP onward, the positive impact of biochar enriched soil on water retention was observed. Therefore, higher values %MCS was recorded on soil supplemented with biochar than on non-supplemented with biochar in both two watering frequencies; every 4 days and 8 days. Not surprisingly, there was no difference in watering every four days and daily watering on 5 DAP because the watering treatment was done every four days. Therefore, the influence of both biochar supplementation and watering was clearly evident on 4 DAP and 7 DAP.

This evidence was the same in the second week of spring onion planting. Both week 1 and week 2 are the beginnings of plant germination, so there may not be much influence on the water use of plants or covering of soil surface from these plants (Tables 34-35). The use of biochar in the soil was able to maintain a high level of soil moisture, although not equal to daily watering, but significantly higher than without biochar. For example, at 4 DAP, added biochar in soil and watering every 4 days and

8 days showed %MCS at 75%, and reduced values on non-added biochar in these watering frequencies at 57-60%, reduced at about 15-17% (Table 34).

The soil moisture content of 75% remained high enough to meet the needs of the spring onions in conditions with limited water for cultivation. Thus, for a watering, every 4 days in the soil with biochar, up to 6 liters of water per pot can be saved compared with watering every day. The soil in this study was sandy loam with low water holding capacity, maximum is 28.64% at the date of watering in field capacity and declining to 13.52% three days after watering in the preliminary test (Tables 6–7, Figure 4). Note: For water holding capacity of the soil, the preliminary test values (13.52%) were lower than field capacity point (28.64%) about > 2 times. The results of the study in the fourth planting cycle at four-day watering under no biochar supplementation, %MCS remained about 57-60% out of 95% at watering every day, not over 2 times. This may be due to the fact that in a preliminary soil moisture test carried out, placing the pots outside the greenhouse in the summer causes a sharp drop in water holding capacity. Together with the results of three planting cycles in Crop 1–3 that may affect the physical structure of the soil as well.

Therefore, the moisture retention of up to 75% when no watering for four days was a property of the enriched biochar in the soil. Taking into account the water holding capacity of the biochar tested, it was found that it was able to hold about 3.02 times its weight with a percentage of water retention capacity of 202.13% (by dry weight bamboo biochar) (Table 9). In this study, biochar was mixed into the soil at the ratio of 1:9 by weight.

Although there was no difference in %MCS between with– and without biochar when watering every day of all weeks of spring onion planting (Tables 34-41). Adding biochar at 20 and 30 ton/ha respectively was found to decrease the bulk density but increased the porosity, compared with the control treatment (0 ton/ha biochar) (Adrias & del Rosario, 2017). Which, increases the aeration of the soil to promote the movement of both water and air in the soil which is more beneficial for plant growth (Masulili et al., 2010);(Mukherjee & Lal, 2013); (Adrias & del Rosario, 2017). Moreover, when biochar supplementation increased in soil could be induced an increase in water holding capacity, field capacity, saturation point, and permanent wilting point (Liu, 2011); (Adrias & del Rosario, 2017). At 10% biochar, (by weight) supplementation in soil showed an increased permanent wilting point of about 2 – 8% (Liu, 2011); (Adrias & del Rosario, 2017). (Adrias & del Rosario, 2017) reported that added biochar at 30 tons/ha (7.3 plantlets) resulted increasing of plantlets per hill more than the control treatment (0 ton/ha) (4.275 plantlets) by about 70.76%.

In weeks 3 – 8 (Tables 36–41), the stage of growth and harvesting in spring onions, the results of biochar supplementation in soil, and frequencies of watering were similar to in weeks 1–2. Clearly positive effect of biochar enriched in soil presented higher values of %MCS in those weeks. For watering, the last date before watering every 4 days showed lower %MCS compared with watering every day. However, the values in every 4 days of watering in weeks 3–8 (65–69%) were found lower %MCS than that found in weeks 1–2. This evidence may relate to the stage of growth in spring onions. In the higher growth stage in weeks 3–8, adult plants need more water for growth and development than a seedling. Thus, every 4 days of watering affected decreased water available in the adult plants in later weeks more than seedlings in early weeks. However, in the case of added biochar with watering every 4 days at weeks 3–8, %MCS still contain at 71–76%. While at non-added biochar in soil with watering every 4 days showed %MCS between 58–65%. For these reasons, drought conditions by scrip watering three days or watering every 4 days tend to severe effect to spring onion growth at adult plants during weeks 3–8. For spring onions,

The effect of three–day cycle dehydration or 4 days of irrigation at different stages of growth in spring onions could be observed from the line graphs (Figures 16–17). There is a graph spacing between 4 and 8 days of irrigation from 1 DAP – to 32 DAP (Figures 16-17). As when the plant gets older, the distance between the two line graphs decreases (Figure 18), reflecting greater water consumption in mature plants than seedlings for biomass accumulation. Although, at seedlings stage is more vulnerable for drought stress than mature plants (Lee et al., 2018). However, it is not about water use efficiency (WUE) of the plant in each growth stage because WUE calculated from the ratio of biomass accumulation per unit water consumption (Vadez et al., 2014);(Brendel, 2021). There was study about the relationship between dry matter accumulation and transpiration in plants. Both these traits are important in plants and showed the complex interaction, these traits are related to water consumption as well (Brendel, 2021). For onions, it required moisture in soil continually, 12 inches' top of soil, thus, frequent irrigations need for this plant species (Roy et al., 2014). Moreover, water stress is dominant observed in stage of bulb sprouting and beginnings of the anthesis (Borgo et al., 1993). However, dried soil surface in sometimes is required for planting the onions to avoid infection from damping off or root rot diseases (Roy et al., 2014).

Therefore, it is important to adjust the frequency of watering the spring onions at different ages of plants. It was noted, however, that the 4 days of irrigation in the biochar enriched soil retained an extremely high moisture content in the soil. This evidence can indicate the benefits of biochar enrichment, especially its ability to retain soil moisture in low water availability.

(Adrias & del Rosario, 2017) reported the permanent wilting point (PWP) of about 20.192% soil moisture content in soil without biochar, and an increase in soil supplemented with biochar 10 –20 tons/ha about 20.962 – 22.029%. This study, at 8 days of watering at biochar enriched soil from weeks 1 to weeks 8 showed that %MCS (14 – 19%) was lower than that reported by (Adrias & del Rosario, 2017) at PWP (20.192 – 22.029%) (Tables 34 – 41). Therefore, there is a risk of reduced growth and yield if water is stopped for 7 days (watering every 8 days).

Soil and bamboo biochar chemical and physical properties after planting in Crop 4

Soil chemical and physical properties

Cation exchange capacity (CEC, cmol/kg)

Cation is very important for uptake in plant for support plant growth and development. The relative ability of soils to store the cations (positively-charged ions) call as cation exchange capacity (CEC). For examples of cations in soil such as calcium (Ca^{2+}), potassium (K^{+}), ammonium (NH_4^{+}), magnesium (Mg^{2+}), sodium (Na^{+}) and hydrogen (H^{+}). for clay and organic matters particles have a net negative charge, cations can hold by these particles. Result of holding between cations and clay and organic matter particles is the replacement of other cations that call exchangeable. Therefore, the cations in this group have the ability to be interchangeable within the group. Higher CEC mean the higher the negative charge or cations can be held on the clay and organic matter as it is capacity of cation exchange in soil. However, CEC in soil base on the amount of clay and organic matter. For this reason, CEC can be estimated from both color and texture of soil as well (Mengel).

In this study, CEC values in biochar and without biochar in soil were 6.95 and 7.48 cmol/kg
(cmol/kg = centimole per kilogram equal meq/100g = milliequivalents per 100 grams) (Table 42). At range between 5.0 to 10.0 cmol/kg, CEC is categorized at quite low level. Moreover, between 3-15 cmol/kg, clay type in this soil sample as Kaolinite, and soil texture as Fine Sandy Loam (range between 5-10 cmol/kg) (Sonon et al., 2014). For CEC values between 6-12 cmol/kg, soils are predominating upland and well-drained red soil. However, it has higher in potassium and low phosphorus than Coastal Plain soil, and soil is acid. Higher cations mean higher source for supply plant roots or can lost by leaching. However, cations can be detected in acid-forming (acidic) or basic (calcium, magnesium, potassium and sodium) by calculation of percent base saturation (%BS) (Mengel). For %BS, higher value was found at biochar enriched soil at 287.70 more than biochar unenriched soil at 239.86 (see note) (Table 42-43). Or to said that, in soil supplemented with biochar had the relation proportion of bases for exchangeable capacity more than soil not supplemented with biochar.

Note: ppm to cmol/kg (meq/100g soil) = [ppm of cation/ ((atomic mass of cation x 10)/ charge of cation)], for the atomic mass of cation such as Ca^{2+} = 40, Mg^{2+} = 24, K^{+} = 39
K^{+} (add biochar) = 296.5 mg/kg or ppm/ ((39 × 10)/1) = 0.76 cmol/kg
K^{+} (without biochar) = 188.5 mg/kg or ppm/((39 × 10)/1) = 0.48 cmol/kg
%BS = [(Ca^{2+} + Mg^{2+} + K^{+})/CEC x 100
%BS (add biochar) = [((13.44+2.47+0.76) cmol/kg /6.95 cmol/kg) × 100] = 239.86
%BS (without biochar) = [((18.54+2.50+0.48) cmol/kg /7.48 cmol/kg) × 100] = 287.70

Although there were no significant differences in CEC between biochar and without biochar supplemented in soil, significantly affected were observed caused by watering frequency. Higher CEC was found at watering every day and followed by watering every four and eight days, respectively (Table 42). Thus, the water available can be promoted the changeable capacity of the cation. However, both are lost by leaching and can be uptake by plants can happen in case of higher CEC in soil. In the case without supplementation biochar in soil with watering every day showed higher CEC (Table 42). Therefore, cation nutrients are highly usable, but there is also a high chance of loss due to leaching. Evaluating BW of the spring onion plants in soil not supplemented with biochar with watering every day, it was found lowest BW (Table 33 and Figure 15), meaning low utilization of these nutrient elements and a high chance of loss due to lack of adsorption by biochar in soil. More than loss of nutrient by leaching, nutrients can transform and lost by solubilized and moved runoff water, and escaped into the atmosphere.

Available phosphorus (P)

Available phosphorus (P) is useful for plant uptake in form as the orthophosphate ion ($H_2PO_4^-$ and HPO_4^{2-}). However, these ions can react easily with other compounds: iron, calcium, aluminum, and organic matter, result to less available form to uptake by plant. In case pH less than 7.0, prenominate form of phosphorus in soil as $H_2PO_4^-$. More than orthophosphate form that can uptake by plants, organic phosphorus form as one source that plant can uptake from soil. However, low phosphorus concentration is quite lower that other elements, range from 0.001 to 1 mg/L (Brady, 2002). For orthodphosphate ion in soil is reported in very low concentration as well, as less than 0.05 mg/L. In this study, available P in soil was 450 and 469.5 mg/kg at biochar and without biochar enriched soil, respectively: determination method is total acid extractable (Table 42). However, there was no statistically significant difference in available phosphorus between supplementation and non-supplementation biochar in the soil. For bamboo biochar used in this study was lower an exchangeable phosphorus (0.30 %), may is reason on not increased exchangeable phosphorus in soil supplemented with biochar (Table 8). Similar to the study by (Glaser & Lehr, 2019) that P available was not significantly affected by supplemented biochar in alkaline soil at pH >7.5. In this study, pH in soil supplemented and non–supplemented biochar were 7.27 and 7.84, however, these values were a significant difference (Table 44). For biochar, a carbon-rich solid product, it was reported play a role to slow-release P fertilizer (Wang et al., 2012); (Zhao et al., 2016);(Glaser & Lehr, 2019). (Glaser & Lehr, 2019) presented that P enrichment in the soil is achieved in biochar was pyrolysis both low temperatures (450°C) and mid-temperature (450-600°C), and there were significant differences in these temperatures. In this study, bamboo biochar was pyrolysis at a low temperature (450°C) (Glaser & Lehr, 2019). However, wood-derived biochar was no effect on P availability in soil, depended on kinds of wood or available P in these material. Moreover, at high application of biochar or above 10 tons/ha showed increase P availability. Nevertheless, at excess biochar above 60 tons/ha resulted negative effect and decrease plant growth. (Glaser & Lehr, 2019).

Note: ppm to cmol/kg (meq/100g soil) = [ppm of cation/ ((atomic mass of cation x 10)/ charge of cation)], for the atomic mass of cation such as P^- = 31

K^+ (add biochar) = 296.5 mg/kg or ppm/ ((39 × 10)/1) = 0.76 cmol/kg
K^+ (without biochar) = 188.5 mg/kg or ppm/((39 × 10)/1) = 0.48 cmol/kg

Available potassium

Potassium (K) is one of the macronutrients because it plays an essential nutrient to plant growth throughout the plant life cycle. The roles of K are associated with the movement of nutrients, water, and carbohydrates in plant tissues, and react with many enzymes within the plant (www.extension.umn.edu). Moreover, K has a role to regulate the activity of stomata, opening and closing stomata, and promoting root growth to improve the resistance of plants to drought stress (www.extension.umn.edu). For exchangeable (available) K+ is one in three forms the adsorbed onto the soil CEC observed in soil. Which, the other two forms included fixed by certain minerals from makes very slowly released in soil and available for use, and unavailable mineral forms (www.extension.psu.edu). For the mobility compared with N and P, K moves into the soil is quick than P, but less than N. For K, it was reported the optimum level is about 2-3.3% of CEC (www.extension.psu.edu). In this study, the overall means of CEC was 7.22 cmol/kg, and K content was 242.5 mg/kg or about 8.59% of CEC (Table 42).

Unlike N and P, K is not associated with organic matter. About 0.3 to >2.5 percent of K was found in soil. However, about in forms of relatively unavailable K and slowly available K (non-exchangeable K) was found around 90-98% and 1-10% of total K, respectively. For readily available K, it was reported about 1-2% of total K in soil (www.passel2.unl.edu). Readily available K forms, it is summarized between K in the soil solution and in the form of exchangeable K. Both these forms are available to plant uptake, however, K in the soil solution phase is more uptake by plants than in exchangeable K form: absorbed on colloid surfaces of soil (www.passel2.unl.edu).

In this study, non-significant difference both between added and non-added biochar, and between watering frequencies and interaction between biochar × watering (Table 42). Although higher available potassium was detected in biochar properties (1.10 %) more than other essential elements (Table 8). However, these results from this study, it determined only from soil not included biochar substance and only for available K, excluded fixed K. Nevertheless, soil moisture was reported affected to increase of K mobility which relate K available in soil, resulted to promote plant growth tested in plant onion (Kuchenbuch et al., 1986).

Note: ppm to cmol/kg (meq/100g soil) = [ppm of cation/ ((atomic mass of cation x 10)/ charge of cation)], for the atomic mass of cation such as Ca^{2+} = 40, Mg^{2+} = 24, K^+ = 39
K^+ = 242.5 mg/kg or ppm/ ((39 × 10)/1) = 0.62 cmol/kg

Exchangeable calcium

In this study, higher exchangeable calcium (Ca^{2+}) was found in soil with non-added biochar (18.54 cmol/kg) than added biochar (13.44 cmol/kg) (Table 43). For bamboo biochar used in this study was lower an exchangeable calcium (0.53 %), may is reason on not increased exchangeable calcium in soil supplemented with biochar (Table 8). Decease exchangeable Ca^{2+} may be influenced by increasing plant uptake of this nutrient. Calcium (Ca) is an important element in the soil as a secondary element to plant growth and development. However, in soil, abundant Ca is formed with other secondary minerals and forms be calcium carbonate that has the roles of soil particle and organic matter. Exchangeable Ca^{2+} (a form of Ca attached to the cation exchange complex on soil particles) and soluble Ca (the free Ca salt in soil solution) are important forms to plants and soil organisms (www. https://www.fertilesoilsolutions.com/ agricultural-news/soluble-vs-exchangeable-calcium/).

Although Ca is adsorbed with low energy to negative electrical charge, this element is usually found in low content compared with others in soil (Li et al., 2017); (Gatiboni et al., 2020). Moreover, in short-run, Ca can be formed in precipitation resulted the decreasing to release nutrient in soil solution and affected to plant nutrient (Melo et al., 2000);(Gatiboni et al., 2020). Nevertheless, in slightly acidic and neutral soil, about 70% (or more) of sites on the cation exchange complex of soil were occupied by Ca. Which, the quantity of Ca was observed in four categories: first, adsorbed into clay particles and react with humus in cation exchange complex; second, complex with humus; third, in primary mineral structure (structural Ca); fourth, secondary minerals (www.terragis.bees.unsw.edu.au).

Soil supplemented with lime in soil acidification showed an affected to K uptake by plants through increased exchangeable Ca^{2+} and decreased exchangeable Al^{3+} (aluminum) (Moore et al., 2008); (Schneider et al., 2016); (Han et al., 2019). However, excess Ca^{2+} concentration in soil may be affected to inhibit plant's ability to uptake K (Otieno & Zingore, 2018).

Exchangeable magnesium

There was lower quantity of exchangeable magnesium (Mg^{2+}) (2.48 cmol/kg) than exchangeable Ca^{2+} (15.99 cmol/kg) (Table 43). This result is explained by Mg ion is not tightly adsorbed by clay particles and other organic colloids relative to Ca. In addition, Mg in many materials was found in lower amounts than Ca. For plant growth, Mg is needed in less amount than Ca, however, Mg is an element that has a role in plant synthesis produced oils, protein and carbohydrate (www.terragis.bees.unsw.edu.au; (Nèjia, 2016). In this study the amount of exchangeable Mg^{2+} lower than exchangeable Ca^{2+} in soil about 6.45 times (Table 43).

Situation showed higher uptake Mg by plants when pH is increased and optimum about pH 5.5 (www.terragis.bees.unsw.edu.au). However, in acidic soil, Mg lacking could occur in low exchangeable Mg. Thus, Mg fertilizer, both types, and amounts have been studied for crop yield and quality improvements (Kashinath et al., 2013);(Wang et al., 2020). Moreover, many factors influenced the availability of Mg in crop production such as climate, agricultural practice, rainfall, crop species, soil texture, and cation exchangeable capacity (Scheffer, 2002); (Hariadi & Shabala, 2004);(Mikkelsen, 2010);(Wang et al., 2020). However, the loss amount of Mg is caused by the degree of mobilization and leaching in soil (Schachtschabel, 1954); (Wang et al., 2020). In this study, pH was neutral at 7.56 (Table 44). While, pH at the acidity of the soil is related to lacking many elements including K, Ca, Mg, P, zine (Zn), and occurred the toxicity of some elements such as Al and manganese (Mn) (Wang et al., 2020). For biochar, in this study, exchangeable Mg was a non-significant difference affected by added or non-added in soil. Similarly, the watering frequencies and interaction of biochar × watering were not significantly affected on exchangeable Mg (Table 43). For bamboo biochar used in this study was lower an exchangeable magnesium (0.28 %), may is reason on not increased exchangeable magnesium in soil supplemented with biochar (Table 3).

Exchangeable sodium

In this study, exchangeable sodium (Na^+) was not significantly affected by added biochar and interaction of biochar × watering. However, it was significantly affected by watering, higher values were observed at watering every four (0.38 cmol/kg) and eight days (0.46 cmol/kg), and lowest at watering every day (0.23 cmol/kg) (Table 43). Exchangeable sodium value is used to evaluate the soil characterization into saline and alkali or not. Exchangeable sodium identifies the amount of cation exchange sites occupied by sodium (https://www.agric.wa.gov.au/ dispersive-and-sodic-soils/identifying-dispersive-sodic-soils). The result showed ESP (see note) was less than 6% at about 4.96% so it was rating in non-sodic soil (Sumner, 1993);(Rengasamy & Churchman, 1999);(Quirk, 2001). Sodic soils is impact to plant growth especially in sensitive plant results from the toxicity and loss of nutrient inside the plants (www.extension.colostate.edu/docs/pubs/ crops/00504.pdf). Daily watering of plants can result in reduced sodium accumulation or reduced soil salinity.

Note: $SAR = {Na^+}/{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$

SAR = Sodium adsorption ratio (cmol/kg); Na^+, Ca^{2+}, Mg^{2+} = measured exchangeable Na^+, Ca^{2+} and Mg^{2+}, respectively (cmol/kg) (Seilsepour et al., 2009)

In this study, SAR (overall mean) = $0.358/\sqrt{(15.99 + 2.48)/2}$ =

0.358/3.0389=0.1178

$ESP = \left({Na^+}/{CEC}\right) x\ 100$

ESP = Exchangeable sodium percentage (%); Na+ = measured exchangeable Na+ (cmol/kg); CEC =cation exchange capacity (cmol/kg)

In this study, ESP (overall mean) = (0.358 / 7.22) x 100 = 0.0496x100 = 4.96%

Moreover, reported expectation for ESP, ESP = 1.95 + 1.03 SAR

Expected for ESP = 1.95 + 1.03(0.1178) = 2.07

Organic matter

There was no statistical difference in the organic matter percentage between plants grown in soil supplemented or non-supplemented with biochar at 1.18-1.29 %. Likely, there was no statistical difference in organic matter percentage affected by watering frequencies and interaction of biochar × watering (Table 44). Although in bamboo biochar properties, organic matter was a higher percentage in biochar at 17.41% (Table 8). In this experiment, only inorganic fertilizers were applied. Organic fertilizer is obtained only from the decomposition of biochar. However, from SEM determination and from soil nutrients after planting in the fourth round of spring onion, it is possible that biochar has not yet fully decomposed. The reason was that the retaining properties of the water were retained in this fourth cycle of planting. Moreover, from SEM determination, the biochar retained its shape, although the porosity of the biochar at the wall began to increase. Bamboo biochar is one of material was reported to enhance soil fertility, organic matter and promote the accumulation of potassium. Moreover, bamboo biochar was found the potential of phytoremediation in plant growth in soil affected by heavy metal such as cadmium (Cd) and zinc (Zn) (Li et al., 2021). (Schnee et al., 2021) reported about biochar supplementation can improve soil organic matter by accumulation of carbon (C). Moreover, biochar was reported to increase organic matter because it can adsorb soil organic molecules. Moreover, biochar can polymer these organic molecules from organic matter through its catalytic activity at the surface (Liang et al., 2010);(Van Zwieten et al., 2010);(Zhang et al., 2019). In this study, there was not complete decomposition of biochar at third cycle of planting in greenhouse (4^{th} planting). Which, slow decomposition of biochar resulted to enhancing the development of humus and supports soil fertility (Kimetu & Lehmann, 2010);(Zhang et al., 2019).

Potential of Hydrogen ion (pH)

There was significant difference in soil pH affected by adding bamboo biochar, lower value was found at soil amendment with biochar (Table 44). However, there were no statistical difference in soil pH affected by watering frequencies and interaction of biochar × watering (Table 44). Biochar was found an effect on both increased and decreased soil pH in different soil types; increased soil pH in acidic soils (yellow-brown soil and fluvo-aquic soil) and reduced in the black soil (Zhang et al., 2019). The reason for unidirectional changes in pH in different soil types was explained as related to pH background in biochar and soil; soil that has higher pH background than biochar may not affect or able to decrease the pH (Zhang et al., 2019). In this study, bamboo biochar and soil pH were 7.31 and 7.7, respectively (Tables 6 and 8). Thus, the higher background pH on soil than on biochar may result in to decreasing in pH value in the soil finally.

Electrical conductivity

There was a significant difference in soil electrical conductivity (EC) affected by individual factors including bamboo biochar and watering, and the interaction of biochar × watering (Table 44). Higher EC was found at soil supplemented with biochar at 0.96 dS/m more than non-supplemented with biochar (0.68 dS/m). Soil EC significantly increases in soil supplemented with biochar and varied depending on the amount of biochar supplementation (Shah, 2017). Since adding biochar at ≥ 5 ton/ha promoted soil EC compared with control at non-supplementation. However, biochar properties that depend on the process to produce biochar were reported as one criterion of the effect on soil EC (Shah, 2017). Soil EC is soil properties to determine the number of salts because EC relates to the concentration of many soil elements including K, Na, Cl, sulfate, nitrates, and ammonia (https://www.nrcs.usda.gov/ Internet/FSE_DOCUMENTS /nrcs142p2_052803.pdf). Which, the amount of salt results from many factors such as cropping, land management, and irrigation. In the soil of rice, planting received dry and wet conditions, although in the short-run, showed a decrease in EC compared with flooding soil (Khairi, 2015).

Bamboo biochar chemical and physical properties

Values of N, OM, C/N ratio and EC, the biochar treatments that were mixed in the soil that were watered daily were lowest values. The highest values on those characters were biochar in soil received the watering every 8 days and followed by the watering every 4 days. For P, the highest value was found in biochar that mixed in soil that was watering every 8 days. However, similar value of P in biochar mixed in soil that was watering every day and every 4 days.

C/N ratio of biochar at watering every 8 days (21.00) showed about two times more than biochar at watering every day (11.50) (Table 45). This result means mass of carbon to mass of nitrogen is still large value in biochar was irrigated every 8 days. That means the lower decomposition of biochar received lower frequency of watering at every 8 days compared with others. Low or high C/N ratio reflect both the water retention ability of biochar and the benefit from nutrient cycling came from residue material that produced biochar (predominantly nitrogen). At high C/N ratio found at biochar at watering every 8 days reflects the incompletely compost of this biochar. Truly, although biochar has the benefit can improve soil chemical properties, these benefits still low because high carbon content in biochar. Moreover, at high C/N ratio of biochar, there are not suitable for microbial availability (Phillips et al., 2022). For C/N ratio in biochar, it can have wide range depend on material to produce biochar. (Bonanomi et al., 2017) reported ratio ranging of C/N in biochar from 6.5 to 640. Although the C/N ratio is value dependent on residue material quality (Manzoni, 2017), between 20 to 32 and over 32 of C/N ratio reduced microbial mobilization of N in soil (Nguyen et al., 2017). Thus, in treatment of watering every 8 days showed C/N ratio at 21 resulted to support microbial immobilization of N in soil. It could say that after four rounds of soil mixed with biochar and used for planting spring onions, the benefit in case to support microbial N demand still is limited at watering every 8 days.

However, at low C/N ratio may mean decay of the biochar briquette and alter biomass carbon in long-lived forms (Baldocka & Smernikb, 2002); (Woolf et al., 2010). This event results to reduce impacts soil microbial function and increases nitrogen availability by plants (Liu et al., 2018); (Gao et al., 2019). For biochar application to amend into the soil, it affected to changing nutrient cycling (Mia et al., 2017). Which, N cycling associated with increasing in microbial abundance (microbial N demand) that is an advantage to plants growth (Zheng et al., 2012); (Ducey et al., 2013).

Moreover, biochar can alter soil pH by increasing the value (Clough & Condron, 2010). Nevertheless, samples were used for chemical analysis was biochar. That why higher value both on N, P, OM and EC were identified in groups of watering at four days and eight days; more than at watering every day (Table 45). High amount of N and C/N ratio in biochar may mean N retention during the process of biochar production that as plant-non available N (Gao et al., 2019). In soil analysis, watering every day showed lower EC (0.53 and 0.81 dS/m) more than watering every 8 days (1.13 dS/m) (Table 44). Moreover, in soil at watering every day showed lowest exchangeable sodium (0.23 cmol/kg) more than watering every four days (0.38 cmol/kg) and every eight days (0.46 cmol/kg) (Table 43). The reason for this explanation may be that the degradation of biochar also affects the soil ability to absorb nutrients in part. Or it could mean that plants can use those elements or elements be washed away after watering as well.

Scanning Electron Microscope (SEM) study for bamboo biochar properties

During the pyrolysis process; temperature, heating time, types of raw material or feedstock, atmosphere, developed micropores in large microscopic surface area of biochar. These micropores respond to water retention and nutrient absorption that induce positive effect on soil fertility improvement (Thies, 2009); (Hernandez-Mena et al., 2014). In this study, the pyrolysis temperature was 450 $^\circ$C. At lower temperature resulted in the large quantity of biochar production, and the pore structure as one of biochar properties was developed by the complete thermal decomposition of cellulose and hemicelluloses at around 500°C (Lee et al., 2013); (Hernandez-Mena et al., 2014). (Lee et al., 2013) reported about the properties of bamboo biochar composed of high carbon content could be used for absorption of the pollutants in soil and for use as energy. Pores sizes measured in bamboo biochar (control treatment or not added in soil) in cross-section were 10.13–18.41 µm, however, many pores were smaller presented in Figure 16B. Nevertheless, longitudinal pores size in bamboo biochar was measured reach to 200 µm. That large pores originated from the vascular bundles of bamboo, this property of this raw material provides habitats for symbiotic microorganisms (Thies, 2009). Pores sizes in diameter in this bamboo biochar more than 50 nm, thus these pores were classified into macrospores; microspores are more than 2 nm, mesopores are between 2–50 nm, and macropores are more than 50 nm in diameter (Parthasarathy et al., 2021).

The effect of biochar on water retention can be of short or long duration, one factor is related to the internal area and residual pores of biochar. Large areas occurred in biochar resulted in the capillarity of water can increase the porosity and water content in soil or increase the water retention capacity of the soil (Batista et al., 2018). Thus, characterization of biochar is necessary before starting to improve the soil by using the capacity of water retention of biochar. Scanning electron microscopy (SEM) is one method to characterize the biochar. The surface morphologies including pore diameter sizes and channels in biochar were varied and highly heterogeneous according to the different biochar materials (Dehkhoda et al., 2010); (Batista et al., 2018). In this study, bamboo biochar was approximately 10–18 µm which is close to pore sizes, approximately 10 µm of charcoal fines and coconut shells biochar, but wider than biochar produced from oil palm bunch and sugarcane bagasse at about 6 µm (Batista et al., 2018). For bamboo biochar has a smooth inner surface when examined under SEM (Figures 19-23). The surface morphology and other physical properties of biochar relate to material types and the pyrolysis process. However, inside the pores were found corrosion and filling with ash in a porous system. The collapse within bamboo biochar pores seen in SEM images between watering frequency treatments is difficult to compare in SEM examination. Filled the residual pores with inorganic material may result in a low surface area was effect to the water retention capacity (Batista et al., 2018). Nevertheless, not only factors of pore water relate to mineral leaching in soil because other factors are influenced also by organic matter and microorganisms (Batista et al., 2018).

The most notable thing is that the inner surface porosity of biochar increases when it is mixed with soil and actually planted. The presence of high levels of porosity in surface in the biochar treatment; which is mixed in the soil and is watered with daily frequency (Figure 20) more than control (Figure 19) and watering every 4 and 8 days (Figures 21-22), perhaps in part related to water retention or nutrient release. These observations must be taken into account in conjunction with plant growth data in all crop planting and soil nutrients. At lower temperatures for pyrolysis (300 and 450 °C), it was reported about the specific surface area was generally low. However, the specific area of biochar was gradually increased when the time for pyrolysis is longer (Batista et al., 2018).

Bamboo biomass is reported to consist of over 50 percent of cellulose and the remainder were hemicellulose, lignin and extractives (Sahoo et al., 2021). For ultimate analysis of bamboo biomass is consist mainly with C (46.98% wt.) and O (46.65% wt.), followed by H (6.21% wt.) and N (0.16% wt.), and H/C and O/C were 0.13 and 0.99, respectively (Sahoo et al., 2021). The chemical characteristics have a remarkable influence biochar morphology (Sahoo et al., 2021). The bulk density of bamboo biomass was around 317 kg/m^3 and was acid in pH of about 5.23 for bamboo biomass as reported by (Sahoo et al., 2021). (Sahoo et al., 2021) reported mean pore diameter in bamboo biochar was between 2.37-3.64 nm.

Small pore size was higher amount at watering every day on biochar inside surface compared to other watering frequencies.

CONCLUSION

Growth-related characteristics and yield in spring onion cultivated in Crop 1 to Crop 4

Comparing between moisture content percentages, higher capacity for water holding was observed in bamboo biochar (202.13% moisture content), temperature of pyrolysis at 450 °C, more than soil (28.64% soil moisture content) about 7 times. Biochar's characteristics such as shape, particle size and the structure are the key factors that play the roles to storage water, and results to increase the water retention in soil.

Agronomic characteristics in spring onion cultivated in Crop 1

In the first cropping, treatments of soil amended with biochar caused a significant reduction in all characteristics, excluding BF.

Slow-release of nutrient in soil amended with biochar until the late crop generations is the main key to promote productivity in spring onions and is not always consistent caused by many factors such as soil properties, plant species and biochar properties. Moreover, the frequencies of watering: every day, every two days, and every three days, could not assess the benefit of supplementation of biochar in soil, especially in rainy season.

Agronomic characteristics in spring onion cultivated in Crop 2

The benefit of supplementation the soil with biochar was start in Crop 2 (continued used the soil from the previous experiments in Crop 1) that was observed in many characteristics. These results caused by changes in both the structure and the properties of biochar or more complete biochar digestion, thus its affecting nutrient availability in the soil.

Positive results in the addition of biochar observed in the second planting cycle may be due to the slow nutrient release of the bamboo biochar (later than 49 days or seven weeks of the spring onion planting life).

Agronomic characteristics in spring onion cultivated in Crop 3

The soil and biochar used in each treatment in pots in Crop 2 continued to be planted in Crop 3. However, the experiment was conducted in greenhouse condition and adjusted the watering frequency as every day, every 4 days, and every 8 days. The positive role of biochar amendment was observed to promote spring onions' growth characteristics and yield (PW and BW) in Crop 3. The predominance of plants grown in biochar enriched soil is likely due to its water retention and nutrient release properties. The extension of the watering time as it was grown in greenhouse conditions in Crop 3 showed different mean values on plant growth parameters affected by the watering frequency distinct from the two experiments conducted outdoors. This result suggests that watering every 8 days is not sufficient to promote the maximum spring onion growth and productivity (PW and BW). However, the presence of interaction of biochar × watering in this plant cycle required both factors in each combination to assess their effect on spring onion growth. Conversely, watering every 4 days in biochar unenriched soil was found to be the least mean of the two characteristics, including PH and LL. it is possible that biochar when added to the soil would absorb excess water that could negatively affect spring onion growth. However, daily watering is likely to have a significant negative impact on spring onions growth, so even adding biochar may not mitigate much. Therefore, the mean at daily watering did not differ between supplementation and non-supplementation of biochar in these growth characteristics (PH and LL). For moderate watering at four days, adding biochar could promote both moisture retention as well as to release the nutrients from the biochar, resulting in to increase in PH and LL in spring onion plants. Adding biochar will partially mitigate the effect, therefore, the mean of plant height at watering every 8 days was higher with supplemented biochar (18.18 cm) compared with non-supplementation (16.41 cm).

In general, spring onion plants are highly variable on water requirement caused by differences in growing conditions relate to season, location, and agroclimatic

Agronomic characteristics in spring onion cultivated in Crop 4

Clearly positive impact of soil supplemented with biochar and watering frequency showed on growth-related characteristics of spring onions in Crop 4.

Biochar supplementation showed an effective result when high amounts of water are required, which is given daily. The results of the study found that adding biochar indicated different characteristics - higher than without biochar. Therefore, excess water that affects growth can be alleviated by adding biochar for water absorption in soil. Biochar supplementation also had a positive effect on characteristics in situations when mild water deficiency and high water deficiency at watering every 4 days and every 8 days. That is probably a result to maintain soil moisture in the presence of biochar in soil. This reflects the ability to maintain the moisture content of biochar in conditions of dehydration in planting.

The changes in the growth-related characteristics of the spring onion were compared from the four planting cycles (Crop 1 to Crop 4)

Outdoor planting is done only in the first round of planting. Growing plants in hot climates in confined spaces such as pots affect soil moisture and the plant's ability to absorb nutrients for growth. This activity could induce water deficit in plants and maybe explained the impact on the number of characteristics in spring onion was lower mean values in the first cycle of planting, including LN, LL, LRL, and BF. Moreover, in Crop 1, the daily watering may exceed moisture and affected plant growth. In addition, biochar as a slow-release nutrient thus may not observed the positive effect in early planting cycle in Crop 1.

Meanwhile, different mean values on LN were found in different treatments in the subsequent planting cycles, Crop 2-4. Spring onions grown in biochar enriched soil were relatively higher mean values than those that were untreated biochar. Mean values were found to be lower than other treatments in soils with the lowest water frequency: every three days in Crop 2 and every eight days in Crop 3 and 4, both enriched and non-enriched soil with biochar. These demonstrate the importance of moisture as a primary factor to promote plant growth.

However, biochar supplementation also had a beneficial effect on plants under these lowest watering frequencies. The combination between water management and the use of biochar in the soil began to show results from the second planting cycle onwards. The differences were seen due to the interaction of the two factors: biochar × watering.

When considering only the yield characteristics, i.e. BF, PW and BW, it found increasing bulb formation capacity in planting cycles two to four, compared to the first planting cycle (Figure 10). However, the weight of the bulbs found in each sub-plant in plot in the second to fourth planting cycles was reduced in size from the first planting cycle (Figure 11). This may be a feature of underground competition that showed the compensation of the number of bulbs and the size/weight of the bulbs. Moreover, it can be explained is that although fertilization, urea, in every planting cycle, successive plantings in the same soil (in pot) may cause a corresponding decrease in other soil nutrients and affect the lower yield or BW value of spring onions in finally. That is, in monoculture practice, a continuous manner required nourishing the soil with fertilizer with a variety of nutrient compositions. In addition to biochar helping the soil can absorb water for longer, it also promotes the plants to achieve proper releasing of nutrients at different times to aid the growth. As a result, the yield of onions grown in biochar enriched soil and daily watered was consistently higher in all planting cycles.

Changes of moisture content of soil (%MCS) with biochar enrichment and watering at different frequencies in Crop 4

Clearly, the positive influence of biochar enriched soil and watering in all weeks. However, differences in values affected by the interaction of biochar × watering vary each day in different weeks after planting. A reduction of %MCS was observed since 1 DAP in the first week.

Therefore, it is important to adjust the frequency of watering the spring onions at different ages of plants. The difference of %MCS was found in the four-day watering group with a greater percentage of soil moisture reduction than in the daily watering group at 3 DAP. That showed that four-day watering had a negative impact on soil moisture, resulting in lower values compared to the daily watering in the control group. It was noted, however, that the 4 days of irrigation in the biochar enriched soil retained an extremely high moisture content in the soil. This evidence can indicate the benefits of biochar enrichment, especially its ability to retain soil moisture in low water availability.

Study of bamboo biochar properties by Scanning Electron Microscope

During the pyrolysis process; temperature, heating time, types of raw material or feedstock, atmosphere, played the role to develop micropores in large microscopic surface area of biochar. These micropores respond to water retention and nutrient absorption that induce positive effect on soil fertility improvement. Pores sizes measured in bamboo biochar (control treatment or not added in soil) in cross-section were 10.13–18.41 µm, on the other hand, longitudinal pores size in bamboo biochar was measured reach to 200 µm.

The most notable thing is that the inner surface porosity of biochar is increasing when it is mixed with soil and actually planted. The presence of high levels of porosity in surface in the biochar treatment; which is mixed in the soil and watered with daily frequency were more than control (Figure 16) and watering every 4 and 8 days, perhaps in part related to water retention or nutrient release.

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